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# Cathodic Protection, Coatings, and the NACE External Corrosion Direct Assessment (ECDA) RP 0502-2002

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## Abstract

The selection of CP and Coating Fault Survey Tools, the type of information is gathered and the analysis of survey data are discussed with respect to the NACE ECDA RP 0502-2002 Specification for the Integrity Management of pipelines that cannot be inspected by Metal Loss tools. Some weaknesses and limitations of the RP are highlighted together with the necessity for data to be fault specific and closely correlated with distance.

**Keywords**: Pipeline, CIPS, DCVG, Corrosion, Surveying, DGPS, ECDA, Direct Assessment, Potential, Cathodic Protection, Resistivity, Data Analysis.

## Introduction.

The NACE ECDA RP0502-2002 has placed into writing practices that have been operated in a variety of disjointed forms by groups within the more competent pipeline operating companies worldwide. The Specification brings many activities together and is specifically aimed at the vast majority of pipelines that cannot be inspected by inline inspection tools (ILI Tools). Hence, the survey of pipelines by above ground techniques and the analysis and interpretation of data is used in attempts to predict metal loss sites. In its first published form RP0502-2002 contains many limitations and a number of inaccuracies and in some cases, inflated claims for various inspection techniques. Subsequent revisions it is hoped will modify and update what was a very difficult document to initially produce and whilst it is very easy to criticise it is hoped the contents of this paper that deals with selective items in Pre and Indirect Assessment will be regarded as constructive.

RP RP0502- 2002 initially aimed at the US market is driven by requirements of the US Department of Transport, (DOT) Office of Pipeline Safety, (OPS). However, it has to be realised that some Pipeline Operators outside USA, in absence of their own document, are implementing this Standard in concept whilst not understanding the full implications and costs of the ECDA process. The RP is having worldwide implications.

The NACE Standard has segregated ECDA into a 4-step process, Pre Assessment (gather data and select inspection tools), Indirect Assessment (use the inspection tools to survey), Direct Assessment (analyse data and dig up pipe), and Post Assessment (look at what you have done and re-assess, including some risk assessment). The concept is to locate, evaluate, predict excavate, inspect and repair faults in ECDA regions where metal loss through corrosion is most likely to have occurred.

The preamble to the RP document lays out various aims, one of which states "ECDA was developed as a process for improving pipeline safety. Its primary purpose is preventing future external corrosion damage." The RP fails to provide clear direction as to how preventing future external corrosion damage is achieved from the ECDA process. The RP also fails to provide direction as to the analysis of indirect survey data to identify critical coating faults for excavation, examination and repair in the Direct Assessment step.

Corrosion, using the definition given in the Standard is "The deterioration of a material, usually a metal that results from a reaction with its environment". In the Corrosion industry, the well documented method of measuring the corrosivity of a soil is via soil resistivity measurements. It is quick and easy to carry out and interpretation is well established. Surely, the measurement of soil resistivity at coating fault locations provides a good indication of those faults where metal loss is most likely to occur and should make soil resistivity measurement mandatory for all ECDA inspections. In general, 99+ % of all coating faults have no metal loss, the CP is doing its job. The difficulty is in identifying the small percentage of coating faults that do have metal loss and these are most likely to be located in areas of low soil resistivity or changes in soil composition (and resistivity) such as from sand to clay.

## ECDA Regions or DOT High Consequence Areas (HCA)

It is normal practice when surveying using CIPS or DCVG or Pearson etc to work from test post to test post. This seems to have been forgotten. RP 0502-2002 splits a pipeline up into ECDA Regions defined as "A section or sections of a pipeline that may have similar characteristics and operating history and in which the same indirect inspection tools are used". This is a silly designation without technical justification as to what constitutes sections of pipeline with similar characteristics. This is different in definition from what the DOT requires. They require HCA's to be identified, a HCA being a segment of pipeline which is within a set distance from a building or location where people gather. This has little thought as to the practical aspects of surveying and has operators installing many new test posts at great cost at either end of HCA areas or ECDA regions. The ECDA regions are implied to cover the whole pipeline, the HCA's just specific areas. All pipeline operating companies in USA have to identify their HCA's and submit a plan to carry out the ECDA process within a specific agreed time period. The problem with the DOT dominant approach is that industry will do only what is necessary to satisfy the DOT-OPS which can leave large sections of a pipeline system not subject to routine inspection as all efforts and budgets for the next few years, are expended on HCA's. Concern is expressed that this disjointed approach will lead to little effort on non HCA's which if they lie in soil of greater corrosivity may be more prone to metal loss resulting in a leak.

A rethink of the ECDA and DOT approach is required to better marry and clarify the survey requirements from a more practical point of view with regard to already installed test posts for the benefit of the whole pipeline rather than limited HCA segments.

## External Corrosion Control of Buried Pipelines

External corrosion mitigation of buried pipelines is achieved by a combination of a protective coating such as FBE or 3 Layer FBE/PE and Cathodic Protection to contain corrosion of steel pipe exposed at faults in the protective coating as all coating systems have faults. For effective corrosion control a balance has to be achieved between the amount of CP applied and the distribution and current consumption of individual coating faults. Too much CP is just as bad as too little as cathodic reactions generate alkali which can accelerate coating failure and generate conditions for Stress Corrosion Cracking. Obviously, priority must be directed to Critical Coating Faults that are most likely to give rise to problems unless repaired

## Critical Coating Faults

What is the definition of a Critical Coating Fault? How do we identify critical coating faults for the excavation and examination required in the Direct Assessment step of ECDA?

Before answering these questions we need to understand what has been happening over the last 20 years. Many companies began to pay more attention to their buried pipelines and rehabilitation (should be more correctly called refurbishment) became the "state of the art" activity. The driving force has been the need to stop metal loss by improving corrosion mitigation techniques principally cathodic protection by a combination of coating repair or replacement and installing additional CP stations. Hence, if we analyse the thinking behind this it can be seen that a critical parameter is to identify those faults that are consuming the largest amount of CP current. Hence by coating repair we release more CP current for those faults that are not repaired as well as improving the "throw" of the CP system along the pipeline, remembering there is never enough money to repair all coating faults. This approach has been modified in ECDA to concentrate initially on locating metal loss sites at critical coating faults and secondly on improving long term corrosion mitigation techniques.

Critical coating faults in order of repair priority can therefore be defined as:-

**Priority1.** Coating Faults were there is known metal loss that places a pipeline in potentially short term risk, irrespective of if its location is in a HCA Segment. The concept behind the ECDA process is to identify these but in general would be delineated defects from an ILI tool inspection.

If there is no ILI data then the following must be the priority as defined by an ECDA study.

**Priority 2.** The identification of critical coating faults where corrosion is most likely to occur. This requires detailed analysis of many sources of information. Most probable metal loss will occur at faults sited in the most corrosive soil particularly where changes in soil type occur, faults not receiving enough CP current (though in some cases fault current can still be high) and hence showing anodic activity (determined by DCVG technique), giving poor pipe to soil potential and high fault severity. These are ECDA faults where priority is given to HCA Segments.

**Priority 3.** The identification of coating faults that are consuming the most CP current irrespective whether located in HCA Segment or not. Such faults are commonly sited close to CP installations and are due to bad CP designs where the ground bed is sited too close to the pipeline. High CP current consuming faults lead to more rapid coating failure and build up of carbonate/bicarbonate environments needed to develop Stress Corrosion Cracking, the most insidious form of pipeline failure.

**Priority 4.** Coating faults with poor pipe to soil potentials. This is a requirement to meet statutory codes irrespective of fact that most codes ignore reality that protection can be achieved at -600 mV in some soils whilst in others -1100 mV may be required. In absence of not knowing what potential to use, industry interprets to the NACE Criteria particularly -850 mV OFF and/or 100mV shift.

More than 99% of all Coating Faults have no metal loss so why excavate to repair? In fact the repair of additional Coating Faults where there is no metal loss is needed to improve CP Distribution to contain the long-term onset of corrosion along a pipeline.

ECDA Tool Selection Matrix

The ECDA specification requires a minimum of two survey techniques to be used to gather data. Figure 1 which is Table 2 in RP 0502-2002 considers 6 CP / Coating Survey Methods (Close Interval Survey, DCVG, ACVG, Pearson, Electromagnetic, and AC Current Attenuation) and presents a very distorted view of practical application of the methods. First there is confusion between AC and DC methods and between CP evaluation techniques and coating fault delineation methods.

Within the AC techniques there is a lack of realising that all AC techniques use the Pearson Technique in various forms to delineate fault locations. For example, the ACVG has the two ground contacting electrodes mounted on an A frame instead of two surveyors, and uses a meter indication instead of an audible signal. The Pearson Technique, but in a different format. All AC techniques are relatively useless when in the locality of overhead power lines, and many pipelines are in fact paralleled by high voltage lines in a common right of way. Electromagnetic techniques cannot be used where a pulsing DC from CIPS or DCVG surveys are being used. Similar comments apply to Electromagnetic Soil Resistivity Measurements, see Figure 2. Hence the right of way has to be traversed twice. Also all EM techniques loose discrimination when soil resistivity is high e.g. greater than 100,000 ohm cm. There exists a major problem with all AC and Electromagnetic techniques and that is that, their data has no direct relationship with the external corrosion control techniques applied to a buried pipeline. This important fact seems to be ignored in the RP. Data obtained by these techniques cannot therefore be specifically correlated with the historical records and the on going operation and control of the pipelines cathodic protection system.

The best available selection of two separate but compatible techniques that have a direct correlation with the data from the operation of the pipelines CP system is the use of CIPS to monitor the pipelines CP profile, interference etc and DCVG to locate coating faults etc. RP Table 2 identifies that DCVG is not applicable to some areas such as city streets, river crossings etc. This is a total distortion of the true facts and presents a typical dominance of vested interests over scientific fact in preparing Specifications. Another distortion again arising out of the North America is confusion between Lateral CIPS, Trailing CIPS and true DCVG.

In Europe we have been using the lateral CIPS technique for more than 25 years. It is called the Intensive Method and is more prevalent in areas under German technical influence. In recent years (2 to 3 years) the North Americans have called this technique combined CIPS /DCVG where the lateral CIPS is thought to be DCVG. Even worse, the Canadians recommend the lateral half-cell be at a distance of 2 metres from the pipeline. Lateral gradients stretch many metres depending on soil resistivity and the CP current flowing to individual faults. 2 metres would represent only a fraction of the total gradient to remote earth so any lateral data is totally useless for analysis for the Direct Assessment step in ECDA. Even worse, in UK the use of one half-cell trailing behind the other at a distance of several metres is also called combined CIPS/DCVG. An analysis of these CIPS variations has been previously published ( 1,2 ). Both of these variations are very poor representations of the correct methodology which is conventional CIPS used in conjunction with analogue DCVG. Considerable confusion and distorted opinions are mostly caused by the lack of surveyors undergoing proper training in the technologies used.

### What Survey Techniques and Information is Required For Direct Assessment

The cost effective approach to effective maintenance of pipelines to minimise ECDA and HCA influences is to limit metal loss by repairing only those coating faults that really need repair in order to bring back into balance the relationship between coating fault severity, number, distribution, and the effectiveness of CP at all individual faults. Supporting this approach is the fact that upon excavation, the vast majority of coating faults on pipelines subject to effective CP show no metal loss. CP does work but the problem is to make it work effectively along the complete pipeline. The above approach suggests that the coating is the premier corrosion protection mechanism and CP is a supportive technique and is probably correct for a reasonably well coated pipeline. However, the reverse is true for pipelines with a very poor coating. Studies of both the coating quality and the CP are therefore important inputs to the decision making process to identify existing or potential metal loss sites. One major failing of all variations of CIPS is that no data is coating fault epicentre specific.

The least CP protected locations on a pipeline are at coating fault epicentres. This fact leads directly to the concept that all data should be coating fault specific; after all, nobody would normally excavate a pipeline in areas of good coating. Coating fault specific data also readily allows computers to be used in the complex analysis which can involve as many as 3,000 data points per Km of pipeline.

To make the best decision using the ECDA concept applied to HCA segments, exactly what data should be gathered and to what criteria should the data be interpreted to affect the most cost effective repair? Gathering data depends upon the survey techniques used and the training and understanding of technique errors and limitations by the surveyors gathering the data. The criteria to which data is interpreted is also subject to variation. In addition it must be remembered that in data analysis not all data is of equal importance in the decision making process as different parameters have different affects on the rate of the corrosion process. Also any one parameter can change in importance as it does not always have the same influence on corrosion rate. Soil Resistivity is a good example of this. It is the data vagaries that exert the biggest effect on the ability to accurately predict metal loss locations.

The NACE External Corrosion Direct Assessment Specification RP2002; by calling for two survey techniques is incorrect. This is considered inadequate to provide the best information for subsequent analysis so four complementary techniques are suggested:-

1. Analogue DCVG, to accurately locate and assess coating faults. This technique was chosen because of its simplicity and undisputed

accuracy at locating and determining the characteristics of coating faults. Analogue DCVG has no attachment to the pipeline and should not be confused with Lateral or Trailing. Lateral CIPS does not provide the same data as analogue DCVG.

2. Close Interval Pipe to Soil Potential Survey, to assess the pipeline's Cathodic Protection System and DC Interference. In this case CIPS equipment modified to operate at the DCVG ON/OFF sequence of 0.45 seconds ON, 0.8 seconds OFF so the two techniques, DCVG and CIPS can be run as a one pass survey at a close distance apart.

3. Soil information including Resistivity to assess the soil Corrosivity at coating fault locations.

4. Sub-metre accuracy DGPS for coating fault location and distance measurement. Accurate distance measurement is in fact the most difficult parameter to record.

The quality of the data collected will also depend upon the type and quality of the survey equipment used. Not all survey equipment is easy to set up and use. A number of North American CIPS equipments use modifications of laptop computers or generally used Data Loggers such as the Allegro. These usually have limited memory and/or battery life and require a certain competence in using computers and are often of limited capability of synchronising with satellite interrupters. Ideally for field surveying, equipment should be simple to set up and use. Significant differences also exist with different manufactured analogue DCVG equipment. Several manufacturers have designed their equipment with an automatic return to the needle centre zero position. This type of circuit design limits the flexibility of the instrument in complex pipeline networks and also prevents the corrosion status being determined. Variations also exist in instruments. For example, on the 10 mV range all the automatic centre instruments are calibrated + or - 10 mV about the centre rest position. The manual bias instruments on their 10 mV range are calibrated + or - 5 mV about the centre rest position making such instruments 2 times as sensitive meaning they can operate at lower pipeline DCVG signal strengths or survey at greater pipe depths. Attempts have been made to produce DCVG instruments with a digital display instead of an analogue meter. The problem with digital instruments is that the response indicator picks up all fluctuations in voltage noise from the rectifier making it very difficult for the surveyor to be certain of what the instrument is indicating particularly at low voltage ranges.

A variety of GPS equipments have been used with the best being the Trimble Pro XRS or equivalent. These instruments are expensive so often cheap inaccurate hand held units are employed which are really insufficient for accurate data comparison work. It is unfortunate that most pipeline operators do not understand the limitations or inaccuracies of the equipment and technologies used so are very much at the professional honesty of the survey company. A real problem within the survey industry exists which limits the quality of data collected and hence the best application of the ECDA concept and interpretation of data. As an example, in a recent survey in the UK in undulating countryside, an earlier CIPS survey distance was 2.441Km short on a survey 31.879Km long, using for distance measurement a wire dispenser. Over this section of pipe, DGPS distances agreed almost exactly with the distance determined by an ILI tool travelling through the buried pipeline.

The only cost effective way to measure soil resistivity of a pipeline right of way is by using electromagnetic techniques to obtain a continuous profile. However, as with all soil resistivity measuring methods the CP must not be pulsing so an EM survey has to be run as a stand alone technique, logging in coating fault and right of way features into the EM data logger together with DGPS locations. Another problem also has to be recognised which is the route plotted is to the side of the pipeline not the actual pipeline trench location itself as the resistivity of the pipeline steel can significantly dominate the data.

**Summary of Type of Survey Data Collected**

**The following information can be collected by the DCVG Technique.**

1. Fault location to within a 15 cm circle.
2. Fault %IR Severity, see Figure 3. This is related to the physical size of the fault but this relationship can be modified by soil pH effects.
3. Fault Corrosivity Factor. see Figure 4. A new factor currently under development and related to active corrosion site prediction.
4. Fault Corrosion Status (net current flow to or from a coating fault which is one of the NACE Criterion for Protection) see Figure 5. Determines if a fault is receiving adequate CP for protection.
5. Individual Coating Fault CP Current Demand. See Figure 6.

6. Fault approximate shape and orientation on the pipeline.

7. Attenuation of the Cathodic Protection from rate of DCVG Signal decay, see Figure 7.

8. Effective Range of a Rectifier influence.

9. Determine % Efficiency of Insulation of Gaskets, separation of Casing and any other foreign structure on the pipeline right of way.

**The following information can be collected by the CIPS Technique.**

10. CIPS ON Potential, uncorrected and corrected for attenuation step.

11. CIPS OFF Potential, uncorrected and corrected for attenuation step, see Figures 8A and 8B.

12. Large Coating Fault indication by CIPS.

13. Effective Range of CP by Potential Decay.

14. Weak areas of CP when ON and OFF come together.

15. Interference effects from AC and other DC Sources and structures.

16. Soil Composition voltage variations due to changes in soil chemistry.

**The following information can be collected by the Soil Monitoring Techniques.**

17. Soil Resistivity measurements, see Figure 9.

18. Change in Soil Type.

19. Moisture Content.

20. Soil pH at fault locations.

21. Rock or Stones present in soil (major source of damage to all coatings).

22. Location of Vegetation at Coating Faults (major source of failure in some coatings).

**The following information can be collected by the Sub-metre DGPS**

23. Location for all survey data points, pipeline features and right of way furniture, see Figure 10.

24. Distance for all survey techniques including ILI tools.

25. Time of day of measurement.

26. Date of Measurement.

27. Cross reference information for different types of survey data.

**The following information can be collected from Historical records.**

28. Past Survey data typically CIPS, Pearson, CP Records, Inline Inspection Records, Ac and DC Interferences. Most data will not be coating fault specific.

29. Past History of pipeline operation, excavations and leak or third party interference reports.

Survey Data Analysis to identify Fault Locations for Excavation

The quantity of data collected even though coating fault specific can be very large and impossible to analyse manually. Consequently ECDA Data Analysis programs (3), have been developed such as that in Figure 11. With all such programs all data has to be coating fault or metal loss site specific and all data has to be correlated using distance (4). For good correlation the start and end points of surveys and any other feature must be clearly delineated in each set of survey data. If data has to be correlated later with ILI tool data then there must also be correlation points that both the above and below ground survey techniques log. There is also another attribute with computerised data bases in that it keeps active all survey data and although no action may be taken at a fault, its characteristics may be useful for on going monitoring and improved interpretation of data from later surveys.

The construction of the databases for the Analysis Program is shown in Figure 12 and are interactive with data only being capable of being manipulated through a Data Editor and not through the analysis program in order to limit data contamination.

The Data Analysis System was set up with several objectives in mind.

1. To identify Critical Coating Faults for repair and also and CP improvements required.
2. From 1 above produce a Table of Packages of Work for issue to Contractors as the Scope of Work for the Direct Assessment step.
3. Provide a data base for all information gathered during the Direct Assessment step.
4. Identify the anticipated Costs involved in carrying out the Scope of Work.
5. The outcome from the analysis requires to be sold, first to the clients Project Engineer as to the logic of the Analysis. The Project Engineer then has to convince his Managers of the Analysis in order to approve Budget Funds to carry out the Scope of Work. The production of graphical data presentations is very useful in the selling operations.

The Analysis System can interrogate the data bases to produce for any part of the pipeline such as individual HCA areas, any one of 25 different types of Graphical Presentations for the Coating and CP

Tabular presentations are the result of interrogating the data bases to identify coating faults with a common or multiple set of parameters that do not meet selected criteria. For example, large severity coating faults in low resistance clay soil with inadequate levels of CP and low pH. The input to the selection process can either weigh all parameters identically or assessed according to the importance of a specific parameter in contributing towards corrosion. This is supplemented by additional data such as the distance apart of coating faults and the location of the coating fault to high-risk areas. The distance apart if matched to field joint spacing enables the cause of coating failure to be identified before excavation begins. The distance apart also helps to recognise additional coating faults for repair as being close enough to a coating fault already identified for repair to be incorporated in the same trench. On badly coated pipe the distance apart analysis also helps in the decision of whether to carry out long line repair, or improved CP using a continuous polymer anode.

The decision process for large severity coating faults is easy, but this is not the case for many small coating faults in close proximity whose total contribution can be equivalent to several large severity coating faults, in terms of their effect on CP distribution. Condition Analysis is a process of assessing the effects of all coating faults in a specific segment of pipeline and modelling how the overall effect of coating damage will change as coating faults are identified for repair. Condition Analysis is very useful for identifying "hot spots" and for estimating the average level of CP current consumption when designing continuous polymer anode systems.

Whilst not part of ECDA, the software package also will accommodate and interrogation ILI Metal Loss Tool data, and the correlation of metal loss with CP data and coating fault location as delineated by DCVG above ground surveys.

**Output from the Analysis Program.**

The output from the Analysis computer program is a list of Coating Faults prioritised for repair. The coating fault locations are arranged into Packages of Work. A Package of Work is either 10 bellholes (short length, 7.5M total hole size) or 250- metres of digging, which ever is the smaller. The concept behind this approach is to exercise control over the Rehabilitation Contractor. Usually at least 60% of the cost of rehabilitation is in moving soil and unless controlled there will be a natural tendency to do as much of this type of work as possible. This can lead to many excavated holes with nothing completed. Three Packages of Work, (30 bellholes) are issued to the Contractor at any one time which is sufficient to allow the Contractor to develop a conveyor belt type process and be efficient. To be issued with Work Package 4, one of the already issued Packages of Work must be completed to a Rehabilitation Specification. One important step in putting together the Packages of Work is to ensure that the selected excavations are not spread too far apart so that effective quality and project control becomes impossible.

The Package of Work document is a list containing only information relevant to the rehabilitation process and can be inserted directly into the Rehabilitation Contract as the Scope of Work along with various Specifications on how to carry out the rehabilitation process.

**Cathodic Protection Assessment and Improvements.**

The desire to improve the effectiveness of available CP to control long-term metal loss is the major reason for rehabilitation. Frequently the amount of coating repair is far in excess of what is required to control metal loss. The Software data interrogation allows those coating faults consuming a larger proportion of CP current to be identified for repair thereby making more CP available for other coating faults not selected for repair. Further, a comparison of CP potential profile with coating fault severity assists in understanding what can be causing low pipe to soil potentials and a further comparison with soil resistivity allows an appraisal of ground bed locations relevant to coating fault locations to be made.

**References.**

1. Understanding Voltage Surveys in Reliable Coating Data
Dr.J.M.Leeds & S.S.Leeds. Pipeline & Gas Industry, March 2001.
2. Pipeline Operators Misled by Sham Methods
Dr.J.M.Leeds & S.S.Leeds. Pipeline & Gas Journal, June/July 2004.
3. ECDA Data Analysis Program from DC Voltage Gradient Technology & Supply Ltd, Corbett House Swan Lane Hindley Green, Wigan, WN2 4EY UK.
4. Correlating Coation and Metal Loss Data can Save O & M Money
Dr.J.M.Leeds & Dr.M.Waterton. Pipeline & Gas Industry, March 1999.

Figure 1. From NACE RP 0502-2002

Table 2: ECDA Tool Selection Matrix [(A)]

| CONDITIONS | Close-Interval Survey (CIS) | Current Voltage Gradient Surveys (ACVG and DCVG) | Pearson[7] | Electro-magnetic | AC Current Attenuation Surveys |
|---|---|---|---|---|---|
| Coating holidays | 2 | 1, 2 | 2 | 2 | 1, 2 |
| Anodic zones on bare pipe | 2 | 3 | 3 | 3 | 3 |
| Near river or water crossing | 2 | 3 | 3 | 2 | 2 |
| Under frozen ground | 3 | 3 | 3 | 2 | 1, 2 |
| Stray currents | 2 | 1, 2 | 2 | 2 | 1, 2 |
| Shielded corrosion activity | 3 | 3 | 3 | 3 | 3 |
| Adjacent metallic structures | 2 | 1, 2 | 3 | 2 | 1, 2 |
| Near parallel pipelines | 2 | 1, 2 | 3 | 2 | 1, 2 |
| Under high-voltage alternating current (HVAC) overhead electric transmission lines | 2 | 1, 2 | 2 | 3 | 3 |
| Shorted casing | 2 | 2 | 2 | 2 | 2 |
| Under paved roads | 3 | 3 | 3 | 2 | 1, 2 |
| Uncased crossing | 2 | 1, 2 | 2 | 2 | 1, 2 |
| Cased piping | 3 | 3 | 3 | 3 | 3 |
| At deep burial locations | 2 | 2 | 2 | 2 | 2 |
| Wetlands (limited) | 2 | 1, 2 | 2 | 2 | 1, 2 |
| Rocky terrain/rock ledges/rock backfill | 3 | 3 | 3 | 2 | 2 |

[(A)]**Limitations and Detection Capabilities:** All survey methods are limited in sensitivity to the type and makeup of the soil, presence of rock and rock ledges, type of coating such as high dielectric tapes, construction practices, interference currents, other structures, etc. At least two or more survey methods may be needed to obtain desired results and confidence levels required.

**Shielding by Disbonded Coating:** None of these survey tools is capable of detecting coating conditions that exhibit no electrically continuous pathway to the soil. If there is an electrically continuous pathway to the soil, such as through a small holiday or orifice, tools such as DCVG or electromagnetic methods may detect these defect areas. This comment pertains to only one type of shielding from disbonded coatings. Current shielding, which may or may not be detectable with the indirect inspection methods listed, can also occur from other metallic structures and from geological conditions.

**Pipe Depths:** All of the survey tools are sensitive in the detection of coating holidays when pipe burials exceed normal depths. Field conditions and terrain may affect depth ranges and detection sensitivity.

KEY

1 = Applicable: Small coating holidays (isolated and typically < 600 $mm^2$ [1 $in.^2$]) and conditions that do not cause fluctuations in CP potentials under normal operating conditions.
2 = Applicable: Large coating holidays (isolated or continuous) or conditions that cause fluctuations in CP potentials under normal operating conditions.
3 = Not Applicable: Not applicable to this tool or not applicable to this tool without additional considerations.

Figure 2. Electromagnetic Soil Resistivity Measurement.

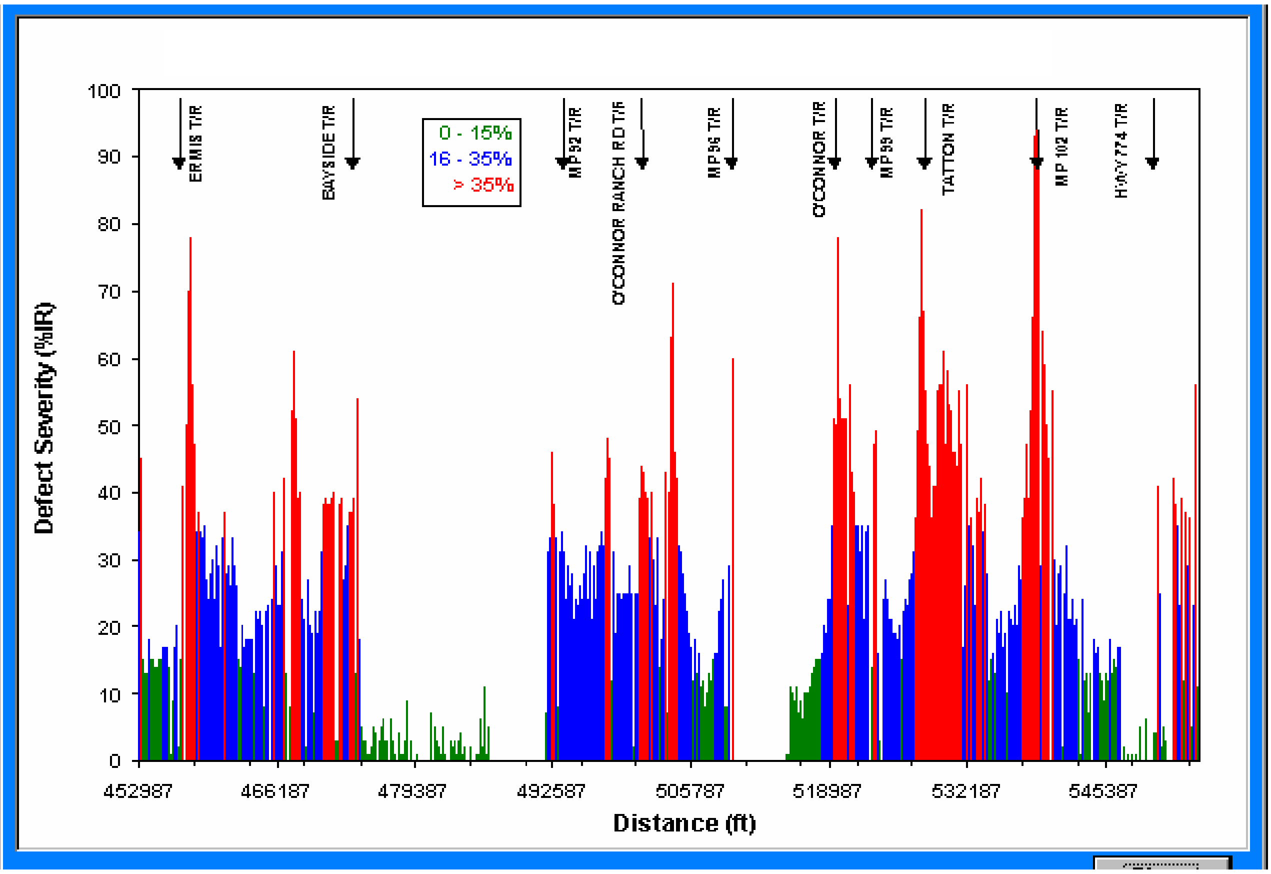



Figure 3. Coating Fault %IR Severity of a Tape Coated Buried Pipeline

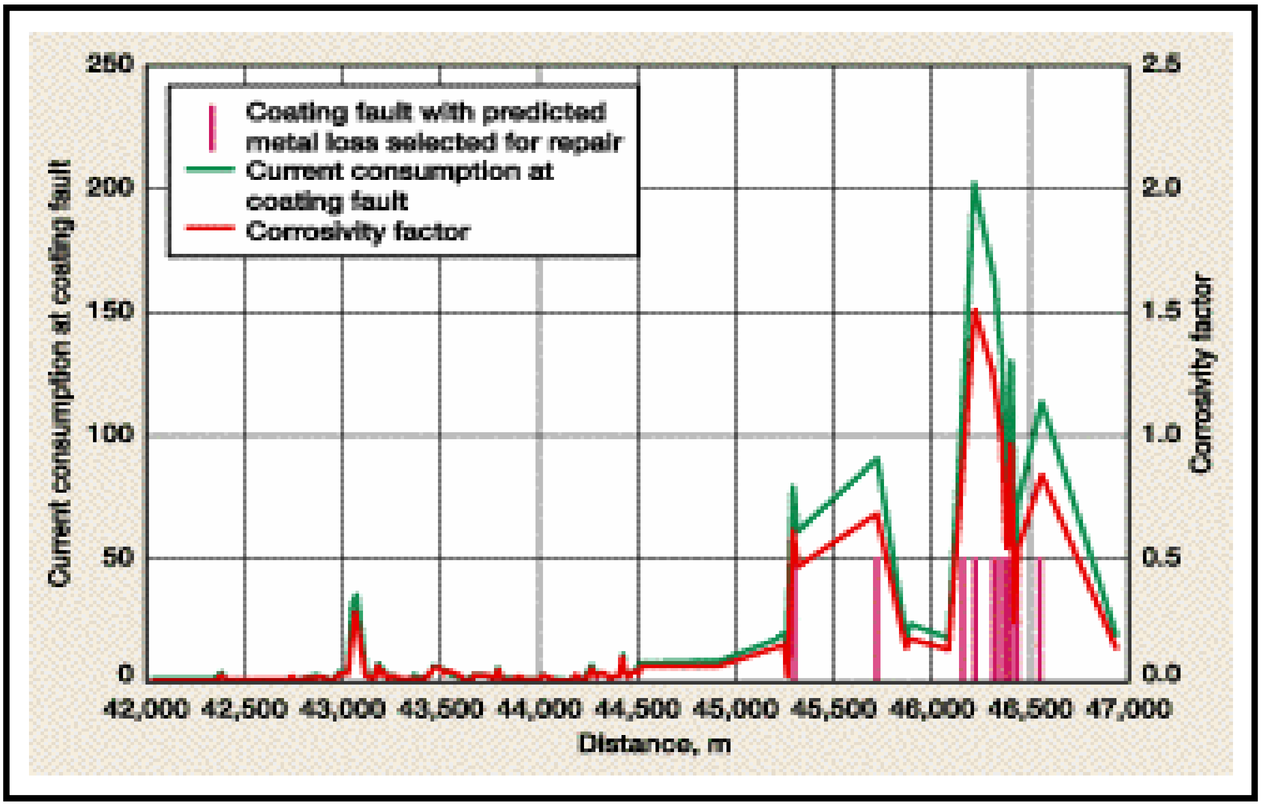



Figure 4. Coating Fault Corrosivity Factor and Fault Current Demand. Coal Tar Coated

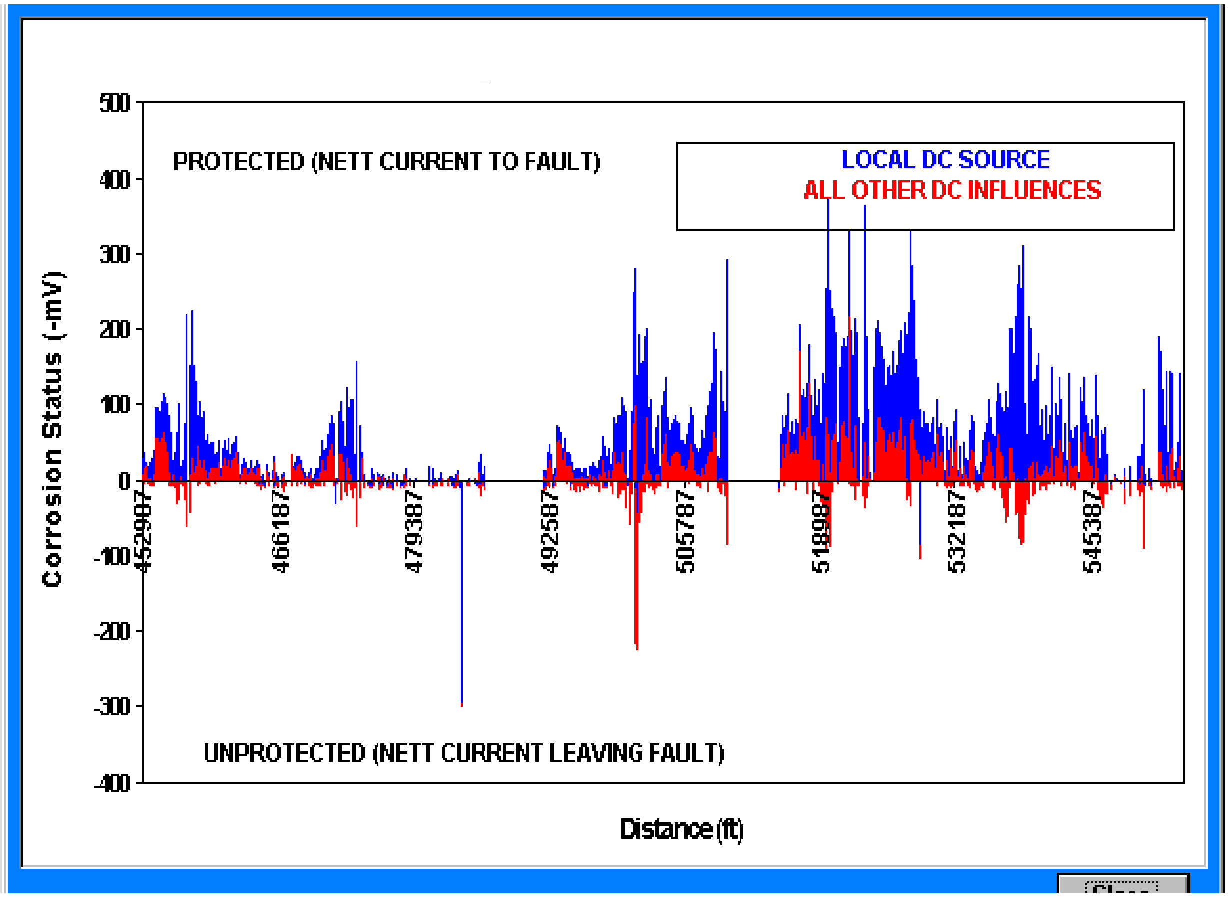



Figure 5. Coating Fault DCVG Corrosion Status (Net Current Flow to or From Fault)

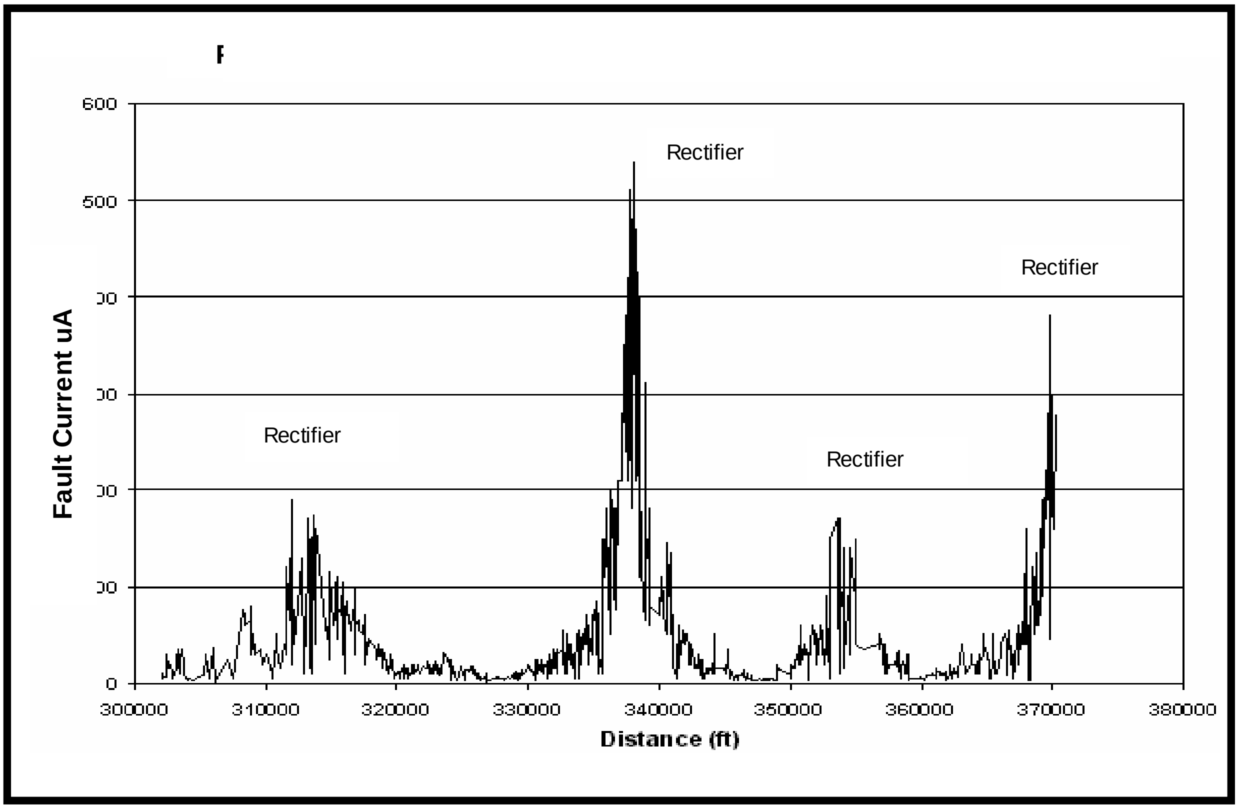



Figure 6. Coating Fault Current Demand Along a Tape Coated Buried Pipeline

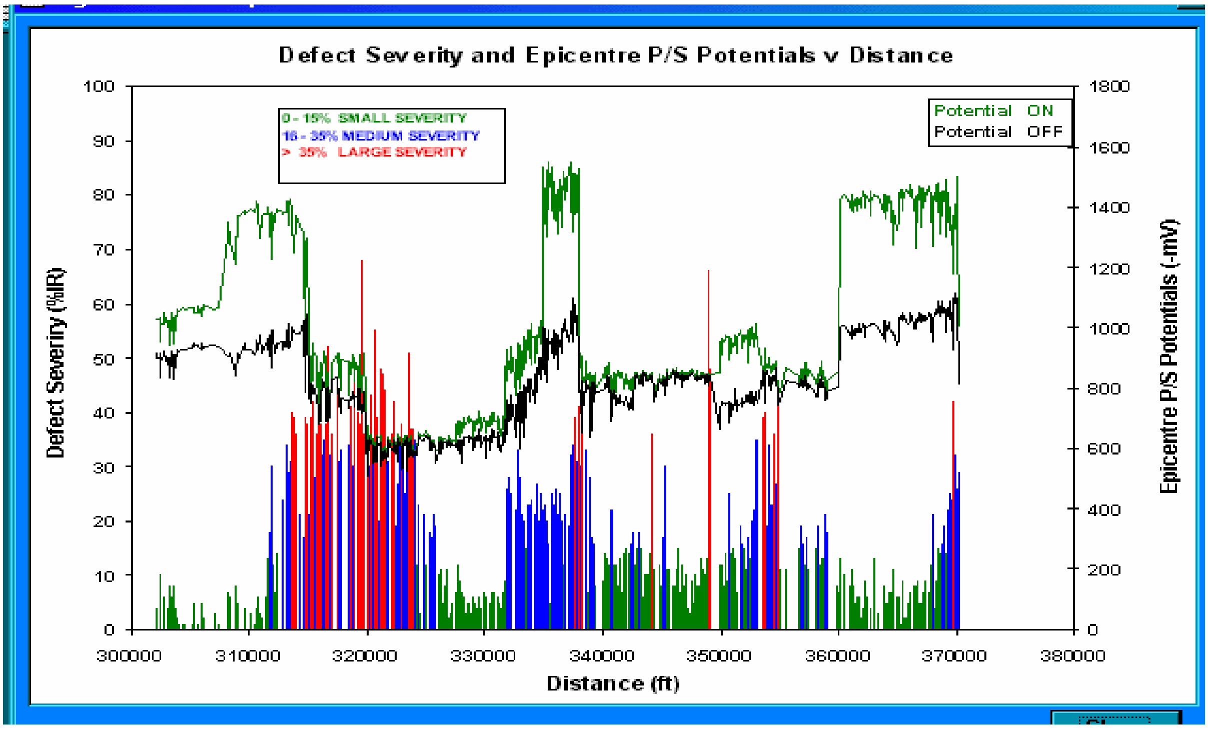



Figure 8A. Uncorrected CIPS Pipe to Soil Potential and Coating Fault Severity.

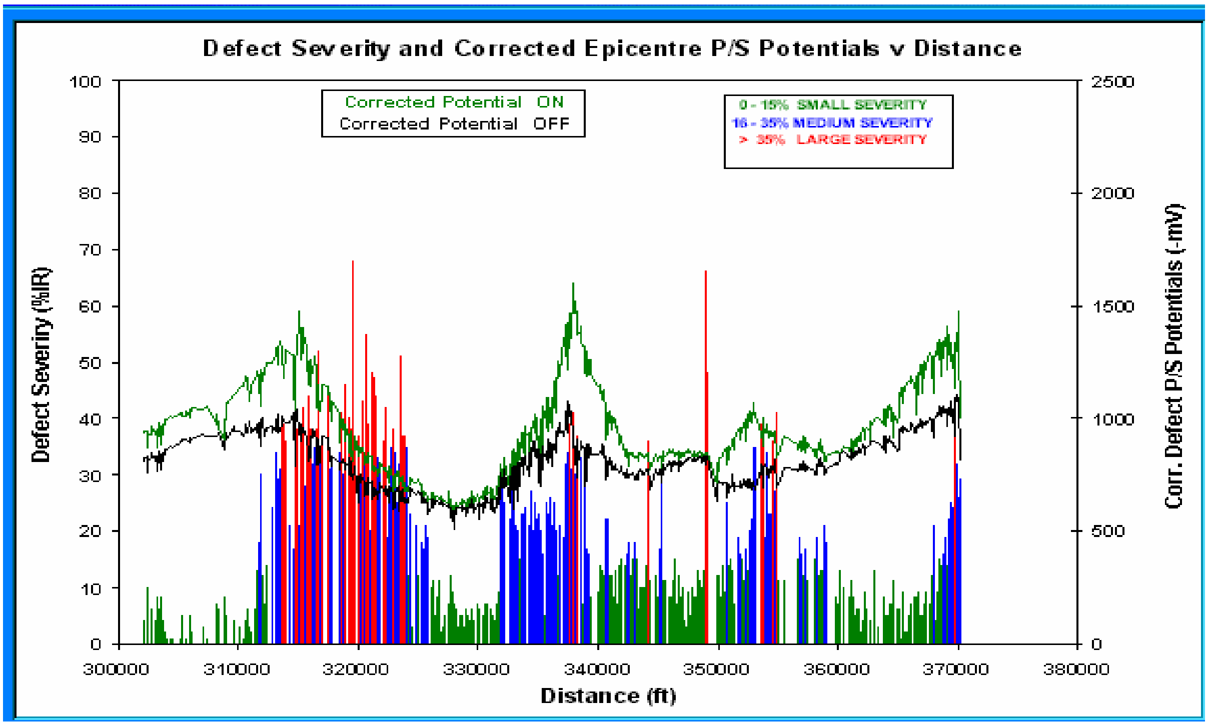



Figure 8B. Corrected CIPS Pipe to Soil Potential and Coating Fault Severity.

CIPS Data from Figure 8A Corrected for Attenuation Step. Tape Coated Pipeline

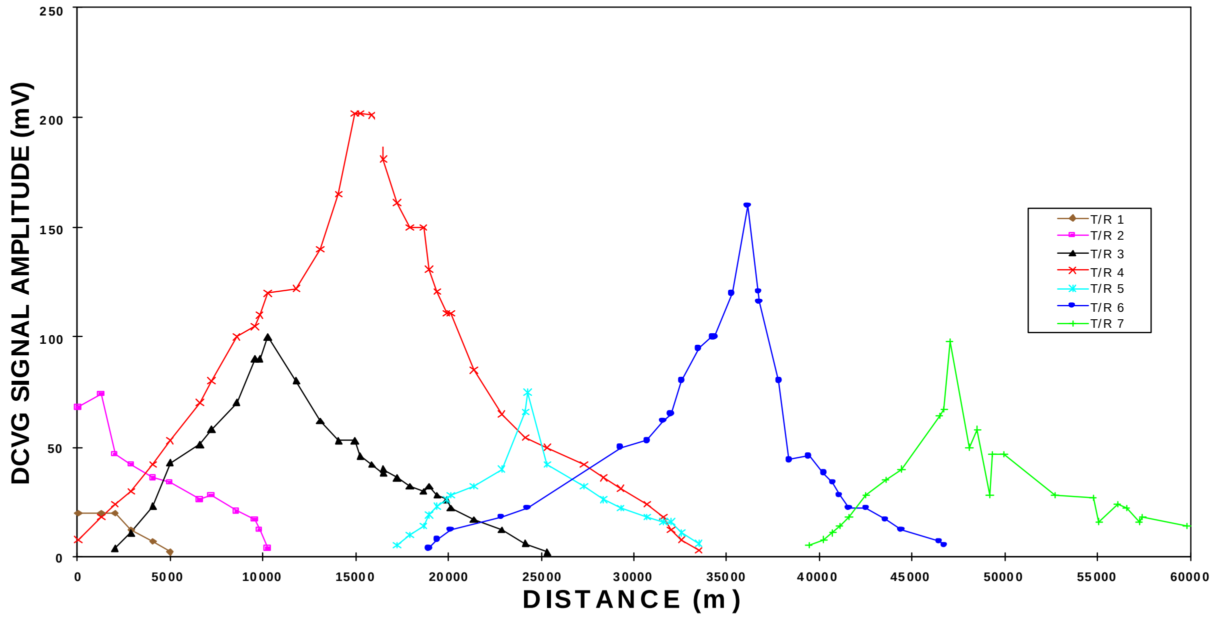
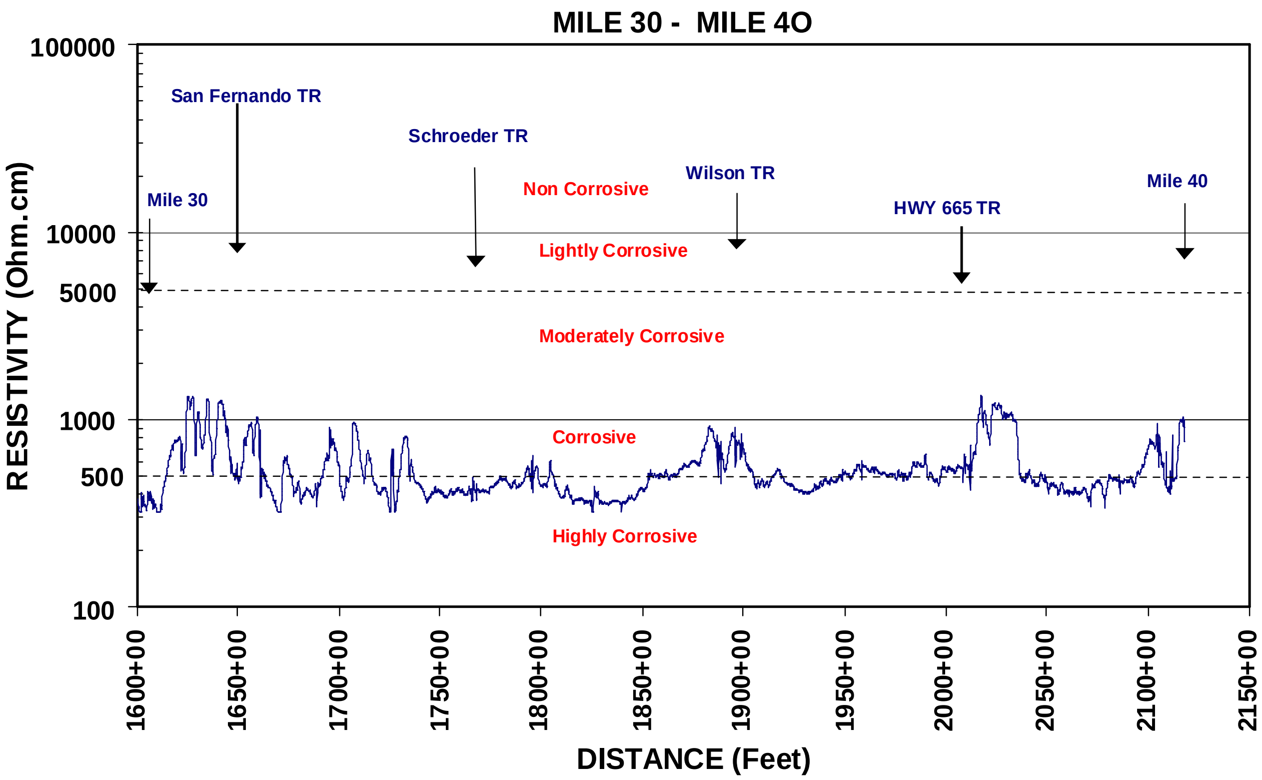



**Figure 7. The effective range of each CP source determined at test posts from measurements of the DCVG signal amplitude to remote earth. This information is invaluable when setting up both DCVG & CIPS surveys**

Figure 8. EM Soil Resistivity in Coastal Salt Contaminated Gumbo Clay



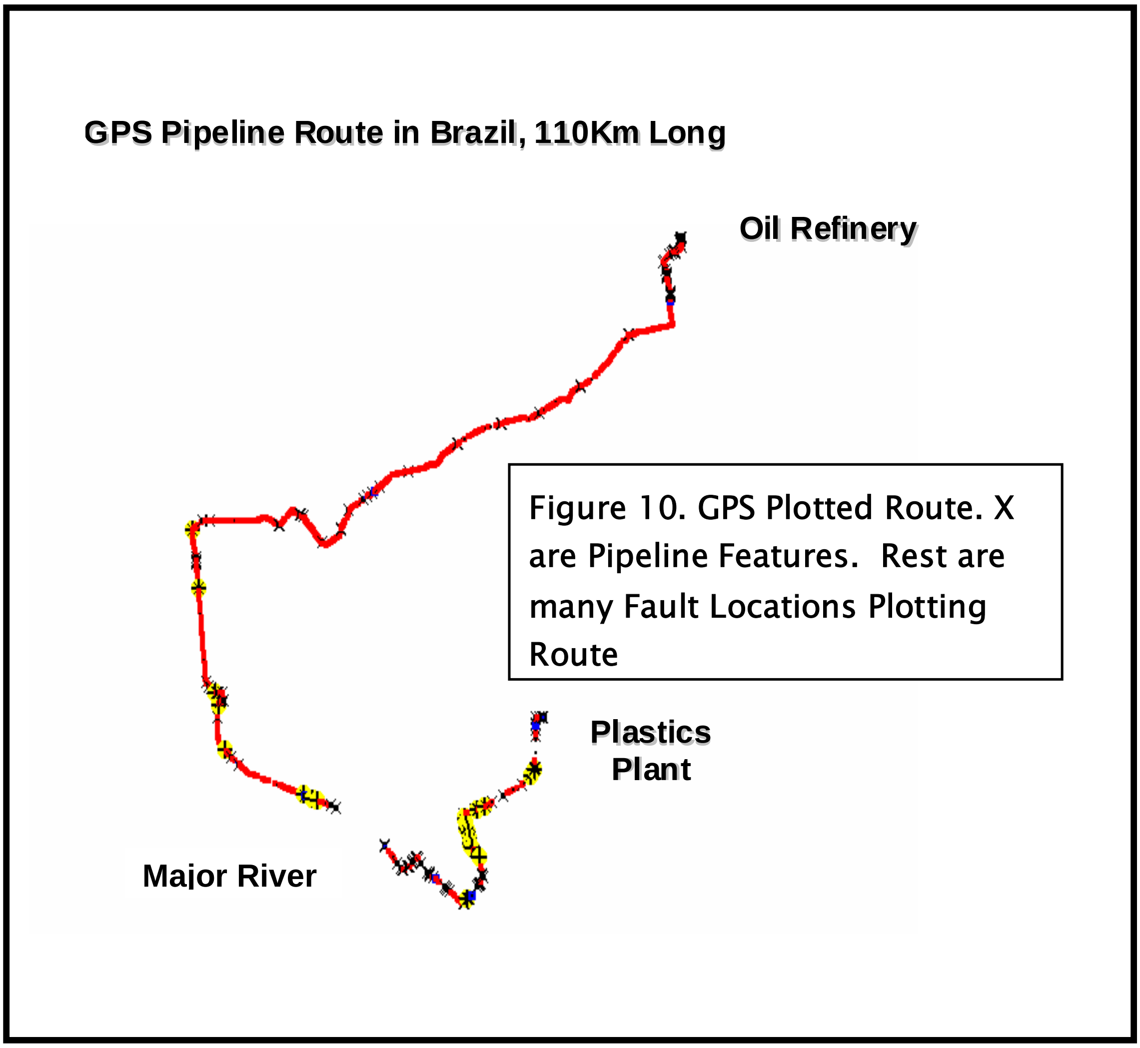



Figure 10. GPS Plotted Route. X are Pipeline Features. Rest are many Fault Locations Plotting Route


Figure 11. Opening Screen of the ECDA Data Analysis Program.

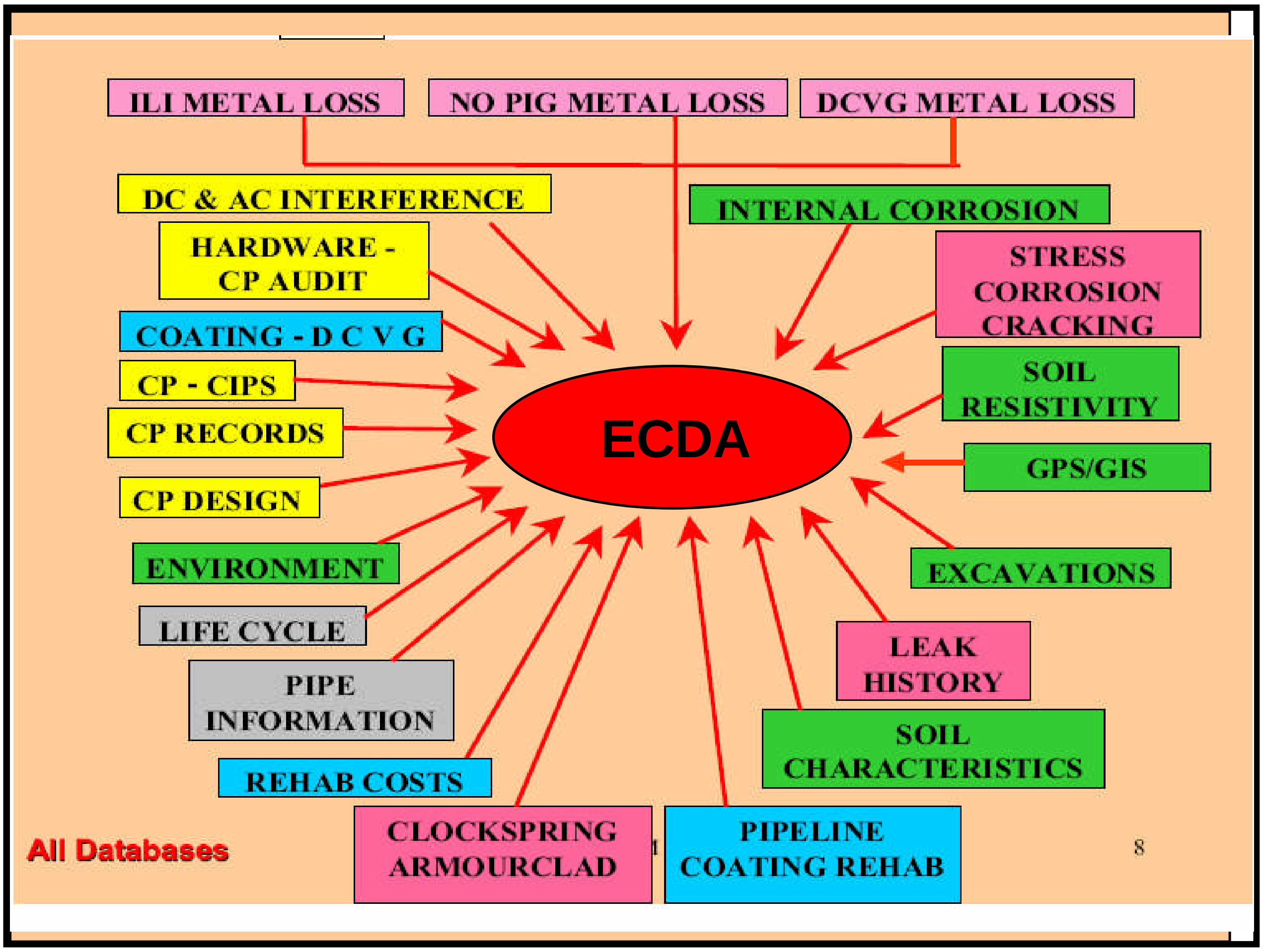



Figure 12. ECDA Interactive Data Bases Holding 516 Different Types of Data