Paper No.
673

CORROSION98

THE BURIED REFERENCE ELECTRODE: A CRITICAL LONG TERM PERFORMANCE STUDY

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ABSTRACT

Accurate monitoring of cathodic protection relies upon the proficiency of the test personnel and the proper operation of the required equipment. The equipment consists of properly insulated test leads, an electronic voltmeter with a known internal circuit resistance, and a reference electrode. The proper operation of each piece of equipment is critical to the accuracy of the cathodic protection test results. However, the reference electrode is not often suspected of being responsible for unexpected cathodic protection readings. This paper will provide background on the use of portable reference electrodes and data used to evaluate the performance of buried reference electrodes installed adjacent to a single, cathodically protected, underground storage tank. Data accumulated at the test site clearly indicates that not all buried reference electrodes provide identical results.

Keywords: buried reference cell (BRC), cathodic protection (CP), copper/copper sulfate electrode (CSE), half-cell potential measurement, reference electrode, underground storage tank (UST)

INTRODUCTION

Cathodic protection (CP) testing for steel underground structures has typically been accomplished using a volt meter suitable for the test, a set of test leads, and a standard half-cell. Generally, this half cell is referred to as a reference electrode, is commonly of the copper/copper sulfate (CSE) variety, and portable in nature. The standard methodology for the use of this equipment has always been; 1) make good electrical connection to the structure to be tested, 2) connect test leads to the meter observing correct polarity, and 3) place the CSE in the electrolyte (soil) directly above the structure.

Over time, test personnel have noted various difficulties in accomplishing step number 3) when attempting to check the CP for steel UST's. Among the problems encountered were contaminated soil, frozen soil, limited or no access to the electrolyte, and excessively dry soil conditions at the available CSE placement location(s). In an effort to control these factors, many of which can lead to inaccurate half-cell potential measurements if not avoided, the buried reference electrode (BRC) was studied by the Steel Tank Institute.

This study was undertaken with the aid of third party corrosion consulting companies. Previously, a third party investigation of nine (9) locations with steel UST's under CP indicated a direct relationship between half-cell potential level, soil resistance, and the depth at which the half-cell potential is obtained by CSE placement[1] as shown in Table 1. With typical UST installations, the portable reference electrode is placed as much as 4-5 feet above the structure and in high resistance, non-conductive soil or backfill. With many cathodically protected UST's the anodes are placed near the bottom of the tank, at each end (head)[2]. This is done to assure full protection to the portion of the structure which is generally in the most corrosive environment, and most likely to have a corrosion failure, the tank bottom. Thus, half-cell potential measurements taken at the surface using a portable reference electrode are not necessarily providing useful data.

In an effort to utilize this information in the best means available, an in depth study was undertaken to examine the feasibility of using the BRC for UST CP measurements. This would place the reference electrode in the same strata which is expected to receive full cathodic protection. This of course is based upon the assumption that, at least at the bottom of the UST excavation, conditions will be conductive enough to allow protective current flow. The data previously described, and found in Table 1, indicates that a non-conductive environment immediately surrounding the anode is possible. In such a situation the dormant condition of the anode can be a result of an inert, homogenous backfill typically specified and installed. These backfills include "sand, crushed rock, and pea gravel ."[3] Uniform, free draining backfill provides several obvious advantages for tank installations, such as uniform compaction and support, ready availability, and less corrosive service conditions than most native fill materials.

Several factors were considered during the development of a prototype BRC for UST's with CP. These considerations included cost, ease of installation, user friendly operation, accuracy of data, and long service life. The prototype was originally designed for installation with a new tank; however, the BRC models used in the study were all retrofit onto a single existing cathodically protected UST. The primary advantage to this approach was that it provided greater control over installation, and allowed a comparison study of the BRC's in the same environment. The comparison was between several different types, and brands of BRC's. Consequently, all of the BRC's were subjected to the same possible changes in resistance and soil chemistry. The BRC types included copper/copper sulfate, zinc/zinc sulfate, and zinc. All of the cells were specially designed to be accommodated by the installation assembly (Figure 1).

EXPERIMENTAL PROCEDURE

The BRC's, six in total, were installed at the same depth and at the same distance from an 8000 gallon UST with factory-installed cathodic protection. The BRC's were oriented alongside the length of the tank (Figure 2). An in depth CP survey had previously verified that the tank was properly installed in accordance with the manufacturers recommendations. At the same time of the BRC installations, a CP half-cell potential measurement was obtained using a portable CSE. Half-cell potentials were obtained both directly above the tank and from a remote reference electrode placement location. The average of these two half-cell potential readings is within 0.055 volts dc when compared to the initial BRC half-cell potentials. Previous half-cell potential measurements obtained at least twelve months earlier had been recorded at -0.8 volts or better when tested with a portable CSE. It should be noted that extensive soil resistance measurements were obtained during the BRC installations. In addition, soil box resistance tests were performed later. The backfill material was recorded as clean sand.

The resistance data recorded during installation was obtained using the single-pin probe technique with a Nilsson, Model 400, soil resistance meter. Resistance measurements were obtained at 2' intervals in depth via an augured hole in the UST backfill area. During the continued auguring backfill samples were removed for soil box resistance measurements using a Miller Soil Box and Nilsson soil resistance meter.

Prior to final connection to the individual at-grade test stations each BRC was checked against a portable CSE as a means of calibration. Once the final connections were complete a half-cell potential was obtained from each of the BRC's (October 31, 1991). The half-cell potentials obtained for the zinc BRC and the zinc/zinc sulfate BRC were converted to the scale of half-cell potentials obtained for copper/copper sulfate BRC's. This was done to allow a more convenient means of evaluating the data simultaneously. The BRC's were monitored weekly for a period of 173 weeks. A final reading was provided for the week of May 29, 1995.

RESULTS

The single-pin resistance results are shown in Table 2. The soil box data indicated the backfill to have a resistance of over 11 megohms-cm when dry; 890,000 ohm-cm when moist; and 79,000 ohm-cm when wet (saturated). The conditions at the site were observed to be very wet near the surface and progressively dryer as the auguring neared the bottom of the excavation. This was attributed to the fact that it had been raining the day before and the morning of the BRC installation.

The initial reading obtained just after the final connection of each BRC is found in Figure 3. This figure uses the local (directly above the UST) half-cell potential as a base line for the initial remote and subsequent BRC readings. The unusual reading provided by the BRC identified as "B" could not be explained and was not considered when the half-cell potential difference of 0.055 volts between the local/remote average and the BRC's was established. The values assigned to the remote half-cell potential and each BRC half-cell potential in Figure 3 reflect the difference between the local and each BRC. The values assigned in Figure 4 represent the change in half-cell potential for each BRC after one week in service. These are considered to be the more stable initial half-cell potentials obtained once the BRC's became acclimated to their environment.

The purpose of the data study was to track the stability of BRC type, as well as the data accuracy. Over the long term, significant trends in half-cell potential reading variations are evident. For the purpose of this study a trend was considered to be an event which impacted the half-cell potential reading for all of the BRC's. The data charted in Figure 5 through Figure 7 is intended to show a data trend or a significant change in half-cell potential for each BRC. Therefore, the corresponding data values are not provided. Figure 5 represents the first example of such a trend. The trends are attributed to changes in moisture content for the backfill, possibly on a seasonal cycle.

Furthermore, several anomalies were noted with individual BRC's, apparently at random. Several of these are indicated in Figure 6 and Figure 7. As the study reached the latter stages of data collection the anomalous half-cell potentials became more frequent, and the data bordered on erratic for several of the BRC's (Figure 8). From the data obtained it was obvious that the differences in BRC location along the length of the tank did not impact the performance enough to result in the erratic data. BRC half-cell potential measurements were compared with half-cell potentials obtained using a portable CSE. These readings were performed at random intervals. The values assigned in Figure 9 and Figure 10 represent the change in half-cell potential for each BRC as compared to the half-cell potentials obtained at the time of installation. For example, Figure 10 indicates the protective level for the tank improved relative to all of the BRC's. The data provided by one of these exercises is found in Figure 9. A more recent follow-up visit was performed on April 17, 1997 when half-cell potentials from the BRC's were once again compared to a portable CSE. This is the data shown in Figure 10.

SUMMARY

Based upon the data obtained during the investigative study it is evident that the copper/copper sulfate BRC's provided more stable performance than their zinc/zinc sulfate and zinc counterparts. However, several of the copper/copper sulfate variety demonstrated unstable performance over the long term. It must be noted that the BRC's began the service portion of the study with half-cell potentials separated by 0.053 volts (excluding BRC 'B') and 0.075 volts at the first week reading. Within 4 months the BRC's had been classified into two distinct groups, separated by 0.20 volts. Similarly, in less than two years erratic data was recorded which caused us to question the reliability of future data obtained from the BRC's affected. To reconcile the discrepancies between the data obtained from the BRC's, one must consider the electrode design, seasonal influences, and the nature of the reference material. The effect of seasonal variations in backfill moisture content can be observed through a comparison of Figure 9 and Figure 10. The data represented in Figure 9 was obtained during a typically dry autumn, whereas the data represented in Figure 10 was obtained during an unusually wet spring. Comparing Figure 9 and Figure 10, the half-cell potentials obtained on the different dates differed by as much as 0.43 volts for the worst case BRC while the local half-cell potential difference was only 0.18 volts.

CONCLUSIONS

1. Significant differences in half-cell potential level were observed between the local, remote, and BRC data obtained during the study. This is significant in the fact that this is further support that a single half-cell potential measurement among a set of data should not be used as a basis for stating that a UST does not meet a criteria for corrosion protection. Hence, tank owner/operators with cathodic protection systems should not make rash upgrade decisions based upon a single measurement taken at a three year interval.

2. Although BRC's are a practical approach to obtaining consistent data for certain types of CP installations, great care should be taken to assure that the BRC is well within an established calibration tolerance. This may be accomplished through several methodologies. The data provided through the use of any reference electrode, including BRC's, should always be examined for accuracy based upon the practical expectations of the CP system performance. Historical CP performance data obtained prior to the installation of a BRC as a retro-fit, when available, is always a beneficial comparison tool. The one consideration which should never be forgotten during the evaluation of data obtained from a BRC is that not all buried reference electrodes provide identical results, hence, not all provide accurate results.

REFERENCES

1. "Underground Storage Tank Cathodic Protection Testing at Nine Sites in Ohio and Wisconsin", Corrpro Companies Inc., June, 1991.

2. Sti-P3®, Specification and Manual for External Corrosion Protection of Underground Steel Storage Tanks, Steel Tank Institute, Lake Zurich, IL., 1996, p. 52.

3. PEI RP100-94, Recommended Practices for Installation of Underground Liquid Storage Systems, Petroleum Equipment Institute, Tulsa, Ok., 1994, p. 8.

Table 1
CP Potential and Soil Resistance by Test Depth

Depth (Feet)	Resistance (ohm-cm)	Potential (v dc)
1	97,000	-725
2	82,000	-760
3	163,000	-743
4	111,000	-755
5	203,000	-781
6	274,000	-824
7	73,000	-844
8	79,000	-912
9	3,200	-989
10	2,900	-1009
11	2,700	-1001

Table 2
Single-pin Resistance Data for BRC Study

Depth (Feet)	Resistance (ohm-cm)
2	4,700
4	6,300
6	14,200
8	12,000
10	34,000
12	77,000

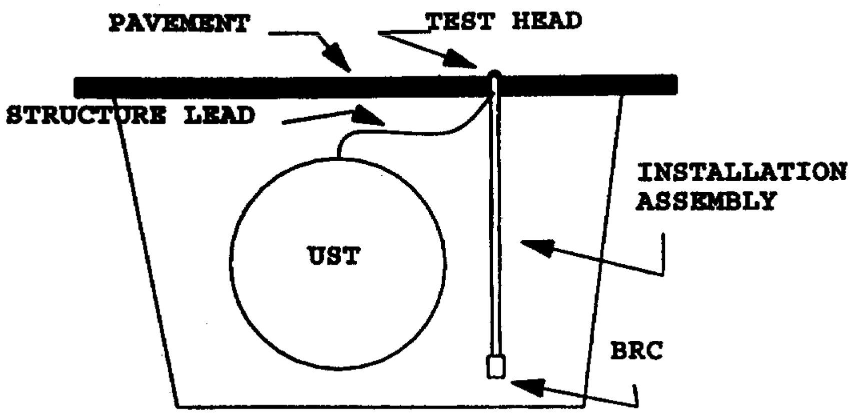


FIGURE 1 - PROTOTYPE BRC

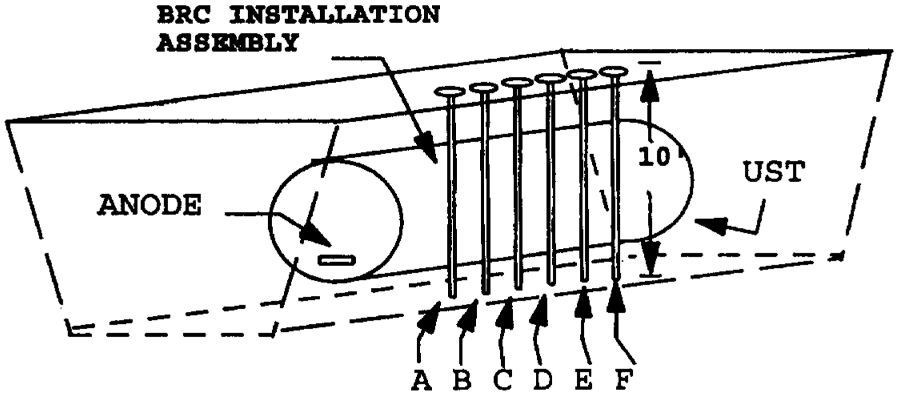
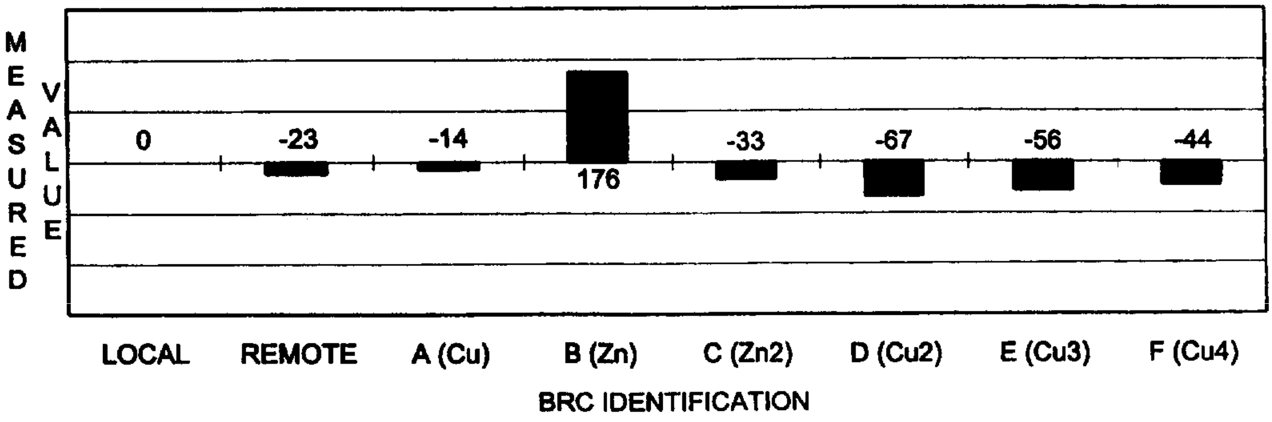


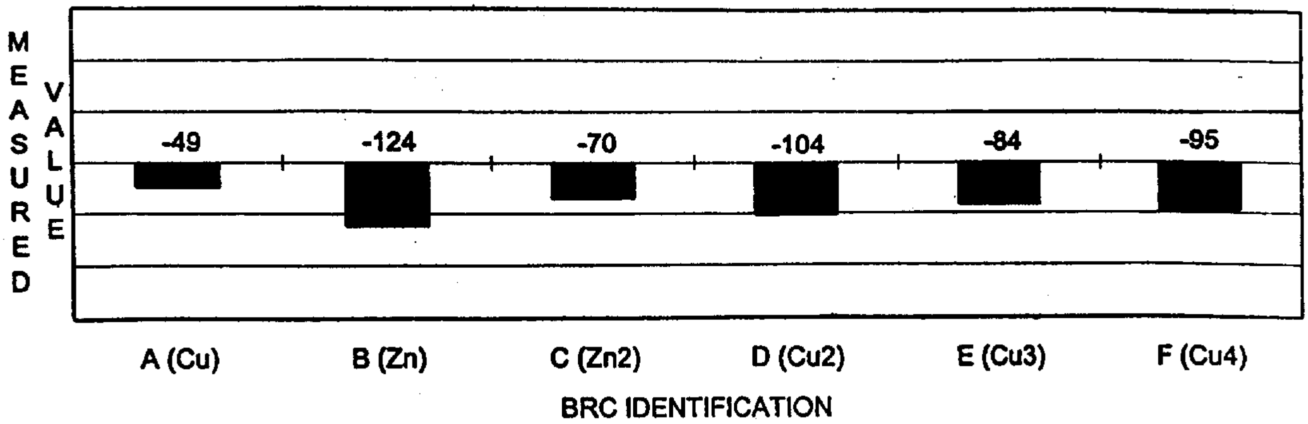
FIGURE 2 - BRC ORIENTATION

FIGURE 3



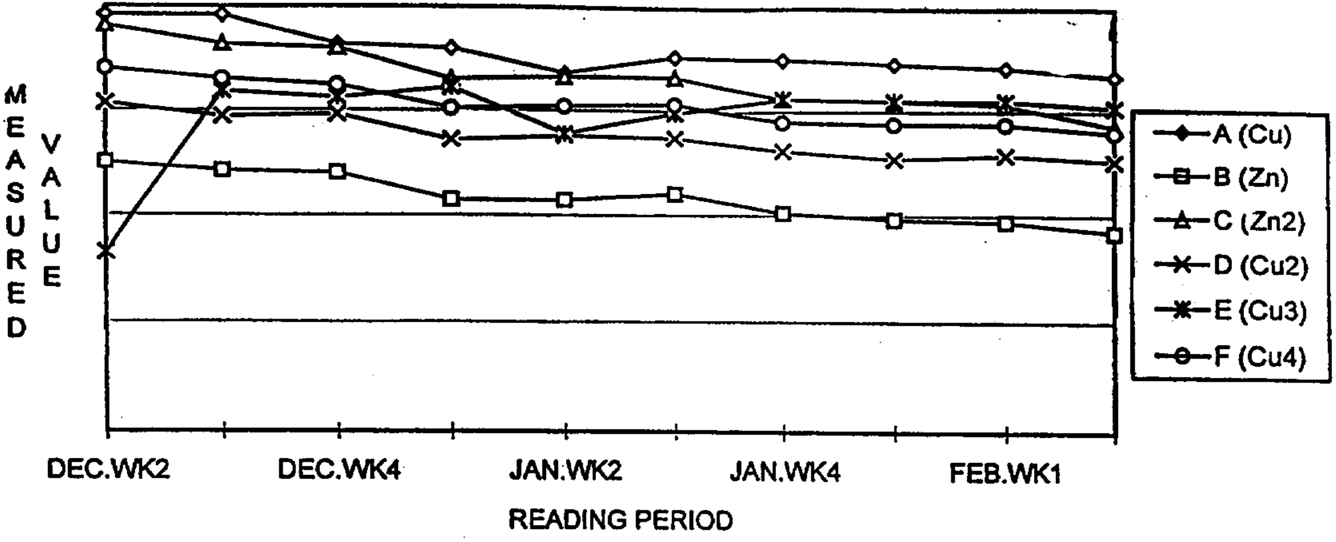
BRC INSTALLATION READINGS

FIGURE 4



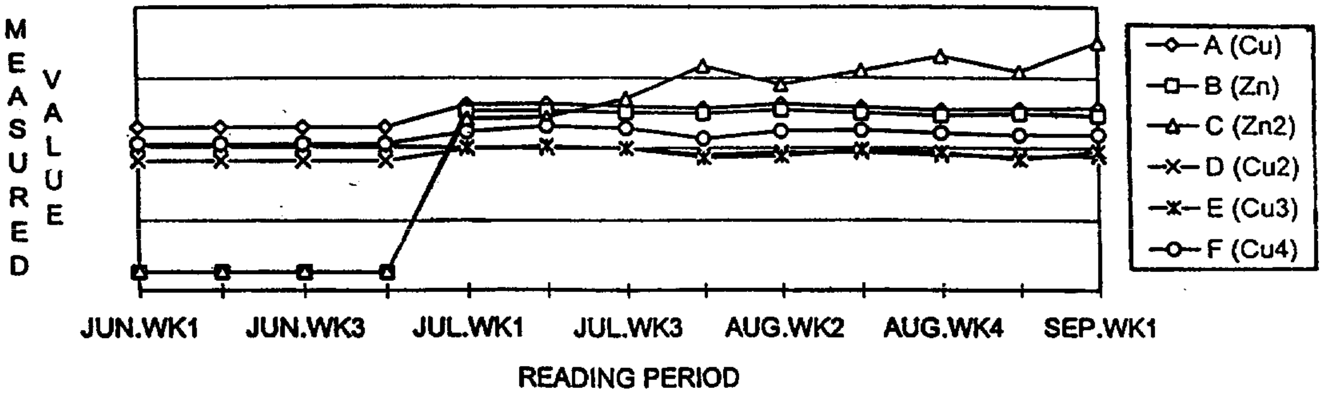
BRC - WEEK 1 READINGS
NOVEMBER-1991

FIGURE 5



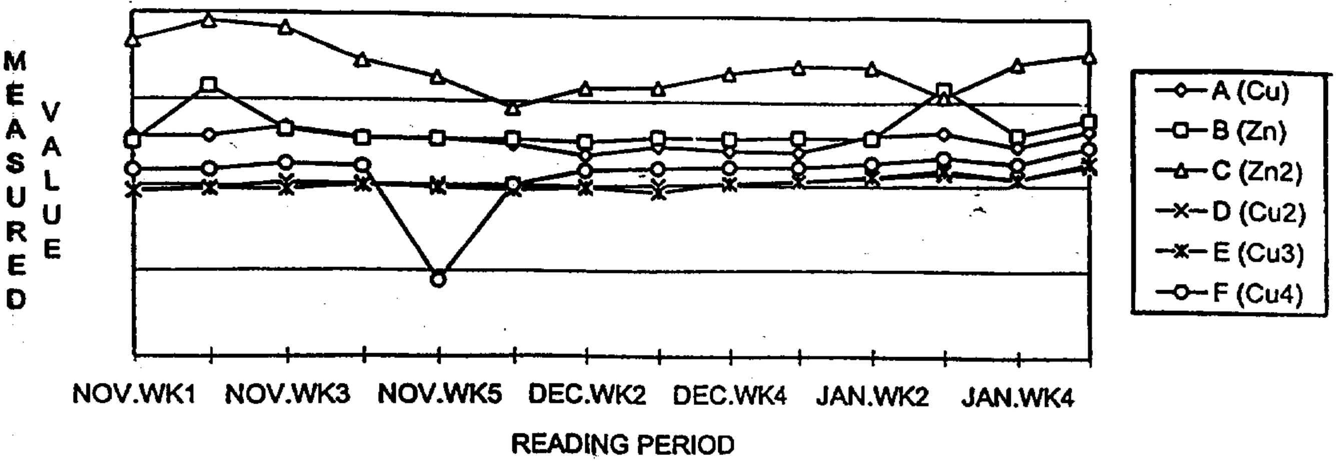
BRC READINGS TREND
DEC. 1991 - FEB.1992

FIGURE 6



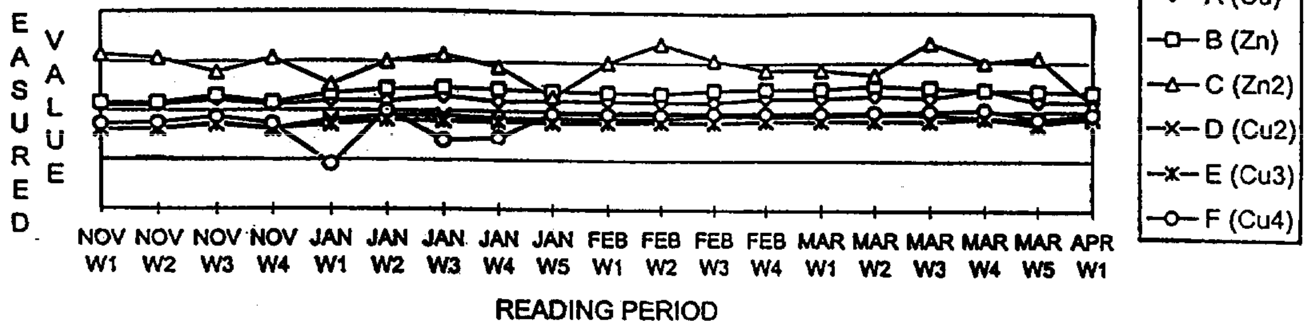
MEASUREMENT ANOMALIES #1
JUNE 1993 - SEPT.1993

FIGURE 7



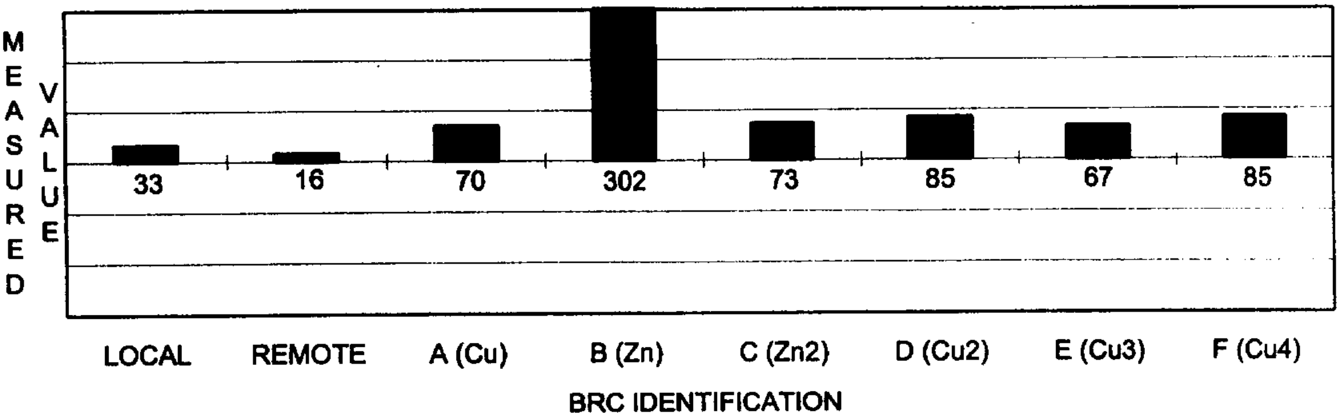
MEASUREMENT ANOMALIES #2
NOV. 1993 - FEB. 1994

FIGURE 8



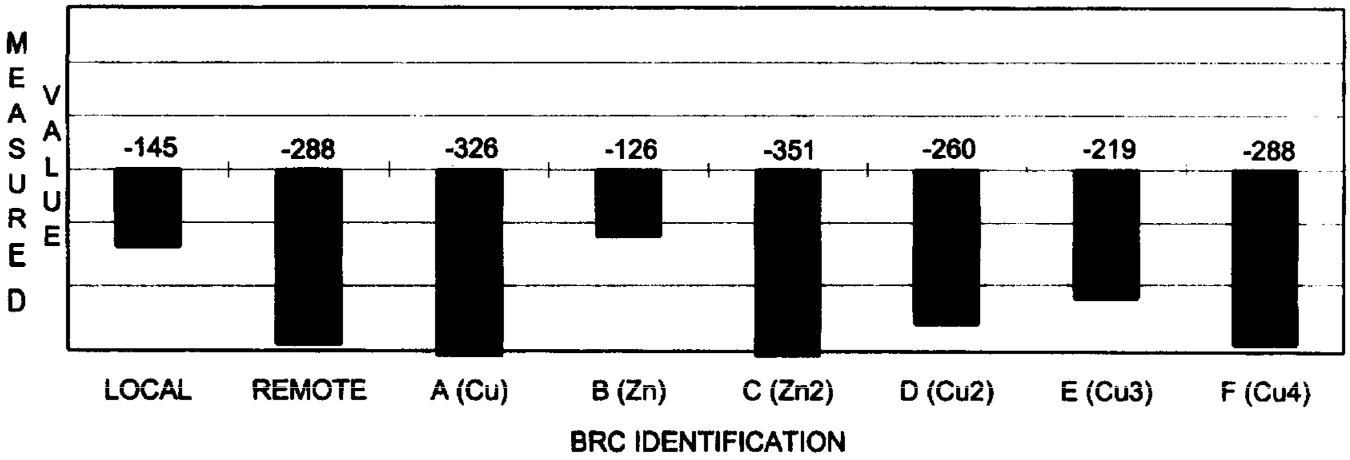
ERRATIC DATA
NOV. 1994 - APRIL 1995

FIGURE 9



FOLLOW-UP #1
OCTOBER 6, 1992

FIGURE 10



FOLLOW-UP #2
APRIL 17, 1997