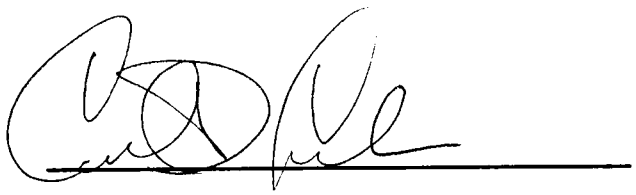
To the Graduate Council:

I am submitting herewith a thesis written by Gary L. Riner entitled "Electrochemical Studies of Microbiologically Influenced Corrosion in Austenitic Stainless Steel Weldments in the Tennessee River, Knoxville, Tennessee, and the Guadalupe River, Victoria, Texas." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Metallurgical Engineering.



Carl D. Lundin, Major Professor

We have read this thesis and recommend its acceptance:

E. E. Stansbury

Raymond A. Buchanan

Accepted for the Council:



Associate Vice Chancellor
and Dean of The Graduate School

STATEMENT OF PERMISSION TO USE

In presenting this thesis in partial fulfillment of the requirements for a Master's degree at The University of Tennessee, Knoxville, I agree that the Library shall make it available to borrowers under rules of the Library. Brief quotations from this thesis are allowable without special permission, provided that accurate acknowledgement of the source is made.

Permission for extensive quotation from or reproduction of this thesis may be granted by my major professor, or in his absence, by the Head of Interlibrary Services when, in the opinion of either, the proposed use of the material is for scholarly purposes. Any copying or use of the material in this thesis for financial gain shall not be allowed without my written permission.

Signature Gary L. Rinn

Date 11/17/93

ELECTROCHEMICAL STUDIES OF MICROBIOLOGICALLY INFLUENCED CORROSION IN AUSTENITIC STAINLESS STEEL WELDMENTS IN THE TENNESSEE RIVER, KNOXVILLE, TENNESSEE, AND THE GUADALUPE RIVER, VICTORIA, TEXAS

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Gary L. Riner

December 1993

DEDICATION

I would like to dedicate this thesis to my family and especially to my mother. I was the first child in either my father's or mother's families to obtain a college degree. Neither of my parents had or have college degrees. My mother was inspirational throughout my early school years in continually instilling in me the value of further education. My mother stood behind me and encouraged me to major in engineering even when my high school guidance councilor suggested I look into another field. My parents worked diligently to pay my way through college and provide me with the spending money necessary for those years. My mother passed away in December of 1990 of a massive heart attack, and I wish she was here today to see me obtain even a further degree of education. It is to her I dedicate this paper.

I would also like to thank my wife, Marcia, and my children, Dena and Travis, for providing me the time and inspiration to keep going and obtain this degree. I know I cannot make up the family time that we have lost, but hopefully we will all be better for it in the long run. I love you all!

ACKNOWLEDGEMENTS

The author would like to thank the Nickel Development Institute (NIDI) and DuPont for sponsoring this project. Mr. Art Tuthill and Mr. Greg Kobrin were the project managers for NIDI and DuPont, respectively, and the author would like to thank them for their guidance and helpful suggestions made during this research.

The author then wishes to express his sincere appreciation to Professor Carl D. Lundin of the Materials Science and Engineering Department for providing the author the opportunity to work on this project. The author also thanks him for his professional leadership, helpful advice, stern stewardship, and patience during this research project.

The author would like to thank Dr. Joseph E. Spruiell, Head of the Material Science and Engineering Department, for writing the graduate school and obtaining an extension of course work. The author should also thank Dr. Carl Lundin and Dr. Ray Buchanan for assisting in the preparation of the extension request.

The author would like to thank the remainder of his committee, Dr. Ray Buchanan of the Materials Science and Engineering Department for his support and guidance during this research paper in the areas of corrosion measurements and Microbiologically

Influenced Corrosion (MIC), and Dr. Eugene E. Stansbury of the Materials Science and Engineering Department for providing the author the understanding of fundamental electrochemical corrosion techniques and theory.

A very special thanks goes out to Ping Li, a doctoral student in the Materials Science and Engineering Department, who assisted the author in setting up the test, in preparing coupons, in taking readings during his absence, in disassembly, and all the other help he provided. Mr. Li has become a very dear friend of the author during this research project and his professional input was truly appreciated.

The author would like to thank Jan Bullen and Dr. Peter Angel from the Center for Environmental Biotechnology (CEB) for their assistance in collecting samples for microbiological analysis. Mr. Angel also assisted in suggesting various research papers to read in support of this research and provided timely response of microbiological analysis data.

The author would also like to thank Alica Sharpe from the Analysas Corporation who was instrumental in assisting the author in the typing of this research project, in the preparation of charts, preparing for presentations, etc. Ms. Sharpe spent many hours in support of this project, and she is commended for her efforts.

Other contributors to this project were Jimmie Patterson, Analysas Corporation; David Arakawa, Department of Energy; Dennis Meinert, Tennessee Valley Authority; and Eddie Black, Knoxville Utilities Board.

ABSTRACT

Microbiologically influenced corrosion (MIC) has been identified as a serious problem in a number of industries including power generation, chemical, pulp and paper, gas transmission, and shipbuilding. The National Association of Corrosion Engineers (NACE) estimates that MIC contributes several billion dollars in costs to industry each year.

The MIC phenomenon is complex and has been observed in sea water, brackish water, fresh water, petroleum products, and even in some deionized water systems. Materials such as carbon steels, low-alloy steels, stainless steels, copper-nickel alloys, and high nickel alloys have been shown to be susceptible to MIC.

The purpose of this study was to determine the basic mechanisms by which MIC attacks austenitic stainless steel weldments (AISI types 304L and 316L) and to determine potential postweld treatments that may mitigate MIC. In order to study these effects, two field test sites were chosen: (1) the Tennessee River in Knoxville, Tennessee, where MIC has been shown to be a problem for the Tennessee Valley Authority (TVA) fossil and nuclear plants; and (2) the Guadalupe River in Victoria, Texas, where MIC of stainless steel weldments has occurred in a Dupont Chemical Facility.

The methodology employed in this study consisted of utilizing test cells containing thirteen welded stainless steel coupons with various postweld treatments and conducting electrochemical measurements as a function of time to determine if and when MIC occurred. A 2-1/2 inch diameter stainless steel pipe string consisting of welds with treatments similar to those in the test cells also was set up to evaluate MIC in an actual pipe weld configuration.

Two sets of test cells were installed at the Tennessee River site, one in April 1992 and the second in August 1992. Both sets were disassembled in September of 1993 and none of the test coupons revealed any MIC. The test coupons in one of the four cells demonstrated low open-circuit potentials. These low potentials were contributed to a depletion of available oxygen on the surface of the test coupons. Visual observations of that cell revealed a thick coating of slime adhered to the coupon surfaces. Microbial analysis on the surfaces of the coupons revealed the presence of sulfate reducing bacteria (SRBs), anaerobic bacteria and aerobic bacteria. Microbial assays performed on samples from each of the cells identified a consortia of bacteria thought to be conducive to MIC. Possible reasons why no MIC was observed in the test cells as opposed to piping systems in the TVA plants are: (1) the cathode to anode area ratio on the coupon surface once it was covered with biofilm may have been insufficient to set up an oxygen-concentration corrosion cell; (2) the kinetics of MIC are not well established and the time for

the corrosion process to occur may have been insufficient; (3) the water temperature of the Tennessee River varied throughout the year from 14 to 25° C, as opposed to water inside plant piping that may sit stagnant at temperatures in excess of 32°C for long periods of time thus enabling the bacteria to grow more rapidly and the corrosion process to occur more quickly; and (4) the probability of obtaining all the critical parameters necessary for MIC to occur on 13 linear inches of weld in a test cell is far less than that in a plant with thousands of linear feet of weld metal. If a certain oxide film, crevice, microstructure, flow rate, water chemistry, etc., is necessary to promote MIC, the probability of having the precise parameters occur coincidentally with a reduced size weldment is low. A more detailed discussion of these findings is found in the conclusion of this report.

The Tennessee River pipe string assembly, installed in August of 1992, was also disassembled in September of 1993 and no MIC was observed. The pipe contained a layer of sediment (approximately one inch deep) which contained Asiatic clams and a wide consortia of bacteria. No explanation other than those mentioned above could contribute to the reason there was no MIC.

Similar test coupons and pipe string have been field exposed on the Guadalupe River in Victoria Texas since March of 1993. To date, there have been no indications of MIC from the electrochemical

measurements or visual inspections on either the coupons in the test cells or the pipe weldments. These test samples will be field exposed for one year or until MIC occurs.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	A. Bacteria Types	1
	B. Corrosion Mechanisms	3
	C. Biological Sampling	6
	D. Preventative Measures	7
	E. Electrochemical Corrosion Fundamentals	8
II.	EXPERIMENTAL PROCEDURES	18
	A. Pipe Fabrication	18
	B. Test Coupons	19
	C. Test Cells	19
	D. Pipe String	20
	E. Electrochemical Measurements	21
	F. Microbiological Test Methodology	22
III.	EXPERIMENTAL SETUP	25
	A. Tennessee River Tests	25
	B. Guadalupe River Tests	27
IV.	EXPERIMENTAL RESULTS	30
	A. Tennessee River Results	30
	B. Guadalupe River Results	39
V.	DISCUSSION AND CONCLUSIONS	40
VI.	FUTURE WORK	45
VII.	LIST OF REFERENCES	47

TABLE OF CONTENTS (CONTINUED)

CHAPTER		PAGE
APPENDICES		51
APPENDIX A.	Tables	52
APPENDIX B.	Figures	60
APPENDIX C.	12" Pipe Weld Information	190
APPENDIX D.	2 1/2" Pipe Weld Information	198
APPENDIX E.	Microbial Assay Reports	203
APPENDIX F.	Knoxville Utilities Board (KUB) Water Chemistry Analysis	215
APPENDIX G.	Tennessee Valley Authority (TVA) Water Chemistry Analysis	219
VITA		228

LIST OF TABLES

TABLE PAGE

Table 1. Initial Test Pipe Welds for MIC TN River 53

Table 2. Initial Test Pipe/Coupon Welds for MIC Investigations Tennessee 54

Table 3. Welded Test/Coupons for MIC Investigations Guadalupe River 55

Table 4. DATE, TIME, and OPEN-CELL POTENTIALS (mV vs. sat. Ag/AgCl) for Cell 1 56

Table 5. DATE, TIME, and OPEN-CELL POTENTIALS (mV vs. sat. Ag/AgCl) for Cell 2 57

Table 6. Chemical Analysis of Tennessee River Water 58

Table 7. Chemical Analysis of Guadalupe River Water 59

LIST OF FIGURES

FIGURE PAGE

Figure 1. Diagrammatic representation of active, corrosion-causing bacterial consortia development on a metal surface. 61

Figure 2. AC impedance methods demonstrating (a) the simplest electrical circuit model and (b) a Bode impedance plot (Bode 1945). 62

Figure 3. Representative test coupon after removal from 12 inch pipe. 63

Figure 4. Schematic diagram of test coupon. 63

Figure 5. Two MIC test cells ready for installation. 64

Figure 6. Closeup of test coupon. 64

Figure 7. Pipe test string on the Tennessee River using PVC couplers and the stainless steel pipe weldments. 65

Figure 8. Map showing Tennessee River, Fort Loudon Reservoir and approximate location of test site. 66

Figure 9. Boat house and Tennessee River location where test were performed. 67

Figure 10. Schematic diagram showing layout of test cells and pipe string on the Tennessee River. 68

Figure 11. Photo of the entire MIC test setup on the Tennessee River. 69

FIGURE PAGE

Figure 12. Photo of test cells and their location inside the wooden crate. 70

Figure 13. Coupons 1-22 and 1-23 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 71

Figure 14. Coupons 2-16 and 2-17 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 72

Figure 15. Coupons 3-19 and 3-22 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 73

Figure 16. Coupons 4-3 and 4-4 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 74

Figure 17. Coupons 5-5 and 5-6 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 75

Figure 18. Coupons 6-4 and 6-5 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 76

Figure 19. Coupons 7-7 and 7-8 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 77

Figure 20. Coupons 8-18 and 8-19 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 78

FIGURE PAGE

Figure 21. Coupons 9-36 and 9-37 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 79

Figure 22. Coupons 11-8 and 11-9 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 80

Figure 23. Coupons 12-19 and 12-20 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 81

Figure 24. Coupons 13-10 and 13-11 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 82

Figure 25. Coupons 14-1 and 14-2 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 83

Figure 26. Photo of MIC pipe string on the Tennessee River 84

Figure 27. Schematic listing stainless welds and their respective location in the Tennessee River pipeweld test string. 85

Figure 28. Map showing Guadalupe River, Victoria, Texas and approximate location of test site. 86

Figure 29. Photograph of the fire station pump house at a Dupont Plant in Victoria, Texas. 87

Figure 30. Photograph of the MIC test setup inside the fire station pump house. 87

FIGURE PAGE

Figure 31. Coupons 1-33 and 1-34 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 88

Figure 32. Coupons 2-26 and 2-27 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 89

Figure 33. Coupons 3-17 and 3-18 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 90

Figure 34. Coupons 4-5 and 4-6 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 91

Figure 35. Coupons 5-17 and 5-18 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 92

Figure 36. Coupons 6B-4-7 and 6B-4-8 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 93

Figure 37. Coupons 7B-4-9 and 7B-4-10 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 94

Figure 38. Coupons 8-20 and 8-21 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 95

Figure 39. Coupons 9B-4-11 and 9B-5-19 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 96

FIGURE PAGE

Figure 40. Coupons 11-10 and 11-11 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 97

Figure 41. Coupons 12-7 and 12-8 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 98

Figure 42. Coupons 13B-5-20 and 13B-5-21 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 99

Figure 43. Coupons 14B-5-22 and 14B-5-23 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo. 100

Figure 44. Schematic listing stainless weldments and their respective location in the Guadalupe River pipe test string. 101

Figure 45. Schematic diagram of test coupons showing area of corrosion product. 102

Figure 46. Coupons 1-17 and 1-18 after being placed in the Tennessee River Water for a year and a half. 103

Figure 47. Coupons 2-13 and 2-14 after being placed in the Tennessee River Water for a year and a half 104

Figure 48. Coupons 3-25 and 3-26 after being placed in the Tennessee River Water for a year and a half 105

Figure 49. Coupons 4-1 and 4-2 after being placed in the Tennessee River Water for a year and a half 106

FIGURE PAGE

Figure 50. Coupons 5-7 and 5-8 after being placed in the Tennessee River Water for a year and a half. 107

Figure 51. Coupons 6-15 and 6-16 after being placed in the Tennessee River Water for a year and a half. 108

Figure 52. Coupons 7-12 and 7-13 after being placed in the Tennessee River Water for a year and a half. 109

Figure 53. Coupons 8-15 and 8-6 after being placed in the Tennessee River Water for a year and a half. 110

Figure 54. Coupons 9-1 and 9-38 after being placed in the Tennessee River Water for a year and a half. 111

Figure 55. Coupons 11-6 and 11-7 after being placed in the Tennessee River Water for a year and a half. 112

Figure 56. Coupons 12-9 and 12-10 after being placed in the Tennessee River Water for a year and a half. 113

Figure 57. Coupons 13-12 and 13-13 after being placed in the Tennessee River Water for a year and a half. 114

Figure 58. Coupons 14-37 and 14-38 after being placed in the Tennessee River Water for a year and a half. 115

Figure 59. Representative photo of the biofilm located on the test coupons. Photo includes diatoms, corrosion product, etc. (20um) 116

Figure 60. Photo demonstrating biofilm from test samples. Photo includes diatoms, corrosion product, etc. (10um) 116

FIGURE PAGE

Figure 61. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 1-22 and 1-23 .. 117

Figure 62. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 1-22 and 1-23. 118

Figure 63. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 1-22 and 1-23. 119

Figure 64. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 2-16 and 2-17 .. 120

Figure 65. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 2-16 and 2-17. 121

Figure 66. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 2-16 and 2-17. 122

Figure 67. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 3-19 and 3-22 .. 123

Figure 68. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 3-19 and 3-22. 124

Figure 69. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 3-19 and 3-22 125

Figure 70. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 4-3 and 4-4. 126

FIGURE PAGE

Figure 71. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 4-3 and 4-4. 127

Figure 72. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 4-3 and 4-4. 128

Figure 73. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 5-5 and 5-6. ... 129

Figure 74. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 5-5 and 5-6. 130

Figure 75. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 5-5 and 5-6. 131

Figure 76. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 6-4 and 6-5. ... 132

Figure 77. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 6-4 and 6-5. 133

Figure 78. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 6-4 and 6-5. 134

Figure 79. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 7-7 and 7-8. ... 135

FIGURE PAGE

Figure 80. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 7-7 and 7-8. 136

Figure 81. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 7-7 and 7-8. 137

Figure 82. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 8-18 and 8-19. 138

Figure 83. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 8-18 and 8-19. 139

Figure 84. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 8-18 and 8-19. 140

Figure 85. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 9-36 and 9-37. 141

Figure 86. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 9-36 and 9-37. 142

Figure 87. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 9-36 and 9-37 143

Figure 88. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 11-8 and 11-9. 144

FIGURE PAGE

Figure 89. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 11-8 and 11-9. 145

Figure 90. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 11-8 and 11-9. 146

Figure 91. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 12-19 and 12-20. 147

Figure 92. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 12-19 and 12-20. 148

Figure 93. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 12-19 and 12-20. 149

Figure 94. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 13-10 and 13-11 150

Figure 95. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 13-10 and 13-11. 151

Figure 96. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 13-10 and 13-11. 152

Figure 97. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 14-1 and 14-2. 153

FIGURE PAGE

Figure 98. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 14-1 and 14-2. 154

Figure 99. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 14-1 and 14-2. 155

Figure 100. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for the Reference Platinum Electrodes in Cells 1 and 2. 156

Figure 101. Photo demonstrating the different biofilm appearances between Cell #1 (bottom) and Cell #2 (top) at the entrance point to the cells. 157

Figure 102. Photo demonstrating the different biofilm appearances between Cell #1 (bottom) and Cell #2 (top) at the mid point of the cells. 158

Figure 103. Photo demonstrating the different biofilm appearances between Cell #1 (bottom) and Cell #2 (top) at the exit point of the cells. 159

Figure 104. Coupons 1-22 and 1-23 after being placed in the Tennessee River Water for a year. 160

Figure 105. Coupons 2-16 and 2-17 after being placed in the Tennessee River Water for a year. 161

Figure 106. Coupons 3-19 and 3-22 after being placed in the Tennessee River Water for a year. 162

Figure 107. Coupons 4-3 and 4-4 after being placed in the Tennessee River Water for a year. 163

FIGURE PAGE

Figure 108. Coupons 5-5 and 5-6 after being placed in the Tennessee River Water for a year. 164

Figure 109. Coupons 6-4 and 6-5 after being placed in the Tennessee River Water for a year. 165

Figure 110. Coupons 7-7 and 7-8 after being placed in the Tennessee River Water for a year. 166

Figure 111. Coupons 8-18 and 8-19 after being placed in the Tennessee River Water for a year. 167

Figure 112. Coupons 9-36 and 9-37 after being placed in the Tennessee River Water for a year. 168

Figure 113. Coupons 11-8 and 11-9 after being placed in the Tennessee River Water for a year. 169

Figure 114. Coupons 12-19 and 12-20 after being placed in the Tennessee River Water for a year. 170

Figure 115. Coupons 13-10 and 13-11 after being placed in the Tennessee River Water for a year. 171

Figure 116. Coupons 14-1 and 14-2 after being placed in the Tennessee River Water for a year. 172

Figure 117. Photo demonstrating the difference in the appearance of the platinum reference electrodes from Cell #1 (left) and Cell #2 (right) 173

Figure 118. Schematic of the pipe string assembly installed at the Tennessee River Site. 174

FIGURE PAGE

Figure 119. Photo demonstrating sediment and Asiatic clams from the pipe string test on the Tennessee River. . . 175

Figure 120. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 1-33 and 1-34. 176

Figure 121. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 2-26 and 2-27. 177

Figure 122. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 3-17 and 3-18. 178

Figure 123. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 4-5 and 4-6. . . 179

Figure 124. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 5-17 and 5-18. 180

Figure 125. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 6B-4-7 and 6B-4-8. 181

Figure 126. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 7B-4-9 and 7B-410. 182

Figure 127. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 8-20 and 8-21. 183

FIGURE PAGE

Figure 128. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 9B-4-11 and 9B-519. 184

Figure 129. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 11-10 and 11-11. 185

Figure 130. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 12-7 and 12-8. 186

Figure 131. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 13B-5-20 and 13B5-21. 187

Figure 132. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 14B-5-22 and 14B5-23. 188

Figure 133. Schematic of pipe string assembly installed at the Guadalupe River Site. 189

I. INTRODUCTION

Corrosion is one of the most costly problems facing industry today. There are several types of corrosion that are well understood and some which are not well characterized. The phenomenon of MIC just recently has been readily accepted as one of the mechanisms whereby corrosion of metallic materials can be initiated or accelerated. The recognition of this phenomenon has spurred numerous investigations both in microbiology and engineering disciplines. This section will summarize some recent findings and identify: (1) the types of bacteria and their postulated role in corrosion; (2) some of the postulated theories for this corrosion; (3) mechanisms for the identification of bacteria related to corrosion; (4) methods for prevention; and (5) electrochemical measurement techniques.

A. BACTERIA TYPES

Microbiological organisms, or microbes as they are more commonly known, may be classified in four general groups: (1) bacteria, (2) fungi, (3) algae, and (4) yeasts. These groups broadly represent all of the flora and fauna of the microbiological world.[1] Certain species from all these groups are known to influence corrosion of metals.[2] In most cases, the corrosion is highly localized and may be difficult to monitor or detect prior to serious damage.

From a corrosion standpoint there are six general classifications of corrosion initiating microbes:

Acid Producers - Some microbes can oxidize sulfur compounds to sulfuric acid; a pH as low as two has been recorded where sulfur oxidizing microbes are active. Others may produce organic acids from organic compounds. An example of this type bacteria is an aerobic sulfur bacteria, *Thiobacillus thiooxidans.*

Mold Growers - These are primarily fungi. Examples of the aerobic spore forming bacteria are *Bacillus mycoides* and other *Bacillus* species. These mold and spore formers add to slime problems.

Slime Formers - Certain algae, yeasts, bacteria, and fungi fit this class. The deposits they form create oxygen concentration cells and foul equipment. Several examples of slime forming bacteria are *Aerobacter aerogenous, Flavobacterium, Proteus vulgans, Pseudomonas aerginosa, Serratia,* and *Alcaligenes.* These slime formers may produce green, yellow, pink, grey, or brown slime on metal surfaces.

Hydrocarbon Feeders - Virtually all microbes feed on hydrocarbons, but those of specific concern to corrosion disbond or destroy organic coatings and linings.

Sulfate Reducers - Perhaps the most publicized class of corrosive microbes, they reduce sulfates to sulfides and depolarize cathodic sites on metal surfaces by consuming hydrogen. An example of the anaerobic sulfate-reducing bacteria is *Desulfovibrio desulfuricans.*

Metal Ion Concentrators/Oxidizers - Iron and manganese bacteria are important examples of this class. They generally form thick, bulky deposits which create concentration cells and/or harbor other corrosive microbes. Examples of these types are iron bacteria such as *Crenothrix, Lepothrix, and Gallionella.*[3,4]

The bacteria mentioned above are commonly found throughout the soils and waters in the United States. Their concentrations may vary but most are able to adapt to the surrounding environment. A brief description of the postulated mechanisms of corrosion related attack for each bacterial category and their interrelationships to each other is detailed under the corrosion mechanisms section.

B. CORROSION MECHANISMS

Most corrosion of metals associated with bacteria begins with the formation of a biofilm by a slime former. This film provides a protective coating by acting as an oxygen scavenger for sulfate reducing bacteria.[5] This is the slime formers primary role in the corrosion of metallics.[6] This role should not be taken lightly

however, without the control of these slime formers it may not be possible to control those bacteria growing under the slime layer causing the corrosion damage.

The sulfate reducers referenced earlier are the most prominent bacteria influencing corrosion in today's industry.[7] They are known, or their by-products are known, to influence attack on just about every metallic material with the exception of titanium.[8] These bacteria use the sulfate ion as an oxidizing agent for the assimilation of organic matter. Most strains also contain the enzyme hydrogenase, which further catalyzes the reduction of sulfate by hydrogen. They also use high levels of iron in their cell structure and are prevalent in iron rich environments. Sulfide reduced from sulfate reacts with available hydrogen and iron ions to form hydrogen sulfides and iron sulfides. The tie up of hydrogen ions leaves an excess of hydroxyl ions which produces an alkaline environment. These bacteria generally thrive in pH ranges of 5 - 9.5. Sulfate reducers are purely anaerobic but are commonly found in highly aerated waters and soils. In order to survive in an oxygenated environment, they coexist with oxygen scavengers like the slime formers mentioned above.[9] While the mechanisms of corrosion by these bacteria are not fully agreed upon, four different mechanisms may occur: 1) Local generation of sulfuric acid which is corrosive; 2) an extreme oxygen differential cell due to strongly

anaerobic conditions; 3) a favoring of the kinetics of metal dissolution due to tying up of metal ions at the surface as insoluble sulfides; and (4) cathodic depolarization by the hydrogenase induced reaction of hydrogen with sulfates.[10]

The acid producers, such as *Thiobacillus* oxidize sulfides to sulfates producing sulfuric acid. They are known to oxidize ferrous ions to ferric ions. These ferric ions are positively charged and draw chlorides from the water or soils thus producing a highly corrosive ferric chloride. In bulk solutions with less than 1 ppm chloride as high as 1000 ppm have been noted in localized areas beneath the biofilm.[11] The formation of the aforementioned compounds results in a highly acidic environment with a pH of approximately 1.0.

The metal ion concentrators/oxidizers, such as *Gallionella,* have unique corrosive tendencies. These bacteria are aerobes but prefer a limited amount of oxygen. They are commonly found in well waters and river basins. These organisms are kidney-shaped and exude metal hydrate in the form of twisted ribbons of filament pairs.[12] They also tend to concentrate chlorides, with the result that deposits are rich in ferric and manganic chlorides. These chloride solutions act as weak hydrochloric acid which is highly aggressive to austenitic stainless steels and causes general corrosion of carbon steels.[13] These bacteria under ambient conditions have caused catastrophic through wall penetrations in weldments and heat-affected zones in

stainless piping and vessels within a matter of weeks.[14] A general schematic demonstrating the interaction of all the different bacteria is shown in Figure 1* taken from an article in Materials Performance by Costerton, Greesy and Jones.[9]

C. BIOLOGICAL SAMPLING

Typical areas where bacteria related corrosion occurs are industrial cooling water systems, oil and gas pipe lines, waste water treatment systems, underground storage tanks, or many processes which contain small amounts of moisture.[15] In the detection of bacteria in industrial process or cooling waters, a mistake is commonly made to only sample the bacteria in the bulk water. This type of sampling only detects planktonic bacteria and can be quite misleading in characterizing the total corrosive bacteria inhabiting the system.[16] It is much more reliable to sample for sessile bacteria, those bacteria which are attached to the pipe wall or are trapped under a biofilm. The discussions above on the interaction of the different bacteria and how they may support one another are related to surface effects, and do not readily occur in the bulk water solution.

There are several sampling techniques for determining sessile bacteria counts. One of the more common instruments is the Robbins Device. This device allows the detection of sessile and planktonic bacteria in the process stream under true process conditions. There

---

* All tables and figures can be found in Appendices A and B, respectively.

are several other inexpensive sampling kits on the market today. However, it is recommended that a microbiologist be involved, at least periodically, in the evaluation and testing.

D. PREVENTATIVE MEASURES

Methods for the prevention and control of bacteria induced corrosion vary widely but consist principally of one of the following: (1) a change to materials of construction resistant to MIC; (2) a change to a new source of water that is free from harmful bacteria; or (3) control of the bacteria. The first two methods are not usually economically feasible for pre-existing plants. For plants which are in the design stages, serious consideration should be given to the first two methods. In active plants in which there is a suspicion of MIC damage or MIC damage has already occurred, the preferred method is usually to control the bacteria. This can be accomplished by a number of chemical treatment schemes which depend on the design of the system, the bacteria present, the process fluid, and if the system is discharged per a National Pollutant Discharge Elimination System (NPDES) permit. The various chemical treatment systems are too numerous to list here but can be readily found in the literature.

A brief introduction to a complex problem reveals that only a few of the various types of corrosion influencing bacteria have been identified and their attack mechanisms proposed. Considerable effort is currently going on in the field of microbiologically

influenced corrosion and more is needed to fully understand the relationship between biofilms and metallic corrosion. The remaining portion of this report is focused on understanding how this mechanism occurs on AISI 304L and 316L austenitic stainless steel weldments, and how various treatments of the metal surface may mitigate attack.

E. ELECTROCHEMICAL CORROSION FUNDAMENTALS

As denoted earlier microbial films with varied composition and thickness develop on metal surfaces in contact with aqueous environments. The microorganisms residing within these biofilms cause metabolic reactions which can promote or impede the biodeterioration of metals. All confirmed cases of MIC on austenitic stainless steels have been localized, with particular occurrences at weldments or heat-affected zones. MIC is no different than other forms of metallic corrosion and the techniques used to study it are electrochemically derived. Three factors are generally important in localized attack of a stainless steel: (1) differential aeration; (2) cathode/anode surface area ratio; and (3) pH changes at anodic and cathodic sites. In many abiotic environments, diffusion of oxygen to the metal surface will be the rate-controlling step in the corrosion process.[17]

Corrosion is defined as the destructive attack of a metal by chemical or electrochemical reaction with its environment. MIC is a

phenomenon where the microbes assist in setting up the environment necessary to induce corrosion. Any metal surface is considered a composite of electrodes electrically short circuited through the body of the metal itself and as long as moisture is not present corrosion is not observed. But upon exposure to an aqueous environment local-action cells are able to function by converting the metal to corrosion products. These areas of electrical charge are known as either a cathode (+ positive local electrode) or an anode (- negative local electrode). The variation in the two surface areas creates a flow of current (i.e., electrons) thus resulting in corrosion.

CORROSION POTENTIAL AND ELECTROCHEMICAL POLARIZATION

The open-circuit corrosion potential, E_{corr}, is the potential at steady state during which the anodic reaction (metal dissolution) is proceeding at the same rate as the cathodic reaction (usually oxygen or hydrogen reduction) in a given environment. The measurement of the corrosion potential requires a stable reference electrode, an electrometer or voltmeter with high input impedance, and in most cases an appropriate recording device.[18]

The corrosion potential is a function of many variables, such as the metal itself, the composition of the electrolyte, the pH value, etc. Thus it provides the least electrochemical information on the corrosion process. The measurement of the corrosion potential alone cannot account for the corrosion mechanisms without other

electrochemical information. With respect to active materials (no passive films), the corrosion potential does not usually change much with time because it is unlikely that the environment will polarize the material far away from the corrosion potential. However, with respect to passive materials, the corrosion potential sometimes can give direct information as to whether the materials are in the active or passive state. Significant changes in potential can occur because a small corrosion current can polarize the materials out of their initial state.

Another electrochemical potential measurement that might be useful is a measurement of the reduction-oxidation (redox) potential of the environment. The redox potential is that potential associated with the equilibrium oxidation and reduction of oxygen, hydrogen or other redox species in a corrosive environment. This is usually measured on an inert electrode such as platinum. It could be used as an indicator of the corrosivity of the environment, and in most cases it can provide the extent of change in oxygen concentration and pH value of the environment, provided proper calibration is made.

Electrochemical polarization is a method capable of providing an overview of the types of reactions which occur for a given corrosion system, such as charge transfer or diffusion controlled reactions, passivity, transpassivity and localized corrosion phenomena. It is a kinetic measurement whereby the electrode

under study is polarized in either the anodic or cathodic direction by application of an external current. The kinetic behaviors of expected or predicted reactions can be studied since the potential and external current are definitely functions of the electrochemical reactions. Other characteristics of materials also can be obtained from electrochemical polarization curves, such as pitting potential, protection potential, susceptibility to localized corrosion, etc. The polarization technique, however, needs to scan the potential to a large extent, which leads to progressive modification of the surface conditions of the material, thus not lending itself to be a useful method for MIC studies.

ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

Electrochemical impedance spectroscopy (EIS) is a new powerful technique which was introduced in corrosion applications in recent years. The power of EIS lies in the fact that it is essentially a steady-state technique that is capable of accessing relaxation phenomena covering a wide range of relaxation times. The steady-state character provides a means of attaining corrosion rate data without destroying interfacial equilibrium, while the study of relaxation permits a method for investigating interfacial reaction mechanisms.[19, 20, 21]

EIS FUNDAMENTALS

EIS is an ac method for evaluating corrosion rates unlike those methods discussed earlier that are all dc derived. AC methods, like EIS, are only capable of measuring those processes fast enough to occur during the alternation of the electric field. The impedance of an electrode is measured over a wide range of frequencies (from a few mHz to several kHz) which provides information on the various processes occurring between the metal and the electrolyte.

The general approach of EIS is to apply an electrical stimulus (a known voltage or current) to the electrodes and observe the response (the resulting current or voltage). The system must satisfy the following conditions:

Causality - The response of the system is due to the perturbation applied and does not contain significant components from sporadic sources.

Linearity - The perturbation/response of the system is described by a set of linear differential laws, or the system satisfies the superposition principle.

Stability - The system is stable in the sense that the properties of the system are time-invariant.

EIS MEASURING TECHNIQUES

Basically, EIS measurements can be classified into two different techniques, i.e., in either frequency domain or time domain. Frequency domain impedance measurements are carried out using a small-amplitude sinusoidal excitation with frequency as the independent variable. A phase-sensitive detector (or lock-in amplifier) is a device that compares two sinusoidal signals to yield an output that can be used to obtain the phase difference between the signals and the ratio of peak amplitudes. Alternatively, the perturbation and response may be recorded in the time domain with time as the independent variable, and the impedance as a function of frequency can then be extracted by time-to-frequency conversion techniques such as Laplace or Fourier transformation. For instance, the Fast Fourier Transform (FFT) technique uses a computer algorithm to make a mixture of excitation waveforms of varying frequencies and then it is applied to the test system simultaneously. After the response is obtained, a Fourier transform operation is performed on this waveform to resolve it into discrete frequency data.

EIS APPLICATIONS TO THE CORROSION OF MATERIALS

Interfacial impedance is usually presented as an equivalent electrical system approximating the real system. Figure 2(a) is an equivalent circuit for a bare metal electrode surface (i.e. stainless steel test coupon) on which a reaction occurs (i.e. MIC) and is

represented as a reaction resistance in parallel with a double layer capacitance in series with a solution resistance.

The most accurate method of plotting the impedance over a wide range of frequencies is the Bode plot. For the equivalent circuit described in Figure 2(a), assuming the solution resistance between the corrosion specimen and reference electrode (R_s) to be negligible, the Bode plot consists of two frequency domains. At low frequencies, log Z is a line with slope zero with log Z corresponding to log R_p, where R_p is the polarization resistance. At high frequencies, log Z is a straight line with a slope of -1; when this line is extrapolated to a phase angle of zero, the intersection is -log C, where C is the double-layer capacitance. The region between the two lines is curved and corresponds to the time constant of the circuit. Figure 2(b) illustrates a typical impedance plot as a solid line (curve 1). Changes in the polarization resistance (R_p) and capacitance (C) will result in the following curve shifts: increase C (curve 2); increase R_p (curve 3); and increase R_p and decrease C (curve 4).

From the Bode plot the polarization resistance (R_p), solution resistance (R_s), and the double layer capacitance (C) can be determined. These values can then be applied to the Stern-Geary equation which provides a direct relationship between the steady state corrosion current and the polarization resistance:

$$i_{corr} = \frac{\beta a \beta c}{2.303(\beta a + \beta c)} \frac{1}{R_P}$$

Where the βa is the Tafel constant for the anodic reaction and βc is the Tafel constant for the cathodic reaction.

Polarization resistance as related to EIS was proposed by Mansfield to be given by the difference of the measured impedance in high and low frequencies due to the natures of capacitive, psuedoinductive and diffusional impedance:

$$R_p = Z(j\omega)_{\omega \to 0} - Z(j\omega)_{\omega \to \infty}$$

Polarization resistance by EIS measurement was compared with other electrochemical techniques such as small amplitude cyclic voltametry and potential step. The results showed it to be in good agreement.

The measurement of corrosion rate is not the only application of EIS as a powerful tool used in corrosion science. Many advances have been made in developing EIS for the analysis of electrochemical reaction mechanism of corroding systems. Since current in general is

a function of potential and concentration of species, which is related to the perturbation through a transfer function, theoretically, measurement of the transfer function or impedance over a wide frequency range is able to provide a great deal of kinetic information on the electrochemical reaction process.[22]

The use of EIS in MIC studies is further complicated by the addition of biofilms, nodules, etc. that have different resistive and capacitive components. These additional factors must be added to the simple circuit shown in Figure 2(a) to utilize this technique for MIC studies. In practice there are problems associated with utilizing ac impedance techniques to study MIC. The only measurement leading to the determination of the metal corrosion rate is the charge transfer resistance, all of the other values obtained from this technique are related to the reaction rates between the electrode and the electrolyte. Thus a technique known as electrochemical noise may be a more useful technique in the study of MIC.

ELECTROCHEMICAL NOISE

Electrochemical noise methods for the study of corrosion can be traced back to the work of Iverson in 1968.[23] This technique involves measuring the open-circuit potential fluctuations between a reference electrode and the working electrode. Studies of potential fluctuations under open-circuit conditions indicate that the standard deviation of the noise is related to the corrosion rate. In the

frequency domain, the form of the noise spectra can give information on the nature of attack and differentiate between uniform and localized corrosion. It has been demonstrated by several researchers that this technique can provide useful information about the corrosion process at the working electrode face. Several postulated mechanisms for observing potential fluctuations are: (1) minute transient changes in electrical charge on the electrode produced as a result of cathodic and anodic reactions during the corrosion process; (2) change in the cathode/anode surface ratios; (3) spontaneous breakdown of a passive film and slow repassivation of the surface; (4) gaseous hydrogen evolution.[24] As described this technique may be able to provide useful information on the kinetics of microbial attack.

II. EXPERIMENTAL PROCEDURES

A. PIPE FABRICATION

AISI Types 304L and 316L, 12-inch schedule 10 piping was used in the preparation of weldments for these tests. Four different butt welds in both 304L and 316L pipes, representative of the type of butt welds from piping shops using current industrial practices for stainless steel pipe were fabricated. The material certification and chemical analysis for the pipe and the welding materials are listed in Appendix C.

Since the pipe internal diameter (ID) surface characteristics are important variables in MIC susceptibility, several variations in surface conditions and postweld treatments were included. The weld number, piping material, filler metal, fit up, penetration, preliminary postweld treatments and remarks on the pipe welds for the investigation are presented in Table 1. The base materials, filler metals and weld preparations were chosen to simulate the most commonly found weldments in industrial applications. Variables such as fitup, various type of filler materials, no filler material, incomplete penetration to simulate a crevice condition, and no purge to simulate heavy oxide were all included in this study to distinguish their role in the occurrence of MIC. Postweld treatments, beyond the aforementioned fitup and welding variables, such as pickling,

electropolishing, grinding, and solution annealing were also chosen to provide a wide array of weldments for this study.

B. TEST COUPONS

Test samples were removed from the 12-inch pipe weldments with care being exercised to assure the ID surface integrity was preserved. A representative coupon, shown in Figure 3, is approximately 1-inch wide by 2 1/2-inches long, parallel and orthogonal respectively to the actual weldment. Prior to placing the coupons in the test cell, the edges were sealed with two coats of Amercoat 400 epoxy paint. The paint was applied to the edges and as a 1/8 inch wide strip around the face of the coupon as shown in the schematic diagram in Figure 4. The purpose of the coating was to decrease the likelihood of producing a crevice between the edge of the coupon and the test cell. Two small diameter stainless steel wires were spot welded to the back of the coupons on opposite ends away from the weld. These wires served as electrical contacts to the sample for subsequent electrochemical measurements.

C. TEST CELLS

After the coupons had been treated, coated, and the wires attached, they were mounted in the test cell apparatus shown in Figure 5. The test cell consisted of a rectangular acrylic plastic box approximately 42 inches long, 4 inches wide, and 1 3/4 inches high. A halogen-free silicone rubber was used to seal the coupons in the

cell. The sample face was mounted approximately flush with the bottom of the cell as shown in Figure 6.

Two quarter-inch stainless steel tubes attached at each end of the cells permitted flow through the cell and across the coupons. A needle valve, placed on the inlet side of the cell, accurately controlled the flow rate. A lid was fabricated for the test cells which incorporated a platinum reference electrode at one end and glass vials centered above each coupon which contained the silver/silver-chloride reference electrode used in measuring the open-circuit corrosion potentials of the coupons. Figure 5 shows a photograph of two final cell configurations ready for testing.

D. PIPE STRING

A length of 2 1/2 inch diameter AISI type 304L pipe was sectioned into several 6-inch pieces. These pipe pieces were then gas tungsten arc welded using 308L filler material. Material certifications and information pertaining to the pipe are listed in Appendix D. Various treatments similar to those utilized for the test coupons were performed on the welded pipe sections. These pipe sections were then joined into a continuous length of pipe using polyvinyl chloride (PVC) couplers as shown Figure 7. These couplers allowed the system to closely simulate a continuous welded pipe while electrochemically separating each weldment. The pipe and couplers were joined mechanically without a sealer; thus allowing for

removal of a single pipe section without destroying MIC nodules or affecting other weldments in the pipe string. This pipe string was installed in parallel with the test cells.

E. ELECTROCHEMICAL MEASUREMENTS

Open-circuit corrosion potential measurements were taken periodically on each sample during the exposure period. A portable field electrometer, Model 672 (Jenco, Taiwan), was used to record the open-circuit corrosion potentials. The electrometer was set to (mV) output and the black (-) lead was attached to a silver/silver-chloride reference electrode which was inserted into the glass vial (shown in Figure 6) containing a 10 percent potassium chloride solution. The glass vial contained a porous vycor filter which allowed the flow of current but negligible transfer of solution. The red lead (+) was attached to the stainless steel wire on the back of the sample. The open-circuit potential difference between the coupon surface and the reference (silver/silver-chloride) electrode was recorded. These data points were then converted to the standard hydrogen reference electrode (SHE) scale and used for graphical presentation.

Electrochemical impedance spectroscopy (EIS) was used to study kinetics of the corrosion process. The system consisted of an EG&G 5208 Lock-In Amplifier, EG&G 273 Potentiostat and a computer. The lock-in amplifier generated sinusoidal wave frequencies from 5 Hz to 100 kHz. The computer used an EG&G Fast

Fourier Transform technique to produce the low-frequency range which was added and sent to the corrosion cell through the potentiostat. Due to the fact that the tests were set up in the field, the EIS data were recorded only at a single point in time, just prior to completion of the exposure. These reading can provide an indication of whether the stainless steel coupons were actively corroding.

Electrochemical noise data were also obtained on each sample at the end of the exposure. The noise data provided an indication of the fluctuations of electrochemical potential at the surface of the sample which can be related to the corrosion process.

F. MICROBIOLOGICAL TEST METHODOLOGY

Several microbiological analyses were performed. Separate techniques were used to determine bacteria in the bulk water as well as on the metal surfaces. Reports provided by the Center for Environmental Biotechnology (CEB), University of Tennessee, are provided in Appendix E, including the methods employed in determining the biological populations.

Bulk water samples were taken at the Tennessee River site on May 29, 1992, from the outlet of a cell. These samples were analyzed for total bacterial count and for the presence of SRB. The following methods were used:

Acridine Orange Direct Counts: Bacteria in the water samples were stained with acridine orange to obtain total bacterial counts. A fluorescent microscope was used to count the bacteria after samples were washed through a 0.2 micron black PC membrane filter.

Sulfate-Reducing Bacteria (SRB): One ml of each water sample was added to 9 mls of an SRB culture medium under nitrogen gas, and a dilution series was carried out to 10^{-6} to test for the presence of sulfate-reducing bacteria. Positive results are obtained when test tube contents turn black from the reduction of sulfates to sulfides. The culture medium for the detection of SRB was as follows: sodium acetate, 2.8 g/L; sodium lactate (60% sol.), 2.9 g/L; yeast extract, 1.0 g/L; ascorbic acid, 0.1 g/L; $MgSO_4 * 7H_2O$, 0.5 g/L; Na_2SO_4, 0.5 g/L; K_2HPO_4, 0.5g/L; NH_4Cl, 0.5 g/L; $FeSO_4 * 7H_2O$, 0.1 g/L; NaCl, 7.0 g/L; sodium thioglycolate, 0.1 g/L.

Two principal methods were used for determining bacteria on the sample surfaces and on the sediment located in the cells: (1) culturing bacteria in an active medium and then based on solution color or direct counts, an indication of the bacteria level can be obtained; or (2) a technique called the Phospho-Lipid Fatty Acid (PLFA) analysis which was developed by Dr. David White at the CEB. An explanation of the latter technique is as follows:

All living organisms contain lipids or fats with different chemical structures as follows: Polar lipids (charge carrying, for example a carboxyl group), sterols, and lastly phospho-lipids. The latter group are those which are the most interesting in MIC studies at the present as there are certain PLFA which are indicative of certain types of metabolism and can therefore be used to differentiate different physiological groups of organisms. Two of the lowest levels of differentiation in "animal" cells are prokaryotic and eukaryotic cells. The former being bacteria which have no cell wall, just a cell membrane, and the latter being all higher organisms including man which have a cell wall, cell organelles, and a cell nucleus. The bacteria are further sub-divided into Gram negative and positive, based on the cell membranes. Gram positive have a double cell membrane and are able to retain the Gram stain consisting of a complex of iodine and crystal violet. Each group is then divided into Genera, such as *Pseudomonas, Vibrio, Bacillus*, etc. and these are subdivided into species. PLFA analysis can often identify bacteria down to the genera level although this is not always true. The ratio of certain fatty acids has been shown to be indicative of microbial stress. This ratio gives an indication of whether a bacterial population is demanding a food source or other conditions vital to their existence (i.e., dissolved oxygen, pH, organic hydrocarbons, lack of dissolved oxygen, etc.).

IV. EXPERIMENTAL SETUP

A. TENNESSEE RIVER TESTS

The specific test site in the Tennessee River was at mile marker 627.1 on the north shore of Fort Loudon Reservoir (Tennessee River), as shown in Figure 8. This location is on the main river channel where there is a continuous current and freshly supplied water. The Tennessee River is known to contain bacteria which are conducive to MIC. Several miles south of the specific test site MIC has occurred in stainless steel cooling water piping in various Tennessee Valley Authority power plants. Several biological assays on both nodules and the river water have been performed to characterize the bacteria at these locations and show sulfate reducing, iron oxidizing, and iron reducing bacteria. Chloride levels as high as 1000 ppm have been documented inside MIC nodules when only small amounts (<10 ppm) were found in the river water.

The test were performed in a boat house extending out over the river as shown in Figure 9. The river water was supplied by a submersible pump approximately 15 feet from the shoreline, and depending on the lake elevation, anywhere from 4 to 10 feet in depth. The pump rested on the bottom of the lake on a silty mud base. The pump capacity was a 1000 gallons per hour, well beyond the capacity necessary for this study. The schematic diagram shown in Figure 10 demonstrates the experimental setup. PVC pipe was

coupled to the pump and the water was supplied to a header containing three valves. Each valve supplied flow to one of three different experiments: original cells (April 92), new cells (August 92), and the pipe string (August 92). Excess water was spilled directly back into the lake through the exit valve. Figure 11 is a photo showing the entire setup inside the boat house on the Tennessee River.

Flow from valves number 1 and 2 supplied the two sets of cells which were setup on April 27, 1992, and August 24, 1992, respectively. Originally, a filter was placed in-line between valve 1 and those cells. The filter size was 5 microns, capable of removing large particles and sediments from the water. This filter was removed in October 1992 in order to increase the probability of biological activity occurring inside the cells. The flow rate was set at one ml/minute which created nearly stagnant flow conditions. The cells were mounted inside a wooden container, as shown in Figure 11, in order to prevent any natural light from impinging directly on the cells. This was done to simulate dark conditions to which a pipe interior wall would be subjected. The wooden container employed a hinged lid that provided access for visual inspections and electrochemical potential measurements. Figure 12 is a photo of the test cells inside the wooden crate.

Both sets of test cells contained coupons with treatments described in Table 2. Some coupons were removed directly from the 12-inch pipe described in Section II, Part A, and installed in the cells and some received further postweld treatments as described in Table 2. Figures 13 through 25 are photographs of the actual test coupons in their final treatment prior to installation in the Tennessee River test cells.

Flow from valve number three provided the pipe string water as shown in Figure 26. The flow in the pipe was set at approximately 2 gpm which results in a flow rate of less than one-foot per second. Figure 27 is a schematic listing the pipeweld treatments and their location within the pipe string.

B. GUADALUPE RIVER TESTS

The specific test site for the Guadalupe River evaluation was the fire station pump house located on the cooling water basin for the Dupont Chemical Plant located in Victoria, Texas. The Guadalupe River is located in the southern portion of Texas near the Gulf Coast as shown in Figure 28. The cooling water basin consists of water that has been used for cooling in the plant and direct makeup from the river. This study was prompted because Dupont had experienced MIC problems in stainless steel tanks and piping systems in the recent past.

Figure 29 is a photograph of the fire station pump house and the cooling water basin chosen for the MIC study on the Guadalupe River. The test consisted of setting up test cells and pipe segments similar to those described for the Tennessee River study. The water was obtained from a small line on a main fire protection header. Figure 30 shows the location of the test cells and pipe string inside the fire station pump house.

At the request of the Dupont engineers and the Nickel Development Institute, the postweld treatments performed on some of the coupons (described in Table 3) are different from those used in the Tennessee River tests. The reason for the changes in postweld treatments, were to try some methods that could be directly applied in the field without the serious environmental concerns created by certain acid treatments (i.e., HNO_3/HF). Treatments such as sand blasting; heat treating at 600°F for 30 minutes; solution annealing and water quenching; pickling with a 25 percent Oakite Liquacid (Oakite Products, Inc., Berkly Heights, New Jersey) solution at 140°F for 30 minutes; and pickling with a 20 percent HNO_3 and 0.25 percent Polyterge (Industrial Colloids and Chemical Co., Knoxville, Tennessee) surfactant at 140°F for 30 minutes replaced some of the standard welds used in the Tennessee River tests. Figures 31 through 43 are photographs of the actual test coupons in their final treatment prior to installation in the Guadalupe River test cells.

The pipe string was attached to the header as shown in Figure 30. A schematic diagram showing the weld treatments and their location within the pipe string is shown in Figure 44. The pipe welds received the same treatments as described for the coupons used in the Guadalupe River tests.

V. EXPERIMENTAL RESULTS

A. TENNESSEE RIVER RESULTS

The following experimental results are provided in three separate sections: (1) the original test cells (April 92), (2) new test cells (August 92), and (3) the pipe string (August 92).

ORIGINAL TEST CELLS (APRIL 92)

The original test cells were installed at the Tennessee River site on April 27, 1992. Open-circuit corrosion potential measurements were made on the samples for one month. The initial results seemed to indicate that active corrosion was taking place. From previous testing in the laboratory and at other sites, it was known that all coupons should not be actively corroding in such a short time period. The open-circuit potential results from the coupons for the two cells are shown in Tables 4 and 5. Typically, when new test cells are installed the welded coupons will have a negative open-circuit corrosion potential until the formation of a passive film characteristic of the environment. This normally occurs during the first week after installation and the open-circuit corrosion potentials will then increase to the positive range. Visual inspection of the coupon surfaces were performed and indications were that small reddish corrosion deposits were forming on the ends of the test coupons away from the weld and the heat affected zone. The deposits were forming on the edges of the samples directly above the locations

where the wires for measuring the corrosion potential were attached to the coupon as depicted in the Figure 45.

Further investigation into this corrosion revealed that carbon steel wires had been attached to the back of the coupons and were corroding from contact with the liquid leaking from inside the cells. A corrosion product was then building up on the surface of the stainless steel coupon. This could be attributed to the fact that the silicone rubber used for mounting the coupons did not completely prevent against water reaching the wires attached to the back of the coupons. At this point, the open-circuit corrosion potential measurements were stopped and new test cells were manufactured. The carbon steel wires were clipped within 1/8 inch of the back of the sample and the cells allowed to continue in the river water for visual inspection only. With time, a layer of silt approximately 1/8 inch deep formed on the coupons and it was impossible to determine their actual surface condition during the remainder of the test. There were no through wall leaks in any of the coupons and no obvious nodules on any of the surfaces at the location of the weld or heat-affected zone.

Shortly after the start of the corrosion tests, bulk-water microbiological and chemical analyses were performed. The microbiological analysis determined that the bulk water samples contained 1.65×10^5 cells/ml total bacterial counts and between 10^2

and 10^3 cells/ml Sulfate-Reducing Bacteria (SRB). This provided an indication that the potential for MIC existed at the test location.

The test cells were dismantled on September 20, 1993. Microbiological samples were taken from the sediment located on top of the coupons and directly from the surface of some coupons. In order to view the presence of any tubercles, the cells were lightly rinsed with lake water and then photographed. Some of the coupons had surface stains but there was no evidence of tubercles or corrosion associated with MIC as shown in Figures 46 through 58. The samples were removed from the acrylic cells and placed in sterilized jars containing lake water or in a glutaraldehyde solution (to enhance observing selected samples in the scanning electron microscope). The samples were taken to the laboratory for more detailed inspections. The samples were ultrasonically treated in a mild nitric acid solution and cleaned by light brushing. The samples were examined with a steromicroscope and no evidence of any pitting or MIC damage was present. The microbiological analysis from the sediment and the coupon surfaces revealed the presence of SRBs and other consortia of bacteria as listed in Appendix E. The direct counts performed on the coupons from the original test cells revealed bacteria populations of 100 cfu/ml of SRBs, 1,000 cfu/ml other anaerobic bacteria such as *Desulforibrio's*, and an over growth of the aerobic bacteria *Actinomycete* which masked the presence of other aerobic bacteria conducive to MIC. The PLFA taken on coupons

from the two cells revealed fatty acids that are indicative of sulfate reducers, diatoms, and possibly *Pseudomonas*.

The samples that were chosen for scanning electron microscopy were preserved using the following technique: The samples were immediately removed from the cell after being photographed and placed in a sterilized bottle containing a solution of 3% glutaraldehyde in 0.1 M sodium cacodylate buffer (pH 7.4) overnight. The following day the samples were given three one hour washes in cacodylate buffer followed by five separate one hour washes in 30%, 50%, 70%, 90% and 99.9% methyl alcohol. The samples were then air dried and placed in a sample bottle until examining in the SEM.

The samples fixed in the above manner were sputter coated with gold and viewed in the scanning electron microscope. A variety of different diatoms, spores, corrosion products, debris, etc. were noted on each sample. The presence of many diatoms was also indicated in the first PLFA performed on filtered water from the test cells. A total of six samples from the original and new test cells were examined. Photomicrographs indicative of all the coupon surfaces observed from both sets of cells are shown in Figures 59 and 60.

A water chemistry analysis was performed at the test site on May 29, 1992, (as shown in Table 6). Water chemistry analyses were also obtained by other organizations on the Tennessee River at

locations above and below the test site. Appendix F contains the results of the river water chemical analysis performed at the Knoxville Utilities Board Waste Water Treatment Plant located 15 miles upstream from the test site. The Tennessee Valley Authority (TVA) also collects water chemistry data on the Tennessee River one mile down stream from the test site. This information is collected as a function of depth and is provided in Appendix G. The chemical analysis confirmed that the nutrients considered to be associated with the growth of bacteria responsible for MIC were present. However, the chloride levels in the Tennessee River are quite low which may have a direct link to MIC on austenitic stainless steel.

NEW TEST CELLS (AUGUST 92)

Following the carbon steel wire difficulty with the original test cells, new cells were fabricated and identically treated stainless steel coupons were installed. The wire used for measuring the open-circuit corrosion potential was changed to type 304 stainless steel to ensure that no detrimental corrosion of the wire would occur. The new test cells were installed on August 24, 1992. Open-circuit corrosion potential measurements were taken from that date until the cells were dismantled on September 23, 1993. The open-circuit corrosion potential, EIS, and electrochemical noise data are given in Figures 61 through 99 for these two cells. The open-circuit corrosion potentials for the two platinum reference electrodes are shown in Figure 100. Note that the open-circuit corrosion potential curves

plotted in Figures 61 through 100 look essentially identical due to the axis range on the plots. The open-circuit potential measurements recorded on any given day usually varied +/- 50 mV which cannot be easily distinguished on the plots. The two new cells are denoted as Cell 1 and Cell 2 for the remainder of this discussion.

Because a substantial difference was noted in the appearance of the biofilm and sediment between the two new cells as shown in Figures 101 through 103, microbiological sampling was performed on July 27, 1993. The data listed in Appendix E confirmed that there was a difference in the biological consortia between the two new cells. Cell number 1 was denoted as brown (BR) and cell number 2 was denoted as black (BL) in the CEB report due to the appearance of the different biofilms. The results from cell number 1 (BR) analysis indicated an older microbial population consisting of SRB's, actinomyces, and other gram positive bacteria. Cell number 2 (BL) analysis was indicative of a highly stressed microbial community probably due to nutrient deprivation. Cell number 2 (BL) contained a higher population of *Desulfovibrio* species, which may account for the solution inside the cells being black. SRB's and numerous gram negative and gram positive bacteria were found in cell number 2 (BL).

Additional microbiological analyses and dismantling of the cells followed the same methodology as described for the original cells.

The biological results from coupons for both cells exhibited similar results. The SRBs ranged from 10^2 to 10^3 cfu/ml, other anaerobic bacteria ranged from 10^3 to 10^4 cfu/ml, and the aerobic bacteria cultures were overgrown with *Actinomycete* bacteria masking the populations of those conducive to MIC. Photographs of the coupons and the platinum reference electrodes taken just prior to removal from the cells are shown in Figures 104 through 117.

Although it was unable to distinguish particular strains of bacteria from work on the scanning electron microscope we were able to confirm a substantial biofilm as evidenced from the photomicrographs in Figures 59 and 60.

The open-circuit corrosion potentials, EIS, and electrochemical noise data, recorded for the two cells are provided in Figures 61 through 100. Coupons from both cells demonstrated open-circuit potentials in the range of +450mV to 700mV (standard hydrogen electrode, SHE) until April 1993 when a significant decrease was observed in cell number 2. This decrease occurred quickly and can be contributed to the formation of a biofilm different from that of cell number 1 as discussed earlier. The bacteria were able to deplete the oxygen level at the surface of the coupon thus causing a 700mV SHE drop in the open-circuit potentials on all coupons and the platinum reference electrode in cell number 2 indicating a change in the biofilm and/or solution.

Due to the arrangement of the four test cells inside the wooden crate, it was necessary to temporarily disconnect the two cells (August 1992) to remove the original cells (April 1992). By doing so, the biofilm in cell number 2 which had shown negative open-circuit potentials was disturbed and when the test cell was reconnected the open-circuit potentials had returned to the +600mV SHE range. This could be contributed to the fact that the solution inside the test cell was stirred during the temporary disconnection process allowing oxygen to diffuse back to the surface of the coupon. Both cells, number 1 and 2, remained in the +600mV to 800mV SHE range until they were dismantled.

The EIS and electrochemical noise data were taken on September 18 and 19, 1993. Unfortunately, this was after the cells were temporally disconnected and both reading positive open-circuit potentials. Both the EIS and noise data indicated that only passive corrosion at extremely low rates was taking place on the surfaces of the coupons. More useful information regarding the accuracy of these techniques in MIC studies may have been obtained if we were able to perform the measurements while the open-circuit potentials in cell number 2 were so low.

PIPE STRING (AUGUST 1992)

The stainless steel pipe string was originally installed at the Tennessee River site on August 1, 1992. On January 2, 1993,

additional welded pipe sections were added. Figure 118 is a schematic of the entire pipe assembly and shows the order (along the flow direction) of the various treated pipe segments. An inspection was performed on the pipe interiors when the loop was disassembled to add the additional sections. A layer of sediment was observed along the entire length of the pipe approximately one-half inch deep. No nodules were observed on the pipe samples but there could possibly have been some growth under the sediment. The pipe string assembly was disassembled on September 19, 1993. The entire pipe string assembly was half full of sediment and Asiatic clams as shown in Figure 119. Each pipe section was systematically removed from the string and rinsed with lake water. Once all of the sediment and clams were washed out, the interior was examined for the appearance of tubercles or pitting corrosion. However, no indications were found on any of the pipe sections. Four of the untreated pipe weldments were sectioned for viewing under the steromicroscope and no indications of pitting were observed. Following this inspection, the pipes were cleaned in a 20 percent nitric acid solution and viewed under the steromicroscope again. No pitting or MIC corrosion was observed. Two pipe sections, which were kept submerged in lake water, underwent microbiological analyses and both confirmed the presence of 10^2 to 10^3 cfu/ml SRBs, 10^4 to 10^6 cfu/ml anaerobic bacteria, and10^4 aerobic bacteria similar to the microbial results obtained from the coupon surfaces.

B. GUADALUPE RIVER RESULTS

The test cells and pipe string were installed at the Guadalupe River site on March 22, 1993. Corrosion potential measurements have been made since this date and are given in Figures 120 through 132.

A chemical analysis was performed on the water from the Guadalupe River at the fire station pump house and is listed in Table 7. Microbiological assays were also performed and the results are given in Appendix E. The microbiological analysis confirmed the presence of a bacteria population which could be conducive to MIC.

There have been no indications either visually or electrochemically to indicate any MIC activity. The pipe string has not been disassembled since installation, but there are no through wall leaks evident at this time. Figure 133 is a schematic of the pipe test string at the Dupont Plant identifying the order and treatment of the various welded sections. Both the test cells and pipe string evaluations are continuing at this time.

VI. DISCUSSION AND CONCLUSIONS

At the Tennessee River site, the original test cell coupons were field exposed for 1 1/2 years and no MIC occurred. The second generation test cells and pipe string were field exposed for 13 months and experienced no MIC. It was anticipated that MIC would occur on austenitic stainless steel welds in this raw water application. Since no MIC was observed it was not possible to determine the behavior of the various weld surface treatments on the prevention of MIC. There were, however, some interesting results, from both microbiological and electrochemical aspects that should be relevant to future studies of MIC.

The open-circuit potential measurements for the coupons from the second generation cells plotted in Figures 61 through 97 provide some interesting results. By examining the curves in Figure 61 it can be seen that on day 240 the corrosion potential significantly decreased in cell number 2. This same potential drop was noted on all of the coupons within that cell including the platinum reference electrode (Figure 100). The decrease in potential was associated with the formation of a biofilm much different from that in the other cell. The color of the water in the active cell (cell number 2) turned black while that in the other cell remained clear with a reddish colored sediment. No explanation for the difference in the cell biofilms can be provided as they both received their water supply from the same

source and had similar flow rates of approximately one ml per minute. Due to the possibility of the needle valves clogging, thus causing non-uniform flow, it is likely that the flow rates may have varied slightly. This flow variation may have been sufficient to create a difference in biofilm by altering the amount of available dissolved oxygen in the cells.

After noting this substantial change a microbiological examination was performed on each of the two cells. The cell with the black biofilm showed a higher population of SRBs and Desulfovibrio bacteria compared to the other cell. Both cells had diverse bacterial communities. The most prominent PLFA detected in both cells was attributed to anaerobic desaturation that is linked to gram negative bacteria.

The change in the open-circuit potentials can be related to the formation of a biofilm which was depleting the available oxygen on the surface of the coupons. Direct measurements of the dissolved oxygen content in the bulk water in the cells revealed a level of less than 2 ppm as compared to 8 ppm in the river. From the microbiological assays and the dissolved oxygen determination it is apparent that the microbial population was capable of depleting the oxygen at the surface of the coupon and allowing the growth of

anaerobic bacteria (SRBs). This is the condition that most researchers agree is necessary to create a microbiologically activated corrosion cell.

Another factor that could account for the lack of active corrosion is the anode to cathode area ratio available on the coupon surfaces due to differential oxygen concentration. It is apparent from the open-circuit potential plots that the biofilm formed rapidly. If the biofilm encompassed the entire surface of the coupon and depleted the oxygen at all points there is no oxygen concentration cell mechanism for enhanced corrosion as opposed to an actual pipe situation where there probably would be sites which were not covered by the biofilm thus setting up the cathode to anode areas necessary to drive the corrosion process.

It was necessary to move the second generation test cells when the original test cells were dismantled. This was accomplished on day 380 of the field exposure. It is to be noted from the open-circuit corrosion potentials measured the day after reinstalling the second generation cells in the box that the potentials shifted positive, an increase of roughly 700mV (SHE). This can be explained by the agitation of the sediment of the cells created during their movement and the disturbance of the biofilm which allowed the oxygen level to increase at the surface of the coupons. Note that all coupons behaved identically including the platinum reference electrode. After this

occurrence the cells remained stable and were dismantled before the biofilm reformed to obstruct the oxygen availability and cause the corrosion potential to decrease. Thus the EIS and electrochemical noise data taken were recorded when the samples were in the high-potential range resulting in little information being gathered related to the action of the preexisting biofilm.

As evidence from the water chemistry data shown in Appendices F and G the chloride content of the natural Tennessee River water is low (<10ppm). At the TVA plants where MIC has been a problem the water is treated with a sodium hypochlorite solution increasing the potential for chlorides which may enhance the corrosion processes. Failure analysis of MIC incident occurring in piping systems of the TVA plants has shown chloride levels in excess of 1000 ppm. The addition of the sodium hypochlorite may be the reason that corrosion occurred inside the plants and none was noted in this study.

There are other factors that may contribute to the reasons why TVA systems have experienced MIC, yet MIC was not observed in the present study. First, the length of weld on each coupon was approximately one inch which totals 13 inches for per test cell. In the TVA plants there are thousands of feet of welds yet the occurrence of MIC is random and isolated. Thus, the probability of the occurrence of proper microstructure/surface condition/

environment/etc., necessary to cause MIC is not favorable when trying to perform MIC studies on limited size coupons in the field or like-wise in the laboratory. A second major factor is time. There is little insight into the kinetics involved in MIC. Investigations suggest that under certain conditions through wall leaks due to MIC have occurred in only a few weeks, and in others, like those sites on the Tennessee River, through wall leaks took years to appear. With this in mind it is possible that the conditions conducive to MIC were present in the test cells but time did not permit the corrosion process to initiate. Thirdly, the temperature of the Tennessee River water varies substantially throughout the year as shown in Appendices F and G. The water used within the TVA plants goes through various heat exchangers and may sit stagnant at temperatures as high as 90°F thus increasing the kinetics of biological growth and the enhancement of the corrosion process. If the bacterial activity is temperature dependent this may be a significant reason why the field studies demonstrated no corrosive attack.

However, even though the effects of weld surface condition could not be determined, the aforementioned information can be applied in future studies. Recommendations for future work are provided in the next section.

VII. FUTURE WORK

It is considered that the test method employed in this study is sufficient to determine if MIC is or is not a problem. However, it is suggested that a location where all the environmental parameters (temperature, water chemistry, bacteria populations, etc.,) are known and where MIC has just been experienced be chosen as the most appropriate test site. This would allow simulation of the identical parameters and conditions where MIC has just occurred and increase the probability of determining the MIC process. To date no one apparently has been successful in causing MIC of stainless steels to occur in a laboratory environment without inducing the corrosion process by unnatural parameters such as an external current. It is suggested that the majority of the MIC research take place in the field where the condition of the test closely resemble those of the natural environment.

The test cells and pipe string on the Guadalupe River will be assessed after 1 year in a manner similar to those on the Tennessee River. Plans are to disassemble the test once there is an indication from the open-circuit potential data that corrosion is occurring. It maybe necessary to transfer the test cells intact to the University of Tennessee for additional electrochemical measurements and other analysis at that time. By maintaining the test cells in place long

term (i.e. pitting corrosion is confirmed) some of the questions remaining from the Tennessee River study may be answered.

LIST OF REFERENCES

REFERENCES

1. Kobrin, Gregory, Corrosion by Microbiological Organisms in Natural Waters, Materials Performance, Vol. 15, No. 7, p. 38.

2. Tartnall, R. E., Fundamentals of Bacteria Induced Corrosion, Materials Performance, Vol. 20, No. 9, p. 32.

3. Posttgate, J. R., The Sulfate Reducing Bacteria, Cambridge University Press (1979).

4. Fletcher, A. W., Cooper Recovery from Low-Grade Ore by Bacterial Leaching, Chapter 8 Microbial Aspects of Metallurgy, American Elsevier Publishing Co. (1970)

5. McComb, G. B., New Light on Anaerobic Corrosion Control Handbook, 1976.

6. Stoecker, J. G. and Pope, D. H., Study of Biological Corrosion in High Temperature Demineralized Water, Materials Performance, Vol. 25, No. 6, p. 51.

7. Franklin, M. J. and White, D. C., Biocorrosion Current Opinion in Biotechnology 1991, 2:450-456.

8. Borenstein, S. W. and Lindsay, P. B., Microbiologically Influenced Corrosion Failure Analyses, Materials Performance, Vol. 27, No. 3, p. 51.

9. Costerton, J. W., Geesey, G. G., and Jones, P. A., Bacterial Biofilms in Relation to Internal Corrosion Monitoring and Biocide Strategies, Materials Performance, Vol. 27, No. 4, p. 49.

10. Stoecker, J. G., Evaluation of Microbiological Corrosion, Metals Handbook, Vol. 13, 9th ED., p. 314.

REFERENCES
(continued)

11. Costerton, J. W. and Lashen, E. S., Influence of Biofilm on Efficacy of Biocides on Corrosion-Causing Bacteria, Materials Performance, Vol. 23, No. 2, p. 13.

12. Postgate, J. R., The Sulfate Reducing Bacteria, Cambridge University Press (1979).

13. Borenstein, S. W., Microbiologically Influenced Corrosion Failures of Austenitic Stainless Steel Welds, Materials Performance, Aug. 1988, p. 62.

14. Tatnall, R. E., Case Histories: Bacteria Induced Corrosion, Materials Performance, Vol. 20, No. 8, p. 41.

15. NACE CORROSION ENGINEER'S REFERENCE BOOK, Sept 1980, Copyright NACE.

16. Colturi, T. F. and Kozelski, K. J., Corrosion and Biofouling Control in a Cooling Tower System, Materials Performance, Vol. 23, No. 8, p. 43.

17. Little, B. J., Wagner, P. A., Characklis, W. J., and Lee, W., Microbial Corrosion, p. 635.

18. Li, Ping, Masters Thesis, University of Tennessee, Knoxville, December 1991, "Electrochemical studies of Microbiologically Influenced Corrosion in Natural Freshwater System."

19. Macdonald, D. D., Corrosion 46 (1990), p. 229.

20. Epelboin, I. and Wiart, R., J. Electrochem. Soc. 118, 1577 (1971).

21. Armstrong, R. D. and Edmonson, K., Electrochem. Acta. 18, 937 (1973).

REFERENCES
(continued)

22. Franklin, M. J. and White, D. C., Biotechnology 1991, 2: p.450.

23. Iverson, W. P., Electrochemical Sci. and Tech., 115, 617 (1968).

24. Searson, P. C. and Dawson, J. L., Electrochemical Sci. and Tech., August 1988, p. 1908.

APPENDICES

APPENDIX A

TABLE 1

Initial Test Pipe Welds for MIC Investigations Tennessee River

Weld	Pipe Material	Filler Metal	Gap (in.)	Penetration	Pipe Treatment	Remarks
1	304L	308L	3/32	Full	None	Reference or Base Case
2	304L	308L	3/32	Full	Pickle ID Surface	Surface Studies
3	304L	308L	3/32	Full	Electropolish ID Surface	Surface Studies
4	304L	308L	3/32	Full	1900° F Solution Anneal Water Quench	Effect of Heat Temperature
5	304L	308L	3/32	Full	Grind off Reinforcement	Surface Studies
6	304L	316L	3/32	Full	None	Filler Material Evaluation
7	304L	304L	3/32	Full	Remove ID Purge after Root Pass	Surface Studies
8	304L	None	None	Full	Fuse Root Pass	Surface Studies
9	304L	None	None	Incomplete	None	Evaluate Effect of Creviced ID
10	304L	308L	3/32	Full	No ID Purge	Surface Studies
11	316L	316L	3/32	Full	None	Reference or Base Case
12	316L	None	None	Full	Fuse Root Pass	Surface Studies
13	316L	None	None	Incomplete	None	Evaluate Effect of Creviced ID
14	316L	316L	3/32	Full	Remove ID Purge after Root Pass	Surface Studies

TABLE 2

Initial Test Pipe/Coupon Welds for MIC Investigations Tennessee River

Weld	Pipe Material	Filler Metal	Gap(in.)	Penetration	Pipe/Coupon Treatment
1	304L	308L	3/32	Full	None
2	304L	308L	3/32	Full	Pickle ID Surface
3	304L	308L	3/32	Full	Electropolish ID Surface
4	304L	308L	3/32	Full	1900°F Solution Anneal Water Quench
5	304L	308L	3/32	Full	Grind off Reinforcement
6	304L	316L	3/32	Full	None
7	304L	304L	3/32	Full	Remove ID Purge after Root Pass
8	304L	None	None	Full	Fuse Root Pass
9	304L	None	None	Incomplete	None
11	316L	316L	3/32	Full	None
12	316L	None	None	Full	Fuse Root Pass
13	316L	None	None	Incomplete	None
14	316L	316L	3/32	Full	Remove ID Purge after Root Pass

TABLE 3

Welded Test/Coupons for MIC Investigations Guadalupe River

Weld	Pipe Material	Filler Metal	Gap (in.)	Penetration	Pipe/Coupon Treatment
1	304L	308L	3/32	Full	None
2	304L	308L	3/32	Full	Pickled HNO_3
3	304L	308L	3/32	Full	Electropolished
4	304L	308L	3/32	Full	1900°F Solution Annealed Water Quenched, Pickled HNO_3
5	304L	308L	3/32	Full	Ground Grind off Reinforcement
6	304L	308L	3/32	Full	Pickled (20% HNO_3, 0.25% Surfactent) 140°F, 20 min.
7	304L	308L	3/32	Full	1900°F Solution Annealed Water Quenched
8	304L	308L	None	Full	Fused Root Pass
9	304L	308L	3/32	Full	Grit blasted
11	316L	316L	3/32	Full	No treatment
12	316L	None	None	Full	Fused Root Pass
13	304L	308L	3/32	Full	Pickled (25% Oakite, 140°F, 30 min.)
14	304L	308L	3/32	Full	Heat-treated, 600°F, 30 minutes

TABLE 4

TENNESSEE

DATE, TIME, and OPEN-CELL POTENTIALS (mV vs. sat. Ag/AgCl) for Cell 1

DATE		4/29	5/1	5/2	5/5	5/6	5/8	5/9	5/11
TIME									
Coupon No.	0: Platinum	330	326	349	412	354	397	406	469
	1: 304L/308L, F No Treatment	-239	-249	-267	-246	-250	-236	-170	-036
	2: 304L/308L, F Pickled	-242	-243	-246	-387	-325	-311	-261	-033
	3: 304L/308L, F Electropolished	-388	-383	-397	-443	-387	-398	-396	-140
	4: 304L/308L, F SA+WQ+Pickled	-224	-115	-132	-389	-363	-357	-309	-044
	5: 304L/308L, F Ground	-344	-326	-327	-353	-340	-312	-206	-019
	6: 304L/308L, F Not Treatment	-319	-301	-294	-308	-268	-230	-121	-030
	7: 304L/316L, F Purge Rem. after RP	-264	-311	-307	-321	-297	-261	-136	-058
	8: 304L/None, F Fuse Root Pass	-264	-262	-253	-259	-197	-111	-043	-000
	9: 304L/308L, F No Treatment	-345	-319	-312	-327	-286	-223	-140	-054
	11: 316L/316L, F No Treatment	-229	-243	-244	-239	-199	-035	009	023
	12: 316L/None, F Fuse Root Pass	-223	-231	-230	-222	-182	-065	-029	-004
	13: 316L/None, I Fuse Root Pass	-262	-255	-257	-232	-169	-069	-044	-022
	14: 316L/316L, F Purge Rem. after RP	-205	-232	-251	-259	-220	-078	-040	-041

TABLE 5

TENNESSEE
DATE, TIME, and OPEN-CELL POTENTIALS (mV vs. sat. Ag/AgCl) for Cell 2

DATE		4/29	5/1	5/2	5/5	5/6	5/8	5/9	5/11
TIME									
Coupon No.	0: Platinum	305	328	316	284	344	397	417	476
	1: 304L/308L, F No Treatment	-326	-311	-247	-267	-242	-243	-241	-005
	2: 304L/308L, F Pickled	-317	-309	-311	-346	-319	-344	-349	-066
	3: 304L/308L, F Electropolished	-404	-417	-395	-497	-370	-379	-341	-044
	4: 304L/308L, F SA+WQ+Pickled	-361	-371	-396	-434	-391	-401	-411	-146
	5: 304L/308L, F Ground	-295	-286	-309	-327	-288	-289	-290	-054
	6: 304L/316L, F No Treatment	-173	-136	-266	-278	-254	-259	-232	-050
	7: 304L/304L, F Purge Rem. after RP	-257	-271	-356	-388	-343	-340	-343	-291
	8: 304L/None, F Fuse Root Pass	-201	-184	-266	-272	-239	-240	-241	-010
	9: 304L/308L, F No Treatment	-183	-156	-218	-255	-236	-234	-237	-012
	11: 316L/316L, F No Treatment	-208	-191	-254	-261	-247	-248	-250	-043
	12: 316L/None, F Fuse Root Pass	-169	-153	-213	-219	-194	-198	-198	013
	13: 316L/None, I Fuse Root Pass	-194	-177	-219	-247	-234	-236	-237	000
	14: 316L/316L, F Purge Rem. after RP	-273	-254	-296	-335	-297	-298	-296	-146

TABLE 6

Chemical Analysis of Tennessee River Water

mg/liter	
SO_4 Calculated as Sulfur	4
Sulfide	<0.02
NO_3 Calculated as Nitrogen	0.8
Chloride	8
Magnesium	19
Iron	0.1
Manganese	<0.05
Total Organic Carbon	3
CO_3 Calculated as Carbon	15
Alkalinity Calculated as $CaCO_3$	56

TABLE 7

Chemical Analysis of Guadalupe River Water

Chloride	54ppm (as $CaCO_3$)
Sulfate	49ppm (as $CaCO_3$)
Nitrite	0.8ppm (as NO_2)
Nitrate	2.5ppm (as $CaCO_3$)
Carbonate	16ppm (as $CaCO_3$)
Iron	0.15ppm (as Fe)
Aluminum	<0.1ppm (detection limit for test 0.1ppm)
Silica	17.3ppm (as $Si0_2$)
Ammonium	0.6 (as $CaCO_3$)
Total Hardness	232ppm (as $CaCO_3$)
Total Alkalinity	166ppm (as $CaCO_3$)
Total Organic Carbon	Have never run.

Dissolved Oxygen - Have not run, but it's likely saturated at atmospheric pressure.

APPENDIX B

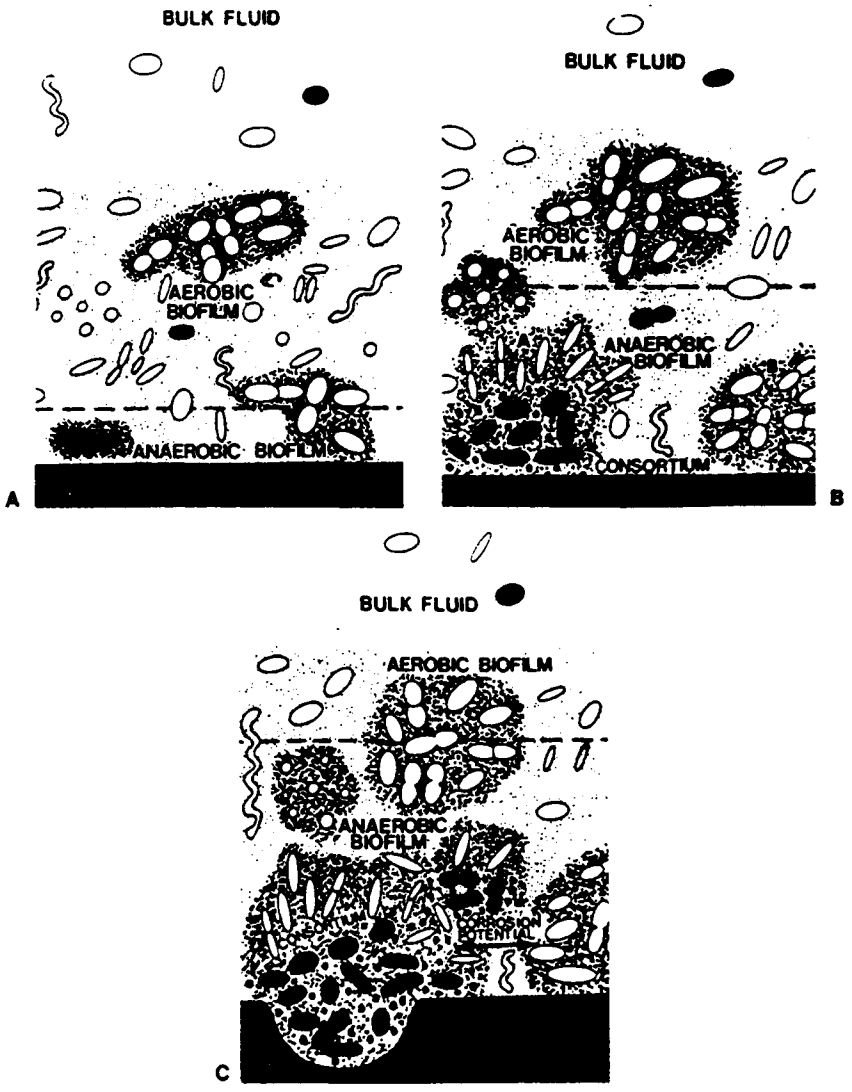
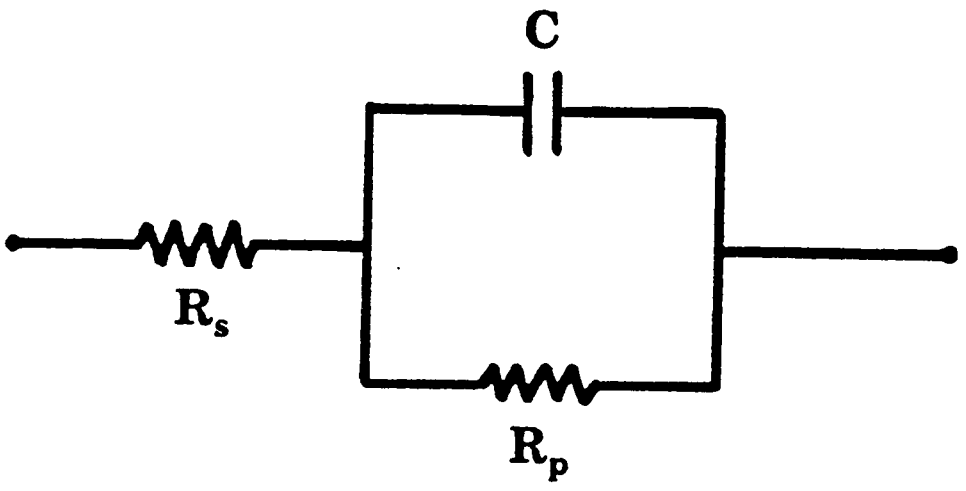


Figure 1. Diagrammatic representation of active, corrosion-causing bacterial consortia development on a metal surface. (A) A thick biofilm develops where individual bacterial species grow rapidly to develop microcolonies where conditions best suit their requirements. When the biofilm attains sufficient thickness to exclude and consume oxygen, an anaerobic zone develops adjacent to the colonized metal surface. (B) SRB (black) and other anaerobic species develop simple microcolonies (right) and complex consortia (left) within which protons and metal cations may be transported ar trapped to produce local chemical and physical differences at the metal surface. (C) An actual corrosion potential is established between specific areas on the metal surface, and metal is mobilized and deposited as in an electrochemical corrosion cell. As the corrosion pit deepens, the corrosion-causing organism come to occupy it. (Materials Performance, Vol. 27, No. 4, p. 49)

(a)



(b)

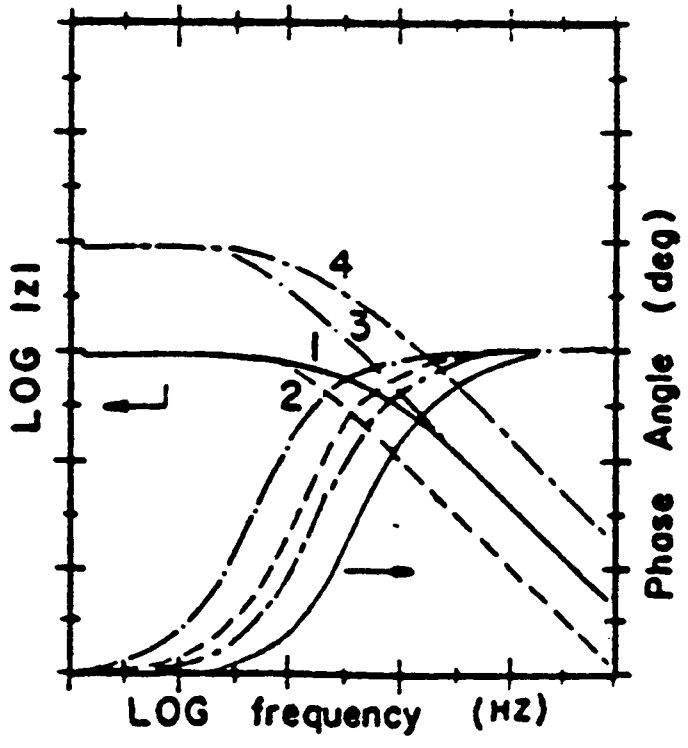


Figure 2. AC impedance methods demonstrating (a) the simplest electrical circuit model and (b) a Bode impedance plot (Bode 1945).

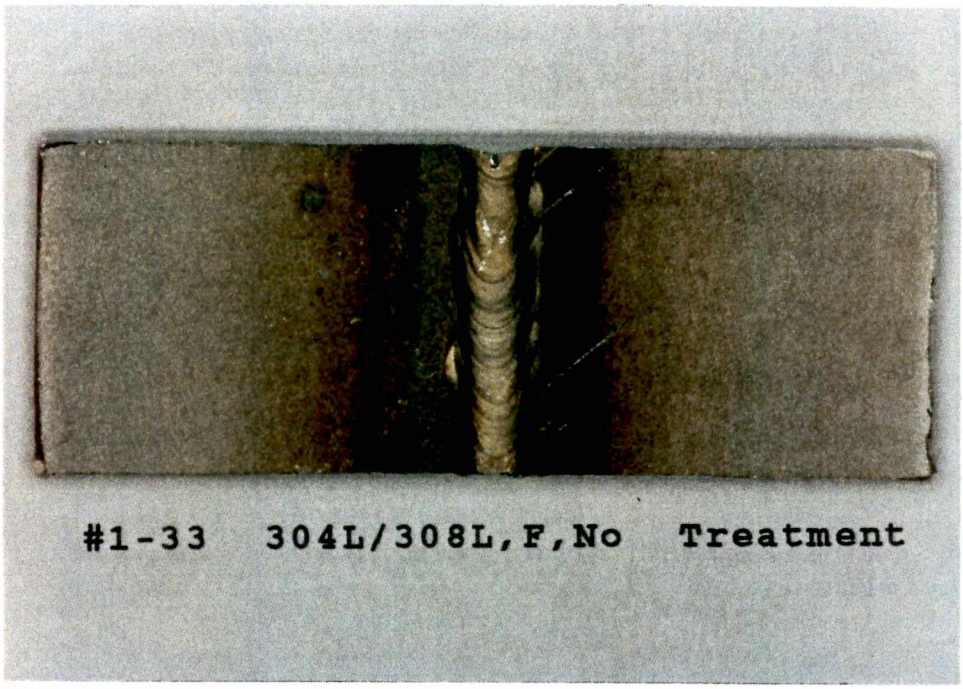


Figure 3. Representative test coupon after removal from 12 inch pipe.

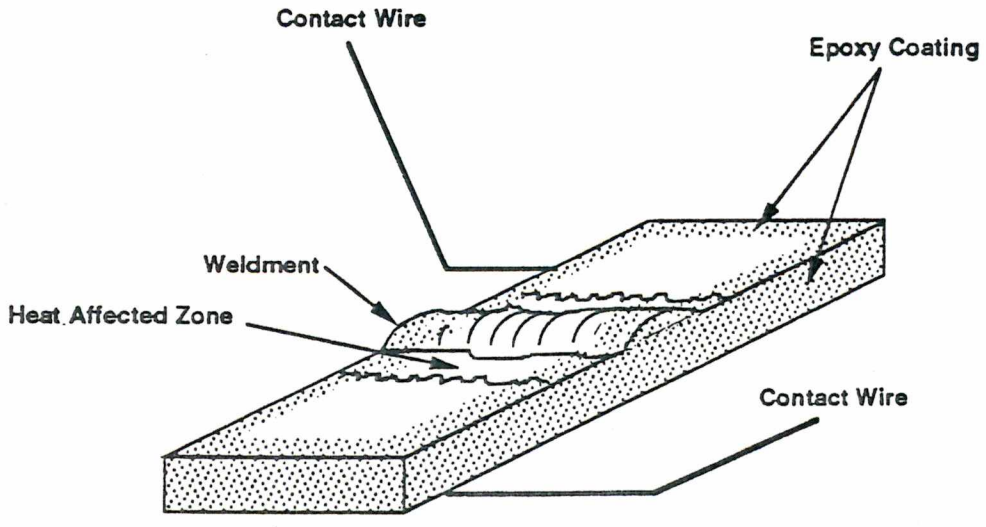


Figure 4. Schematic diagram of test coupon.

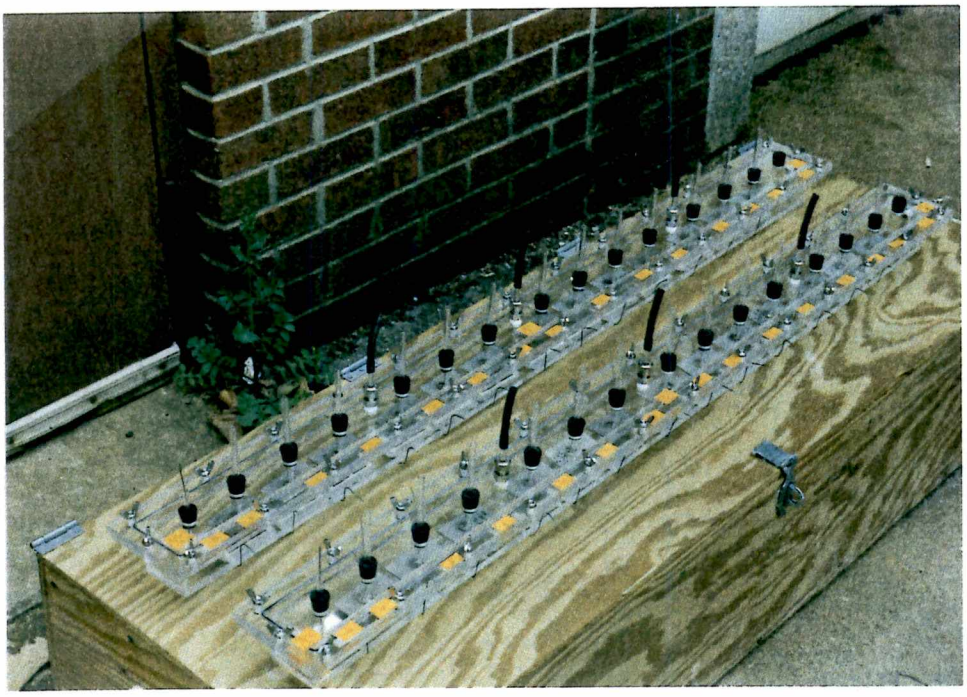


Figure 5. Two MIC test cells ready for installation.

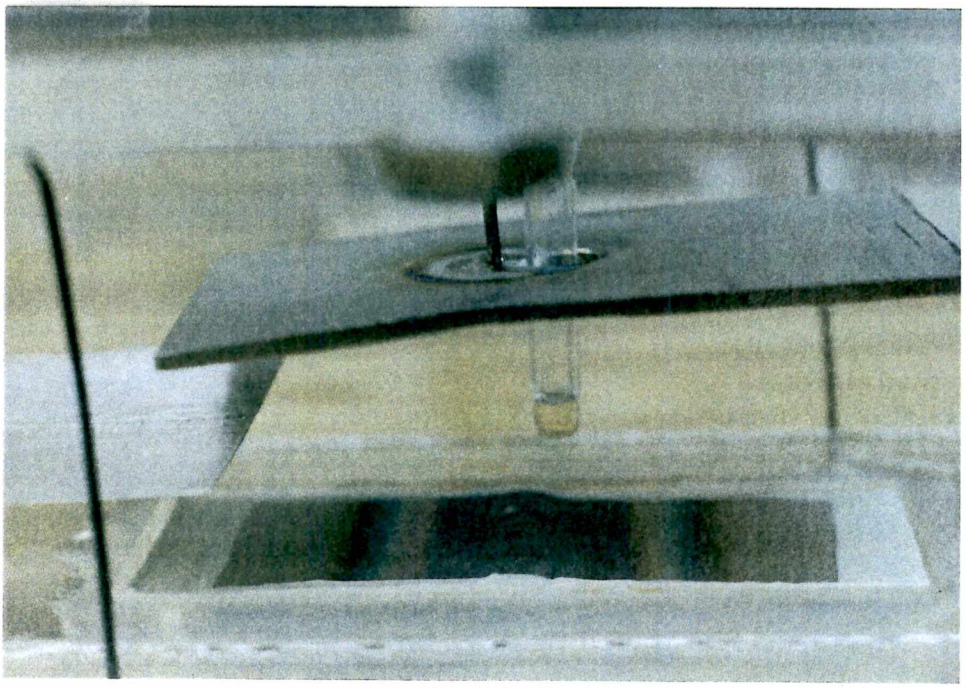


Figure 6. Closeup of test coupon.



Figure 7. Pipe test string on the Tennessee River using PVC couplers and the stainless steel pipe weldments.

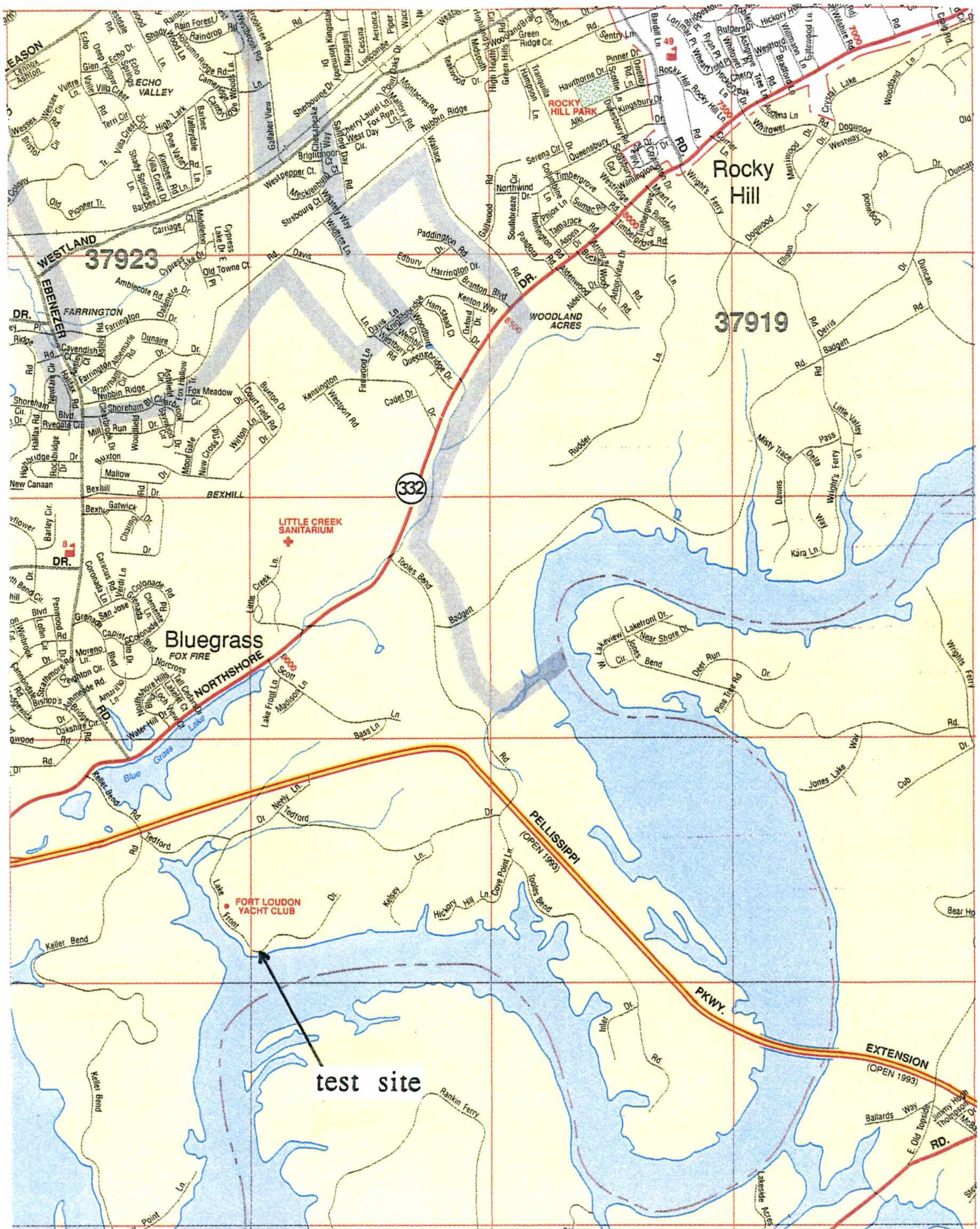


Figure 8. Map showing Tennessee River, Fort Loudon Reservoir and approximate location of test site.



Figure 9. Boat house and Tennessee River location where tests were performed.

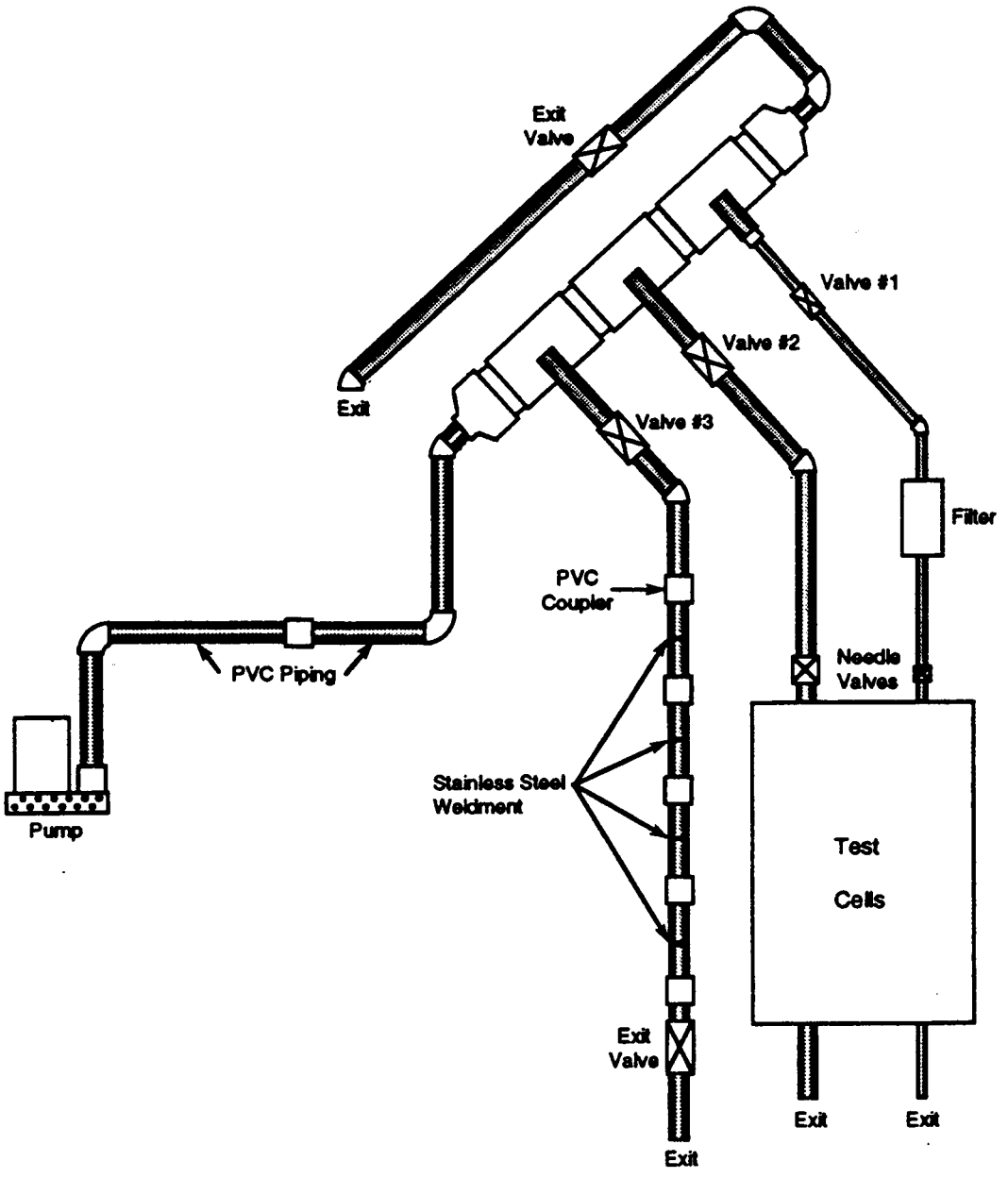


Figure 10. Schematic diagram showing layout of test cells and pipe string on the Tennessee River.



Figure 11. Photo of the entire MIC test setup on the Tennessee River.

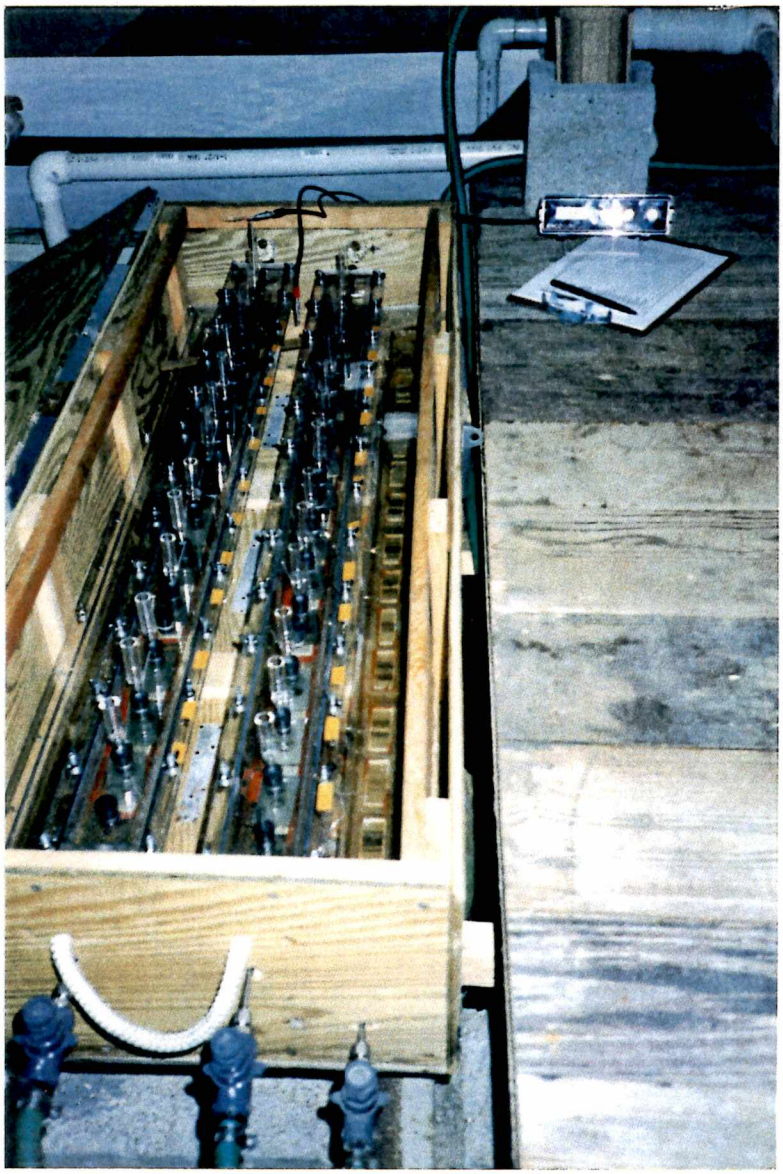
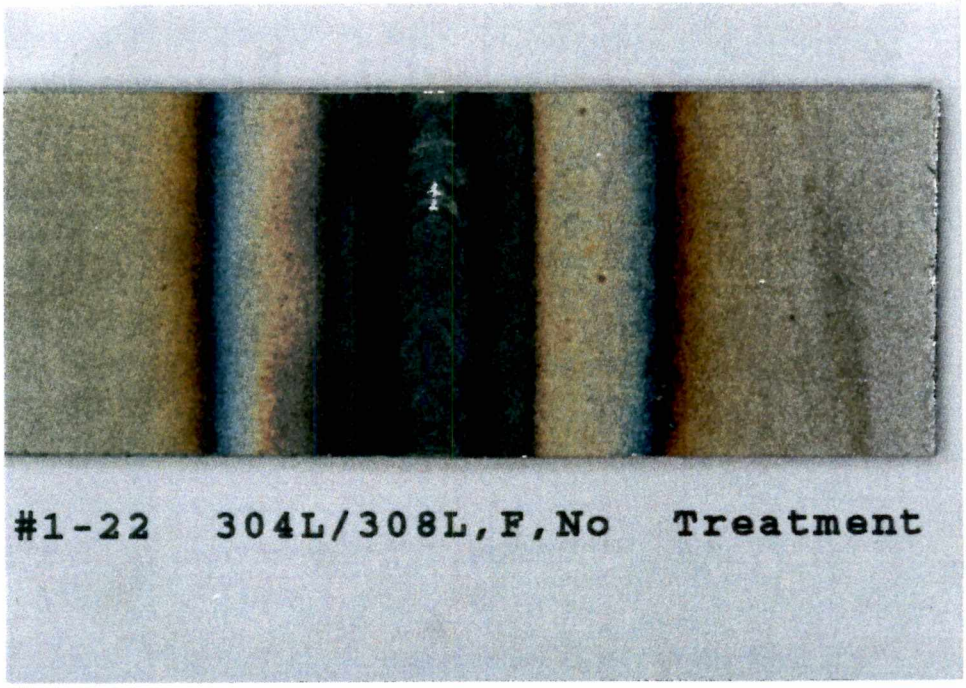


Figure 12. Photo of test cells and their location inside the wooden crate.

(a)



(b)

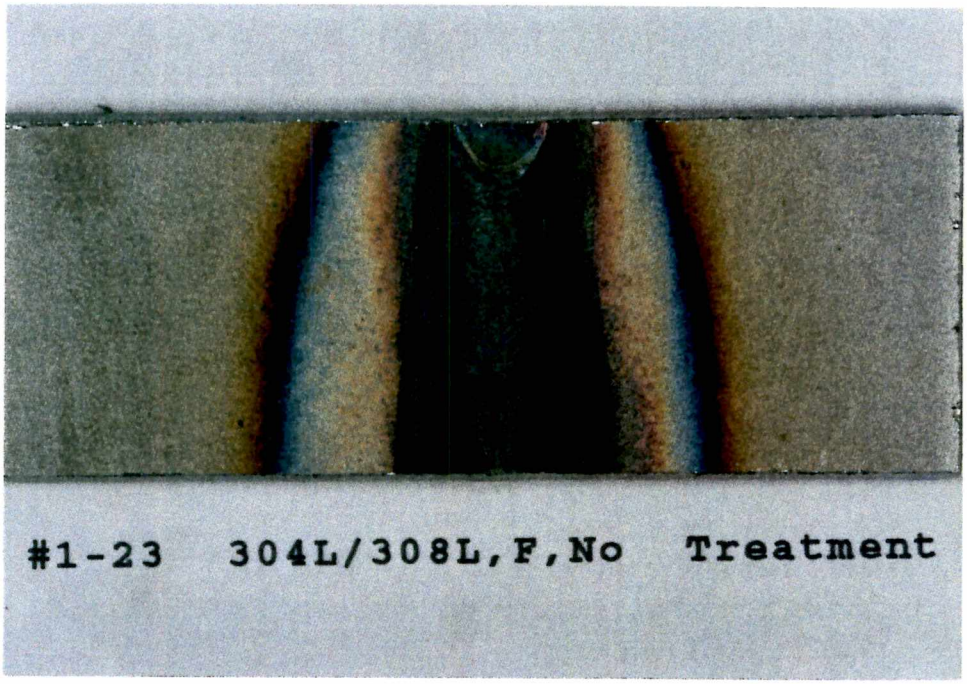
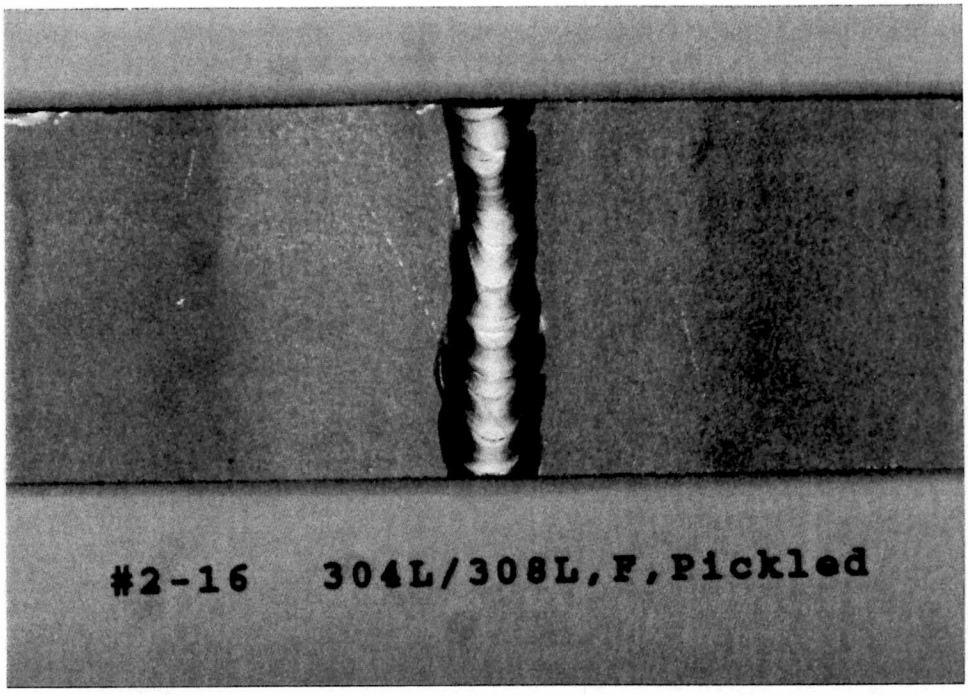


Figure 13. Coupons 1-22 and 1-23 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

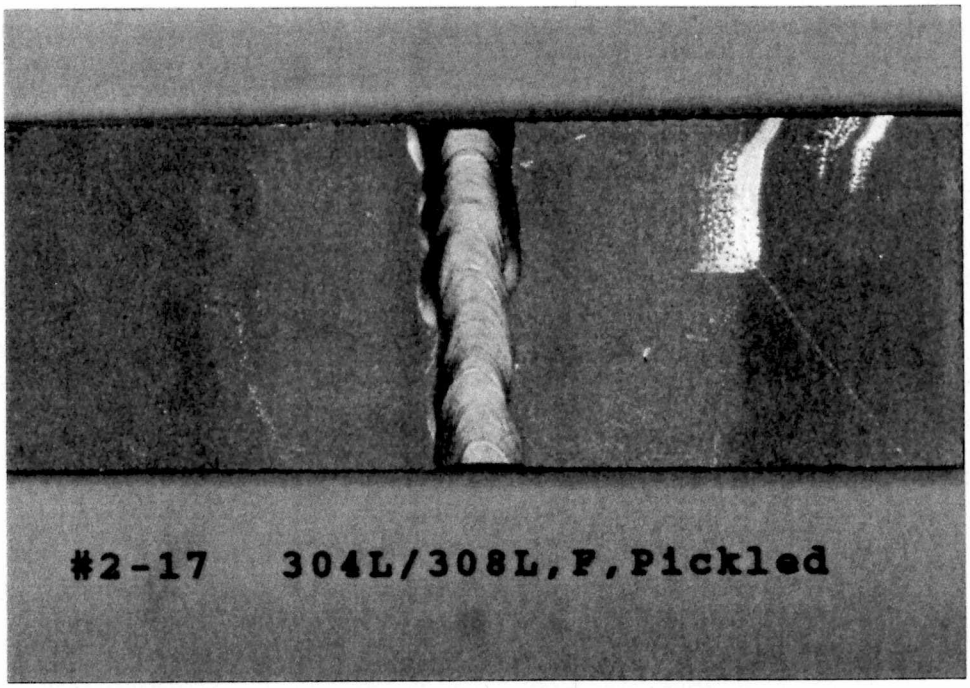
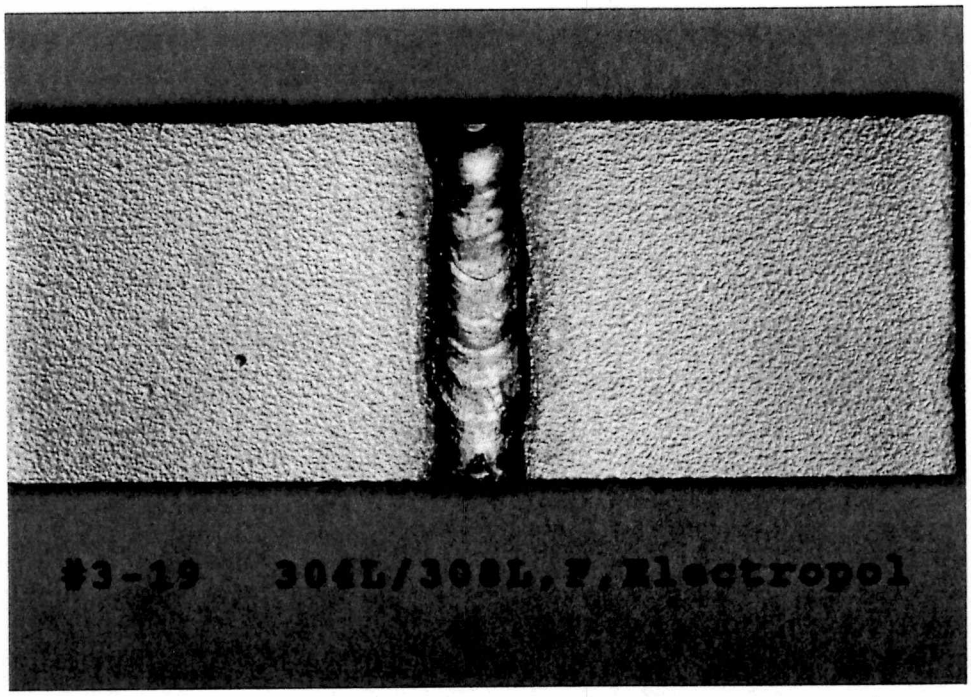


Figure 14. Coupons 2-16 and 2-17 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

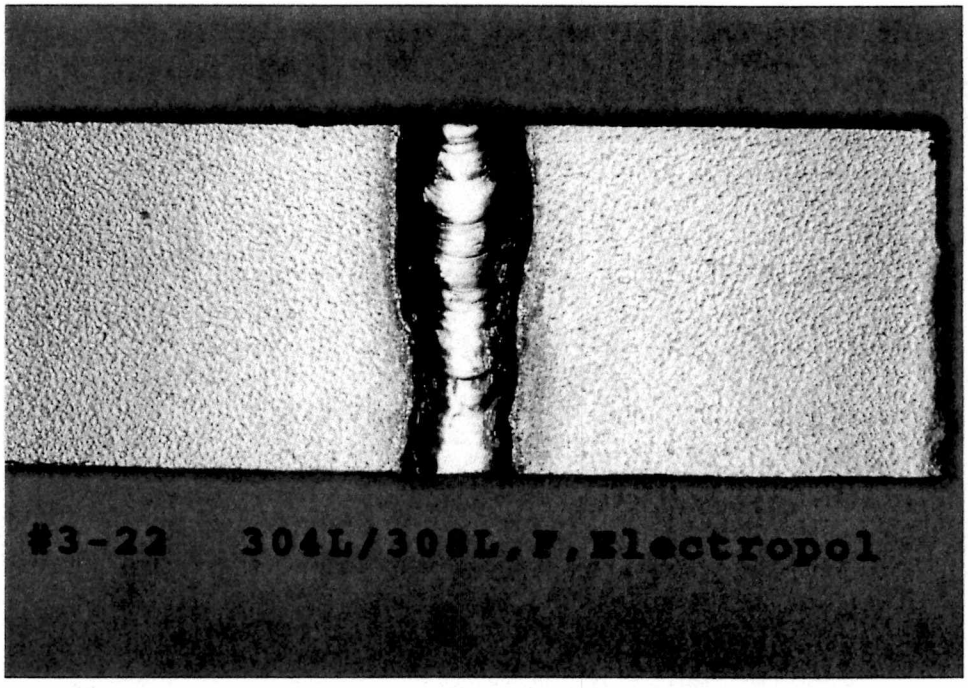
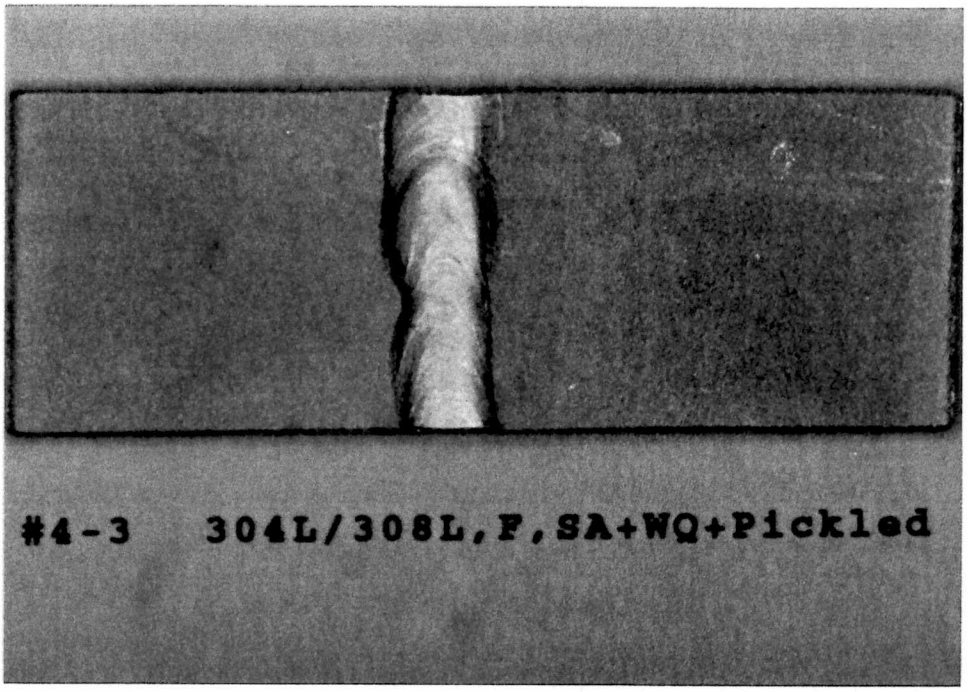


Figure 15. Coupons 3-19 and 3-22 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

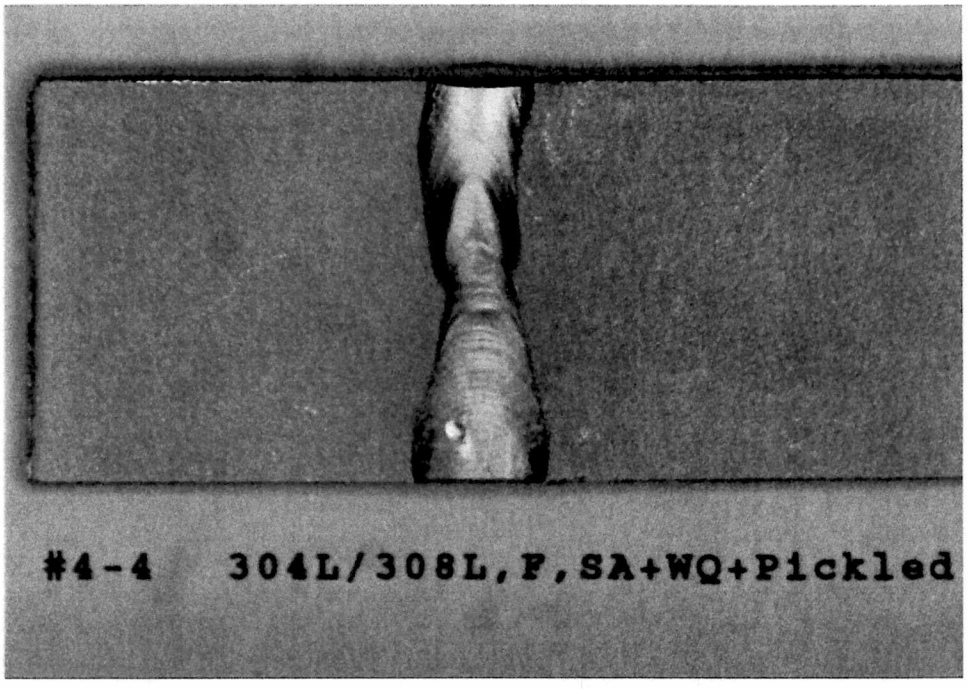
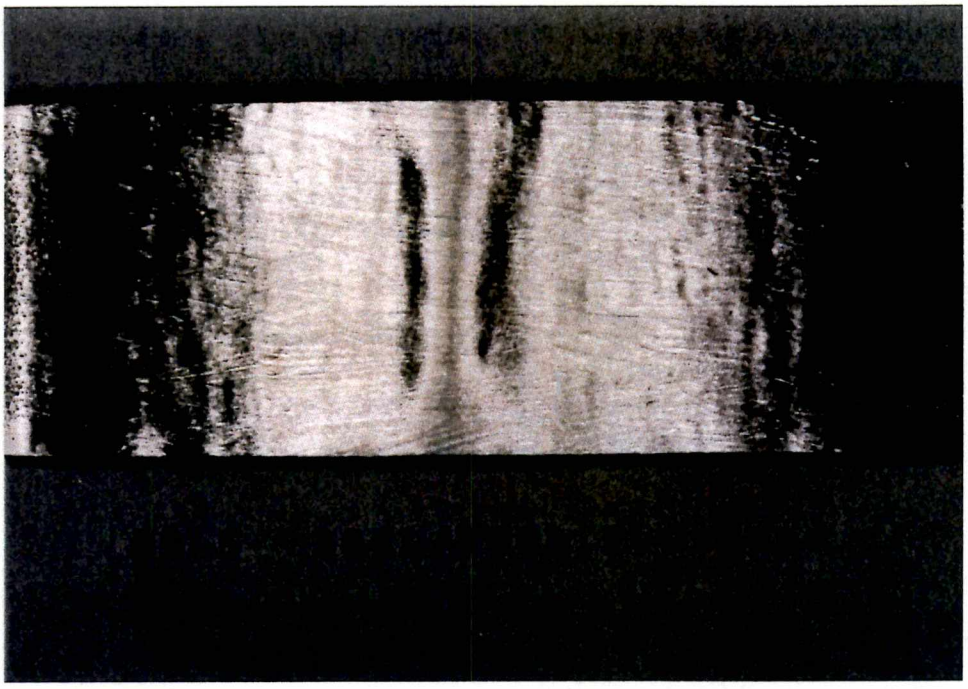


Figure 16. Coupons 4-3 and 4-4 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

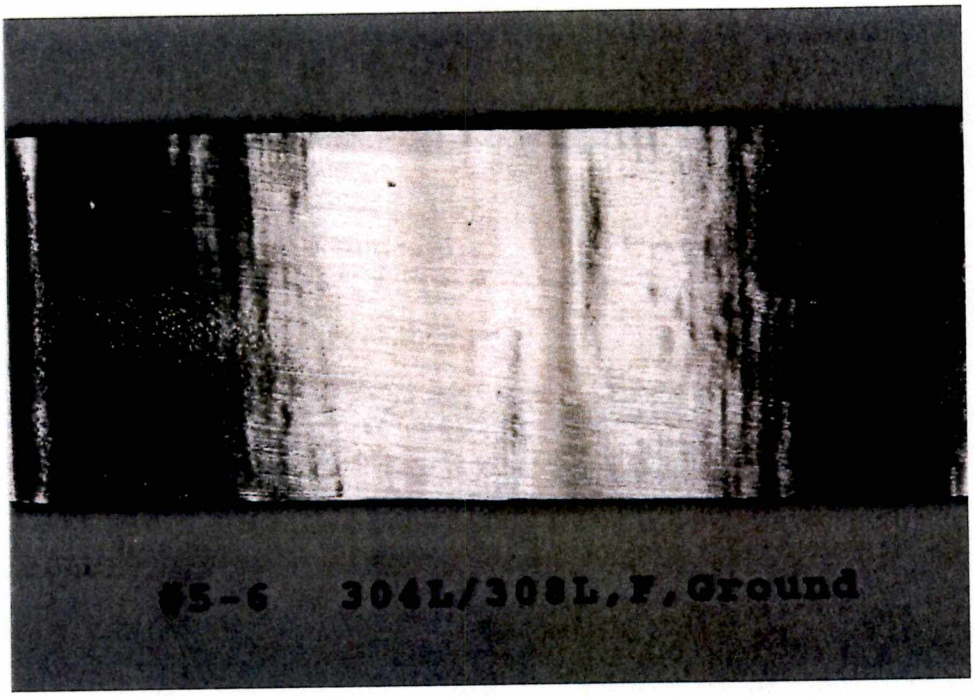


Figure 17. Coupons 5-5 and 5-6 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



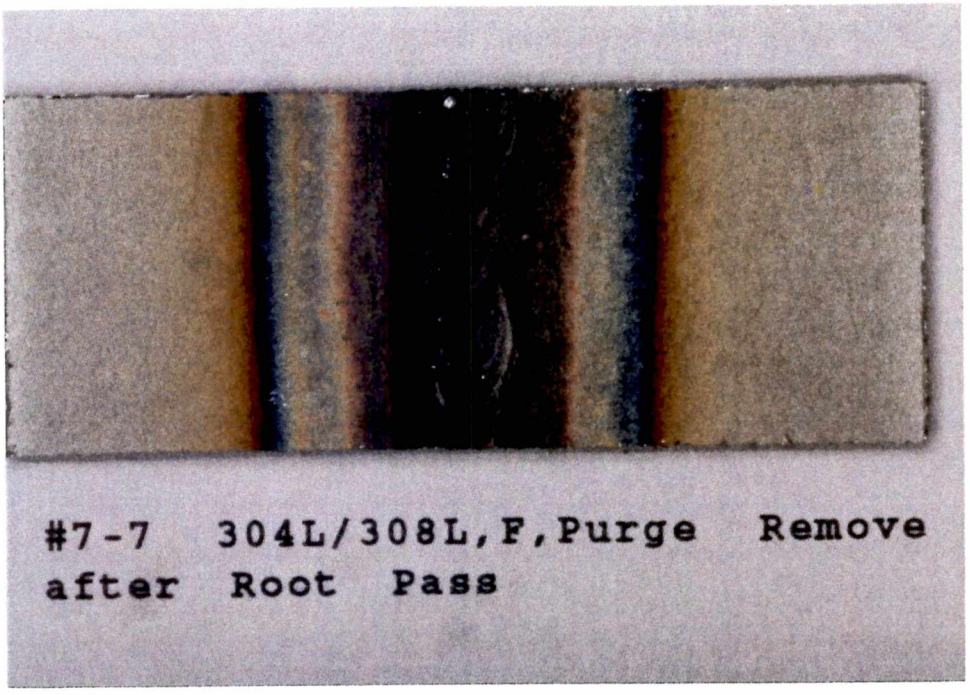
(b)



Figure 18. Coupons 6-4 and 6-5 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

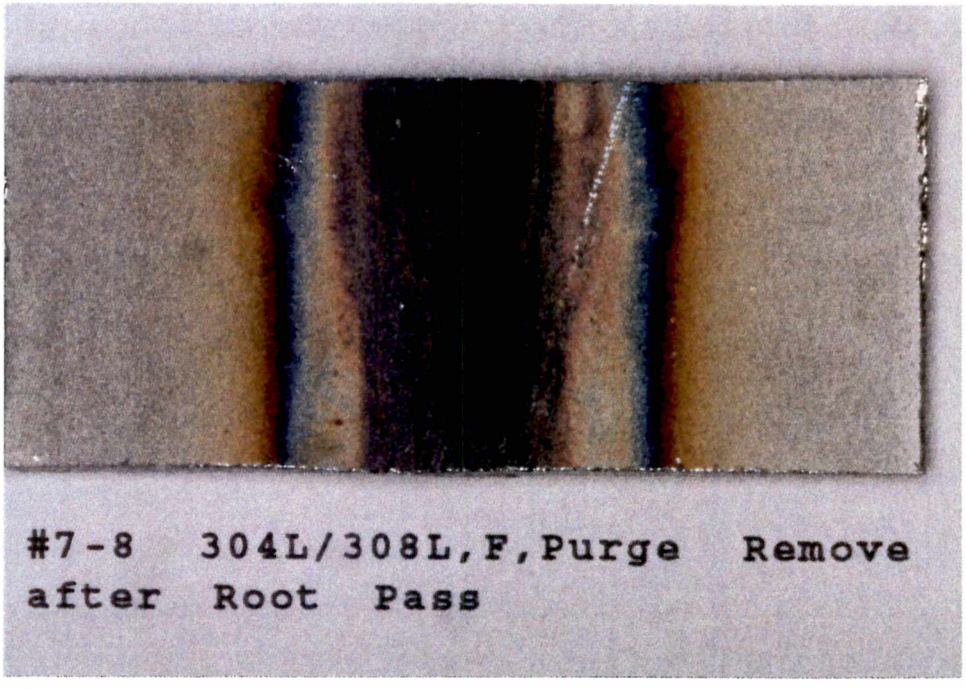
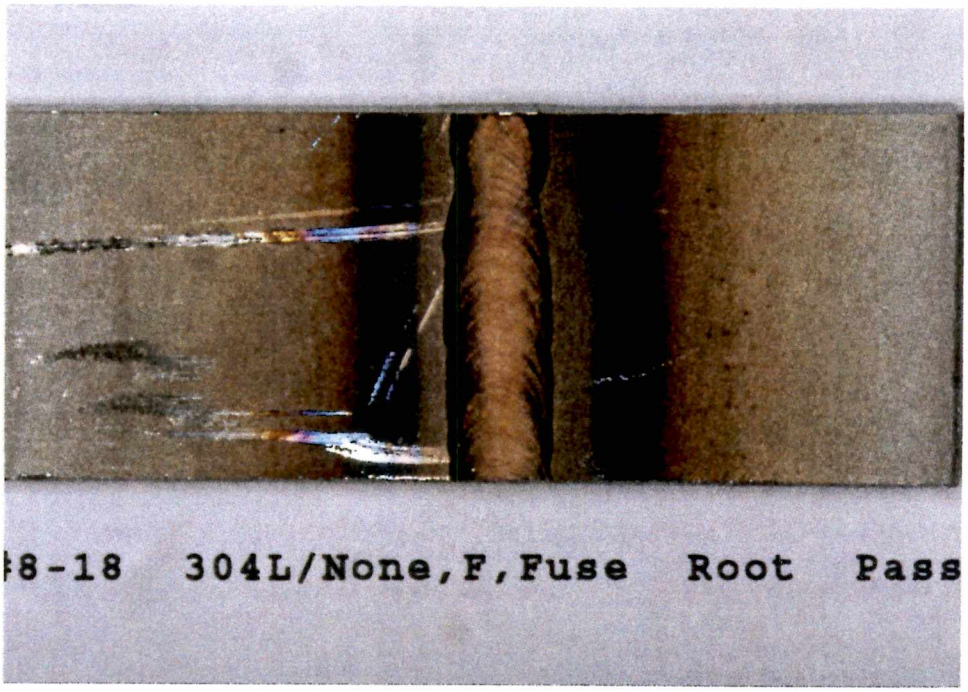


Figure 19. Coupons 7-7 and 7-8 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

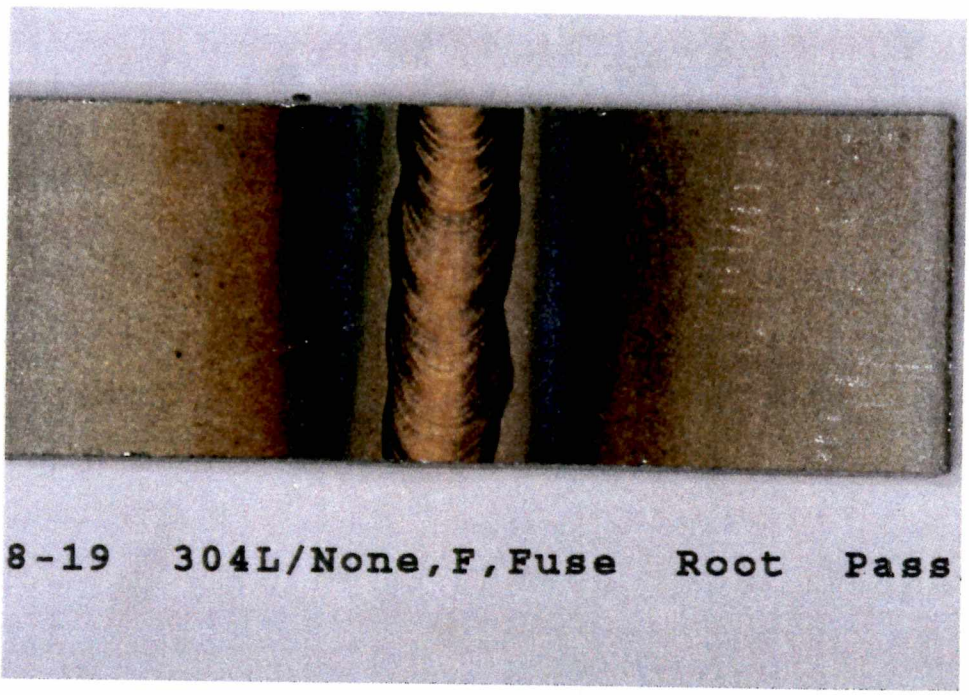
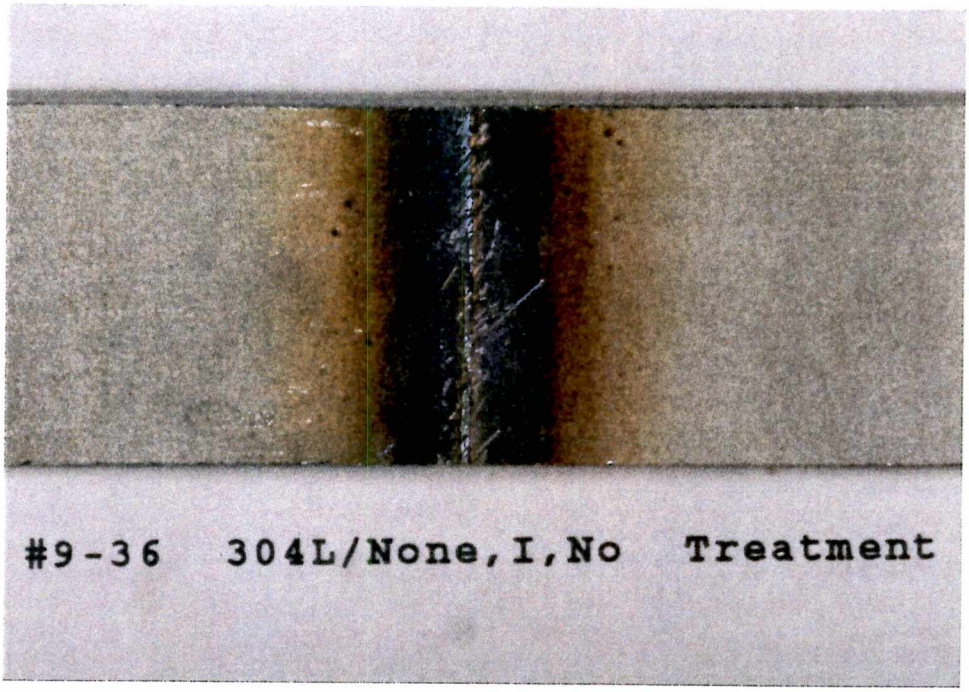


Figure 20. Coupons 8-18 and 8-19 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

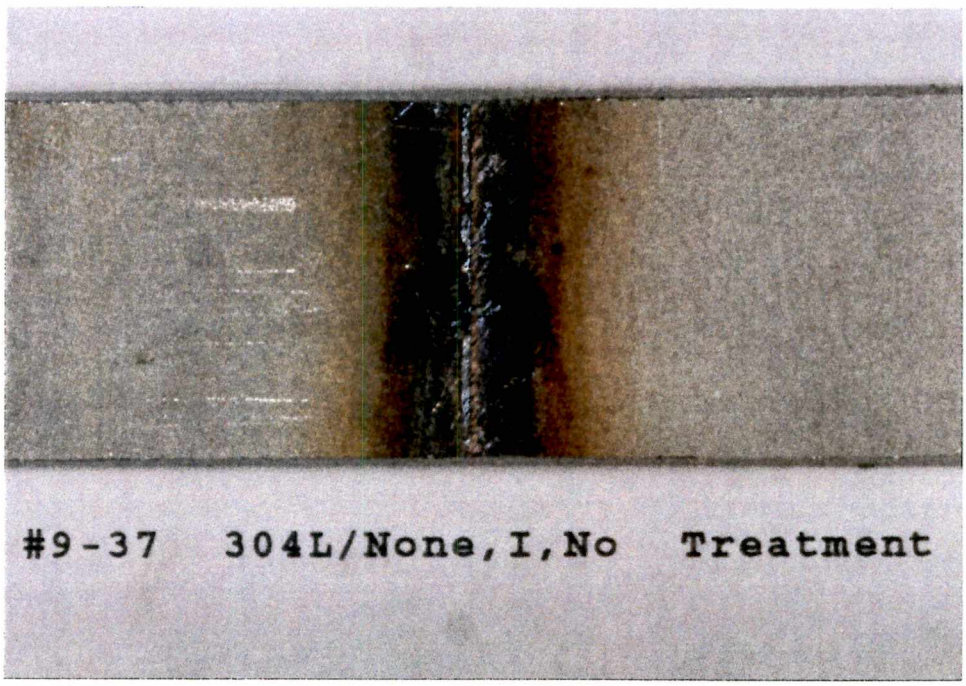
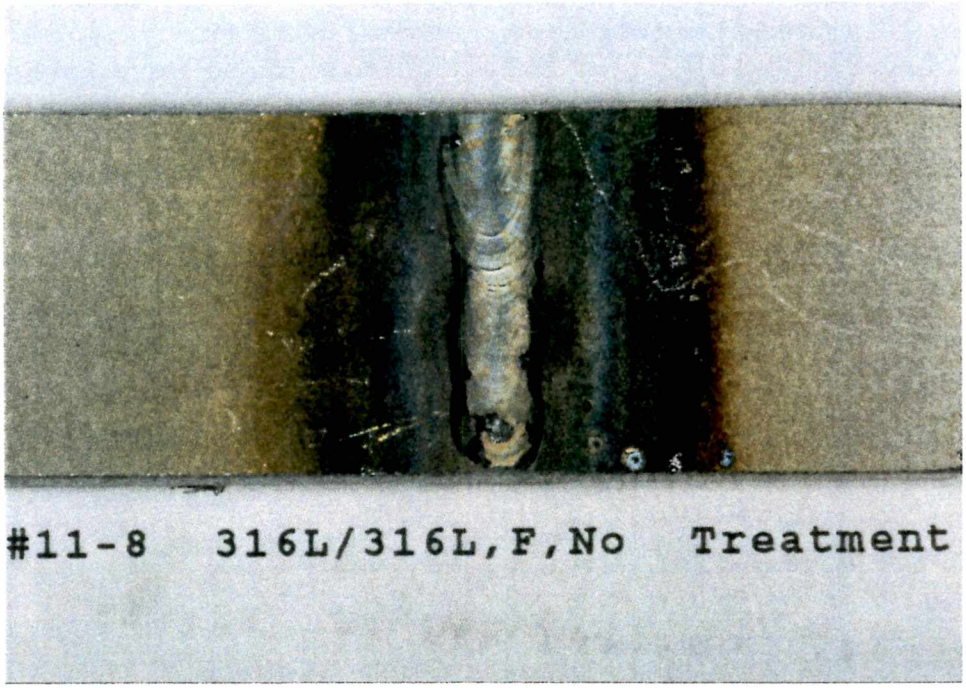


Figure 21. Coupons 9-36 and 9-37 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

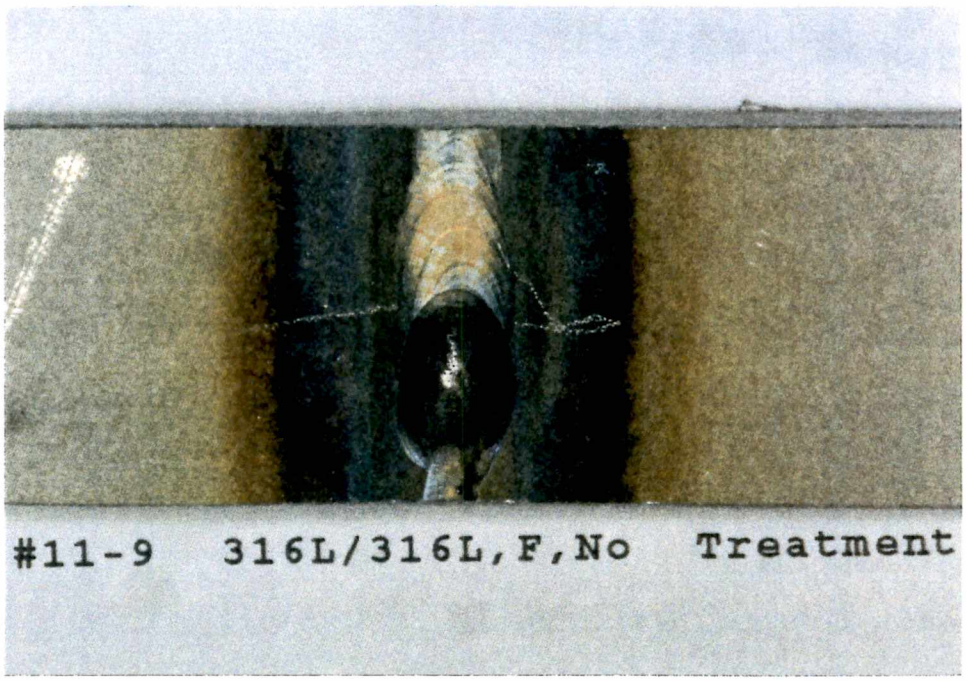
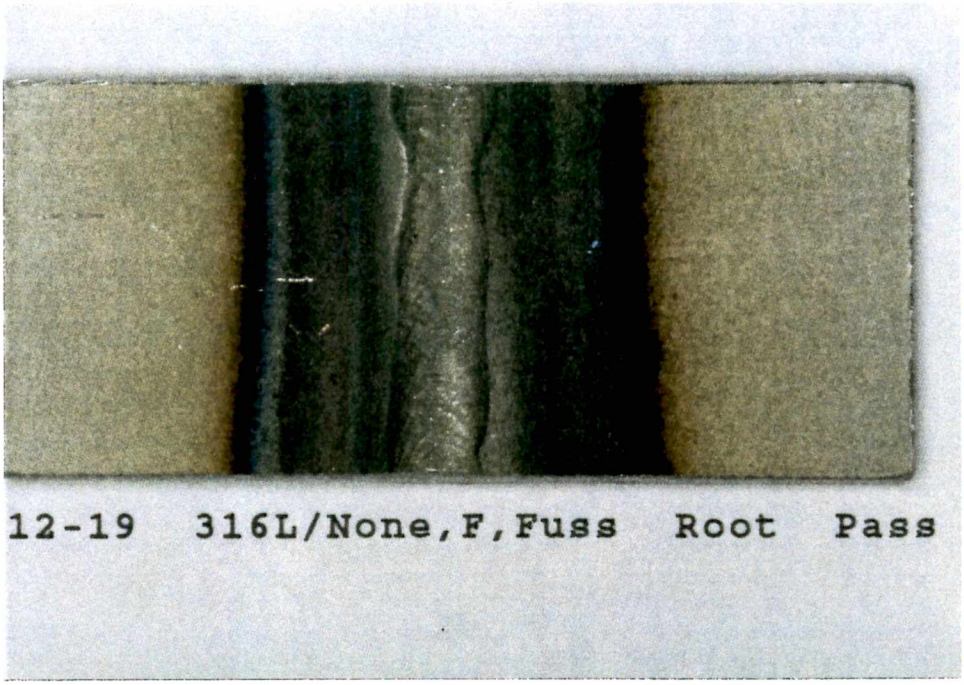


Figure 22. Coupons 11-8 and 11-9 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

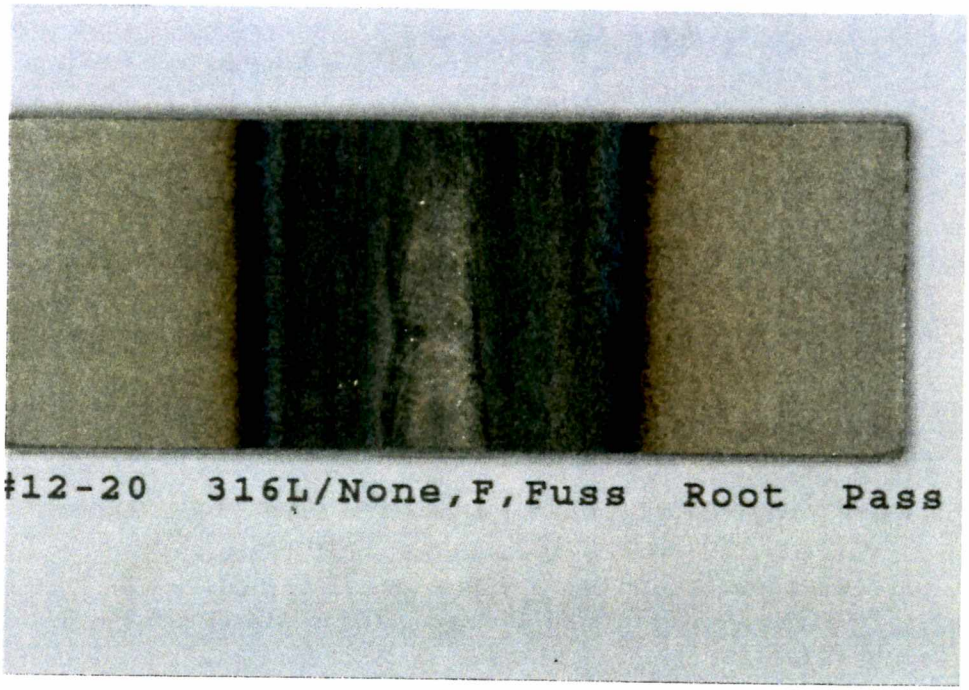
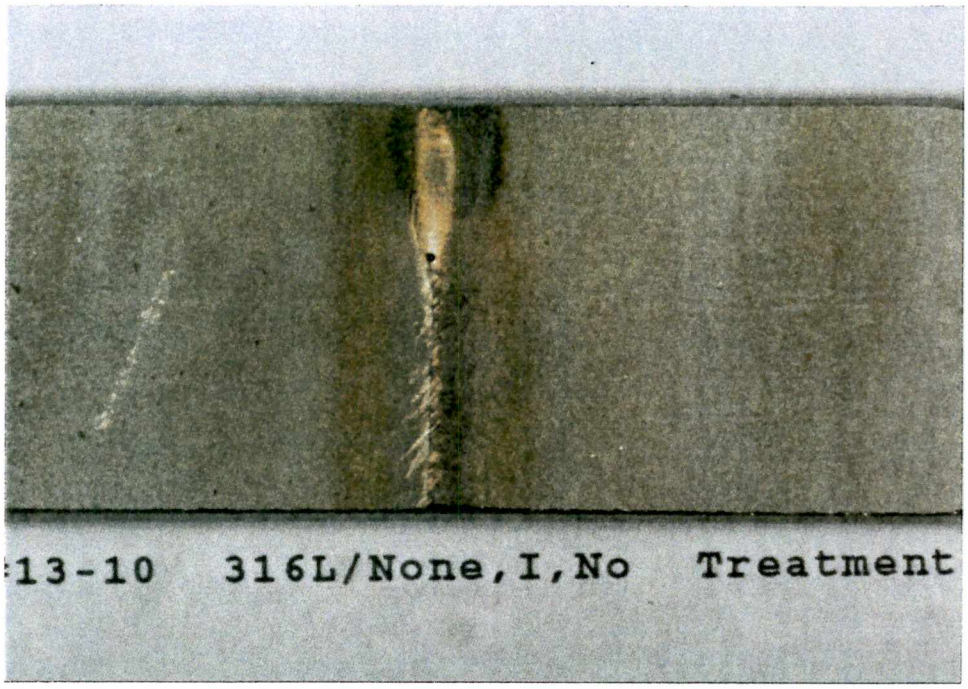


Figure 23. Coupons 12-19 and 12-20 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

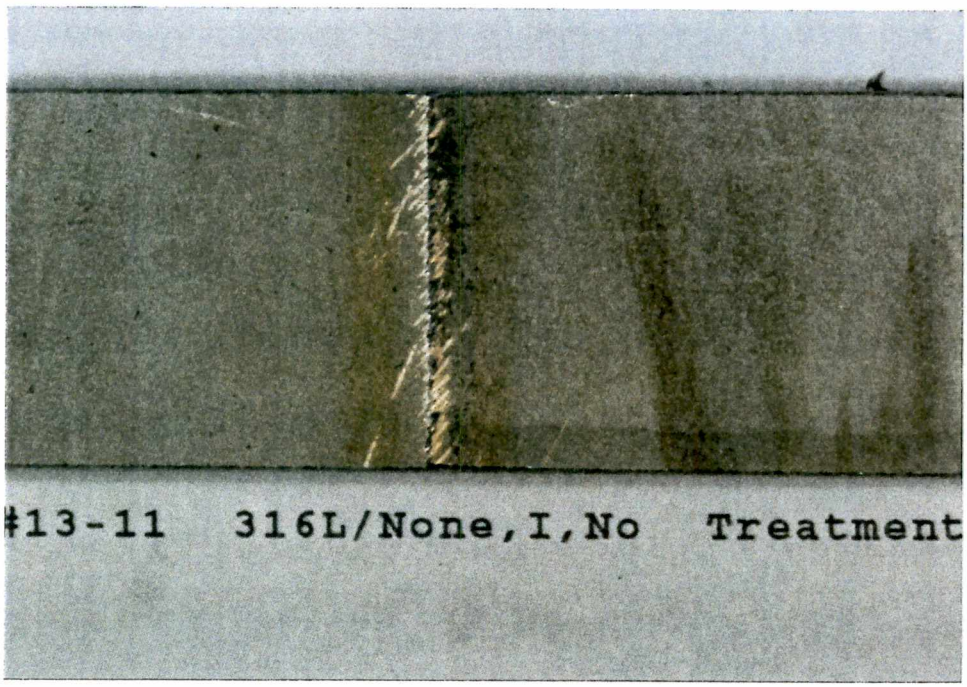
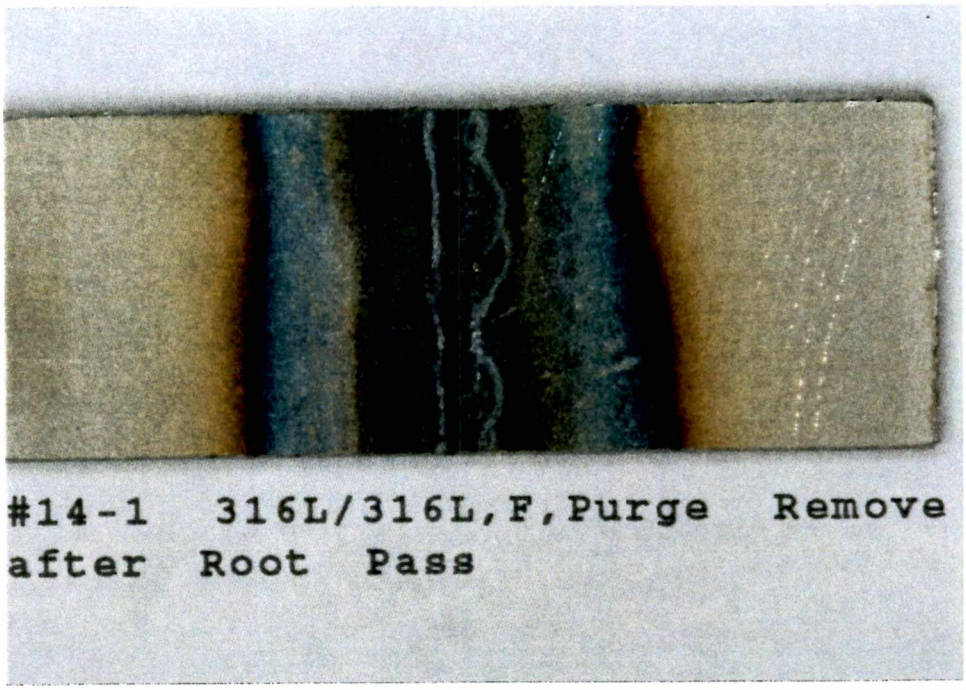


Figure 24. Coupons 13-10 and 13-11 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

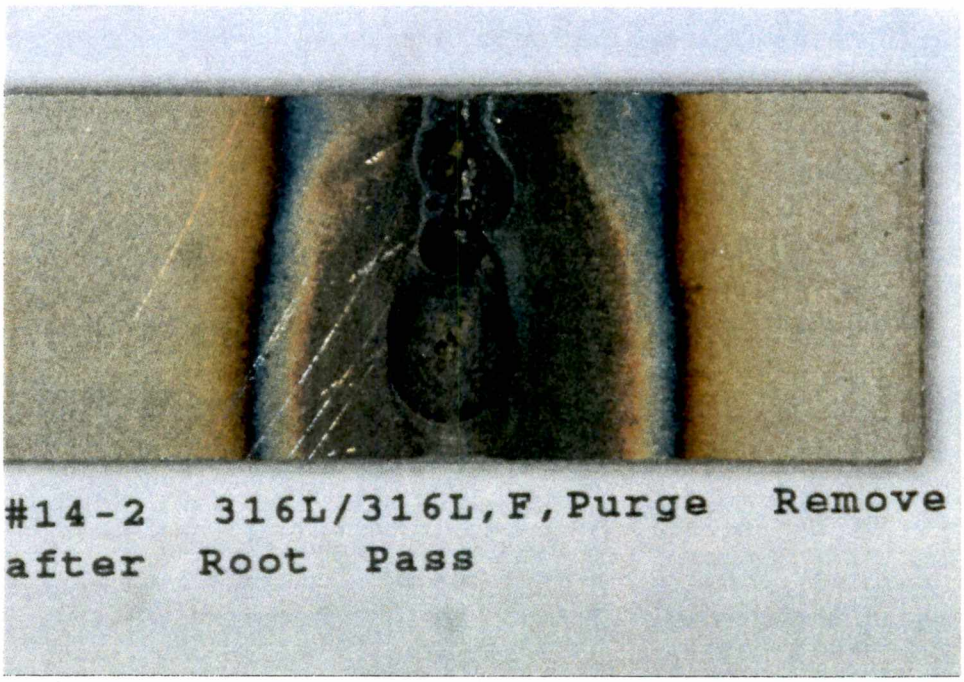


Figure 25. Coupons 14-1 and 14-2 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2



Figure 26. Photo of MIC pipe string on the Tennessee River

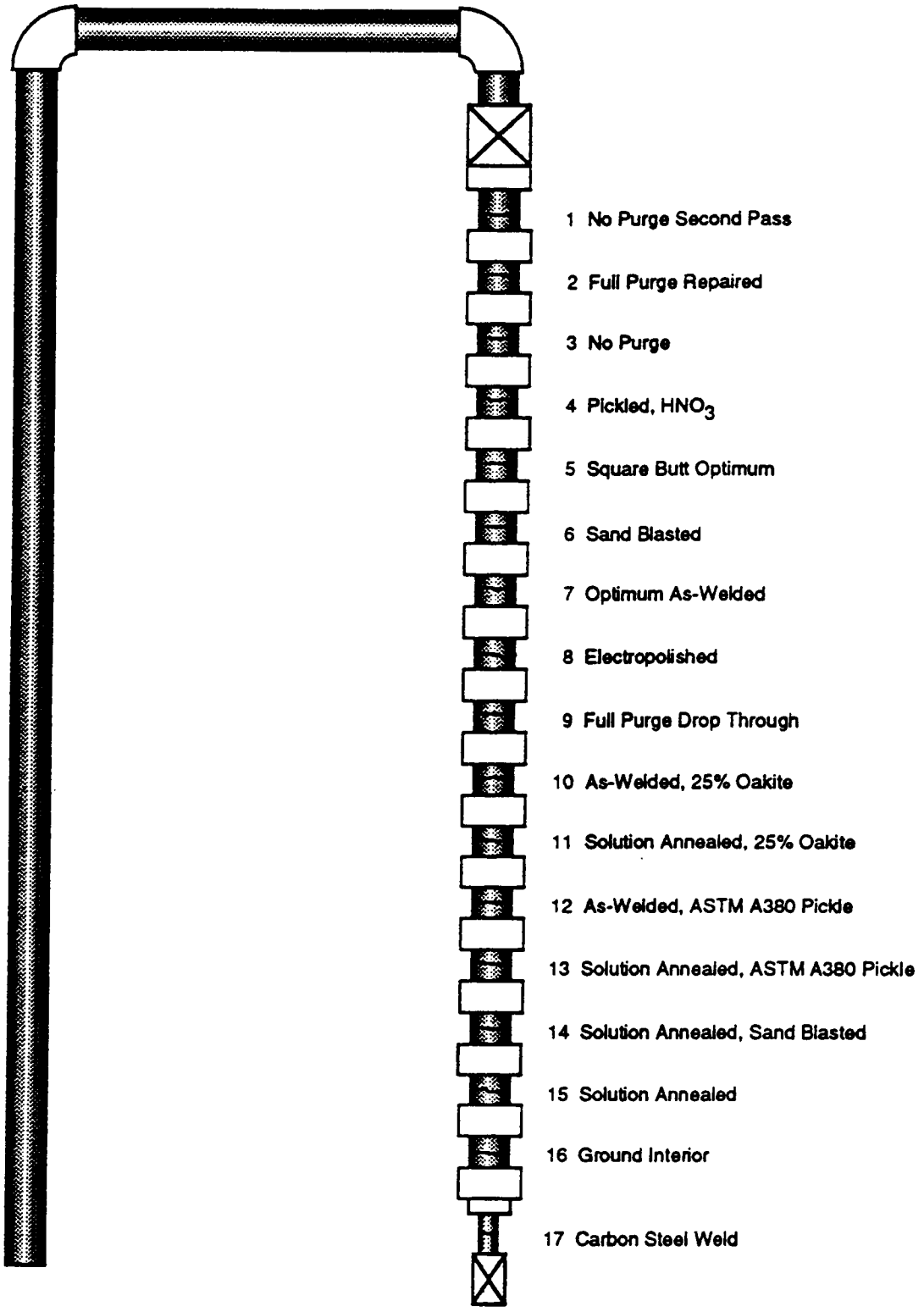


Figure 27. Schematic listing stainless welds and their respective location in the Tennessee River pipeweld test string.

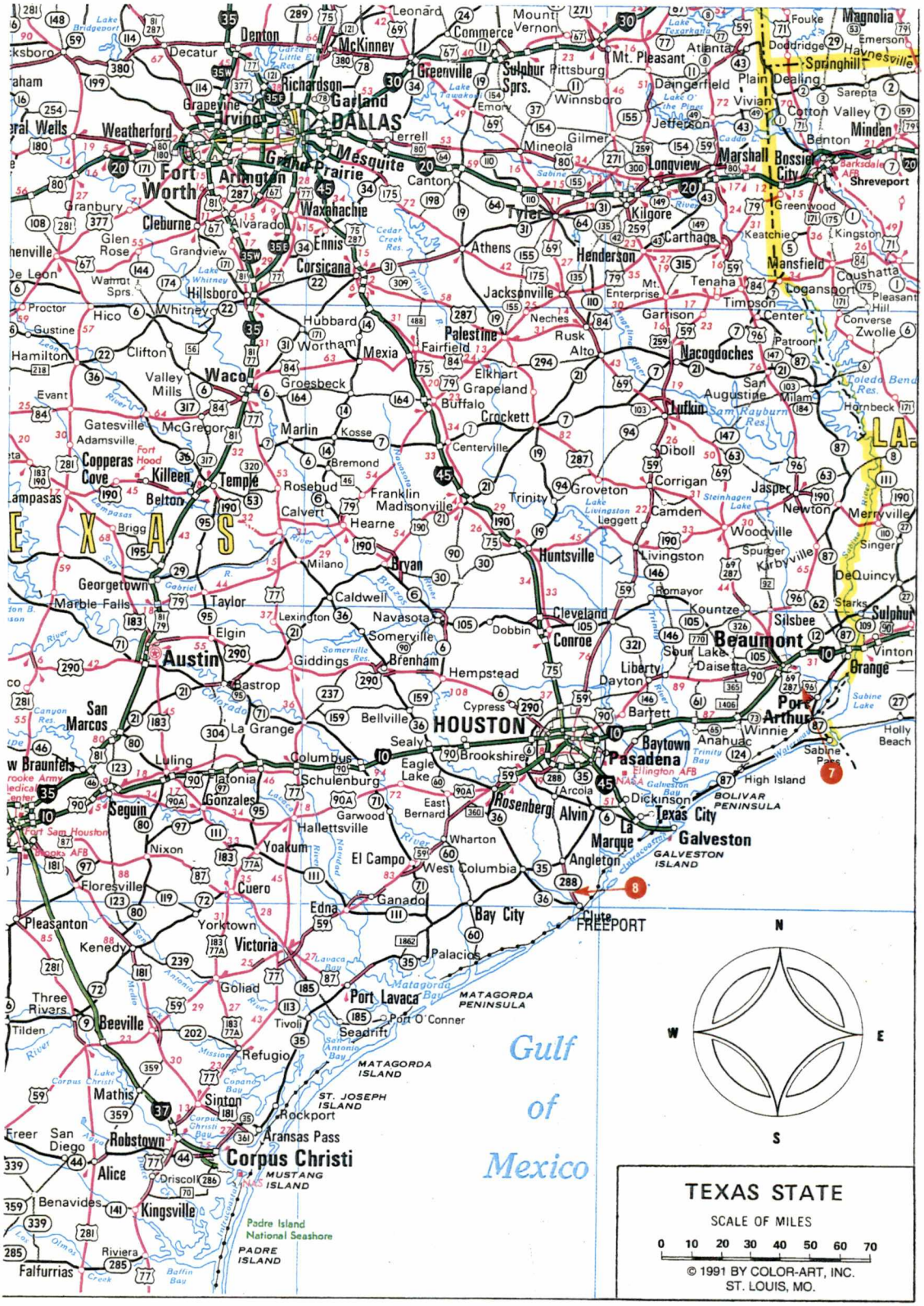


Figure 28. Map showing Guadalupe River, Victoria, Texas and approximate location of test site.

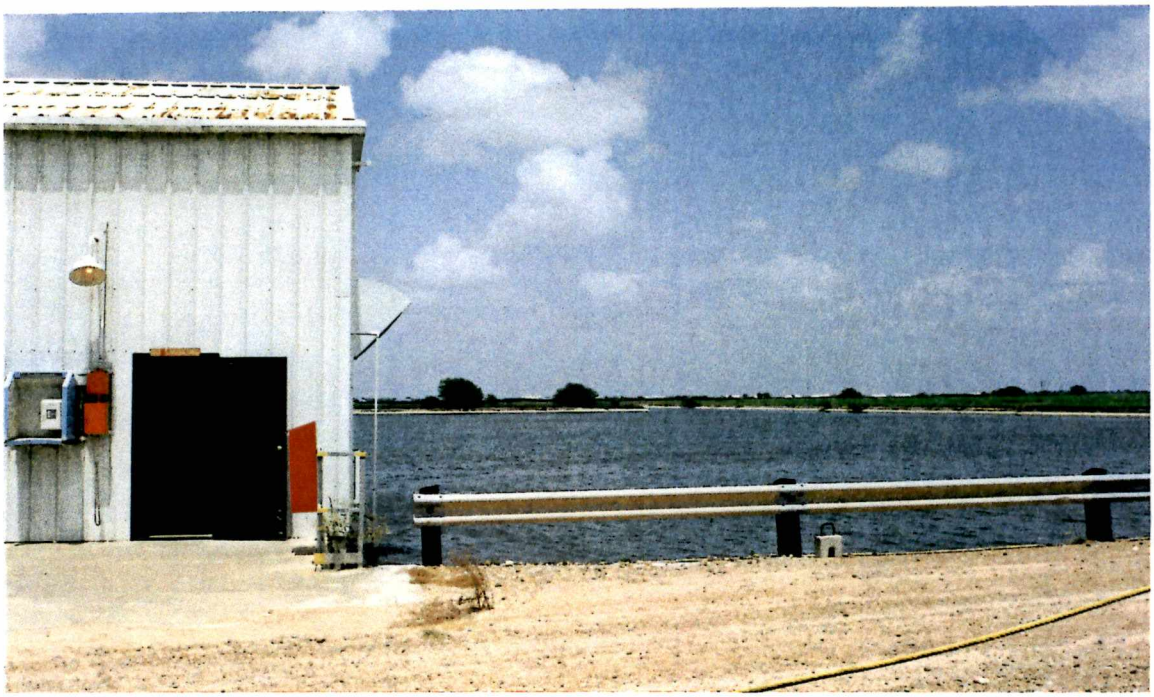


Figure 29. Photograph of the fire station pump house at a Dupont Plant in Victoria, Texas.

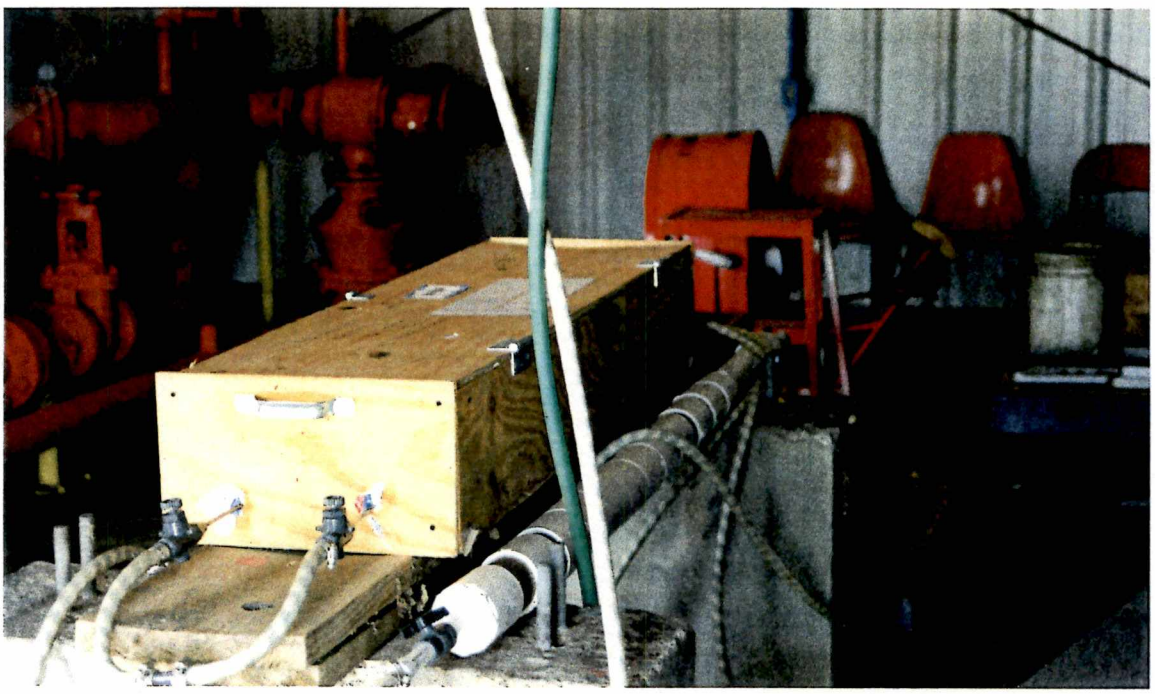
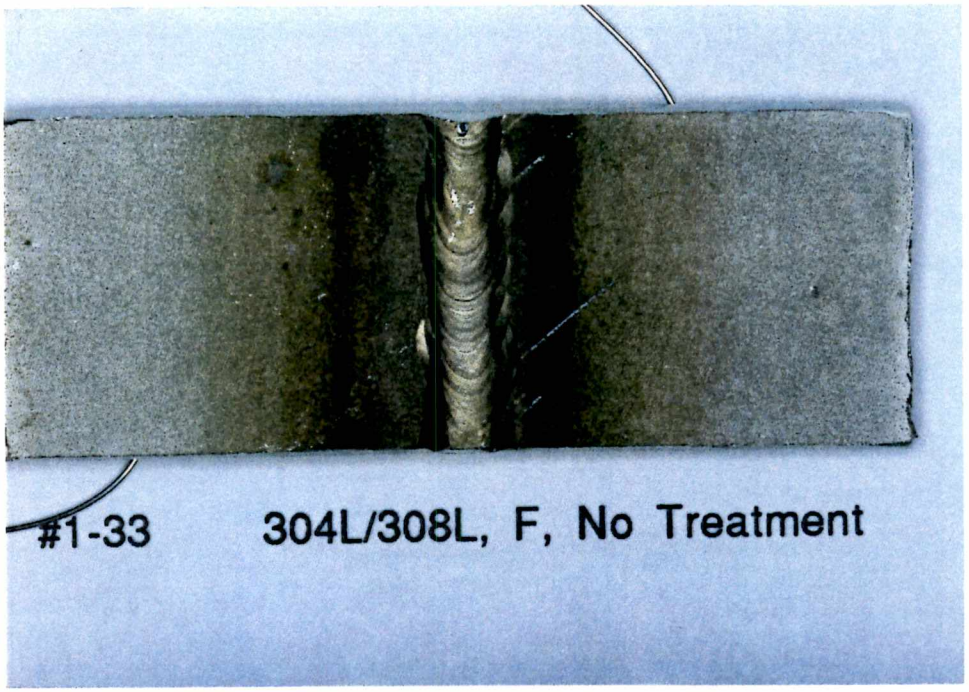


Figure 30. Photograph of the MIC test setup inside the fire station pump house.

(a)



(b)

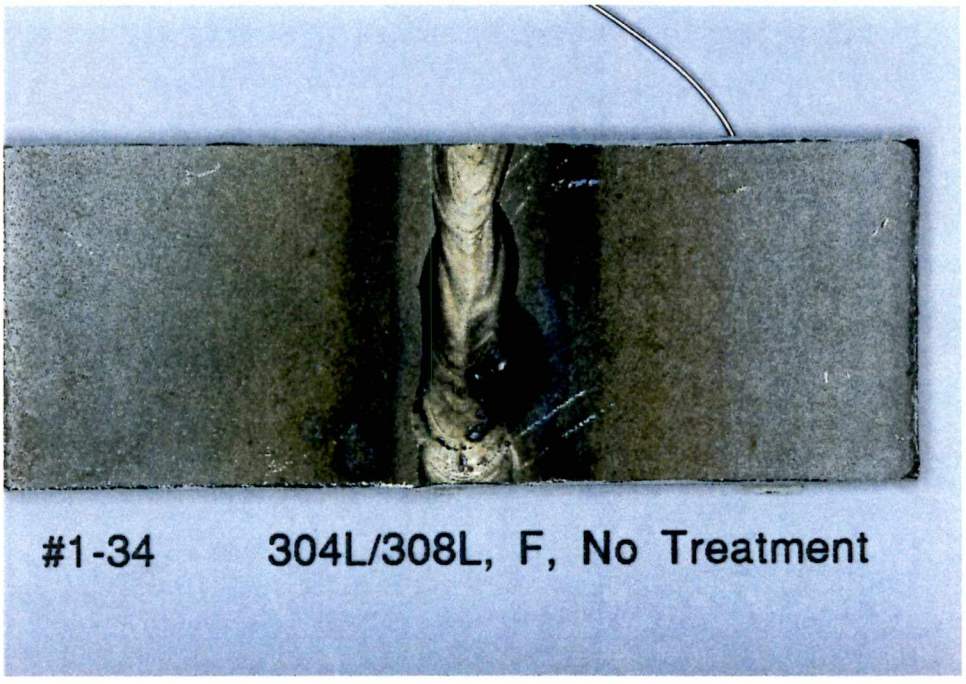
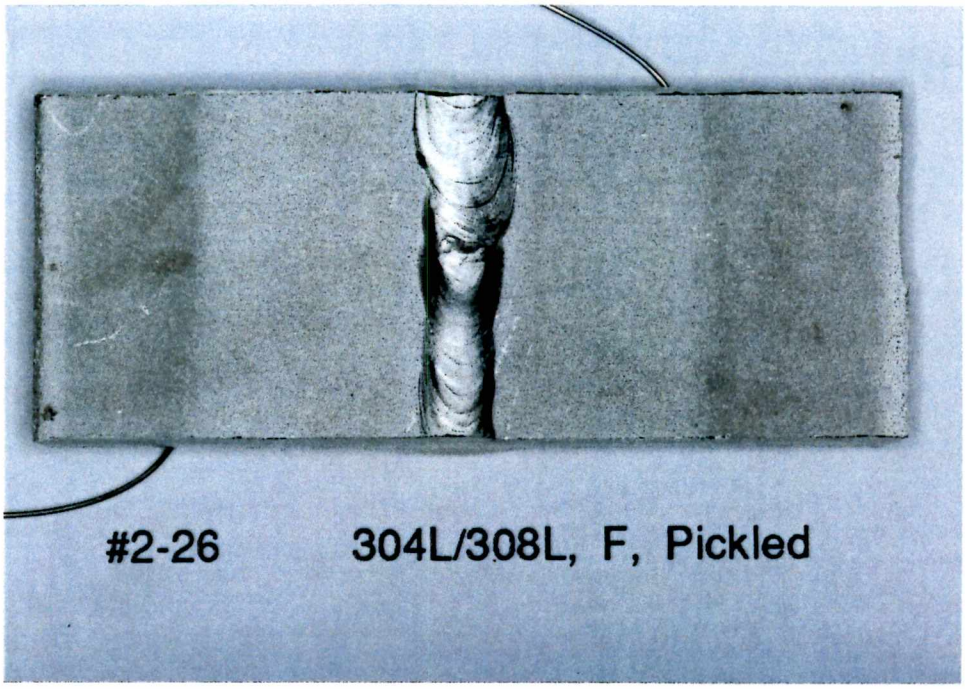


Figure 31. Coupons 1-33 and 1-34 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

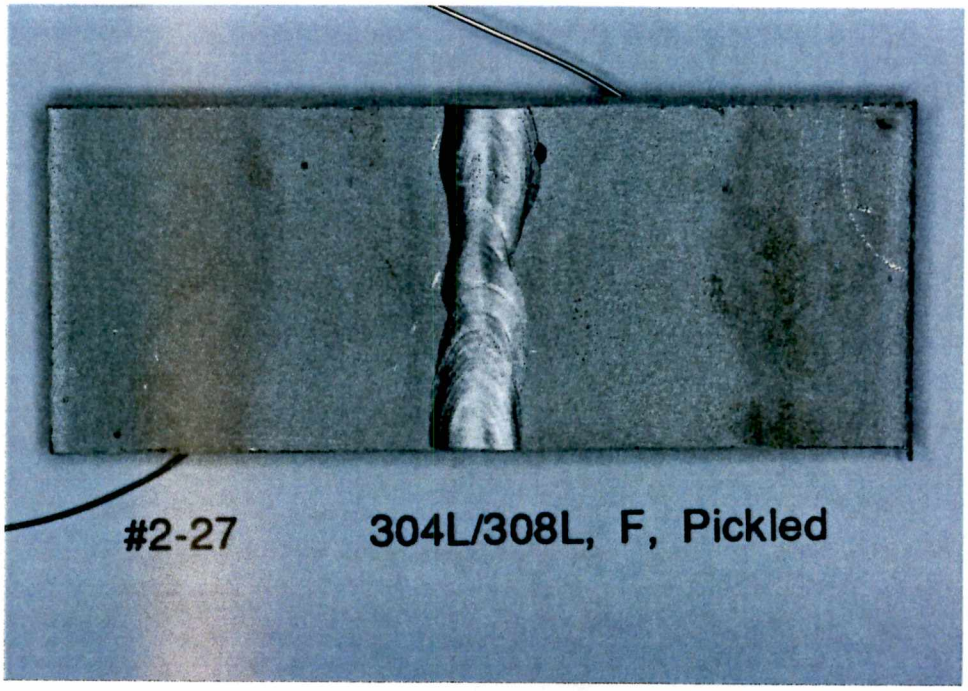
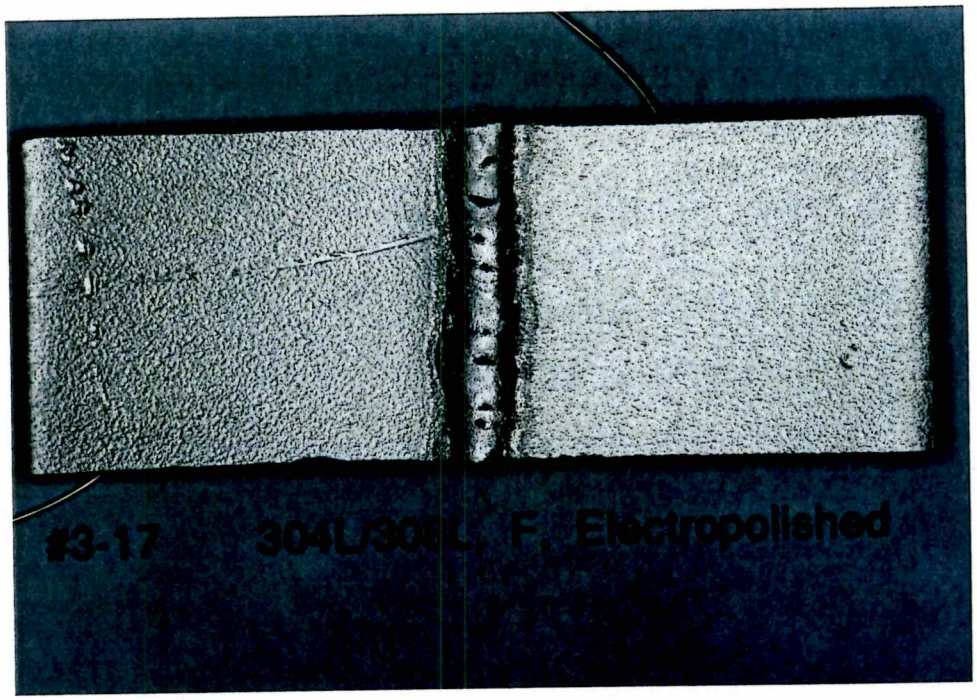


Figure 32. Coupons 2-26 and 2-27 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

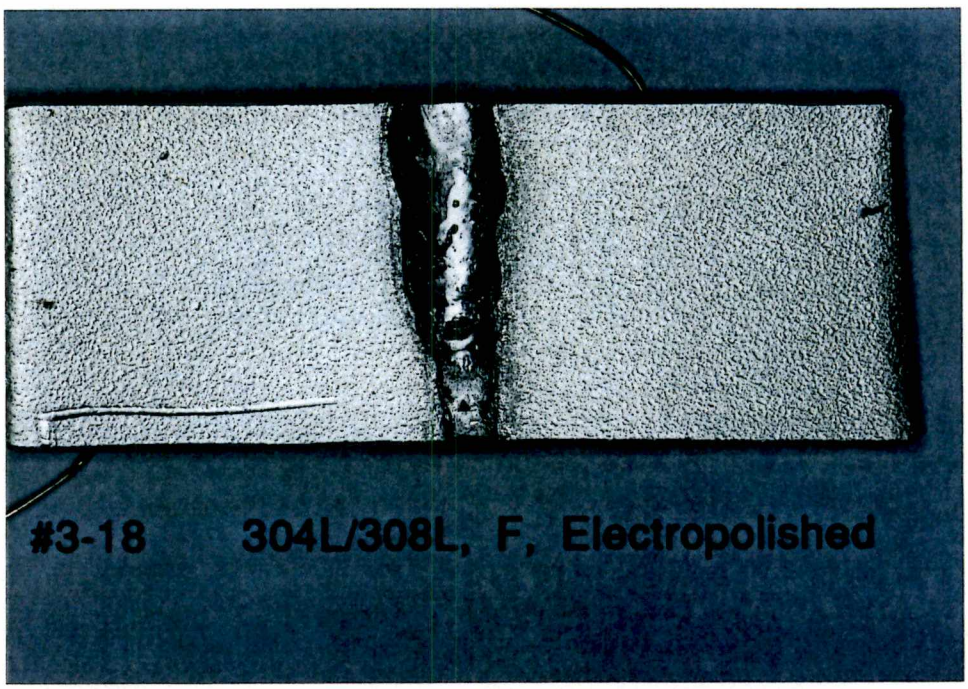
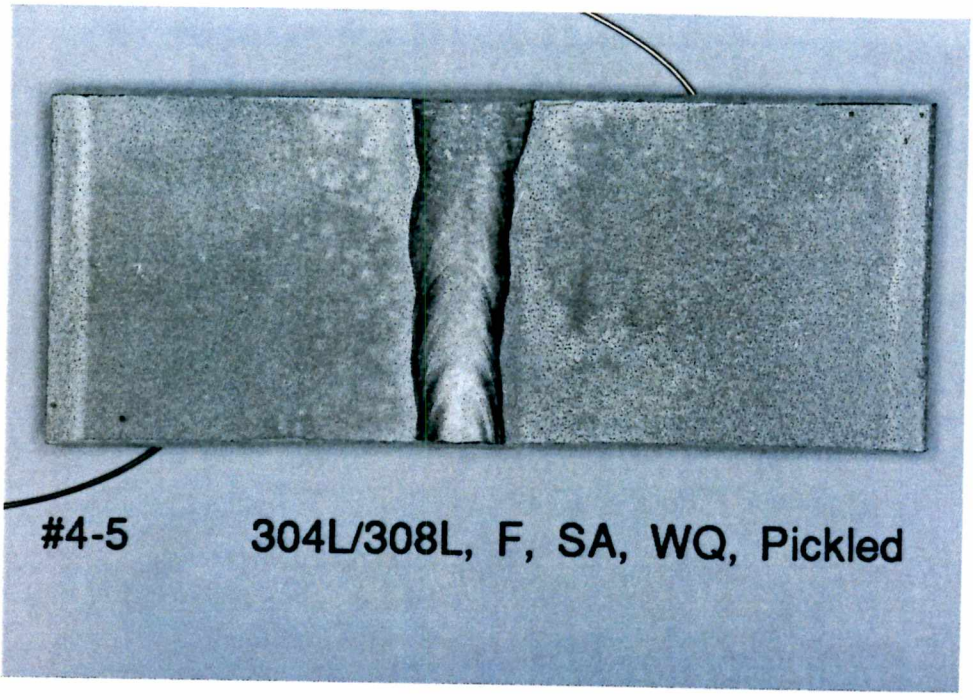


Figure 33. Coupons 3-17 and 3-18 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

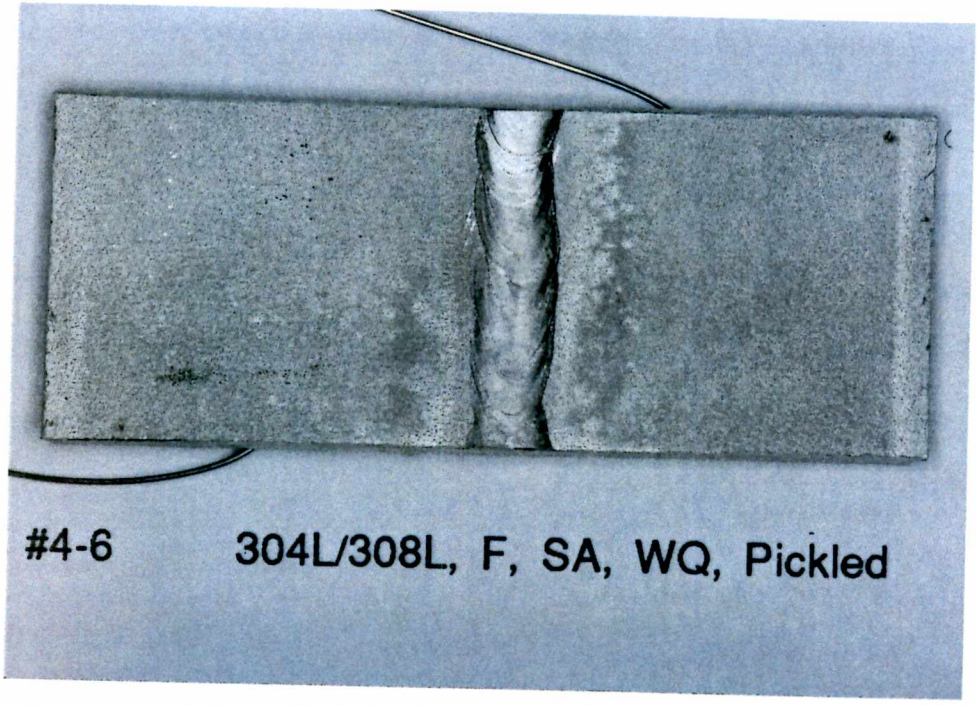
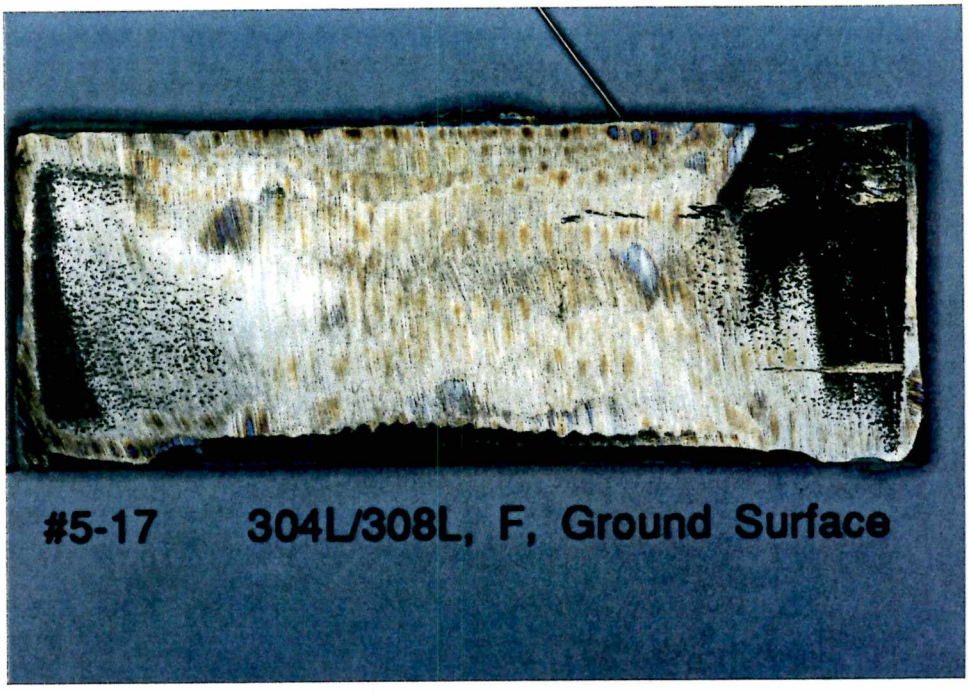


Figure 34. Coupons 4-5 and 4-6 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

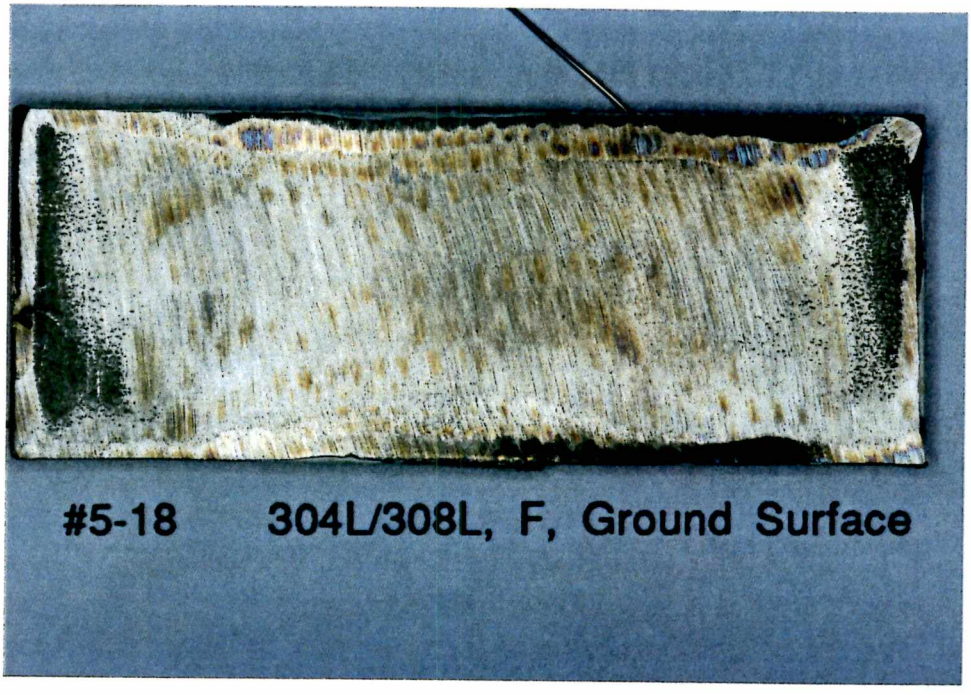
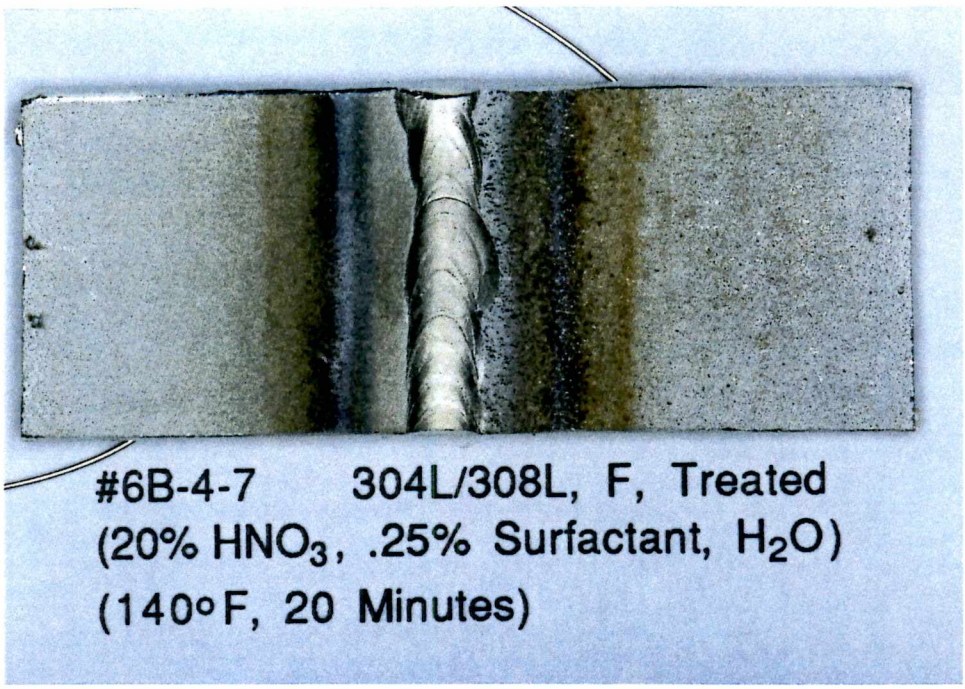


Figure 35. Coupons 5-17 and 5-18 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

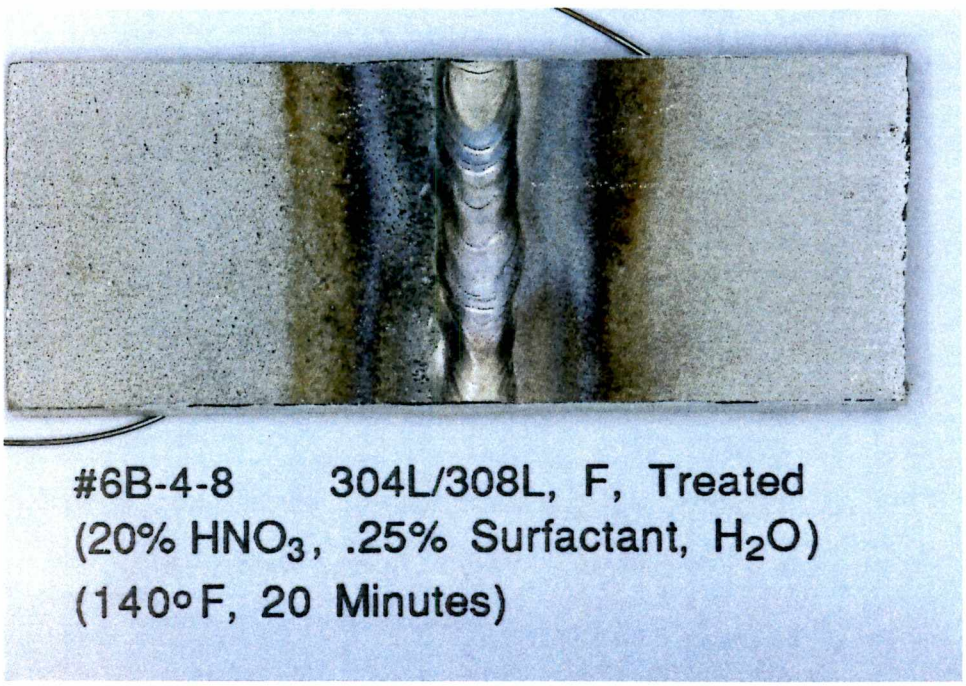


Figure 36. Coupons 6B-4-7 and 6B-4-8 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



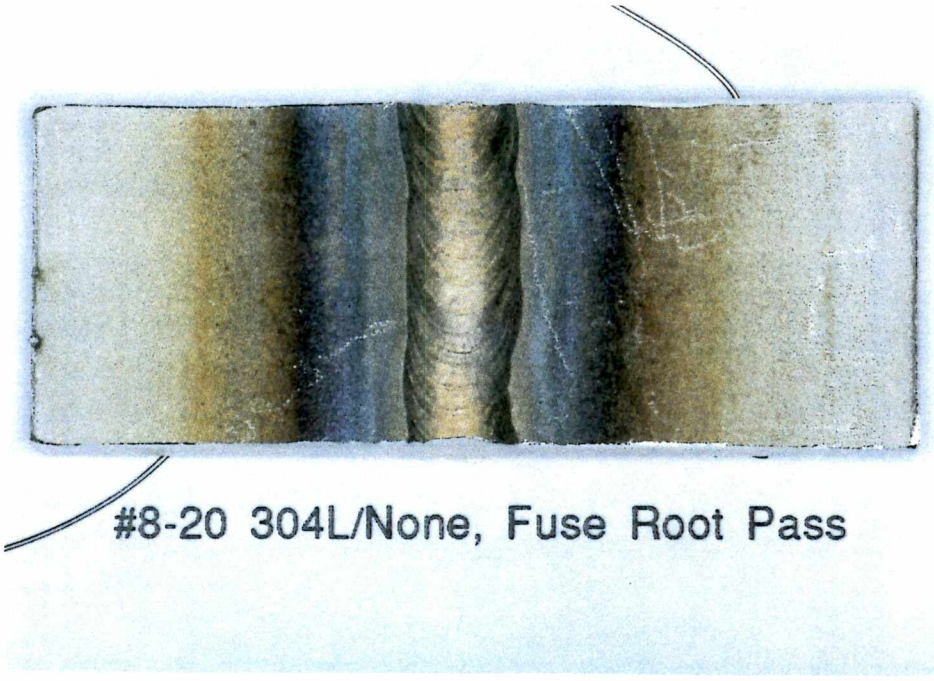
(b)



Figure 37. Coupons 7B-4-9 and 7B-4-10 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

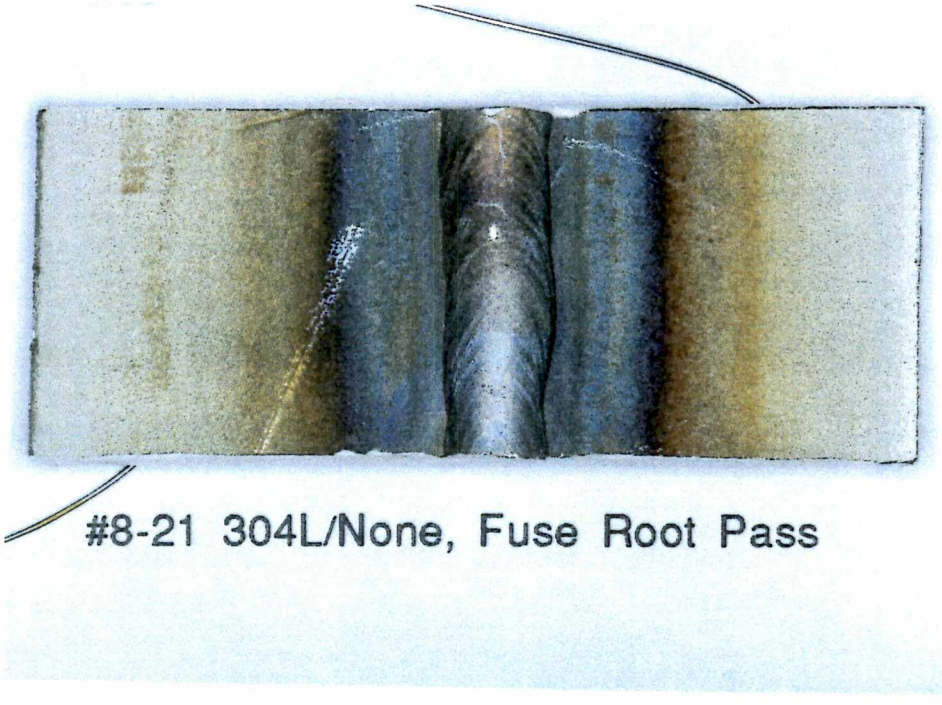
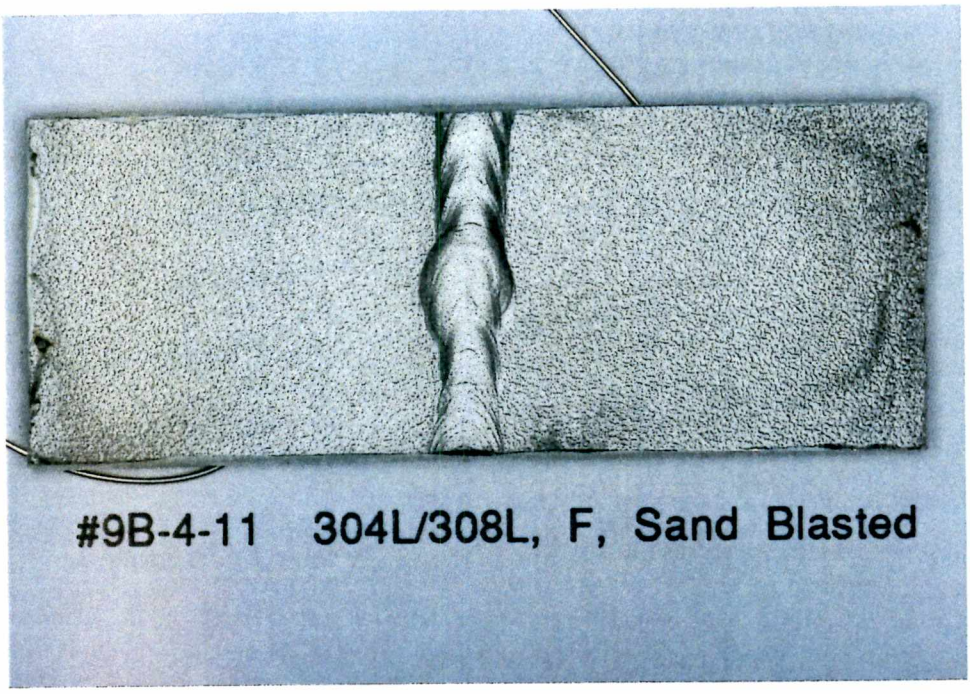


Figure 38. Coupons 8-20 and 8-21 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

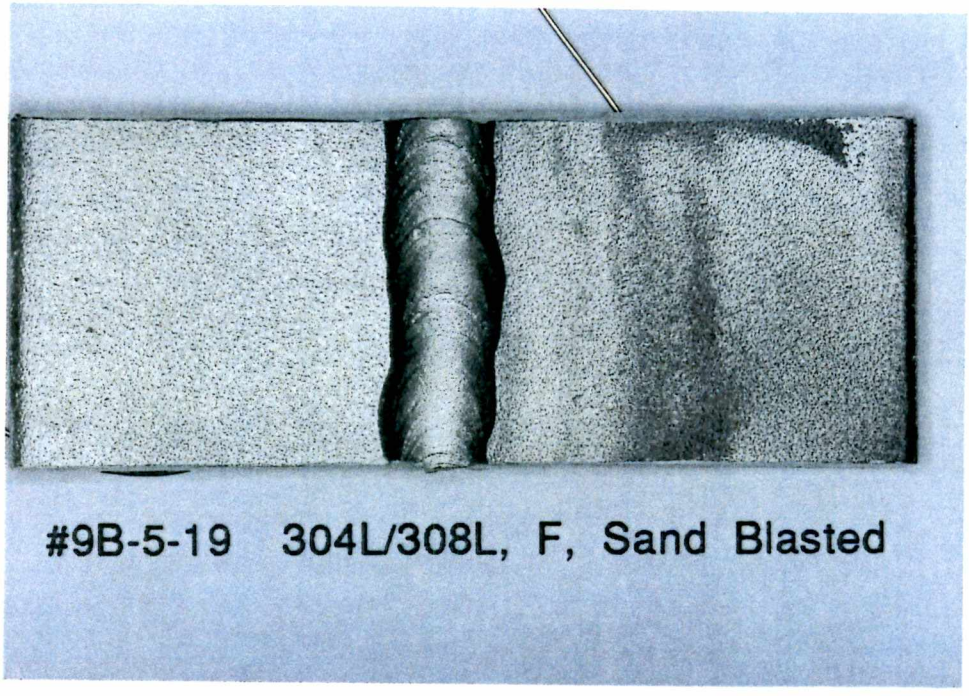
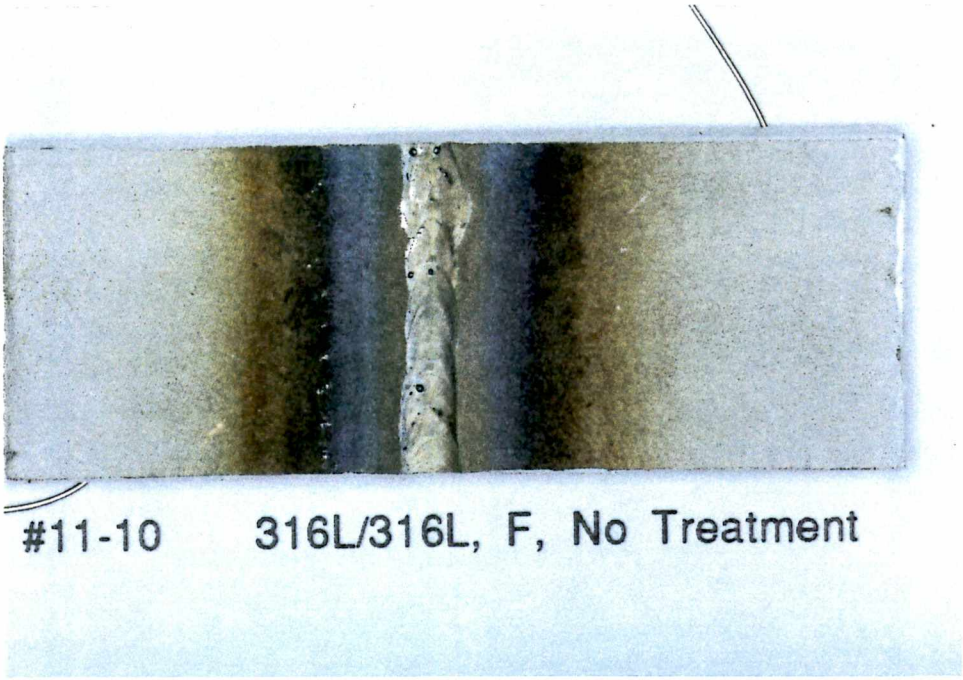


Figure 39. Coupons 9B-4-11 and 9B-5-19 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

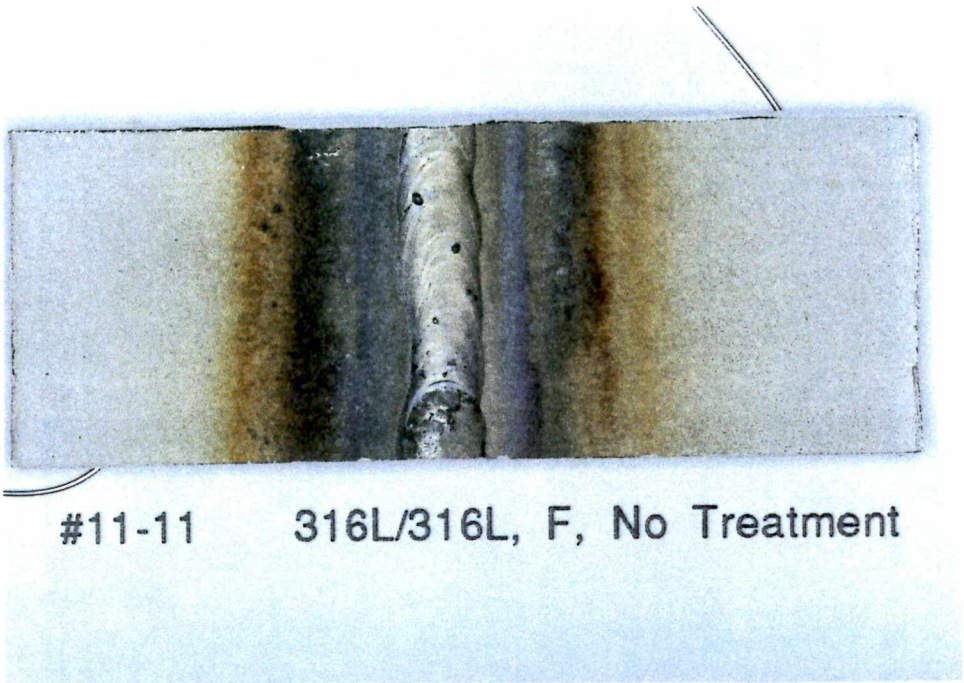
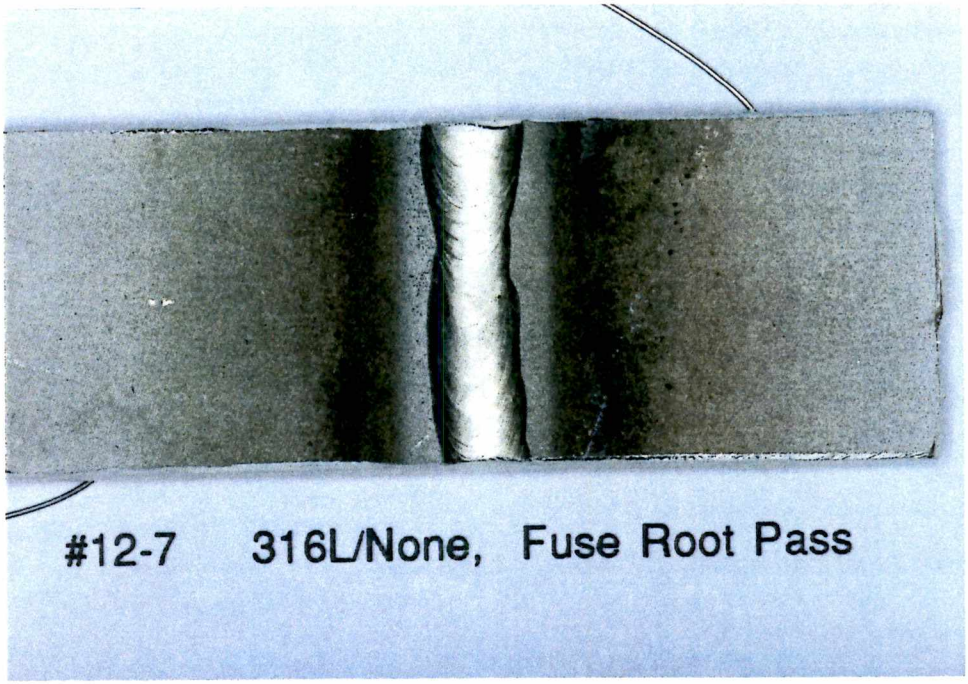


Figure 40. Coupons 11-10 and 11-11 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

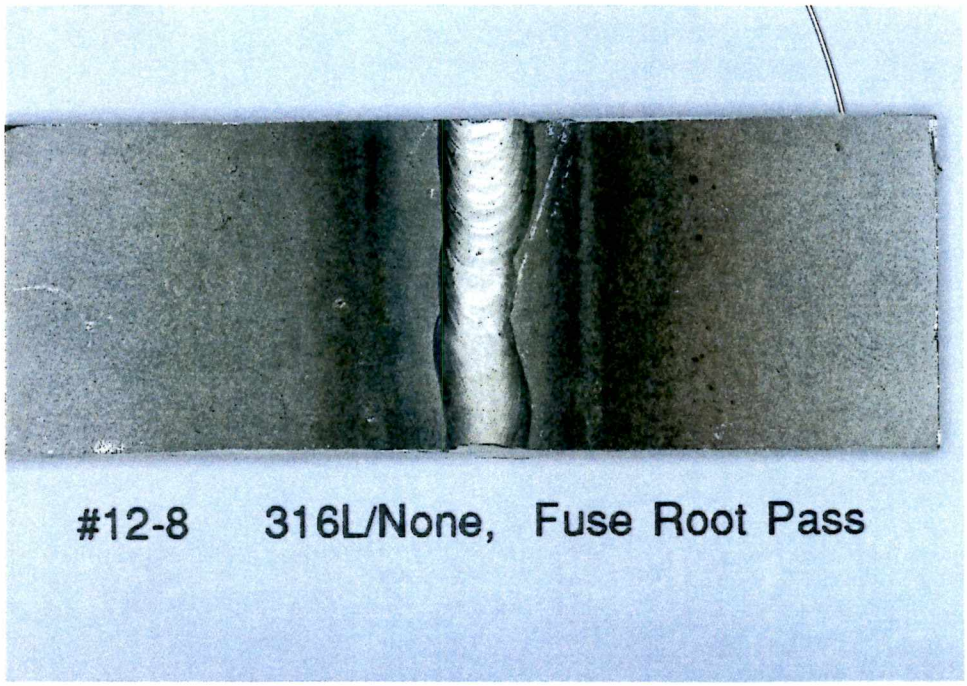
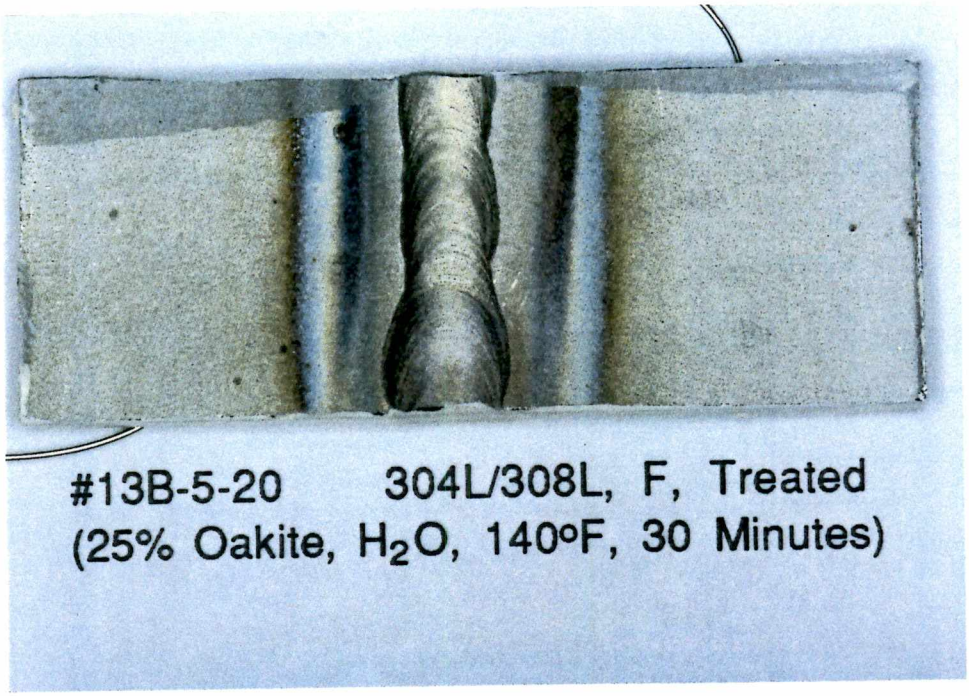


Figure 41. Coupons 12-7 and 12-8 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

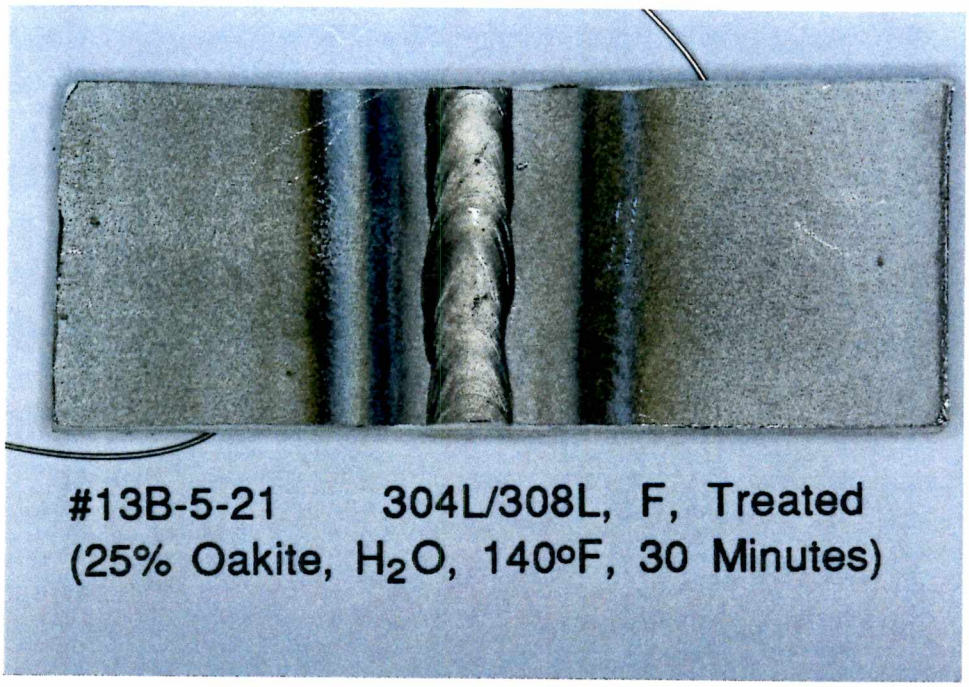
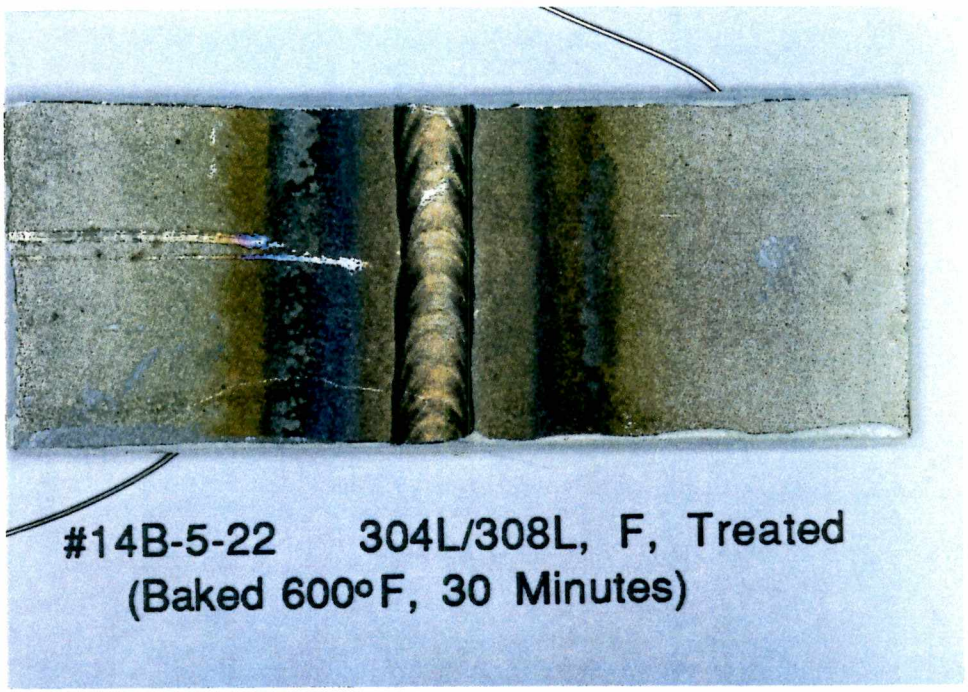


Figure 42. Coupons 13B-5-20 and 13B-5-21 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)



Figure 43. Coupons 14B-5-22 and 14B-5-23 demonstrating final surface prep prior to testing. Material type, filler metal, and treatment listed on photo.

(a) Sample for Cell #1 (b) Sample for Cell #2

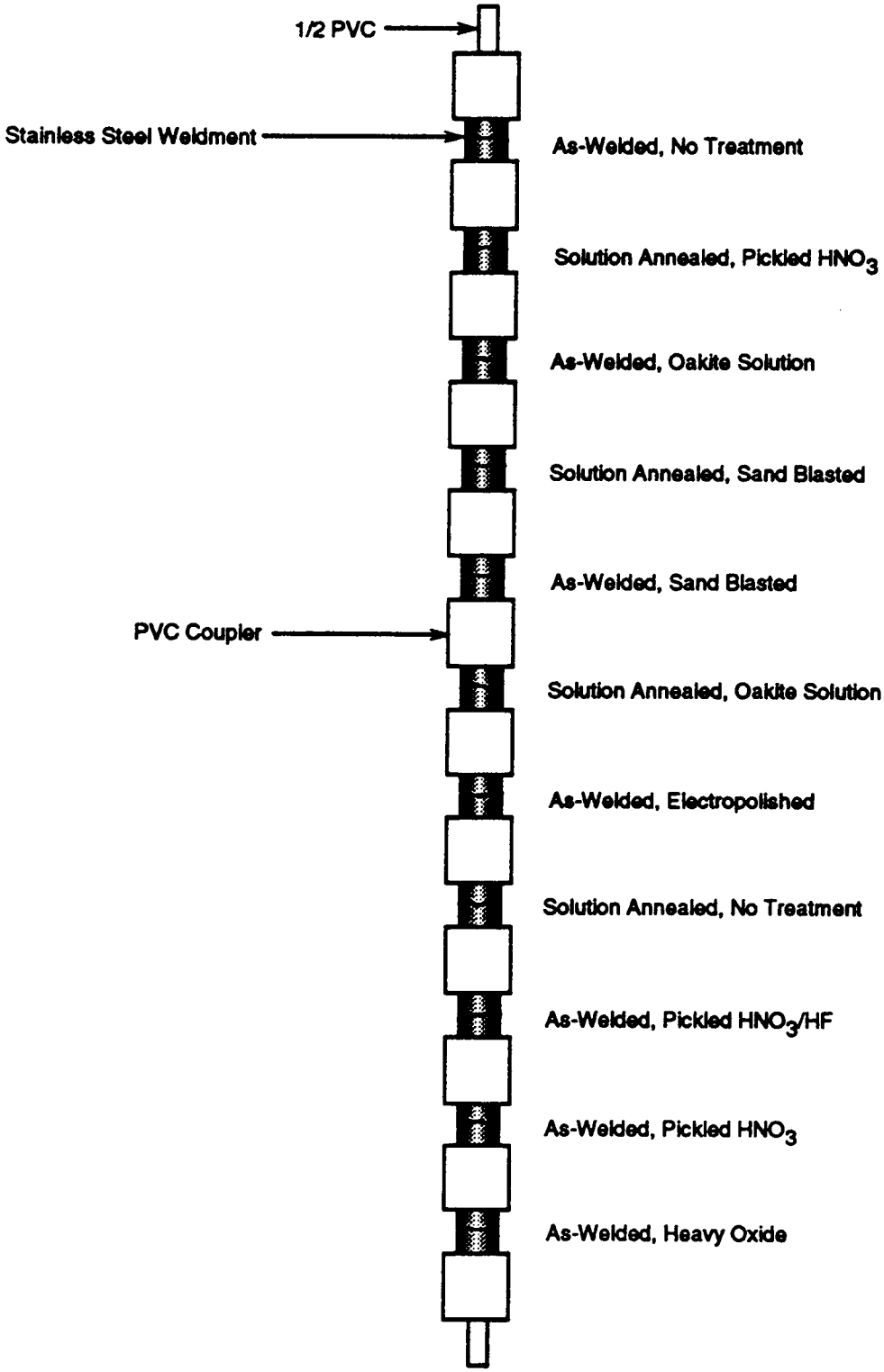


Figure 44. Schematic listing stainless weldments and their respective location in the Gaudlupe River pipe test string.

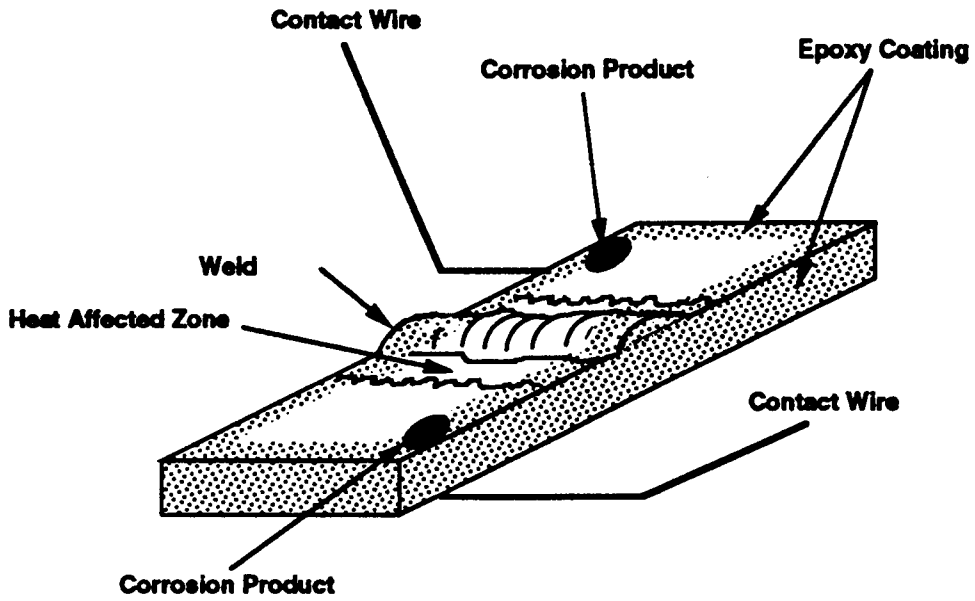
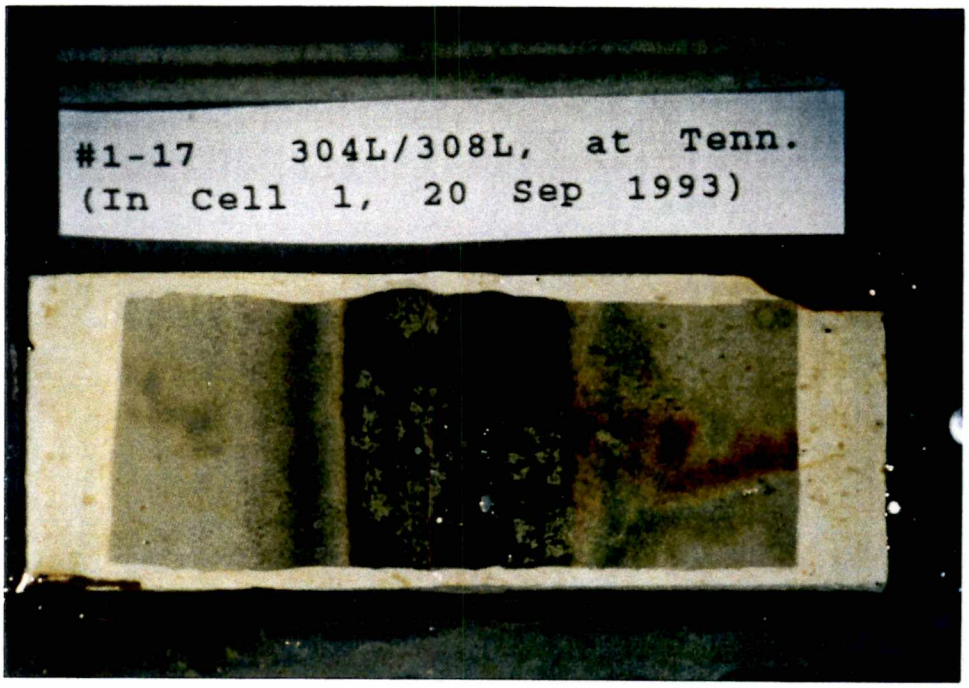


Figure 45. Schematic diagram of test coupons showing area of corrosion product.

(a)



(b)

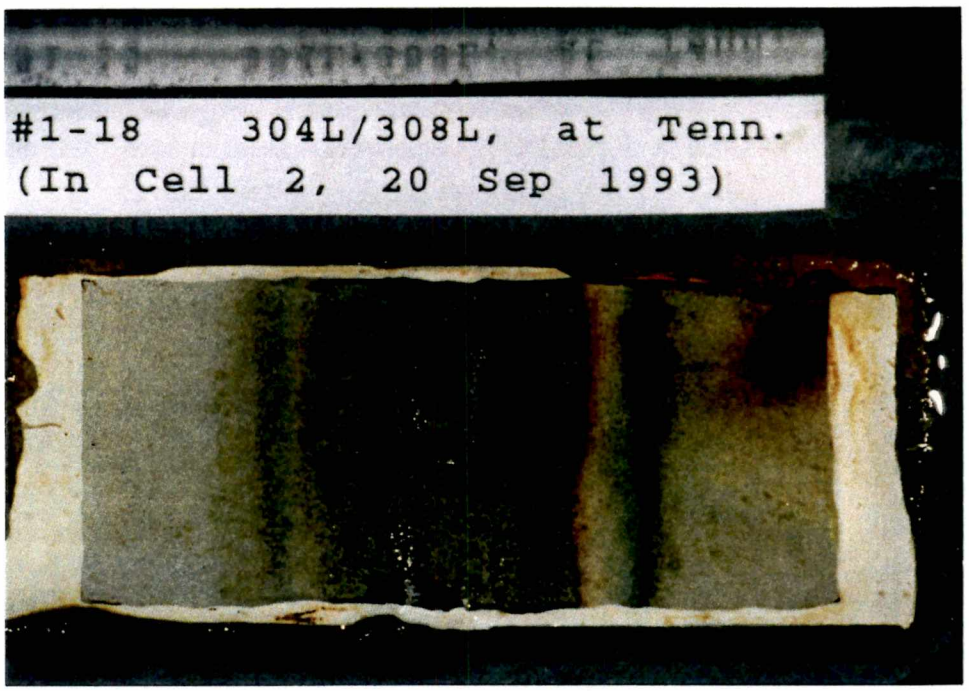
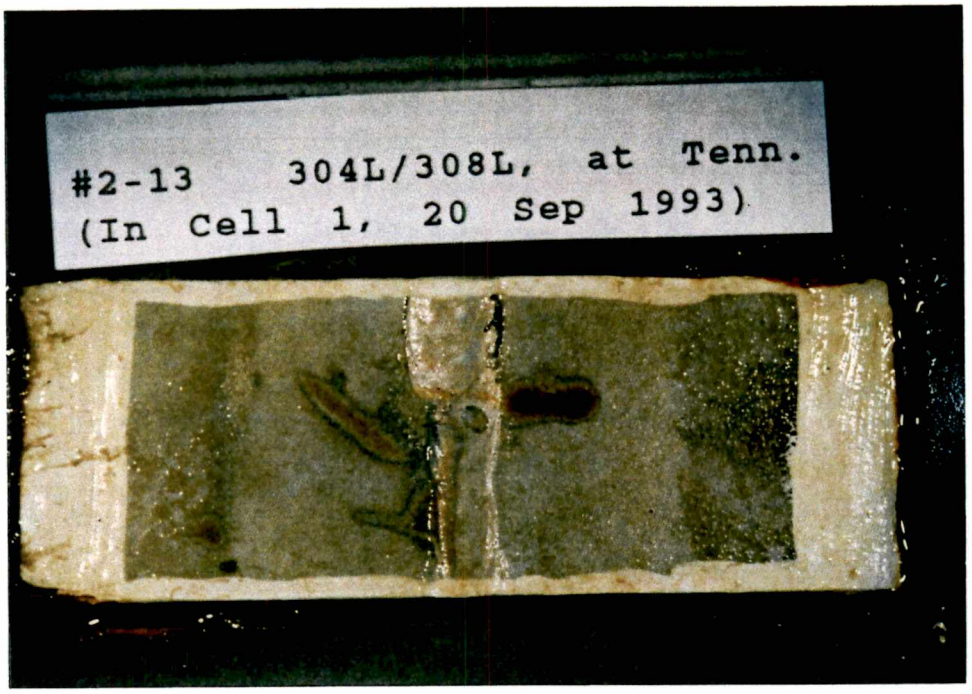


Figure 46. Coupons 1-17 and 1-18 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

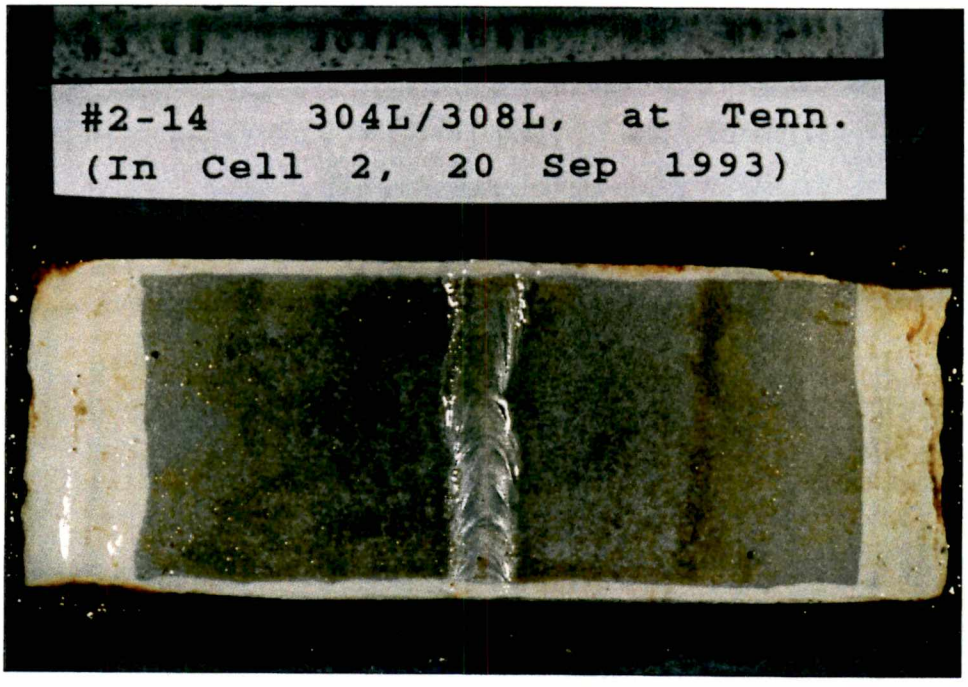
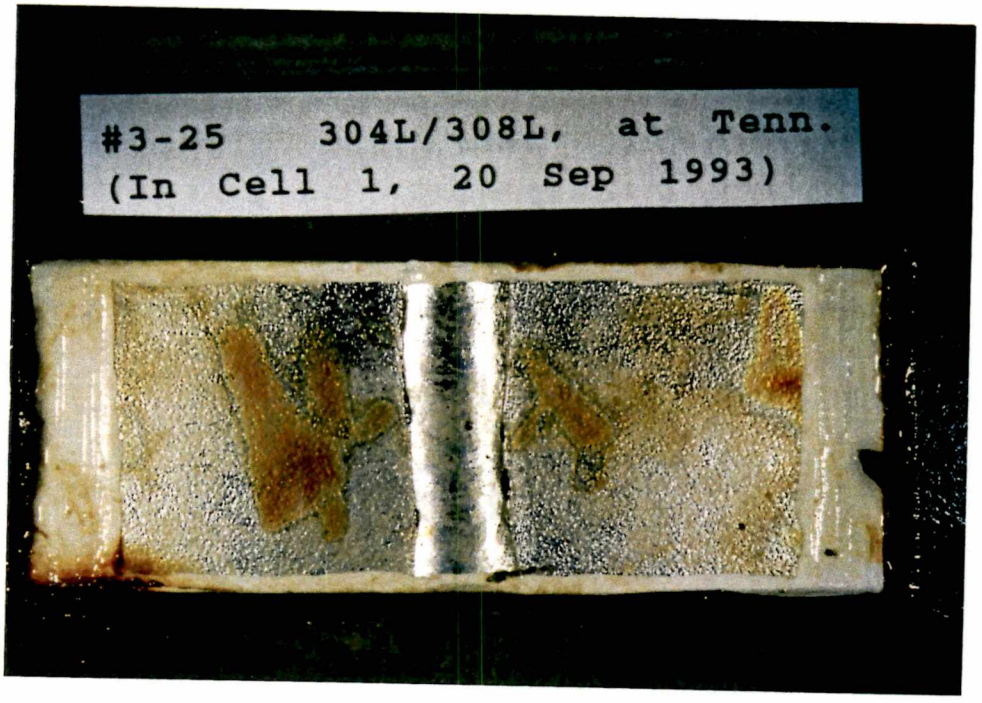


Figure 47 Coupons 2-13 and 2-14 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

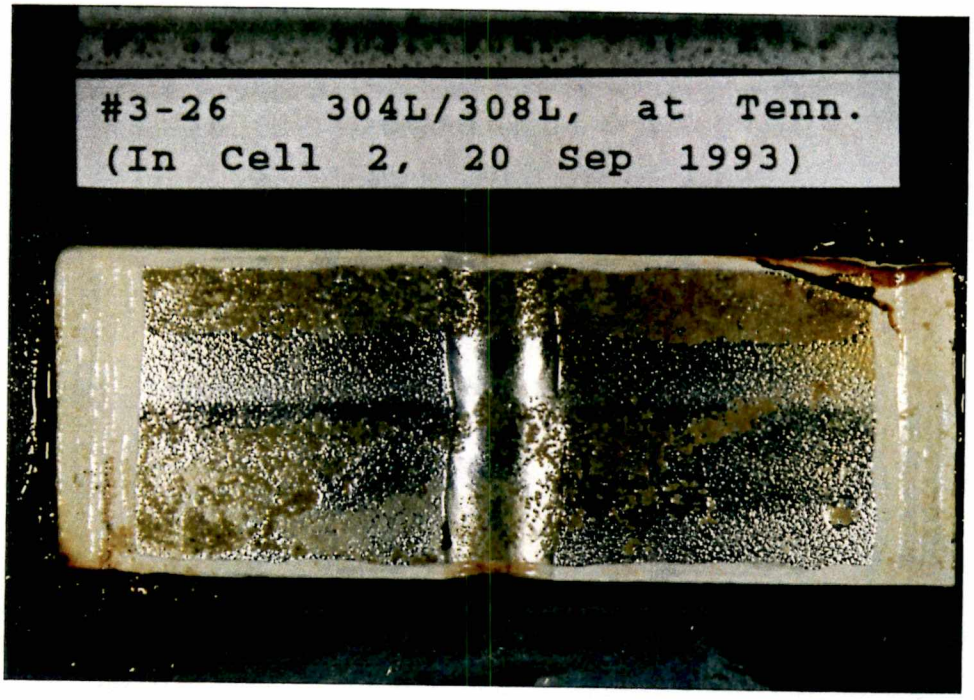
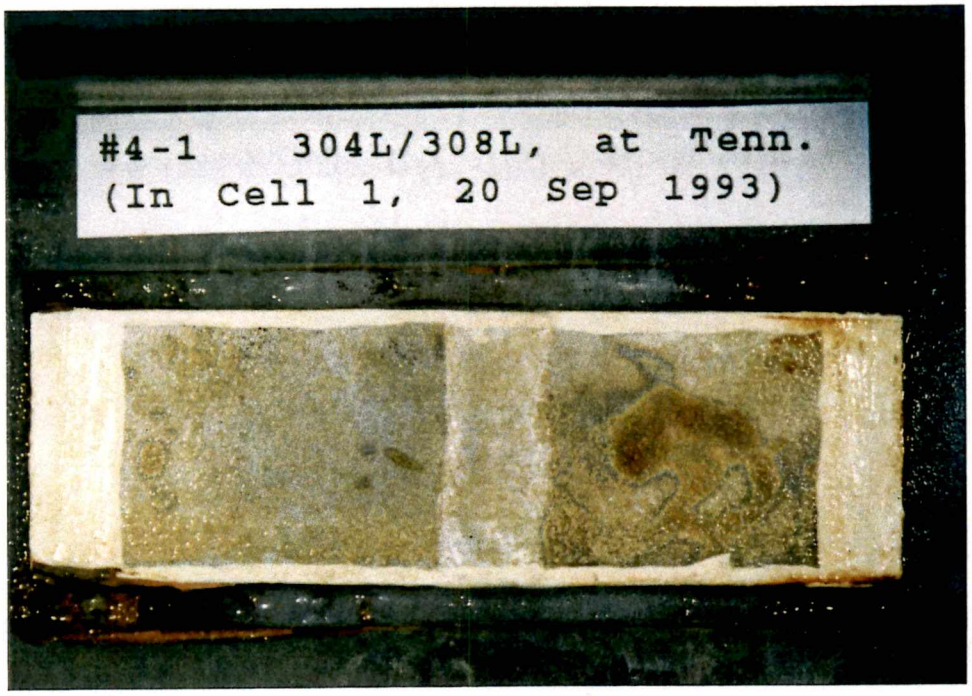


Figure 48. Coupons 3-25 and 3-26 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

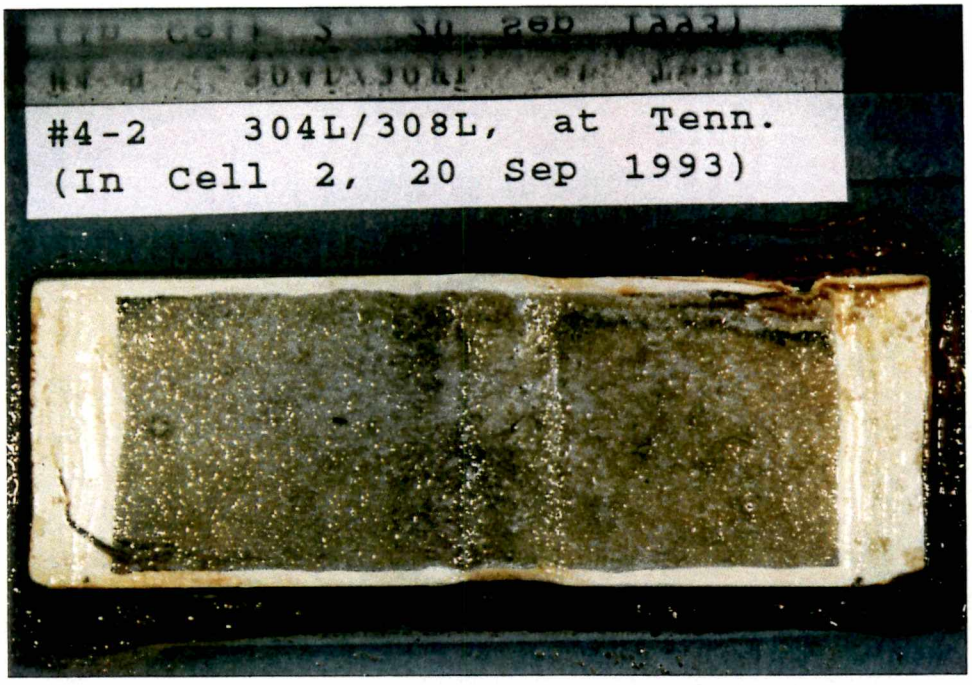


Figure 49. Coupons 4-1 and 4-2 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

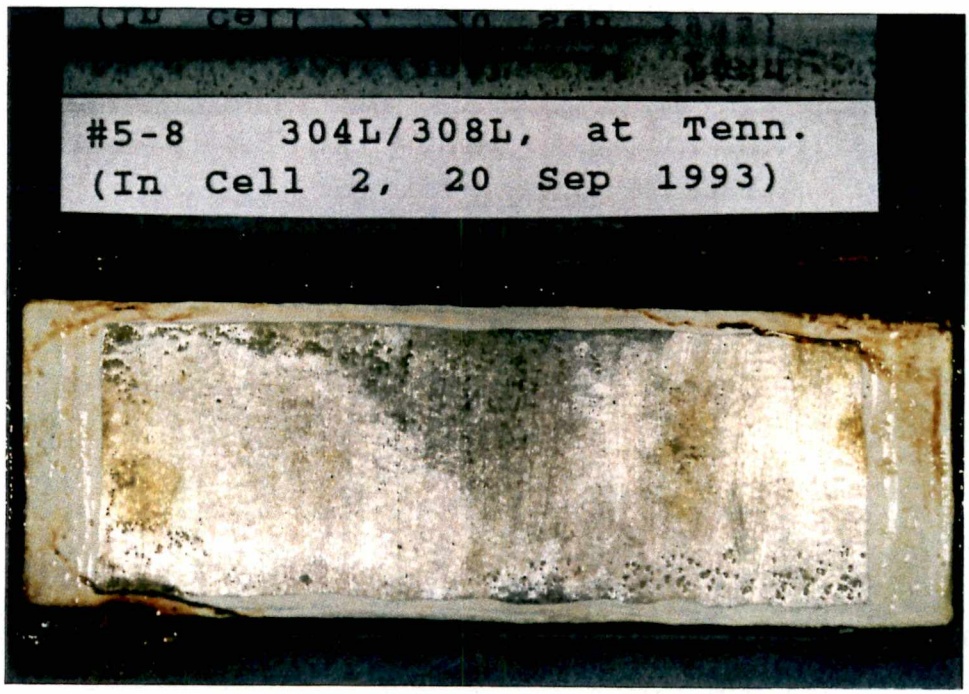
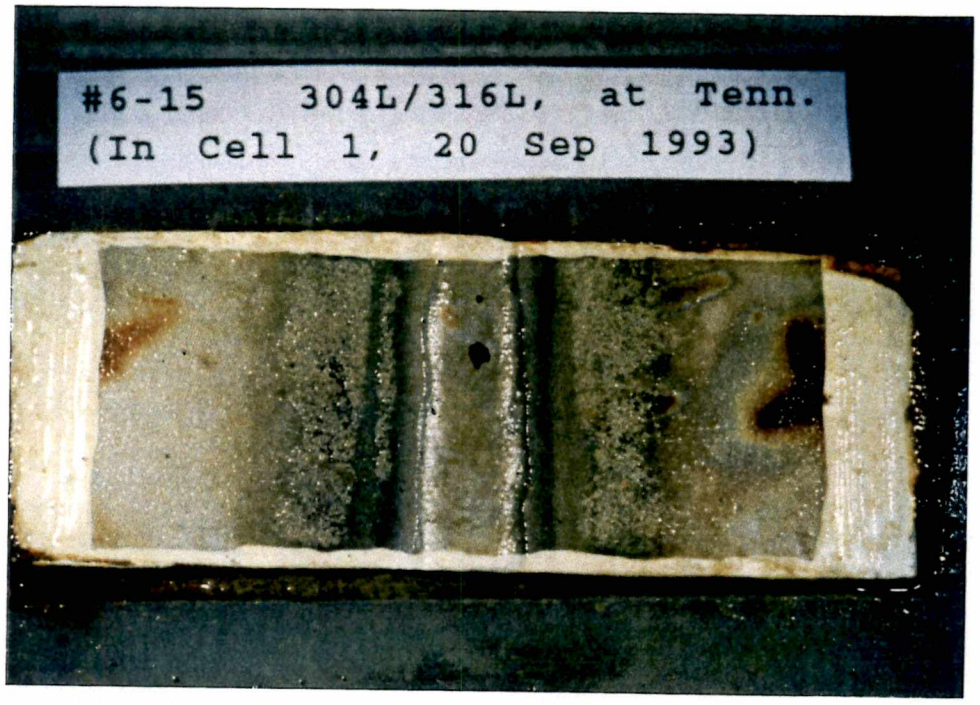


Figure 50. Coupons 5-7 and 5-8 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

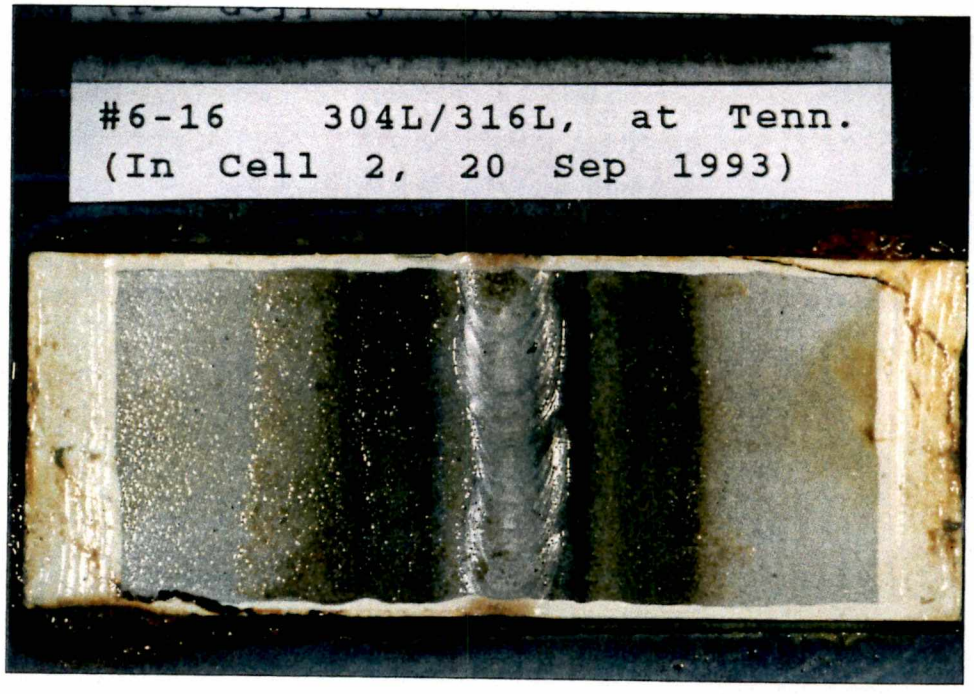
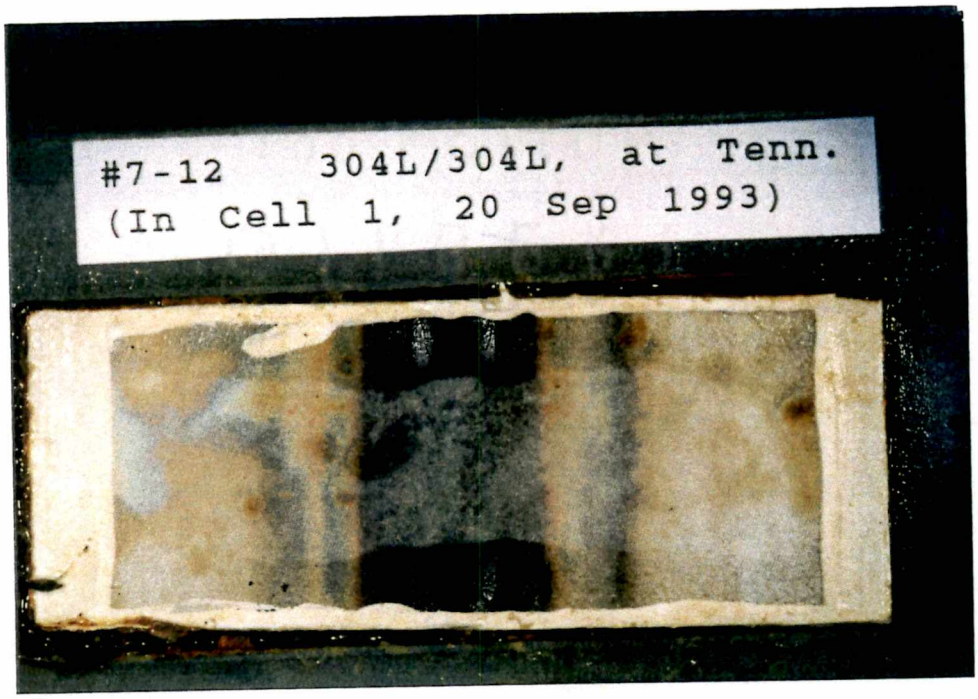


Figure 51. Coupons 6-15 and 6-16 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

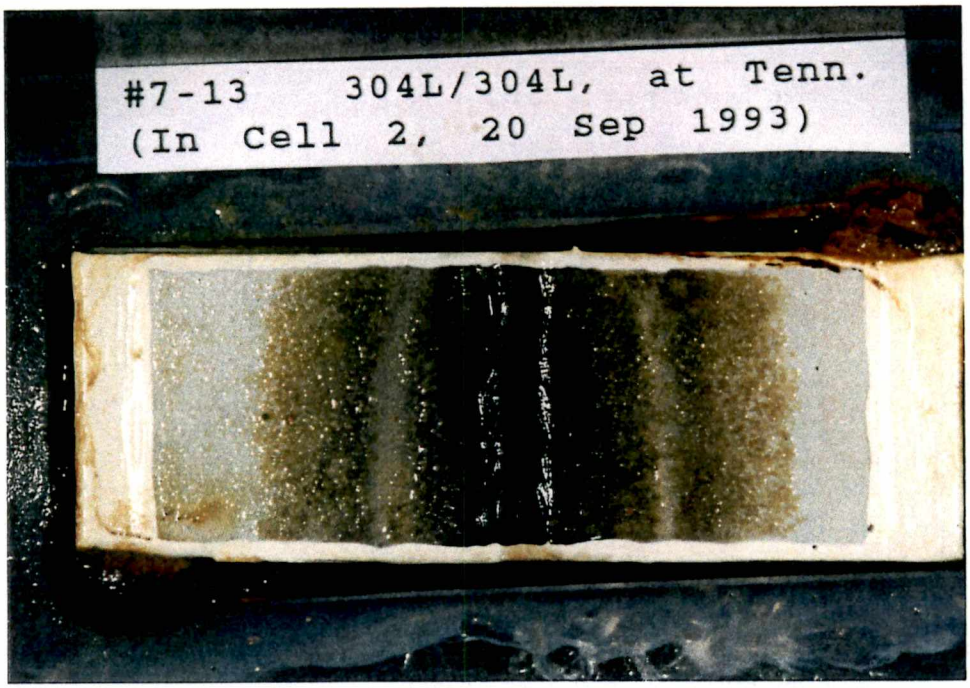


Figure 52. Coupons 7-12 and 7-13 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



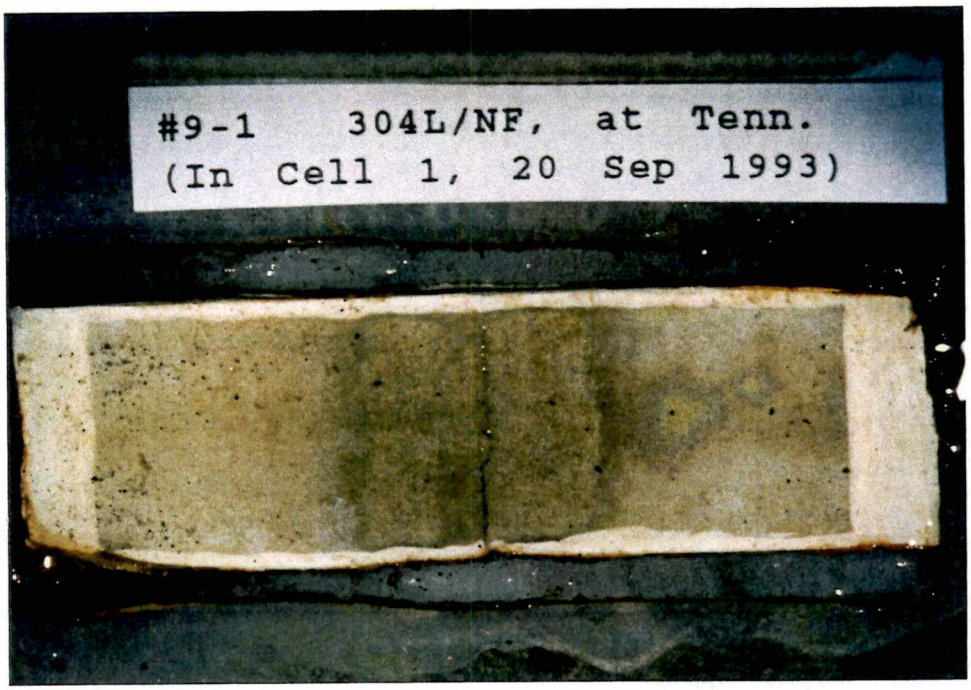
(b)



Figure 53. Coupons 8-15 and 8-6 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



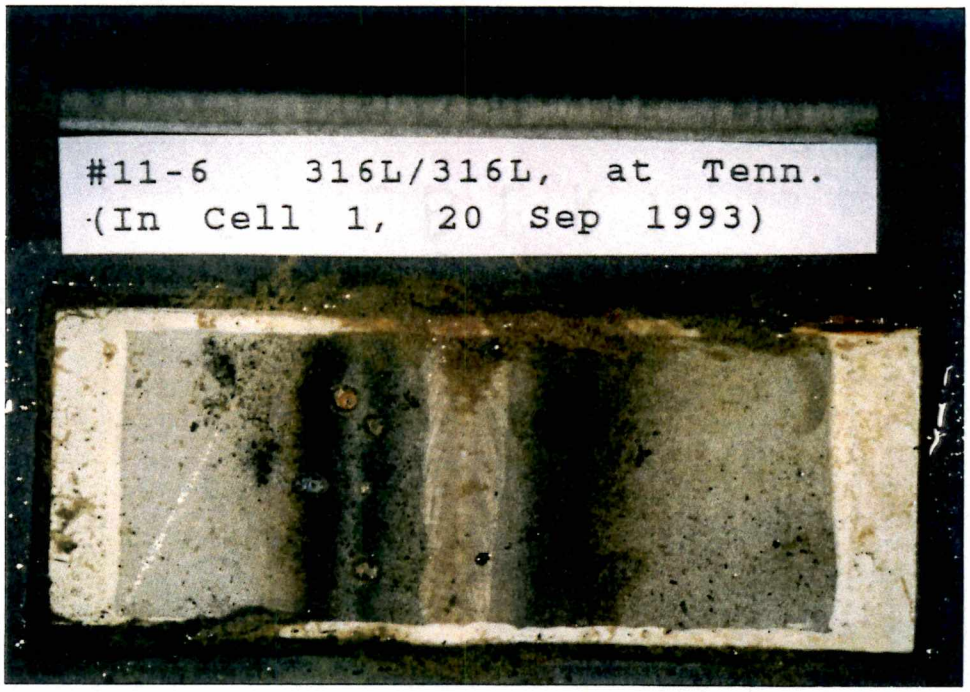
(b)



Figure 54. Coupons 9-1 and 9-38 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

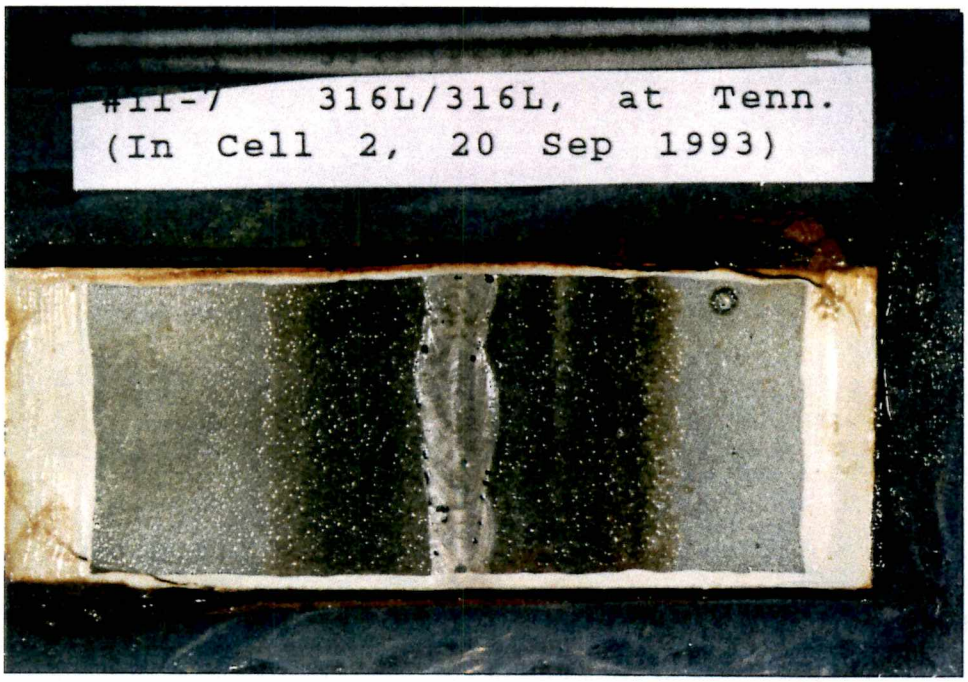
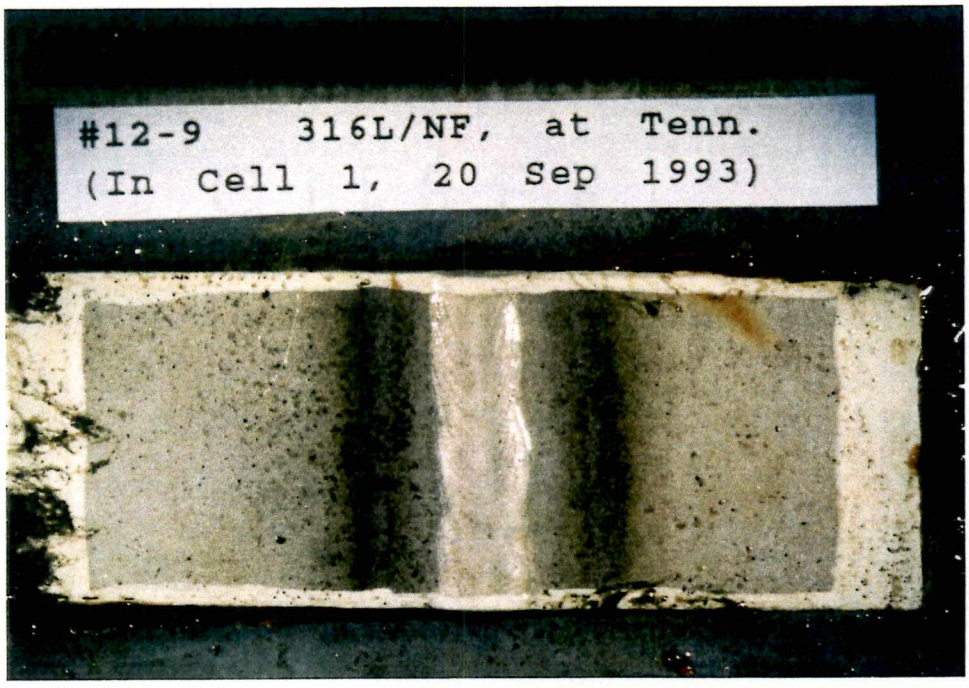


Figure 55. Coupons 11-6 and 11-7 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

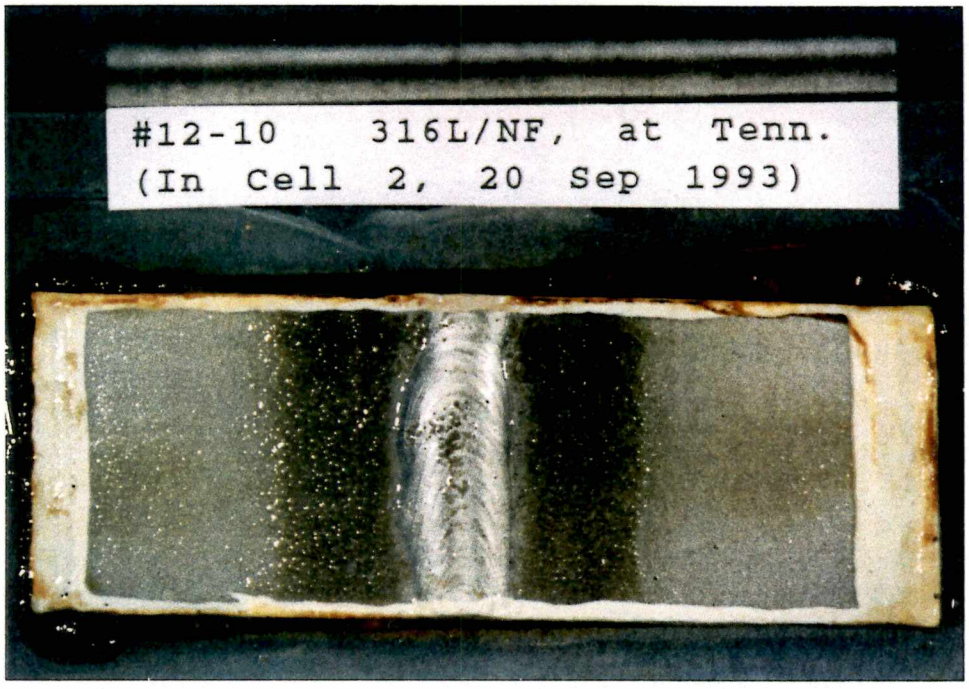


Figure 56. Coupons 12-9 and 12-10 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

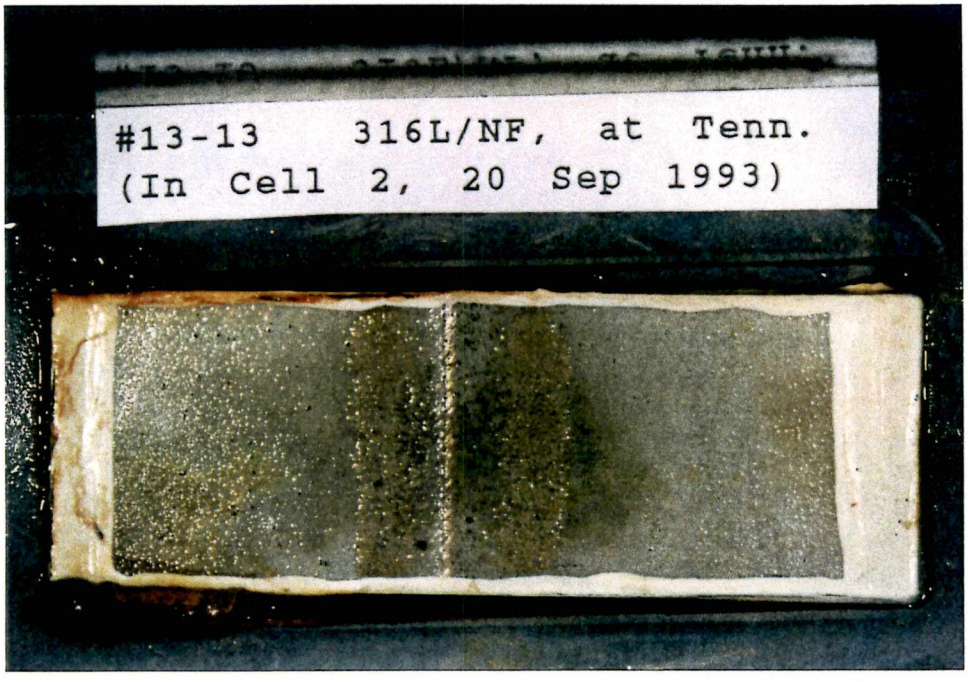
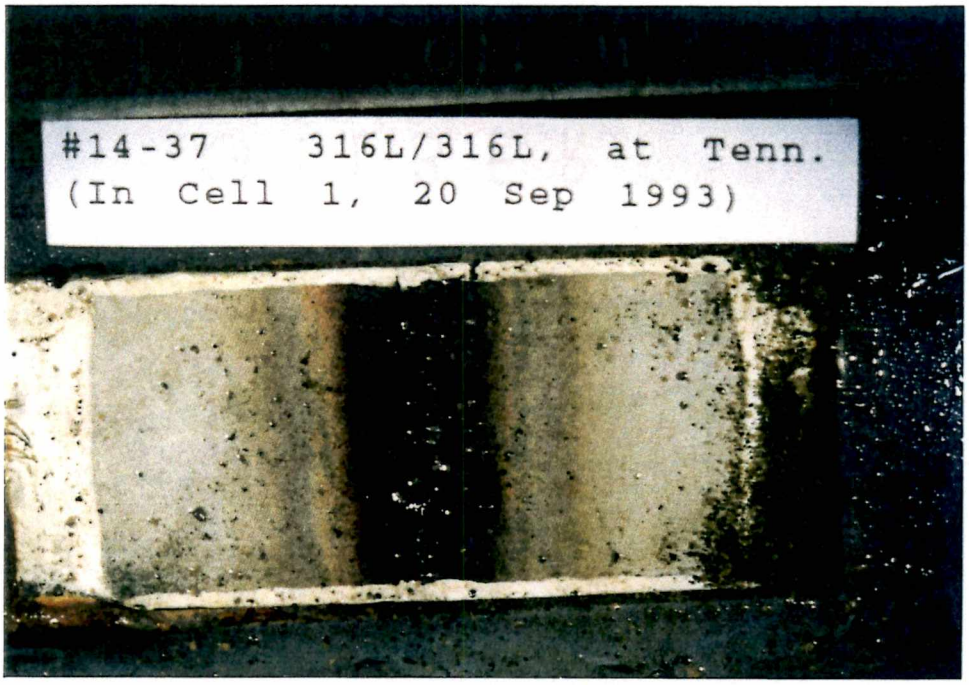


Figure 57. Coupons 13-12 and 13-13 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)



Figure 58. Coupons 14-37 and 14-38 after being placed in the Tennessee River Water for a year and a half.

(a) Sample for Cell #1 (b) Sample for Cell #2

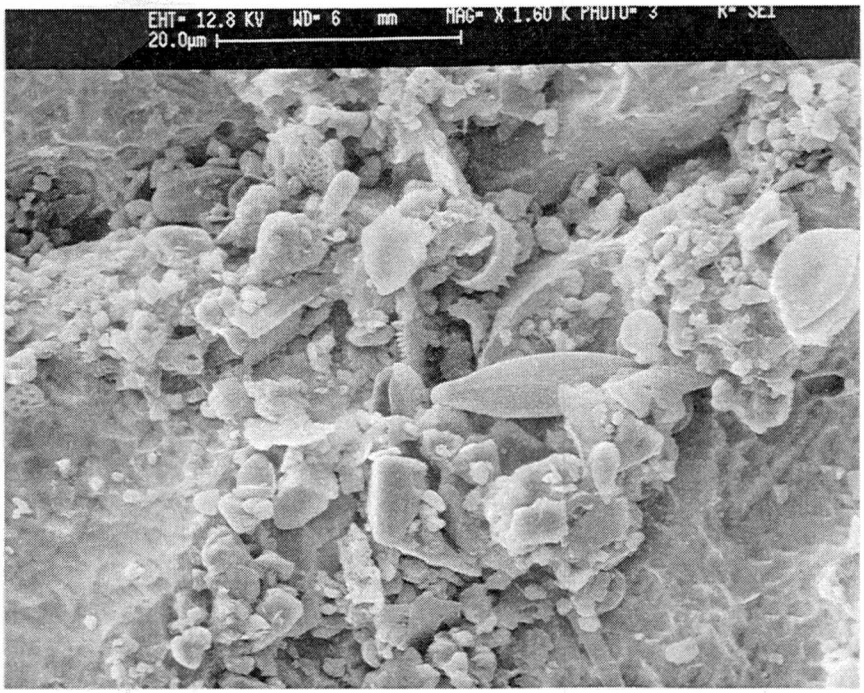


Figure 59. Representative photo of the biofilm located on the test coupons. Photo includes diatoms, corrosion product, etc. (20um)

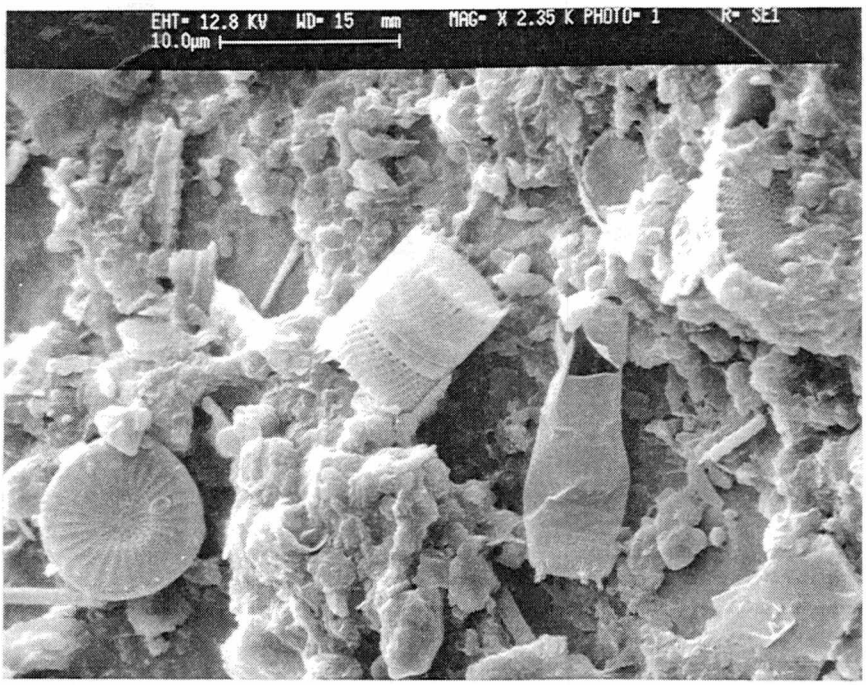


Figure 60. Photo demonstrating biofilm from test samples. Photo includes diatoms, corrosion product, etc. (10um)

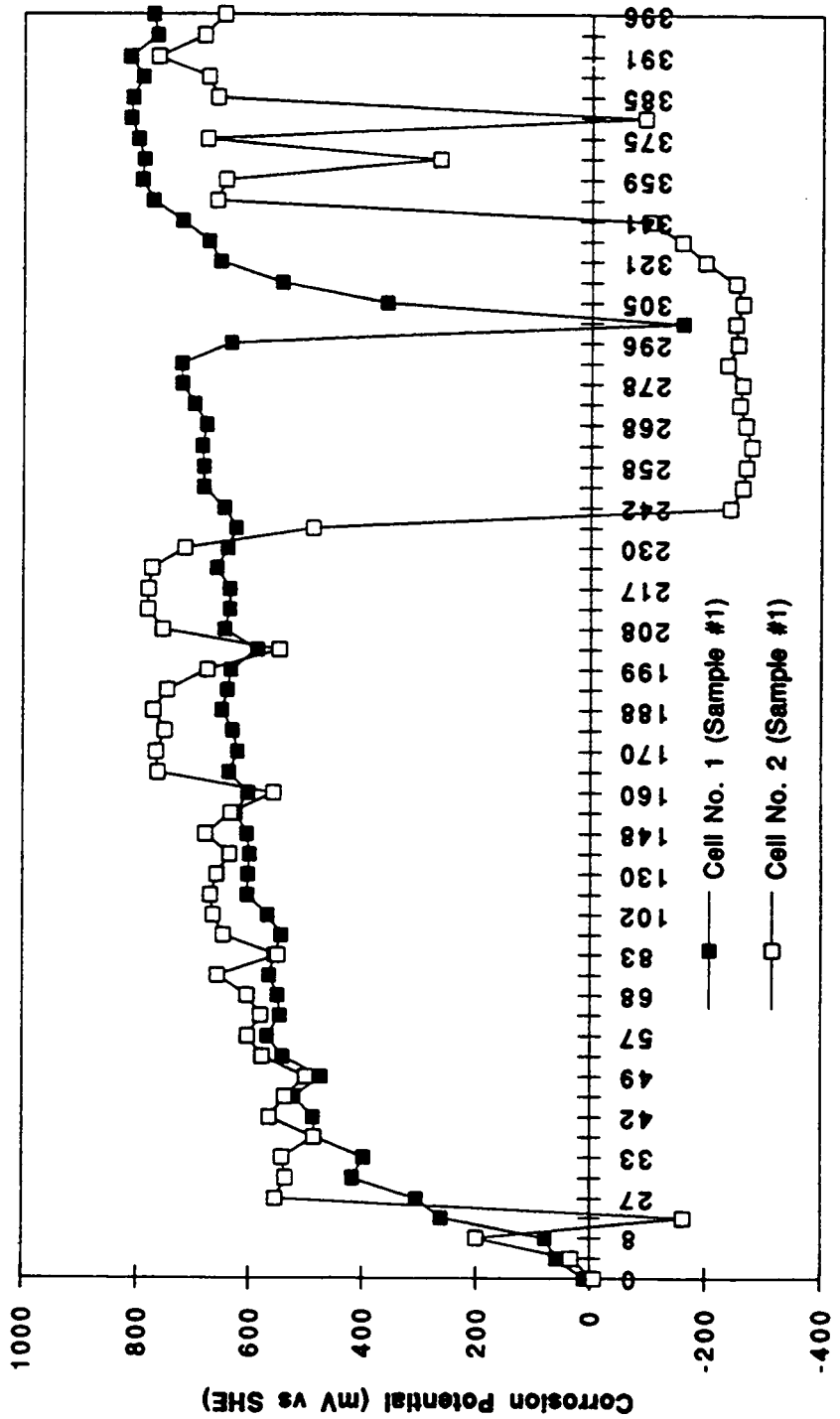


Figure 61. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 1-22 and 1-23.

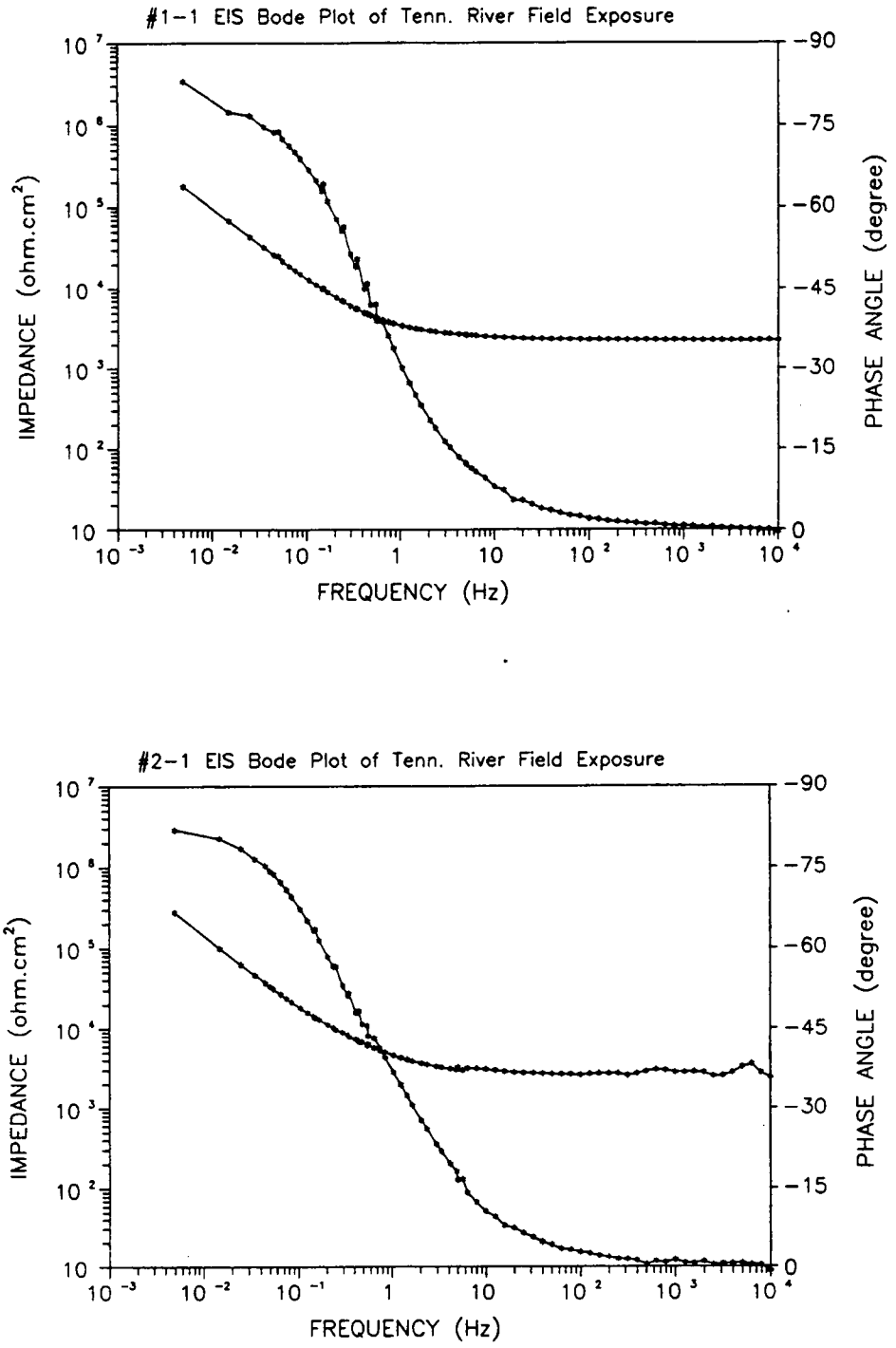


Figure 62. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 1-22 and 1-23.

(a) Sample for Cell #1 (b) Sample for Cell #2

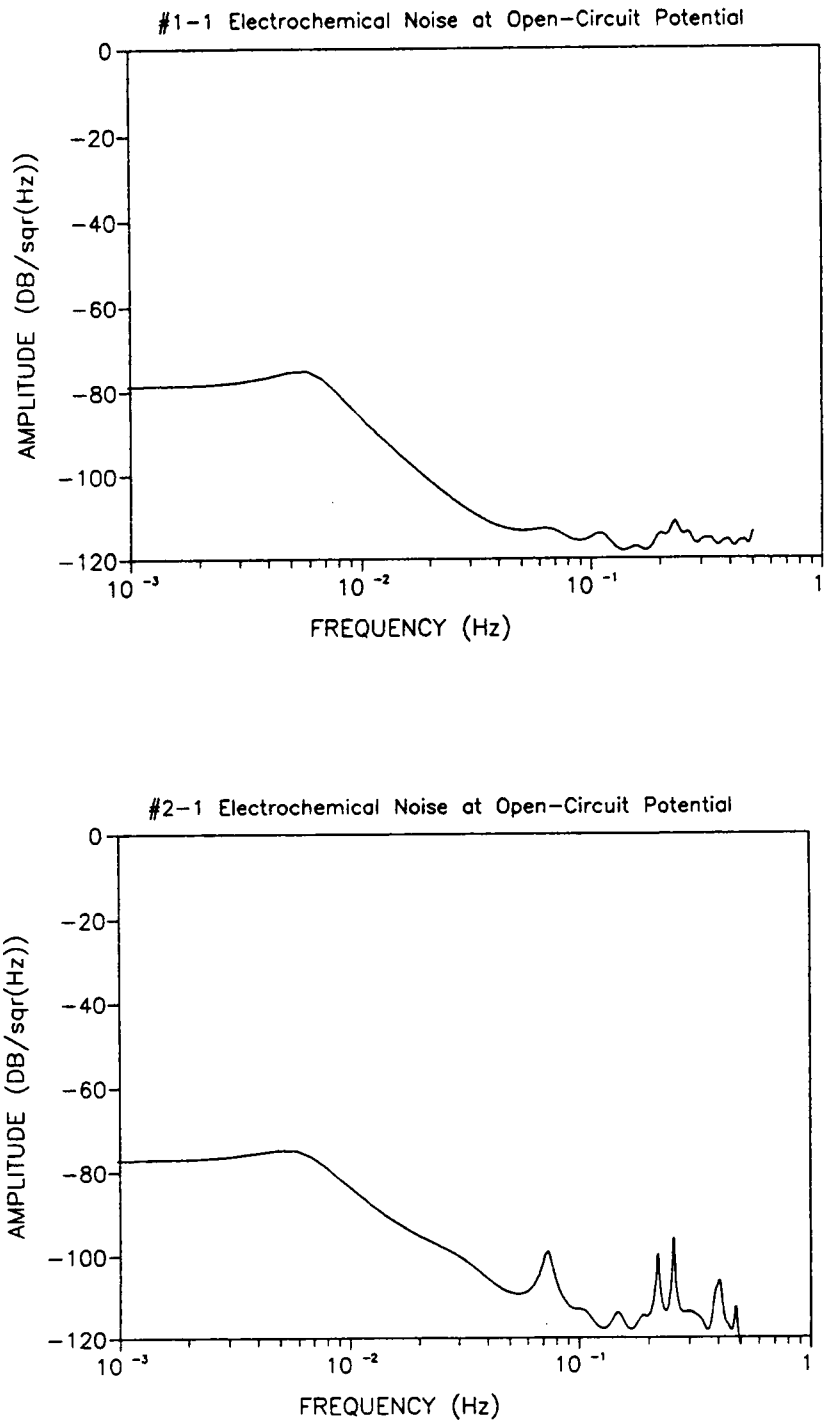


Figure 63. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 1-22 and 1-23.

(a) Sample for Cell #1 (b) Sample for Cell #2

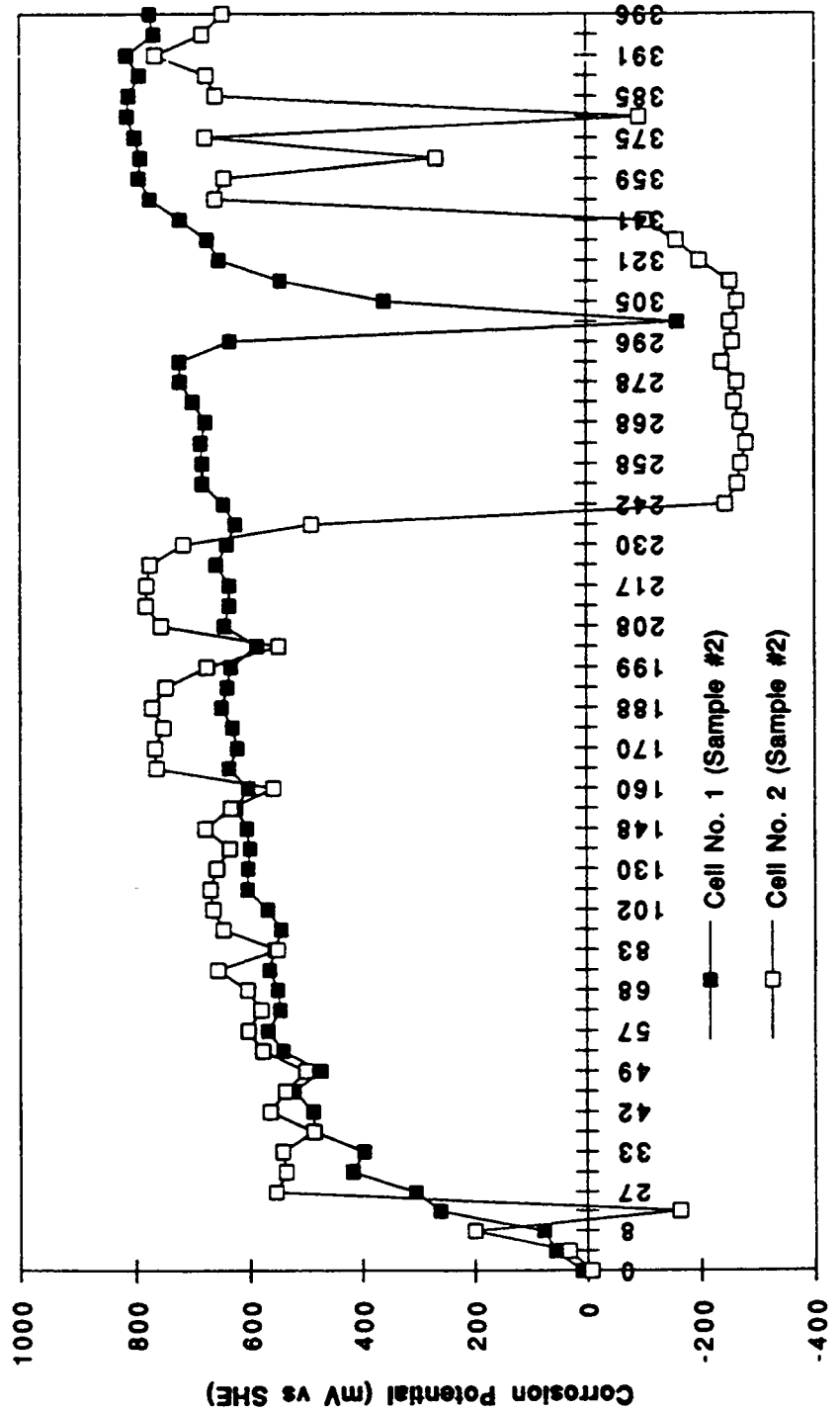


Figure 64. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 2-16 and 2-17.

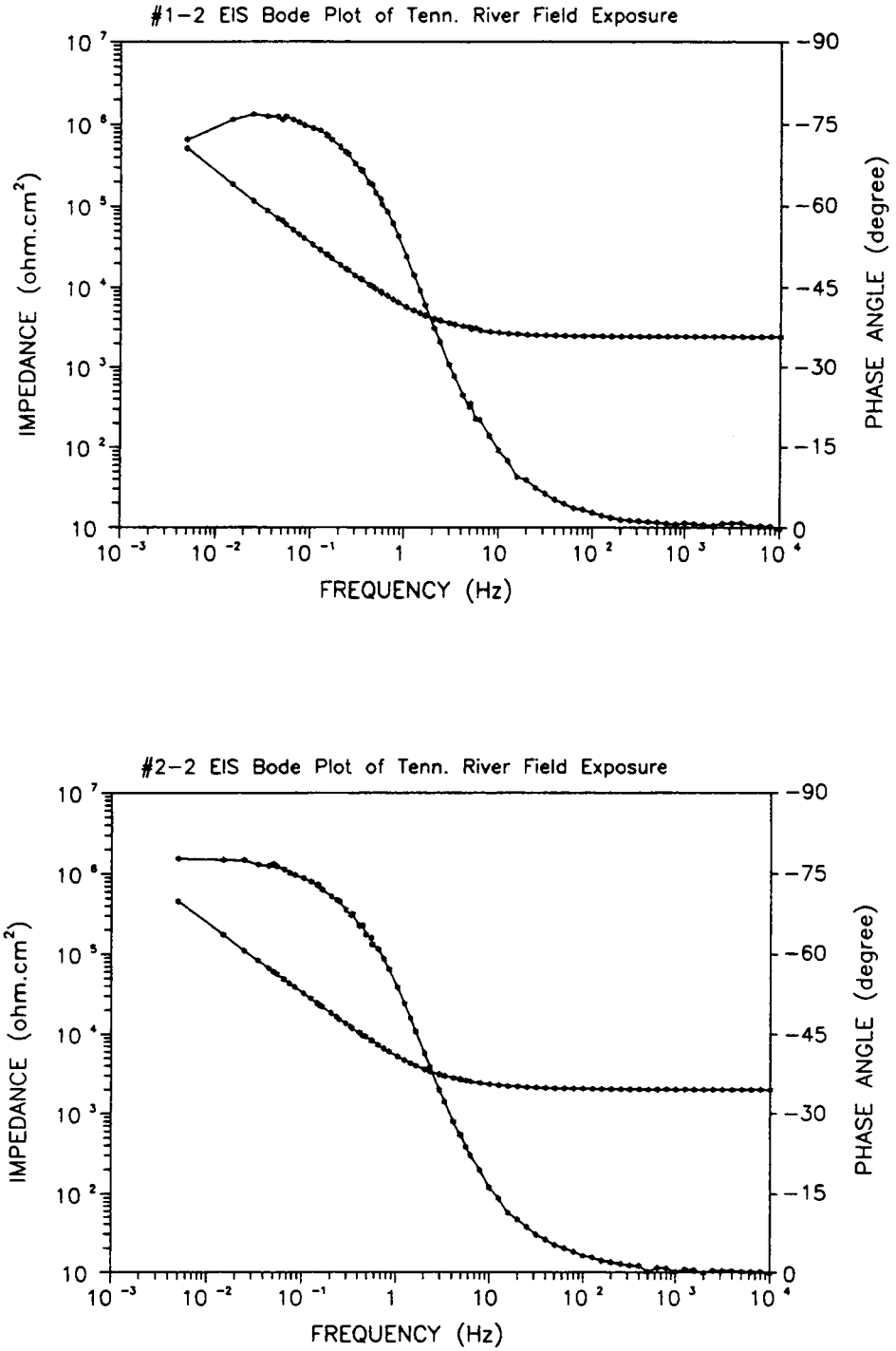


Figure 65. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 2-16 and 2-17.

(a) Sample for Cell #1 (b) Sample for Cell #2

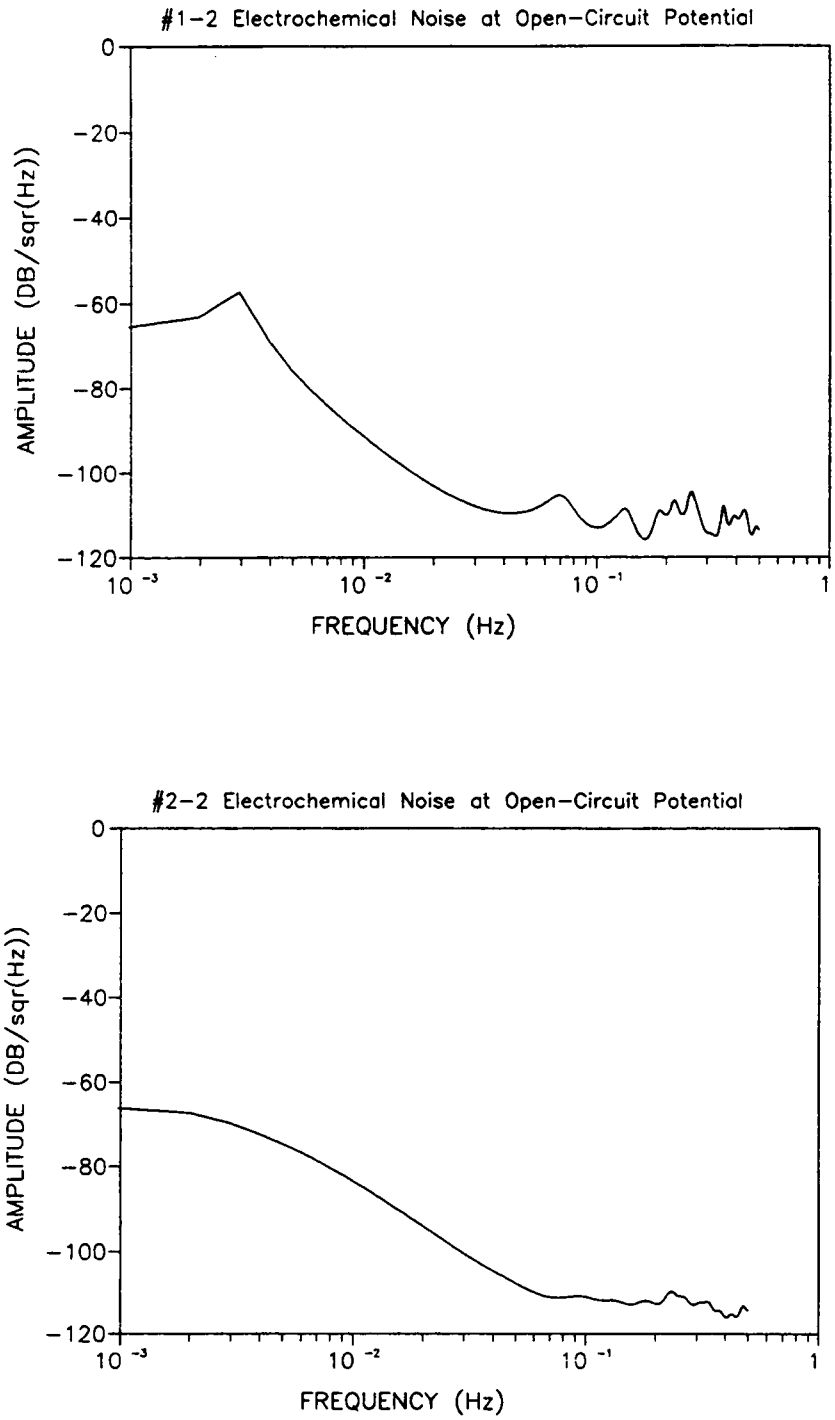


Figure 66. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 2-16 and 2-17.

(a) Sample for Cell #1 (b) Sample for Cell #2

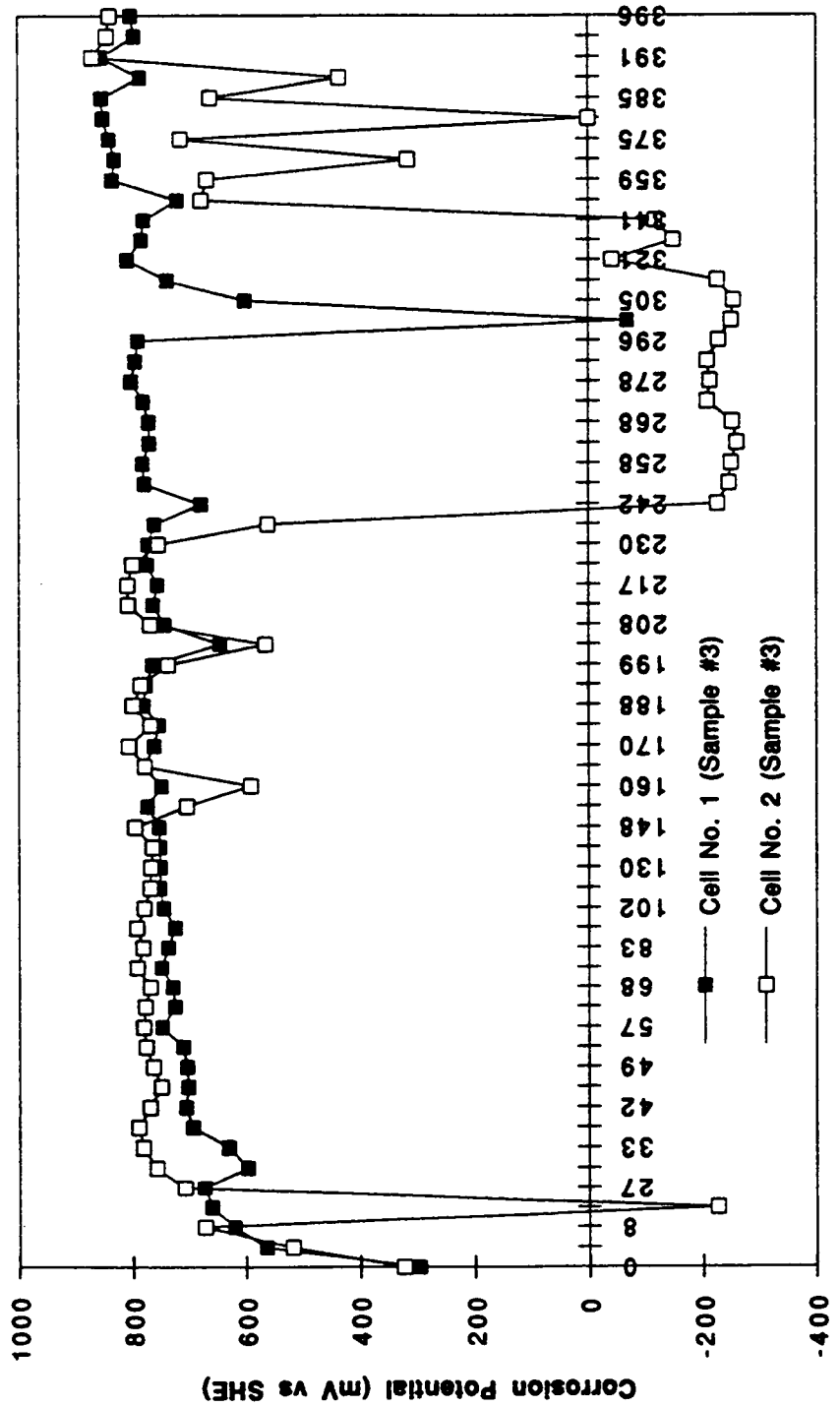


Figure 67. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 3-19 and 3-22.

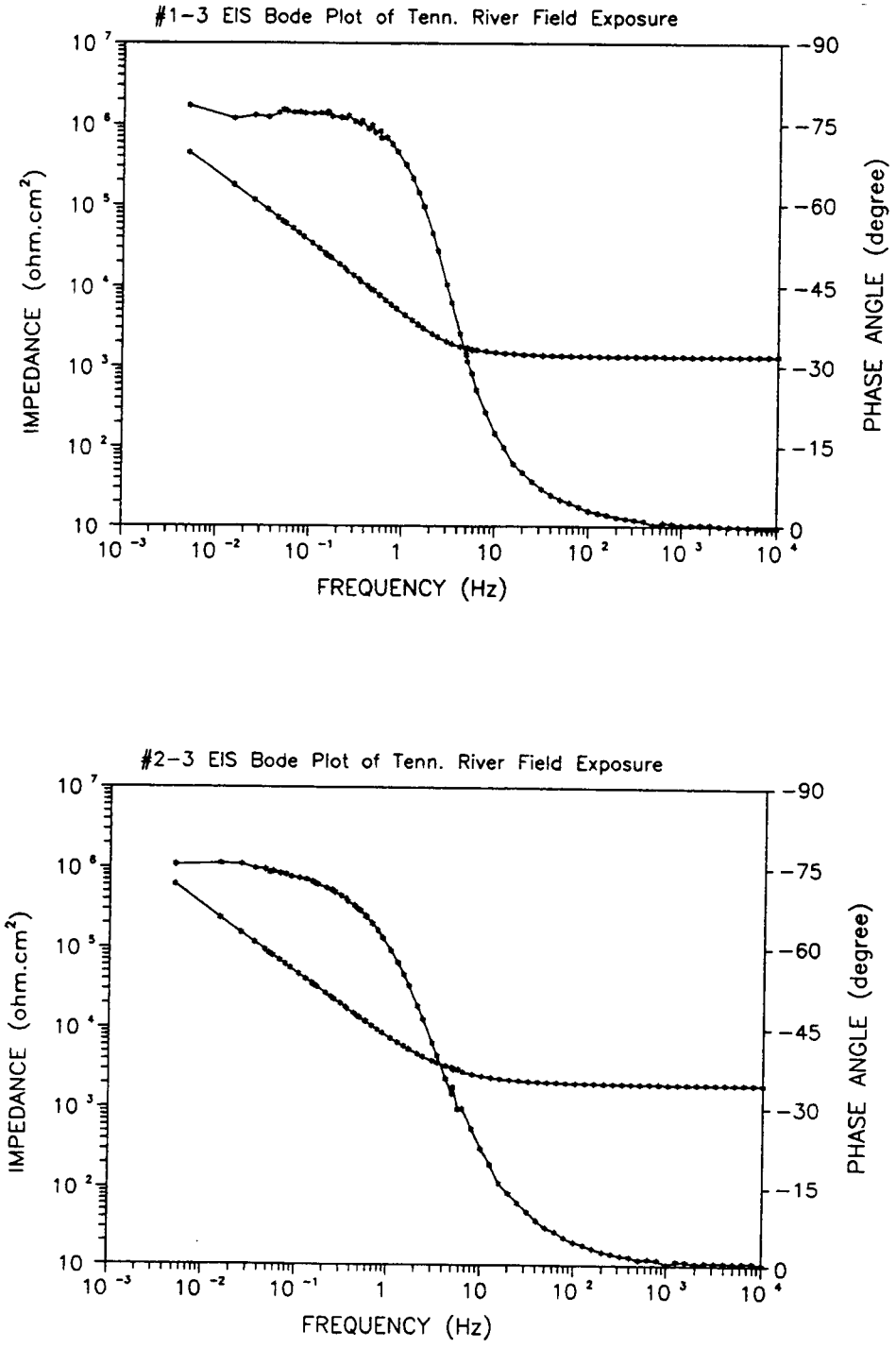


Figure 68. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 3-19 and 3-22.

(a) Sample for Cell #1 (b) Sample for Cell #2

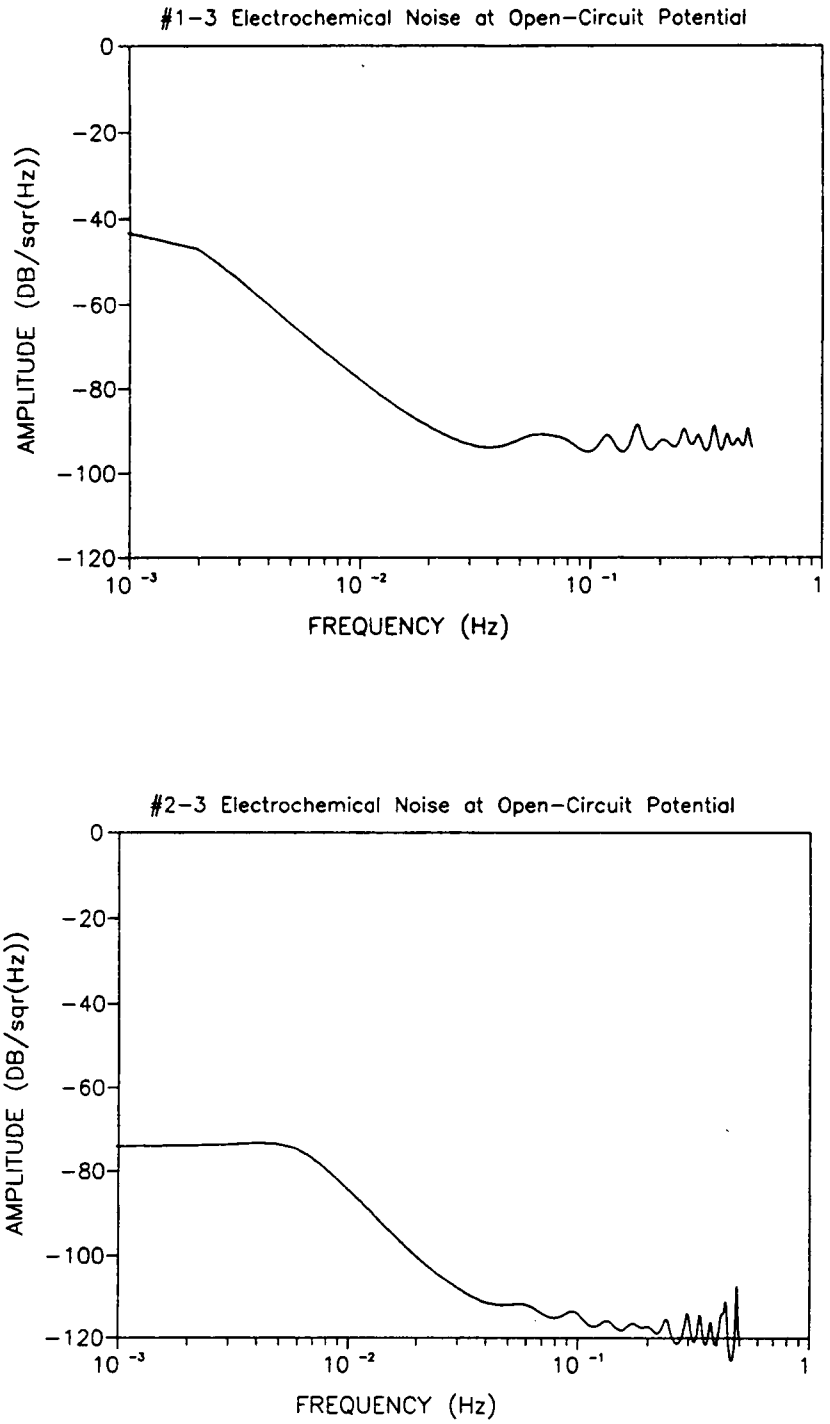


Figure 69. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 3-19 and 3-22.

(a) Sample for Cell #1 (b) Sample for Cell #2

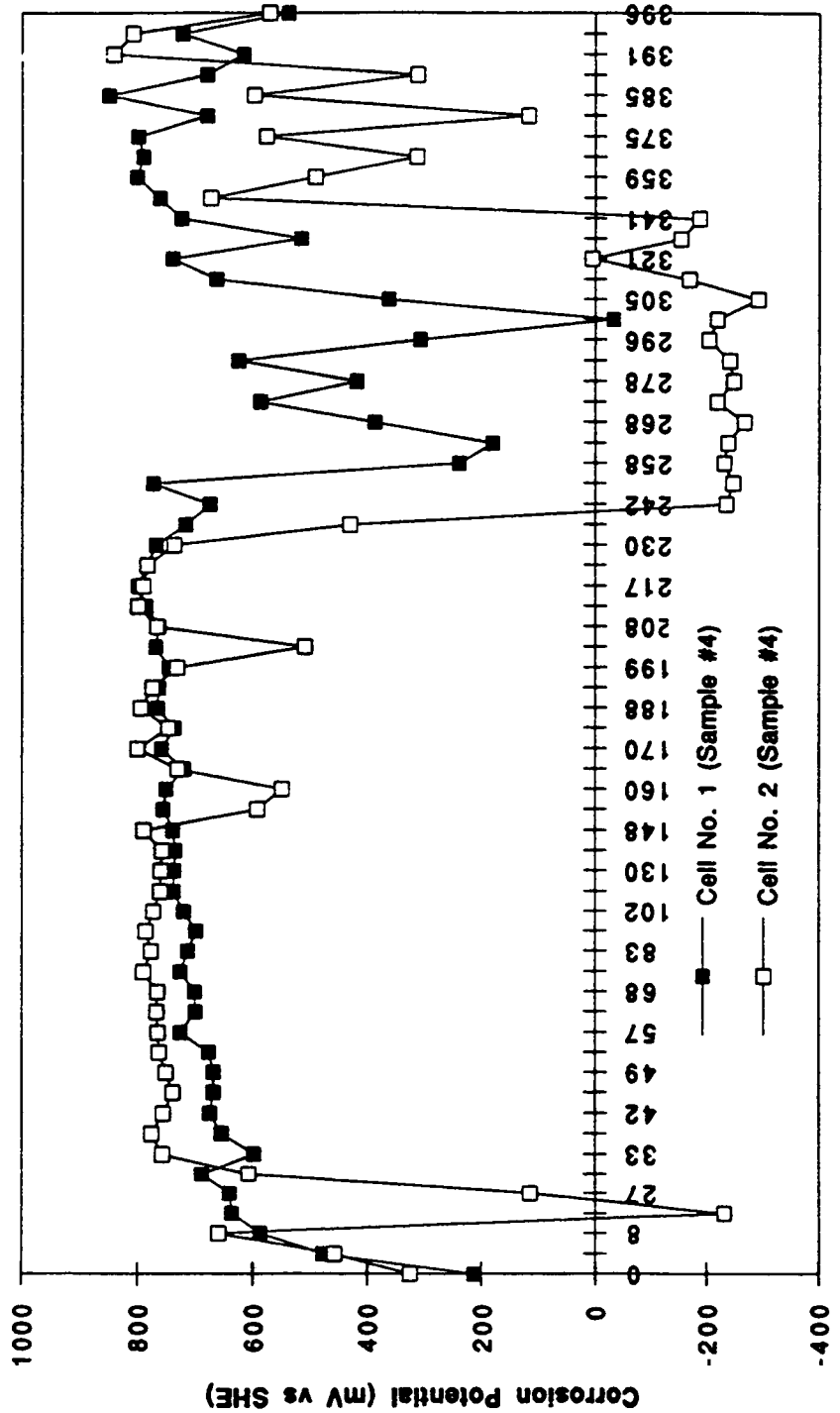


Figure 70. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 4-3 and 4-4.

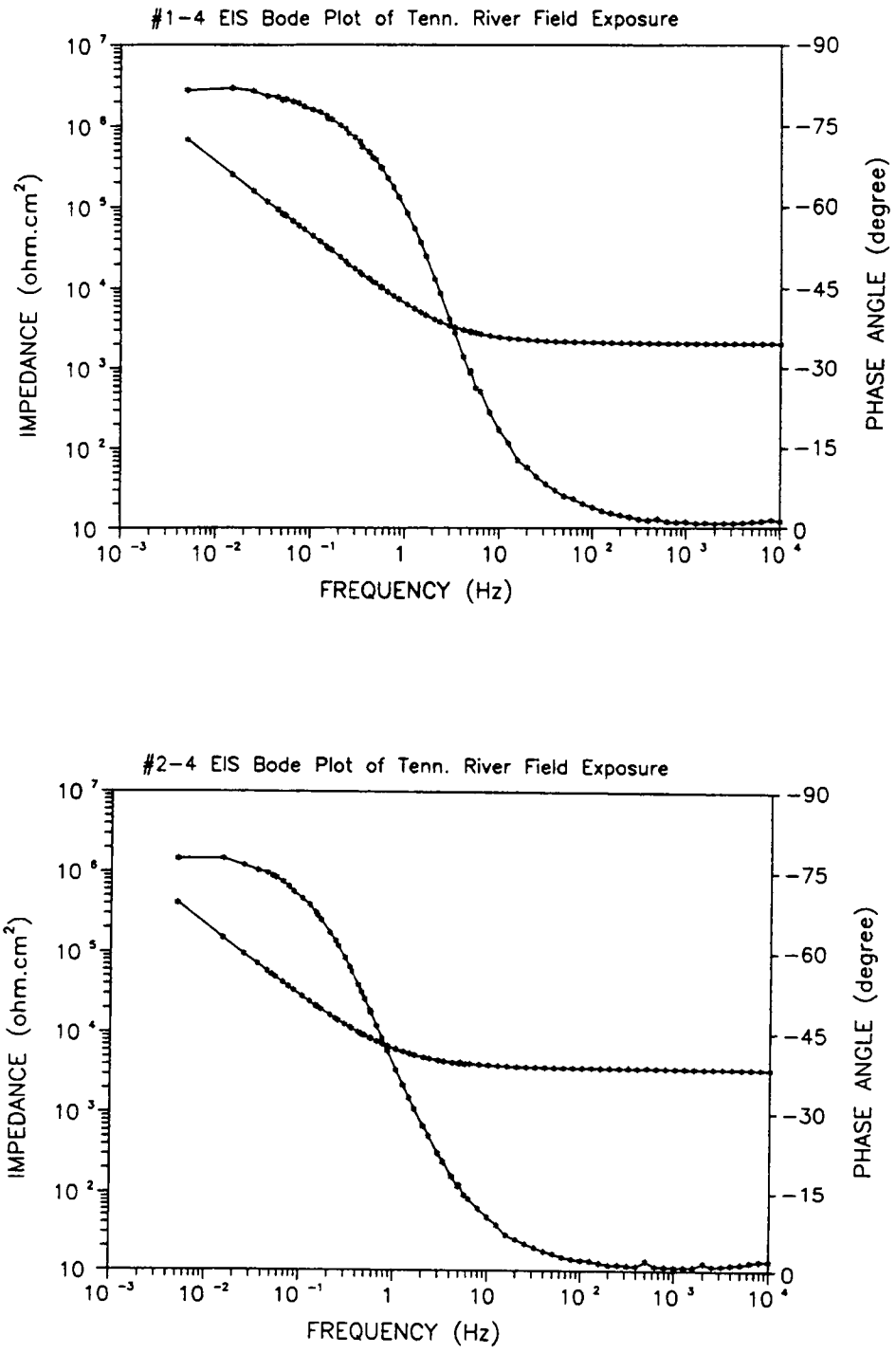


Figure 71. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 4-3 and 4-4.

(a) Sample for Cell #1 (b) Sample for Cell #2

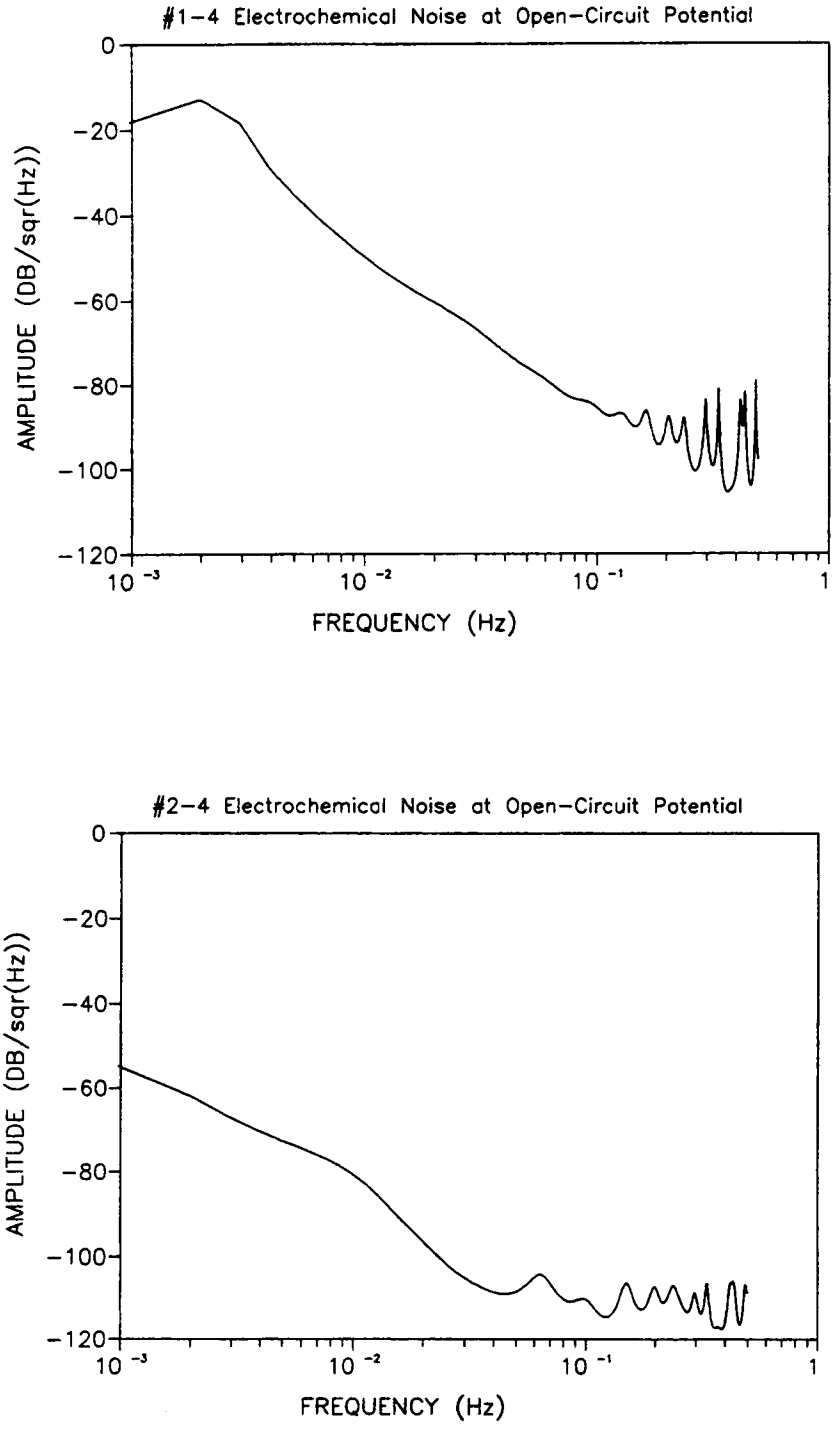


Figure 72. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 4-3 and 4-4.

(a) Sample for Cell #1 (b) Sample for Cell #2

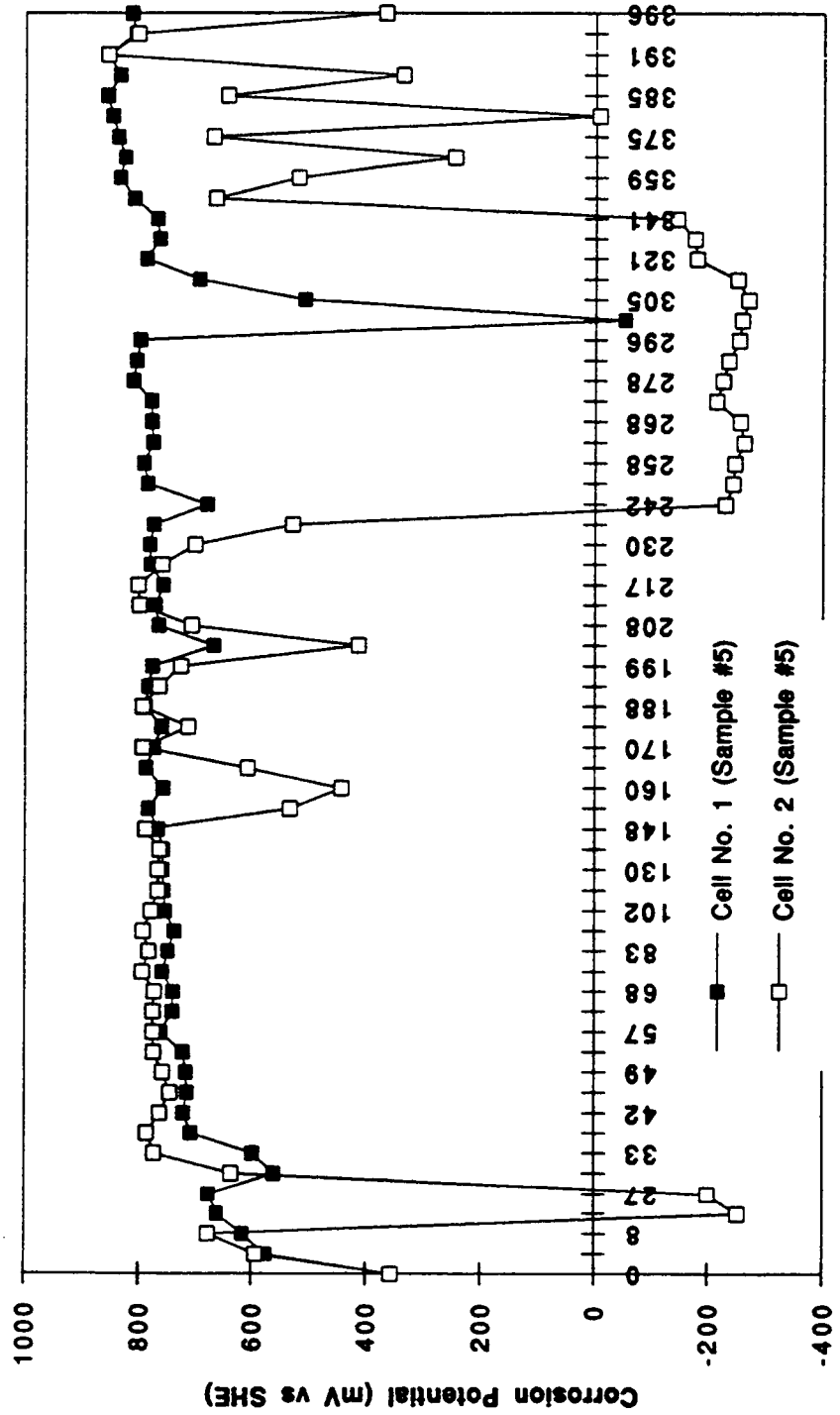


Figure 73. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 5-5 and 5-6.

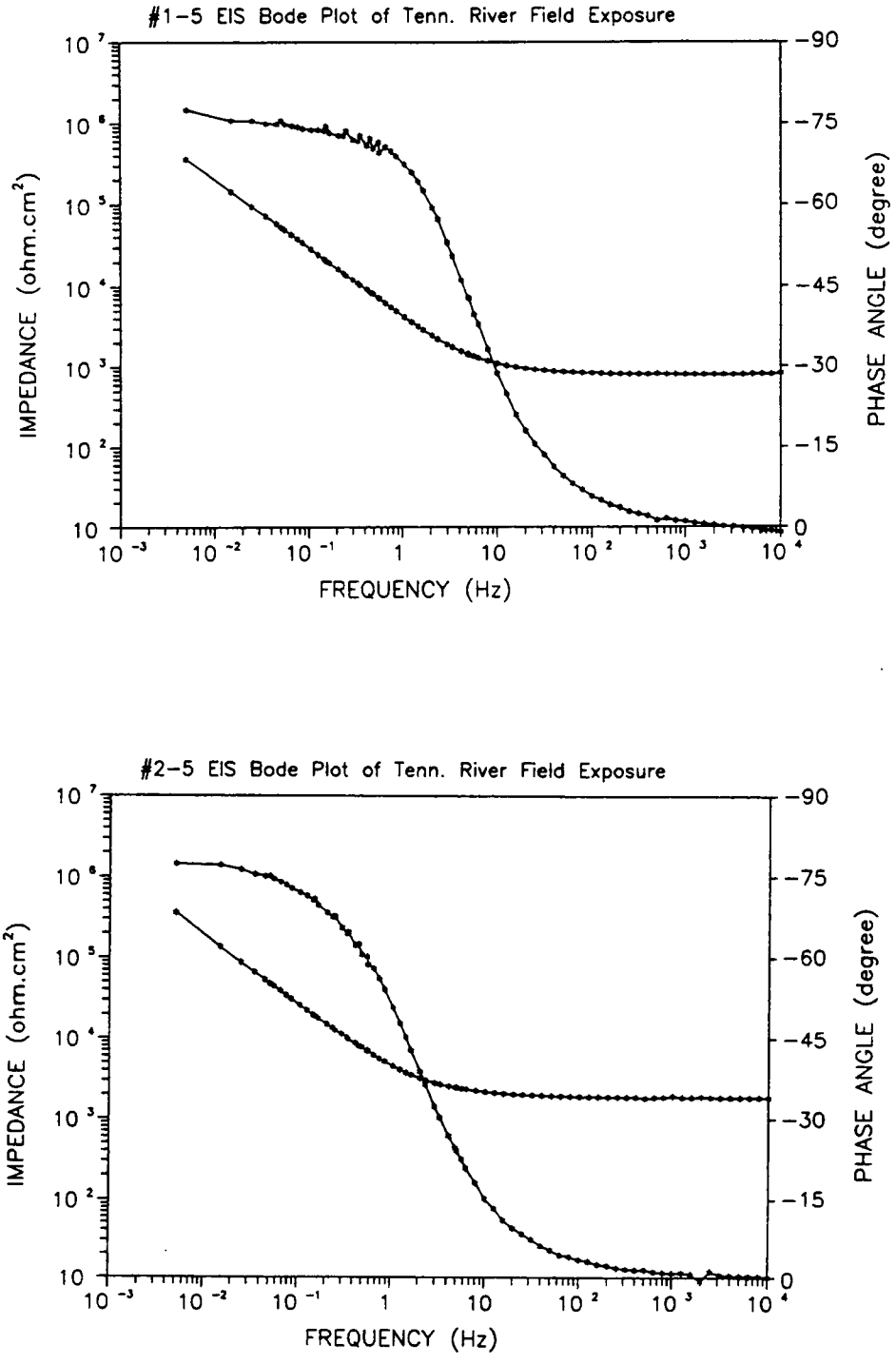


Figure 74. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 5-5 and 5-6.

(a) Sample for Cell #1 (b) Sample for Cell #2

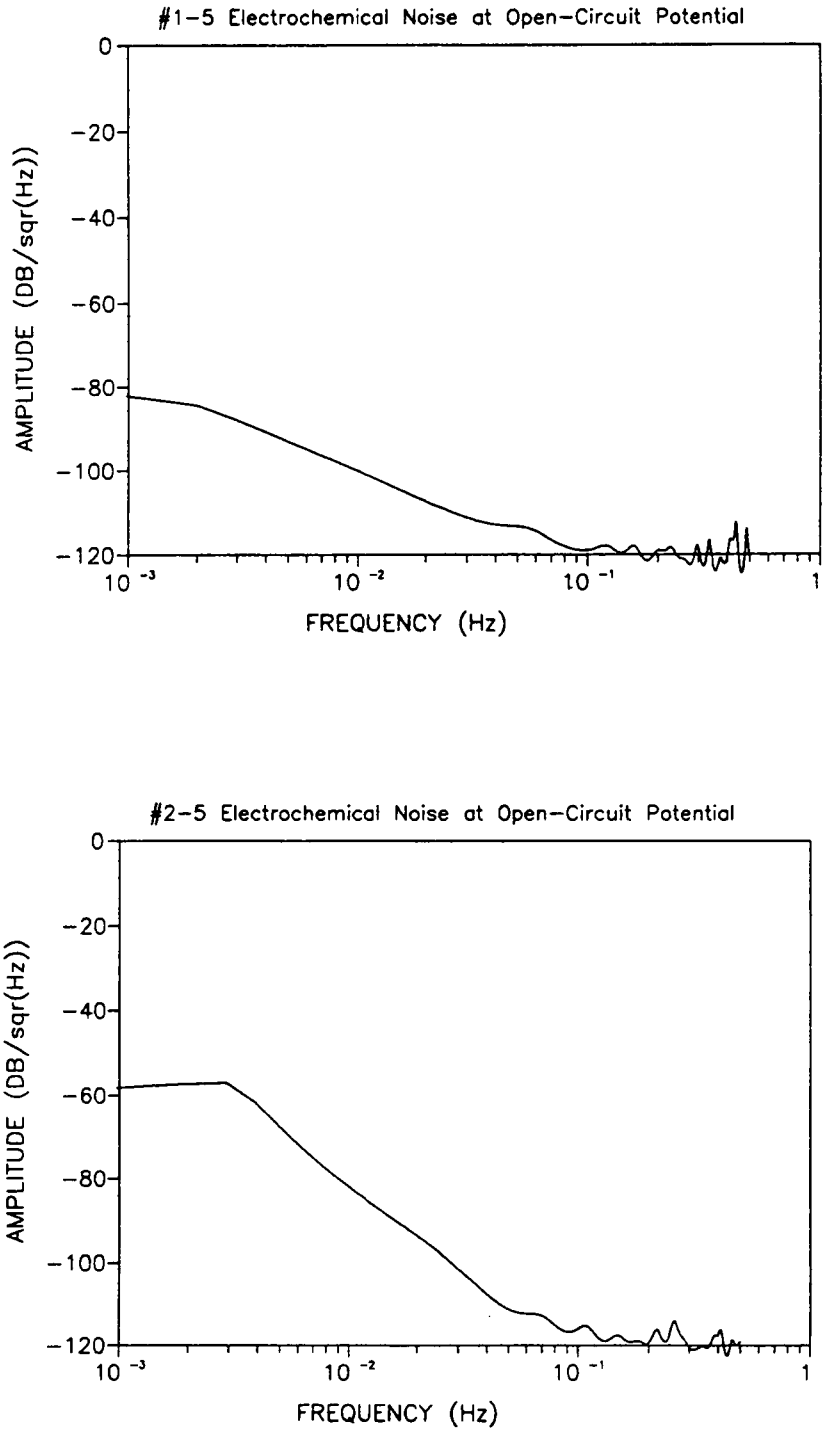


Figure 75. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 5-5 and 5-6.

(a) Sample for Cell #1 (b) Sample for Cell #2

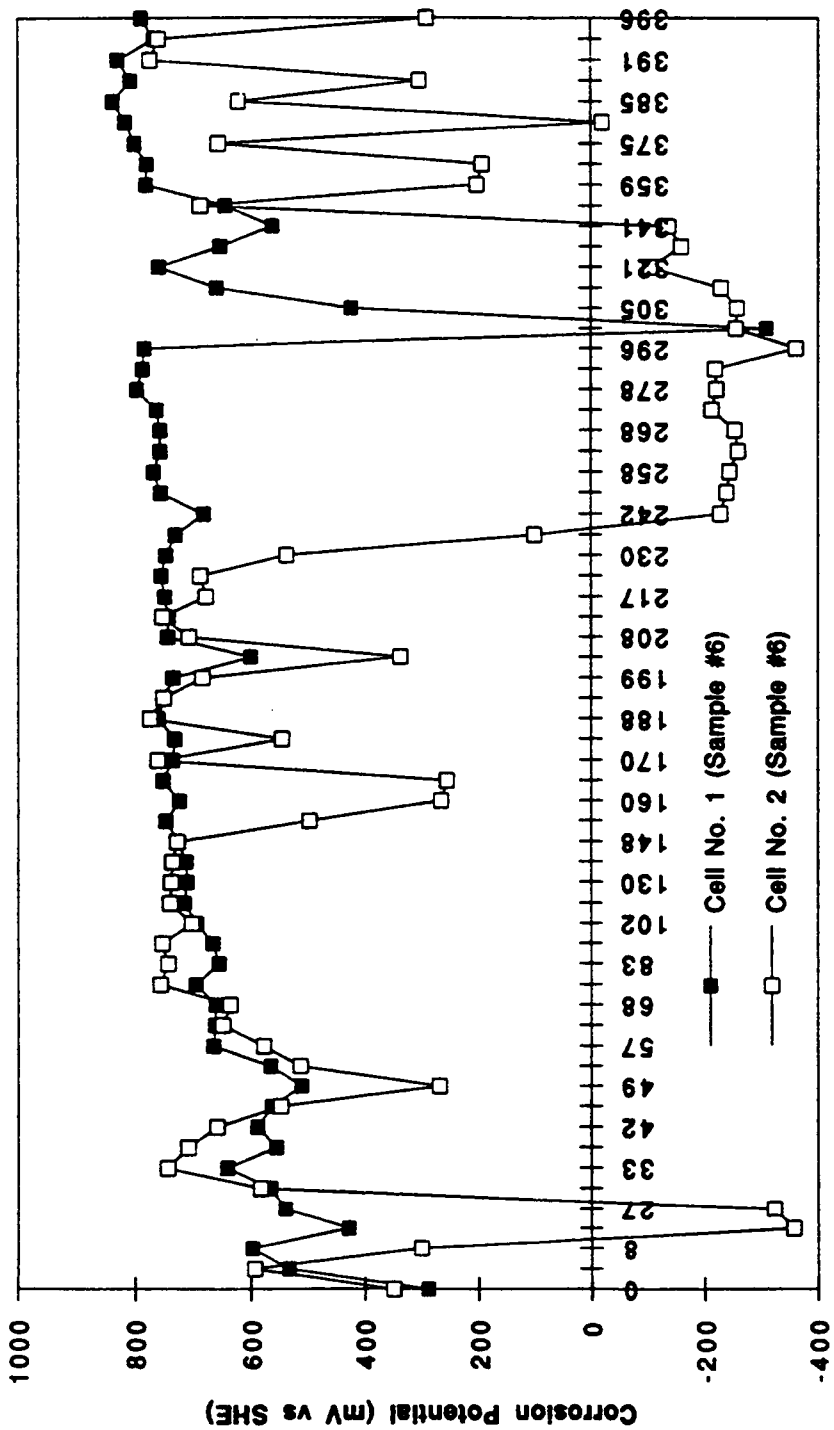


Figure 76. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 6-4 and 6-5.

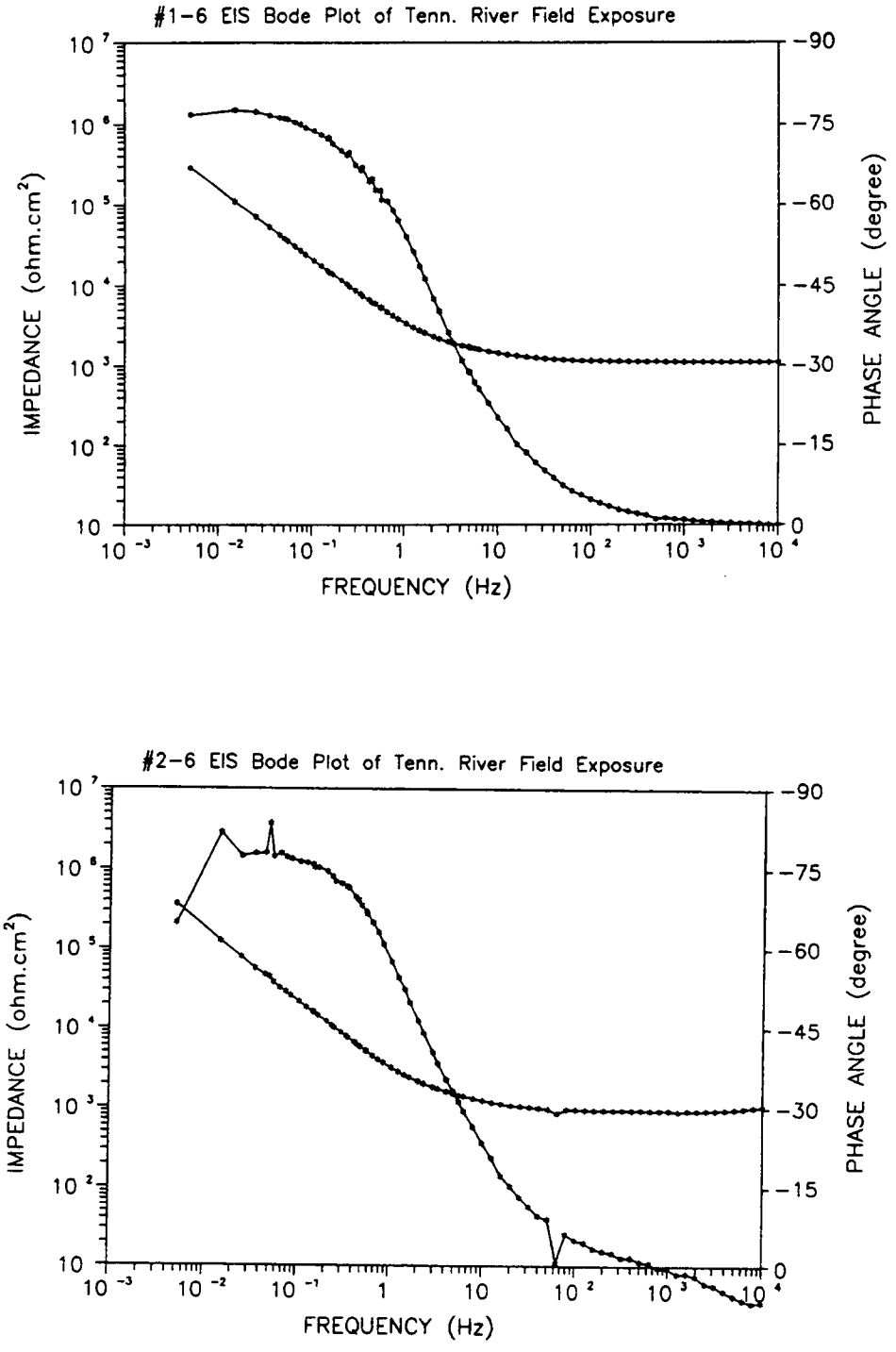


Figure 77. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 6-4 and 6-5.

(a) Sample for Cell #1 (b) Sample for Cell #2

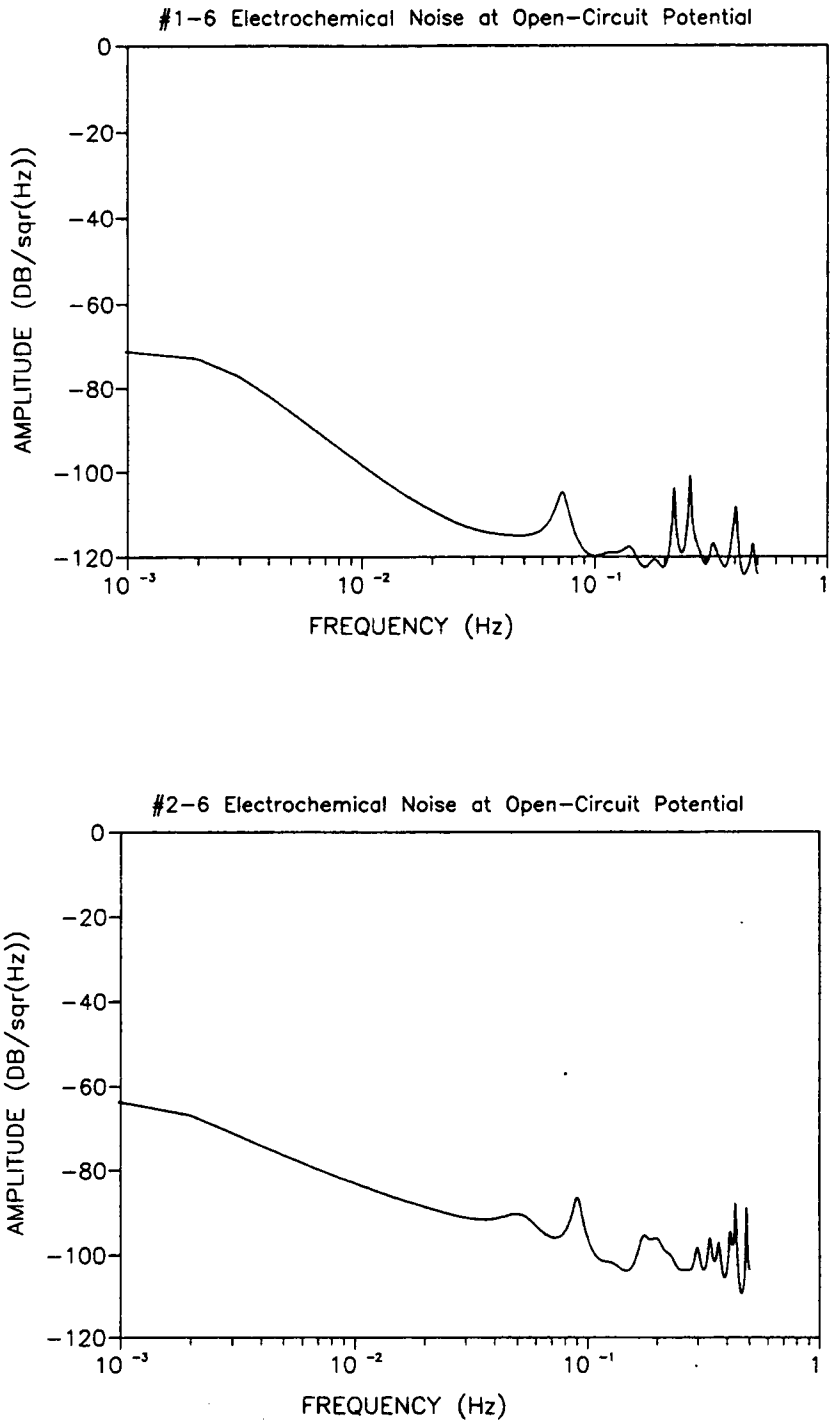


Figure 78. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 6-4 and 6-5.

(a) Sample for Cell #1 (b) Sample for Cell #2

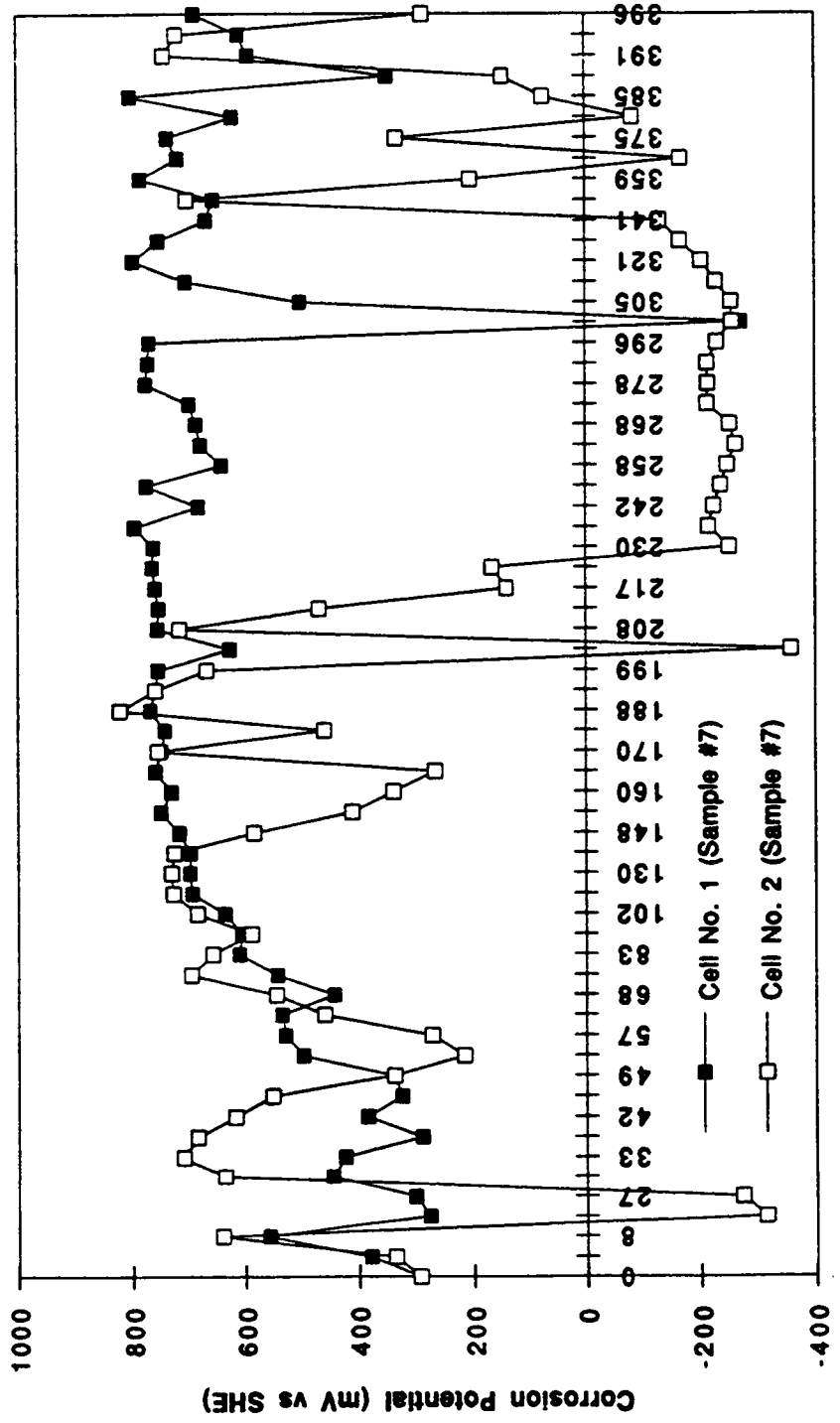


Figure 79. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 7-7 and 7-8.

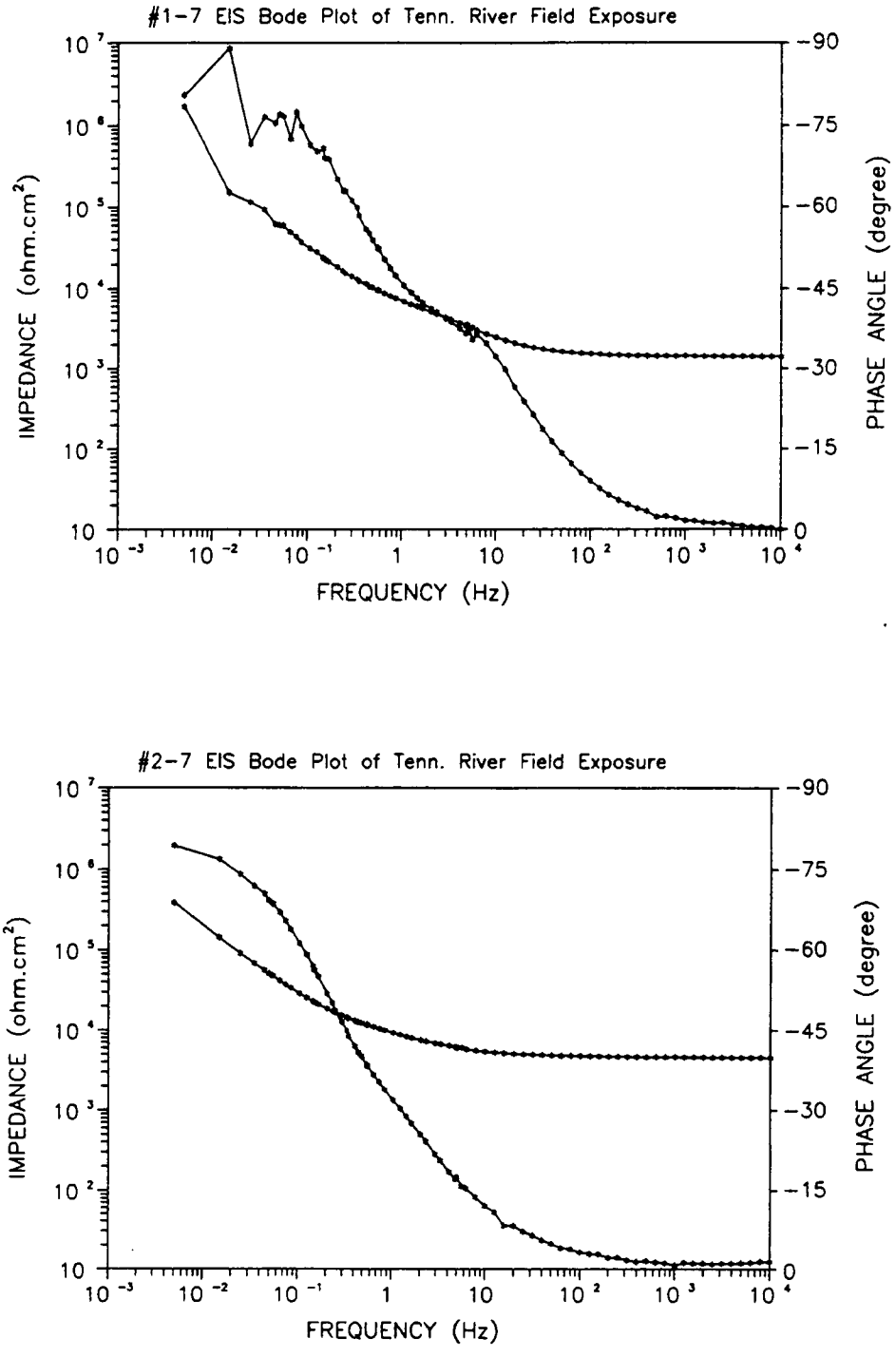
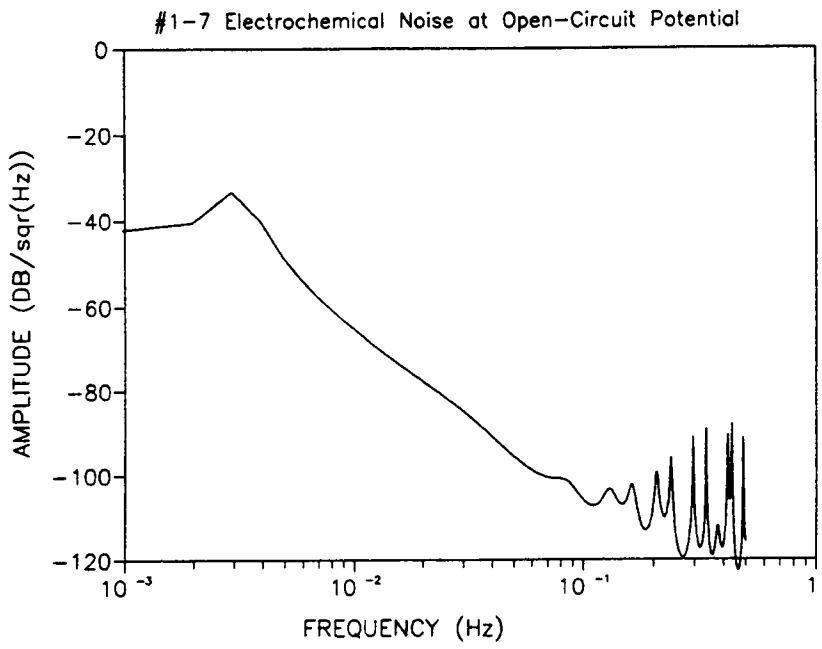


Figure 80. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 7-7 and 7-8.

(a) Sample for Cell #1 (b) Sample for Cell #2



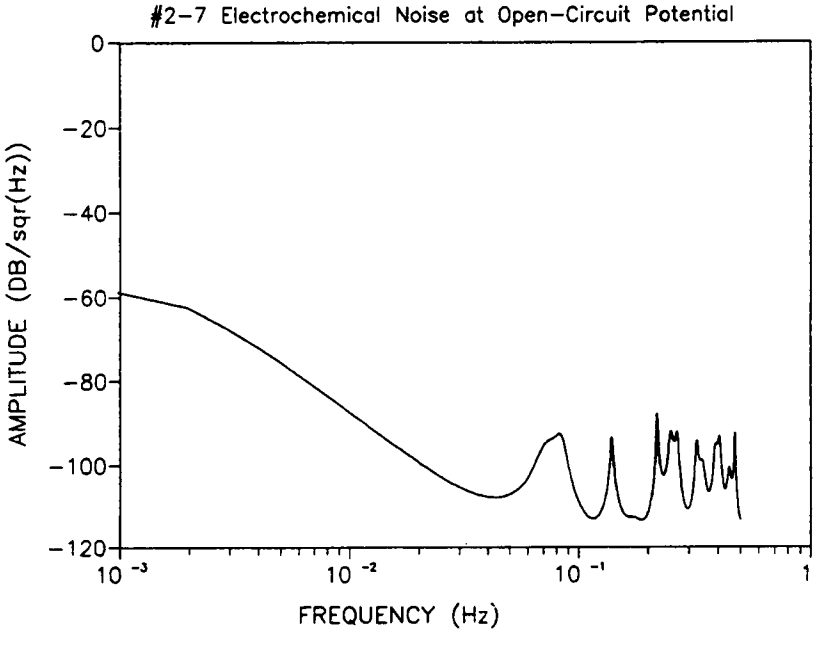


Figure 81. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 7-7 and 7-8.

(a) Sample for Cell #1 (b) Sample for Cell #2

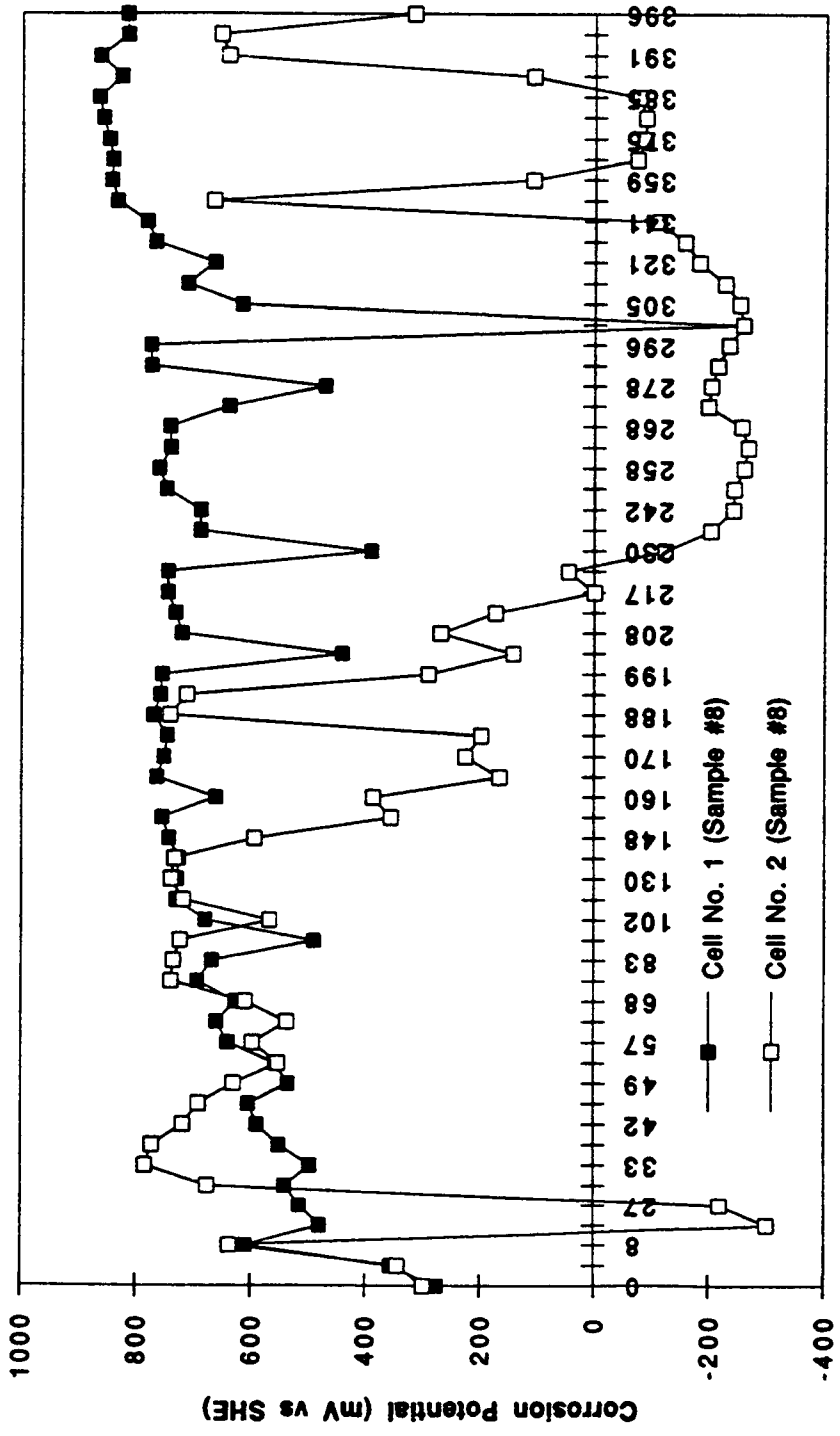


Figure 82. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 8-18 and 8-19.

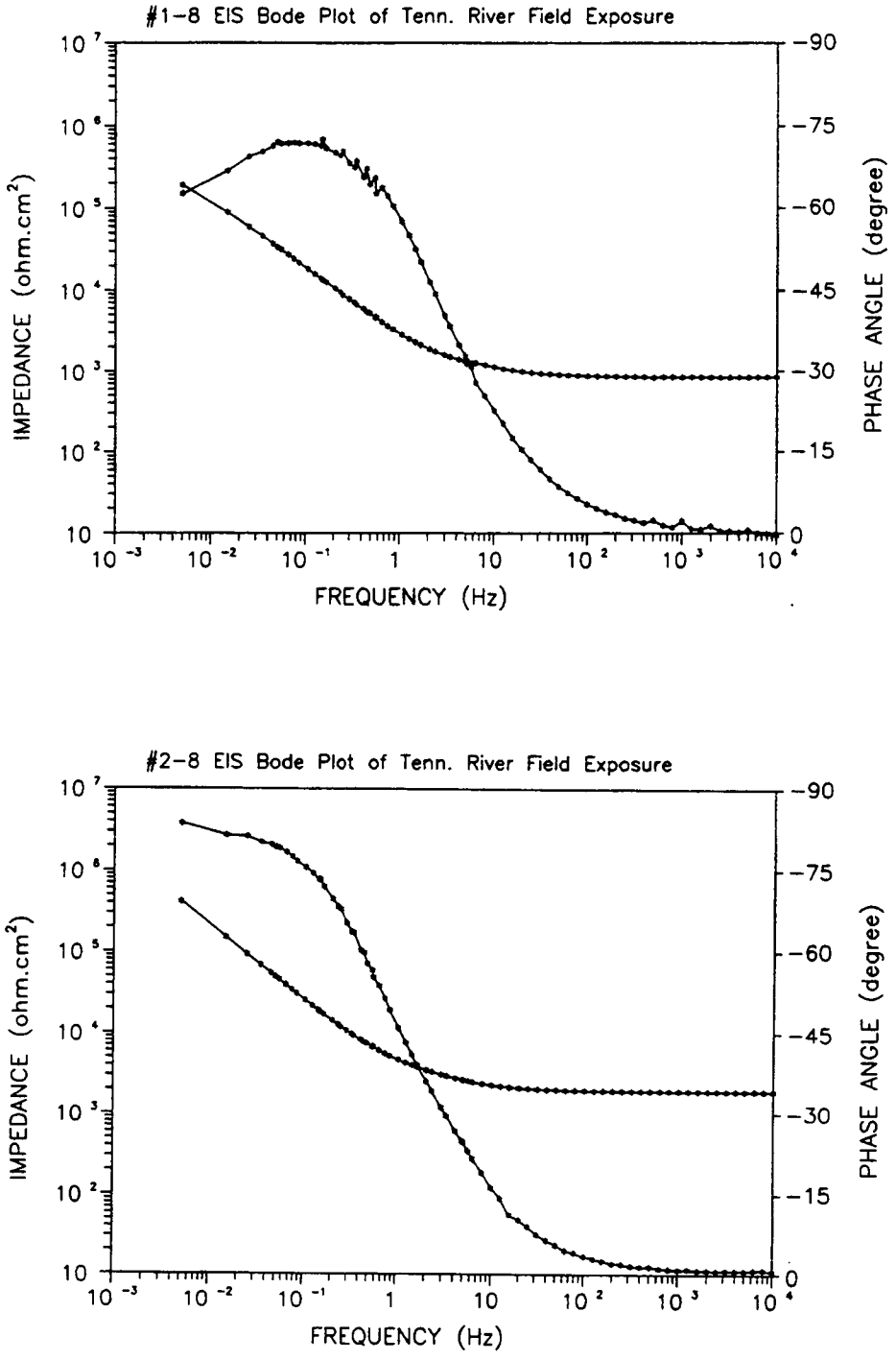
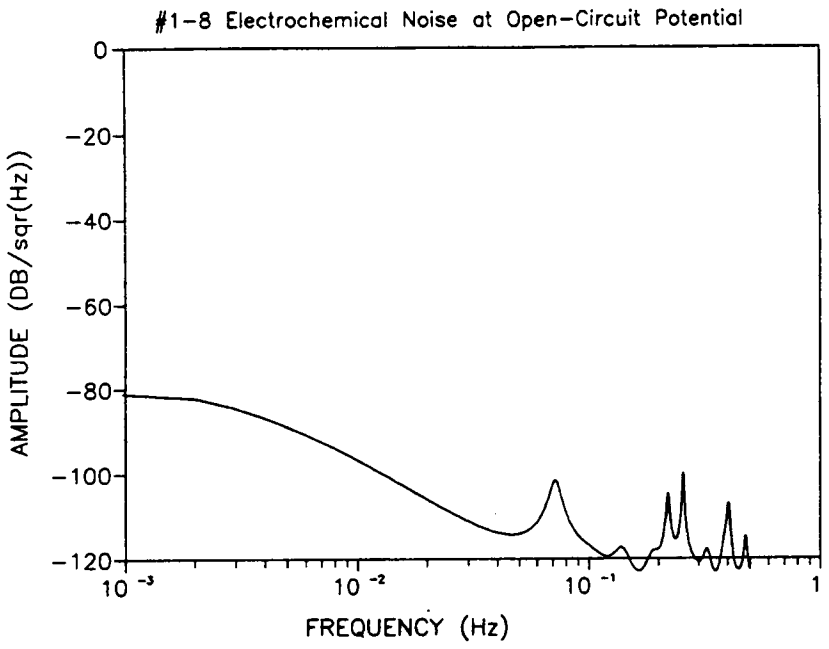


Figure 83. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 8-18 and 8-19.

(a) Sample for Cell #1 (b) Sample for Cell #2



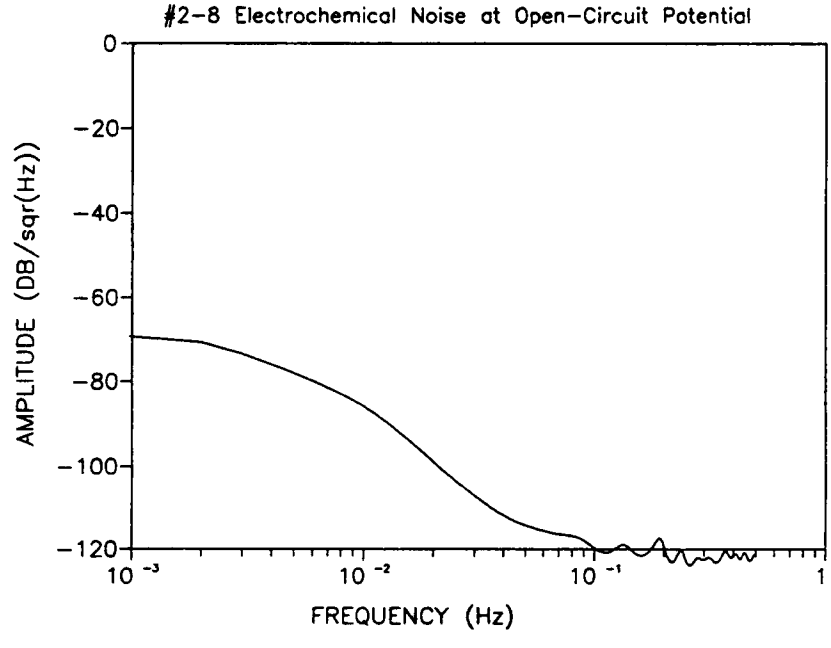


Figure 84. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 8-18 and 8-19.

(a) Sample for Cell #1 (b) Sample for Cell #2

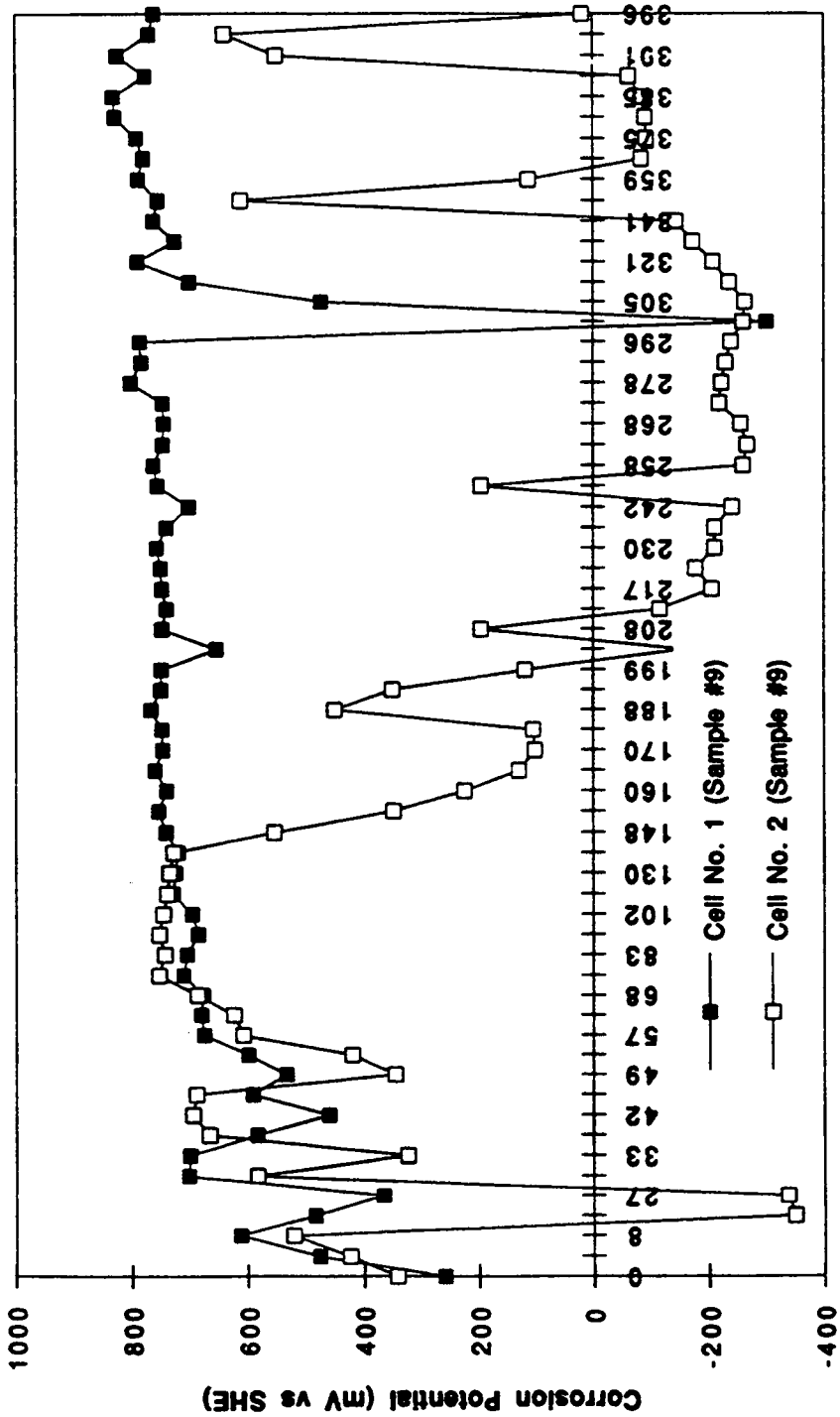


Figure 85. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 9-36 and 9-37.

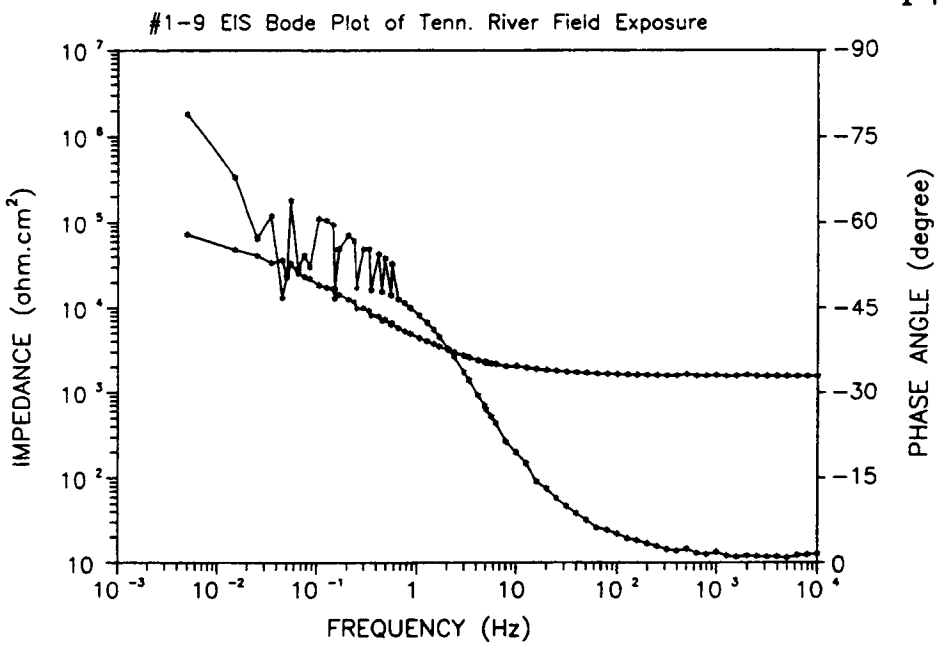


Figure 86. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 9-36 and 9-37.

(a) Sample for Cell #1 (b) Sample for Cell #2

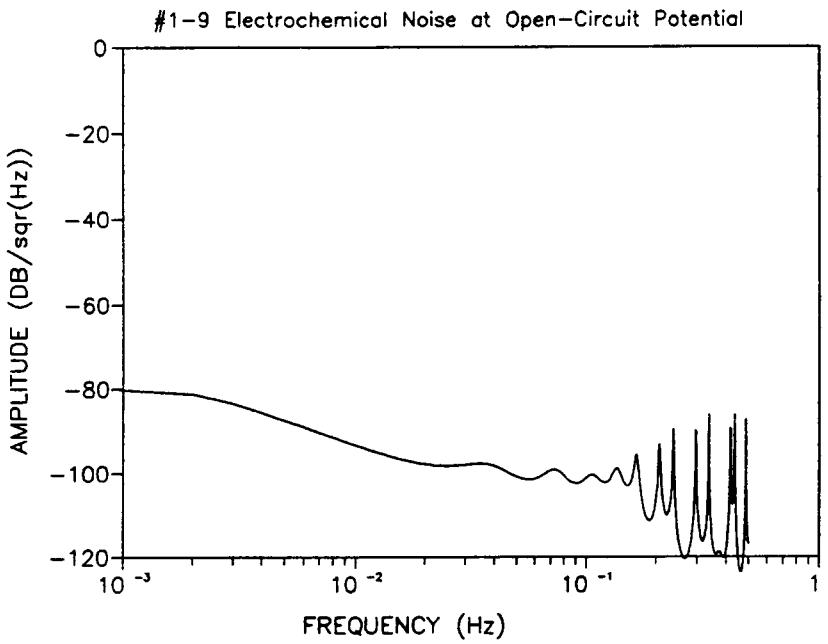


Figure 87. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 9-36 and 9-37.

(a) Sample for Cell #1 (b) Sample for Cell #2

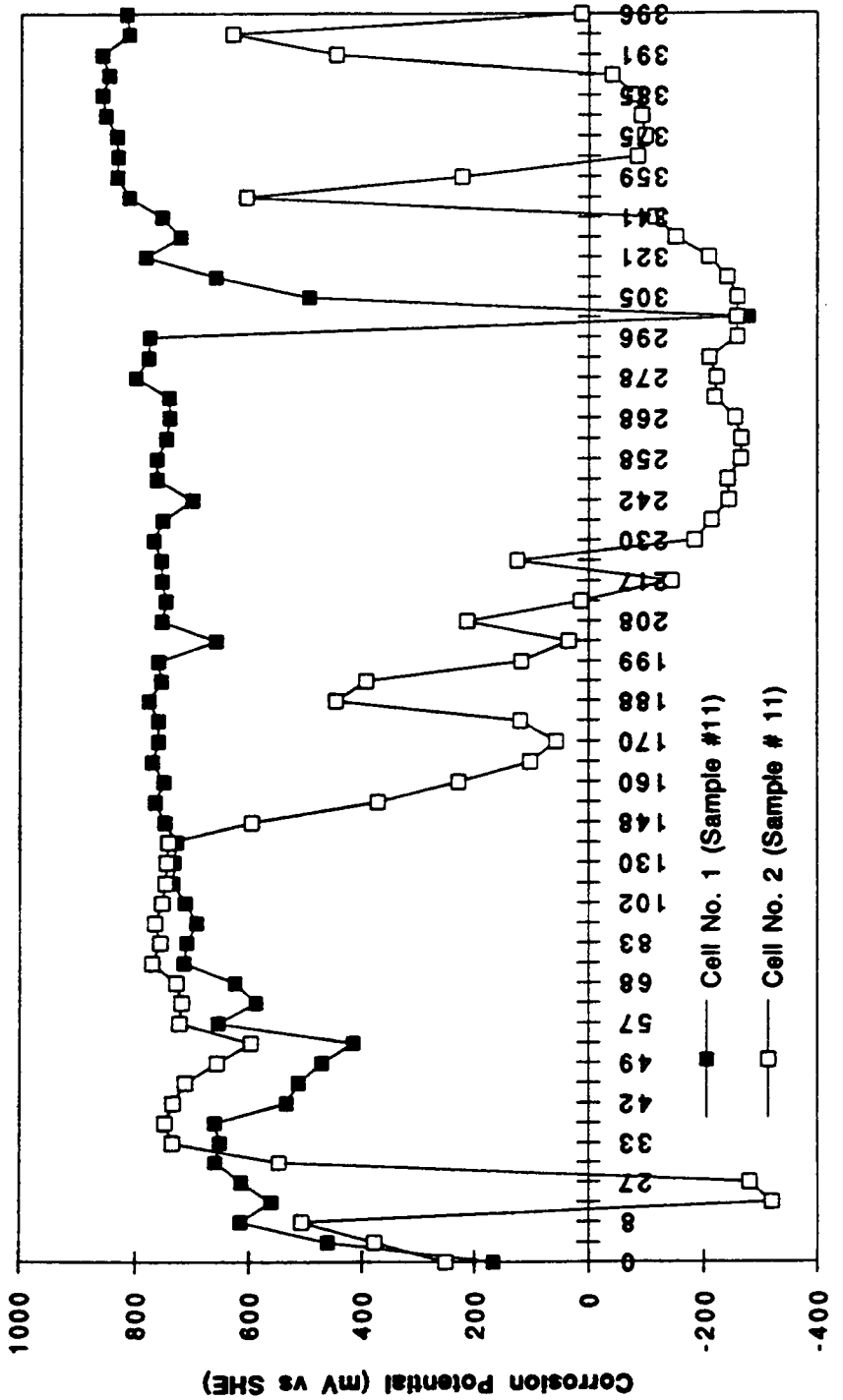


Figure 88. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 11-8 and 11-9.

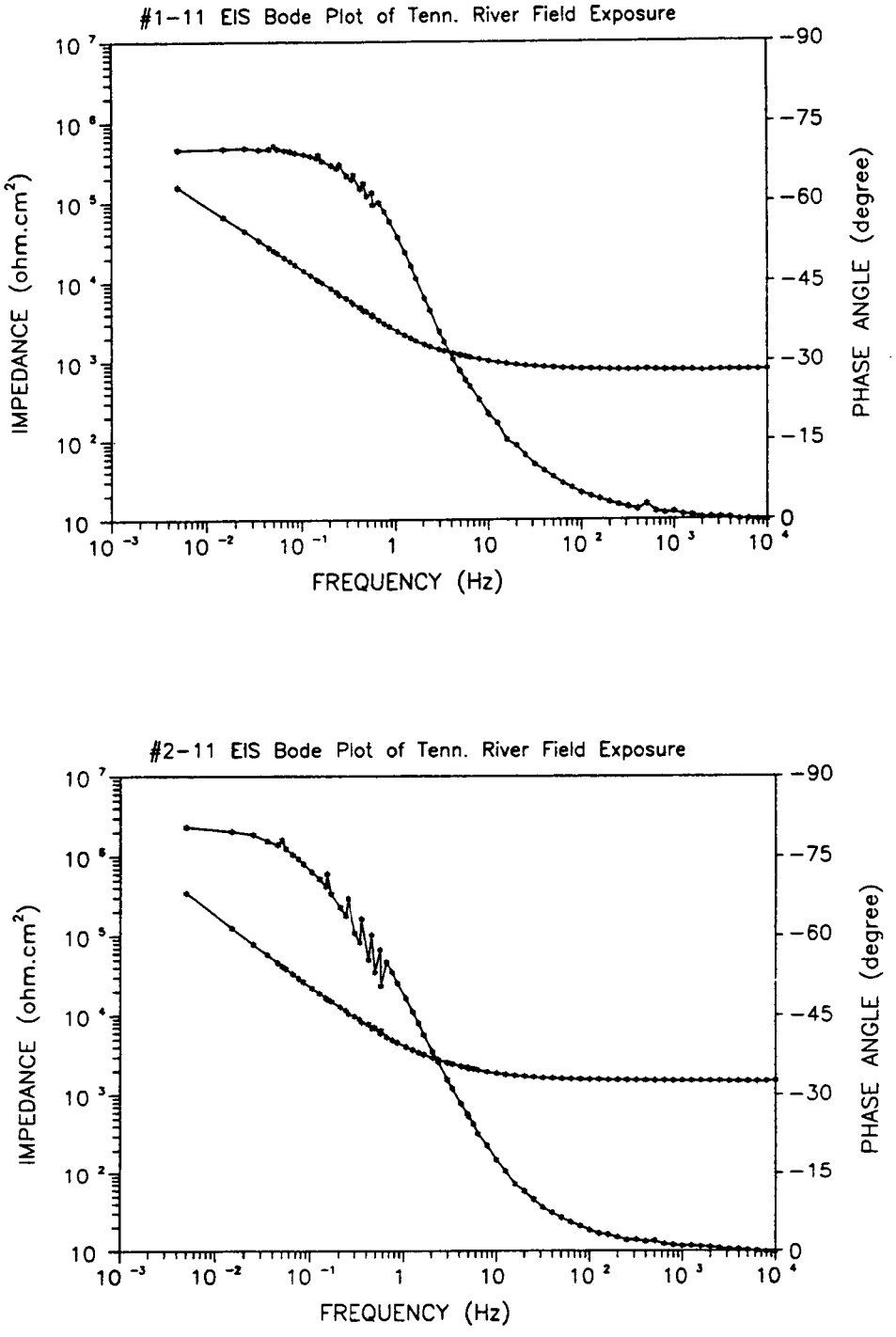


Figure 89. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 11-8 and 11-9.

(a) Sample for Cell #1 (b) Sample for Cell #2

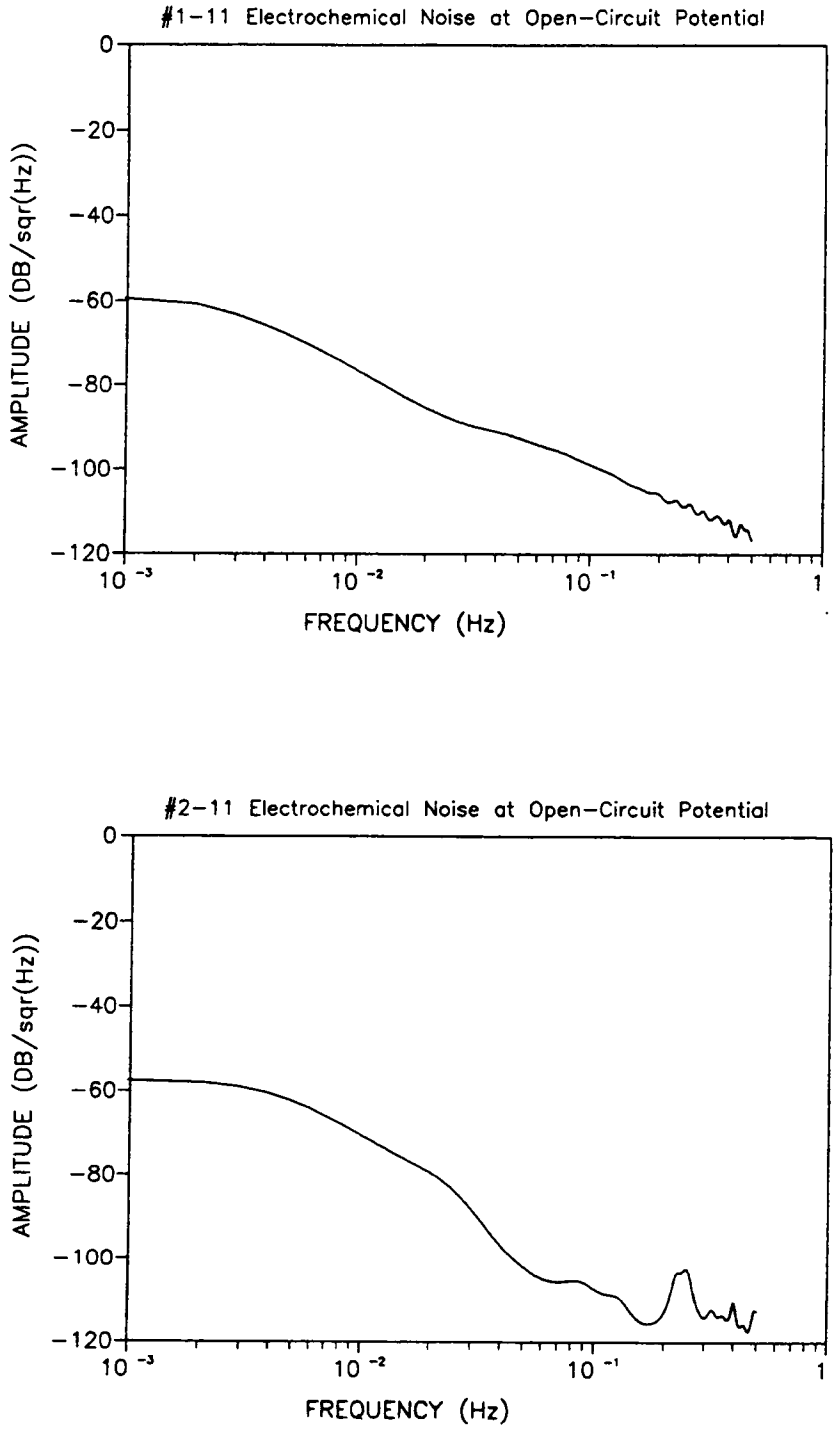


Figure 90. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 11-8 and 11-9.

(a) Sample for Cell #1 (b) Sample for Cell #2

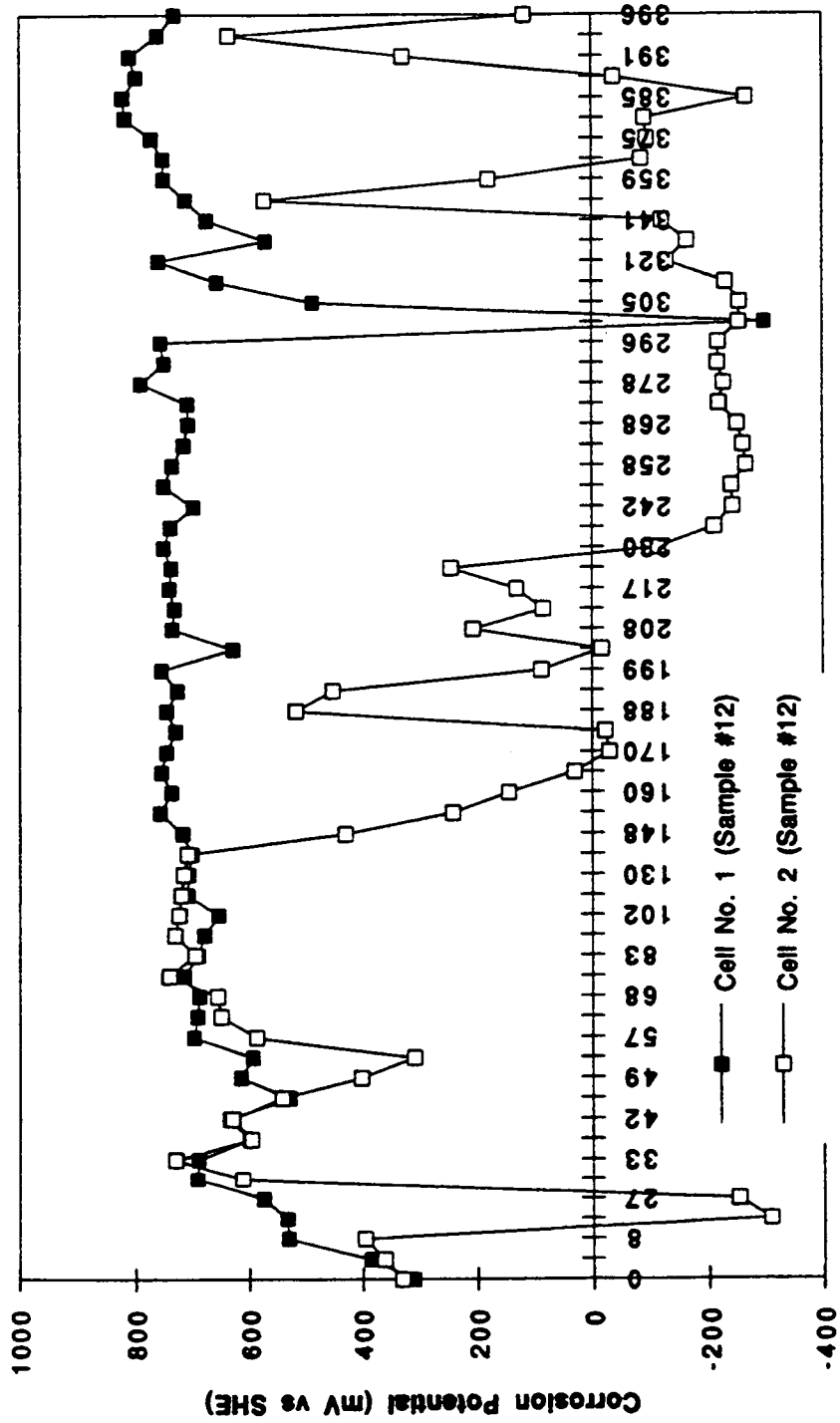


Figure 91. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 12-19 and 12-20.

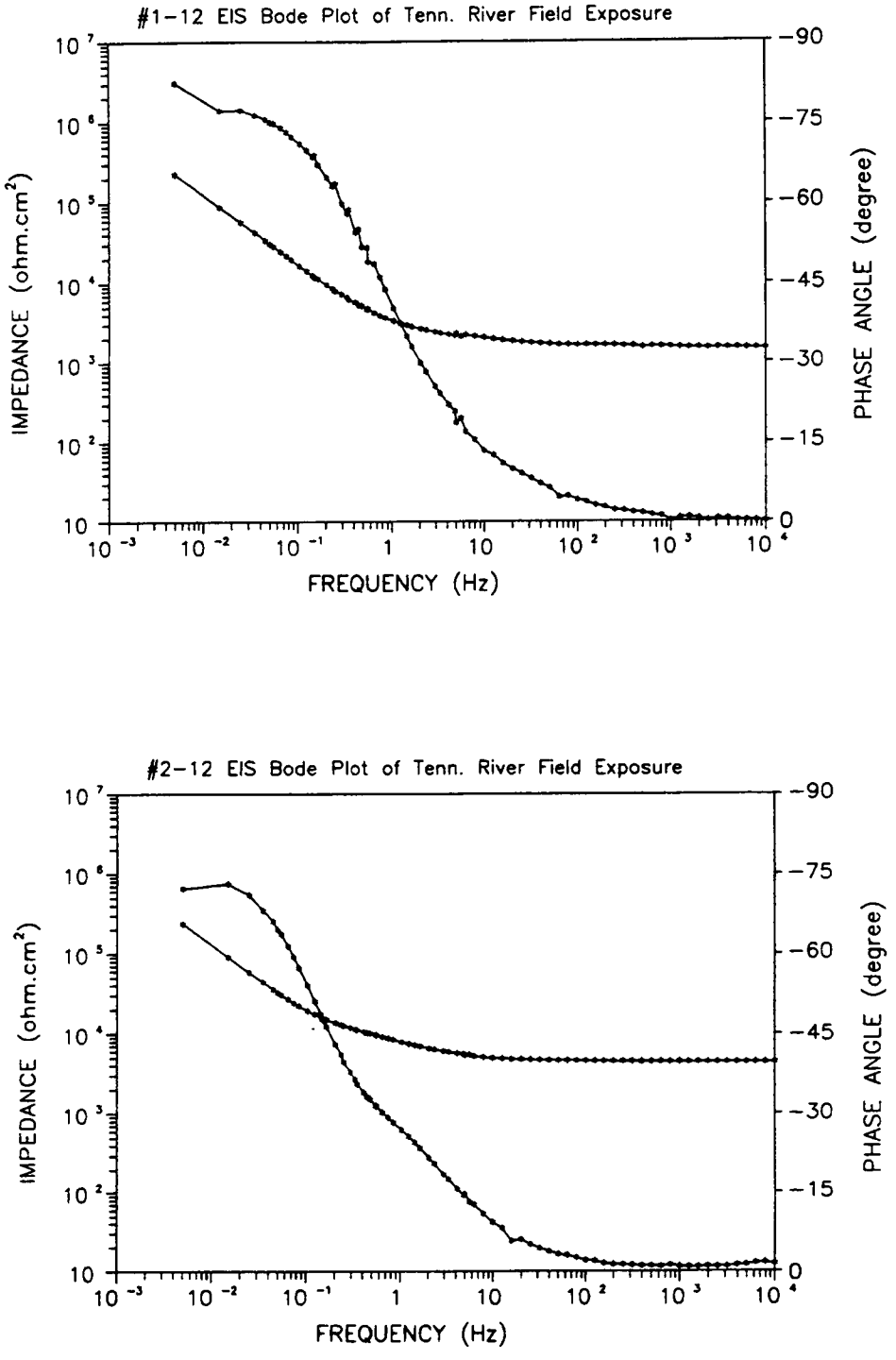
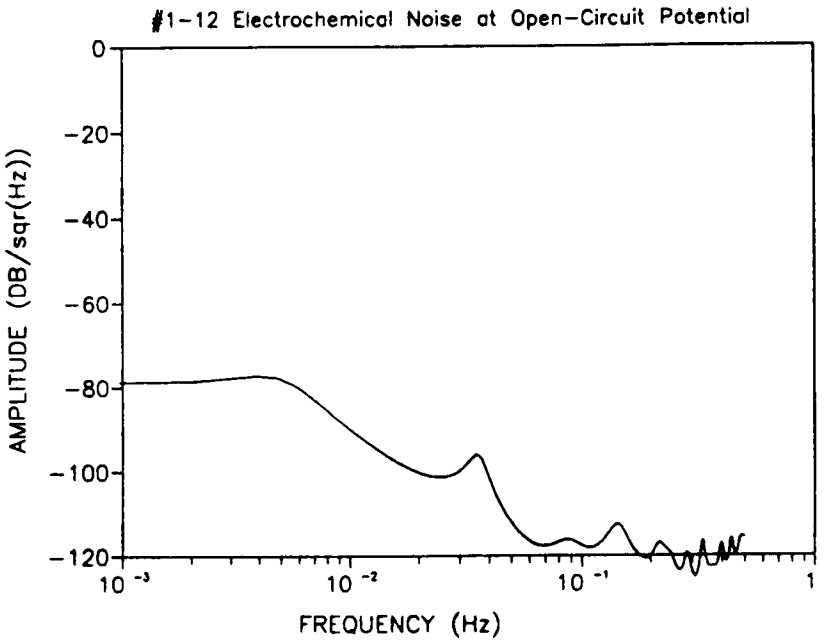


Figure 92. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 12-19 and 12-20.

(a) Sample for Cell #1 (b) Sample for Cell #2



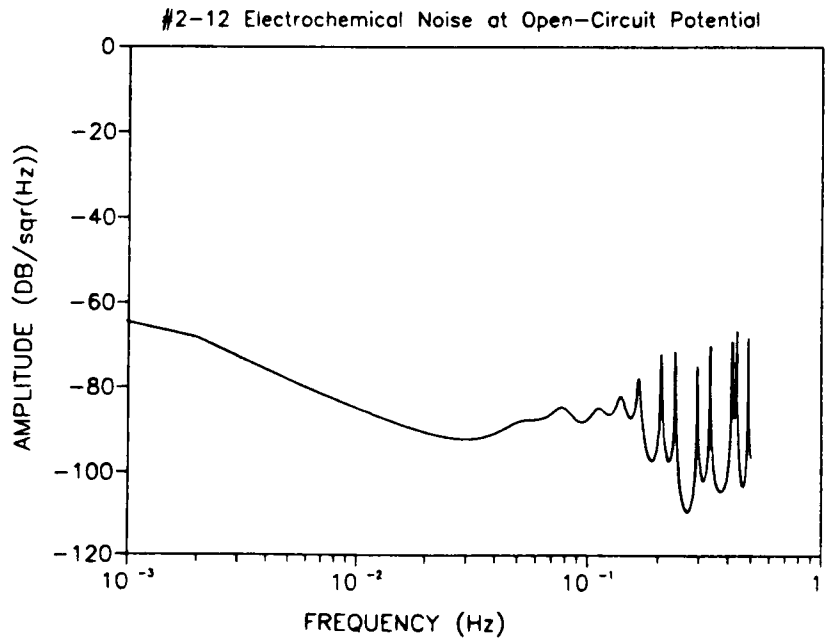


Figure 93. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 12-19 and 12-20.

(a) Sample for Cell #1 (b) Sample for Cell #2

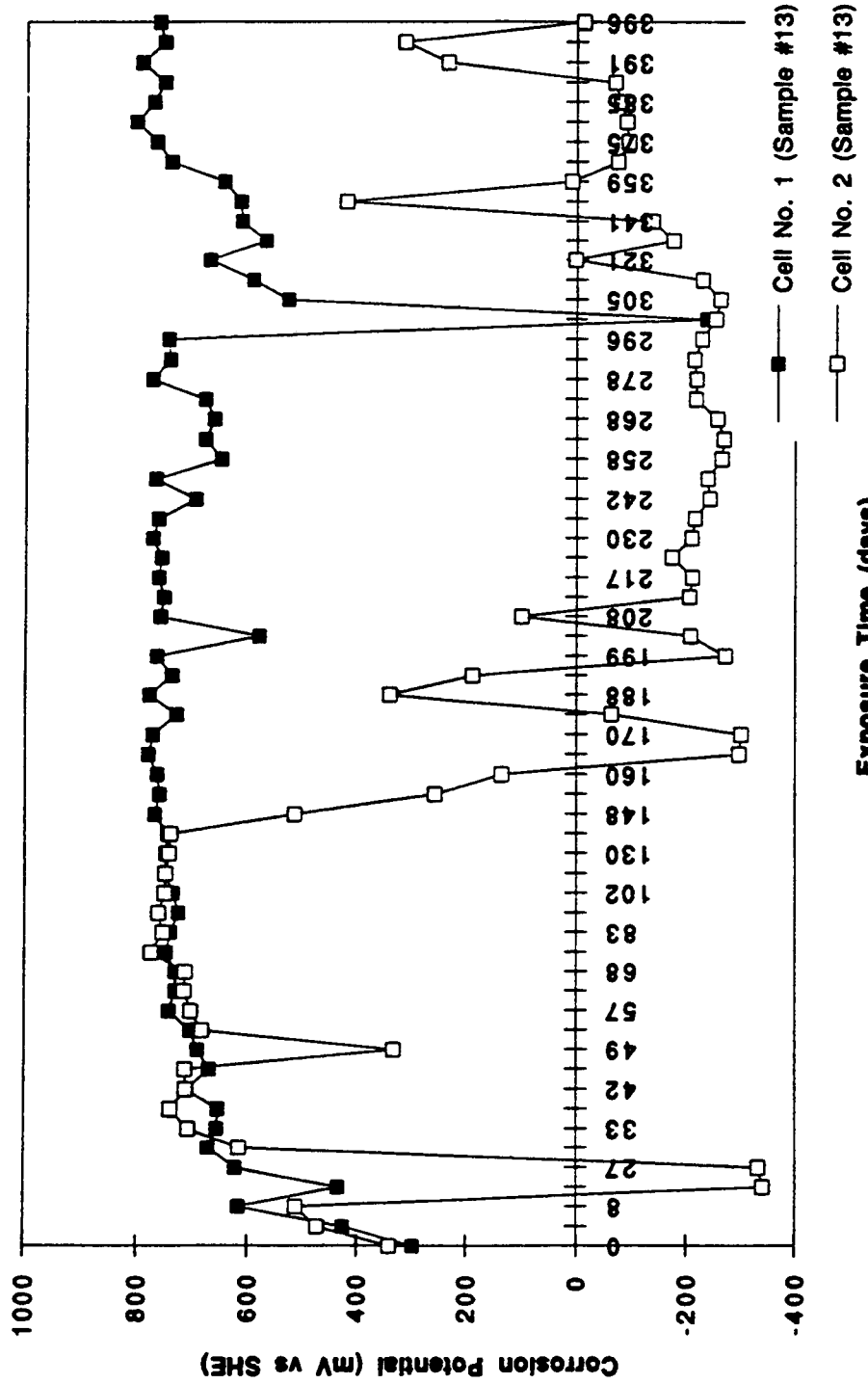


Figure 94. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 13-10 and 13-11

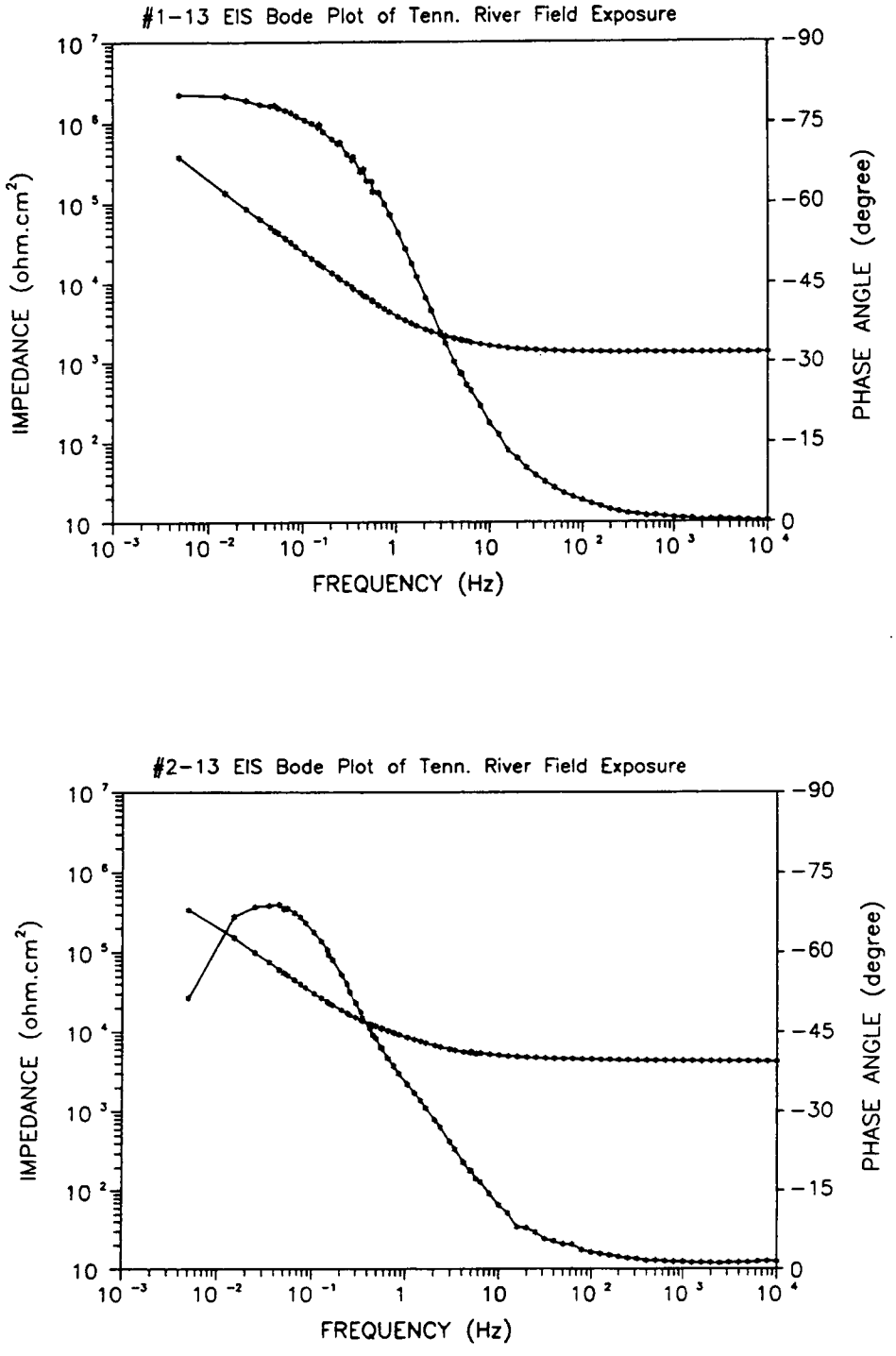


Figure 95. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 13-10 and 13-11.

(a) Sample for Cell #1 (b) Sample for Cell #2

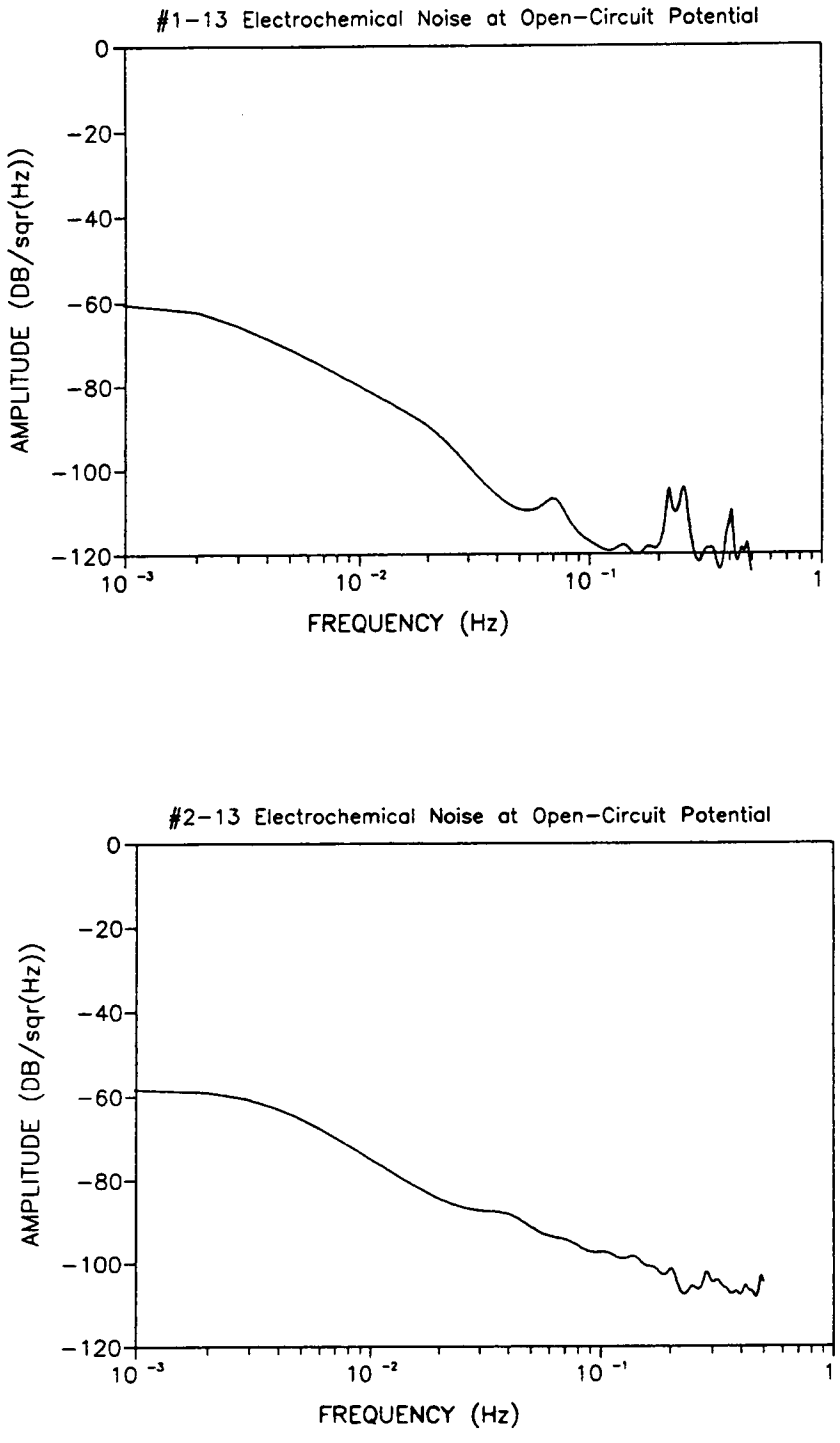


Figure 96. **Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 13-10 and 13-11.**

(a) Sample for Cell #1 **(b) Sample for Cell #2**

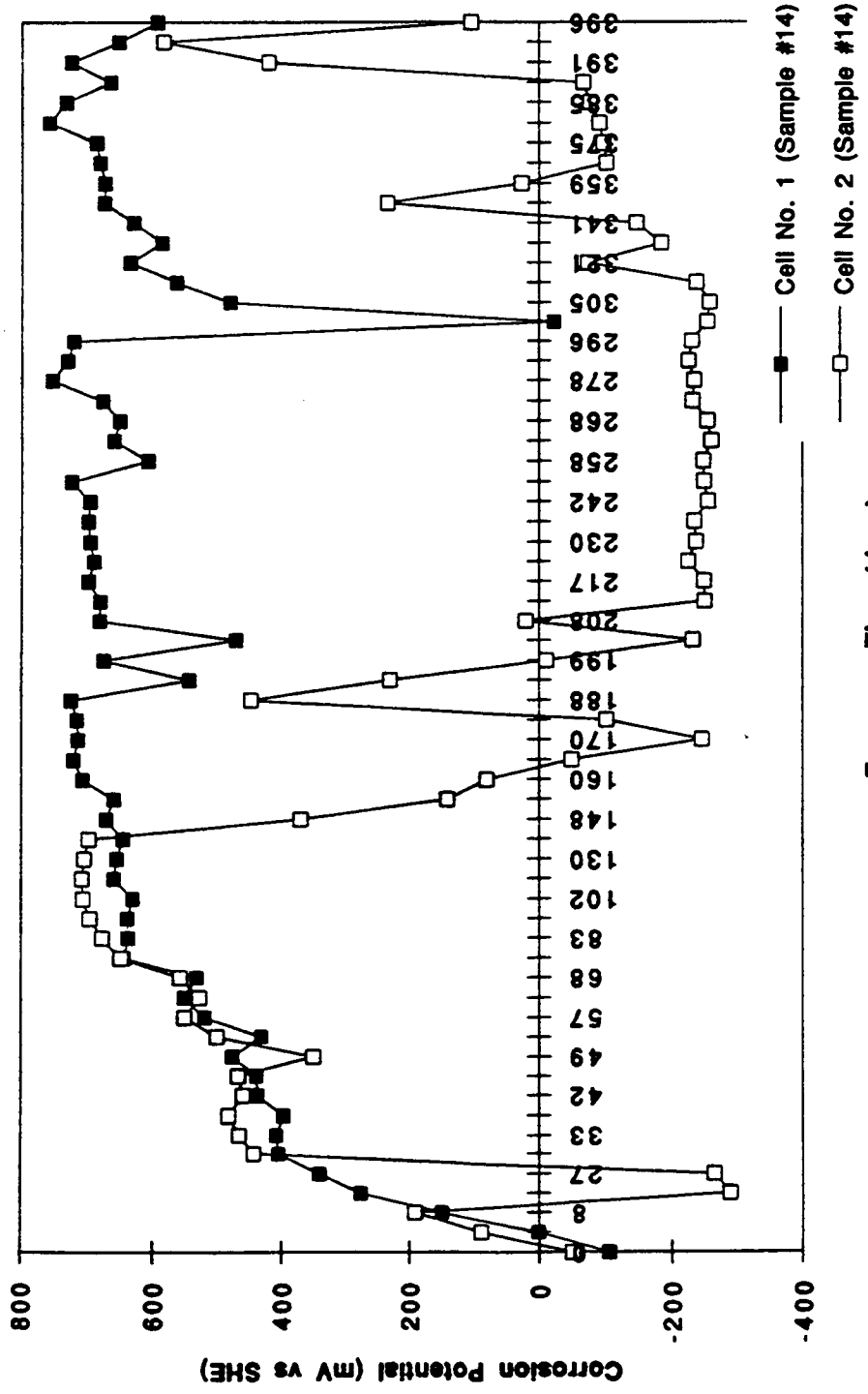


Figure 97. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for Coupons 14-1 and 14-2.

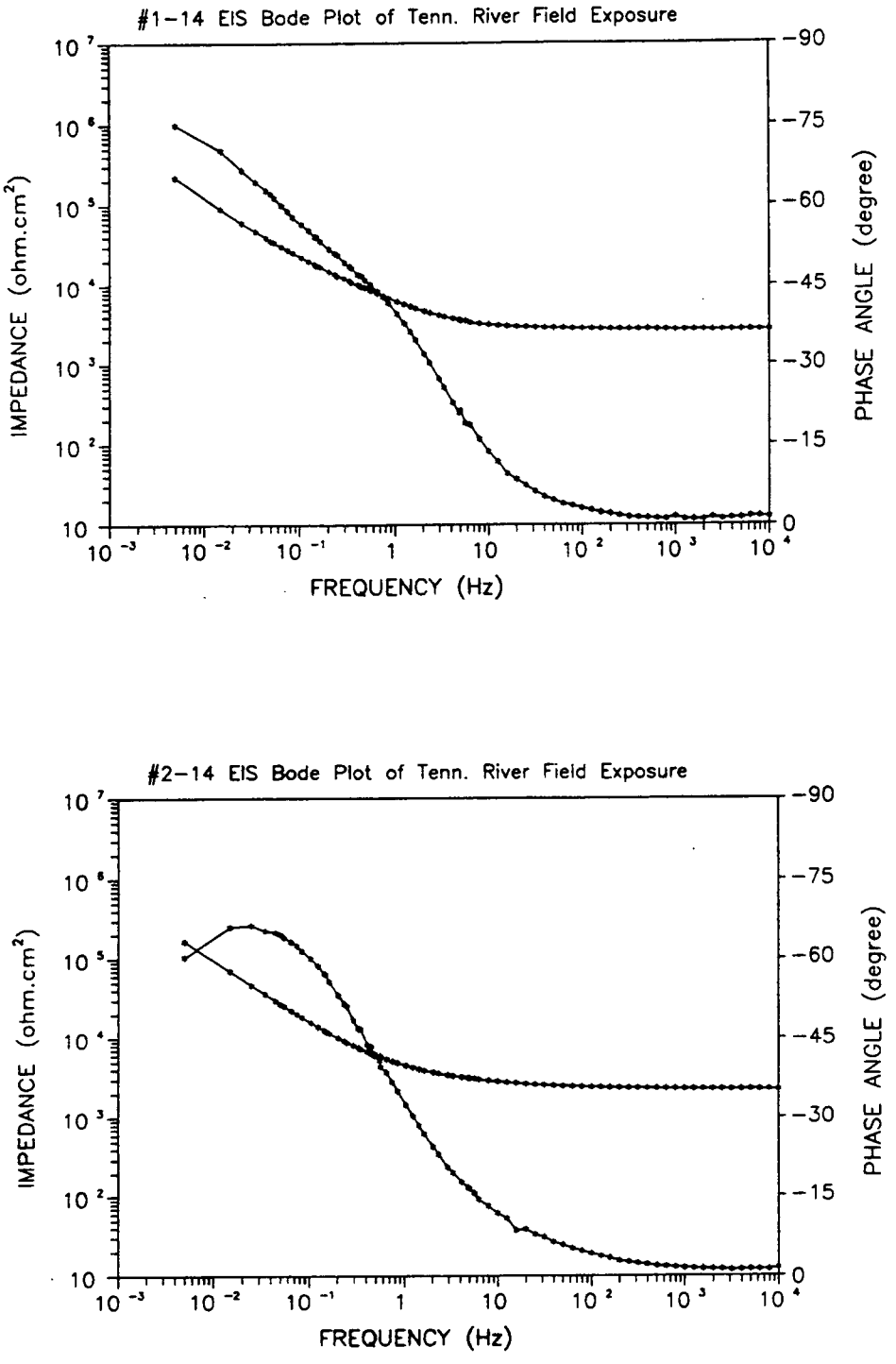


Figure 98. Electrochemical impedance spectroscopy results at the end of the exposure time in the Tennessee River Water for Coupons 14-1 and 14-2.

(a) Sample for Cell #1 (b) Sample for Cell #2

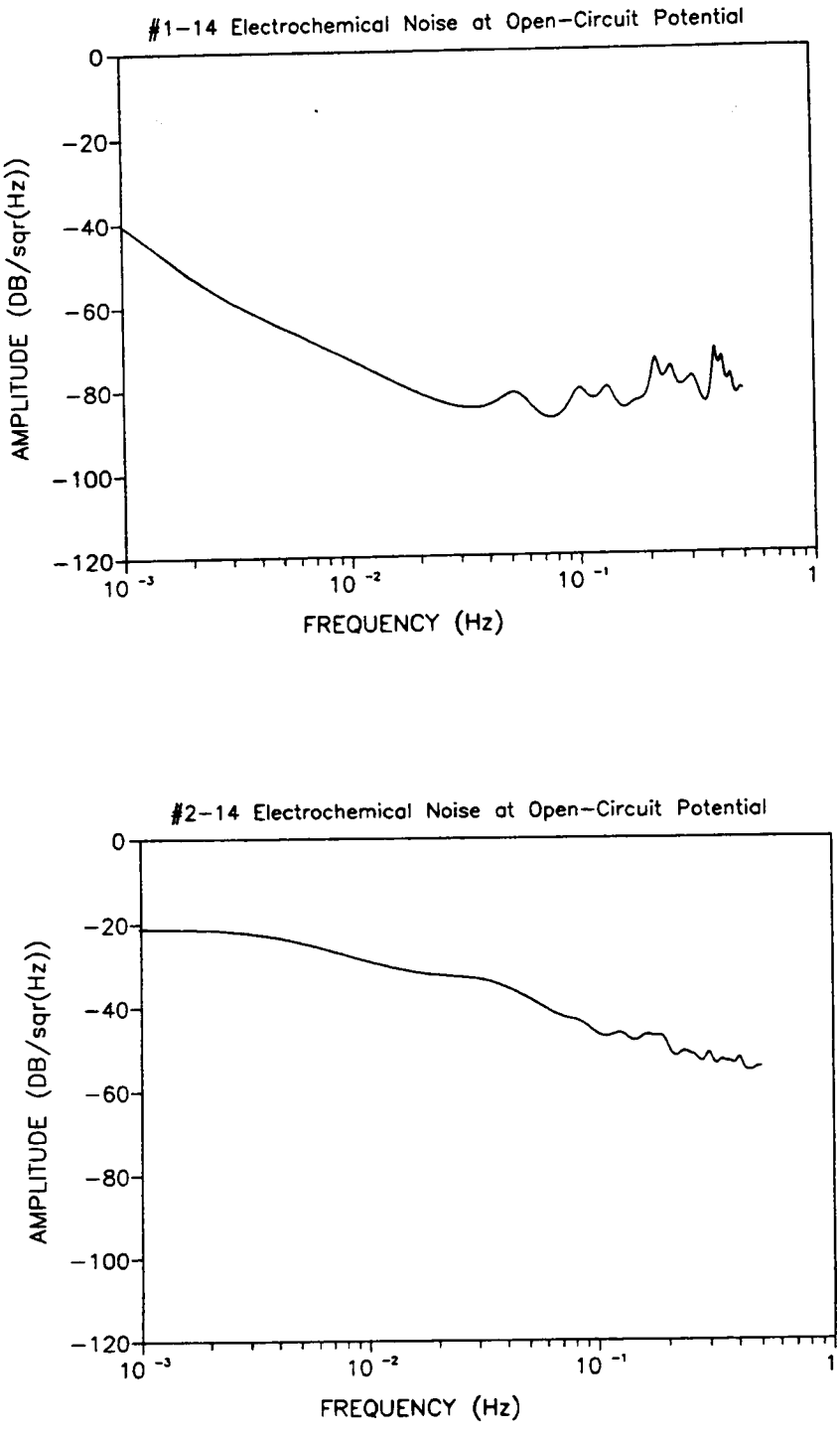


Figure 99. Electrochemical noise results at the end of the exposure in the Tennessee River Water for Coupons 14-1 and 14-2.

(a) Sample for Cell #1 (b) Sample for Cell #2

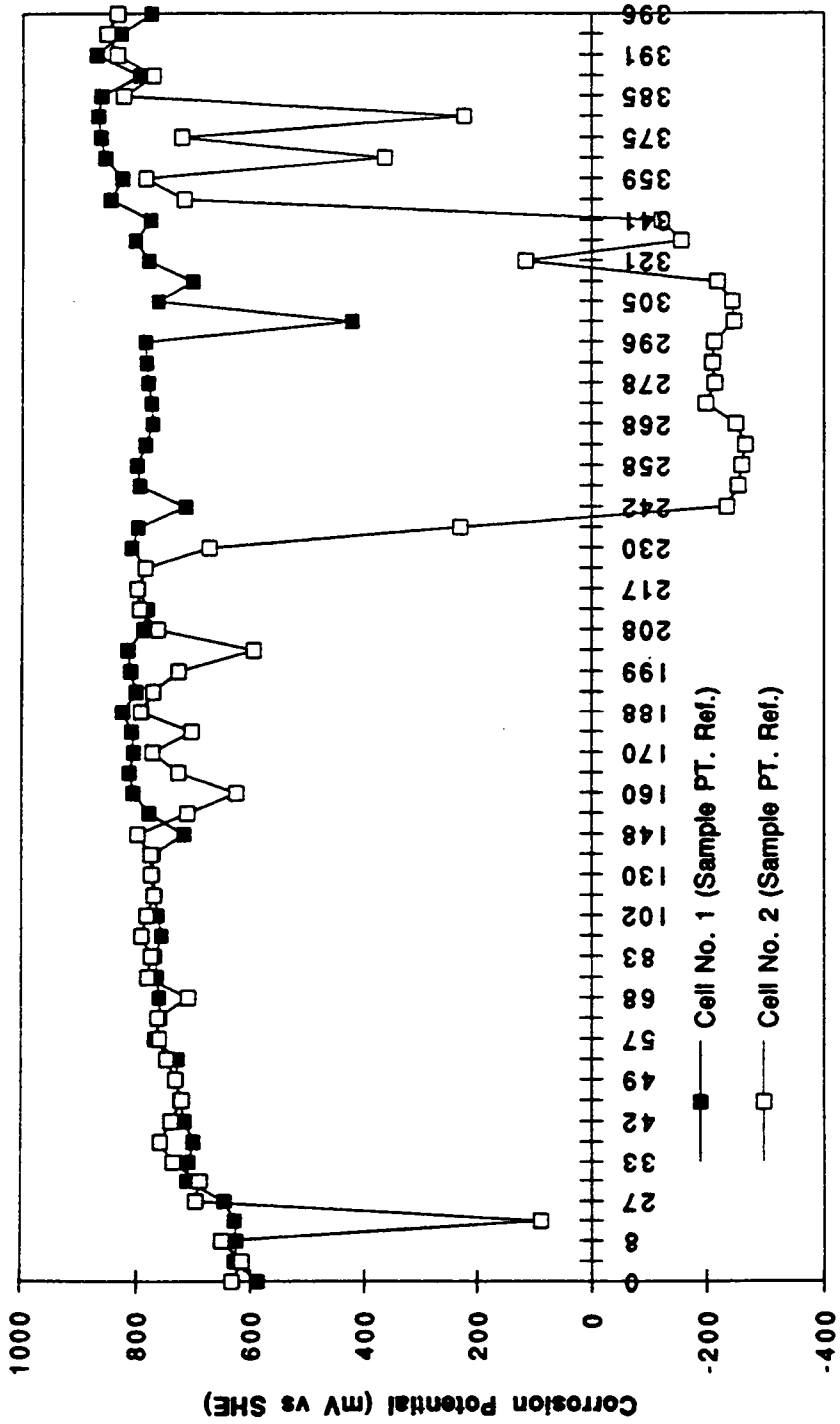


Figure 100. Open-Circuit Potentials vs Time while exposed to Tennessee River Water for the Reference Platinum Electrodes in Cells 1 and 2.

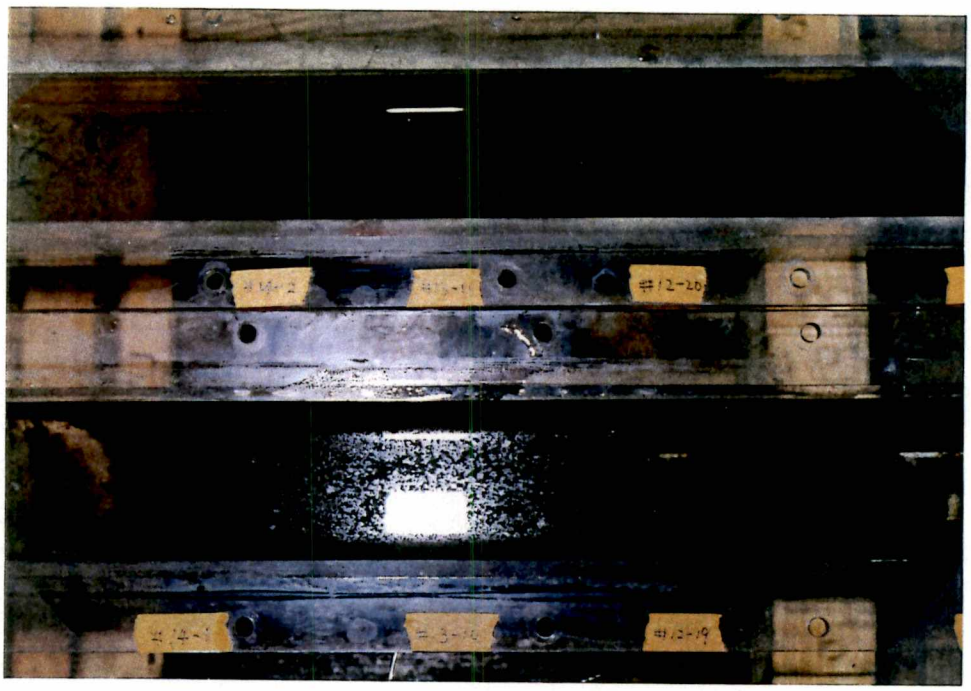


Figure 101. Photo demonstrating the different biofilm appearances between Cell #1 (botttom) and Cell #2 (top) at the entrance point to the cells.

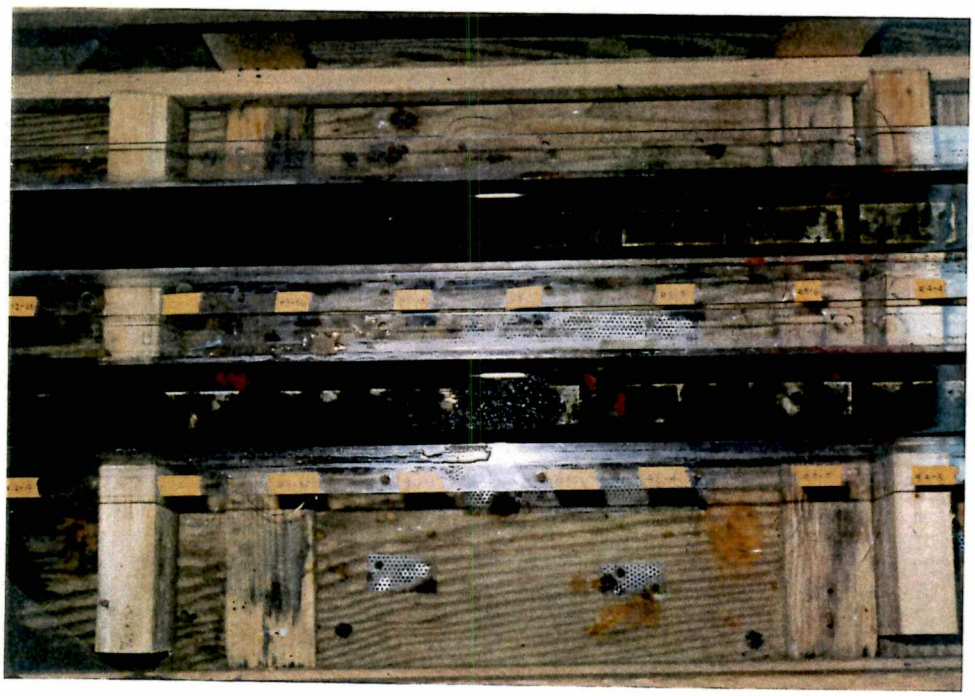
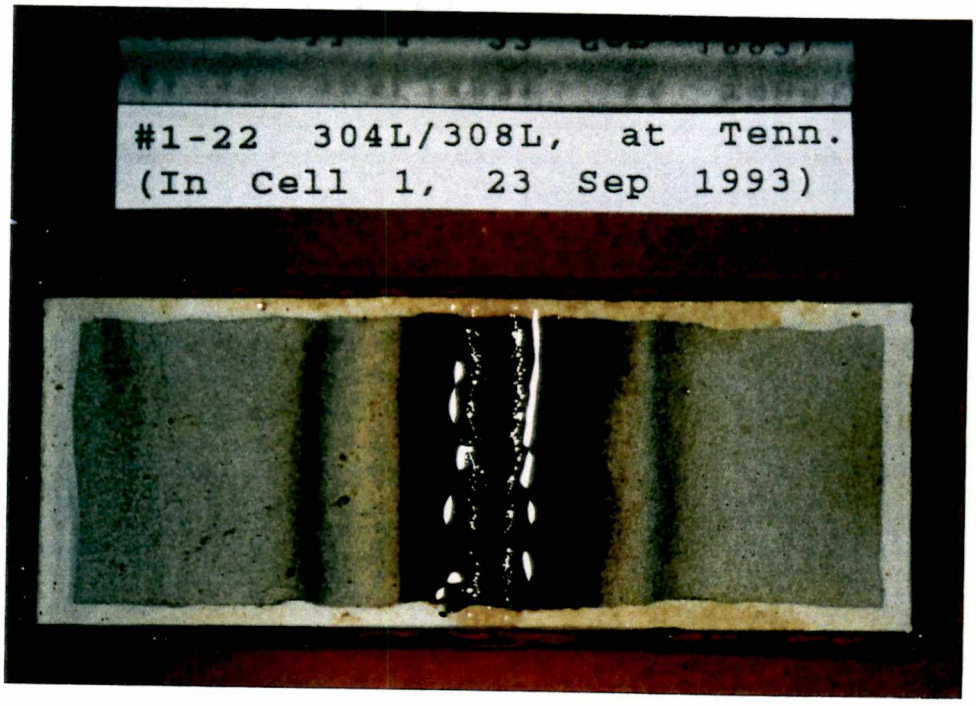


Figure 102. Photo demonstrating the different biofilm appearances between Cell #1 (bottom) and Cell #2 (top) at the mid point of the cells.



Figure 103. Photo demonstrating the different biofilm appearances between Cell #1 (bottom) and Cell #2 (top) at the exit point of the cells.

(a)



(b)

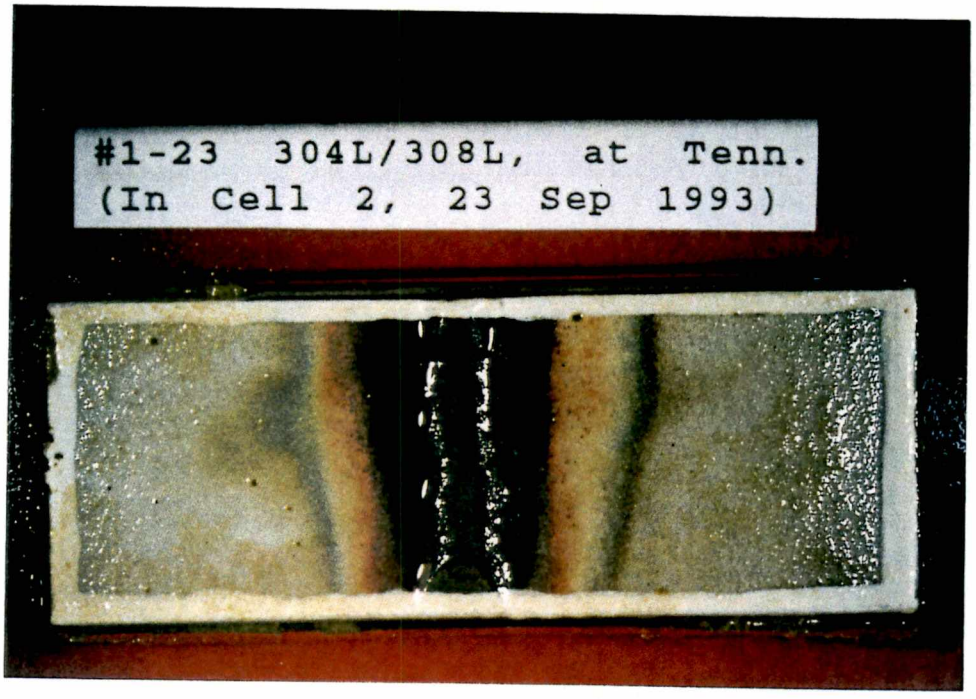
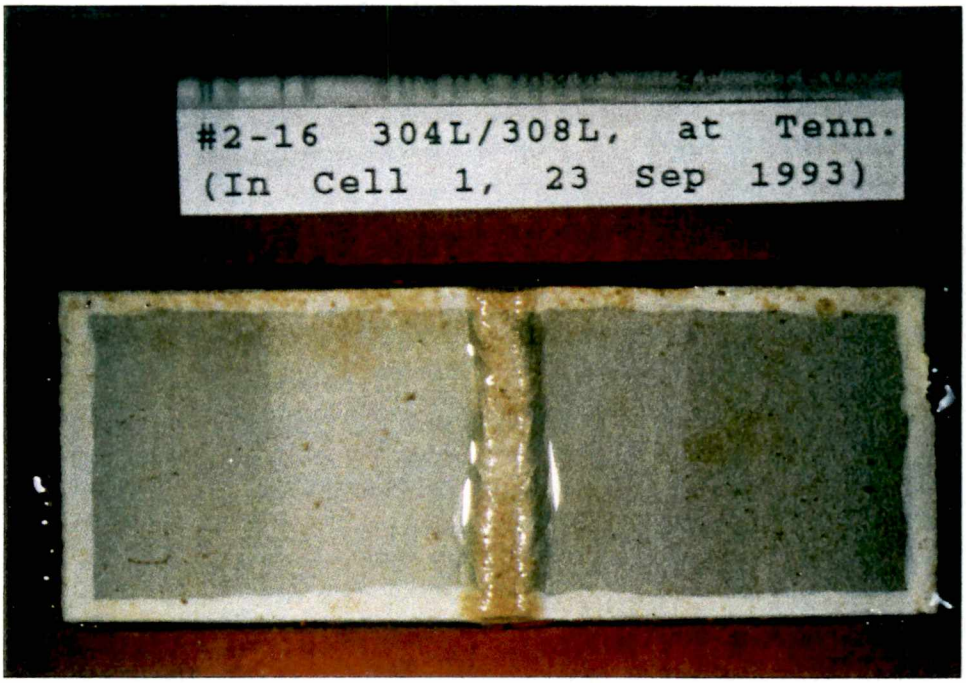


Figure 104. Coupons 1-22 and 1-23 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)



Figure 105. Coupons 2-16 and 2-17 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)



Figure 106. Coupons 3-19 and 3-22 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

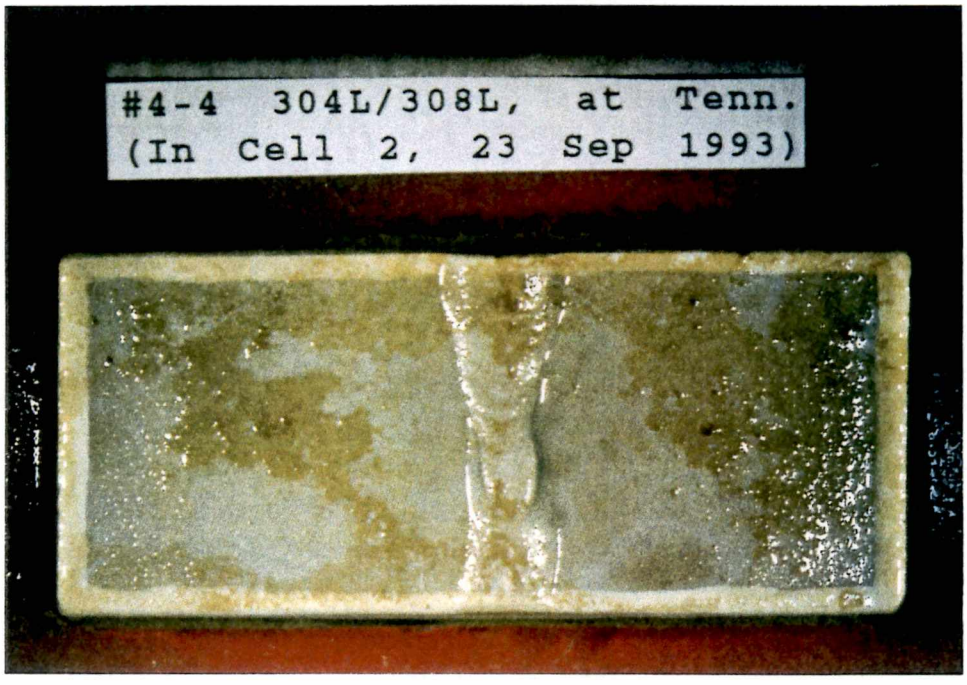


Figure 107. Coupons 4-3 and 4-4 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



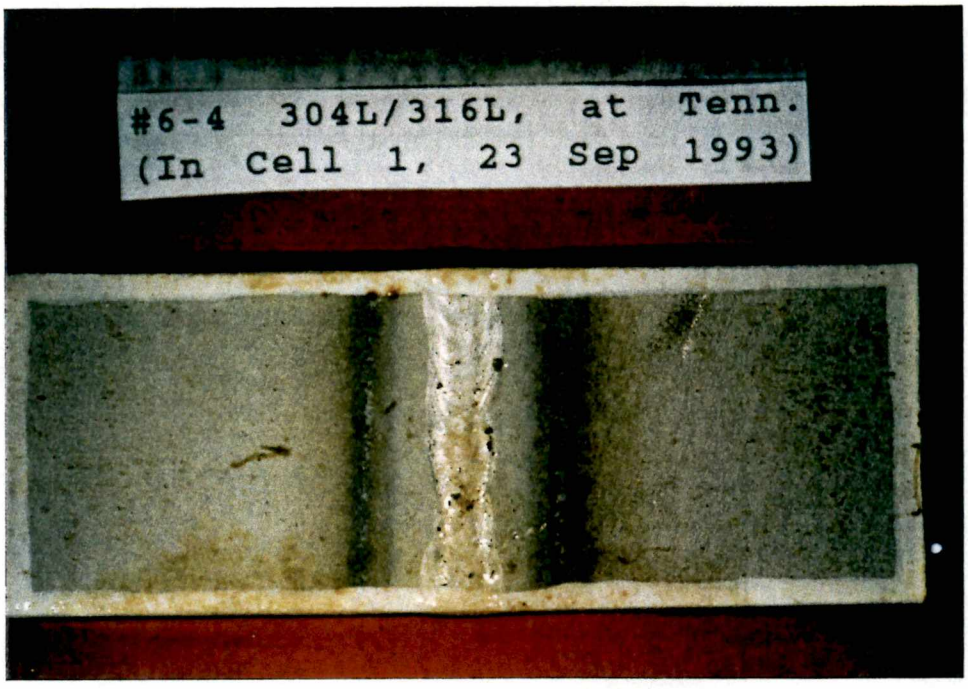
(b)



Figure 108. Coupons 5-5 and 5-6 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

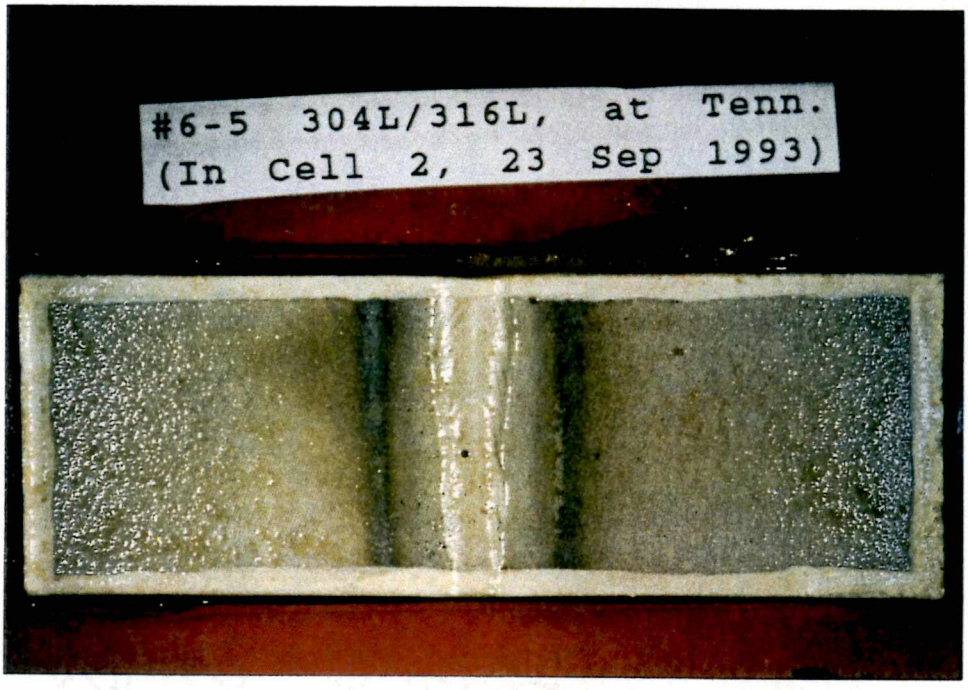


Figure 109. Coupons 6-4 and 6-5 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



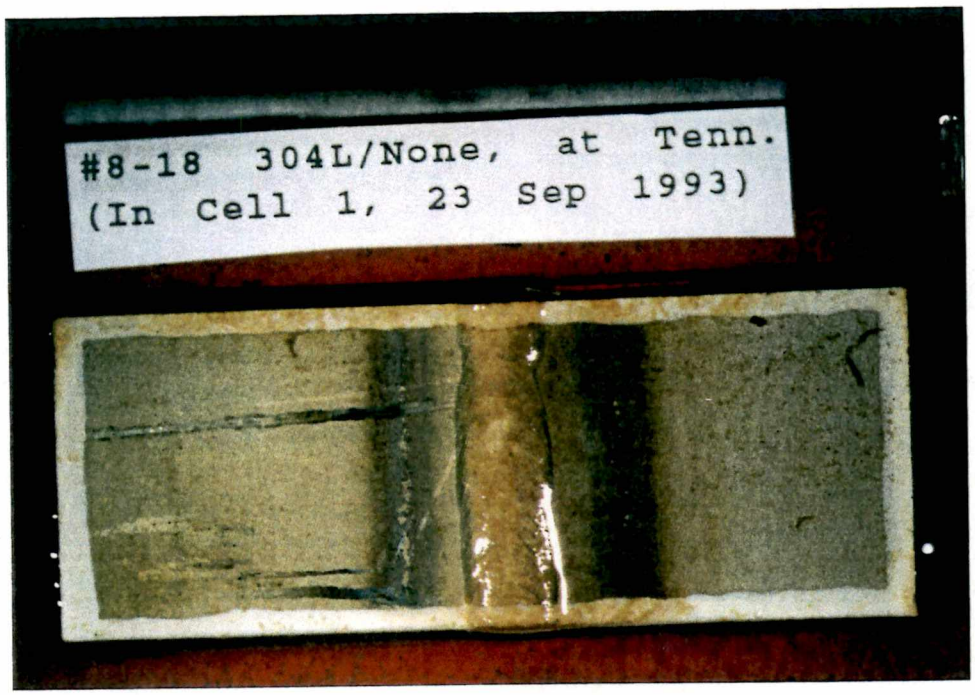
(b)



Figure 110. Coupons 7-7 and 7-8 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

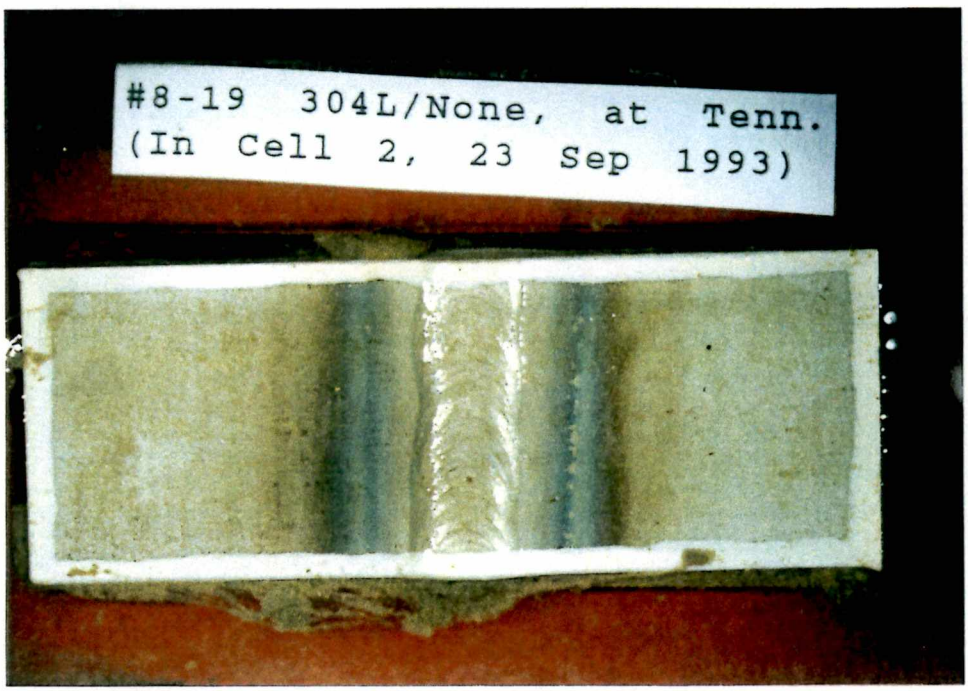
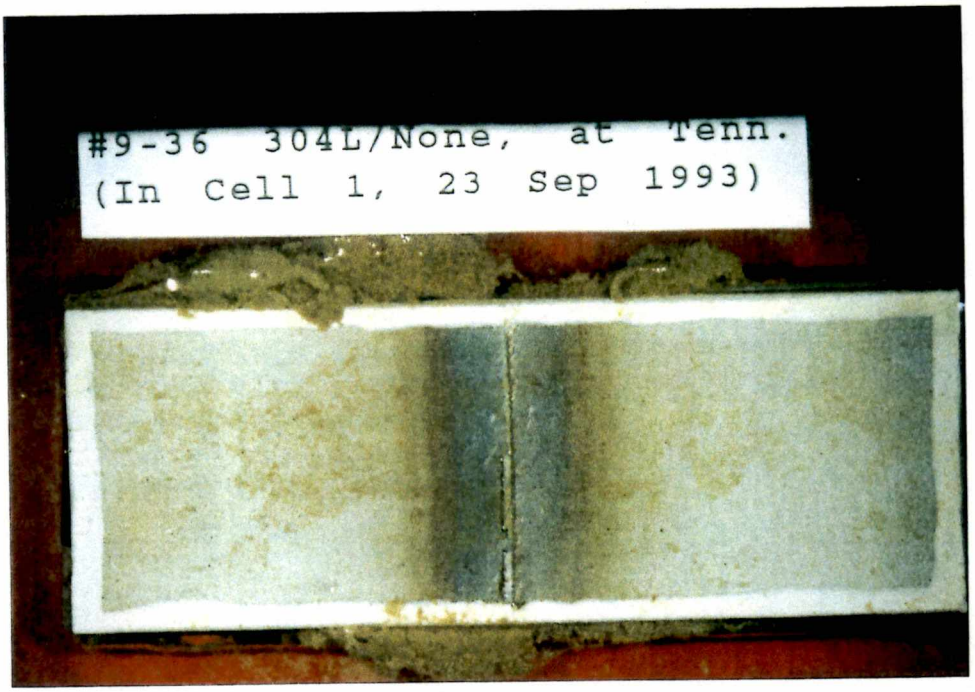


Figure 111. Coupons 8-18 and 8-19 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)



Figure 112. Coupons 9-36 and 9-37 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

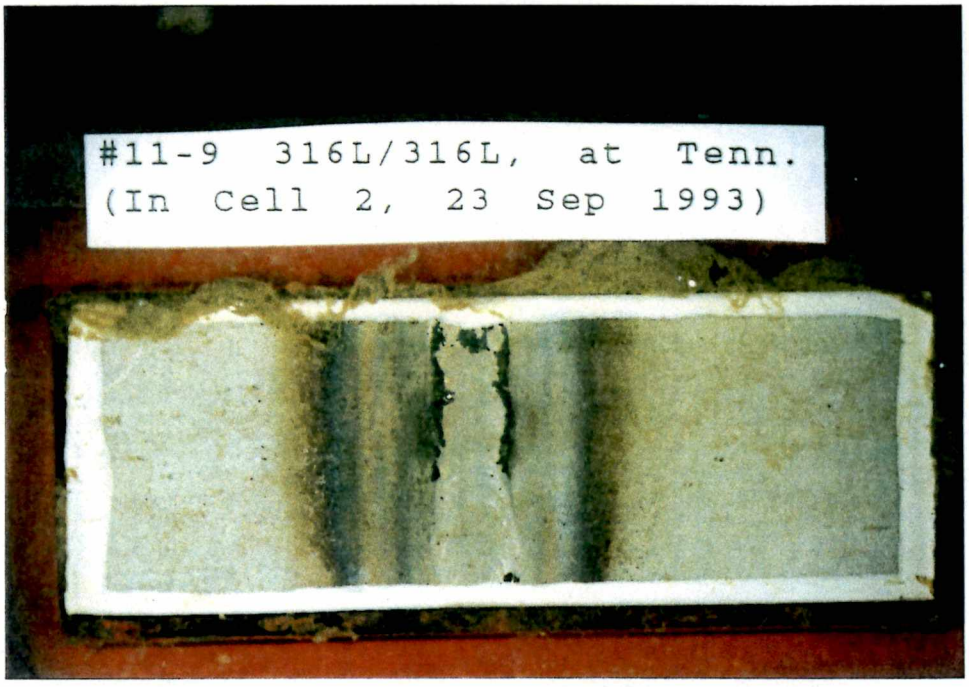
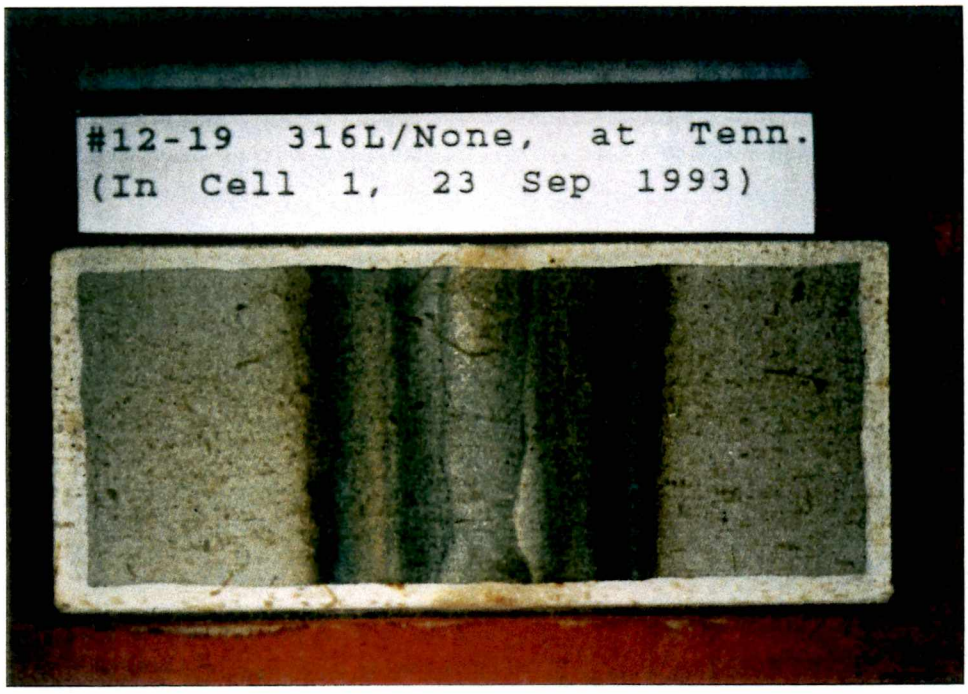


Figure 113. Coupons 11-8 and 11-9 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



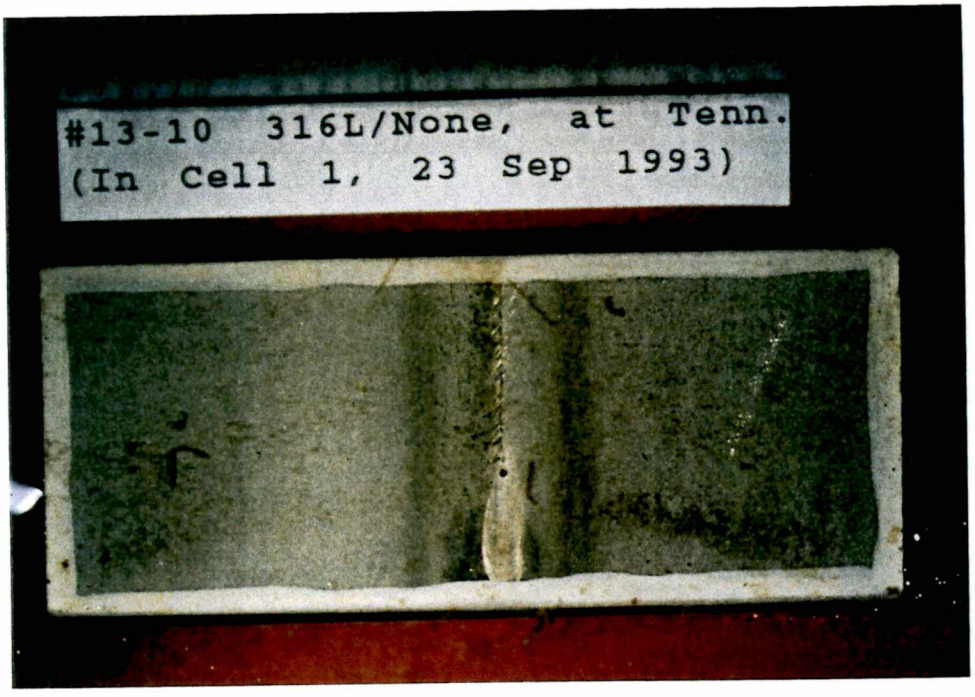
(b)



Figure 114. Coupons 12-19 and 12-20 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

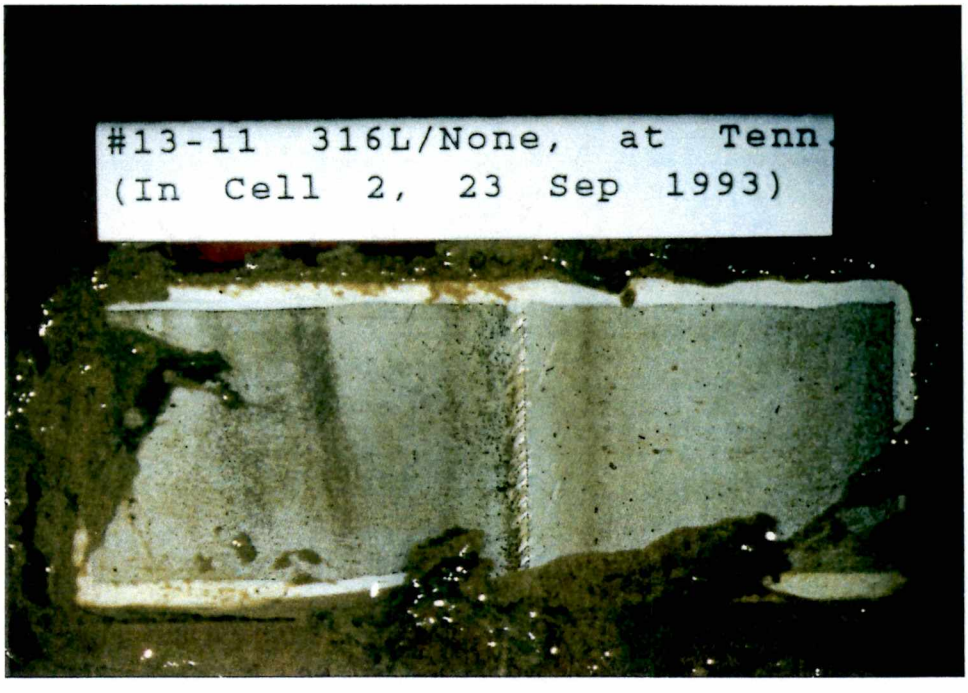


Figure 115. Coupons 13-10 and 13-11 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2

(a)



(b)

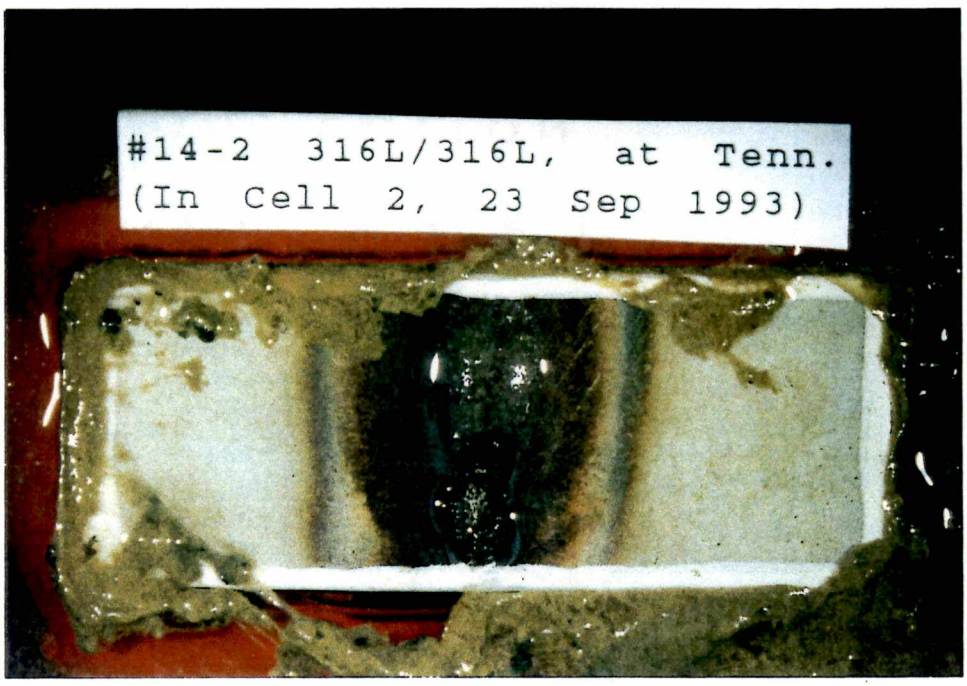


Figure 116. Coupons 14-1 and 14-2 after being placed in the Tennessee River Water for a year.

(a) Sample for Cell #1 (b) Sample for Cell #2



Figure 117. Photo demonstrating the difference in the appearance of the platinum reference electrodes from Cell #1 (left) and Cell #2 (right)

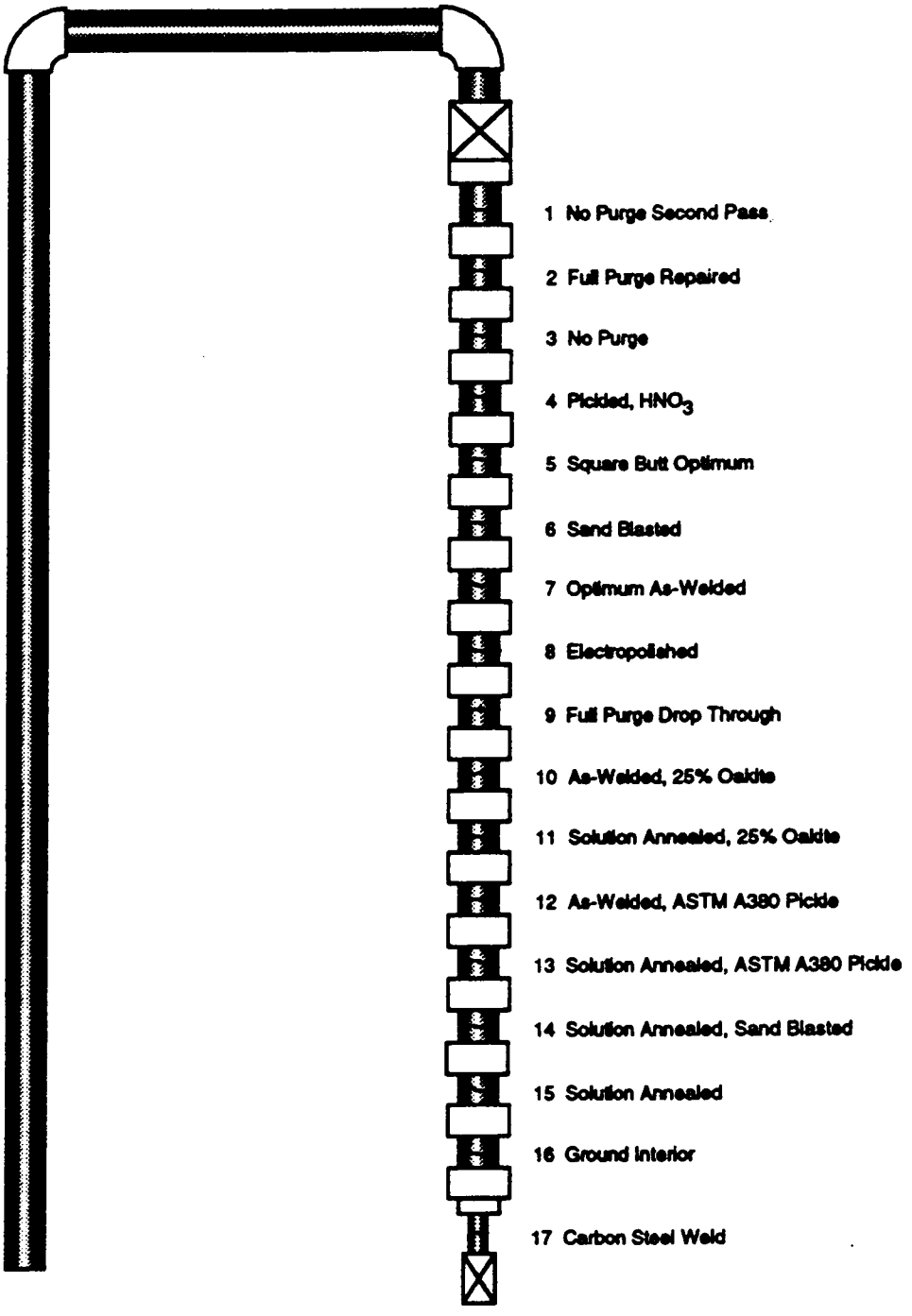


Figure 118. Schematic of the pipe string assembly installed at the Tennessee River Site.



Figure 119. Photo demonstrating sediment and Asiatic clams from the pipe string test on the Tennessee River.

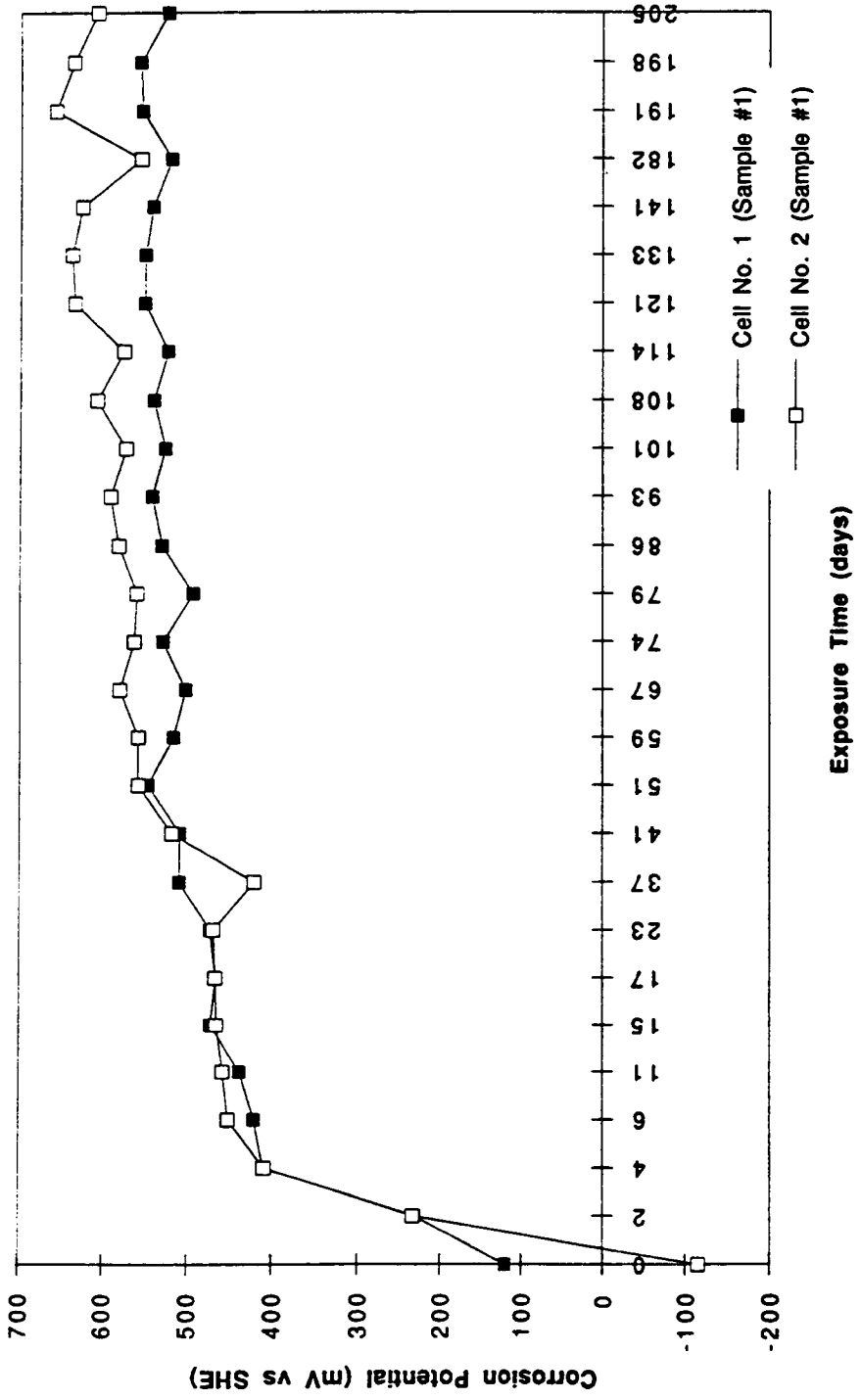


Figure 120. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 1-33 and 1-34.

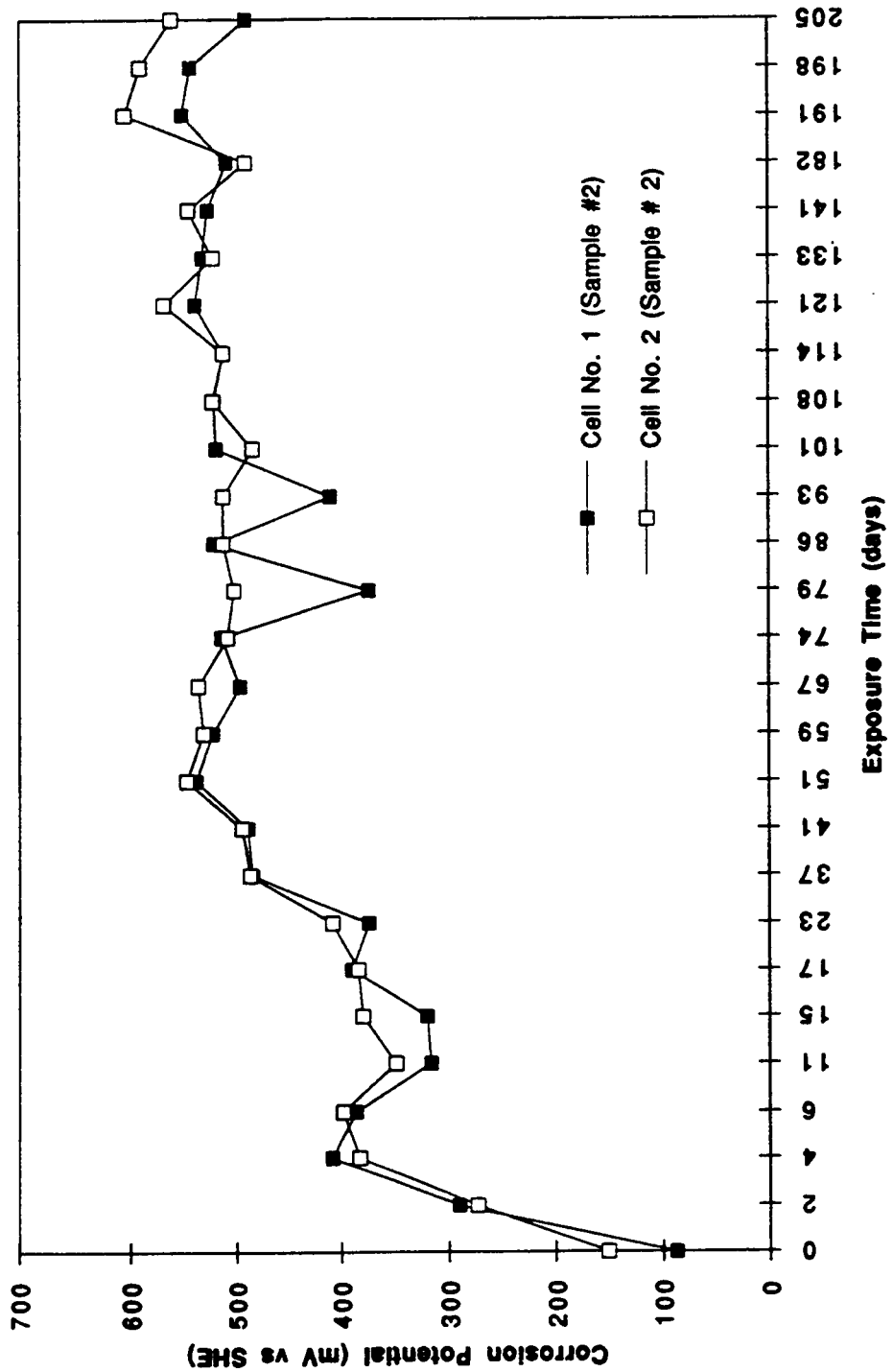


Figure 121. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 2-26 and 2-27.

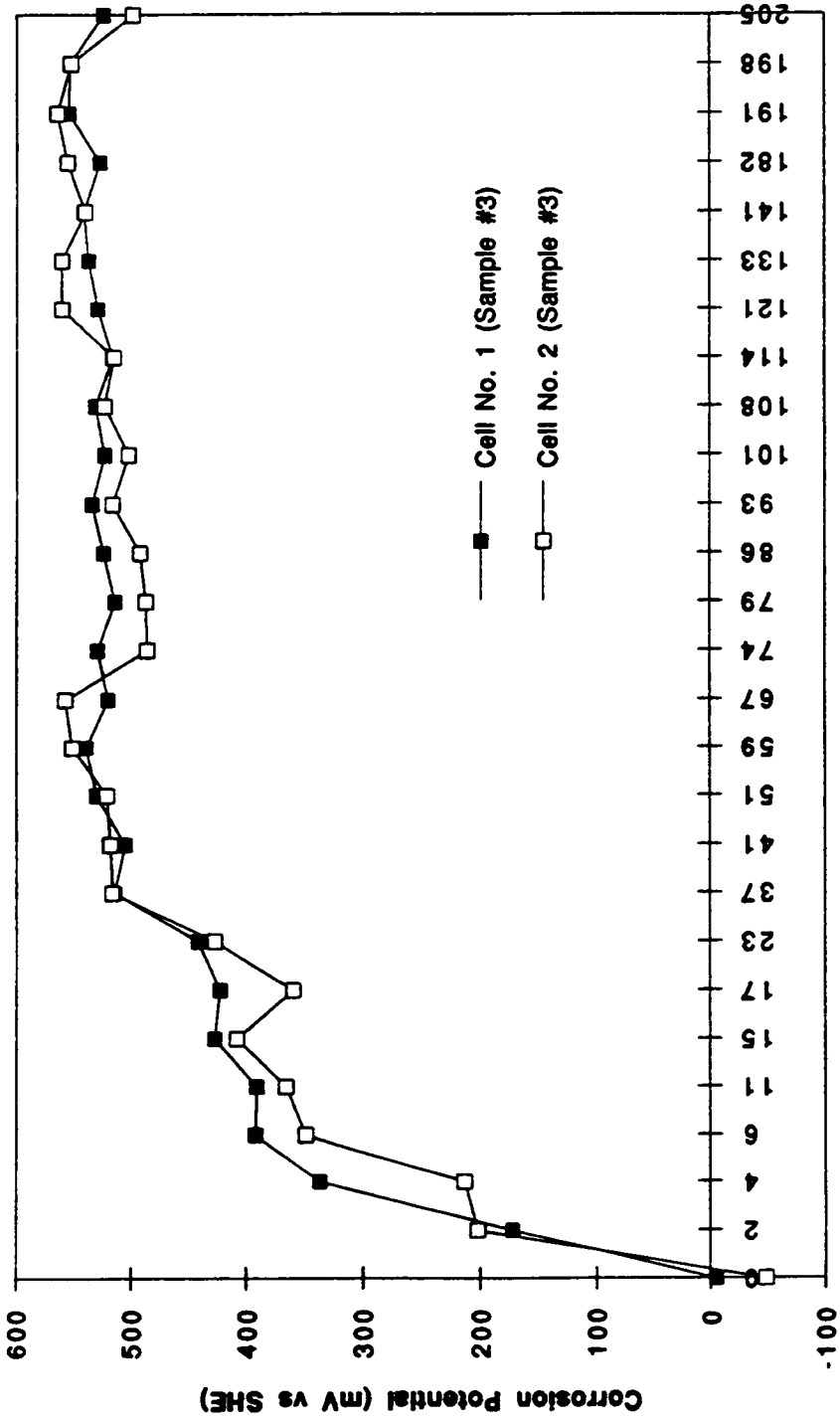


Figure 122. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 3-17 and 3-18.

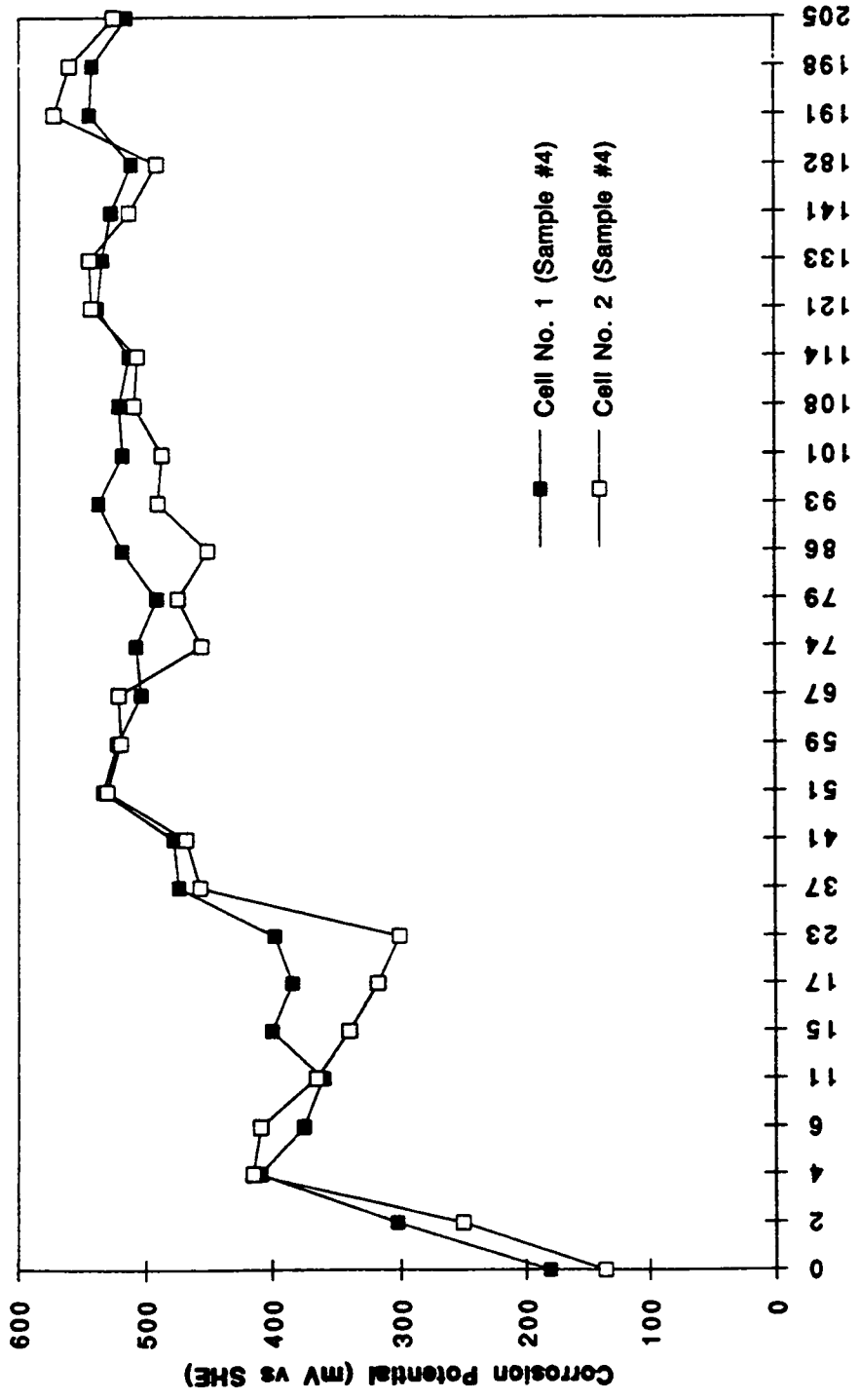


Figure 123. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 4-5 and 4-6.

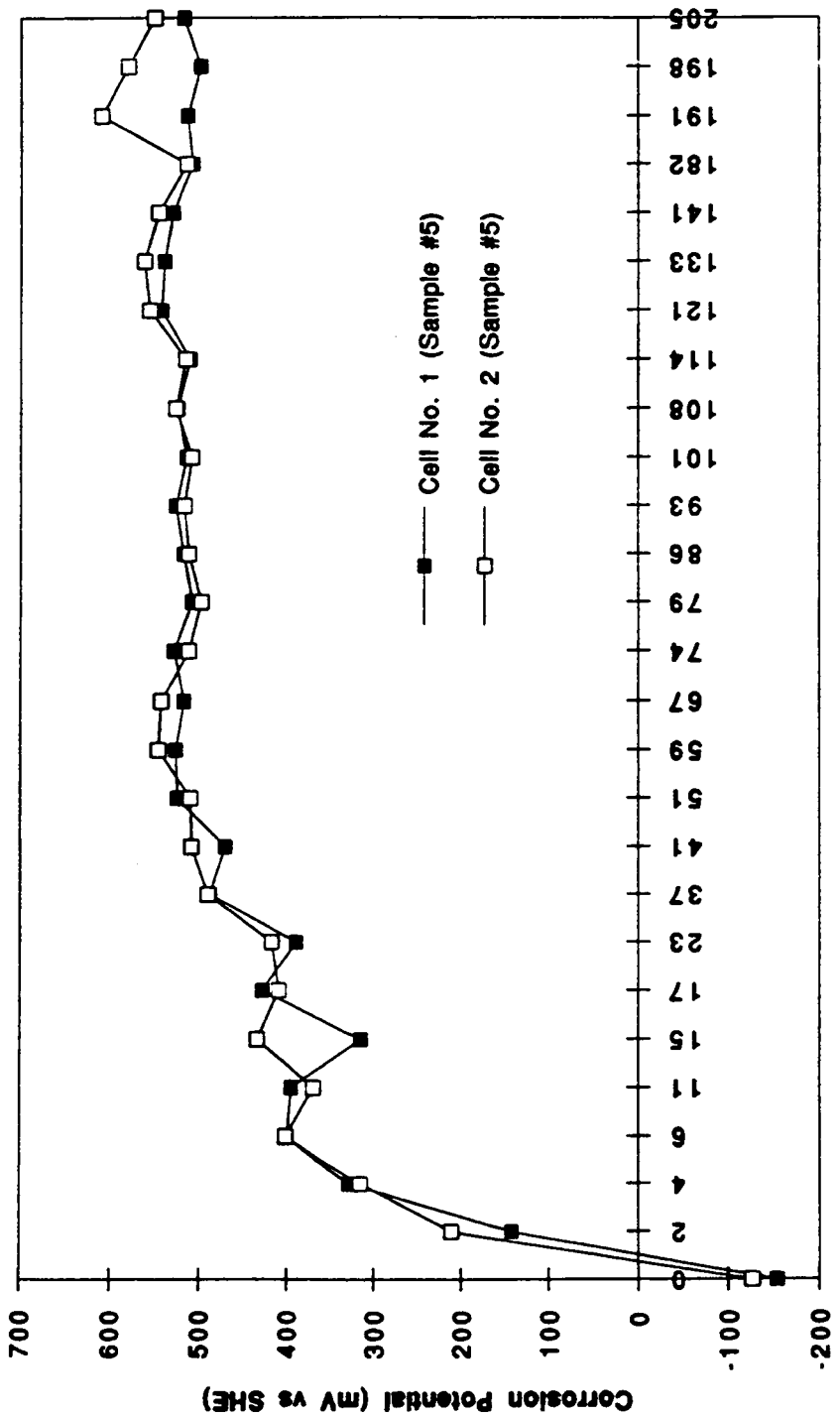


Figure 124. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 5-17 and 5-18.

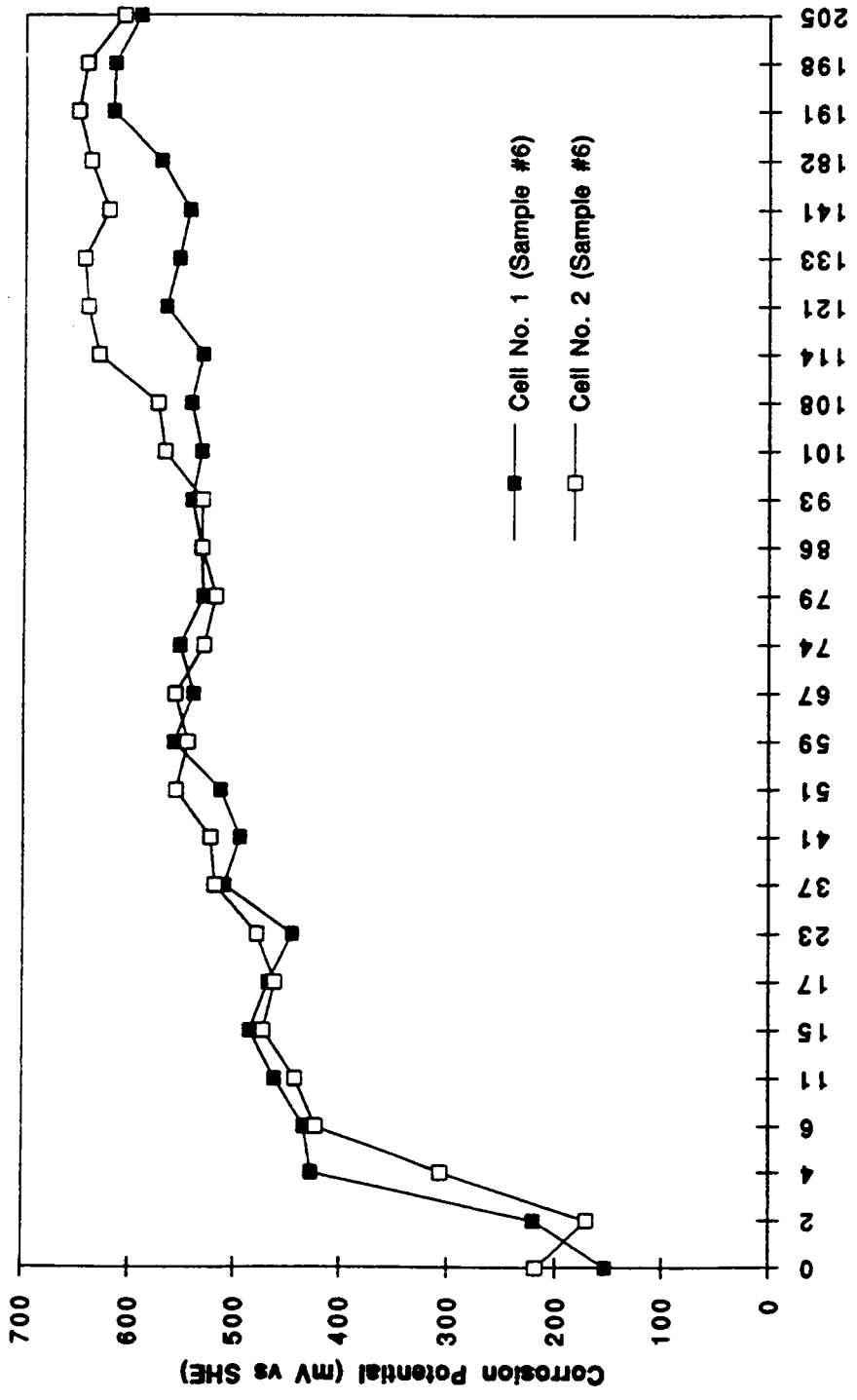


Figure 125. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 6B-4-7 and 6B-4-8.

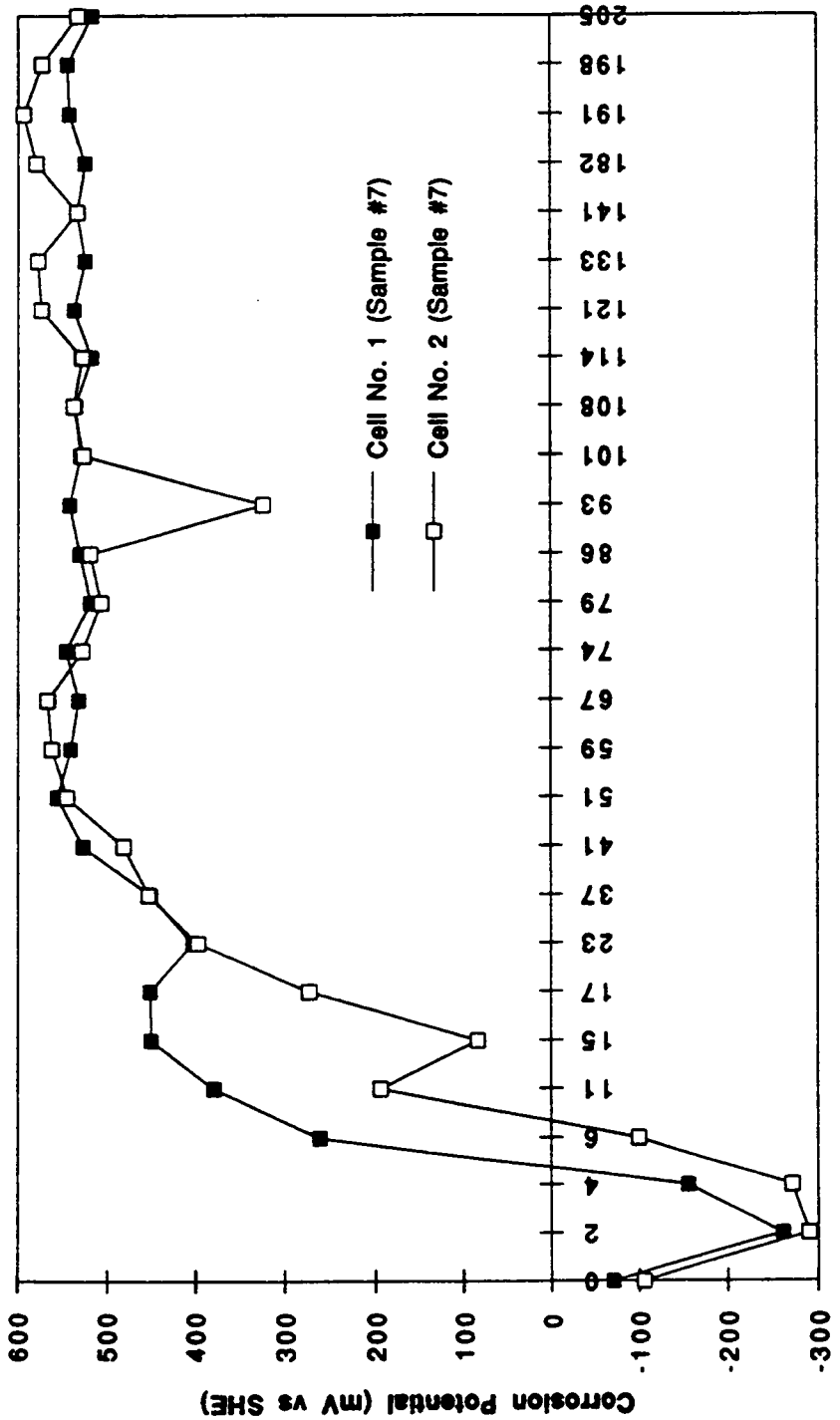


Figure 126. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 7B-4-9 and 7B-4-10.

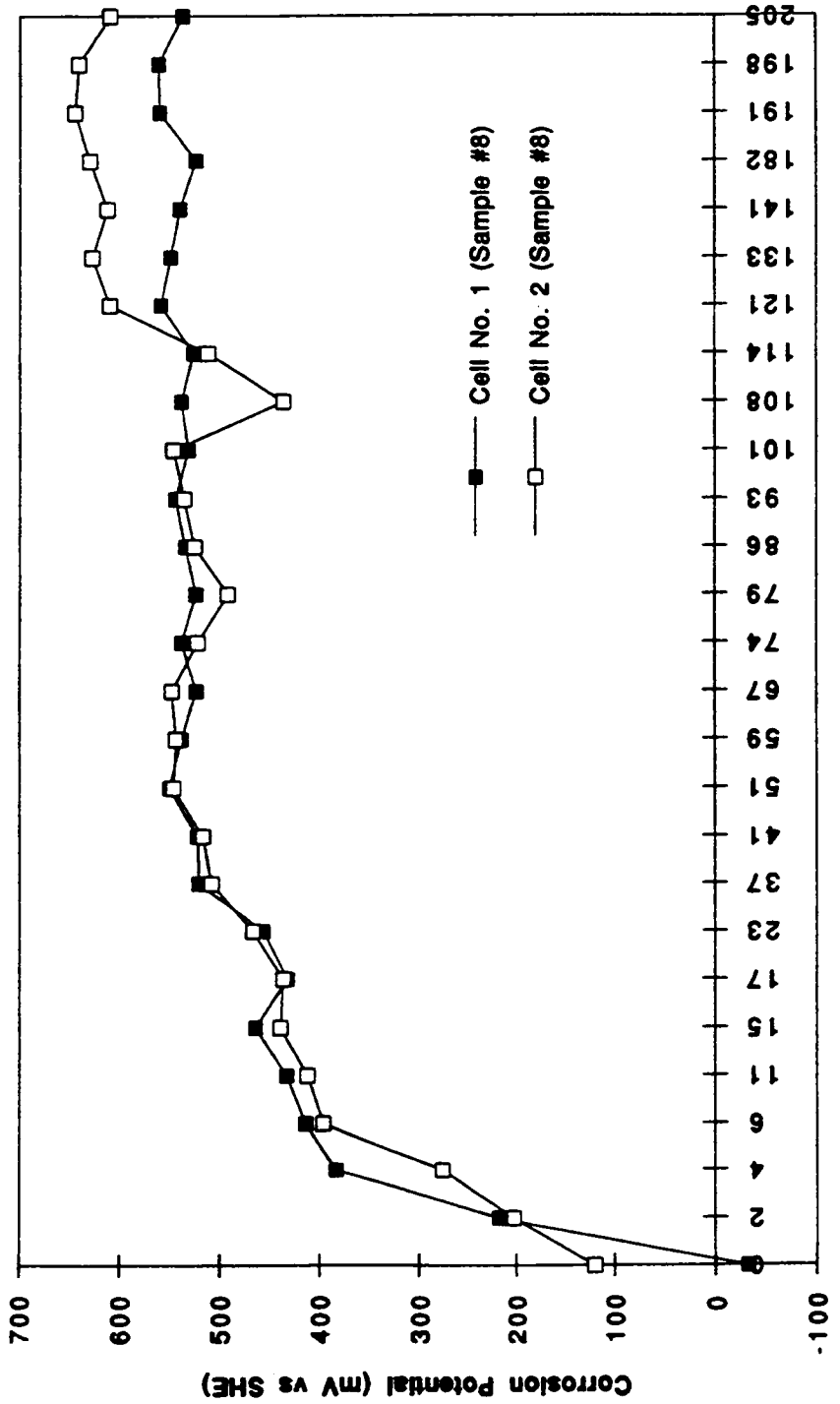


Figure 127. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 8-20 and 8-21.

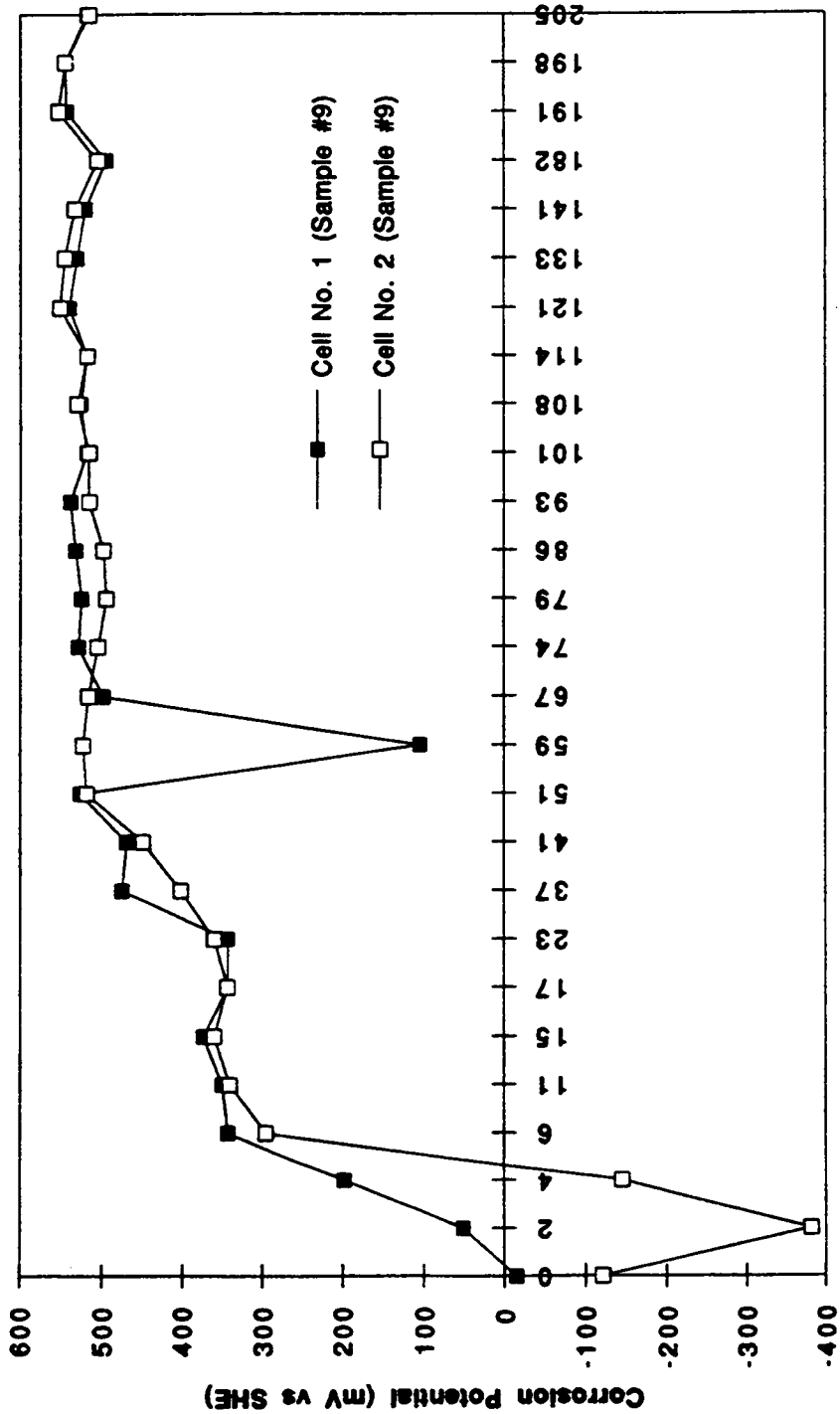


Figure 128. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 9B-4-11 and 9B-5-19.

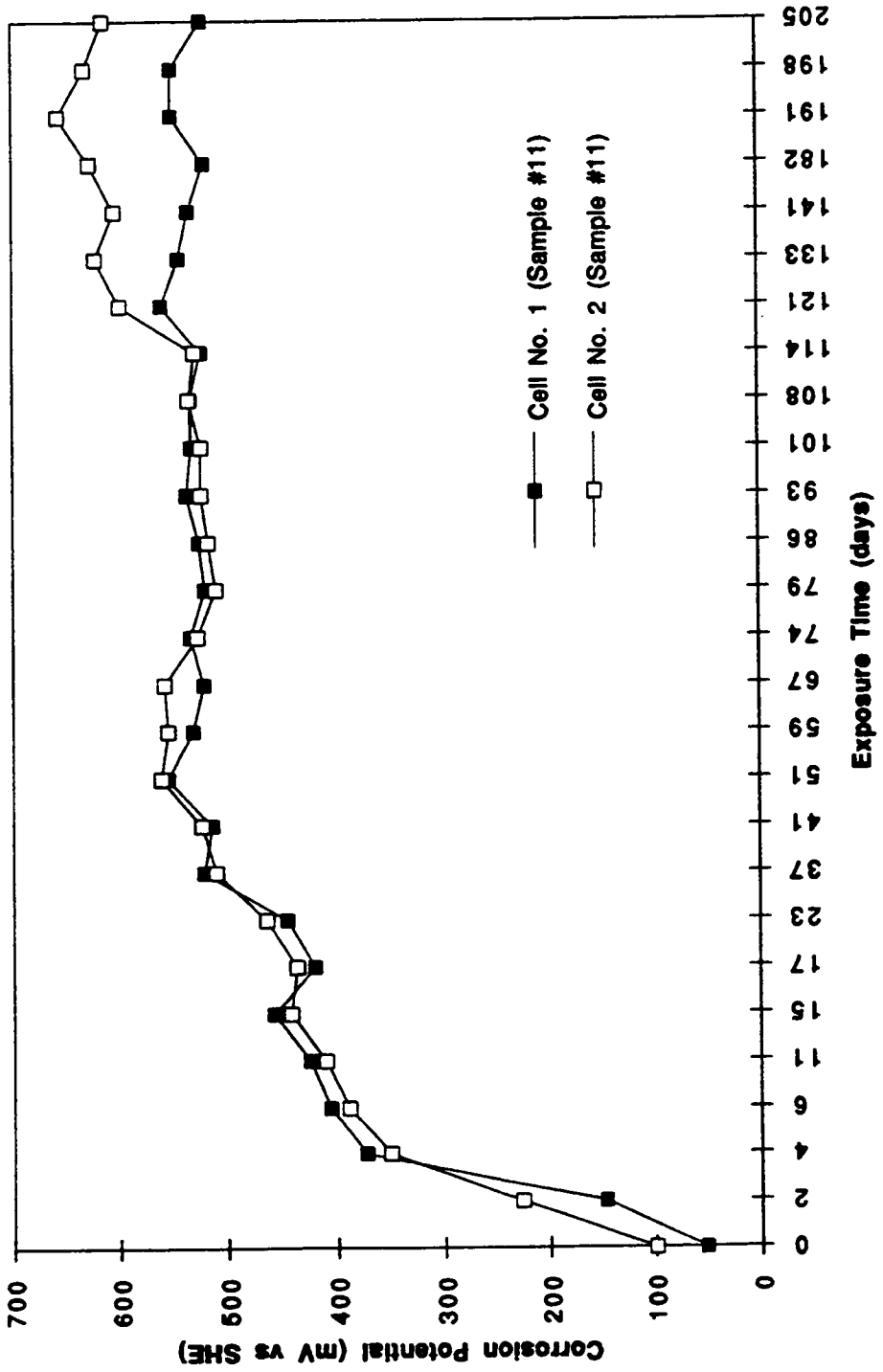


Figure 129. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 11-10 and 11-11.

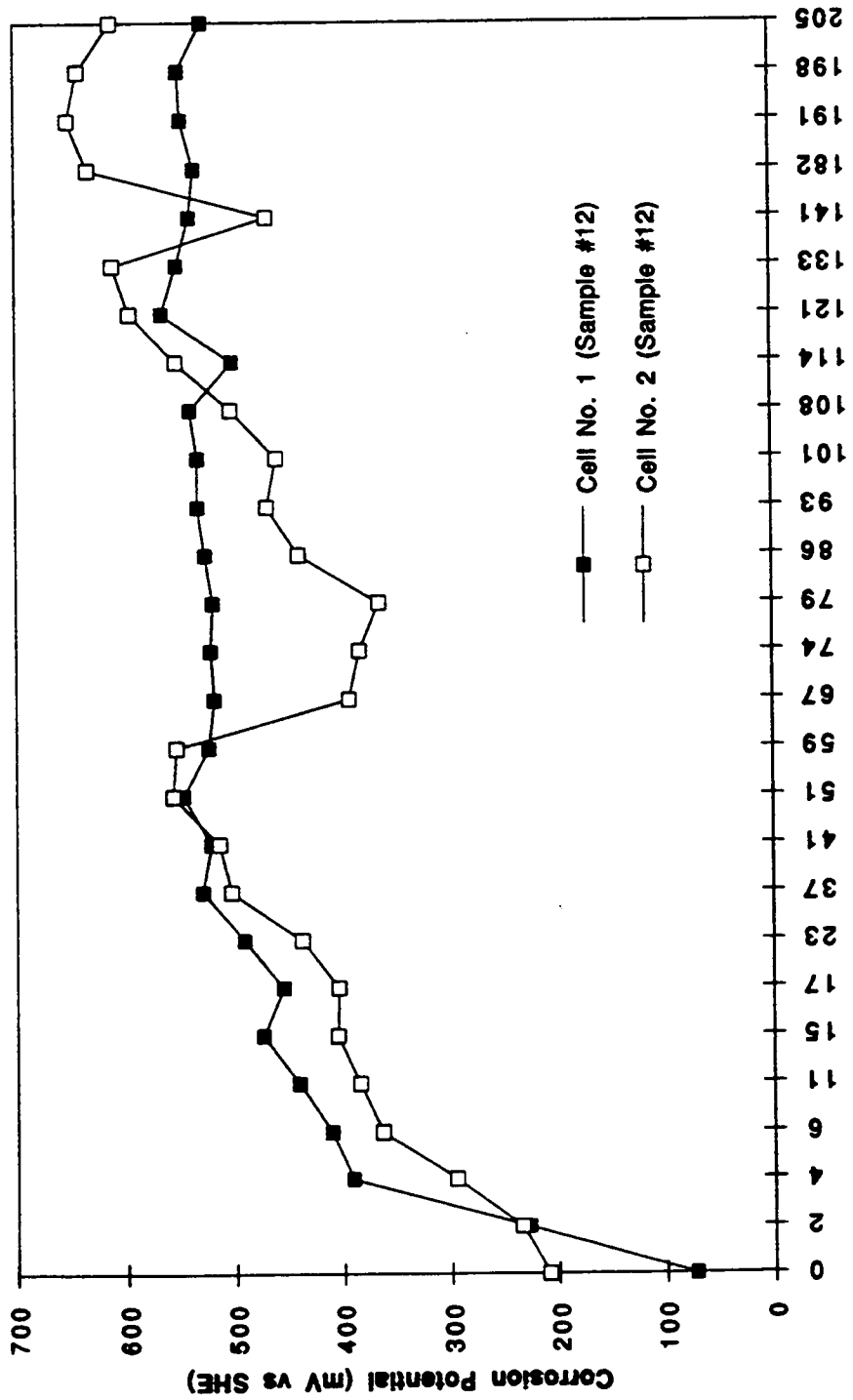


Figure 130. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons12-7 and 12-8.

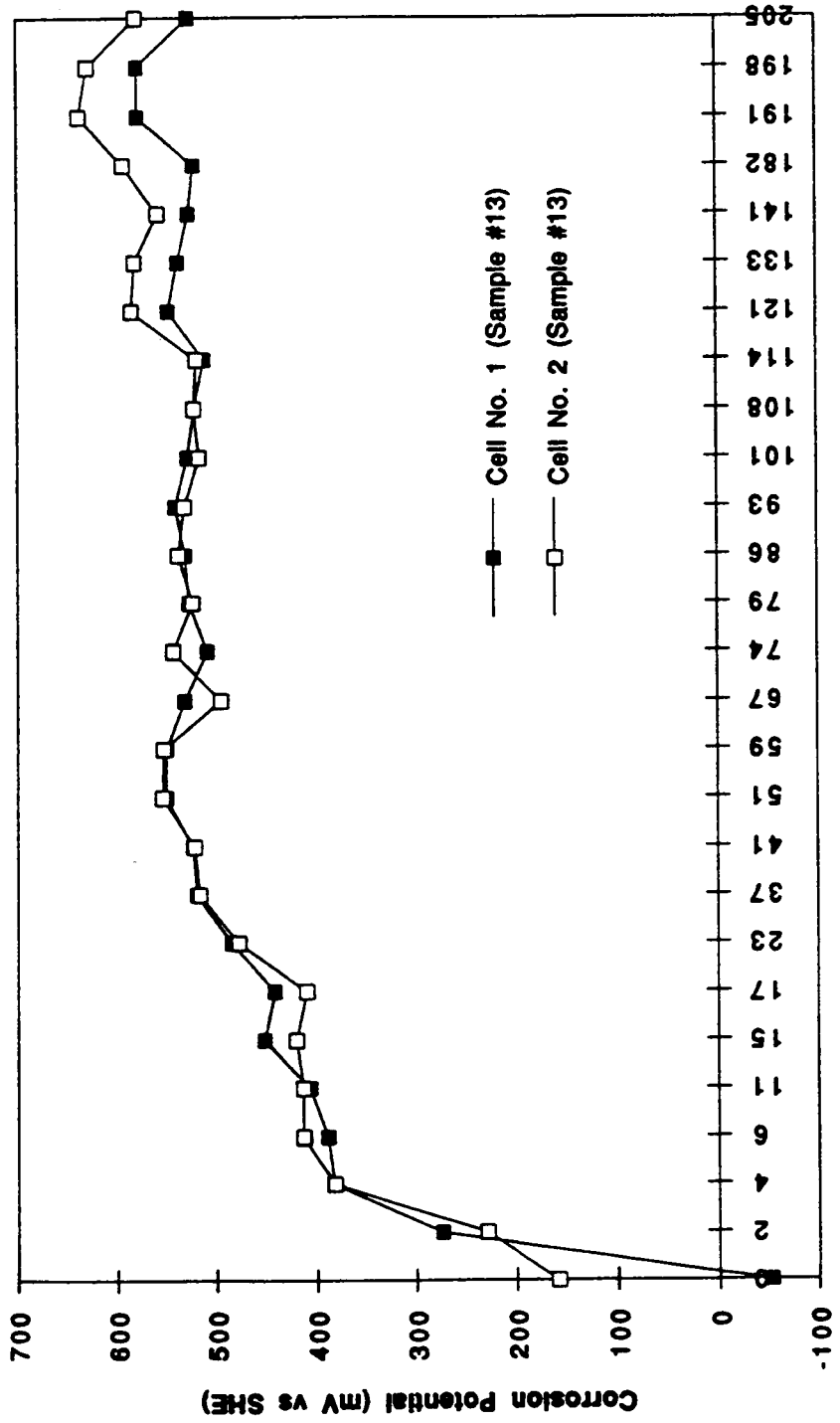


Figure 131. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 13B-5-20 and 13B-5-21.

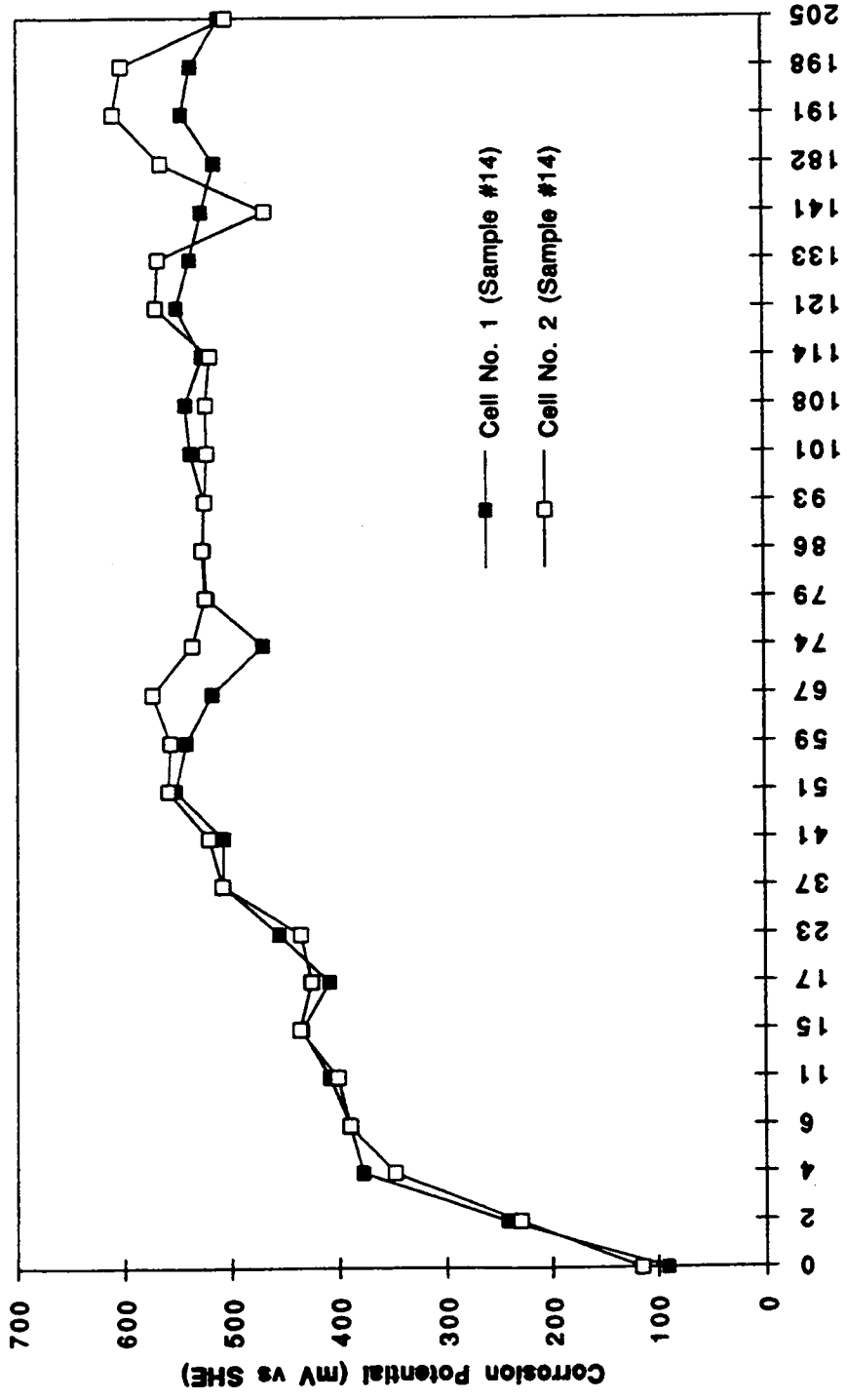


Figure 132. Open-Circuit Potentials vs Time while exposed to Guadalupe River Water for Coupons 14B-5-22 and 14B-5-23.

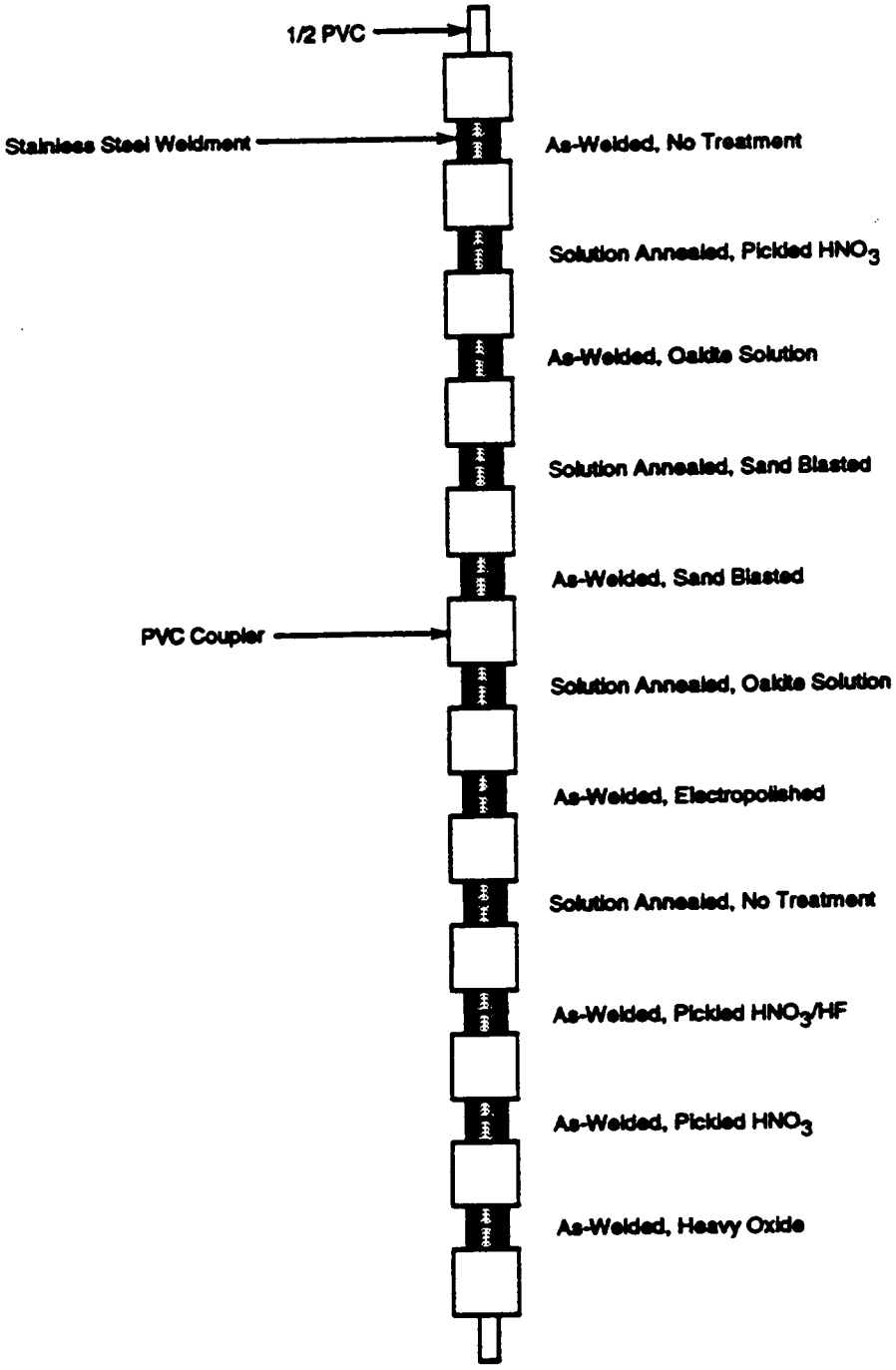


Figure 133. Schematic of pipe string assembly installed at the Guadalupe River Site.

APPENDIX C

NiDI

Avery Consulting Associates, Inc.
117 Winterwood Drive
Londonderry, NH 03053
Tel. (603) 434 2625
FAX (603) 425 2542

Nickel
Development
Institute

To: A. H. Tuthill

From: R. E. Avery

Subject: Pipe Welding at Douglas Bros. for the MIC Program at University of Tennessee

Date: December 7, 1990

cc: REB, JHL, MOP - NiDI
Joseph Danko, Carl Lundin - U.T.
Dan Caputo, Cliff Anderson - Douglas Bros.

Summary of Pipe Welding at Douglas Bros. - On November 28 and 29, Douglas Bros. provided, at no charge, the manpower and facilities to make 13 butt welds in 12 " diameter schedule 10 pipe. We are grateful to Dan Caputo, President, Cliff Anderson, Technical Director, Rudy Kaserman, Shop Superintendent and their two, most cooperative, welders.

The welds were made manually, under typical shop conditions such as used for commercial piping systems in water treatment, waste water treatment and similar plants. The standard practice with Douglas Bros. is to use a tight butt (no gap) weld joint. However, in order to evaluate a number of variables in the MIC testing program, it was necessary to make most of the welds with a 3/32" gap. Using the "gap" joint and essentially the same purging practice employed on a "no gap" joint, possibly explains the ID root pass heat tint on some of the welds. See Tables I and II for a summary of the welding procedures and comments on each weld.

Welding Details - Additional comments that may be useful to U. T. in sample preparation follows.

1. Marking Identification on the Pipe - One end of each pipe was marked to indicate the start of the root pass, direction of travel and a "T" to locate each tack weld.

2. Joint Preparation - Bevels were made with a hand grinder which is standard shop practice. The bevel and land were sufficiently uniform for a manual root but possibly not if automatic root pass welding had been used. Grinding burrs were removed by a file. The pipe was quite round and there was a good match on the OD and ID.

3. Fitup and Tacking - Joints were tacked at 7 or 8 locations with an argon purge flowing during tacking. In root pass welding, a 3/32" gap was maintained until the point between the last tack and the weld start when it closed to about 1/16".

4. Purging - Standard aluminum disk baffles with rubber gaskets were used with flow rates of 50 to 60 cfh. Joints were taped and the tape pulled back in advance of the weld. The purge system was quite adequate for the "no gap" joint but with a gap, there were varying degrees of ID heat tint.

5. Root Welding - The pipes were rotated on turning rolls so that all welding was down hand. One welder made all the Tig root welds. We tried to add a healthy amount of filler metal but it is hard to estimate by observing, how much of the root pass came from filler metal. There was no welding done to the inside root, e.g., to correct any rough spots.

6. Filler Metals - The Tig filler metal was furnished by Teledyne McKay, a copy of their test report is attached. We purchased Type 308L and 316L, 3/32" diameter, Sandvik Spray Arc covered electrodes for the fill passes. However, Douglas Bros. 1/8" diameter Sandvik Spray Arc was substituted to save time on all welds except numbers 9 and 13.

7. Photographs - A number of 35 mm slide photos were taken of the ID roots and general views of the welding. However, the ID shots were taken from the end of the pipe and U. T. will be able to take better pictures to record the root appearance once the pipes are cut longitudinally.

TABLE I
Initial Test Pipe Welds for MIC Investigation

Weld	Pipe Material	Filler Metal	Gap (in.)	Penetration	Pipe Treatment	Remarks
1	304L	308L	3/32	Full	None	Reference or Base Case
2	304L	308L	3/32	Full	Pickle ID Surface	Surface Studies
3	304L	308L	3/32	Full	Electropolish ID Surface	Surface Studies
4	304L	308L	3/32	Full	1900°F Solution Anneal Water Quench	Effect of Heat Treatment
5	304L	308L	3/32	Full	Grind off Reinforcement	Surface Studies
6	304L	316L	3/32	Full	None	Filler Material Evaluation
7	304L	304L	3/32	Full	Remove ID Purge after Root Pass	Surface Studies
8	304L	None	None	Full	Fuse Root Pass	Surface Studies
9	304L	None	None	Incomplete	None	Evaluate Effect of Creviced ID
10	304L	308L	3/32	Full	No ID Purge	Surface Studies
11	316L	316L	3/32	Full	None	Reference or Base Case
12	316L	None	None	Full	Fuse Root Pass	Surface Studies
13	316L	None	None	Incomplete	None	Evaluate Effect of Creviced ID
14	316L	316L	3/32	Full	Remove ID Purge after Root Pass	Surface Studies

TABLE II
Comments on Welding of Initial Test Pipe Welds for MIC Investigation

Weld	Comments on Welding and Weld Appearance
1	Base Case Weld - ID heat tint varying from 3/4 to 1 1/4" wide in 30% of circumference. 70% fairly free for ID oxide. This weld and all others except No. 9 and 13 were filled with 1 pass of 1/8" covered electrodes.
2 - 5	ID roots were all similar to weld 1, with some areas of more pronounced heat tint.
6	316L root and fill filler metal. Root weld metal appeared to have had less oxide than 1-5 made with 308L.
7	Purge removed after root pass to give oxidized root. Dark, fairly heavy but tight oxide formed on the weld. No "sugar" oxide.
8	Tight butt, no filler metal added on root pass. ID quite free of heat tint.
9	Light butt. Land increased and weld travel increased to give lack of fusion. Obtained lack of fusion except at some tacks. Very little heat tint. Fill weld made with 3/32" dia. electrode.
10	Weld not made because of insufficient material.
11	Root appearance similar to weld 6 also made with 316L filler metal.
12	Same heat tint, typical of most 304L welds.
13	Root appearance like weld 9.
14	Modified procedure by removing purge in making the last 1/4 of the root pass plus all of the fill pass. Root section with not purge had crusty, "sugary" oxide. Other portion similar weld 7.

Trent Tube A Division of Crucible Materials Corp. — SHIPPING NOTICE

TRENT TUBE
CARROLLTON PLANT
2188 CHURCH ST.
EAST TROY, WI 53120

CUSTOMER ORDER NO.	CPO. DATE	RATING	S C	ENTRY DATE	SHIP	MARKS	MILL ORDER NO.
SAMPLE				92090		M	2T3-51548-0
TUTBLAA				DOUPORB		C	

SOLD TO: TUTHILL ASSOCIATES, INC.
PO BOX 204
BLACKSBURG, VA 24060

SHIP TO: DOUGLAS BROTHERS
RIVERSIDE INDUSTRIAL PWKY
1039 RIVERSIDE STREET
PORTLAND, ME 04104

SPECIAL INSTRUCTIONS: Area C

10 | 240 9 | SHIPPING NOTICE

12750 180 M 100000 4 130 | 24.391 LB/FT SOURCE
12 108 10 - FT RML
FULL FINISHED ANNEALED & PICKLED
TRENTWELD STAINLESS PIPE
ASTM A312 ASME SA312
316L

10 FT / LBS / PCS — QUANTITY ORDERED
9/20/90 WANTED
9/24/90 PROMISED

FEET	12.833
NET	315
PCS	1
GROSS	325
Boxes	1
Complete Shipment	
B/L MC-40065-01	
DATE	25-SEP-90
CAROLINA	PPD

HEAT # 910229

Source: C303113

PACKING TALLY

BDL	LOT #	PIECES	FOOTAGE	GROSS	TARE	NET	HEAT #
1		1	12.833	325	10	315	910229
TOTAL		1	12.833	325	10	315	

REPORT OF TESTS

CHEMICAL ANALYSIS

HEAT #	C	MN	P	S	SI	NI	CR	MO	CU	N	CO
910229	.014	1.69	.032	.018	.61	10.15	16.32	2.07	.50	.033	.15

Mechanical and NDE Tests

HEAT #	FLAN	FLAT	FLAR	RFLT	RBND	BEND	EDDY	UT	XRAY	DYPN	HYDRO	AIR
910229		OK									350	

HEAT #	LOT #	TENSILE	YIELD	ELON	HARDNS.	ID	RMS OD GRAIN	CORROSION TEST	CORROSION VALUE
910229		83,600	48,100	49 %					

We Hereby Certify This Report To Be True and Correct
According To The Records in Possession of this Corporation.
TRENT TUBE DIVISION - CRUCIBLE MATERIALS CORPORATION

Signed: M. E. Neuron Dated: 9-25-90

kx

Trent Tube
A Division of Crucible Materials Corp

SHIPPING NOTICE

TRENT TUBE
CARROLLTON PLANT
2188 CHURCH ST.
EAST TROY, WI 53120

CUSTOMER ORDER NO.	CPD. DATE	RATING	ENTRY DATE	SHIP	MARKS	MILL ORDER NO.
MDLE			92090		M	7T3-51547-0
TUTBLAA			DCUPORB		C	

SOLD TO: TUTHILL ASSOCIATES, INC.
PO BOX 204
BLACKSBURG, VA 24060

SHIP TO: DOUGLAS BROTHERS
RIVERSIDE INDUSTRIAL PWKY
1039 RIVERSIDE STREET
PORTLAND. ME 04104

SPECIAL INSTRUCTIONS: Area C

10 | 240 9 F.O.B. S/P | SHIPPING NOTICE

TERMS: 30-15-10

12750 180 M 100000 2 130 | 24.391 LAST SOURCE
12 108 10 - FT RML

11 FT / LBS / PCS — QUANTITY ORDERED

AS WELDED ANNEALED & PICKLED
TRENTWELD STAINLESS PIPE
ASTM A312 ASME SA312
304L
MARKED 'FOR MIC TEST PROGRAM AT UT"
TAG: ATTN: MR. CLIFF ANDERSON
HEAT # 910427

9/20/90 WANTED
9/24/90 PROMISED

FEET	10.583
NET	250
PCS	1
GROSS	260
Boxes	1
Complete Shipment	
B/L MC-40065-02	
DATE	25-SEP-90
CAROLINA	PPD

Source: C303112

PACKING TALLY

BDL	LOT #	PIECES	FOOTAGE	GROSS	TARE	NET	HEAT #
1		1	10.583	260	10	250	910427
TOTAL		1	10.583	260	10	250	

REPORT OF TESTS

CHEMICAL ANALYSIS

HEAT #	C	MN	P	S	SI	NI	CR	MO	CU	N	CO
910427	.014	1.68	.032	.011	.59	8.78	18.38	.28	.27	.075	.12

Mechanical and NDE Tests

HEAT #	FLAN	FLAT	FLAR	RFLT	RBND	BEND	EDDY	UT	XRAY	DYPN	HYDRO	AIR
910427		OK									350	

HEAT #	LOT #	TENSILE	YIELD	ELON	HARDNS.	ID	RMS OD	GRAIN	CORROSION TEST	CORROSION VALUE
910427		83,900	42,800	50 %						

REMARKS

TAG: ATTN: MR. CLIFF ANDERSON

We Hereby Certify This Report To Be True and Correct
According To The Records in Possesion of this Corporation.
TRENT TUBE DIVISION - CRUCIBLE MATERIALS CORPORATION

Signed: M. E. Pearson Dated: 9-25-90

TELEDYNE MCKAY
P. O. BOX 1509
YORK, PA. 17405-1509

MATERIAL TEST REPORT

DATE: 09/25/90

R & D
SAMPLE ACCOUNT
850 GRANTLEY RD. PO BOX 1509
YORK, PA 17405-1509

CUST. ORDER # N/C SAMPLE
MARKED FOR...
MCKAY ORDER NO.... 37715-01
DATE SHIPPED..... 09/25/90

MATERIAL DESCRIPTION AND SPECIFICATIONS

ITEM	WEIGHT	SIZE	CLASSIFICATION	MCKAY DESIGNATION
01	20	3/32	ER308L	BARE WIRE 308L
02	20	3/32	ER316L	BARE WIRE 316L

ITEM	HEAT NO.	LOT NO.	BATCH NO.	SPECIFICATION
01	PB932	2502950		AWS A5.9-81; ASME SFA5.9
02	26568	2704445		AWS A5.9-81; ASME SFA5.9

ACTUAL CHEMISTRY:

ITEM	C	MN	P	S	SI	CR	NI	MO	N	CB
01	.010	1.730	.020	.009	.430	19.860	9.700	.190	.044	.010
02	.019	1.700	.018	.002	.500	19.170	12.790	2.180	.047	.010

ITEM	V	CU	H2O	TI	AR	CO	AS	SN	SB	W
01		.190								
02		.110								

FERRITE(S):

ITEM	WRC	DELONG	SCHAEFFLER
01		12.5	
02		7.3	

WE HEREBY CERTIFY THAT THE ABOVE PRODUCT HAS BEEN CLASSIFIED IN ACCORDANCE WITH THE LISTED SPECIFICATIONS AND CONFORMS TO ALL APPLICABLE REQUIREMENTS THEREOF.

L. T. Finch

AUTHORIZED SIGNATURE

Brismet
America's Leader in Stainless Steel Piping

WALTER R. RENTON
Product Manager - Special Alloys

BRISTOL METALS, INC.
Subsidiary of Synalloy Corporation
Post Office Box 1589
Bristol, Tennessee 37621
Tel.: 615/989-4700
Telefax #: 615/968-3205

America's Leader in Stainless Steel Piping

P. O. Box 1589
Bristol, Tennessee 37621-1589
Phone 615-968-2151
TWX 510-573-9042
FAX 615-968-3205

June 25, 1992

Tuthill Associates, Inc.
P. O. Box 204
Blacksburg, Virginia 24060

Re: Heat No. 710232 - 2-1/2" Sch. 10s Type 304L

ATTENTION: Mr. Arthur H. Tuthill

Dear Arthur,

Enclosed are three (3) copies of the above test report you requested from Joe via fax of June 23. Should you need additional information for your test program, please let me know.

I have also enclosed my business card for your records. My specific responsibility is to market and develop additional special alloys - (duplex, nickel, etc.) and I am sure at some future date we will have additional contact.

Very truly yours,

Walter R. Renton
Product Manager - Special Alloys

WRR:jlc

Encl. 3

BRISTOL METALS INC.
MILL TEST REPORT

TO: BRISTOL METALS INC
P O BOX 1589
BRISTOL TN
37620

CUST NO: 10700011
JOB NO: 3762H
PO NO: MTR'S
DATE: 06/24/92

HEAT NO. ITEM DESCRIPTION

710232 2 1/2" PIPE SCH 10S 304L ASTM A312-91B/ASME SA312,WELDED

HEAT NO.	C	MN	P	S	SI	NI	CR
710232	.010	01.700	.031	.012	.57	08.700	18.370

HEAT NO.	MO	CU	CO	N2	TENSILE	YIELD
710232	0.28	.28	.14	.067	85,680	38,400

HEAT NO.	HARDNESS	ELONGATION	BEND	FLATTENING	TENSION
710232	RB83	50.00 %	NA	OK	OK

	FLANGE	FLARE	EDDY CURRENT	HYDRO
	NA	NA	NA	1000. PSI

HEAT NO.	ANNEALED AT 1950 DEG. F. AND WATER QUENCHED	RADIOGRAPHIC EXAMINATION COMPLETED
710232	YES	NA

WE CERTIFY THIS REPORT TO BE TRUE AND ACCURATE, ACCORDING TO OUR RECORDS ON FILE.

BRISTOL METALS INC.

John Eaton

REPRESENTATIVE

ABB
ASEA BROWN BOVERI

CHEMICAL ANALYSIS REPORT

C-E LAB NO.: P31087
DESCRIPTION: University of Tennesse - Dept. of Materials Science
Type 304L Stainless Tubing (LPO-13223)

Carbon	0.017
Manganese	1.75
Phosphorus	0.029
Sulfur	0.012
Silicon	0.60
Nickel	8.72
Chromium	18.25
Molybdenum	0.28
Vanadium	0.06
Columbium	0.01
Titanium	0.01
Cobalt	0.13
Copper	0.28
Aluminum	0.006
Boron	<0.001
Nitrogen	0.066

REPORTED BY : _____
July 23, 1992

ABB C-E Power Products Manufacturing

Combustion Engineering, Inc 1119 Riverfront Parkway Chattanooga, Tennessee 37402 Telephone (615) 752-9840 Fax (615) 756-2288

TUTHILL ASSOCIATES INC.
P.O. BOX 204
2903 WAKEFIELD DRIVE
BLACKSBURG, VA 24060
Tel: (703) 953-2626 Fax: (703) 953-2636

Jan. 9, 1991

Report: NIDI RD 90-6 Jan. 8, 1991 Meeting at UT

Present: Drs. Ray Buchanan, Joe Danko, Nick Dowling, Eugene Stansbury and Jean Guezennec and Kameel Al-ejel (welding) and Ping Li (Corrosion) from UT, and A. H. Tuthill representing NIDI.

Status: Welded pipe sections have been received from Douglas Brothers and characterization studies have been completed.

Base plate type 304L: Few inclusions well distributed #3 GS
Type 316L: Few inclusions well distributed #8 GS
light banding in direction of rolling
Welds: 304L and 316L with and without filler
sound normal structure.
Ferrite number 304L -0-, Long. weld 1.75, Butt weld 1
316L 0.25-0.5, Long. weld 1, butt weld 6.5
Hardness 304L 81.3 RB
316L 78.7 RB

Electrochemical cell design for laboratory and concurrent Tennessee River water tests under low to no flow conditions - completed, ready for fabrication. Actual site for Tennessee River water tests under active investigation. Criteria avoid excessive algae formation.

Arizona Test site: Dr. Danko will meet with APS week of Jan. 14. Dr. Dowling agreed to a target date of Feb. 5, 1991 for installation of test cell to mesh with AHT's Denver visit on Feb. 4, 1991. This is a tight schedule but may be possible.

Buchanan will proceed with fabrication of electrochemical test cell and initial trial runs with a target date of Feb. 15, 1991 for starting initial laboratory test. Buchanan and Dowling will select Tennessee River water test site with target date for start of test of Feb. 22, 1991.

Lundin and Al-jel will start cutting specimens from 12" welded pipe to meet these target dates.

Arthur H. Tuthill
Consultant to NIDI

cc UT
NIDI
EPRI
Advisory Group
File: RUTMIC2

APPENDIX E

THE UNIVERSITY OF TENNESSEE
KNOXVILLE

Center for Environmental Biotechnology
University of Tennessee / Oak Ridge National Laboratory
10515 Research Drive, Suite 300
Knoxville, TN 37932-2575
(615) 974-8030
FAX (615) 974-8086

July 28, 1993

To: Peter Angell
From: D. Ringelberg
Re: Lake Loudon Samples (LLBL and LLBR)

The two samples showed a considerable difference in the amount of PLFA each contained when normalized to the gram weight extracted. Sample BR contained 2.5 times more PLFA than sample BL.

The two samples showed similar community structures (fig.1) based on a comparison of the relative percentages of specific groups of PLFA (described earlier). There appeared to be subtle differences in the levels of terminally branched saturates and polyenoics.

(Of course, without replication, there is no way to determine if the differences are significant. Assuming the samples to be representative of the place they came from and that the place is homogenous with respect to community structure (PLFA distribution) the differences may be related to either microbial or eukaryotic community shifts.)

Figs.2 and 3 illustrate a comparison of the individual PLFA making up the total presented in fig.1 for the terminally branched and polyenoic PLFA, respectively. Higher percentages of i15:0, a15:0 and a16:0 were observed in sample BR while sample BL showed a greater percentage of a17:0. i and a15:0 are major PLFA in the cell membranes of a number of gram positive bacteria but are also found in SRB's and actinomyces. a17:0 is also commonly found in gram positives and is a prominent (5-8%) PLFA in some Desulfovibrio species. Sample BL also showed a higher percentage of i17:1w7c which is also indicative of Desulfovibrio's.

The PLFA profiles, on whole, showed a diverse bacterial community. The two most prominent PLFA detected were 16:1w7c and 18:1w7c which are both terminal points in anaerobic desaturation, a fatty acid biosynthetic pathway utilized by numerous gram negative bacteria.

Fig.3 illustrates the polyenoic distribution between the two samples. Sample BL contained higher percentages of all of the polyenoics detected indicating a greater eukaryotic input. What the source of the input is can't be determined from the limited amount of data obtained here.

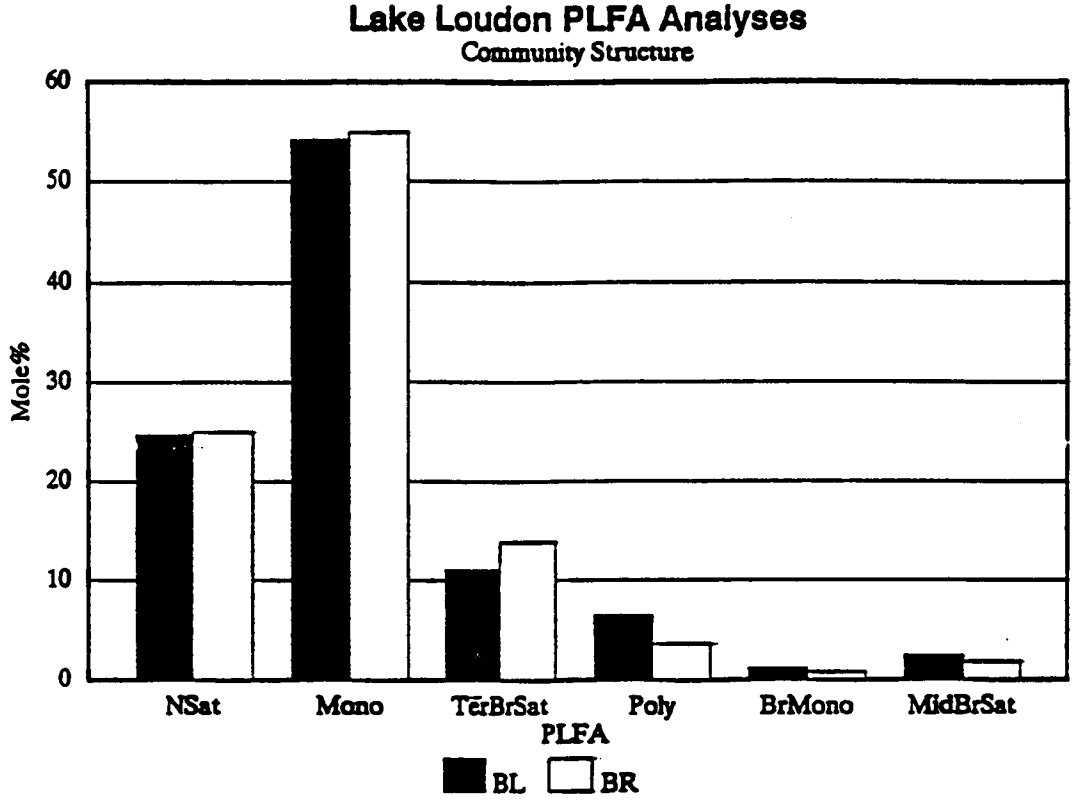
The two samples also showed differences in the levels of stress ratios. Higher cyclopropyl to monoenoic ratios were observed in sample BR (greater biomass) suggesting an "older" microbial population was present and higher trans/cis ratios were observed in sample BL (lower biomass) suggesting the microbial community in this sample was either exposed to a xenobiotic or nutrient deprivation. Of course, their could be other environmental factors involved.

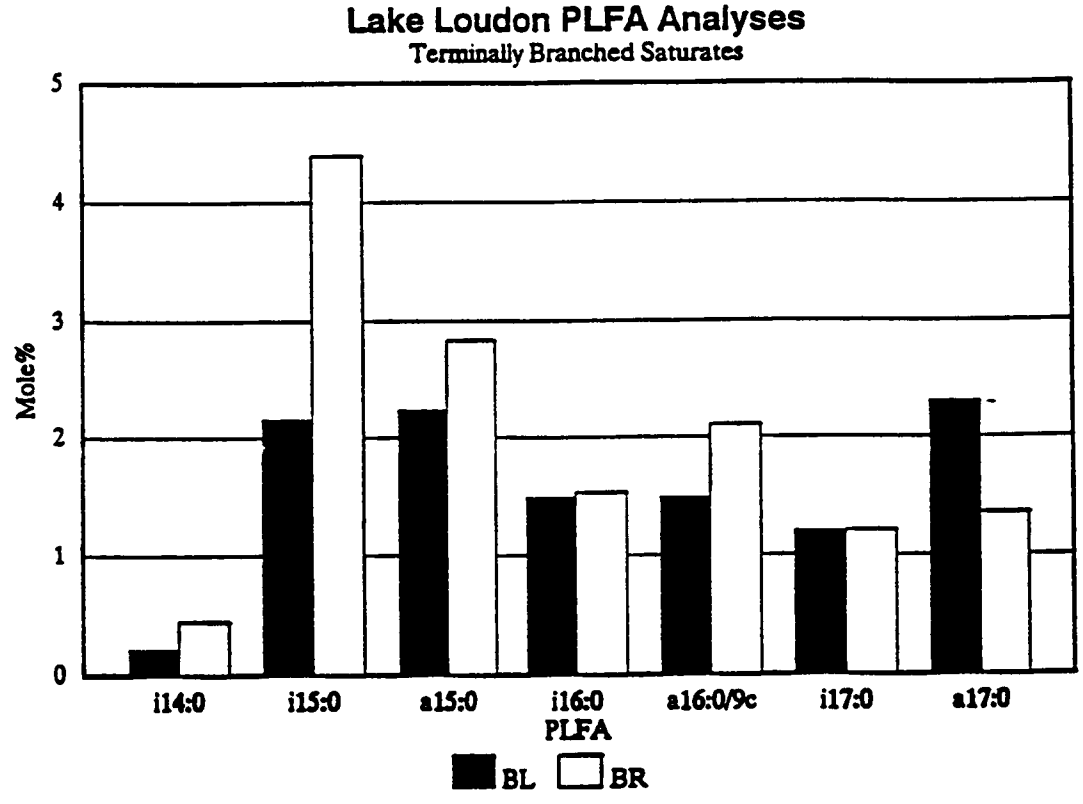
Lake Loudon Filter PLFA Analyses
July 27, 1993

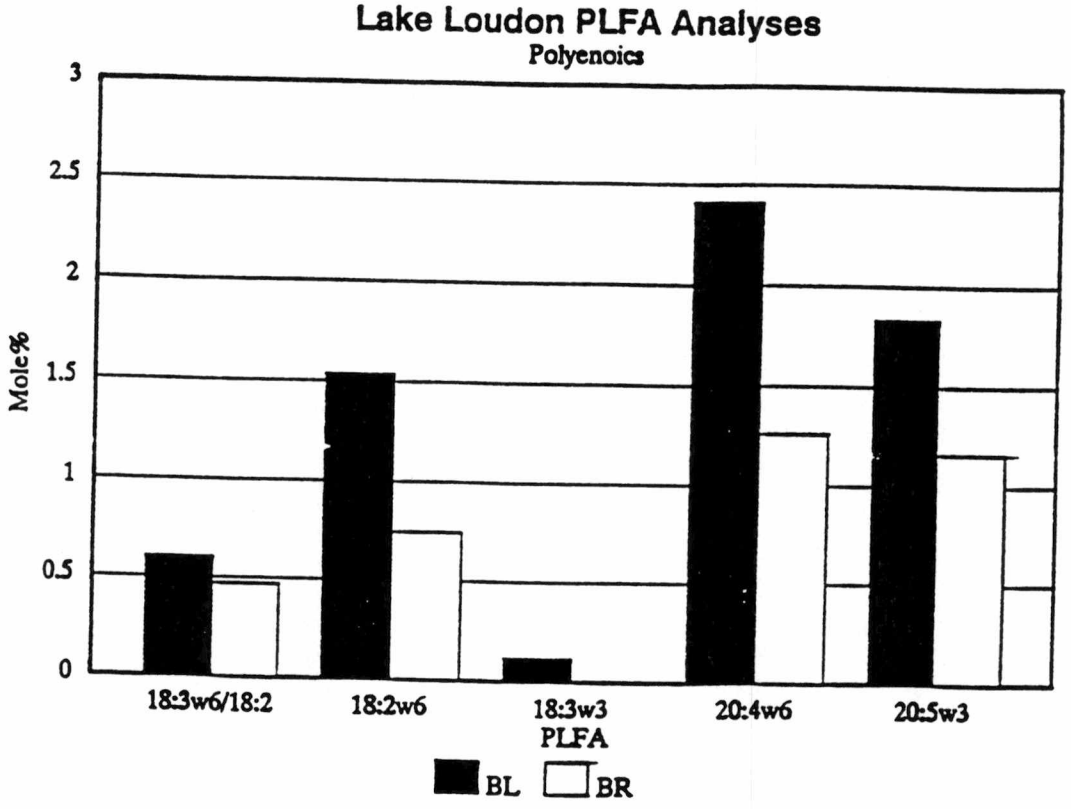
PLFA	BL	BR
Normal Saturates (NSats)		
14:0	0.60	1.40
15:0	0.88	0.82
16:0	15.86	19.19
17:0	2.24	0.82
18:0	3.87	2.29
20:0	1.39	0.46
TOTAL	24.85	24.98
Monoenoics (Monos)		
16:1w7c	15.81	23.62
16:1w7t	3.27	1.09
16:1w5c	4.17	4.36
17:1w6c	0.87	0.49
cy17:0	1.73	4.70
18:1w9c	5.75	3.35
18:1w7c	14.73	12.65
18:1w7t	1.37	0.45
18:1w5c/phytol	4.53	1.92
br18:1	0.73	0.72
cy19:0	1.38	1.55
TOTAL	54.15	54.91
Terminally Branched Saturates (TerBRSats)		
i14:0	0.21	0.45
i15:0	2.15	4.39
a15:0	2.23	2.84
i16:0	1.49	1.53
a16:0/9c	1.49	2.11
i17:0	1.20	1.21
a17:0	2.30	1.36
TOTAL	11.06	13.88
Polyenoics (Polys)		
18:3w6/18:2	0.60	0.47
18:2w6	1.54	0.74
18:3w3	0.12	0.00
20:4w6	2.41	1.26
20:5w3	1.83	1.16
TOTAL	6.50	3.63
Branched Monoenoics (BrMonos)		
i17:1w7c	1.17	0.80
Mid-chain Branched Saturates (MidBrSats)		
10me16:0	1.60	1.51
10me18:0	0.86	0.30
TOTAL	2.46	1.80
Total Mole%	100	100

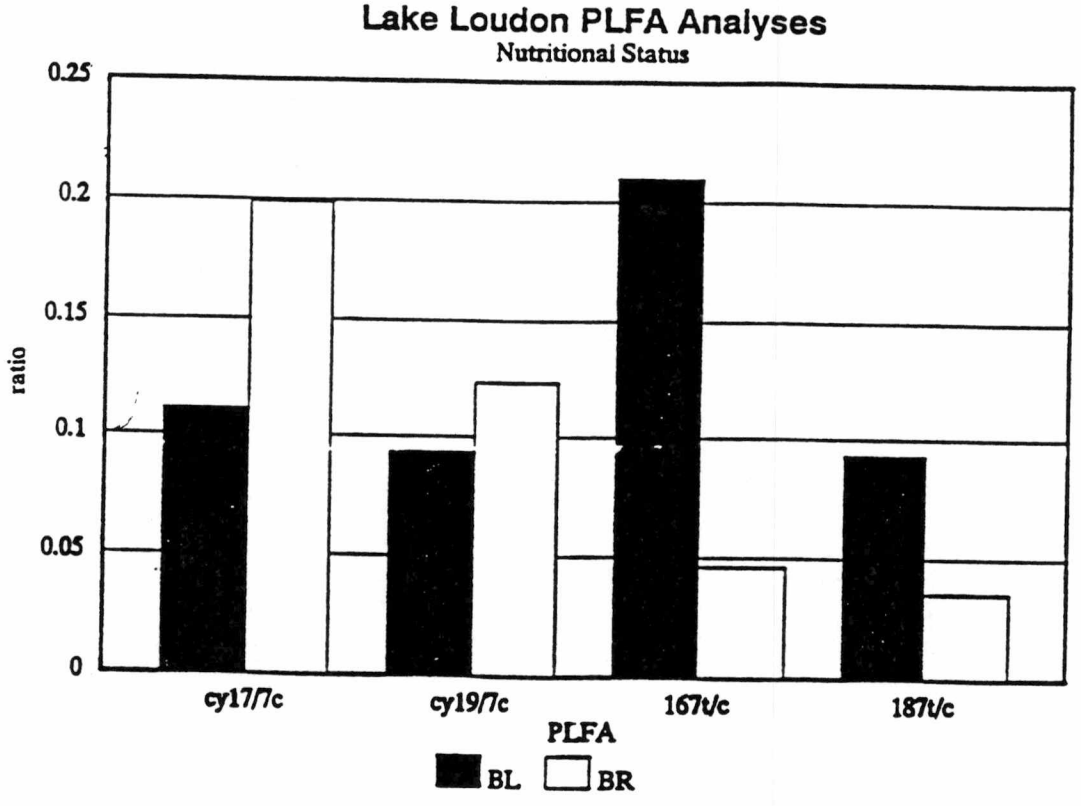
Biomass Estimates		
pmol/gdw	63526	162649

Nutritional Status		
cy17:0/16:1w7c	0.11	0.20
cy19:0/18:1w7c	0.09	0.12
16:1w7t/16:1w7c	0.21	0.08
18:1w7t/18:1w7c	0.09	0.04


Lake Loudon PLFA Analyses
Community Structure
60
50
40
30
20
10
0
Mole%
NSat
Mono
TerBrSat
Poly
BrMono
MidBrSat
PLFA
BL
BR


Lake Loudon PLFA Analyses
Terminally Branched Saturates
5
4
3
2
1
0
Mole%
i14:0
i15:0
a15:0
i16:0
a16:0/9c
i17:0
a17:0
PLFA
BL
BR


Lake Loudon PLFA Analyses
Polyenoics
Mole%
3
2.5
2
1.5
1
0.5
0
18:3w6/18:2
18:2w6
18:3w3
20:4w6
20:5w3
PLFA
BL
BR


Lake Loudon PLFA Analyses
Nutritional Status
ratio
0.25
0.2
0.15
0.1
0.05
0
cy17/7c
cy19/7c
16?t/c
18?t/c
PLFA
BL
BR

THE UNIVERSITY OF TENNESSEE
KNOXVILLE

Center for Environmental Biotechnology
University of Tennessee/Oak Ridge National Laboratory
10515 Research Drive; Suite 300
Knoxville, TN 37932-2575
(615) 974-8030
FAX (615) 974-8086

June 22, 1993

To: Peter Angell
From:
Re:

Lake Loudon Filter PLFA Analyses

Three sets of filters exposed to Lake Loudon waters were extracted for PLFA content. One filter was labelled LL422a, one was labelled LL422b and the other was a combination of three filters with no label which was given the name "Combo". Sample LL422b showed no detectable PLFA and as a result has been omitted from the discussions below. The results of the analyses are expressed in Table 1 and Figure 1.

Table 1 lists the individual PLFA detected per sample grouped according to structure and expressed as a molar percentage. At the bottom of the table are two boxes: one containing biomass estimates as total recovered PLFA as pmol/sample (since no known volume of water filtered was available) and the other containing specific ratios of PLFA known to be related to microbial nutritional status. Biomass levels were considerably higher in the Combo sample likely due to there being three filters extracted versus only one filter for the LL42a sample. Little information regarding microbial nutritional status could be deduced from the data due to the lack of detection of cyclopropyl and trans fatty acids in the LL42a sample. The combo sample showed a high (>0.1) 16:1w7t/7c ratio as well as a considerable amount of cy19:0 (6.68%) both of which (if from a microbial source) would indicate stressed organisms.

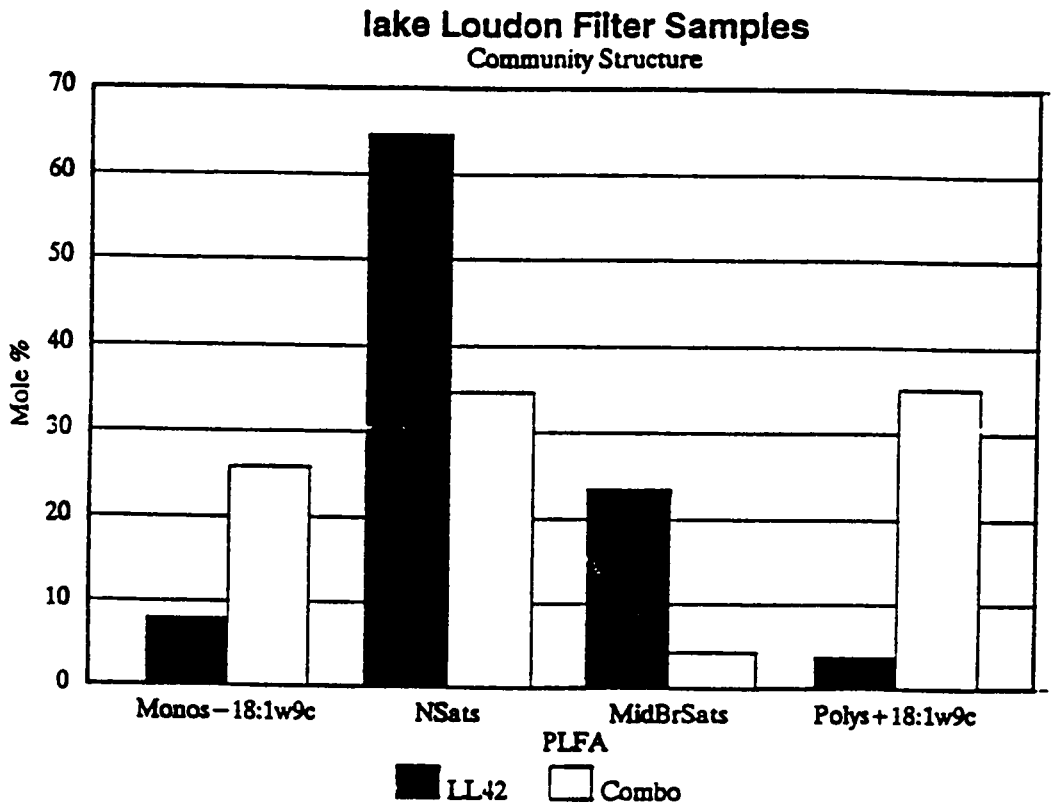
The PLFA profiles obtained from each sample were significantly different (fig 1). Levels of monoenoics and polyenoics were higher in the combo sample while saturates (both normal and mid-chain branched) were higher in the LL42a sample. The profile obtained for sample Combo indicates a strong eukaryotic presence. 43% of the profile was made up of 16:1w13t (photosynthesis), 18:1w9c (precursor for polyenoic formation) and polyenoics. The likely input of these PLFA would be Diatoms (20:4w6 and 20:5w3). The only indication of bacteria in the sample was the presence of the 16 carbon monoenoics and cy19:0. If these fatty acids are from a bacterial source (16:1w7c is also synthesized by Diatoms), they would indicate the presence of gram negative type organism like a Pseudomonas. Sample LL42a contained no detectable polyenoics or 16:1w13t but did contain a series of 14, 16,18 and 20 carbon monoenoics which may have originated from a microbial source (specifically 16:1w7c and 18:1w7c). This sample also contained mid-chain branched saturates which are known to be synthesized by certain soil microorganisms. However, the lack of terminally branched saturates in association with the mid-chain branched saturates raises the possibility of "contamination" probably from the filter or the handling process (see note at the bottom of table 1). To eliminate this possibility, filter blanks could be run through the assay.

Let me know if you have any questions or if you require any additional information.

Lake Loudon Filter Samples
PLFA Analyses

PLFA	ECL	LL422a	Combo
Monoenoics (Monos)			
14:1w7c	13860	0.67	0
16:1w7c	15729	3.06	2.89
16:1w7t	15802	0	4.86
16:1w5c	15829	0	3.55
16:1w13t	15920	0	7.89
cy17:0	16811	0.54	0
18:1w9c	17692	3.77	16.34
18:1w7c	17763	2.32	0
cy19:0	18821	0	6.68
20:1w7c	19760	1.38	0
Total		11.74	42.20
Normal Saturates (NSats)			
16:0	16000	11.84	10.33
18:0	18000	13.41	14.54
20:0	20000	6.33	4.84
21:0	21000	0	4.96
22:0	22000	12.82	0
23:0	23000	7.15	0
24:0	24000	13.15	0
Total		64.71	34.67
Mid-Chain Branched Saturates (MidBrSats)			
br17:0	17052	2.99	0
10me18:0	18397	0	4.28
br18:0		2.62	0
br20:0		4.98	0
br21:0a		3.84	0
br21:0b		5.44	0
br24:0		3.67	0
Total		23.55	4.28
Polyenoics (Polys)			
18:2w6	17584	0	4.67
20:4w6	19132	0	8.17
20:5w3	19186	0	6.01
Total		0	18.85
Total Mole %		100.00	100.00
Biomass Estimates			
pmol PLFA/sample		110	6734
Nutritional Status			
cy17:0/16:1w7c		0.18	0
cy19:0/18:1w7c		0	0
16:1w7t/16:1w7c		0	1.88

Note: Both filters were very wet and stuck to the foil.
Buffer was used to wash the foil.


lake Loudon Filter Samples
Community Structure
70
60
50
40
30
20
10
0
Mole %
Monos−18:1w9c
NSats
MidBrSats
Polys+18:1w9c
PLFA
LL42
Combo

Peter Angell Ph.D., BPc
Center for Environmental Biotechnology
10515 Research Drive, Suite 300;
Knoxville, TN 37932
(615) 974-8014 Fax (615) 974-8086

October 6, 1993

Dear Gary,

Here is a report on the culturing of the bacteria from the coupons exposed at Lake Loudon, two coupons were collected from each cell. In order to obtain enough biomas for the PLFA these were combined giving results for each cell. The biomas was extracted from four 1.32 cm^2 areas per coupon. The total extractant (phosphate buffer) used was 10 ml. The extraction was carried out by sonicating with three one second blasts, twice per spot.

The extracted material was serial ten fold diluted to 10^{-6} in phosphate buffer. These dilutions were then plated out on ½ strength nutrient agar using the Miles and Misera technique (6 x 20 μl drops per dilution). One set of these plates was incubated at 25 °C aerobically another was incubated at the same temperature in an anaerobic jar degassed with a Gaspak. SRB were enumerated using the MPN technique and "BP" medium, incubation again was at 25 °C.

The tube samples were swabbed (approx 1 cm^2) in the area of a tubercule and resuspended in 10 ml of phosphate buffer, which was then diluted and plated as described above.

The cells were designated the following numbers cell1 - cell1.1 & cell2 - cell2.1 for those removed on the first day and cell1.2 & cell2.2 for those removed on the second day.

Sample	aerobic ½NA	anaerobic ½NA	MPN (SRB)
cell1.1 (5)	OG	8.3 x10e2	no growth
cell1.1 (8)	OG	No growth	10e2
cell 2.1 (1)	OG	5 x10e3	10e2
cell 2.1 (2)	OG	4 x 10e4	10e2
cell 1.2 (6-4)	OG	No growth	
cell 1.2 (8-18)	OG	6 x 10e3	10e2
cell 2.2 (9-31)	OG	5 x 10e3	10e3
cell 2.2 (12-20)	OG	3 x 10e3	10e2
large tube	5 x10e4	4 x 10e4	10e2
small	5.2 x 10e4	3 x 10e6	10e2
large tube (NoP)	4.7 x 10e4	4 x 10e4	10e3

OG indicates plates were rapidly overgrown by an *Actinomycete* these are commonly found in soils etc and are currently the source of much interest due to their ability to produce antibiotics.

Center for Environmental Biotechnology
University of Tennessee/Oak Ridge National Laboratory
10515 Research Drive, Suite 300
Knoxville, TN 37932-2567
615-974-8030
FAX 615-974-8086

October 7, 1993

Lake Loudon Filter PLFA Analyses

Four filter samples were assayed for PLFA content. The results are illustrated in the attached table. Unfortunately, the resulting PLFA profiles are not indicative of a bacterial population. Two PLFA, 16:0 and 18:0, comprise @50% or greater of the total profile. These two acids are common to most microorganisms if not all.

Biomass levels were higher in the cell 2 samples although all of the samples contained less biomass than that observed in the procedural blank. The detection of i and a17:0 in the cell 2 sample may also indicate the presence of a sulfate reducer or other microorganism. In short, the PLFA profiles presented here are not indicative of bacterial biosynthetic pathways for fatty acid synthesis.

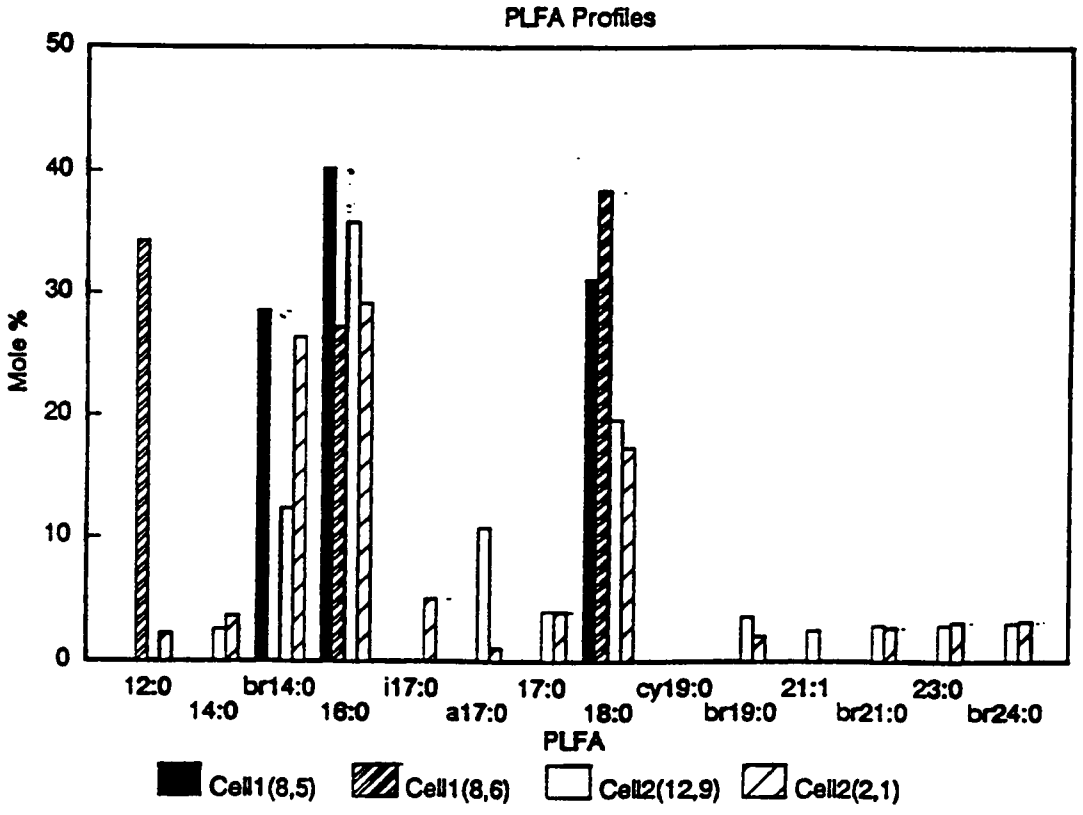
The high level of PLFA in the procedural blank (6.5 pmol/mL) is likely the result of a 10x concentrated solution of PO^4 buffer used in the initial recovery of the cells from the coupons. The concentrated buffer also influenced the behavior of the organic solvent extraction system used in recovering total lipids. To what extent the PO^4 influenced the extraction efficiency is unknown. Please keep this information in mind when interpreting this data.

Lake Loudon PLFA Data September 1993
Picomole Table
#picomole/ml buffer

PLFA	Cell 1 8 & 5	Cell 1 8-18 & 6-4	Cell 2 12-20 & 9-37	Cell 2 2 & 1	Buffer Blank
12:0	0.00	0.54	0.00	0.07	0.00
14:0	0.00	0.00	0.14	0.11	0.08
br14:0	0.48	0.00	0.67	0.76	0.24
16:0	0.67	0.43	1.93	0.84	1.40
i17:0	0.00	0.00	0.00	0.15	0.00
a17:0	0.00	0.00	0.58	0.03	0.00
17:0	0.00	0.00	0.22	0.11	0.00
18:0	0.52	0.61	1.06	0.50	1.65
cy19:0	0.00	0.00	0.00	0.00	3.16
br19:0	0.00	0.00	0.19	0.06	0.00
21:1	0.00	0.00	0.13	0.00	0.00
br21:0	0.00	0.00	0.16	0.08	0.00
23:0	0.00	0.00	0.16	0.09	0.00
br24:0	0.00	0.00	0.17	0.09	0.00
Total	1.67	1.59	5.40	2.88	6.53

Mole Percent Table

PLFA	Cell 1 8 & 5	Cell 1 8-18 & 6-4	Cell 2 12-20 & 9-37	Cell 2 2 & 1	Buffer Blank
12:0	0.00	34.34	0.00	2.27	0.00
14:0	0.00	0.00	2.57	3.66	1.16
br14:0	28.62	0.00	12.34	26.39	3.70
16:0	40.24	27.22	35.85	29.10	21.49
i17:0	0.00	0.00	0.00	5.04	0.00
a17:0	0.00	0.00	10.73	1.08	0.00
17:0	0.00	0.00	4.00	3.98	0.00
18:0	31.14	38.45	19.57	17.30	25.19
cy19:0	0.00	0.00	0.00	0.00	48.46
br19:0	0.00	0.00	3.58	2.05	0.00
21:1	0.00	0.00	2.49	0.00	0.00
br21:0	0.00	0.00	2.90	2.70	0.00
23:0	0.00	0.00	2.91	3.17	0.00
br24:0	0.00	0.00	3.08	3.27	0.00
Total	100	100	100	100	100


PLFA Profiles
50
40
30
20
10
0
Mole %
12:0
14:0
br14:0
16:0
i17:0
a17:0
17:0
18:0
cy19:0
br19:0
21:1
br21:0
23:0
br24:0
PLFA
Cell1(8,5)
Cell1(8,6)
Cell2(12,9)
Cell2(2,1)

APPENDIX F

ANALYSIS OF COMPOSITES OF DAILY SAMPLES OF RAW & TAP WATER
JANUARY - JUNE 1992
NEW WATER PLANT - KNOXVILLE, TENNESSEE
ALL FIGURES PPM EXCEPT AS NOTED.

DETERMINATION RAW WATER	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	AVERAGE
TURBIDITY NTU	16	13	18	9	10	13	13
pH	7.96	8.04	7.7	8.0	7.69	7.7	7.86
TEMPERATURE (C)	15	14	15	19	20	20.3	17
SUSPENDED SOLIDS	7.5	7	8	5.6	7.1	9.6	7.47
DISSOLVED SOLIDS	138.5	131	129	143.5	124	152	136
TOTAL SOLIDS	146	138	137	149.1	132	162	144
ALKALINITY as CaCO3	83	81	79	97	75	60	79
HARDNESS as CaCO3	100	96	97	115	84	75	95
CHLORIDE	11	11.0	12	11	11.0	9	10.8
CHLORINE RESIDUAL	0	0	0	0	0	0	0
CONDUCTIVITY	3665	3183	3005	3370	3179	2932	3221.0
FLUORIDE	0.1	0.05	0.12	0.12	0.10	0.09	0.10
PHOSPHATE-ORTHO	0.02	0.02	0.03	0.03	0.02	0.03	0.03
SULFATE	27	24	26	29	22	15	24
ALUMINUM (ppb)	129	227	276	276	237	172	220
CADMIUM	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
CALCIUM	32.5	30.1	26.1	31.3	30.1	23.8	29.0
CHROMIUM, (ppb)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
COPPER, (ppb)	90	78	105	89	115	119	99
IRON, (ppb)	235	314	269	162	199	161	223
MAGNESIUM	7.1	6.7	6.4	7.7	5	5.1	6.3
MANGANESE, (ppb)	36	41	37	30	36	38	36
MERCURY, (ppb)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
NICKEL, (ppb)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
SODIUM	9.5	8	7.6	7	7.4	8.3	8.0
ZINC, (ppb)	9	7	9	6	8	5	7
NITRATES as N, (ppm)			1.50	1.39	1.25	2.11	1.56
COLOR (APPARENT)	16	16	18	12	14	15	15
DISSOLVED OXYGEN	11.5	12	10.05	9.92	8.26	7.82	9.9

ANALYSIS OF COMPOSITES OF DAILY SAMPLES OF RAW & TAP WATER
JULY – DECEMBER 1992
MBW WATER PLANT – KNOXVILLE, TENNESSEE
ALL FIGURES PPM EXCEPT AS NOTED.

DETERMINATION	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	AVERAGE
RAW WATER							
TURBIDITY NTU	8	6	8	7	9	13	9
pH	8.16	7.9	8.0	8.0	8	7.9	7.99
TEMPERATURE (C)	22	25	25	22	17	14	21
SUSPENDED SOLIDS	7.2	3.9	2.1	2.3	3.0	4.0	3.75
DISSOLVED SOLIDS	147.8	136	138.9	114.8	127	124	131
TOTAL SOLIDS	155	140	141	117.1	130	128	135
ALKALINITY as CaCO3	87	83	70	65	61	61	71
HARDNESS as CaCO3	101	92	85	80	81	79	86
CHLORIDE	12	9.0	12	12.9	14.0	12.2	12.0
CHLORINE RESIDUAL	0	0	0	0	0	0	0
CONDUCTIVITY	2302	2176	1988	1815	1908	1854	2007.2
FLUORIDE	0.08	0.11	0.1	0.11	0.20	0.2	0.13
PHOSPHATE–ORTHO	0.03	0.03	0.03	0.03	0.03	0.03	0.03
SULFATE	19	15	15	16	17	16	16
ALUMINUM (ppb)	260	131	107	163	191	190	174
CADMIUM	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
CALCIUM	32.5	27.2	21.7	17.8	21.3	21.2	23.6
CHROMIUM, (ppb)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
COPPER, (ppb)	133	187	195	186	137	101	157
IRON, (ppb)	160	120	161	142	166	228	163
MAGNESIUM	7.1	5.9	5.2	4.8	5.9	5.6	5.8
MANGANESE, (ppb)	44	41	52	24	38	21	37
MERCURY, (ppb)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
NICKEL, (ppb)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
SODIUM	9.8	8.3	8.9	9.2	10	8.1	9.1
ZINC, (ppb)	8	5	9	5	6	5	6
NITRATES as N, (ppm)	1.84	1.32	1.35	1.31	1.31	1.67	1.5
COLOR (APPARENT)	12	14	16	14	12	14	14
DISSOLVED OXYGEN	7.12	5.8	4.7	7.3	8.2	11.7	7.5

ANALYSIS OF COMPOSITES OF DAILY SAMPLES OF RAW & TAP WATER
JANUARY – JUNE 1993
MBW WATER PLANT – KNOXVILLE, TENNESSEE
ALL FIGURES PPM EXCEPT AS NOTED.

DETERMINATION	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	AVERAGE
RAW WATER							
TURBIDITY NTU	19	14	16	10	5	4	12
pH	7.90	7.92	8.01	8.01	8.02	8.04	7.98
TEMPERATURE (C)	14	12	12	12	19	22	15
SUSPENDED SOLIDS	8	4	6	6	4	3	5
DISSOLVED SOLIDS	146	137	138	138	142	119	137
TOTAL SOLIDS	154	141	144	144	146	122	142
ALKALINITY as CaCO3	62	64	61	66	62	64	63
HARDNESS as CaCO3	81	79	81	91	85	86	84
CHLORIDE	9.5	6.9	6.9	7	5.0	7	7.1
CHLORINE RESIDUAL	0	0	0	0	0	0	0
CONDUCTIVITY	1855	1715	1630	1580	1690	1130	1600
FLUORIDE	0.12	0.13	0.13	0.10	0.10	0.15	0.12
PHOSPHATE-ORTHO	0.04	0.03	0.03	0.03	0.02	0.03	0.03
SULFATE	15	14	15	13	11	14	14
ALUMINUM (ppb)	176	363	384	227	117	169	239
CADMIUM	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
CALCIUM	25.1	21.9	23.2	26.2	20.2	25.5	23.7
CHROMIUM, (ppb)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
COPPER, (ppb)	67	86	44	50	88	87	70
IRON, (ppb)	338	228	170	145	77	68	171
MAGNESIUM	5.7	6.2	5.4	6.6	4.7	5.6	5.7
MANGANESE, (ppb)	25	16	21	18	14	10	17
MERCURY, (ppb)	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
NICKEL, (ppb)	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0
SODIUM	6.5	5.3	6.1	6.0	4.3	5.0	5.5
ZINC, (ppb)	5	4	7	3	9	6	6
NITRATES as N, (ppm)	1.99	1.89	1.60	2.10	2.20	2.10	2.0
COLOR (APPARENT)	13	11	0	12	12	11	10
DISSOLVED OXYGEN	11.7	5.8	10.8	10.8	8.9	8.9	9.5

APPENDIX G

475603 1161
35 49 51.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE KNOX
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
131TVAC HN 06010201025 0002.020 OFF
0000 FEET DEPTH

/TYPA/AMBNT/STREAM/SOLIDS

	INITIAL DATE			92/01/23	92/01/23	92/01/23	92/01/23	92/01/23	92/01/23	92/01/23	92/01/23
	INITIAL TIME			1456	1457	1458	1459	1500	1501	1502	1503	1504
	MEDIUM			WATER	WATER	WATER	VERT	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			0.983999	4.92	13.12	13.12	19.68	26.24	32.8	39.36	45.92
00002	MSAMPLOC	I FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER				867					
00010	WATER	TEMP	CENT	6.1	6.0	6.0		6.0	5.9	5.9	5.9	5.9
00011	WATER	TEMP	FAHN	43.0§	42.8§	42.8§		42.8§	42.6§	42.6§	42.6§	42.6§
00062	WATER	SURF ELE	IN FEET	809.3								
00078	TRANSP	SECCHI	METERS	.80								
00080	COLOR	PT-CO	UNITS				15					
00081	AP COLOR	PT-CO	UNITS				35					
00094	CNDUCTVY	FIELD	MICROMHO	235	235	236		236	235	235	234	234
00300	DO		MG/L	14.3	14.0	14.3		14.2	14.1	13.9	13.3	12.8
00301	DO	SATUR	PERCENT	114.4§	112.0§	114.4§		113.6§	112.8§	111.2§	106.4§	102.4§
00400	PH		SU	7.90	7.90	7.90		7.90	7.90	7.90	7.90	7.90
00530	RESIDUE	TOT NFLT	MG/L				7					
00605	ORG N	N	MG/L				.190					
00610	NH3+NH4-	N TOTAL	MG/L				.060					
00630	NO2&NO3	N-TOTAL	MG/L				.91					
00665	PHOS-TOT		MG/L P				.050					
00671	PHOS-DIS	ORTHO	MG/L P				.030					
00680	T ORG C	C	MG/L				2.3					
00681	D ORG C	C	MG/L				2.2					
31616	FEC COLI	MFM-FCBR	/100ML	1K								
32211	CHLRPHYL	A UG/L	CORRECTD				3.00					
32212	CHLRPHYL	B	UG/L				1.00K					
32214	CHLRPHYL	C	UG/L				1.00K					
32218	PHEOPHTN	A	UG/L				1.00					
74041	WDF	SAMPLE	UPDATED	920225	920225	920225	920313	920221	920221	920221	920221	920221
82079	TURBIDTY	LAB	NTU				8.0					
84068	SERIES	CODE	ALPHA				FLTC					

	INITIAL DATE			92/01/23	92/01/23	92/01/23	92/01/23	92/04/22	92/04/22	92/04/22	92/04/22	92/04/22
	INITIAL TIME			1505	1506	1507	1508	1328	1329	1330	1331	1332
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	VERT	WATER
	DEPTH-FT(SMK)			52.48	59.04	63.96	65.6	0.983999	4.92	13.12	13.12	16.4
00002	MSAMPLOC	I FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER			868					4197	
00010	WATER	TEMP	CENT	5.9	5.9		5.9	20.7	20.2	19.8		19.5
00011	WATER	TEMP	FAHN	42.6§	42.6§		42.6§	69.3§	68.4§	67.6§		67.1§
00062	WATER	SURF ELE	IN FEET					811.6				
00078	TRANSP	SECCHI	METERS					1.00				
00080	COLOR	PT-CO	UNITS			15					15	
00081	AP COLOR	PT-CO	UNITS			30						
00094	CNDUCTVY	FIELD	MICROMHO	234	235		234	234	235	238		239
00300	DO		MG/L	12.5	12.4		12.3	9.9	9.6	8.7		8.5
00301	DO	SATUR	PERCENT	100.0§	99.2§		98.4§	110.0§	104.3§	94.4§		90.4§
00400	PH		SU	7.90	7.90		7.90	8.80	8.70	8.50		8.40
00530	RESIDUE	TOT NFLT	MG/L			9					8	
00605	ORG N	N	MG/L			.230					.620	
00610	NH3+NH4-	N TOTAL	MG/L			.070					.040	
00630	NO2&NO3	N-TOTAL	MG/L			.91					.35	
00665	PHOS-TOT		MG/L P			.050					.040	
00671	PHOS-DIS	ORTHO	MG/L P			.030					.004	
00680	T ORG C	C	MG/L			2.4					2.0	
00681	D ORG C	C	MG/L			2.2						
31616	FEC COLI	MFM-FCBR	/100ML					1K				
32211	CHLRPHYL	A UG/L	CORRECTD								10.00	
32212	CHLRPHYL	B	UG/L								1.00	
32214	CHLRPHYL	C	UG/L								2.00	
32218	PHEOPHTN	A	UG/L								3.00	
74041	WDF	SAMPLE	UPDATED	920221	920221	920313	920221	920501	920501	920501	920405	920501
82079	TURBIDTY	LAB	NTU			9.0						
84068	SERIES	CODE	ALPHA			FLTB					FLTC	

475603 1161
35 09 31.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE CNTY
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
/TYPA/AMBNT/STREAM/SOLIDS 131TVAC HU 06010201025 0002.020 OFF
0000 FEET DEPTH

	INITIAL DATE			92/04/22	92/04/22	92/04/22	92/04/22	92/04/22	92/04/22	92/04/22	92/04/22
	INITIAL TIME			1333	1334	1335	1336	1337	1338	1339	1340	1341
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			19.68	26.24	32.8	36.08	39.36	42.64	45.92	52.48	59.04
00002	HSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00010	WATER	TEMP	CENT	18.7	17.6	16.4	15.5	13.9	12.3	11.7	11.0	10.9
00011	WATER	TEMP	FAHN	65.7%	63.7%	61.5%	59.9%	57.0%	54.1%	53.1%	51.8%	51.6%
00094	CNDUCTVY	FIELD	MICROMHO	250	253	255	252	248	236	232	223	220
00300	DO		MG/L	7.0	6.5	6.7	6.8	7.1	7.1	7.1	7.0	7.0
00301	DO	SATUR	PERCENT	74.5%	68.4%	67.0%	66.7%	68.3%	65.7%	65.7%	63.1%	63.1%
00400	PH		SU	8.00	7.90	7.80	7.70	7.70	7.60	7.70	7.60	7.60
74041	MOF	SAMPLE	UPDATED	920501	920501	920501	920501	920501	920501	920501	920501	920501

	INITIAL DATE			92/04/22	92/04/22	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13
	INITIAL TIME			1342	1343	1318	1319	1320	1321	1322	1323	1324
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	VERT	WATER	WATER
	DEPTH-FT(SMK)			65.6	66.912	0.983999	4.92	9.84	13.12	13.12	19.68	26.24
00002	HSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER		4198					5390		
00010	WATER	TEMP	CENT	10.8	10.8	19.1	18.8	15.9	15.8		15.2	14.7
00011	WATER	TEMP	FAHN	51.4%	51.4%	66.4%	65.8%	60.6%	60.4%		59.4%	58.5%
00062	WATER	SURF ELE	IN FEET			812.8'						
00078	TRANSP	SECCHI	METERS			.00						
00080	COLOR	PT-CO	UNITS		10					15		
00094	CNDUCTVY	FIELD	MICROMHO	219	219	210	210	188	185		183	175
00300	DO		MG/L	7.0	7.0	11.5	11.6	9.4	9.3		9.1	9.0
00301	DO	SATUR	PERCENT	63.1%	63.1%	122.3%	123.4%	94.0%	93.0%		89.2%	88.2%
00400	PH		SU	7.60'	7.60'	8.40'	8.50'	7.70'	7.60'		7.50'	7.40
00530	RESIDUE	TOT NFLT	MG/L		5					8		
00605	ORG N	N	MG/L		.500					.410		
00610	NH3+NH4-	N TOTAL	MG/L		.180					.020		
00612	UN-IONIZD	NH3-N	MG/L		.0018							
00619	UN-IONIZD	NH3-NH3	MG/L		.0020							
00630	NO2&NO3	N-TOTAL	MG/L		.68					.50		
00665	PHOS-TOT		MG/L P		.050					.040		
00671	PHOS-DIS	ORTHO	MG/L P		.030					.006		
00680	T ORG C	C	MG/L		2.2					2.7		
31616	FEC COLI	MFM-FCBR	/100ML			1E						

(SAMPLE CONTINUED FROM PREVIOUS PAGE)

	INITIAL DATE			92/04/22	92/04/22	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13
	INITIAL TIME			1342	1343	1318	1319	1320	1321	1322	1323	1324
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	VERT	WATER	WATER
	DEPTH-FT(SMK)			65.6	66.912	0.983999	4.92	9.84	13.12	13.12	19.68	26.24
32211	CHLRPHYL	A UG/L	CORRECTD							13.00		
32212	CHLRPHYL	B	UG/L							1.00K		
32214	CHLRPHYL	C	UG/L							2.00		
32218	PHEOPHTN	A	UG/L							1.00K		
74041	MOF	SAMPLE	UPDATED	920501	920605	920601	920601	920601	920601	920821	920601	920601
84060	SERIES	CODE	ALPHA		FLTD					FLTC		

	INITIAL DATE			92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/05/13	92/06/17	92/06/17
	INITIAL TIME			1325	1326	1327	1328	1329	1330	1331	1316	1319
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			32.8	39.36	45.92	52.48	59.04	62.32	65.6	0.983999	4.92
00002	HSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER						5389			
00010	WATER	TEMP	CENT	14.4	14.3	14.3	14.2	14.2	14.1	14.1	19.7	19.5
00011	WATER	TEMP	FAHN	57.9%	57.7%	57.7%	57.6%	57.6%	57.4%	57.4%	67.5%	67.1%
00062	WATER	SURF ELE	IN FEET								812.9'	
00078	TRANSP	SECCHI	METERS								.60	
00080	COLOR	PT-CO	UNITS						15			
00094	CNDUCTVY	FIELD	MICROMHO	170	165	173	165	165	168	169	185	182
00300	DO		MG/L	9.0	9.0	9.0	9.0	9.0	9.0	8.9	7.8	7.7
00301	DO	SATUR	PERCENT	86.5%	86.5%	86.5%	86.5%	86.5%	86.5%	85.6%	84.0%	81.9%
00400	PH		SU	7.40	7.40	7.40	7.40	7.40	7.40	7.40	7.70	7.60
00530	RESIDUE	TOT NFLT	MG/L						19			
00605	ORG N	N	MG/L						.330			
00610	NH3+NH4-	N TOTAL	MG/L						.050			
00612	UN-IONIZD	NH3-N	MG/L						.00036			
00619	UN-IONIZD	NH3-NH3	MG/L						.00046			
00630	NO2&NO3	N-TOTAL	MG/L						.62			
00665	PHOS-TOT		MG/L P						.050			
00671	PHOS-DIS	ORTHO	MG/L P						.020			
00680	T ORG C	C	MG/L						3.0			
31616	FEC COLI	MFM-FCBR	/100ML								1K	
74041	MOF	SAMPLE	UPDATED	920601	920601	920601	920601	920601	920731	920626	921228	920717
84060	SERIES	CODE	ALPHA						FLTD			

/TYPA/AMBNT/STREAM/SOLIDS

475603 1161
35 49 51.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE KNOX
TENNESSEE RIVER BASIN 040801
TENNESSEE RIVER 624.6
131TVAC HQ 06010201025 0002.020 OFF
0000 FEET DEPTH

	INITIAL DATE			92/06/17	92/06/17	92/06/17	92/06/17	92/06/17	92/06/17	92/06/17	92/06/17	92/06/17
	INITIAL TIME			1322	1325	1328	1331	1334	1337	1340	1343	1346
	MEDIUM			WATER	VERT	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			13.12	13.12	19.68	26.24	32.8	39.36	45.92	52.48	55.76
00002	HSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER		7335						7336	
00010	WATER	TEMP	CENT	19.2		19.0	19.0	18.9	18.9	18.9	18.9	18.9
00011	WATER	TEMP	FAHN	66.6%		66.2%	66.2%	66.0%	66.0%	66.0%	66.0%	66.0%
00080	COLOR	PT-CO	UNITS		10						10	
00094	CNDUCTVY	FIELD	MICROMHO	185		189	184	183	184	184	182	182
00300	DO		MG/L	7.6		7.6	7.6	7.6	7.6	7.6	7.6	7.6
00301	DO	SATUR	PERCENT	80.9%		80.9%	80.9%	80.9%	80.9%	80.9%	80.9%	80.9%
00400	PH		SU	7.60		7.60	7.60	7.60	7.60	7.60	7.60	7.50
00530	RESIDUE	TOT NFLT	MG/L		11						26	
00605	ORG N	N	MG/L		.130						.150	
00610	NH3+NH4-	N TOTAL	MG/L		.050						.030	
00612	UN-IONZD	NH3-N	MG/L								.00048	
00619	UN-IONZD	NH3-NH3	MG/L								.00058	
00630	NO2&NO3	N-TOTAL	MG/L		.54						.53	
00665	PHOS-TOT		MG/L P		.030						.050	
00671	PHOS-DIS	ORTHO	MG/L P		.020						.020	
00680	T ORG C	C	MG/L		2.4						2.3	
32211	CHLRPHYL	A UG/L	CORRECTD		3.00							
32212	CHLRPHYL	B	UG/L		1.00K							
32214	CHLRPHYL	C	UG/L		1.00							
32218	PHEOPHTN	A	UG/L		1.00K							
74041	MDF	SAMPLE	UPDATED	920717	920814	920717	920717	920717	920717	920717	920814	920717
84068	SERIES	CODE	ALPHA		FLTC						FLTB	

	INITIAL DATE			92/07/22	92/07/22	92/07/22	92/07/22	92/07/22	92/07/22	92/07/22	92/07/22	92/07/22
	INITIAL TIME			1256	1257	1258	1259	1300	1301	1302	1303	1304
	MEDIUM			WATER	WATER	WATER	WATER	VERT	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			0.983999	4.92	9.84	13.12	13.12	16.4	19.68	26.24	32.8
00002	HSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER					8997				
00010	WATER	TEMP	CENT	25.7	25.4	24.5	23.1		22.2	21.2	20.5	20.2
00011	WATER	TEMP	FAHN	78.3%	77.7%	76.1%	73.6%		72.0%	70.2%	68.9%	68.4%
00062	WATER	SURF ELE	IN FEET	812.5								
00078	TRANSP	SECCHI	METERS	.00								
00080	COLOR	PT-CO	UNITS					15				
00094	CNDUCTVY	FIELD	MICROMHO	232	233	239	245		243	246	245	246
00300	DO		MG/L	11.3	11.1	9.4	8.7		7.8	6.8	6.1	5.8
00301	DO	SATUR	PERCENT	137.8%	132.1%	110.6%	100.0%		88.6%	75.6%	66.3%	63.0%
00400	PH		SU	8.70	8.60	8.30	8.00		7.70	7.50	7.40	7.40
00530	RESIDUE	TOT NFLT	MG/L					5				
00605	ORG N	N	MG/L					.380				
00610	NH3+NH4-	N TOTAL	MG/L					.020				
00630	NO2&NO3	N-TOTAL	MG/L					.34				
00665	PHOS-TOT		MG/L P					.030				
00671	PHOS-DIS	ORTHO	MG/L P					.006				
00680	T ORG C	C	MG/L					3.9				
31616	FEC COLI	MFM-FCBR	/100ML	1								
32211	CHLRPHYL	A UG/L	CORRECTD					9.00				
32212	CHLRPHYL	B	UG/L					1.00K				
32214	CHLRPHYL	C	UG/L					1.00				
32218	PHEOPHTN	A	UG/L					1.00				
74041	MDF	SAMPLE	UPDATED	920807	920807	920807	920807	920925	920807	920807	920807	920807
84068	SERIES	CODE	ALPHA					FLTC				

	INITIAL DATE			92/07/22	92/07/22	92/07/22	92/07/22	92/08/11	92/08/19	92/08/19	92/08/19	92/08/19
	INITIAL TIME			1305	1306	1307	1308		1130	1132	1134	1136
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	VERT
	DEPTH-FT(SMK)			39.36	45.92	50.84	52.48		0.983999	4.92	13.12	13.12
00002	HSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0					
00008	LAB	IDENT.	NUMBER			8998		14554				11316
00010	WATER	TEMP	CENT	20.0	19.8	19.7	19.7		23.2	23.0	22.8	
00011	WATER	TEMP	FAHN	68.0%	67.6%	67.5%	67.5%		73.8%	73.4%	73.0%	
00078	TRANSP	SECCHI	METERS						.90			
00080	COLOR	PT-CO	UNITS			15						15
00094	CNDUCTVY	FIELD	MICROMHO	243	240	240	238		211	210	213	
00300	DO		MG/L	5.6	5.3	5.3	5.3		7.4	7.2	6.8	
00301	DO	SATUR	PERCENT	68.9%	57.6%	57.6%	57.6%		85.1%	82.8%	73.6%	
00400	PH		SU	7.40	7.30	7.30	7.30		7.70	7.70	7.50	
00530	RESIDUE	TOT NFLT	MG/L			18						8
00605	ORG N	N	MG/L			.250						.188

(SAMPLE CONTINUED ON NEXT PAGE)

475603 1161
35 49 51.0 084 03 34.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE KNOX
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
131TVAC HQ 06010201025 0002.020 OFF
0000 FEET DEPTH

/TYPA/AMBNT/STREAM/SOLIDS

(SAMPLE CONTINUED FROM PREVIOUS PAGE)

	INITIAL DATE			92/07/22	92/07/22	92/07/22	92/07/22	92/08/11	92/08/19	92/08/19	92/08/19	92/08/19
	INITIAL TIME			1305	1306	1307	1308		1130	1132	1134	1136
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	VERT
	DEPTH-FT(SMK)			39.36	45.92	50.84	52.48		0.983999	4.92	13.12	13.12
00610	NH3+NH4-	N TOTAL	MG/L			.060						.070
00612	UN-IONZD	NH3-N	MG/L			.00056						
00619	UN-IONZD	NH3-NH3	MG/L			.00069						
00630	NO2&NO3	N-TOTAL	MG/L			.53						.39
00665	PHOS-TOT		MG/L P			.050						.030
00671	PHOS-DIS	ORTHO	MG/L P			.020						.020
00680	T ORG C	C	MG/L			2.6						2.3
00917	CA MUD	DRY WGT	MG/KG-CA					9600.00				
00924	MG MUD	DRY WGT	MG/KG-MG					6100.00				
01028	CD MUD	DRY WGT	MG/KG-CD					.50K				
01029	CHROMIUM	SEDMG/KG	DRY WGT					20.00				
01043	COPPER	SEDMG/KG	DRY WGT					31.00				
01052	LEAD	SEDMG/KG	DRY WGT					40.00				
01053	MN MUD	DRY WGT	MG/KG-MN					2300.00				
01068	NICKEL	SEDMG/KG	DRY WGT					10.00K				
01093	ZINC	SEDMG/KG	DRY WGT					350.00				
01106	AL MUD	DRY WGT	MG/KG-AL					16000.00				
01170	FE MUD	DRY WGT	MG/KG-FE					38000.00				
31616	FEC COLI	MFM-FCBR	/100ML						14			
32211	CHLRPHYL	A UG/L	CORRECTD									5.00
32212	CHLRPHYL	B	UG/L									1.00K
32214	CHLRPHYL	C	UG/L									1.00
32218	PHEOPHTN	A	UG/L									1.00
34257	BETA BHC	SEDUG/KG	DRY WGT					10.000K				
34262	DELTABHC	SEDUG/KG	DRY WGT					10.000K				
34354	ENDOSULSF	SEDUG/KG	DRY WGT					10.000K				
34359	ENDOSUL	SEDUG/KG	DRY WGT					10.000K				
34364	AENDOSUL	SEDUG/KG	DRY WGT					10.000K				
34369	ENDRINAL	SEDUG/KG	DRY WGT					1000.000K				
39076	ALPHABHC	SEDUG/KG	DRY WGT					10.000K				
39301	P,P'DDT	SEDUG/KG	DRY WGT					10.00K				
39311	P,P'DDD	SEDUG/KG	DRY WGT					10.00K				
39321	P,P'DDE	SEDUG/KG	DRY WGT					10.00K				
39333	ALDRIN	SEDUG/KG	DRY WGT					10.00K				
39393	ENDRIN	SEDUG/KG	DRY WGT					10.00K				
39403	TOXAPHEN	SEDUG/KG	DRY WGT					500.00K				
39413	HEPTCHLR	SEDUG/KG	DRY WGT					10.00K				
39423	HPCHLREP	SEDUG/KG	DRY WGT					10.00K				
39481	METHYCLR	MUD DRY	UG/KG					10.00K				
39491	PCB-1221	SEDUG/KG	DRY WGT					100.00K				
39495	PCB-1232	SEDUG/KG	DRY WGT					100.00K				
39499	PCB-1242	SEDUG/KG	DRY WGT					100.00K				
39503	PCB-1248	SEDUG/KG	DRY WGT					100.00K				
39507	PCB-1254	SEDUG/KG	DRY WGT					100.00K				
39511	PCB-1260	SEDUG/KG	DRY WGT					100.00K				
39514	PCB-1016	SEDUG/KG	DRY WGT					100.00K				
70318	RESIDUE	TOTAL	PERCENT					41.8				
70322	RESIDUE	TOT VOL	PERCENT					7.1				
71921	MERCURY	SEDMG/KG	DRY WGT					.1				
74041	MOF	SAMPLE	UPDATED	920807	920807	920925	920807	930125	920904	920904	920904	921023
80203	TOT SED	SIEVE	%(.062MM					91.5				
80204	TOT SED	SIEVE	%(.125MM					97.8				
80206	TOT SED	SIEVE	%(.500MM					100.0				
80208	TOT SED	SIEVE	%(2.00MM					100.0				
84068	SERIES	CODE	ALPHA			FLTB						FLTC

	INITIAL DATE			92/08/19	92/08/19	92/08/19	92/08/19	92/08/19	92/08/19	92/09/24	92/09/24	92/09/24
	INITIAL TIME			1138	1140	1142	1144	1146	1148	1138	1140	1142
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			19.68	26.24	32.8	39.36	45.92	48.544	0.983999	4.92	13.12
									11317			
00000	LAB	IDENT.	NUMBER									
00010	WATER	TEMP	CENT	22.7	22.5	22.4	22.4	22.2	22.2	23.6	23.6	23.5
00011	WATER	TEMP	FAHR	72.9	72.5	72.3	72.3	72.0	72.0	74.5	74.5	74.3
00062	WATER	SURF ELE	IN FEET							812.5		
00078	TRANSP	SECCHI	METERS							.90		
00080	COLOR	PT-CO	UNITS						10			
00094	CNDUCTVY	FIELD	MICROMHO	213	214	214	214	214	214	214	214	214
00300	DO		MG/L	6.2	5.8	5.6	5.4	5.2	5.1	5.5	5.6	5.6
00301	DO	SATUR	PERCENT	71.3	63.9	61.6	61.0	59.1	58.0	64.7	65.5	62.1
00400	PH		SU	7.5	7.5	7.4	7.4	7.4	7.4	7.3	7.3	7.3
									12			
00530	RESIDUE	TOT NFLT	MG/L									

(SAMPLE CONTINUED ON NEXT PAGE)

475603 1161
35 09 51.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE 0401
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
131TVAC MD 06010201025 0002.020 OFF
0000 FEET DEPTH

/TYPA/AMBNT/STREAM/SOLIDS

(SAMPLE CONTINUED FROM PREVIOUS PAGE)

	INITIAL DATE			92/08/19	92/08/19	92/08/19	92/08/19	92/08/19	92/08/19	92/09/24	92/09/24	92/09/24
	INITIAL TIME			1138	1140	1142	1144	1146	1148	1138	1140	1142
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			19.68	26.24	32.8	39.36	45.92	48.544	0.983999	4.92	13.12
00605	ORG N	N	MG/L						.210			
00610	NH3+NH4-	N TOTAL	MG/L						.060			
00612	UN-IONIZD	NH3-N	MG/L						.00079			
00619	UN-IONIZD	NH3-NH3	MG/L						.00089			
00630	NO2&NO3	N-TOTAL	MG/L						.43			
00665	PHOS-TOT		MG/L P						.060			
00671	PHOS-DIS	ORTHO	MG/L P						.020			
00680	T ORG C	C	MG/L						2.4			
31616	FEC COLI	MFM-FCBR	/100ML							1		
74041	NOF	SAMPLE	UPDATED	920904	920904	920904	920904	920904	921023	921008	921008	921008
84068	SERIES	CODE	ALPHA						FLTB			

	INITIAL DATE			92/09/24	92/09/24	92/09/24	92/09/24	92/09/24	92/09/24	92/09/24	93/04/14	93/04/14
	INITIAL TIME			1144	1146	1148	1150	1152	1154	1156	1355	1358
	MEDIUM			VERT	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			13.12	19.68	26.24	32.8	39.36	45.92	50.184	0.983999	4.92
00002	MSAMPLOC	% FROM	RT BANK								30.0	30.0
00008	LAB	IDENT.	NUMBER	13953					13954			
00010	WATER	TEMP	CENT		23.5	23.4	23.4	23.3	23.3	23.3	15.5	14.1
00011	WATER	TEMP	FAHN		74.36	74.18	74.19	73.94	73.94	73.94	59.94	57.48
00062	WATER	SURF ELE	IN FEET								812.6	
00078	TRANSP	SECCHI	METERS								.70	
00080	COLOR	PT-CO	UNITS	10					10			
00094	CNDUCTVY	FIELD	MICROMHO		214	211	209	203	201	200	205	202
00300	DO		MG/L		5.3	5.2	5.3	5.3	5.3	5.3	10.7	10.7
00301	DO	SATUR	PERCENT		60.9%	59.8%	60.9%	60.9%	60.9%	60.9%	104.9%	102.9%
00400	PH		SU		7.30	7.30	7.20	7.20	7.20	7.20	8.00	8.00
00530	RESIDUE	TOT NFLT	MG/L	7					15			
00605	ORG N	N	MG/L	.070					.120			
00610	NH3+NH4-	N TOTAL	MG/L	.050					.040			
00612	UN-IONIZD	NH3-N	MG/L						.00036			
00619	UN-IONIZD	NH3-NH3	MG/L						.00049			
00630	NO2&NO3	N-TOTAL	MG/L	.49					.49			
00665	PHOS-TOT		MG/L P	.060					.040			
00671	PHOS-DIS	ORTHO	MG/L P	.030					.030			
00680	T ORG C	C	MG/L	2.6					2.5			
31616	FEC COLI	MFM-FCBR	/100ML								600L	
32211	CHLRPHYL	A UG/L	CORRECTD	3.00								
32212	CHLRPHYL	B	UG/L	1.00								
32214	CHLRPHYL	C	UG/L	1.00								
32218	PHEOPHTN	A	UG/L	1.00								
74041	NOF	SAMPLE	UPDATED	921120	921008	921008	921008	921008	921120	921008	930520	930520
84068	SERIES	CODE	ALPHA	FLTC					FLTB			

	INITIAL DATE			93/04/14	93/04/14	93/04/14	93/04/14	93/04/14	93/04/14	93/04/14	93/04/14	93/04/14
	INITIAL TIME			1401	1404	1407	1410	1413	1417	1420	1425	1430
	MEDIUM			WATER	VERT	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			13.12	13.12	19.68	26.24	32.8	39.36	45.92	52.48	55.76
00002	MSAMPLOC	% FROM	RT BANK	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0	30.0
00008	LAB	IDENT.	NUMBER		2859						2861	
00010	WATER	TEMP	CENT	13.7		13.7	13.6	13.6	13.5	13.5	13.4	13.4
00011	WATER	TEMP	FAHN	56.7%		56.7%	56.5%	56.5%	56.3%	56.3%	56.1%	56.1%
00080	COLOR	PT-CO	UNITS		10						15	
00094	CNDUCTVY	FIELD	MICROMHO	197		193	190	191	190	190	185	185
00300	DO		MG/L	10.3		10.3	10.3	10.3	10.3	10.2	10.2	10.2
00301	DO	SATUR	PERCENT	99.0%		99.0%	99.0%	99.0%	97.2%	96.2%	96.2%	96.2%
00400	PH		SU	7.90		7.90	7.90	7.90	7.90	7.90	7.80	7.90
00530	RESIDUE	TOT NFLT	MG/L		11						18	
00605	ORG N	N	MG/L		.300						.210	
00610	NH3+NH4-	N TOTAL	MG/L		.010K						.020	
00612	UN-IONIZD	NH3-N	MG/L								.00036	
00619	UN-IONIZD	NH3-NH3	MG/L								.00048	
00630	NO2&NO3	N-TOTAL	MG/L		.71						.69	
00665	PHOS-TOT		MG/L P		.060						.060	
00671	PHOS-DIS	ORTHO	MG/L P		.010						.010	
00680	T ORG C	C	MG/L		2.4						2.3	
32211	CHLRPHYL	A UG/L	CORRECTD		11.00							
32212	CHLRPHYL	B	UG/L		1.00K							
32214	CHLRPHYL	C	UG/L		2.00							
32218	PHEOPHTN	A	UG/L		1.00							
74041	NOF	SAMPLE	UPDATED	930520	930630	930520	930520	930520	930520	930520	930630	930520
84068	SERIES	CODE	ALPHA		FLTC						FLTB	

/TYPA/AMBNT/STREAM/SOLIDS

475603 1161
35 49 51.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE KNOX
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
131TVAC HQ 06010201025 0002.020 OFF
0000 FEET DEPTH

	INITIAL DATE			93/05/11	93/05/11	93/05/11	93/05/11	93/05/11	93/05/11	93/05/11	93/05/11	93/05/11
	INITIAL TIME			1325	1328	1330	1333	1335	1335	1337	1340	1343
	MEDIUM			WATER	WATER	WATER	WATER	WATER	VERT	WATER	WATER	WATER
	DEPTH-FT(SMK)			0.983999	4.92	9.84	13.12	13.12	13.12	16.4	19.68	26.24
00000	LAB	IDENT.	NUMBER					4098				
00010	WATER	TEMP	CENT	22.5	21.0	20.2	19.8			19.2	18.9	18.6
00011	WATER	TEMP	FAHN	72.5%	69.8%	68.4%	67.6%			66.6%	66.0%	65.5%
00062	WATER	SURF ELE	IN FEET	812.6								
00078	TRANSP	SECCHI	METERS	.60								
00080	COLOR	PT-CO	UNITS					10				
00094	CNDUCTVY	FIELD	MICROMHO	188	185	184	185			184	185	186
00300	DO		MG/L	12.8	12.6	11.2	10.5			9.8	9.5	9.1
00301	DO	SATUR	PERCENT	145.5%	140.0%	121.7%	114.1%			104.3%	101.1%	96.8%
00400	PH		SU	8.80	8.60	8.30	8.20			7.90	7.90	7.80
00530	RESIDUE	TOT NFLT	MG/L					8				
00605	ORG N	N	MG/L					.240				
00610	NH3+NH4-	N TOTAL	MG/L					.020				
00630	NO2&NO3	N-TOTAL	MG/L					.43				
00665	PHOS-TOT		MG/L P					.050				
00671	PHOS-DIS	ORTHO	MG/L P					.004				
00680	T ORG C	C	MG/L					2.6				
31616	FEC COLI	MFM-FCBR	/100ML	1K								
32211	CHLRPHYL	A UG/L	CORRECTD					19.00				
32212	CHLRPHYL	B	UG/L					1.00K				
32214	CHLRPHYL	C	UG/L					3.00				
32218	PHEOPHTN	A	UG/L					3.00				
74041	MOF	SAMPLE	UPDATED	930527	930527	930527	930527	930624	930527	930527	930527	930527
84060	SERIES	CODE	ALPHA						FLTC			

	INITIAL DATE			93/05/11	93/05/11	93/05/11	93/05/11	93/05/11	93/05/25	93/05/25	93/06/16	93/06/16
	INITIAL TIME			1347	1349	1351	1353	1355	1010	1110	1223	1226
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			32.8	39.36	45.92	52.48	54.448			0.983999	4.92
00010	WATER	TEMP	CENT	17.5	17.4	17.2	17.1	17.1			26.4	25.1
00011	WATER	TEMP	FAHN	63.5%	63.3%	63.0%	62.8%	62.8%			79.5%	77.2%
00062	WATER	SURF ELE	IN FEET								813.0	
00078	TRANSP	SECCHI	METERS								1.20	
00080	COLOR	PT-CO	UNITS					10				
00094	CNDUCTVY	FIELD	MICROMHO	190	193	190	194	198			174	179
00300	DO		MG/L	8.7	8.6	8.4	8.4	8.3			13.2	11.5
00301	DO	SATUR	PERCENT	89.7%	88.7%	86.6%	86.6%	85.6%			161.0%	136.9%
00400	PH		SU	7.70	7.70	7.70	7.70	7.70			9.40	9.10
00530	RESIDUE	TOT NFLT	MG/L					13				
00605	ORG N	N	MG/L					.140				
00610	NH3+NH4-	N TOTAL	MG/L					.120				
00612	UN-IONZD	NH3-N	MG/L					.0026				
00619	UN-IONZD	NH3-NH3	MG/L					.0020				
00630	NO2&NO3	N-TOTAL	MG/L					.61				
00665	PHOS-TOT		MG/L P					.060				
00671	PHOS-DIS	ORTHO	MG/L P					.010				
00680	T ORG C	C	MG/L					2.0				
31616	FEC COLI	MFM-FCBR	/100ML								1K	
74041	MOF	SAMPLE	UPDATED	930527	930527	930527	930527	930624	930603	930603	930625	930625
84002	CODE	GENERAL	REMARKS						01	02		
84060	SERIES	CODE	ALPHA					FLTB	SED	SED		

	INITIAL DATE			93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16
	INITIAL TIME			1228	1230	1231	1232	1234	1236	1238	1241	1248
	MEDIUM			WATER	WATER	VERT	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			9.84	13.12	13.12	16.4	19.68	26.24	32.8	39.36	45.92
00000	LAB	IDENT.	NUMBER			5504						
00010	WATER	TEMP	CENT	22.5	21.7		19.9	18.7	18.0	17.7	17.6	17.6
00011	WATER	TEMP	FAHN	72.5%	71.1%		67.8%	65.7%	64.4%	63.9%	63.7%	63.7%
00080	COLOR	PT-CO	UNITS			10						
00094	CNDUCTVY	FIELD	MICROMHO	191	197		205	213	218	220	220	219
00300	DO		MG/L	9.1	9.2		7.8	7.7	7.7	7.7	7.7	7.8
00301	DO	SATUR	PERCENT	103.4%	104.5%		84.8%	81.9%	81.1%	81.1%	81.1%	82.1%
00400	PH		SU	8.30	8.30		7.90	7.80	7.70	7.70	7.70	7.70
00530	RESIDUE	TOT NFLT	MG/L			6						
00605	ORG N	N	MG/L			.200						
00610	NH3+NH4-	N TOTAL	MG/L			.020						
00630	NO2&NO3	N-TOTAL	MG/L			.29						
00665	PHOS-TOT		MG/L P			.050						
00671	PHOS-DIS	ORTHO	MG/L P			.005						
00680	T ORG C	C	MG/L			2.7						

(SAMPLE CONTINUED ON NEXT PAGE)

475603 1161
35 49 51.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE KNOI
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
131TVAC HQ 06010201025 0002.020 OFF
0000 FEET DEPTH

/TYPA/AMBNT/STREAM/SOLIDS

(SAMPLE CONTINUED FROM PREVIOUS PAGE)

	INITIAL DATE			93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16	93/06/16
	INITIAL TIME			1228	1230	1231	1232	1234	1236	1238	1241	1240
	MEDIUM			WATER	WATER	VERT	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			9.84	13.12	13.12	16.4	19.68	26.24	32.8	39.36	45.92
32211	CHLRPHYL	A UG/L	CORRECTD			17.00						
32212	CHLRPHYL	B	UG/L			1.00						
32214	CHLRPHYL	C	UG/L			2.00						
32218	PHEOPHTN	A	UG/L			4.00						
74041	MOF	SAMPLE	UPDATED	930625	930625	930823	930625	930625	930625	930625	930625	930625
84068	SERIES	CODE	ALPHA			FLTC						

	INITIAL DATE			93/06/16	93/06/16	93/06/16	93/07/12	93/07/12	93/07/12	93/07/12	93/07/12	93/07/12
	INITIAL TIME			1254	1255	1256	1203	1205	1207	1208	1209	1210
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	VERT	WATER
	DEPTH-FT(SMK)			52.48	54.776	57.728	0.983999	6.92	9.84	13.12	13.12	16.4
00008	LAB	IDENT.	NUMBER		5505						6735	
00010	WATER	TEMP	CENT	17.6	17.5	17.5	30.4	29.8	27.2	24.1		23.7
00011	WATER	TEMP	FAHR	63.7$	63.5$	63.5$	86.7$	85.6$	81.0$	75.4$		74.7$
00078	TRANSP	SECCHI	METERS				1.30					
00080	COLOR	PT-CO	UNITS		10						10	
00094	CNDUCTVY	FIELD	MICROMHO	221	221	221	171	172	195	207		211
00300	DO		MG/L	7.7	7.7	7.7	10.0	10.1	7.4	6.1		6.4
00301	DO	SATUR	PERCENT	81.1$	79.4$	79.4$	131.4$	132.9$	91.4$	71.8$		75.3$
00400	PH		SU	7.70	7.70	7.70	9.30	9.30	8.60	8.10		8.00
00530	RESIDUE	TOT NFLT	MG/L		20						6	
00605	ORG N	N	MG/L		.160						.370	
00610	NH3+NH4-	N TOTAL	MG/L		.060						.010K	
00612	UN-IONZD	NH3-N	MG/L		.0010$							
00619	UN-IONZD	NH3-NH3	MG/L		.0010							
00630	NO2&NO3	N-TOTAL	MG/L		.68						.13	
00665	PHOS-TOT		MG/L P		.050						.040	
00671	PHOS-DIS	ORTHO	MG/L P		.020						.002	
00680	T ORG C	C	MG/L		2.0						2.9	
31616	FEC COLI	MFM-FCBR	/100ML				1K					
32211	CHLRPHYL	A UG/L	CORRECTD								13.00	
32212	CHLRPHYL	B	UG/L								1.00K	

	INITIAL DATE			93/07/12	93/07/12	93/07/12	93/07/12	93/07/12	93/07/12	93/07/12	93/07/12	93/08/10
	INITIAL TIME			1211	1212	1213	1215	1216	1217	1218	1219	1056
	MEDIUM			WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			19.68	26.24	32.8	39.36	45.92	52.48	55.76	59.04	0.983999
00008	LAB	IDENT.	NUMBER							6734		
00010	WATER	TEMP	CENT	22.6	21.6	20.8	20.4	20.3	20.2	20.2	20.2	22.6
00011	WATER	TEMP	FAHR	72.7$	70.9$	69.4$	68.7$	68.5$	68.4$	68.4$	68.4$	72.7$
00062	WATER	SURF ELE	IN FEET									812.8
00078	TRANSP	SECCHI	METERS									1.00
00080	COLOR	PT-CO	UNITS							10		
00094	CNDUCTVY	FIELD	MICROMHO	214	213	212	212	213	213	214	214	205
00300	DO		MG/L	6.2	6.3	6.3	6.1	6.0	5.9	5.9	5.9	7.9
00301	DO	SATUR	PERCENT	71.3$	73.9$	70.0$	66.3$	65.2$	64.1$	64.1$	64.1$	90.8$
00400	PH		SU	7.90	7.90	7.80	7.80	7.80	7.80	7.70	7.80	7.80
00530	RESIDUE	TOT NFLT	MG/L							24		
00605	ORG N	N	MG/L							.180		
00610	NH3+NH4-	N TOTAL	MG/L							.070		
00612	UN-IONZD	NH3-N	MG/L							.0010		
00619	UN-IONZD	NH3-NH3	MG/L							.0020		
00630	NO2&NO3	N-TOTAL	MG/L							.67		
00665	PHOS-TOT		MG/L P							.040		
00671	PHOS-DIS	ORTHO	MG/L P							.010		
00680	T ORG C	C	MG/L							2.1		
31616	FEC COLI	MFM-FCBR	/100ML									4
74041	MOF	SAMPLE	UPDATED	930716	930716	930716	930716	930716	930716	930824	930716	930903
84068	SERIES	CODE	ALPHA							FLTB		

	INITIAL DATE			93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10
	INITIAL TIME			1057	1058	1059	1100	1102	1103	1104	1105	1106
	MEDIUM			WATER	WATER	WATER	VERT	WATER	WATER	WATER	WATER	WATER
	DEPTH-FT(SMK)			6.92	9.84	13.12	13.12	19.68	26.24	32.8	39.36	45.92
00010	WATER	TEMP	CENT	22.3	22.0	22.0		21.7	21.3	21.2	21.2	21.2
00011	WATER	TEMP	FAHR	72.1$	71.6$	71.6$		71.1$	70.3$	70.2$	70.2$	70.2$
00094	CNDUCTVY	FIELD	MICROMHO	206	206	206		206	206	207	207	208
00300	DO		MG/L	6.7	6.5	6.5		5.9	5.6	5.4	5.4	5.3
00301	DO	SATUR	PERCENT	76.1$	73.9$	73.9$		67.0$	62.2$	60.0$	60.0$	59.9$
00400	PH		SU	7.60	7.50	7.50		7.60	7.40	7.40	7.30	7.30
74041	MOF	SAMPLE	UPDATED	930818	930818	930818	930818	930818	930818	930818	930818	930818

(SAMPLE CONTINUED ON NEXT PAGE)

475603 1161
35 49 51.0 084 03 54.0 2
FORT LOUDOUN RESERVOIR
47093 TENNESSEE KNOX
TENNESSEE RIVER BASIN 040001
TENNESSEE RIVER 624.6
131TVAC HQ 06010201025 0002.020 OFF
0000 FEET DEPTH

/TYPA/AMBNT/STREAM/SOLIDS

(SAMPLE CONTINUED FROM PREVIOUS PAGE)

INITIAL DATE				93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10	93/08/10
INITIAL TIME				1057	1058	1059	1100	1102	1103	1104	1105	1106
MEDIUM				WATER	WATER	WATER	VERT	WATER	WATER	WATER	WATER	WATER
DEPTH-FT(SMK)				4.92	9.84	13.12	13.12	19.68	26.24	32.8	39.36	45.92
84068 SERIES	CODE	ALPHA					FLTC					

INITIAL DATE				93/08/10	93/08/10	93/08/10
INITIAL TIME				1107	1108	1110
MEDIUM				WATER	WATER	WATER
DEPTH-FT(SMK)				52.48	55.104	58.384
00010 WATER	TEMP	CENT		21.1	21.1	21.1
00011 WATER	TEMP	FAHN		70.0	70.0	70.0
00094 CNDUCTVY	FIELD	MICROMHO		207	207	208
00300 DO		MG/L		5.2	5.1	5.1
00301 DO	SATUR	PERCENT		57.8	56.7	56.7
00400 PH		SU		7.30	7.30	7.30
74041 WDF	SAMPLE	UPDATED		930818	930818	930818
84068 SERIES	CODE	ALPHA			FLTB	

VITA

Gary Lynn Riner was born in Knoxville, Tennessee on November 21, 1960. He attended elementary school at New Market, in the Jefferson County, Tennessee School District, and graduated from Jefferson County High School in June 1978. That fall he entered Lees McRae Junior College in Banner Elk, North Carolina, on a football scholarship and curriculum of pre-engineering. He had a successful two years at Lees McRae in both athletics and academia. He started two years at defensive back and made all-district, all conference, and played in the Junior College North-South all-star game, and graduated from Lees McRae in May 1980 with an Associate of Science degree in Pre-Engineering. That fall he entered the University of Tennessee, Knoxville and received a Bachelor of Science degree in Metallurgical Engineering in June of 1983.

In August of 1983, he went to work for the Tennessee Valley Authority (TVA) at Singleton Materials Engineering Laboratory (SMEL). He worked at SMEL for five years and then transferred to the TVA Watts Bar Nuclear Plant as a Sr. Metallurgical Engineer and Program Manager. In October of 1991, he performed a federal transfer, and currently works as a Program Manager for the U. S. Department of Energy at the Oak Ridge National Laboratory in Oak Ridge, Tennessee.