
CORROSION FIELD TEST OF STEELS COMMONLY USED IN WELL CASING AND SCREEN

City of Fountain Valley

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CITY OF FOUNTAIN VALLEY

WELL NO. 7

CORROSION FIELD TEST OF STEELS COMMONLY USED IN WELL CASING AND SCREEN

1.0 INTRODUCTION

1.1 Purpose And Scope

This report presents the data, findings and conclusions of a corrosion field test performed for the City of Fountain Valley by GEOSCIENCE Support Services, Inc. (GEOSCIENCE). The purpose of the study was to determine the most appropriate well casing and screen materials for replacement Well No. 12, using downhole metal coupons in Well No. 7, located in Mile Square Regional Park, City of Fountain Valley, California. Information from this study will also be used to design future wells in the area. Specifically the study involved:

- Selection of potential casing and screen materials;
- Fabrication of the metal coupons and the coupon holder apparatus;
- Installation of the coupons in Well No. 7;
- Retrieval of the coupons at various exposure times; and
- Calculation of Corrosion Rates.

1.2. Methodology

Three sets of six types of metal coupons were placed downhole in Well No. 7 on March 11, 1998. The first set was removed after seven weeks on July 1, 1998, the second set was removed after eleven weeks on July 29, 1998, and the remaining set was removed after eleven months on April 2, 1999. All coupons were weighed before and after placement downhole. The coupons removed from the well were weighed after being cleaned of scale.

The coupons that were exposed for eleven months were photographed before cleaning using a light microscope. These samples were also analyzed using a scanning electron microscope (SEM) and an energy dispersive spectrometer (EDS) at the Center for Electron Microscopy and Microanalysis (CEMMA) at the University of Southern California.

The metal coupons were manufactured from five different steels commonly used in well casings and screens: Mild, Copper Bearing, Corrosion Resistant High Strength Low Alloy (Corten), Type 304 Stainless (SS 304), and Type 316L Stainless (SS 316L). The chemical compositions of these five steels are depicted in Figure 1 and the following table:

CHEMICAL COMPOSITION OF MATERIALS (WEIGHT PERCENT)

Material	C	Fe	Ni	Co	Mn	P	Cr	Mo	S	Cu	N	Si	Al
Mild Steel	0.110	BAL	-	-	0.540	0.009	-	-	0.010	-	-	-	-
Cu-Bearing	0.140	BAL	0.010	-	0.830	0.010	0.01	-	0.006	0.250	-	0.150	0.041
Corten	0.080	BAL	0.280	-	0.770	0.049	0.58	-	0.023	0.279	-	0.252	0.066
SS 304	0.052	BAL	8.050	0.07	1.720	0.028	18.35	0.19	0.016	0.270	0.05	0.510	-
SS 316L	0.013	BAL	10.12	0.21	1.530	0.027	16.29	2.07	0.001	0.250	0.06	0.510	-

All coupons except for the Copper Bearing were manufactured by Metal Samples Co. in Munford, Alabama, and include an autogeneous weld. These four sets of four coupons are numbered 1-4 (no. 1 in each set is a reference coupon that was not placed downhole; no. 2 was exposed for 11 months, no. 3 for 11 weeks, and no. 4 for 7 weeks).

The Copper Bearing coupons were made by Roscoe Moss Manufacturing Co., and comprise two sets of three coupons each. The set identified A to C contains an autogeneous weld and the set identified 1 to 3 does not. Coupons A and 3 were downhole for 11 months, B and 2 for 11 weeks, and C and 3 for 7 weeks. All coupons are 1/8 in. x 3/4 in. x 2 in. with a 3/8 in. diameter hole in the center. The initial weights of the coupons can be found in Appendix A.

The coupons were placed in the well at a depth of 250 feet within a holding rack manufactured by Metal Samples Co. The coupons are separated by teflon spacers within a stainless steel 316L frame that is housed within plexiglass. The coupons and apparatus are shown in Figures 2 and 2a. The rack apparatus was lowered down the 18 inch diameter well using 1/8 in. stainless steel 304 cable. The coupons were retrieved using a 7/16 in. socket.

2.0 HISTORY OF WELL NO. 7

Well No. 7, completed in 1977 and 785 ft deep, is screened at 245-298, 337-435, 467-553, and 568-772 ft. It has an inside diameter of 18 in. and an inner wall thickness of 5/16 inches. The well screen is a Roscoe Moss Co. Ful-Flo Shutter Screen. Detail specifications from the City of Fountain Valley state "fabrication (of pump chamber casing) shall be from 5/16 in. thick prime quality hot rolled steel plates containing not less than 0.20% copper." The following table shows the chemical composition for the well casing and screen as established by the City of Fountain Valley:

CHEMICAL COMPOSITION OF WELL CASING AND SCREEN (CORTEN)

Copper	0.41%
Sulfur	0.033%
Chromium	0.84%
Nickel	0.28%
Carbon	0.09%
Manganese	0.38%
Silicon	0.48%
Phosphorous	0.09%

Water quality records exist for Well No. 12, located approximately 90 ft from Well No. 7. The following table shows water quality characteristics at various depths in the nearby well:

WATER QUALITY - WELL NO. 12 (VALUES IN MG/L)

Depth ft bgs	pH	CaCO ₃	Alkalinity	TDS	Cl	SO ₄	Ca	Hard- ness
390-410	7.4	170	170	297	17	42	47	162
535-555	7.8	165	165	270	18	34	45	158
720-740	8.0	176	176	320	17	44	48	165
850-870	8.3	139	139	202	14	28	33	102
1050-1070	7.5	131	131	213	12	32	31	92

Note: Water quality data represents samples taken 06-Dec-98 to 10-Dec-98

3.0 COUPON TEST RESULTS

The metal coupons were cleaned after their removal from the well and then weighed to determine volume loss:

$$V_{\text{lost}} = \frac{M_{\text{initial}} - M_{\text{final}}}{\rho}; \text{ M = mass, } \rho = \text{density, V = volume}$$

Material loss in mils per year (1 mil = 0.001 in.) was then calculated by the following equation:

$$\text{LOSS [mils / yr]} = \frac{(1 \text{ mil})(V_{\text{lost}} \text{ cm}^3)(1 \text{ in.}^3)(24 \text{ hrs})(365 \text{ days})}{(0.001 \text{ in.})(A_{\text{surf}} \text{ in.}^2)(2.54^3 \text{ cm}^3)(T \text{ hrs})(1 \text{ day})(1 \text{ year})};$$

where: A_{surf} = coupon surface area, and
 T = duration in hrs coupon downhole

The results of the metal coupon test are summarized below:

SUMMARY OF MATERIAL LOSS, IN MILS/YR

Material	Removed 1-Jul-98 1176 hrs exposure	Removed 29-Jul-98 1852 hrs exposure	Removed 2-Apr-99 7776 hrs exposure
Mild Steel	0.1812	0.2858	2.8794
Cu-Bearing (no weld)	0.9527	0.5457	0.9389
Cu-Bearing (weld)	1.2108	0.8726	0.5487
Corten	0.8137	0.5935	0.3131
SS 304	0.0846	0.0369	0.0118
SS 316L	0.0799	0.0461	0.0061

3.1 Seven Week Exposure

After seven weeks all the metal coupons except for the two stainless steel samples became black, though there was some discoloration on the weld bends of the stainless steel coupons (see Figure 3).

The coupons were sent to Metal Samples Co. for cleaning, weighing and analysis (see Appendix A). Metal Samples Co. cleaned each sample using acetone to remove corrosion. The analysis by Metal Samples Co. determined that after seven weeks, the Copper Bearing coupons had areas of attack and spotty etch, the Corten coupon suffered spotty etch, and the Mild, SS 304, and SS 316L coupons were characterized by even etch. Following is a table summarizing the qualitative characteristics of the metal coupons throughout the eleven month field test.

SUMMARY OF MACROSCOPIC CORROSION CHARACTERISTICS

Material	7 weeks	11 weeks	11 months
Mild Steel	Even etch	Areas of attack/spotty etch	General overall attack
Cu-Bearing (no weld)	Areas of attack/spotty etch	Areas of attack/spotty etch	Areas of attack
Cu-Bearing (weld)	Areas of attack/spotty etch	Areas of attack/spotty etch	Areas of attack/spotty etch
Corten	Spotty etch	Areas of attack/spotty etch	Areas of attack/spotty etch
SS 304	Even etch	Even etch	Even etch
SS 316L	Even etch	Areas of attack	Even etch

3.2 Eleven Week Exposure

After eleven weeks of exposure the stainless steel coupons again showed negligible discoloration. The SS 316L coupon had areas of attack, and the SS 304 experienced even etch. All other coupons had areas of attack and spotty etch.

3.3 Eleven Month Exposure

After eleven months downhole, the Mild steel underwent the most corrosion, becoming severely pitted (see Figures 4 and 4a). Scanning Electron Microscope (SEM) photographs of non-scale areas on the Mild steel coupon reveal iron oxide nodules and hexagonal crystals after eleven months that are not present on the reference coupon (see Appendix B, pages B-1 to B-2). SEM photographs of the scale on the Mild steel coupon show it consists of string-like material (see Appendix B, page B-4). Energy dispersive spectrometer (EDS) analysis reveals that the scale on the Mild steel coupon contains elevated calcium, silicon, oxygen, and sulfur levels compared to the reference coupon (see Appendix C, pages C-2 to C-4).

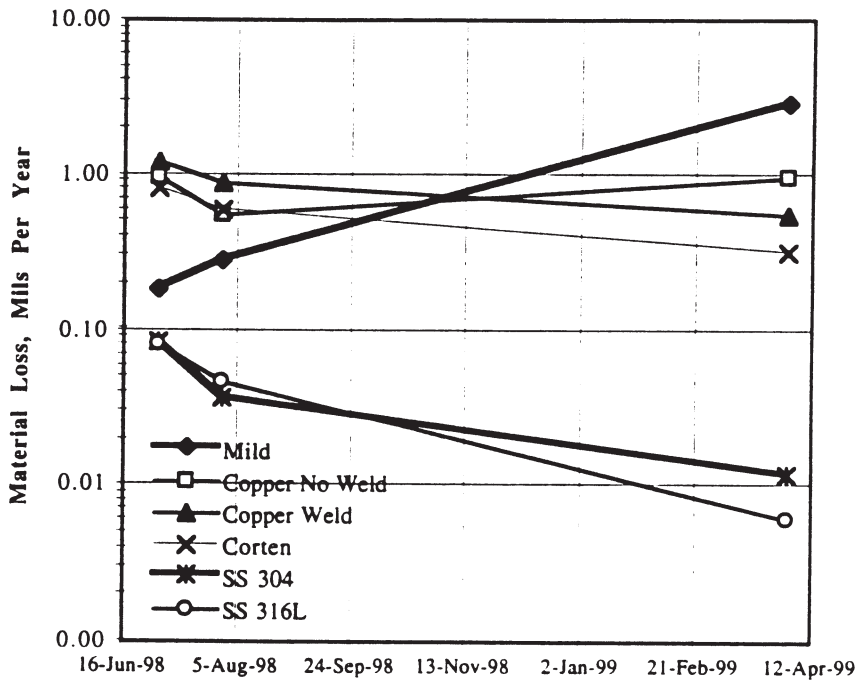
The Copper Bearing and Corten coupons suffered spotty etch and areas of attack. SEM photographs reveal the grain boundaries of the Corten to be more disfigured after eleven months than grain boundaries in the stainless steel coupons (see Appendix B). Light microscope photographs showing the Copper Bearing and Corten steel coupons after eleven months of submergence (before cleaning) can be found in Figure 5.

The stainless steel coupons suffered the least corrosion, classified as even etch. The scale area on the stainless steel 316L coupon is characterized by elevated oxygen, sulfur, silicon, and calcium levels compared to the reference coupon. Non-scale areas nearly perfectly retain the same chemical signature as the reference coupon as determined by EDS (see Appendix C). Light microscope photographs showing the stainless steel coupons after eleven months of submergence (before cleaning) can be found in Figures 6 and 6a.

4.0 RECOMMENDATIONS OF MATERIALS FOR REPLACEMENT WELL

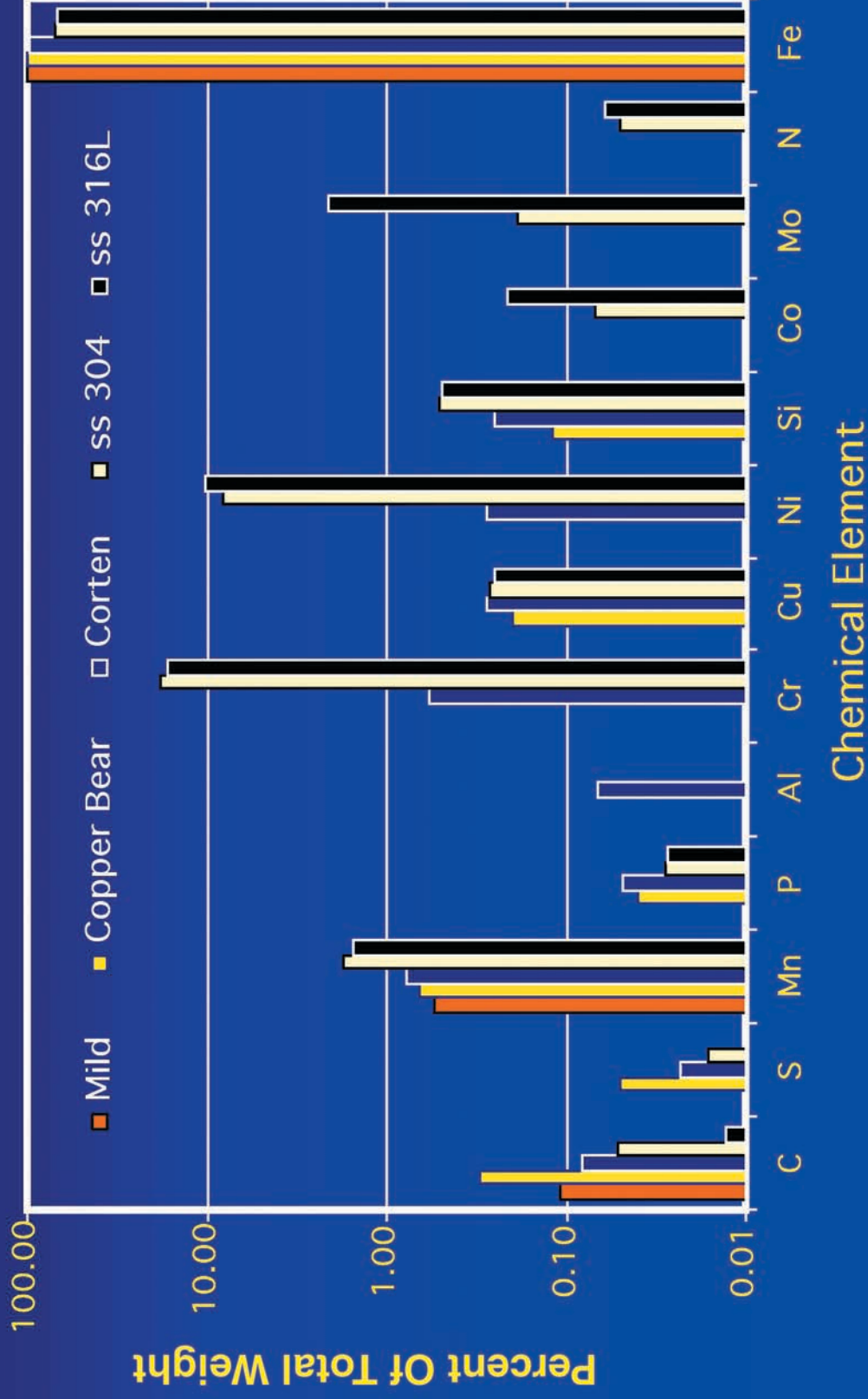
Due to its greatest resistance to corrosion effects such as pitting and material loss, stainless steel 316L is recommended for use in future well projects in the vicinity of Well No. 7. Both stainless steel coupons, especially Type 316L, had significantly lower material loss than the others. The following figure shows corrosion rates and summarizes the results of this study:

**Results of Steel Coupon Testing
City of Fountain Valley - Well No. 7**



FIGURES

Chemical Composition Of Casing And Screen Materials

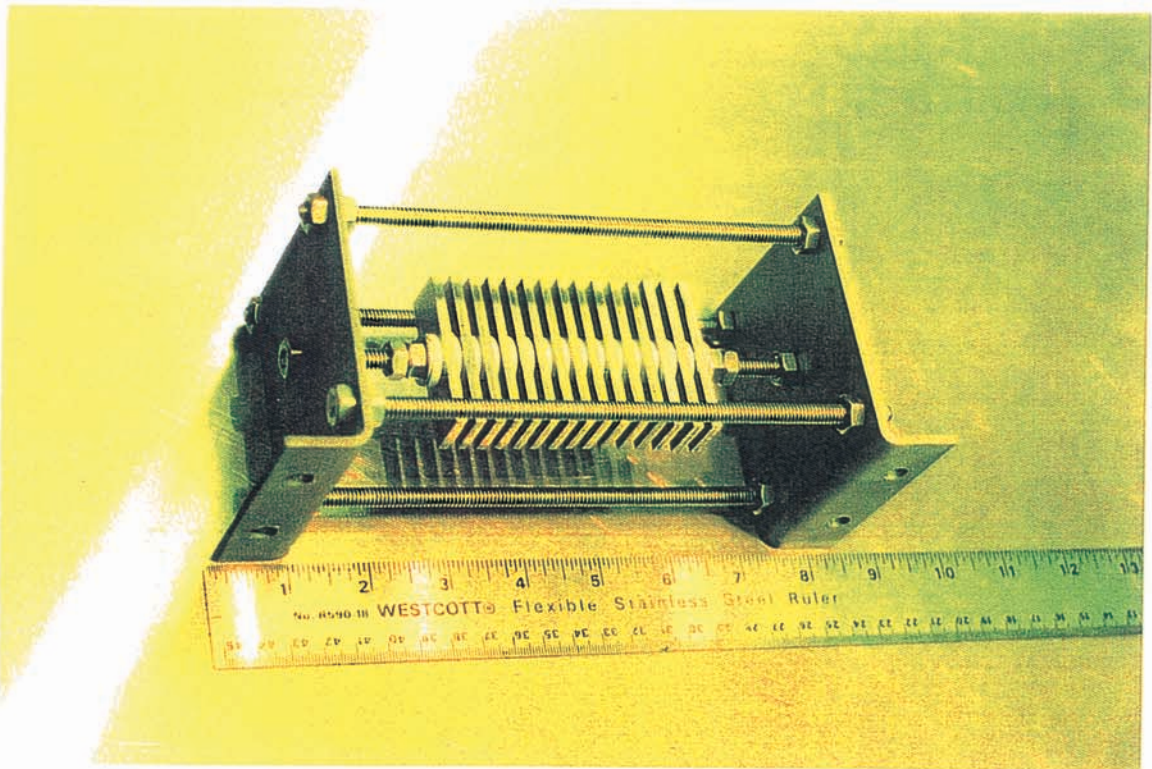


Metal Coupons and Apparatus

Figure 2



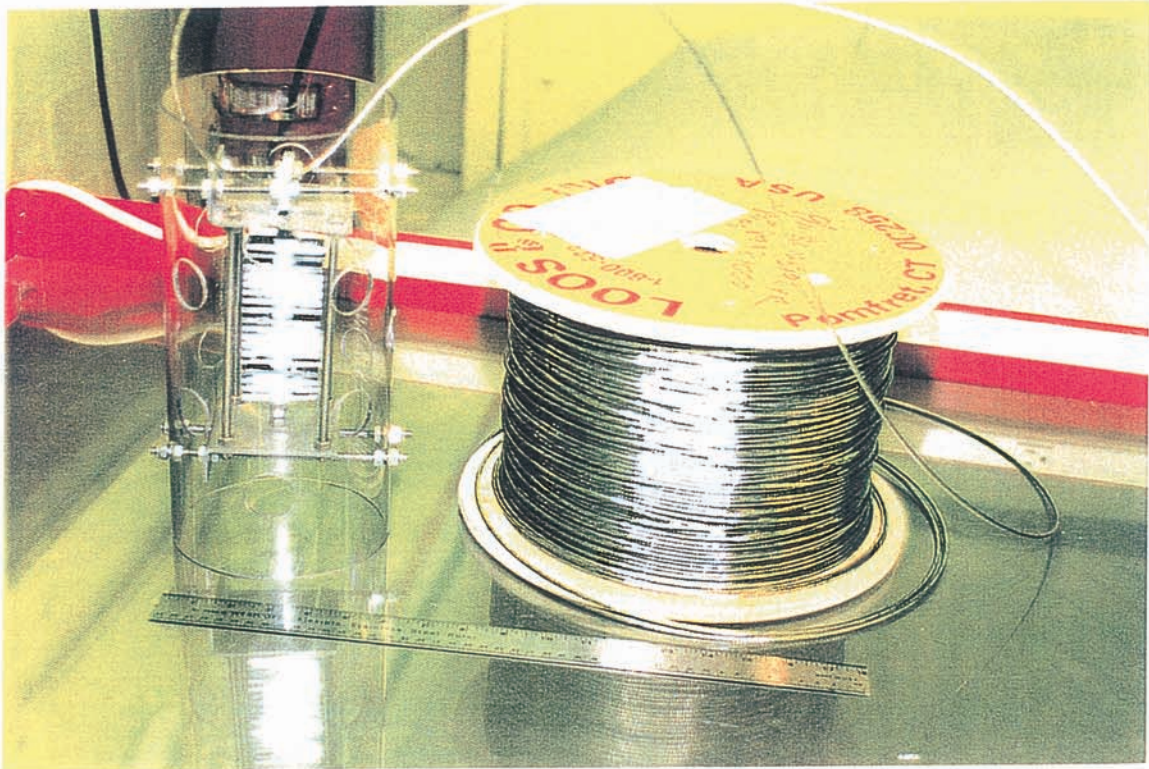
Metal Coupons Before Placement In Well No. 7



Coupons Inside Rack Apparatus

Metal Coupons and Apparatus

Figure 2a



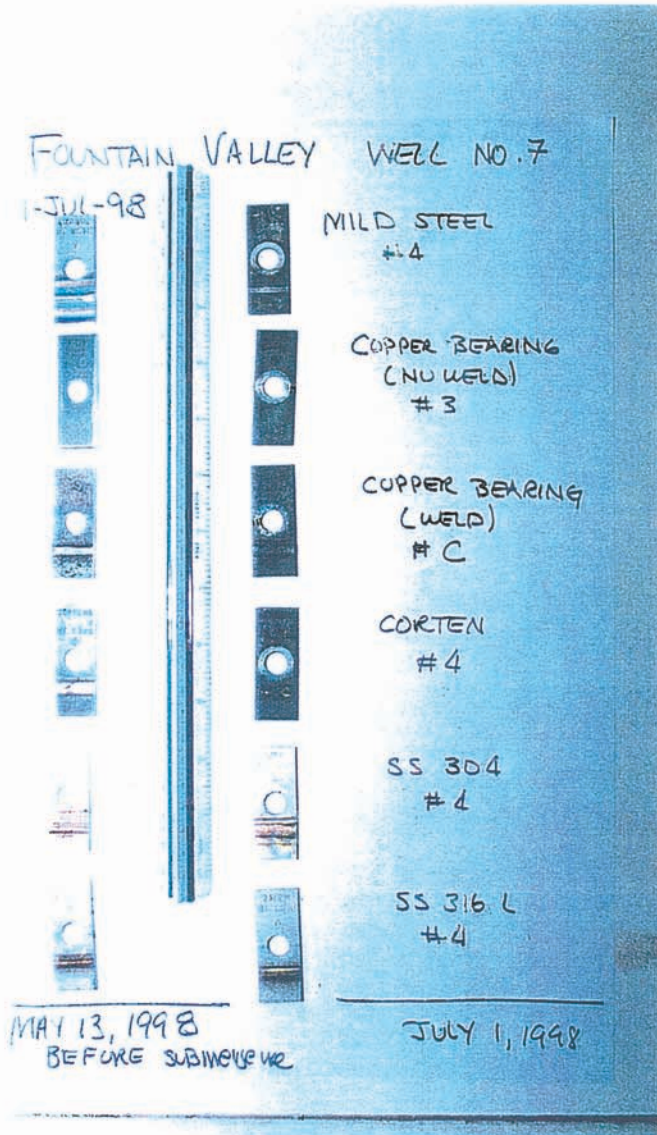
Rack Apparatus and Cable



Lowering Coupons In Well No. 7

Seven Week Comparison

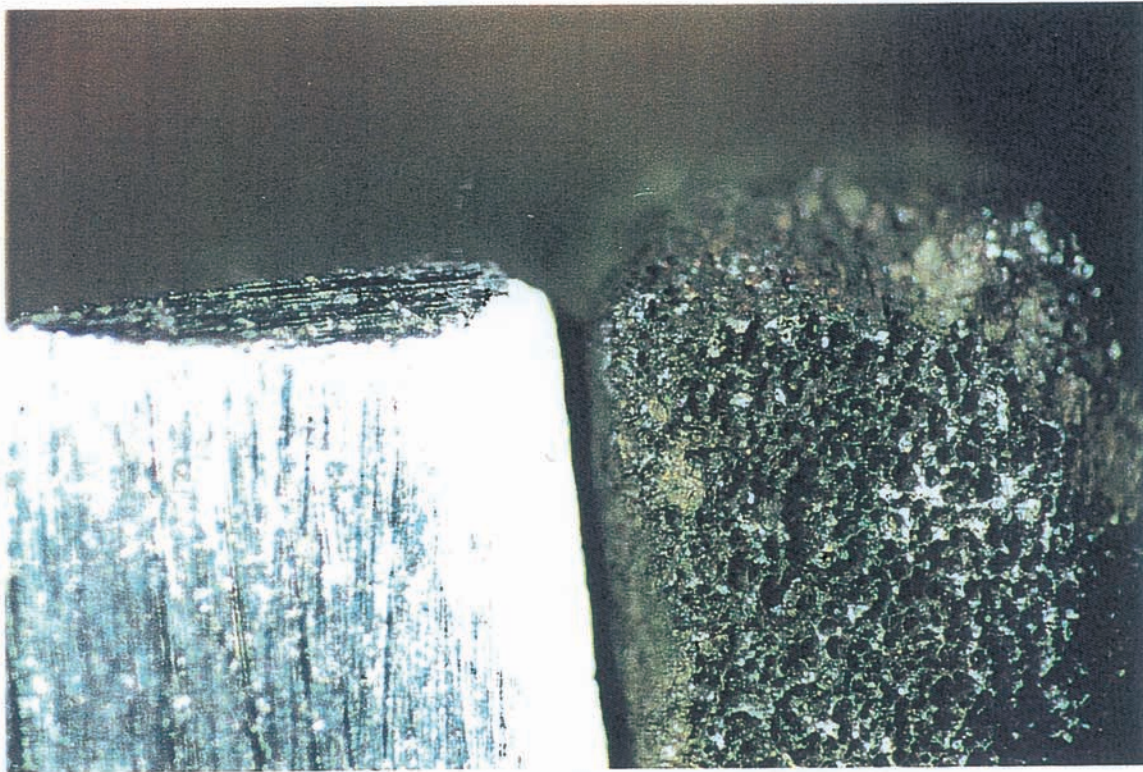
Figure 3



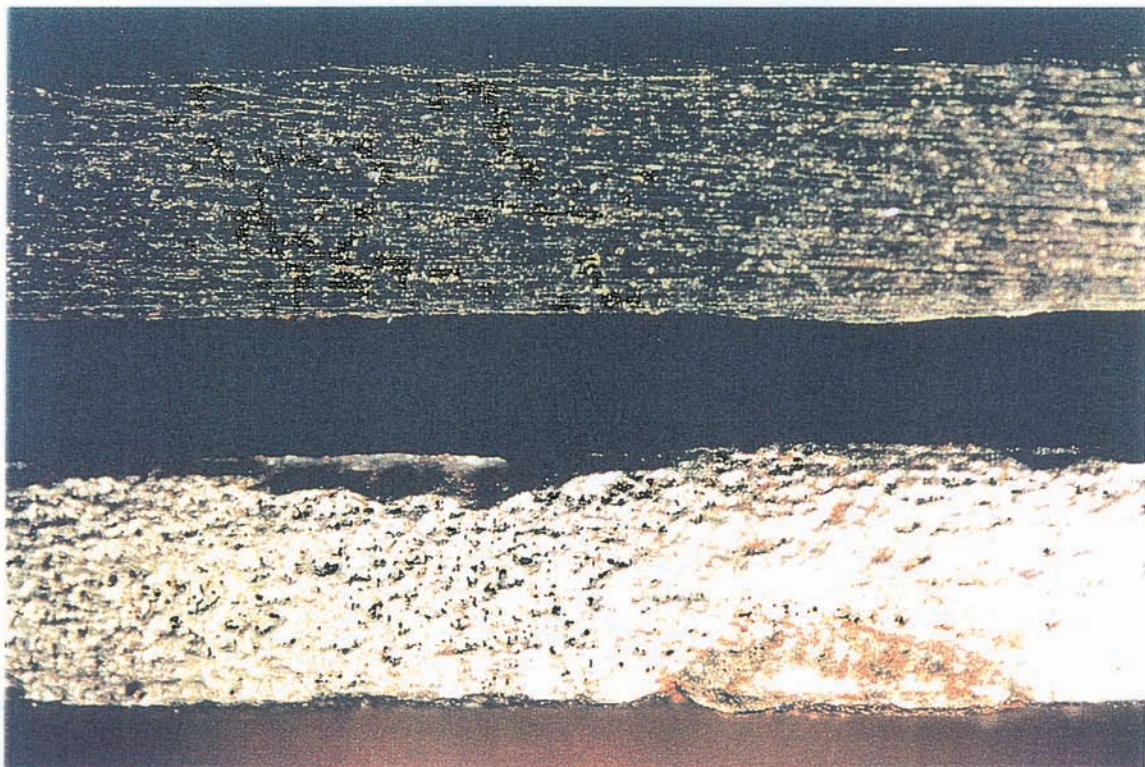
Reference Coupons (left) and Coupons After 7 Weeks Submersion (right)

**Mild Steel Coupons
After 11 Months Submergence**

Figure 4



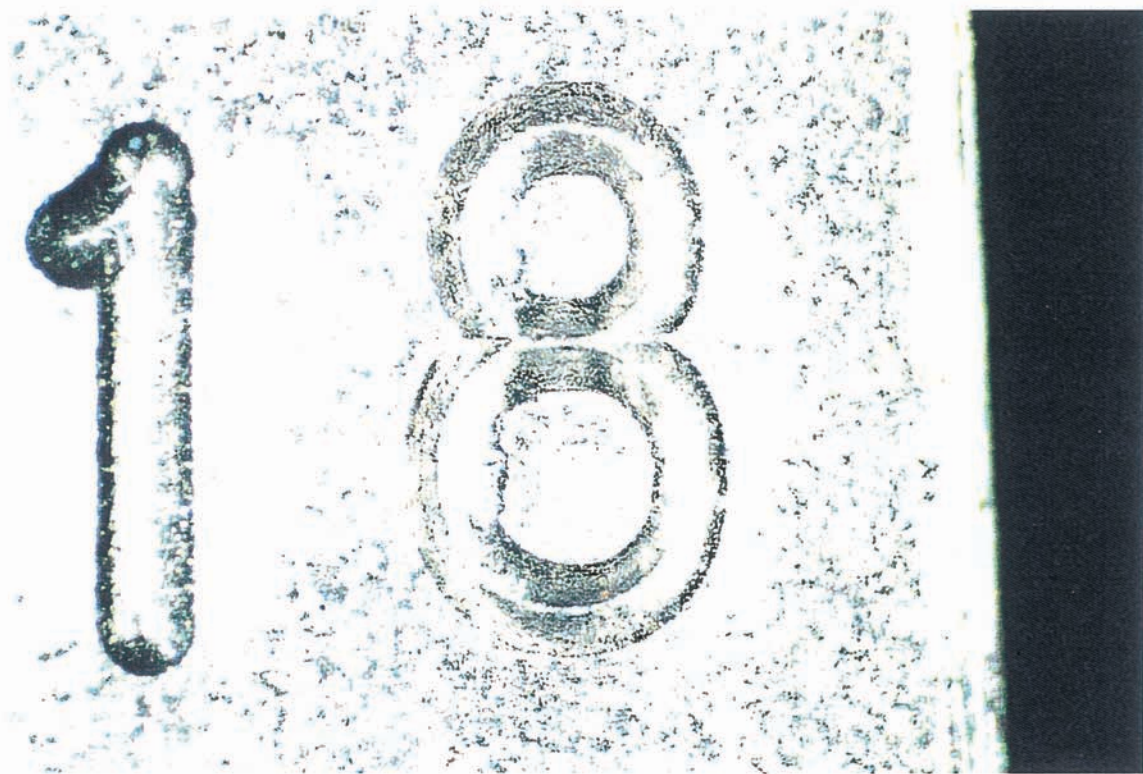
Reference (left) and Severely Pitted Mild Steel (right, x 3.5)



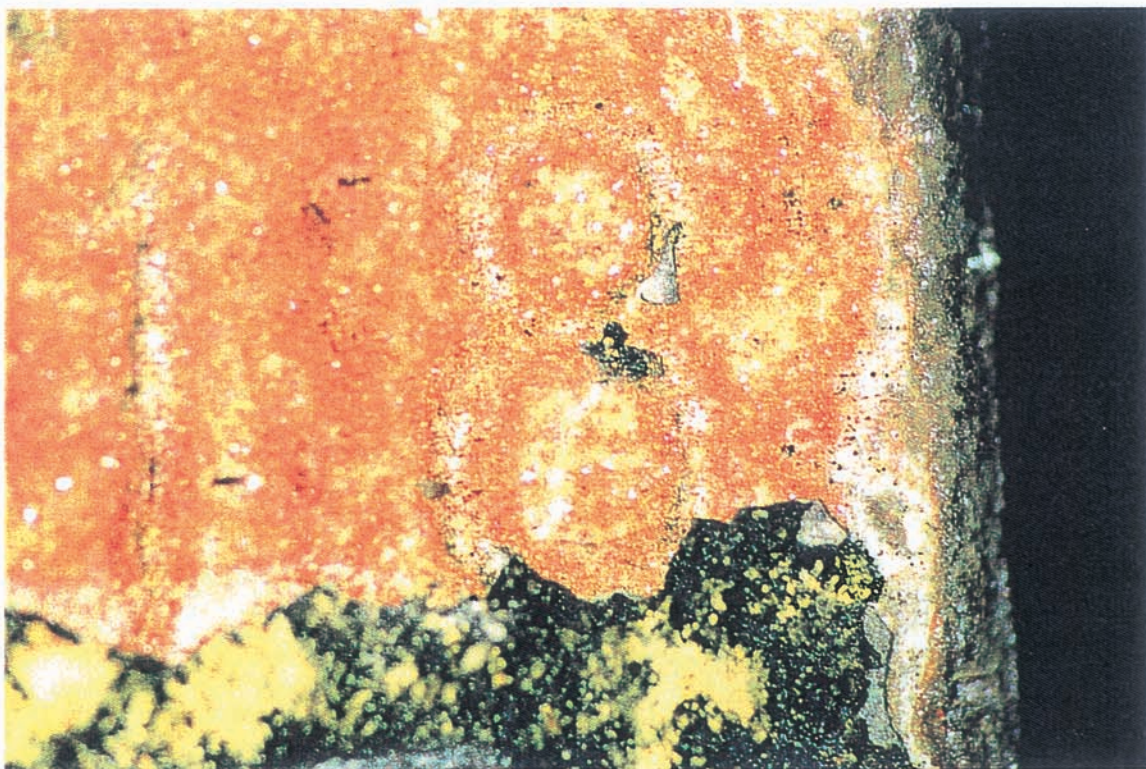
Reference (above) and Pitted Mild Steel (side view)

Mild Steel Coupons
After 11 Months Submergence

Figure 4a



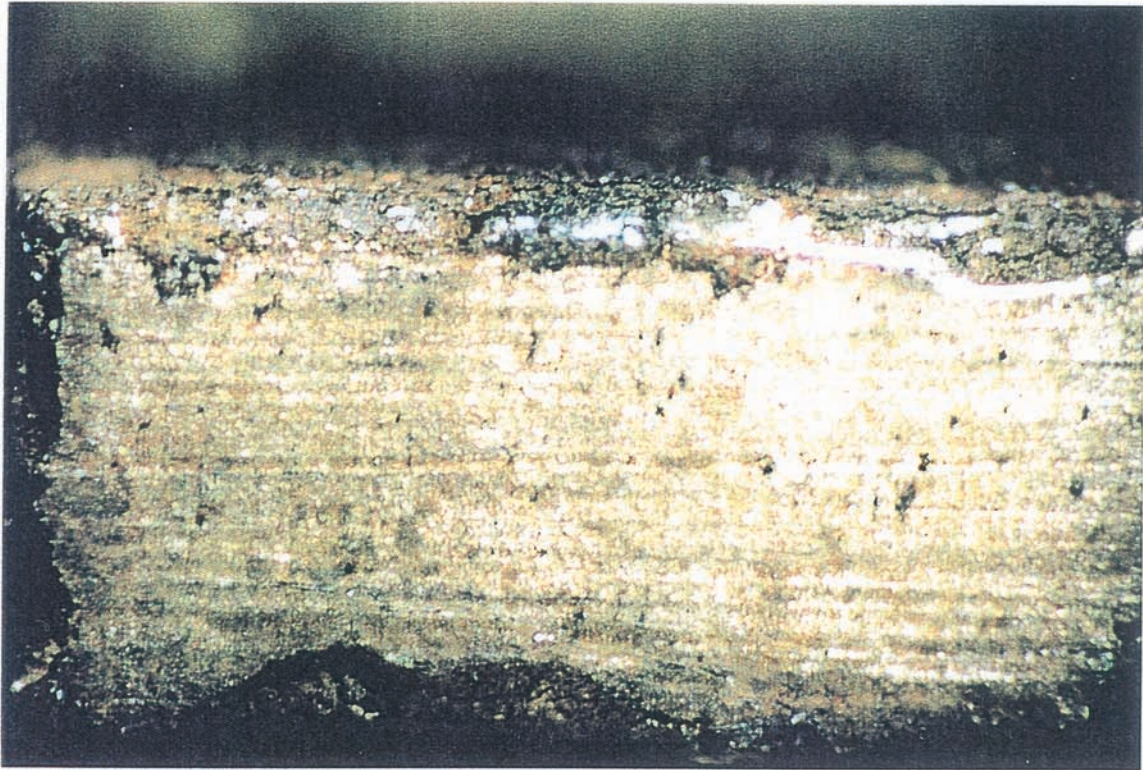
Before (x 3.5)



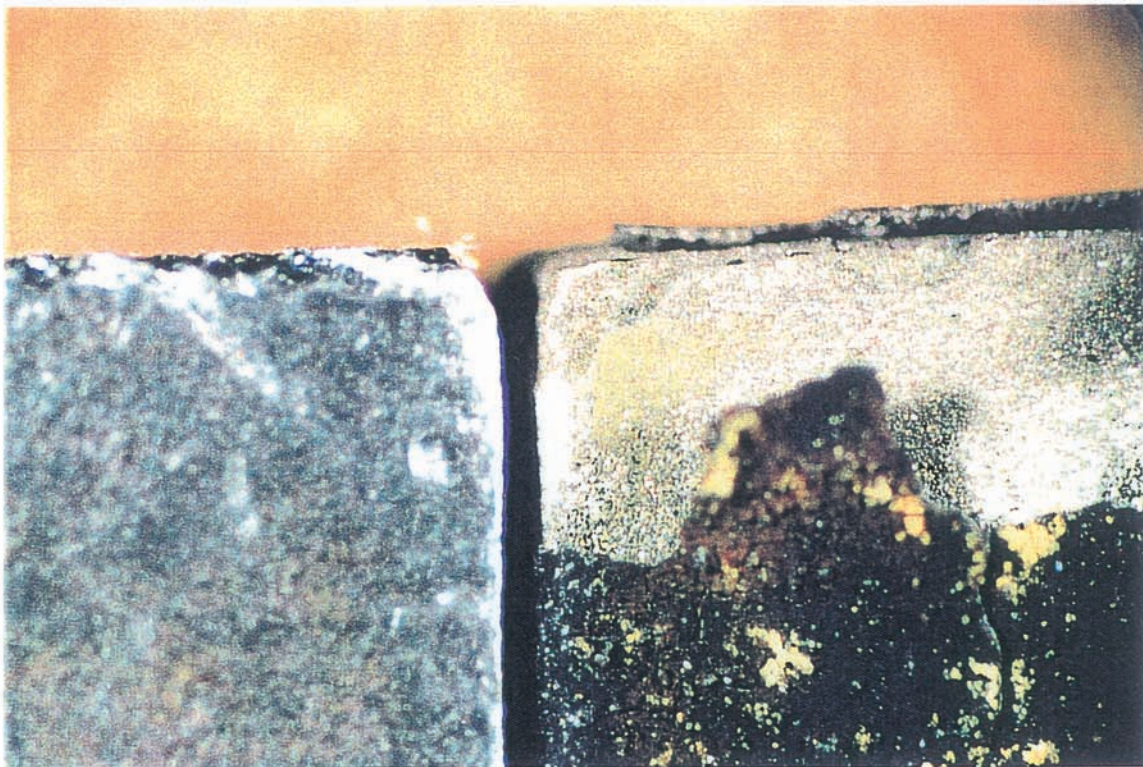
After (x 3.5)

**Corten and Copper Bearing Steel Coupons
After 11 Months Submergence**

Figure 5



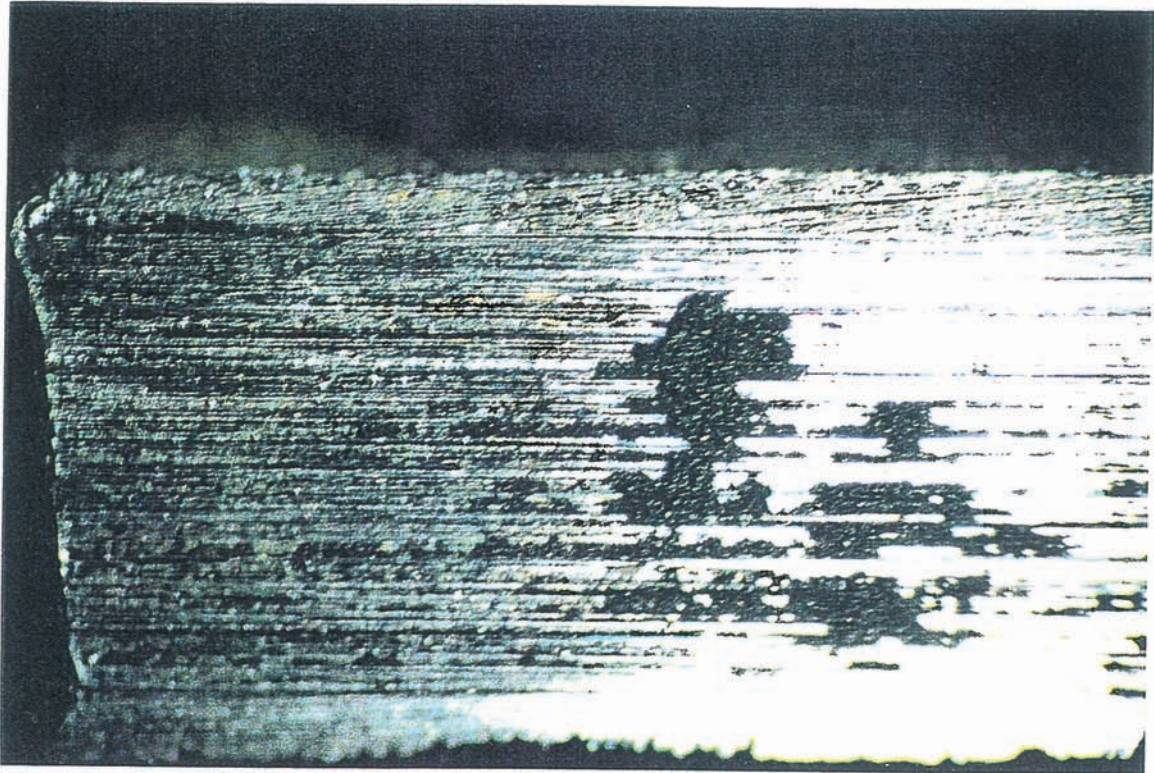
Corten Steel Coupon (x 3.5)



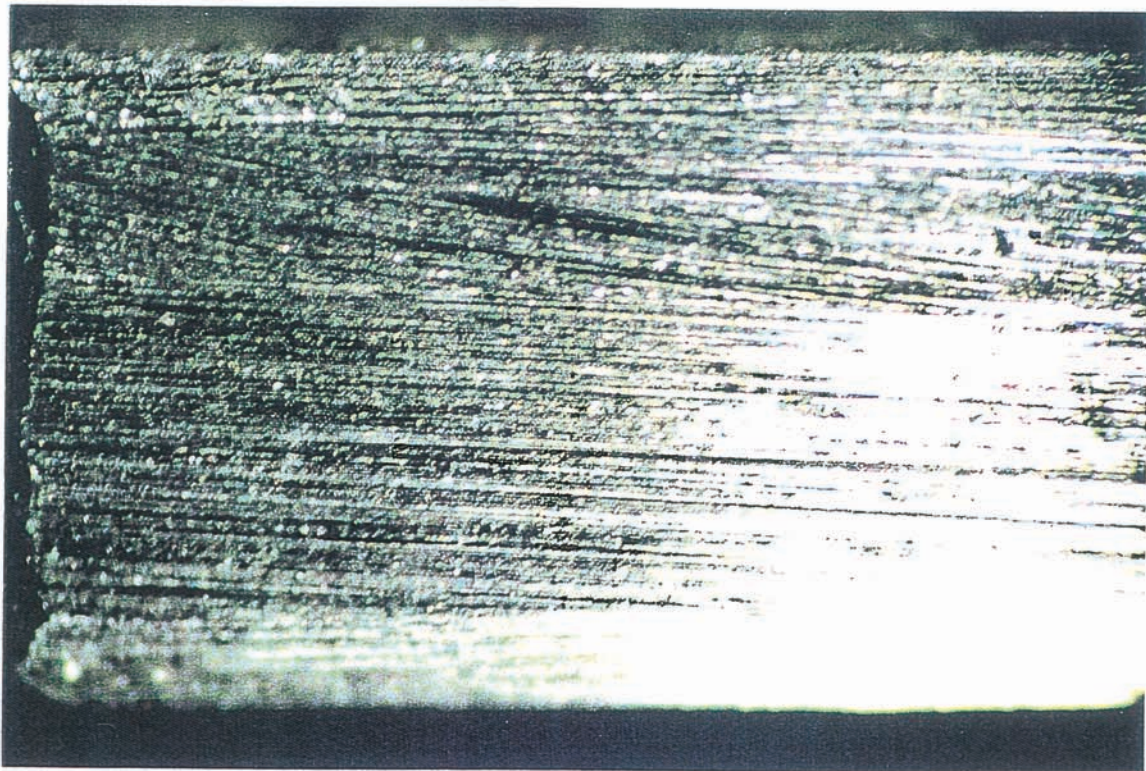
**Copper Bearing Steel Coupon (x 3.5), Reference (left) and Field
Coupon (right)**

**Stainless Steel Coupons
After 11 Months Submergence**

Figure 6



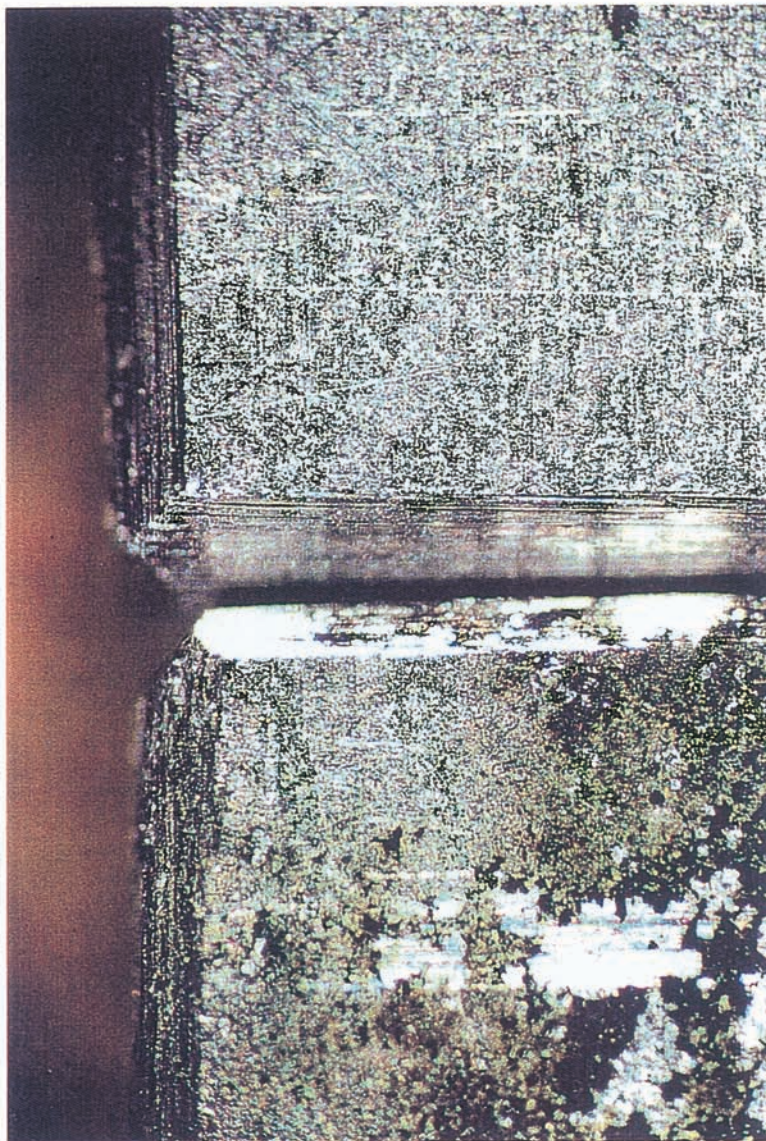
Stainless Steel 304 (x 3.5)



Stainless Steel 316L (x 3.5)

**Stainless Steel Coupons
After 11 Months Submergence**

Figure 6a



**Stainless Steel 316L (x 3.5),
Reference (above) and Field Coupon (below)**

APPENDIX A
CORROSION ANALYSIS DATASHEETS
FROM METAL SAMPLES CO., INC.

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APPENDIX A
CORROSION ANALYSIS DATA SHEETS FROM METAL SAMPLES CO., INC.

Data Sheet for Coupons Submerged 7 Weeks	A-1
Data Sheet for Coupons Submerged 11 Weeks	A-3
Data Sheet for Coupons Submerged 11 Months	A-5

Date: 07/10/98

Metal Samples Co., Inc.
 Phone: (205) 358-4202
 Corrosion Analysis Data Sheet

Customer: GEOSCIENCE
 Purchase Order: MAIL ORDER

Shop Order: 28250

Alloy	: 304	ID Number	: 4
Initial Weight	: 21.1904	Installed	: 05/13/98
Final Weight	: 21.1853	Removed	: 07/01/98
Weight Loss	: 0.0051	Hours Exposed	: 1176
Density	: 7.94 g/cm ³	Surface Area	: 3.4461 in ²
Mils Per Year	: 0.0846		
Comments	: EVEN ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: 316L	ID Number	: 4
Initial Weight	: 23.9169	Installed	: 05/13/98
Final Weight	: 23.9119	Removed	: 07/01/98
Weight Loss	: 0.0050	Hours Exposed	: 1176
Density	: 7.98 g/cm ³	Surface Area	: 3.5537 in ²
Mils Per Year	: 0.0799		
Comments	: EVEN ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: C1010	ID Number	: 4
Initial Weight	: 22.8776	Installed	: 05/13/98
Final Weight	: 22.8666	Removed	: 07/01/98
Weight Loss	: 0.0110	Hours Exposed	: 1176
Density	: 7.87 g/cm ³	Surface Area	: 3.5020 in ²
Mils Per Year	: 0.1812		
Comments	: EVEN ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: 304110	ID Number	: 3
Initial Weight	: 24.0756	Installed	: 05/13/98
Final Weight	: 24.0094	Removed	: 07/01/98
Weight Loss	: 0.0662	Hours Exposed	: 1176
Density	: 8.89 g/cm ³	Surface Area	: 3.8491 in ²
Mils Per Year	: 0.9507		
Comments	: AREAS OF ATTACK/SPOTTY ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Date: 07/10/98

Metal Samples Co., Inc.
 Phone: (205) 358-4202
 Corrosion Analysis Data Sheet

Customer: GEOSCIENCE
 Purchase Order: MAIL ORDER

Shop Order: 29250

Alloy	: CDA110	ID Number	: C
Initial Weight	: 25.0568	Installed	: 05/13/98
Final Weight	: 24.9731	Removed	: 07/01/98
Weight Loss	: 0.0837	Hours Exposed	: 1176
Density	: 8.89 g/cm ³	Surface Area	: 3.5308 in ²
Mils Per Year	: 1.2108		
Comments	: AREAS OF ATTACK/SPOTTY ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: CORTEN A	ID Number	: 4
Initial Weight	: 20.4787	Installed	: 05/13/98
Final Weight	: 20.4301	Removed	: 07/01/98
Weight Loss	: 0.0486	Hours Exposed	: 1176
Density	: 7.89 g/cm ³	Surface Area	: 3.4372 in ²
Mils Per Year	: 0.9137		
Comments	: SPOTTY ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Date: 05/10/99

Appendix A

Metal Samples Co., Inc.
Phone: (205) 358-4202
Corrosion Analysis Data Sheet

Customer: GEOSCIENCE
Purchase Order: MAIL ORDER

Shop Order: 29825

Alloy	: 304	ID Number	: 3
Initial Weight	: 21.3417	Installed	: 05/13/98
Final Weight	: 21.3382	Removed	: 07/29/98
Weight Loss	: 0.0035	Hours Exposed	: 1848
Density	: 7.94 g/cm3	Surface Area	: 3.4519 in2
Mils Per Year	: 0.0039		
Comments	: EVEN ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: 316	ID Number	: 3
Initial Weight	: 23.8245	Installed	: 05/13/98
Final Weight	: 23.8200	Removed	: 07/29/98
Weight Loss	: 0.0045	Hours Exposed	: 1848
Density	: 7.98 g/cm3	Surface Area	: 3.5274 in2
Mils Per Year	: 0.0462		
Comments	: AREAS OF ATTACK		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: 31010	ID Number	: 3
Initial Weight	: 22.9341	Installed	: 05/13/98
Final Weight	: 22.9066	Removed	: 07/29/98
Weight Loss	: 0.0275	Hours Exposed	: 1848
Density	: 7.87 g/cm3	Surface Area	: 3.5296 in2
Mils Per Year	: 0.1281		
Comments	: AREAS OF ATTACK/SPOTTY ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Alloy	: 304110	ID Number	: 2
Initial Weight	: 24.1027	Installed	: 05/13/98
Final Weight	: 24.0426	Removed	: 07/29/98
Weight Loss	: 0.0601	Hours Exposed	: 1848
Density	: 8.99 g/cm3	Surface Area	: 3.5758 in2
Mils Per Year	: 0.5463		
Comments	: AREAS OF ATTACK/SPOTTY ETCH		
Location	: FOUNTAIN VALLEY WELL NO. 7		

Date: 05/10/99

metal Samples Co., Inc.
 Phone: (205) 358-4202
 Corrosion Analysis Data Sheet

Customer: GEOSCIENCE
 Purchase Order: MAIL ORDER

Shop Order: 29625

Alloy : CDA110
 Initial Weight : 25.0474
 Final Weight : 24.9513
 Weight Loss : 0.0961
 Density : 8.89 g/cm³

ID Number : 8
 Installed : 05/13/98
 Removed : 07/29/98
 Hours Exposed : 1848
 Surface Area : 3.5758 in²

Mils Per Year : 0.8736
 Comments : AREAS OF ATTACK/SPOTTY ETCH
 Location : FOUNTAIN VALLEY WELL NO. 7

Alloy : CORTEN A
 Initial Weight : 20.4439
 Final Weight : 20.3888
 Weight Loss : 0.0551
 Density : 7.89 g/cm³

ID Number : 3
 Installed : 05/13/98
 Removed : 07/29/98
 Hours Exposed : 1848
 Surface Area : 3.3964 in²

Mils Per Year : 0.5941
 Comments : AREAS OF ATTACK/SPOTTY ETCH
 Location : FOUNTAIN VALLEY WELL NO. 7

Date: 04/14/99

Metal Samples Co., Inc.
Phone: (205) 358-4202
Corrosion Analysis Data Sheet

Customer: GEOSCIENCE
Purchase Order: MAIL ORDER

Shop Order: 35540

Alloy	: 304	ID Number	: 2
Initial Weight	: 21.3013	Installed	: 05/13/98
Final Weight	: 21.2966	Removed	: 04/02/99
Weight Loss	: 0.0047	Hours Exposed	: 7776
Density	: 7.94 g/cm ³	Surface Area	: 3.4734 in ²
Mils Per Year	: 0.0118		
Comments	: EVEN ETCH		
Location	: FOUNTAIN VALLEY WELL		

Alloy	: 316L	ID Number	: 2
Initial Weight	: 23.7475	Installed	: 05/13/98
Final Weight	: 23.7450	Removed	: 04/02/99
Weight Loss	: 0.0025	Hours Exposed	: 7776
Density	: 7.98 g/cm ³	Surface Area	: 3.5071 in ²
Mils Per Year	: 0.0061		
Comments	: EVEN ETCH		
Location	: FOUNTAIN VALLEY WELL		

Alloy	: C1010	ID Number	: 2
Initial Weight	: 22.8772	Installed	: 05/13/98
Final Weight	: 21.7268	Removed	: 04/02/99
Weight Loss	: 1.1504	Hours Exposed	: 7776
Density	: 7.87 g/cm ³	Surface Area	: 3.4862 in ²
Mils Per Year	: 2.8794		
Comments	: GENERAL OVERALL ATTACK		
Location	: FOUNTAIN VALLEY WELL		

Alloy	: CDA110	ID Number	: 1
Initial Weight	: 23.9882	Installed	: 05/13/98
Final Weight	: 23.5627	Removed	: 04/02/99
Weight Loss	: 0.4255	Hours Exposed	: 7776
Density	: 8.29 g/cm ³	Surface Area	: 3.5017 in ²
Mils Per Year	: 0.9389		
Comments	: AREAS OF ATTACK		
Location	: FOUNTAIN VALLEY WELL		

Appendix A

Date: 04/14/99

Metal Samples Co., Inc.
Phone: (205) 356-4202
Corrosion Analysis Data Sheet

Customer: GEOSCIENCE
Purchase Order: MAIL ORDER

Shop Order: 35540

Alloy : CDA110
Initial Weight : 24.9704
Final Weight : 24.7210
Weight Loss : 0.2492
Density : 8.89 g/cm³
ID Number : A
Installed : 05/13/98
Removed : 04/02/99
Hours Exposed : 7776
Surface Area : 3.5084 in²
Mils Per Year : 0.5487
Comments : AREAS OF ATTACK/SPOTTY ETCH
Location : FOUNTAIN VALLEY WELL

Alloy : CORTEN A
Initial Weight : 19.9477
Final Weight : 19.8263
Weight Loss : 0.1214
Density : 7.89 g/cm³
ID Number : 2
Installed : 05/13/98
Removed : 04/02/99
Hours Exposed : 7776
Surface Area : 3.3749 in²
Mils Per Year : 0.3131
Comments : AREAS OF ATTACK/SPOTTY ETCH
Location : FOUNTAIN VALLEY WELL

APPENDIX B
SCANNING ELECTRON
MICROSCOPE PHOTOGRAPHS

CONTENTS
APPENDIX B
SCANNING ELECTRON MICROSCOPE PHOTOGRAPHS
TAKEN AFTER 11 MONTHS

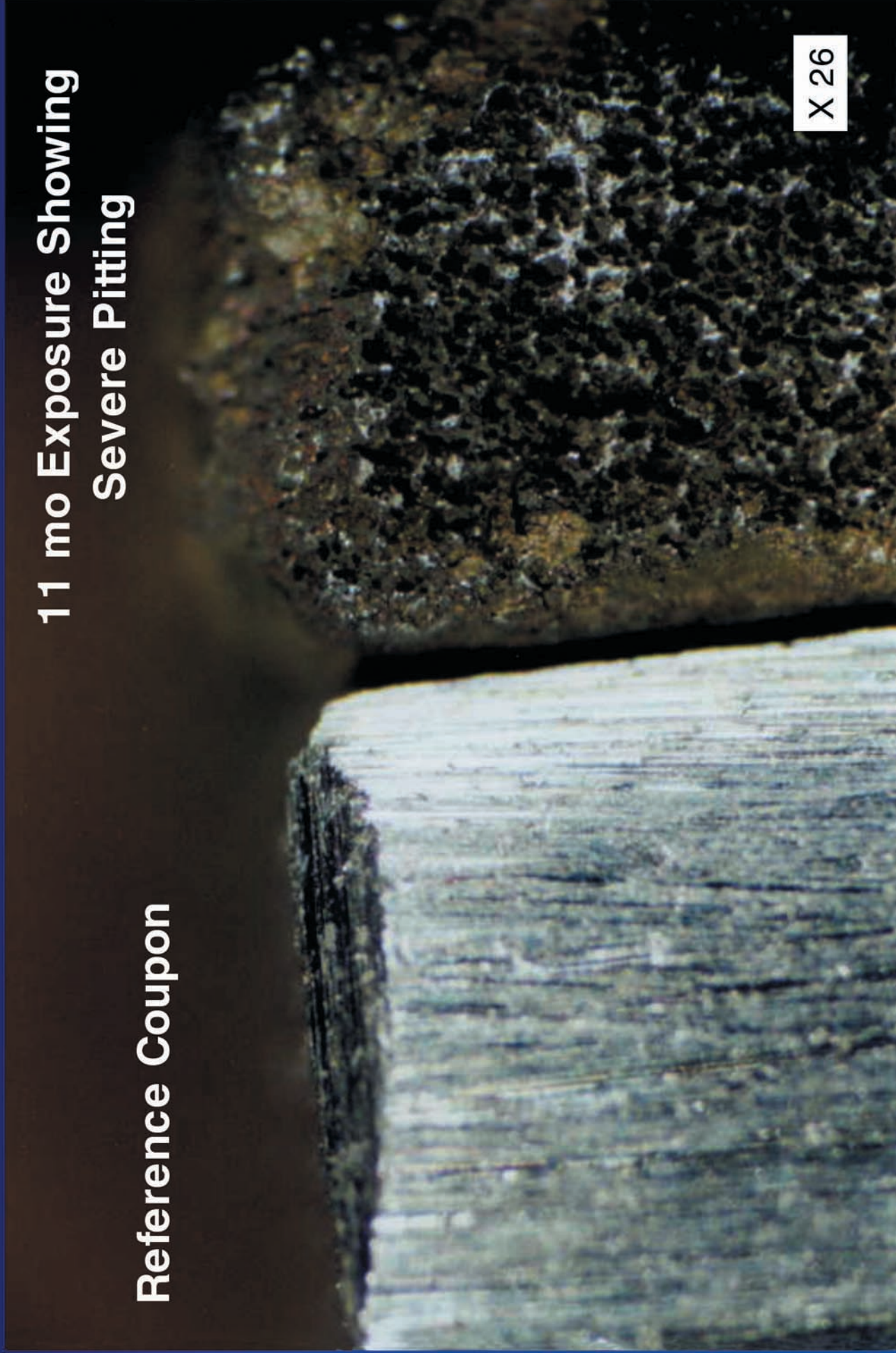
Mild Steel - Reference Coupon (x300)	B-1
Mild Steel - Non-Scale Area (x300)	B-2
Mild Steel - Scale Area (x300)	B-3
Mild Steel - Scale Area (x1400)	B-4
Copper Bearing Steel - Reference Coupon (x300)	B-5
Copper Bearing Steel - Non-Scale Area (x300)	B-6
Copper Bearing Steel - Non-Scale Area (x2000)	B-7
Copper Bearing Steel - Scale Area (x300)	B-8
Copper Bearing Steel - Scale Area (x50)	B-9
Corten Steel - Reference Coupon (x300)	B-10
Corten Steel - Non-Scale Area (x300)	B-11
Corten Steel - Scale Area (x300)	B-12
Corten Steel - Scale Area - Crystals (x300)	B-13

Corten Steel - Non-Scale Area (x20)	B-14
Corten Steel - Non-Scale Area (x300)	B-15
Corten Steel - Non-Scale Area (x800)	B-16
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Stainless Steel 304 - Reference Coupon (x300)	B-18
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Light Microscope Photographs - Mild Steel

11 mo Exposure Showing
Severe Pitting

Reference Coupon



X 26

Mild Steel Coupon After 11 Months

SEVERE PITTING

SCALE

X 26



Mild Steel After 11 Mo. Exposure



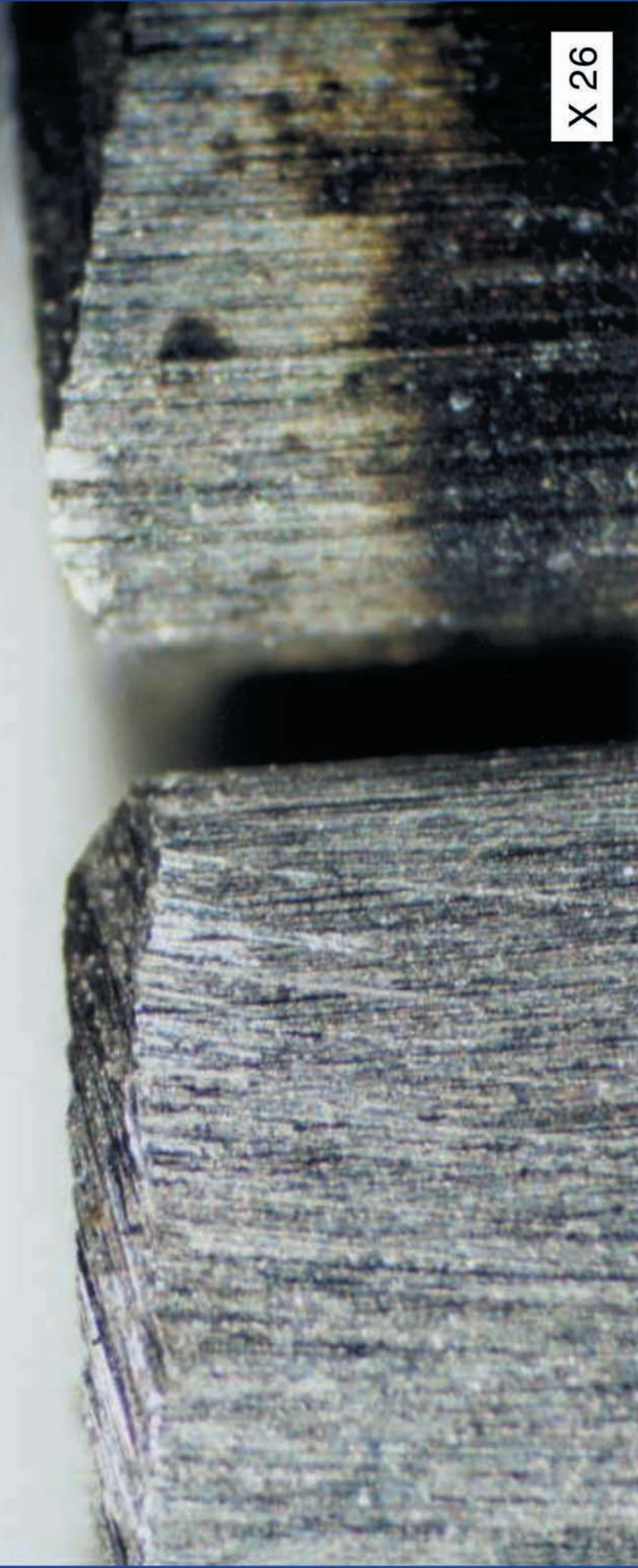
Note Severe Pitting

X 26

Stainless Steel 316L

Reference Coupon

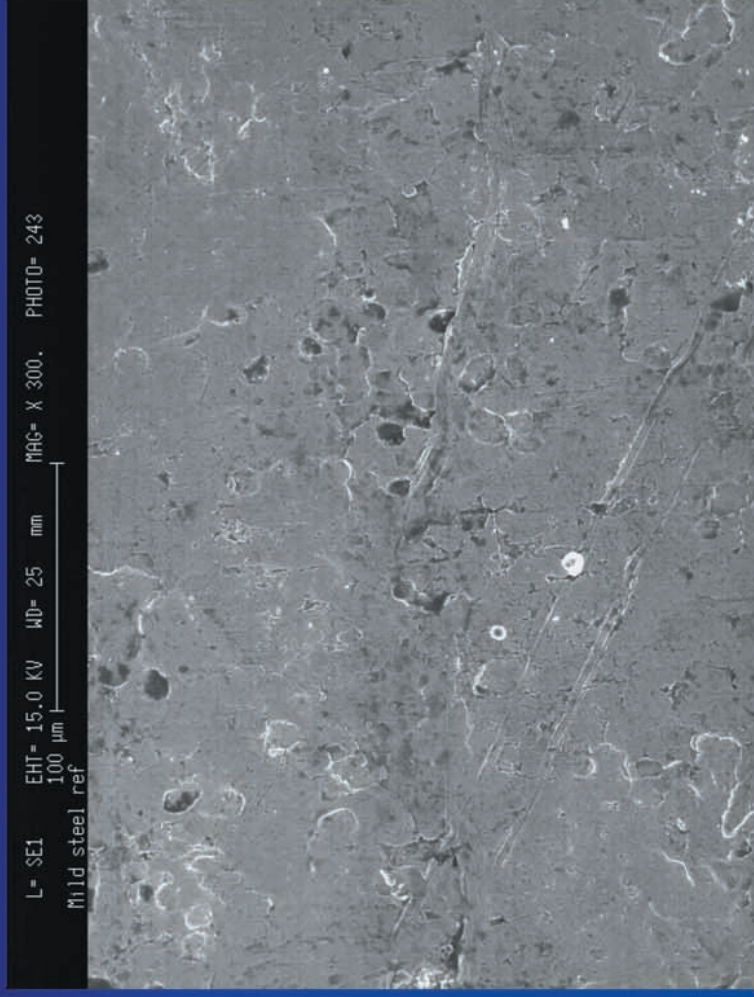
11 mo Exposure



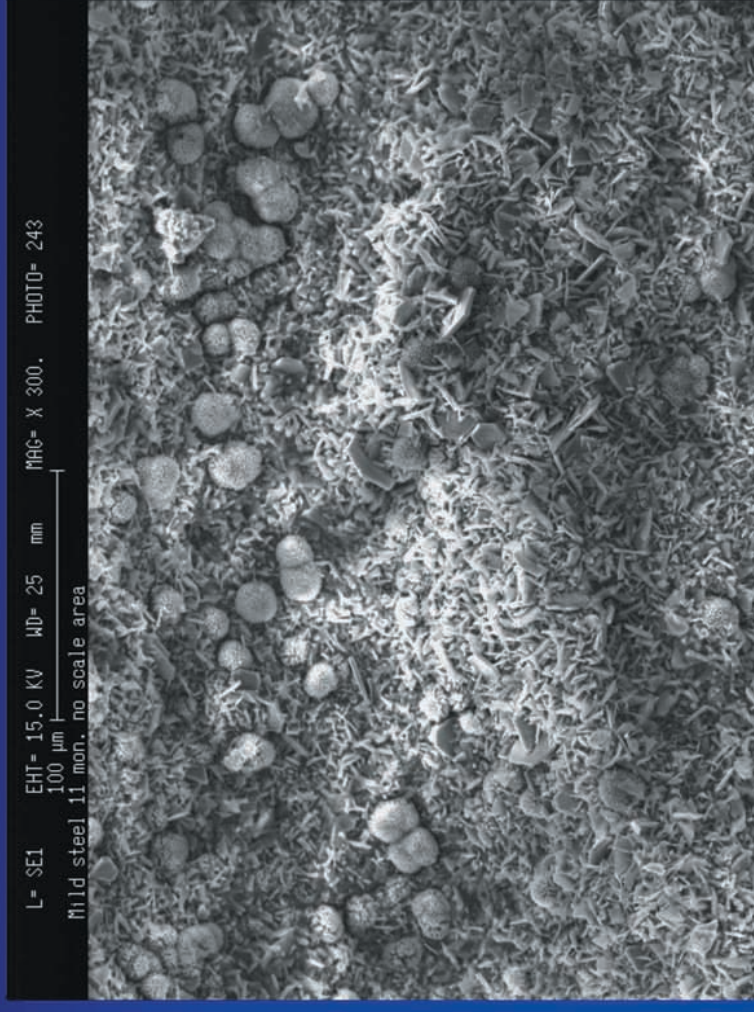
X 26

Scanning Electron Microscope (SEM) - Mild Steel

Reference Coupon Surface



11 Month Exposure



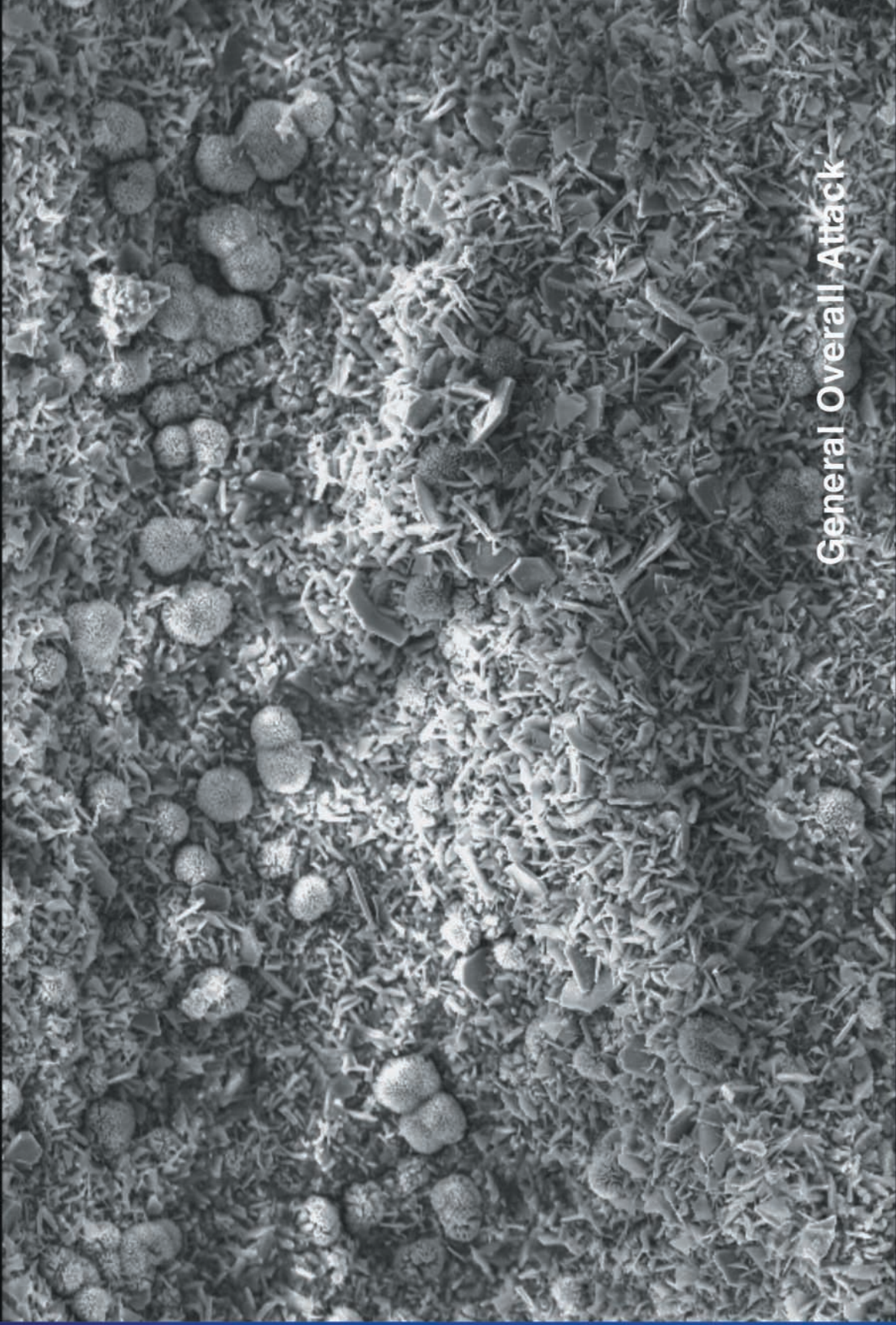
General Overall Attack

X 300

USC Center For Electron Microscopy And Microanalysis (CEMMA)

Exposure

L= SE1 EHT= 15.0 KV WD= 25 mm MAG= X 300. PHOTO= 243
100 μ m
Mild steel 11 mon. no scale area



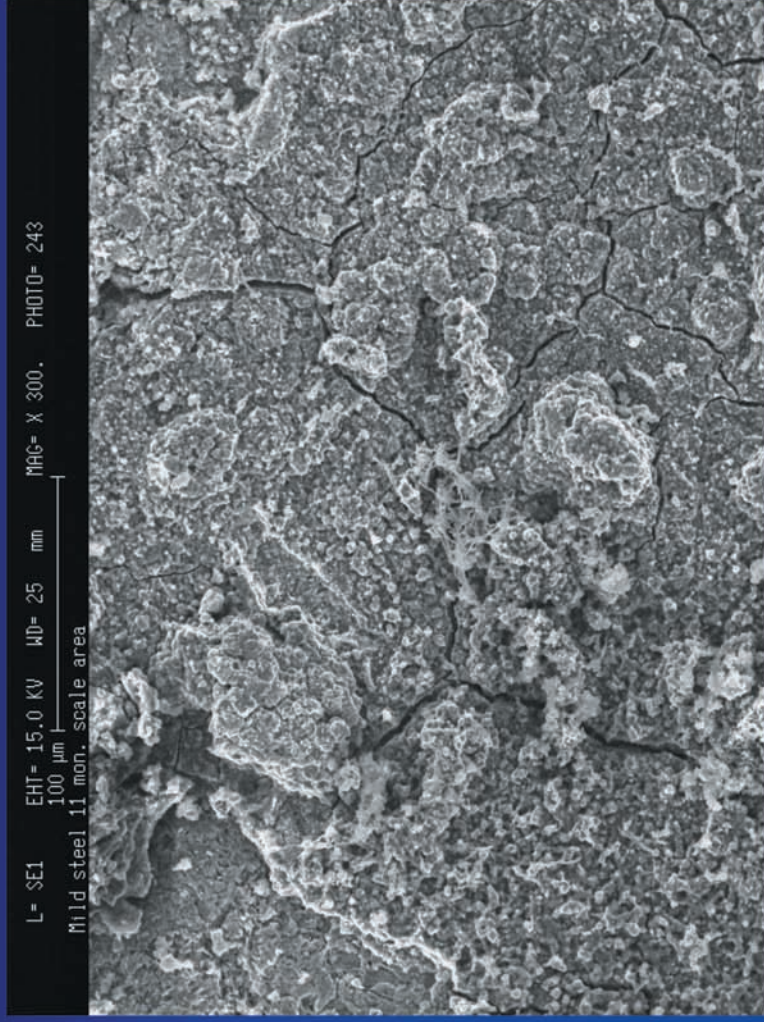
General Overall Attack

Iron Oxide
Nodules And
Hexagonal
Crystals

X 300

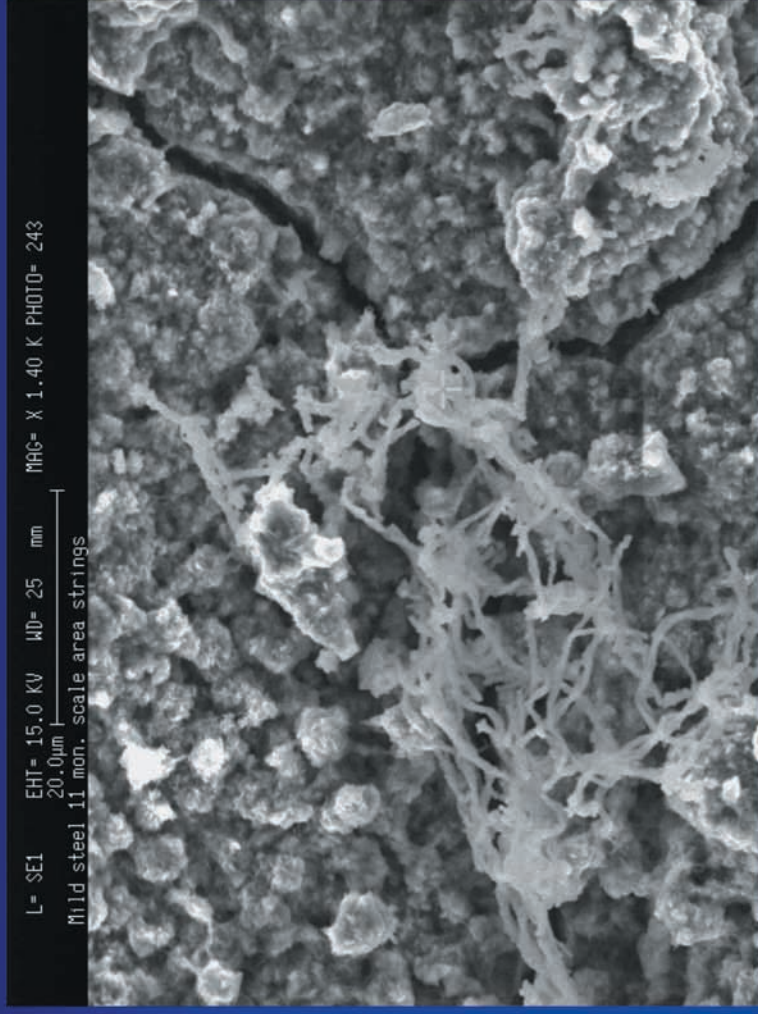
Scanning Electron Microscope - Mild Steel

11-Mo Exposure



Scale

X 300

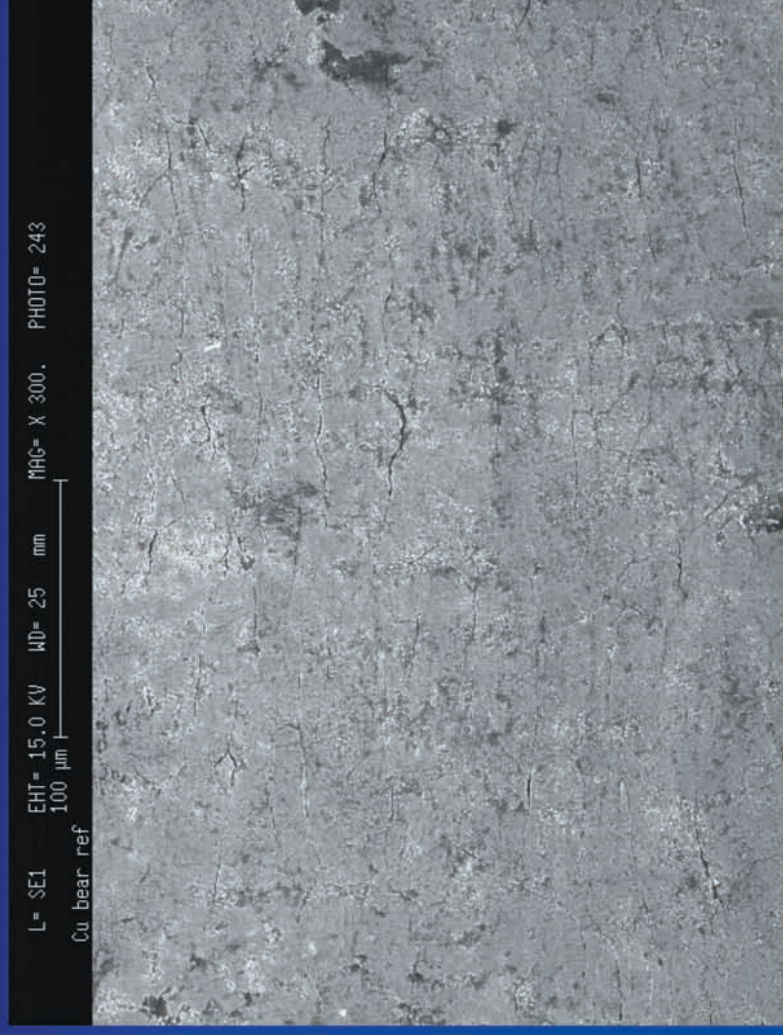


Note "String"
Like Material

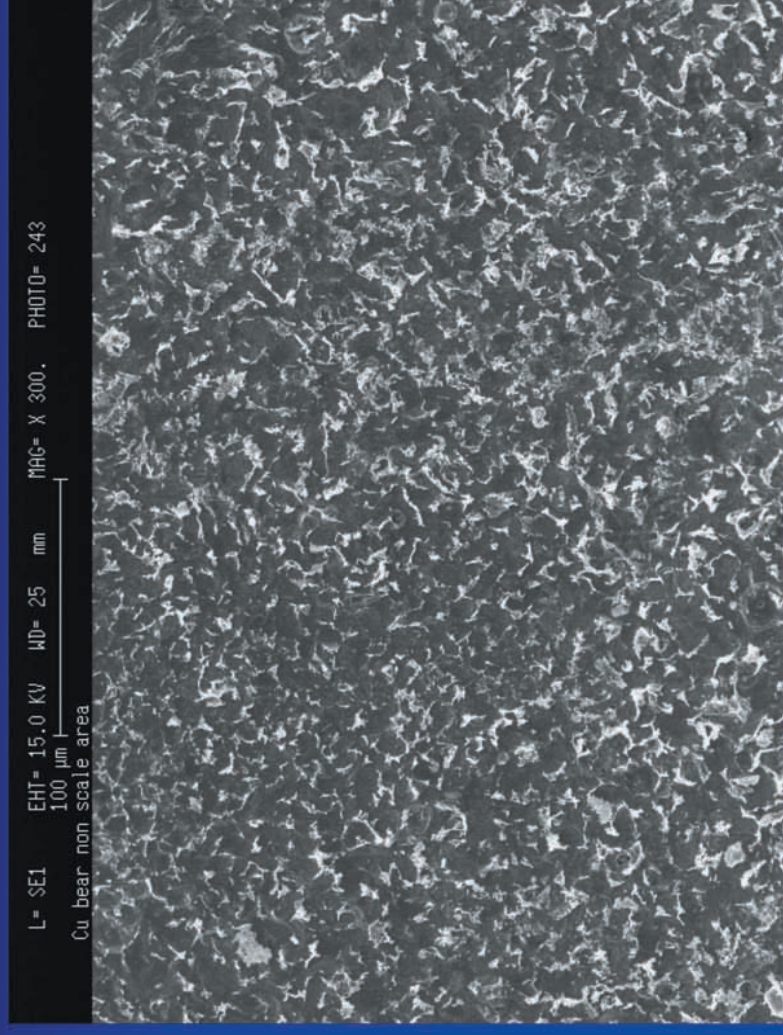
X 1400

SEM Copper Bearing Steel

Reference Coupon Surface



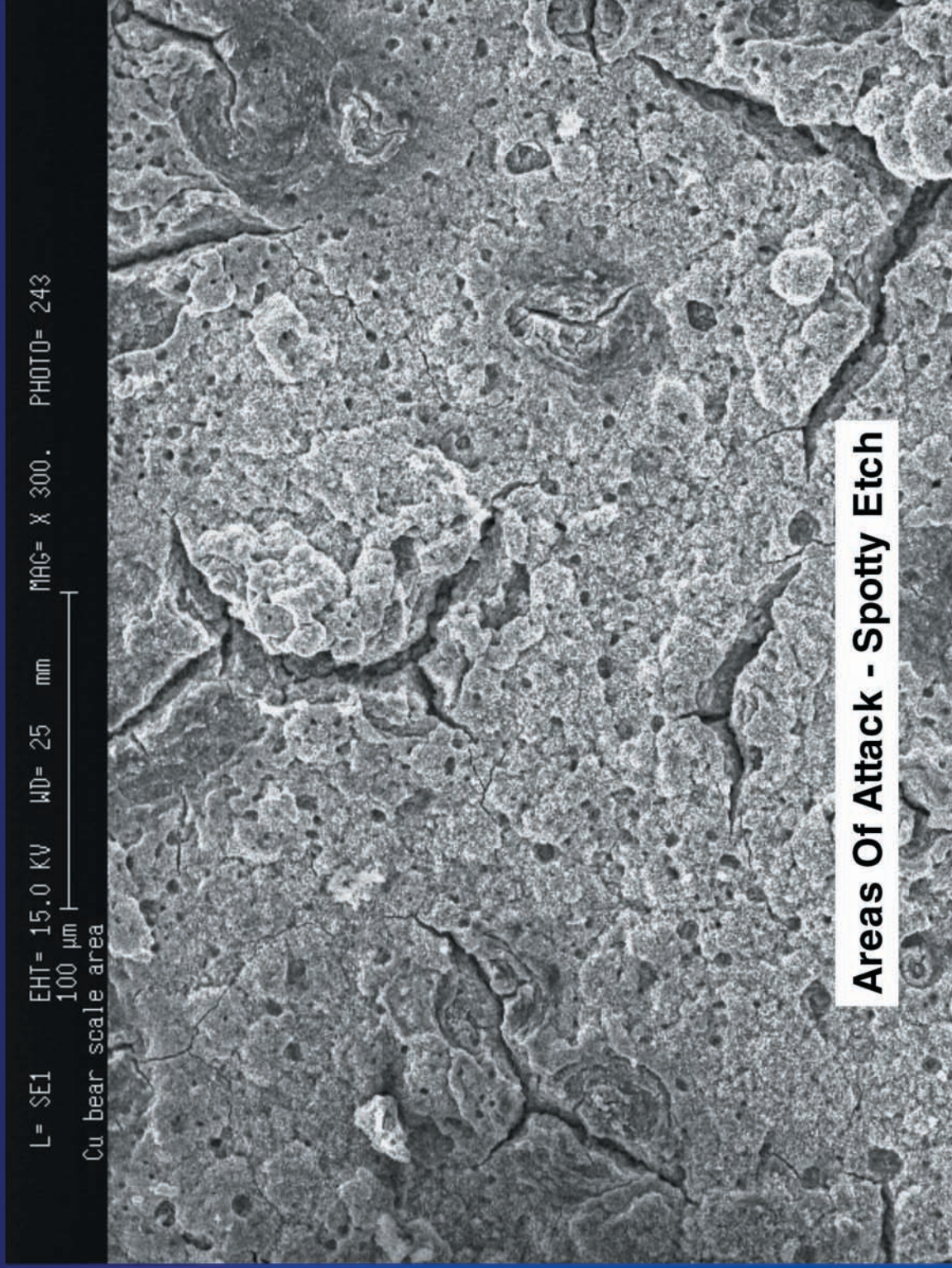
11 Month Exposure



Areas Of Attack - Spotty Etch

X 300

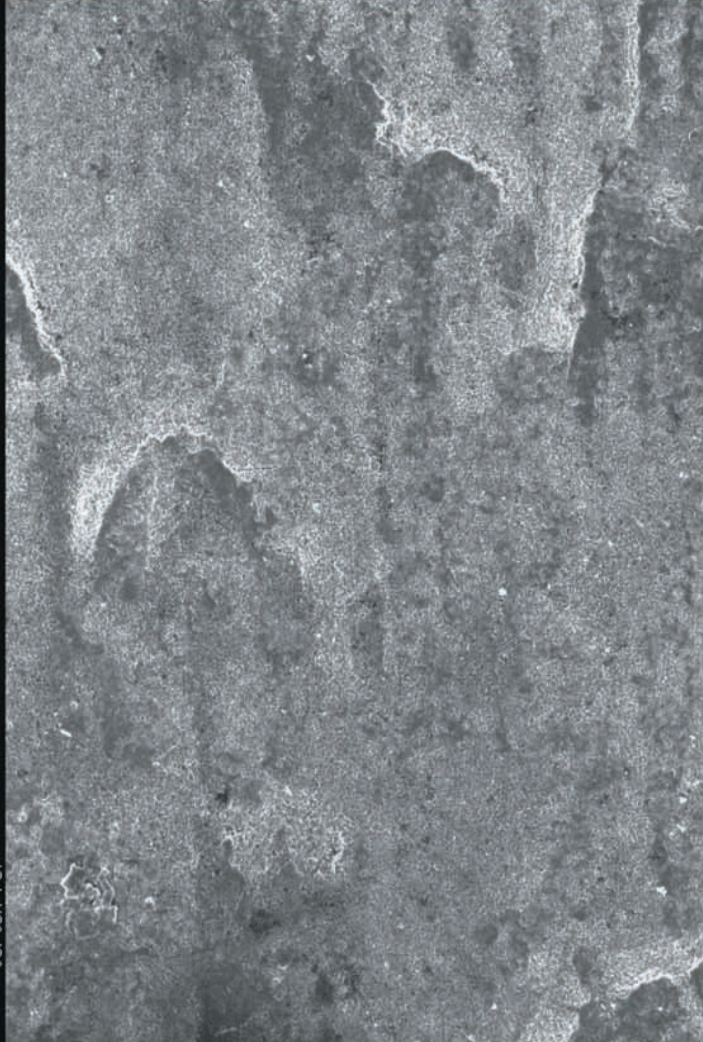
Copper Bearing Steel (11 Mo. Exposure)



SEM Corten Steel

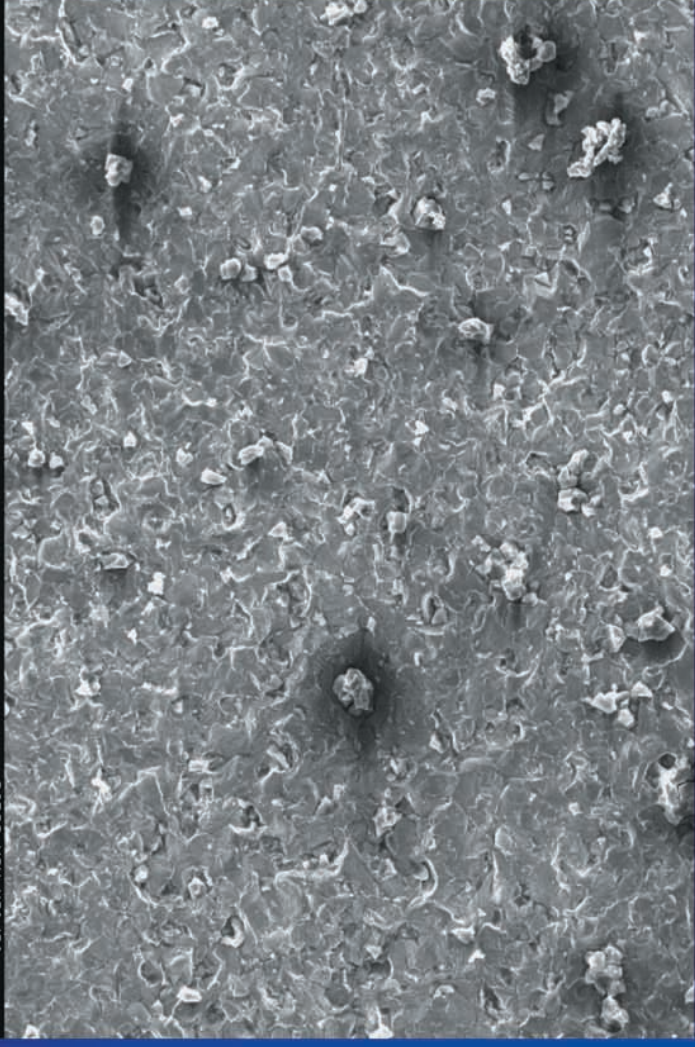
Reference Coupon Surface

L= SE1 EHT= 15.0 KV WD= 25 mm MAG= X 300. PHOTO= 243
Corten.ref
100 µm



11 Month Exposure

L= SE1 EHT= 15.0 KV WD= 26 mm MAG= X 300. PHOTO= 243
Corten.non scale
100 µm

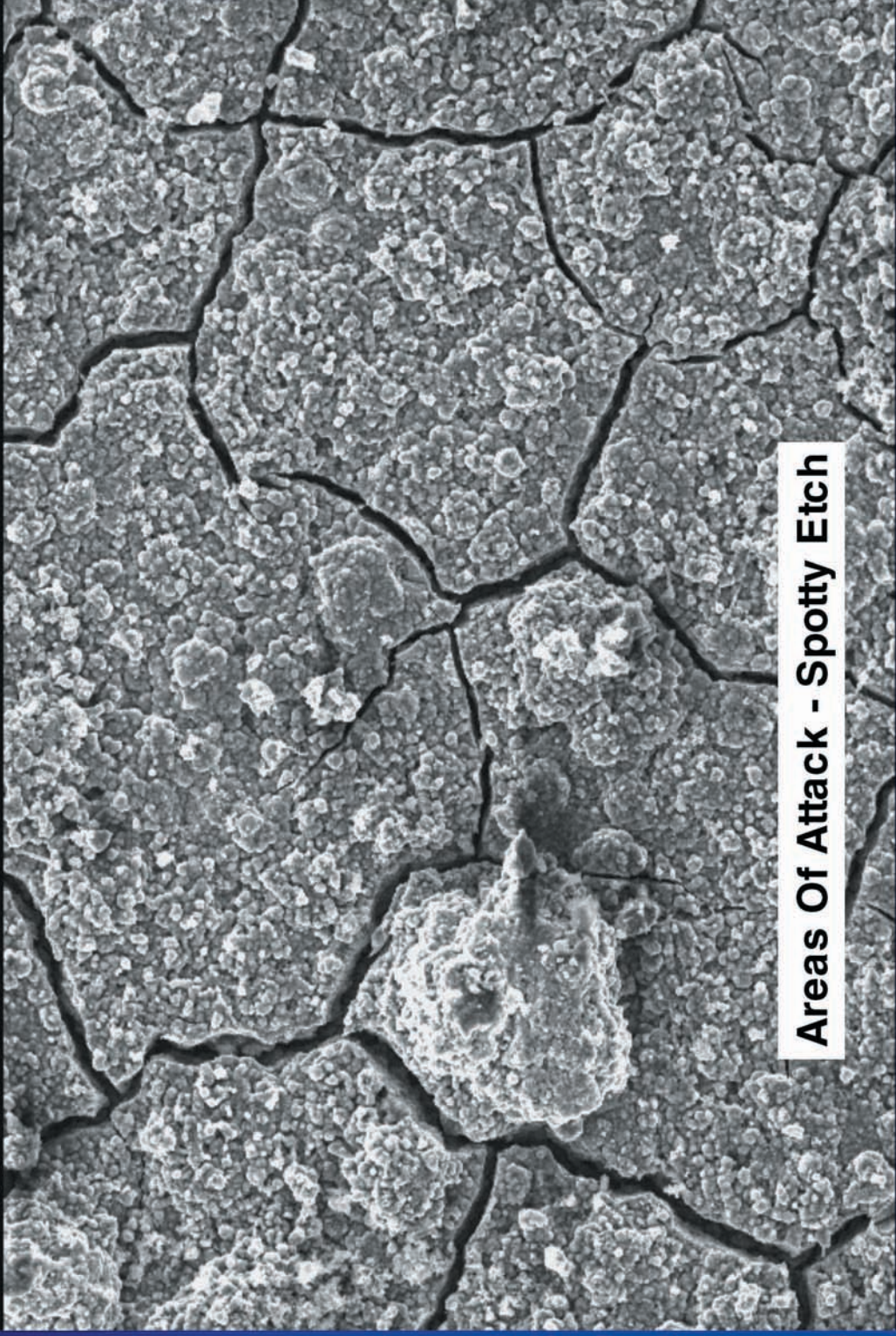


Areas Of Attack - Spotty Etch

X 300

Corten Steel (11 Mo. Exposure)

L= SE1 EHT= 15.0 KV WD= 26 mm MAG= X 300. PHOTO= 243
100 µm
Corten non scale

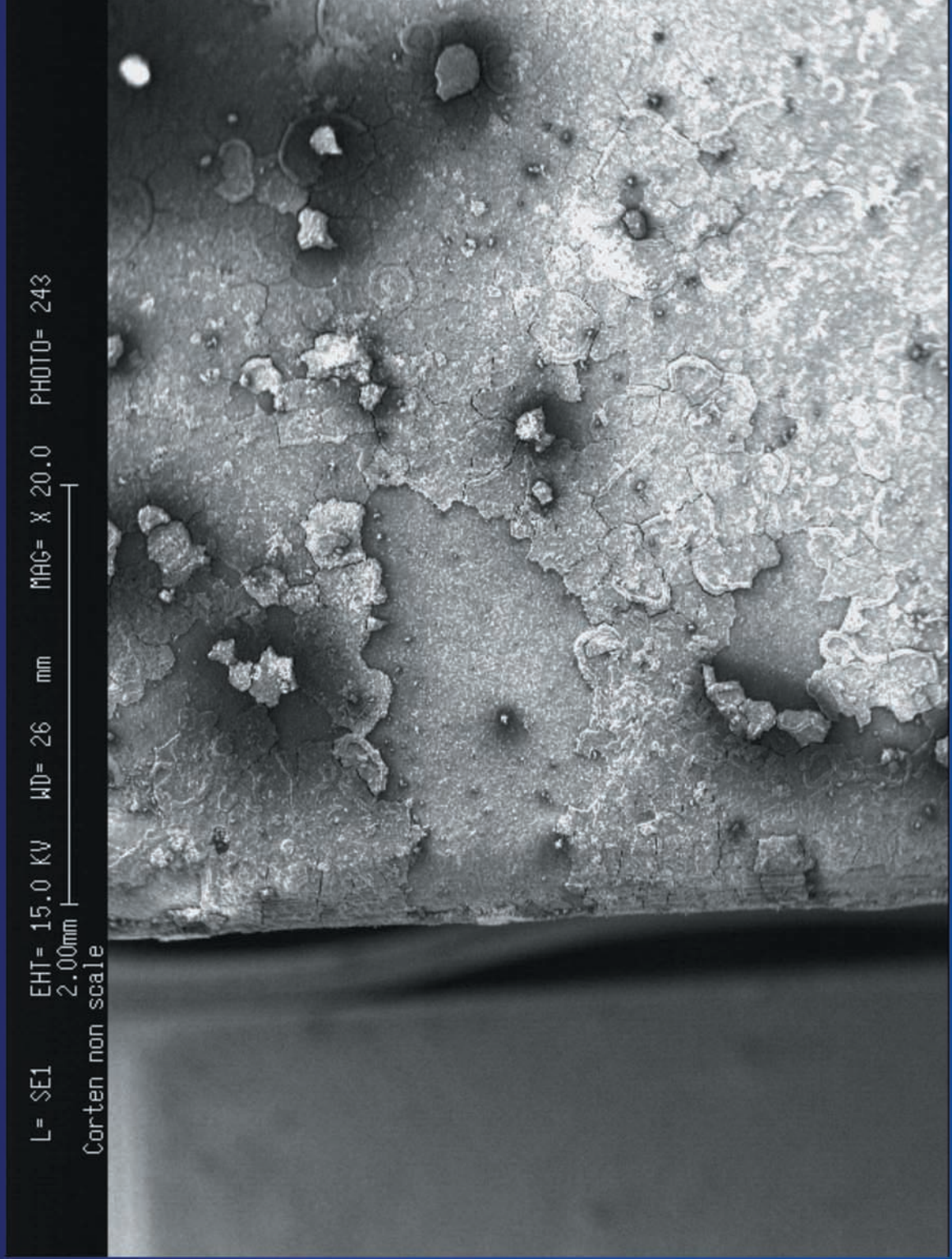


Areas Of Attack - Spotty Etch

Scale Area

X 300

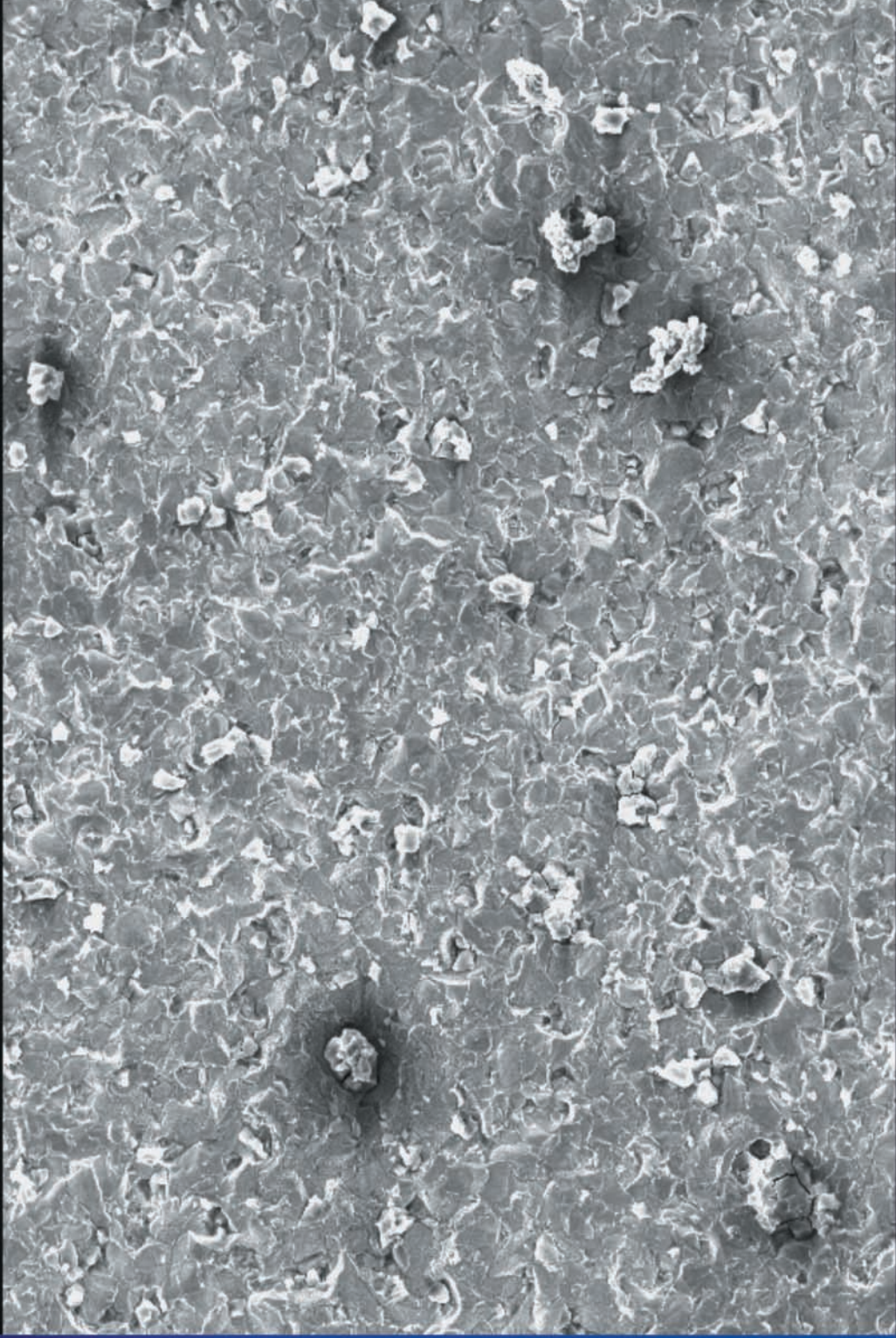
Corten Steel (11 Mo. Exposure)



X 20

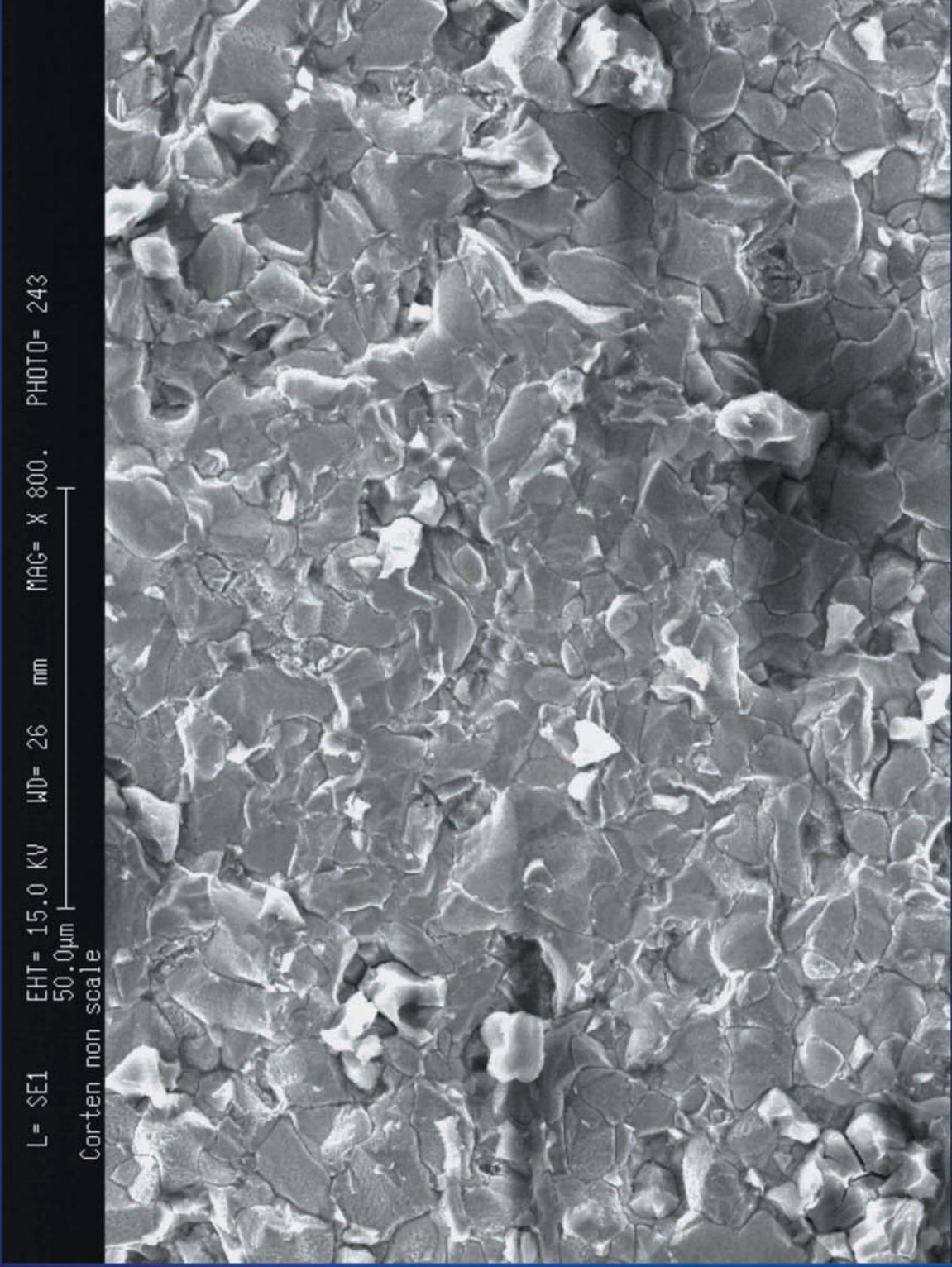
Corten Steel (11 Mo. Exposure)

L= SE1 EHT= 15.0 KV WD= 26 mm MAG= X 302. PHOTO= 243
100 μ m
Corten non scale



X 300

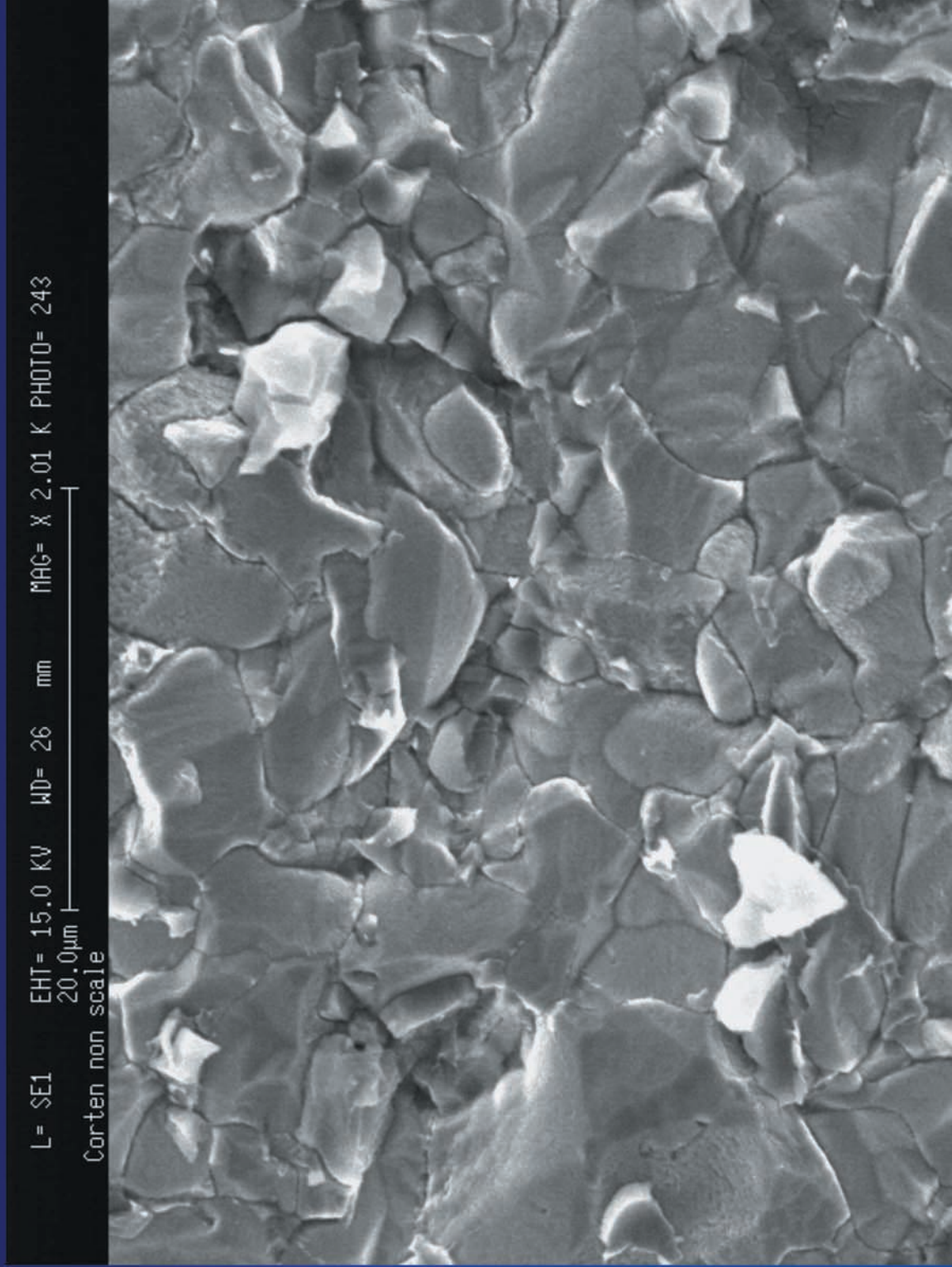
Corten Steel (11 Mo. Exposure)



Note
Grain
Boundaries

X 800

Corten Steel (11 Mo. Exposure)



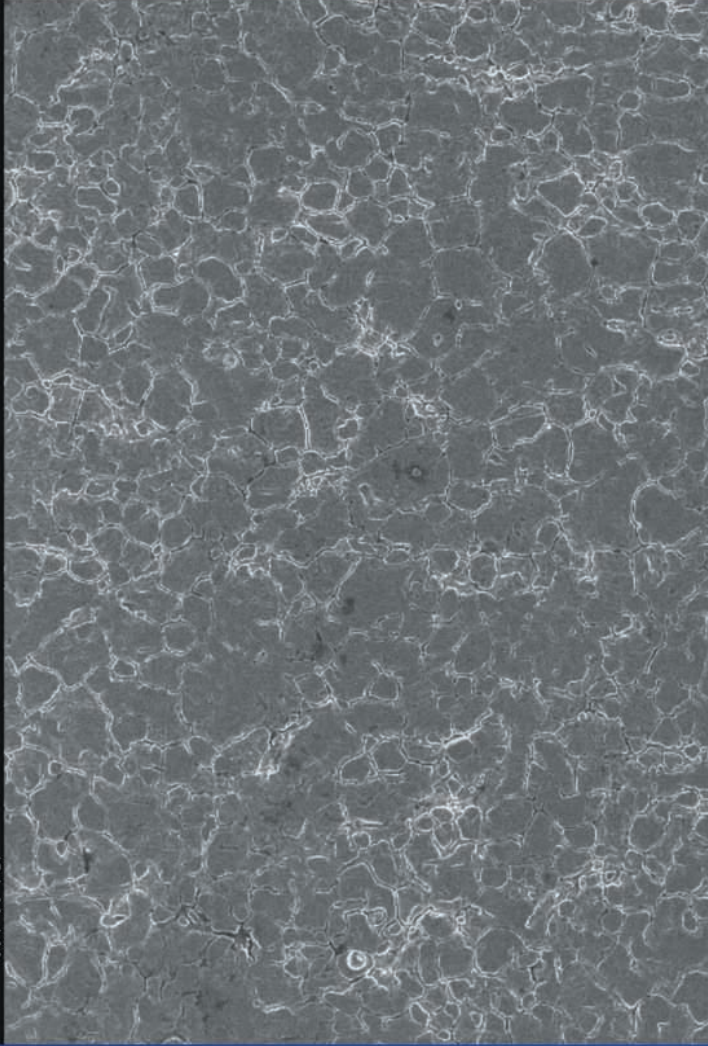
Note
Grain
Boundaries

X 2000

SEM Stainless Steel 304

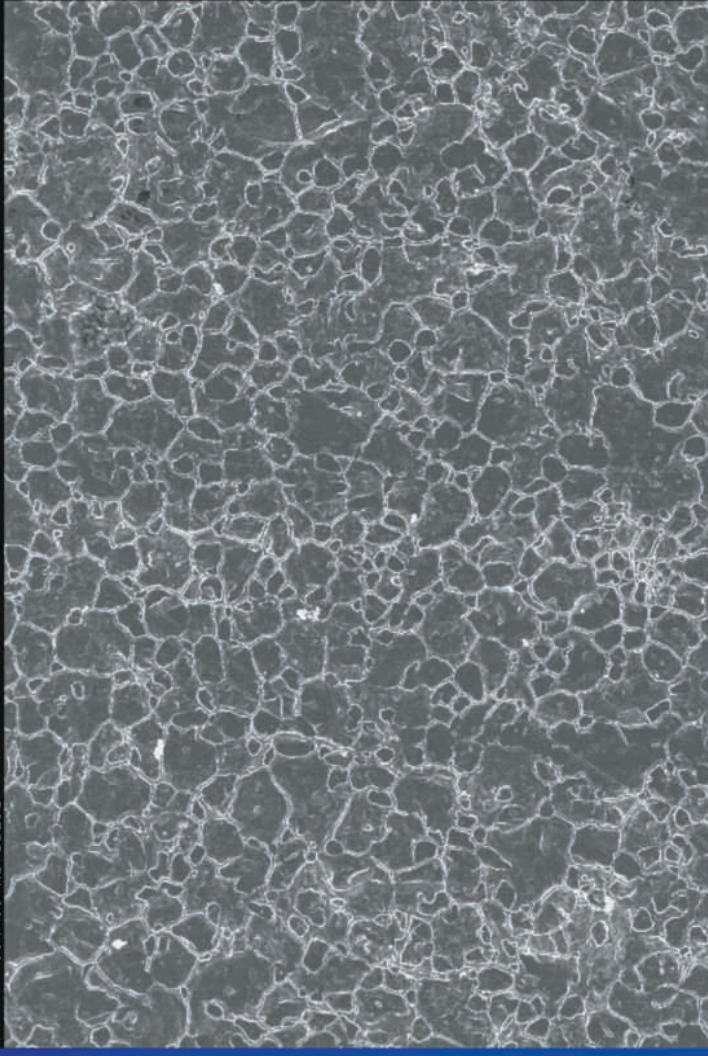
Reference Coupon Surface

L= SE1 EHT= 15.0 KV WD= 25 mm MAG= X 300. PHOTO= 243
304 \$\$ ref



11 Month Exposure

L= SE1 EHT= 15.0 KV WD= 25 mm MAG= X 300. PHOTO= 243
304 \$\$ no scale

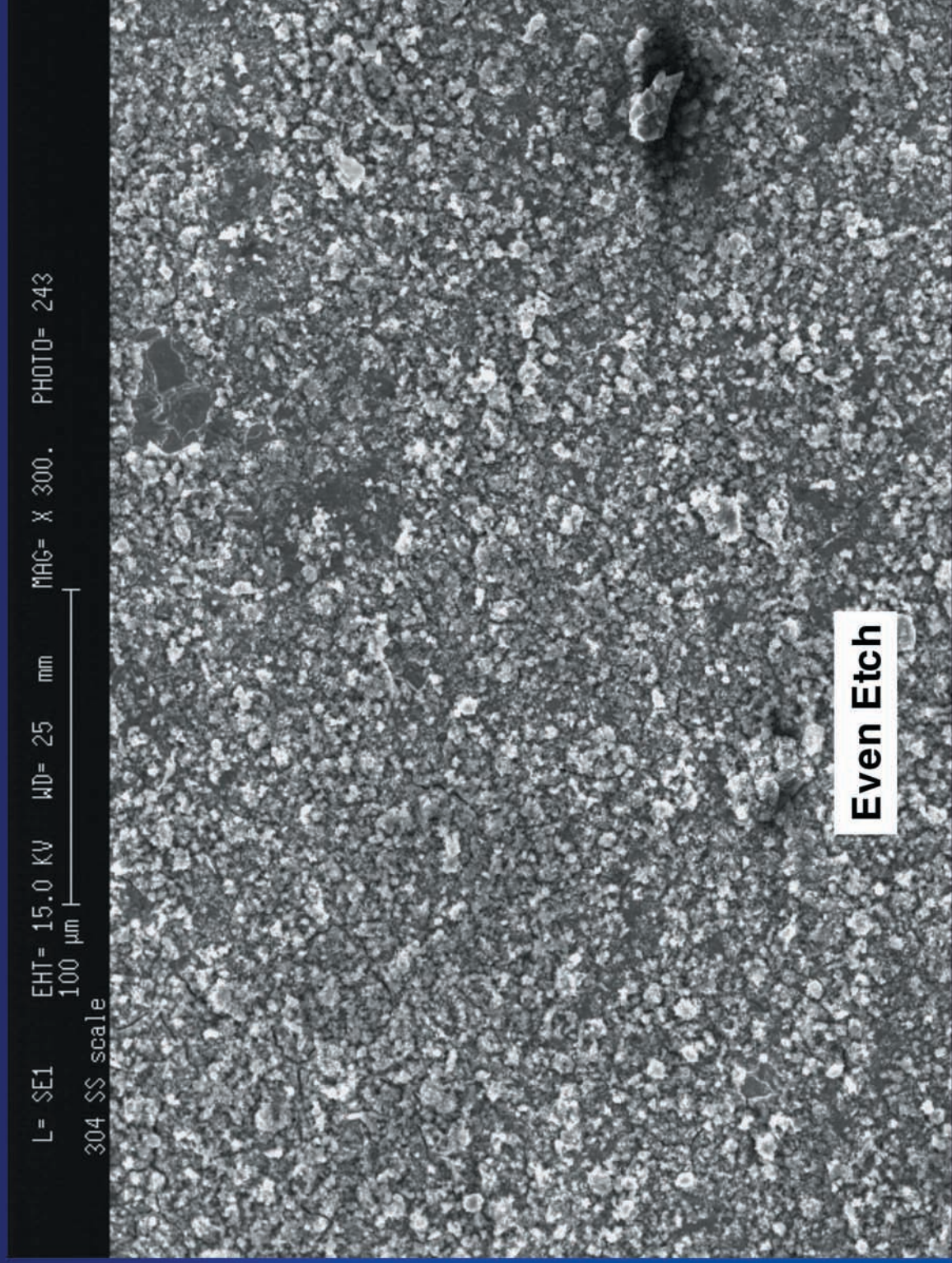


Note
Grain Boundaries

Even Etch

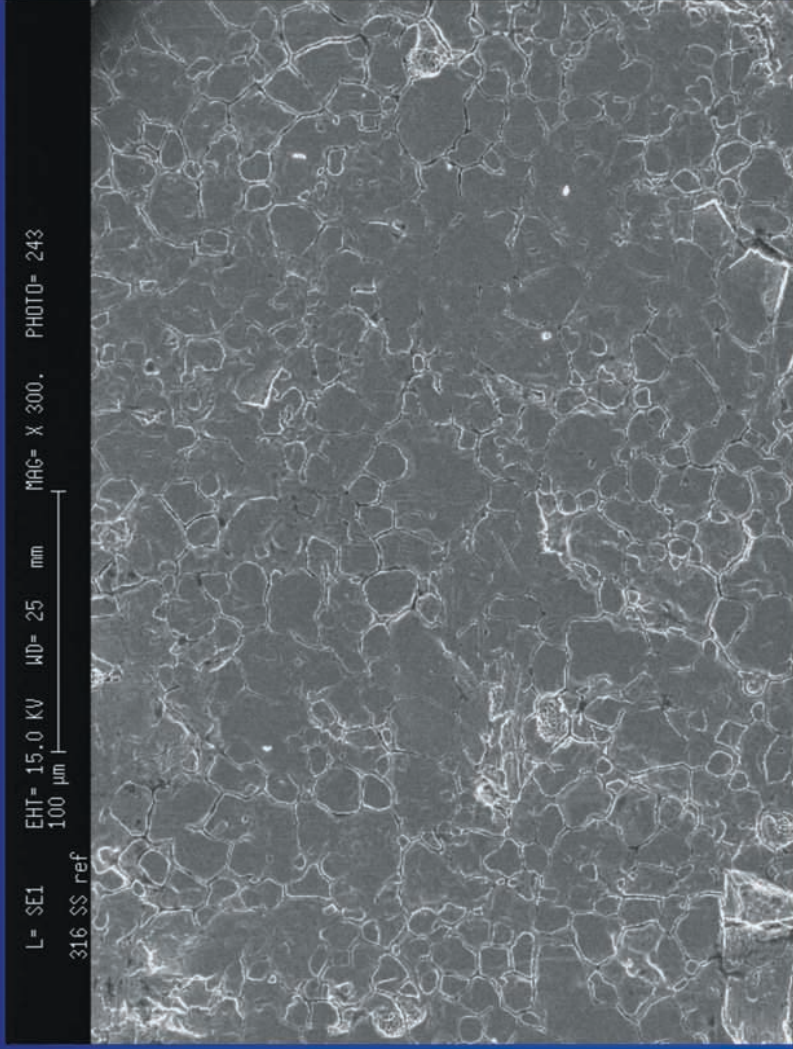
X 300

Stainless Steel 304 (11 Mo. Submergence)



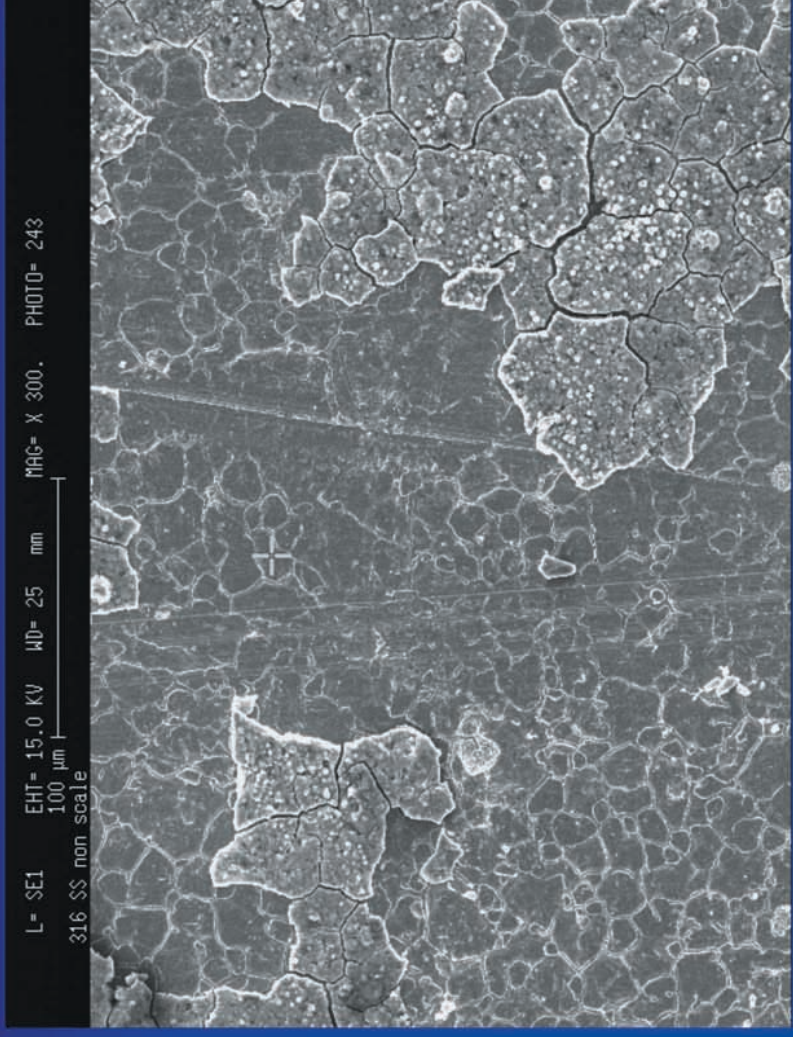
Stainless Steel 316L - Reference Coupon

Reference Coupon Surface



Note
Grain Boundaries

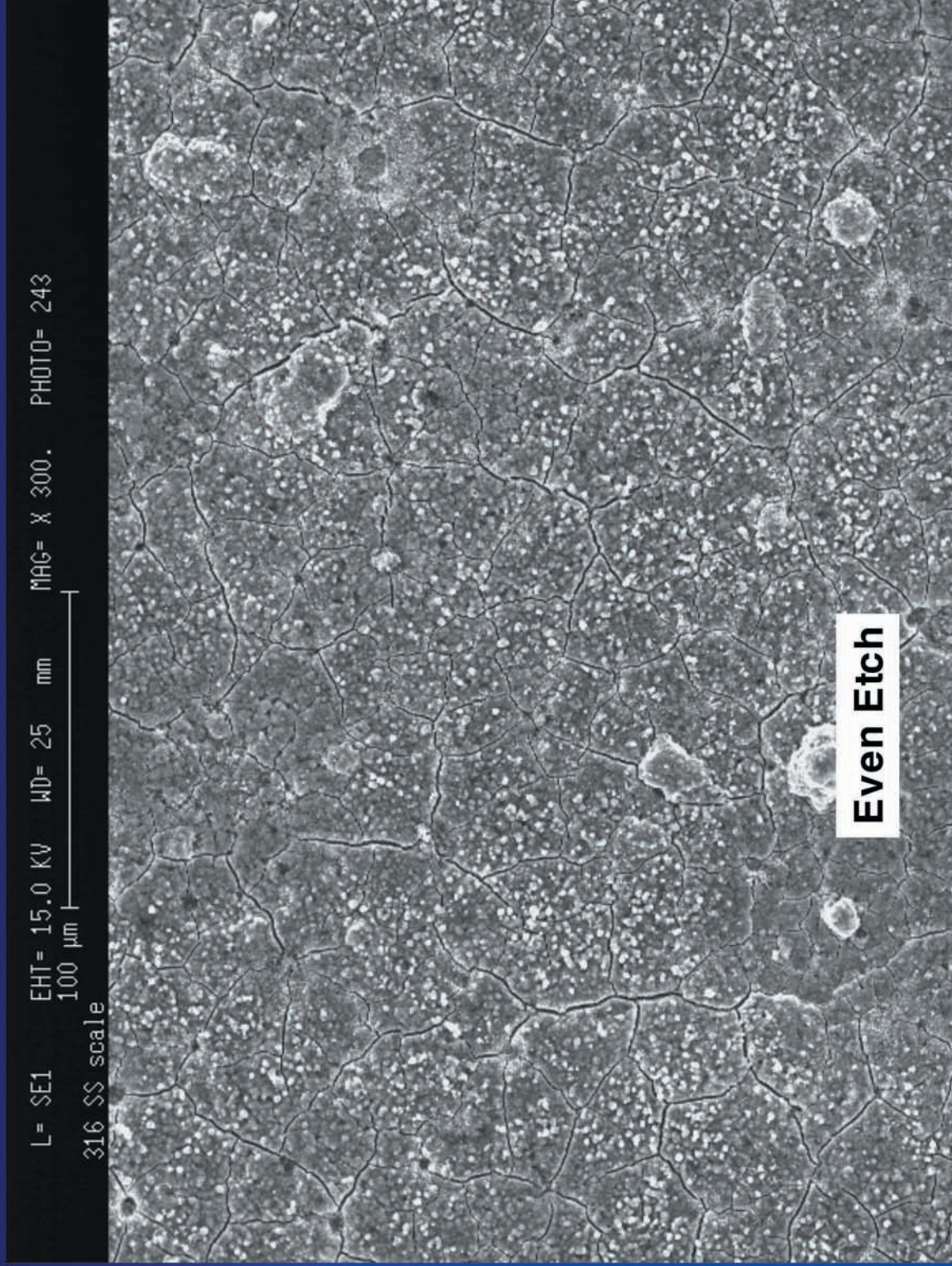
11 Month Exposure



Even Etch

X 300

Stainless Steel 316L (11 Mo. Submergence)

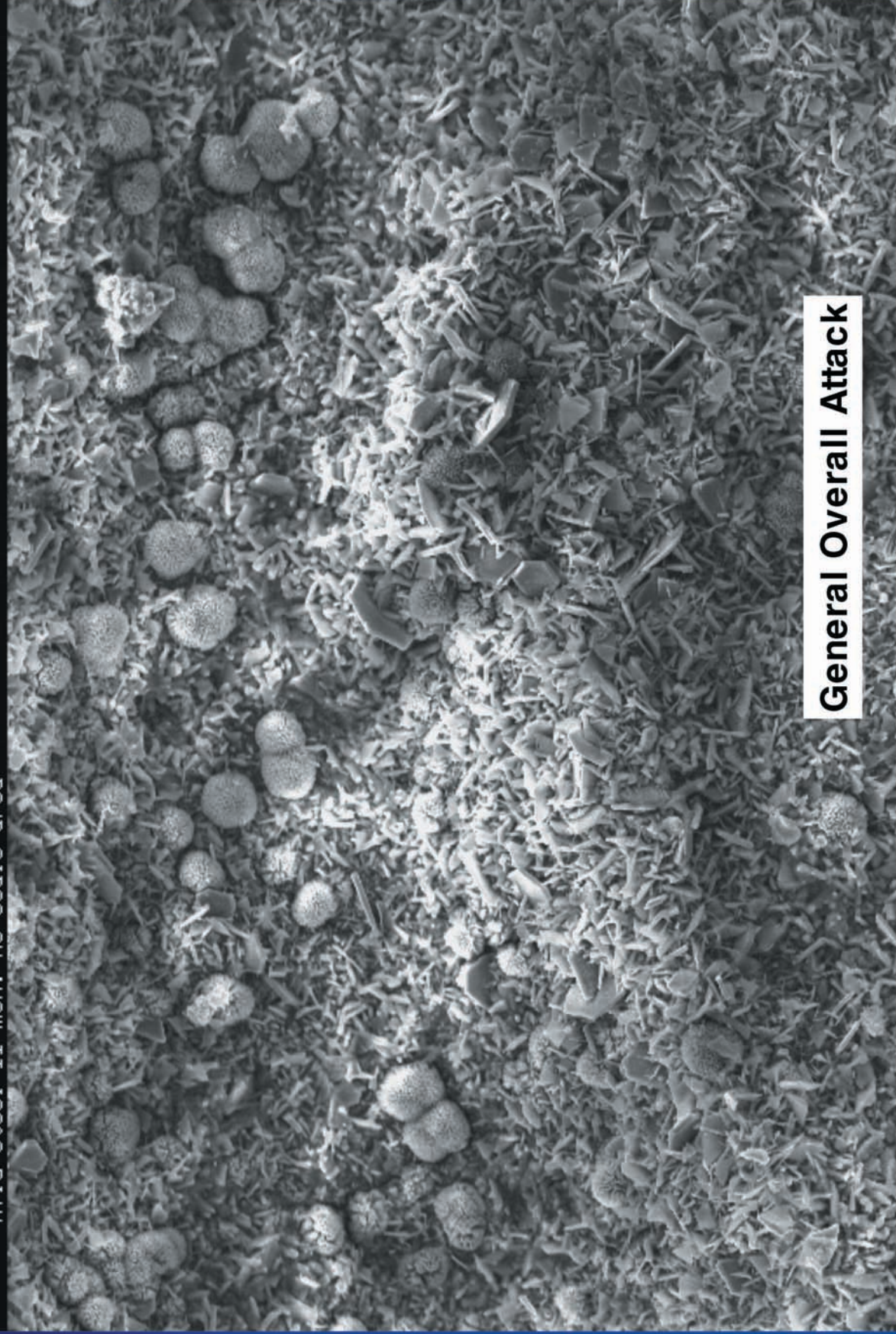


Exposure

L= SE1 EHT= 15.0 KV WD= 25 mm MAG= X 300. PHOTO= 243

100 μ m

Mild steel 11 mon. no scale area

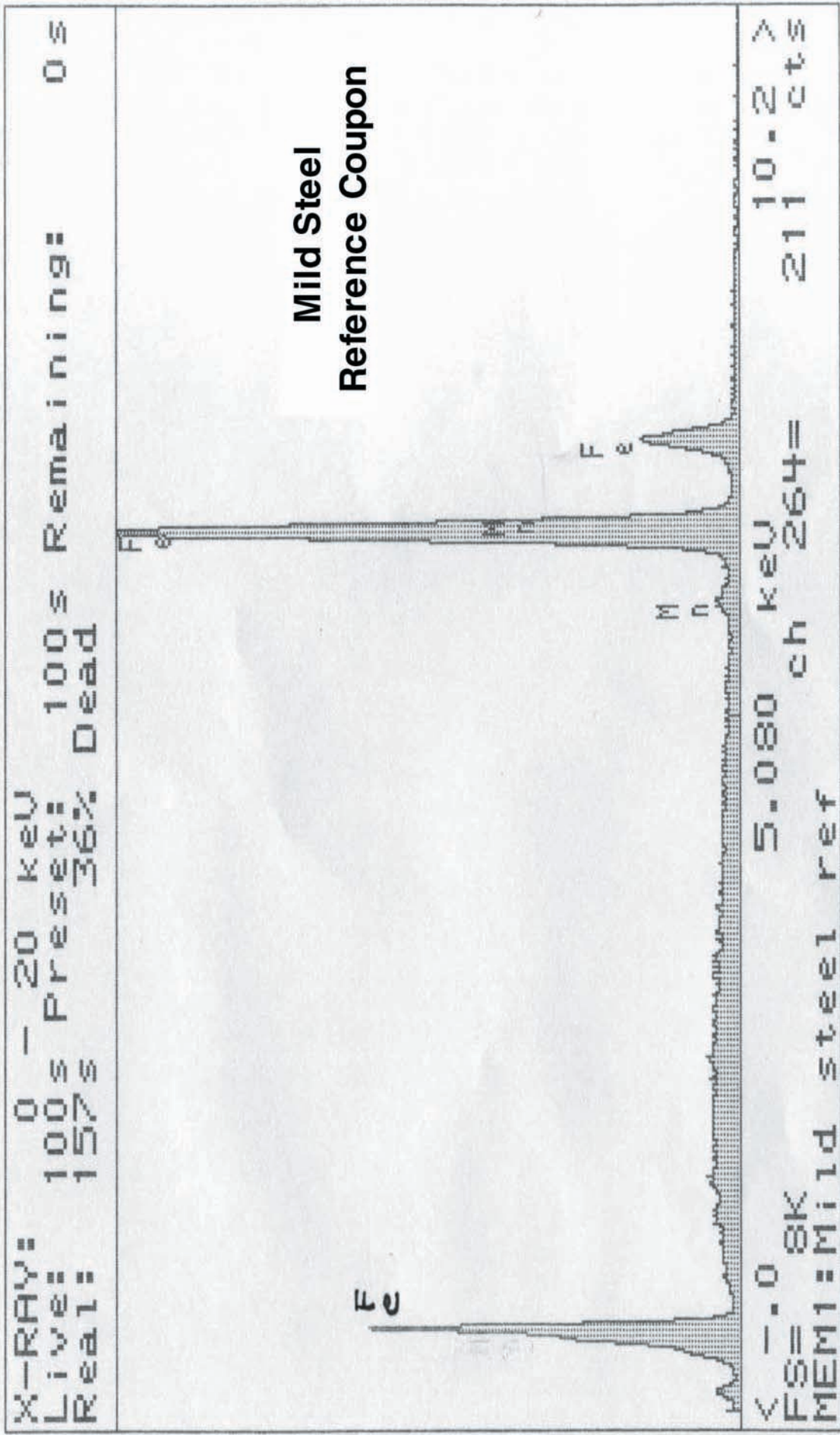


General Overall Attack

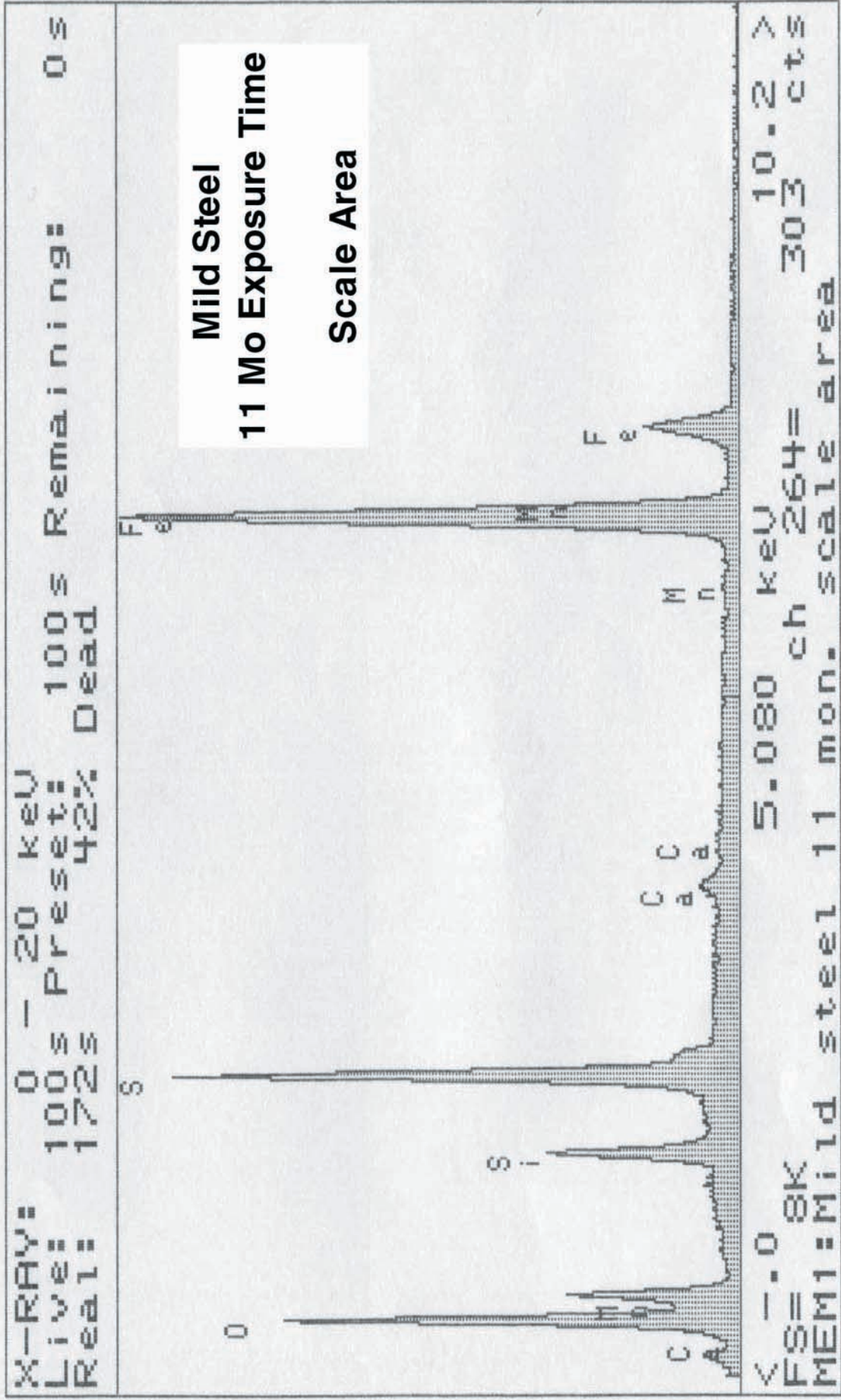
Iron Oxide
Nodules And
Hexagonal
Crystals

X 300

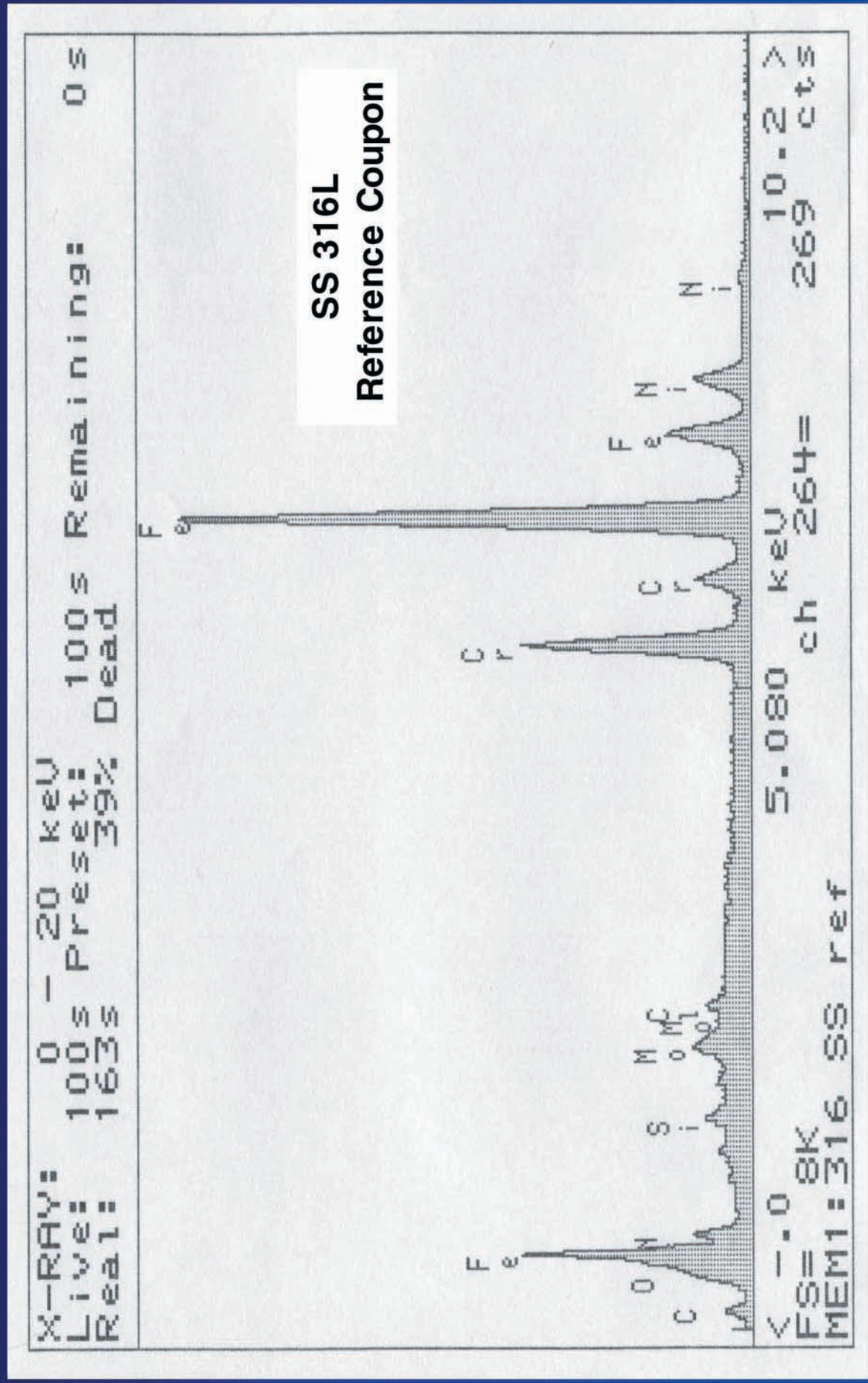
Energy Dispersive Spectrometer (EDS)



Energy Dispersive Spectrometer (EDS)



Energy Dispersive Spectrometer (EDS)



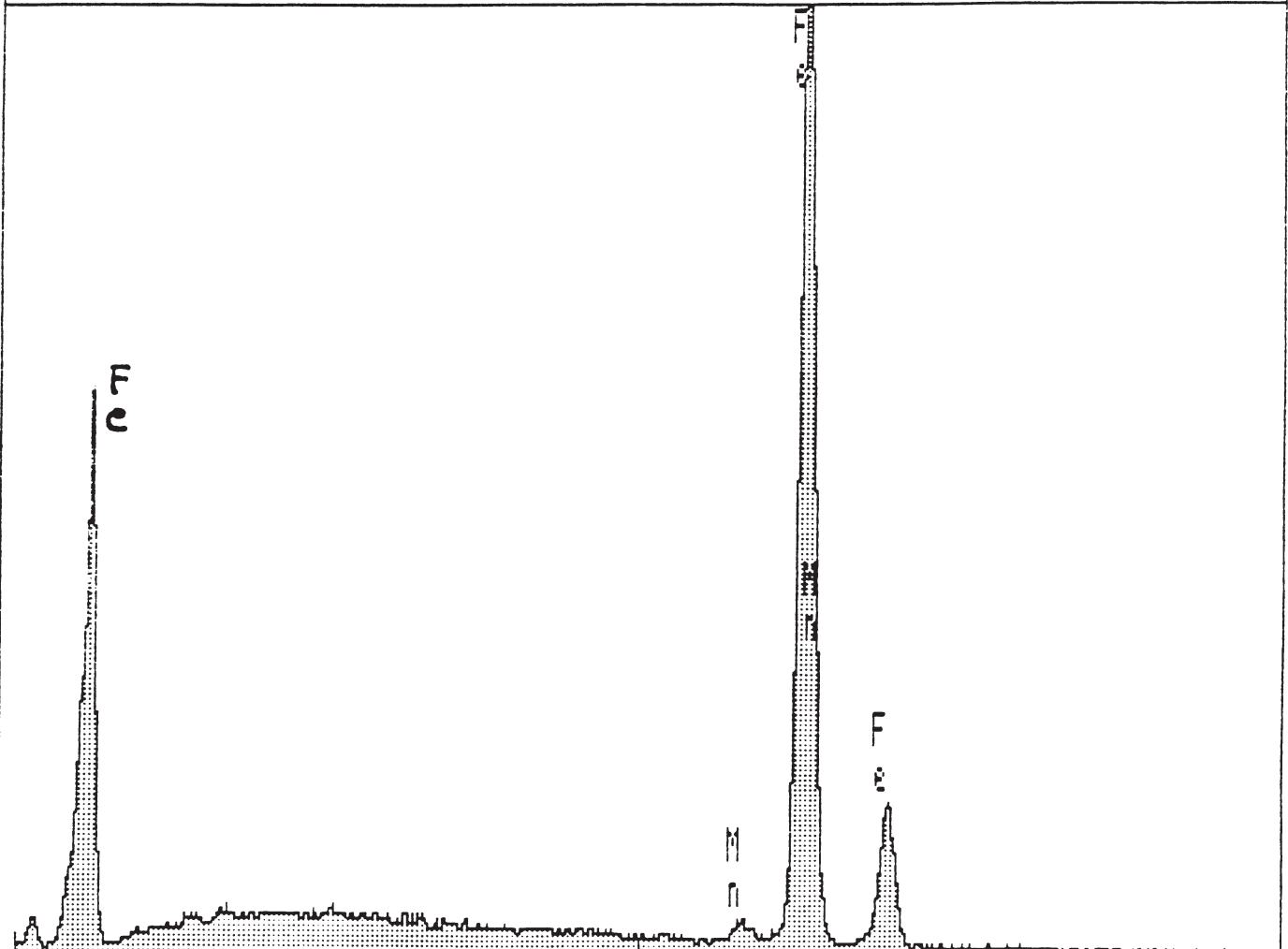
APPENDIX C
ENERGY DISPERSIVE
SPECTROMETER RESULTS

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APPENDIX C
ENERGY DISPERSIVE SPECTROMETER RESULTS
TAKEN AFTER 11 MONTHS

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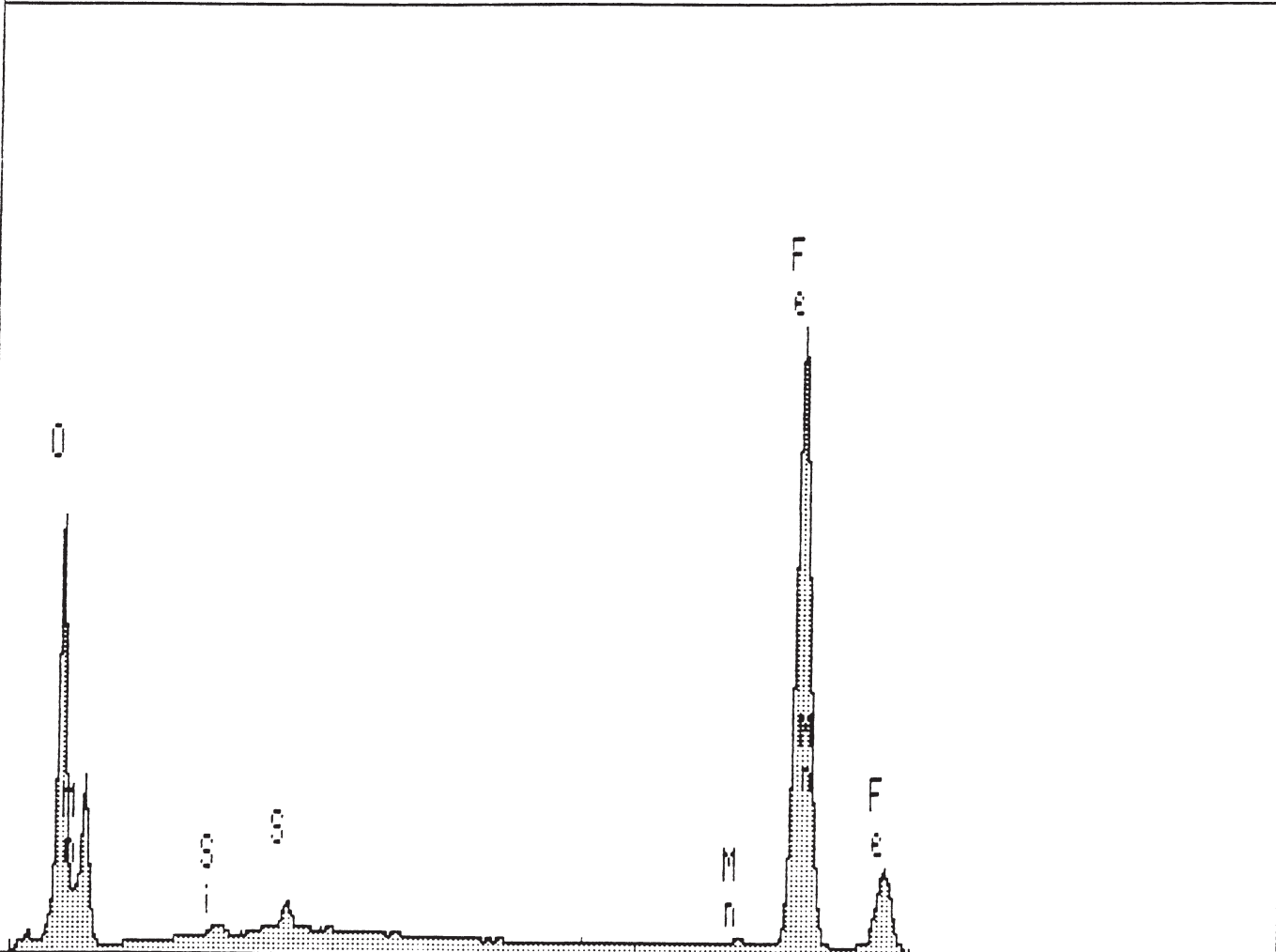
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X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 157s 36% Dead



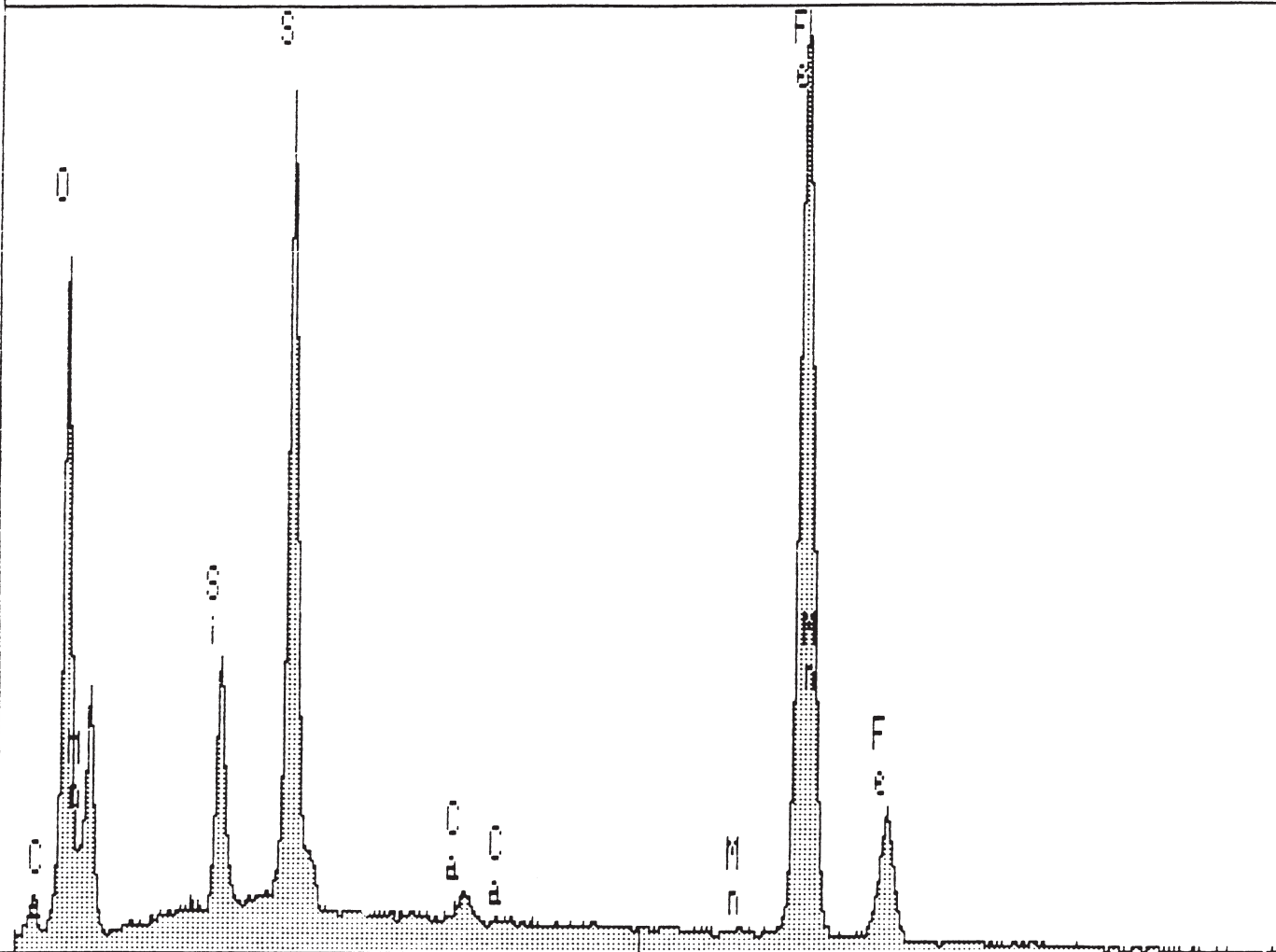
< -.0 5.080 keV 10.2 >
FS= 8K ch 264= 211 cts
MEM1:Mild steel ref

X-RAY: 0 - 20 keV
 Live: 200s Preset: 200s Remaining: 0s
 Real: 347s 42% Dead



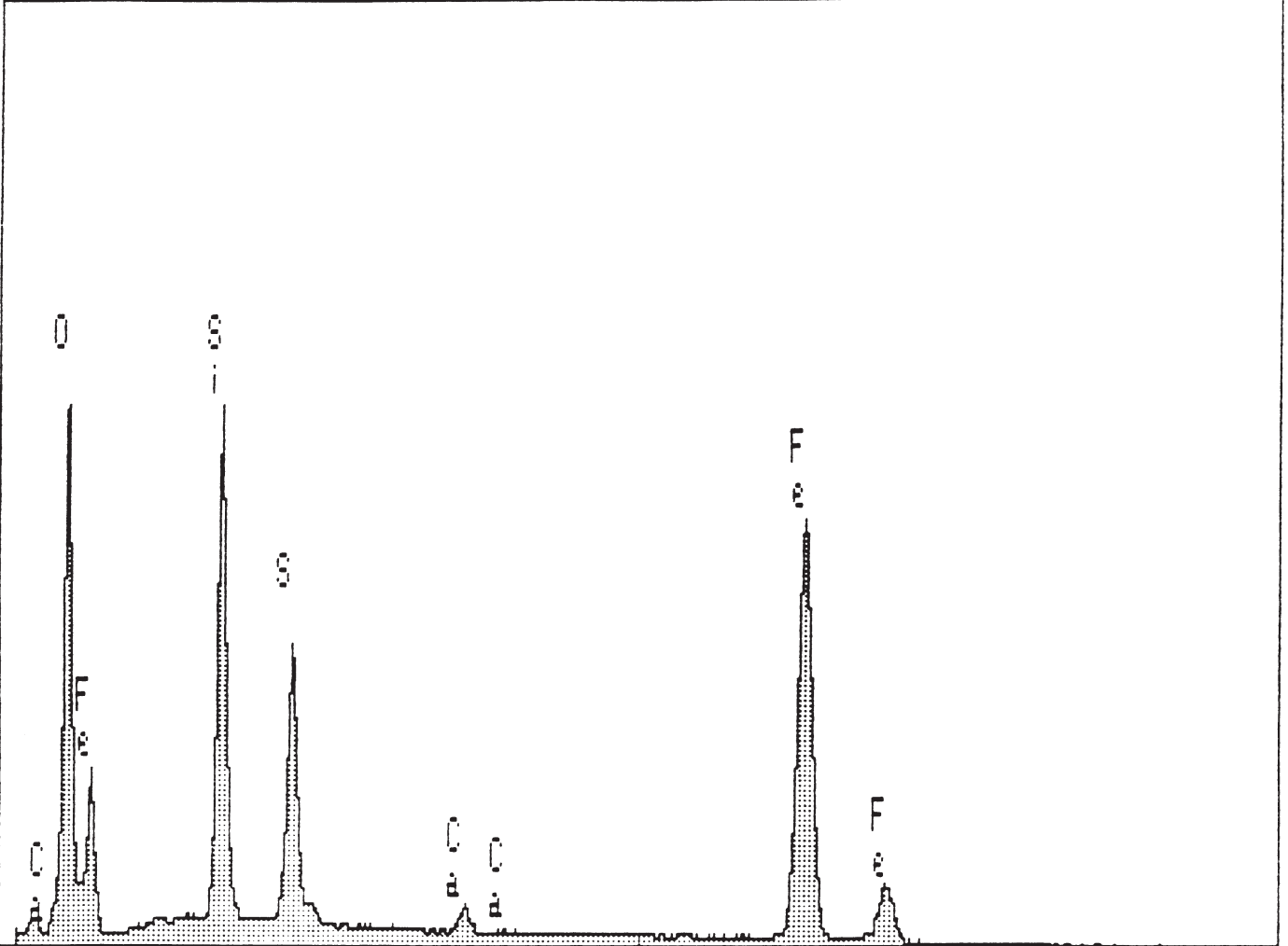
< -0.0 5.080 keV 10.2 >
 FS= 32K ch 264= 625 cts
 MEM1:Mild steel 11 mon. no scale area

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 172s 42% Dead



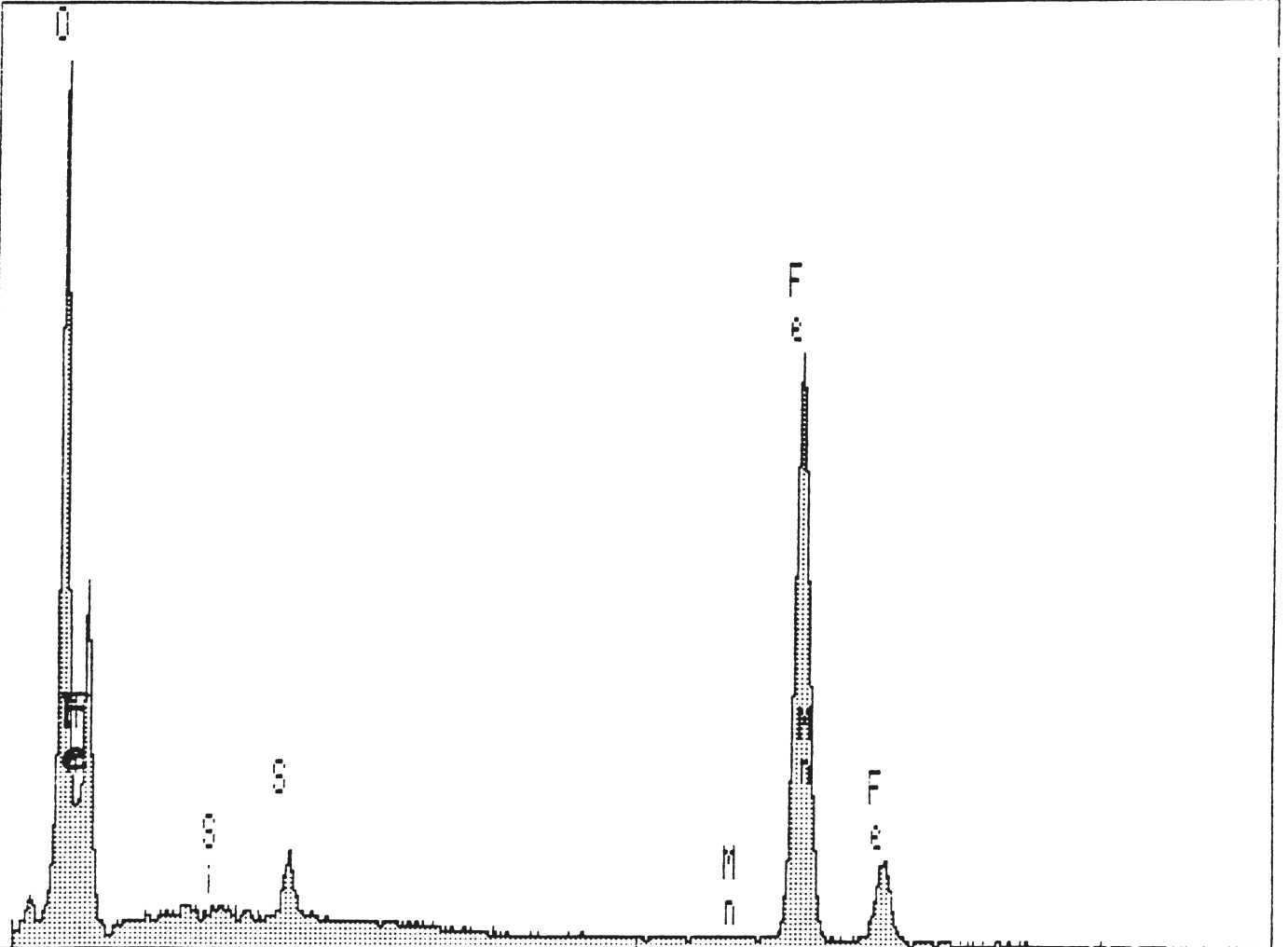
< - .0 5.080 keV 10.2 >
FS= 8K ch 264= 303 cts
MEM1: Mild steel 11 mon. scale area

X-RAY: 0 - 20 keV
 Live: 100s Preset: 100s Remaining: 0s
 Real: 187s 47% Dead



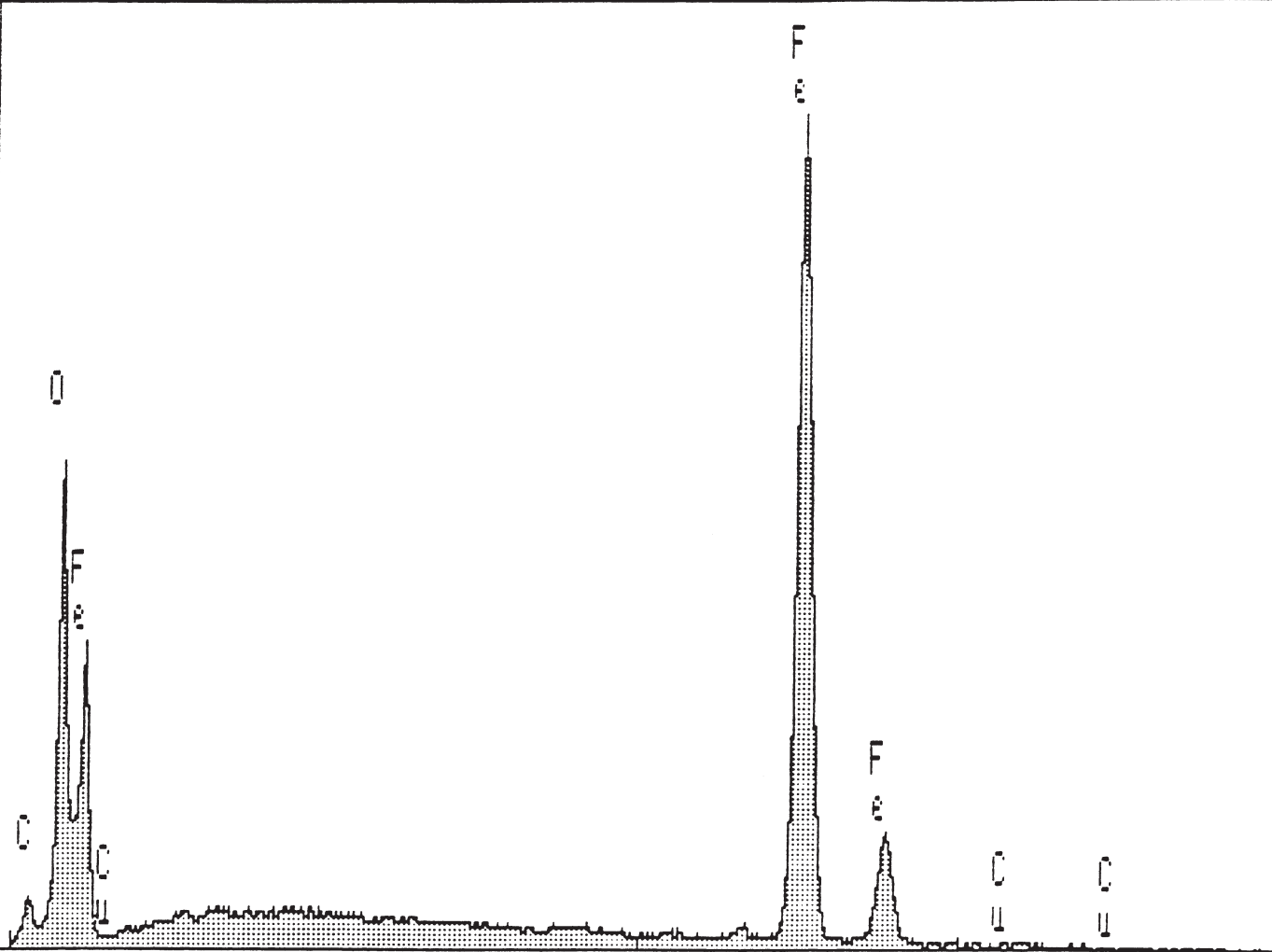
< -0.0 5.080 keV 10.2 >
 FS= 16K ch 264= 296 cts
 MEM1:Mild steel 11 mon. scale area 2

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 159s 37% Dead



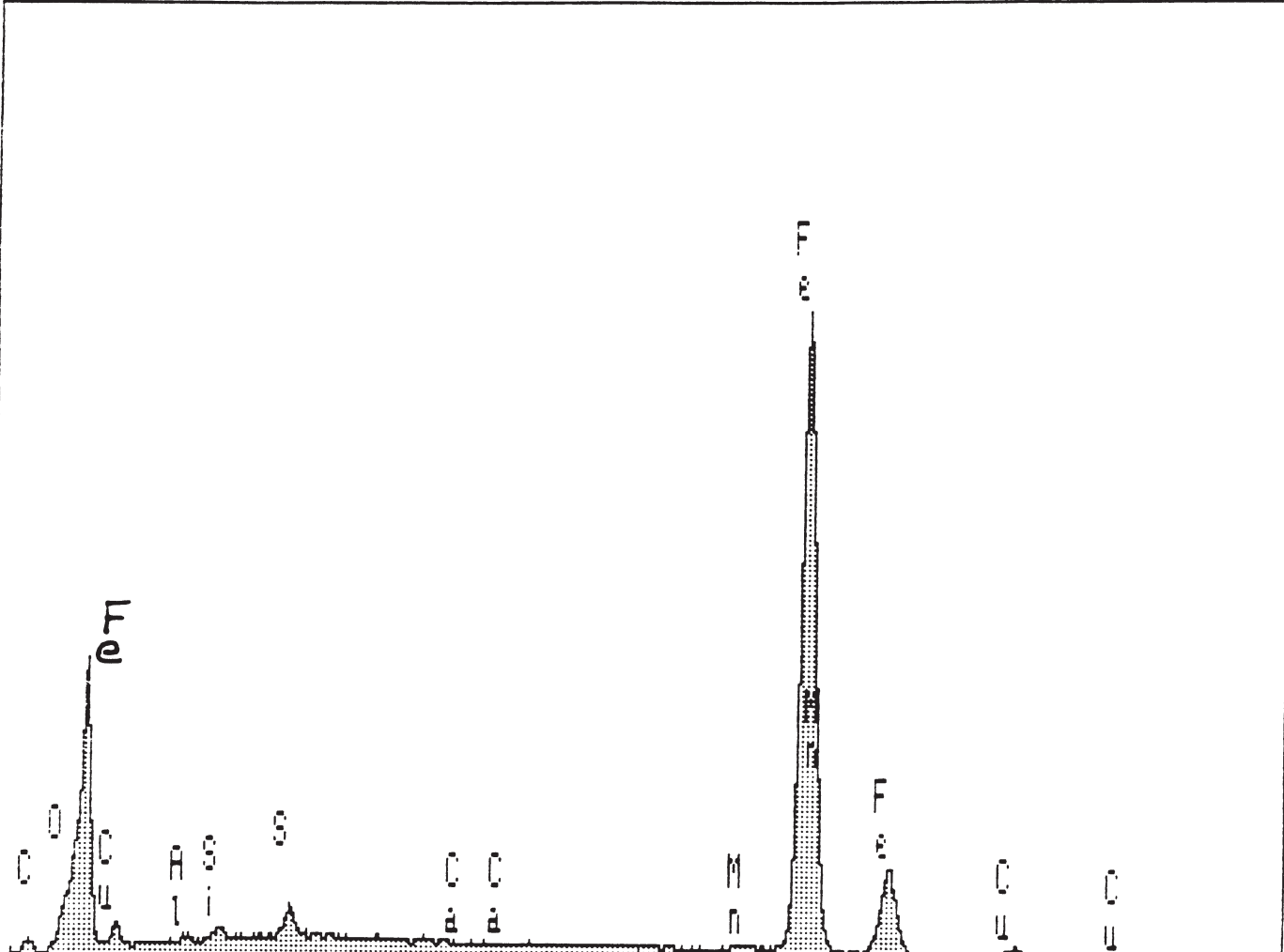
< -.0 5.080 keV 10.2 >
FS= 8K ch 264= 168 cts
MEM1:Mild steel 11 mon. no scale nodu

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 155s 35% Dead



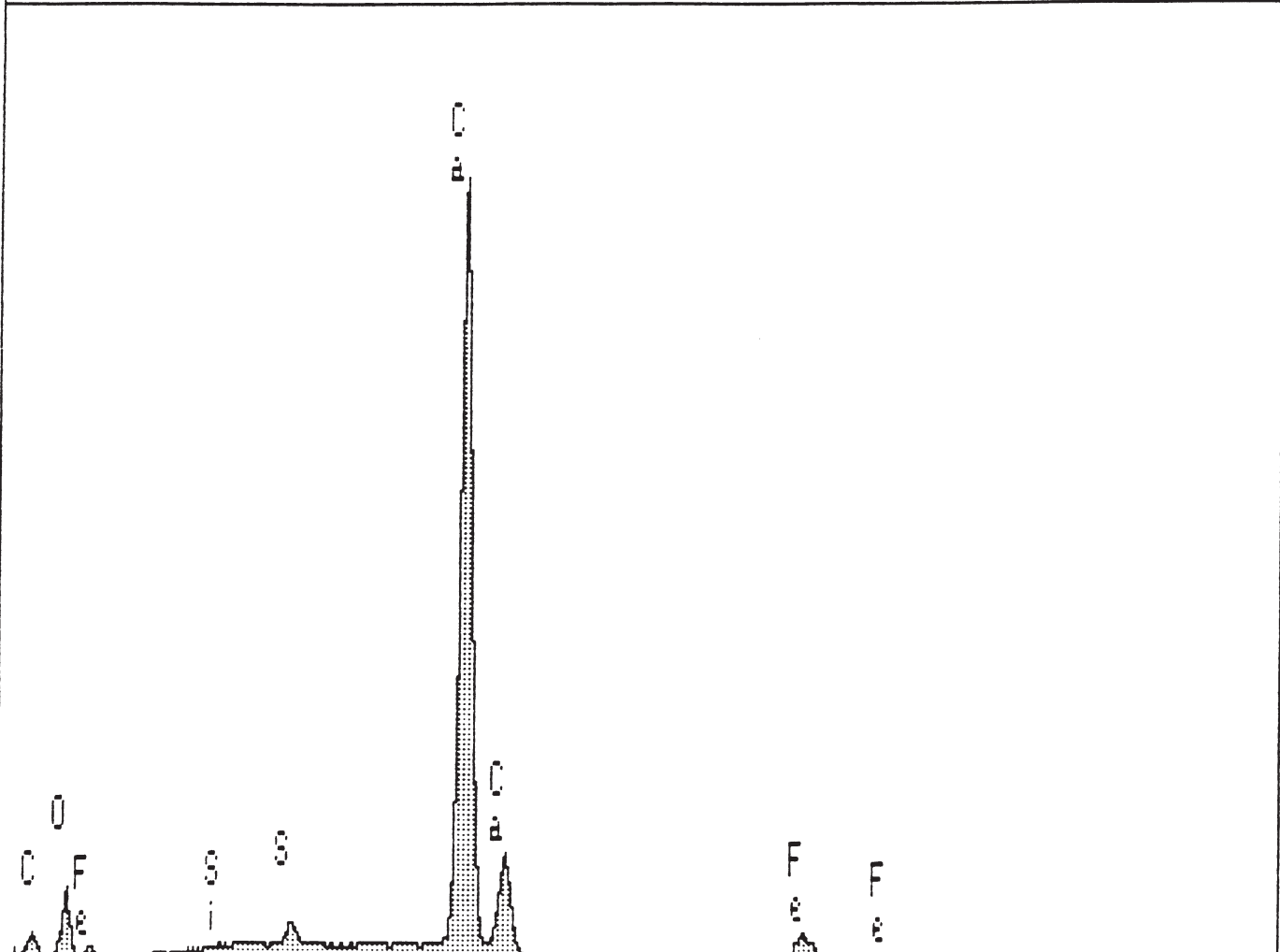
< - .0 5.080 keV 10.2 >
FS= 8K ch 264= 163 cts
MEM1:Cu bear ref

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 163s 39% Dead



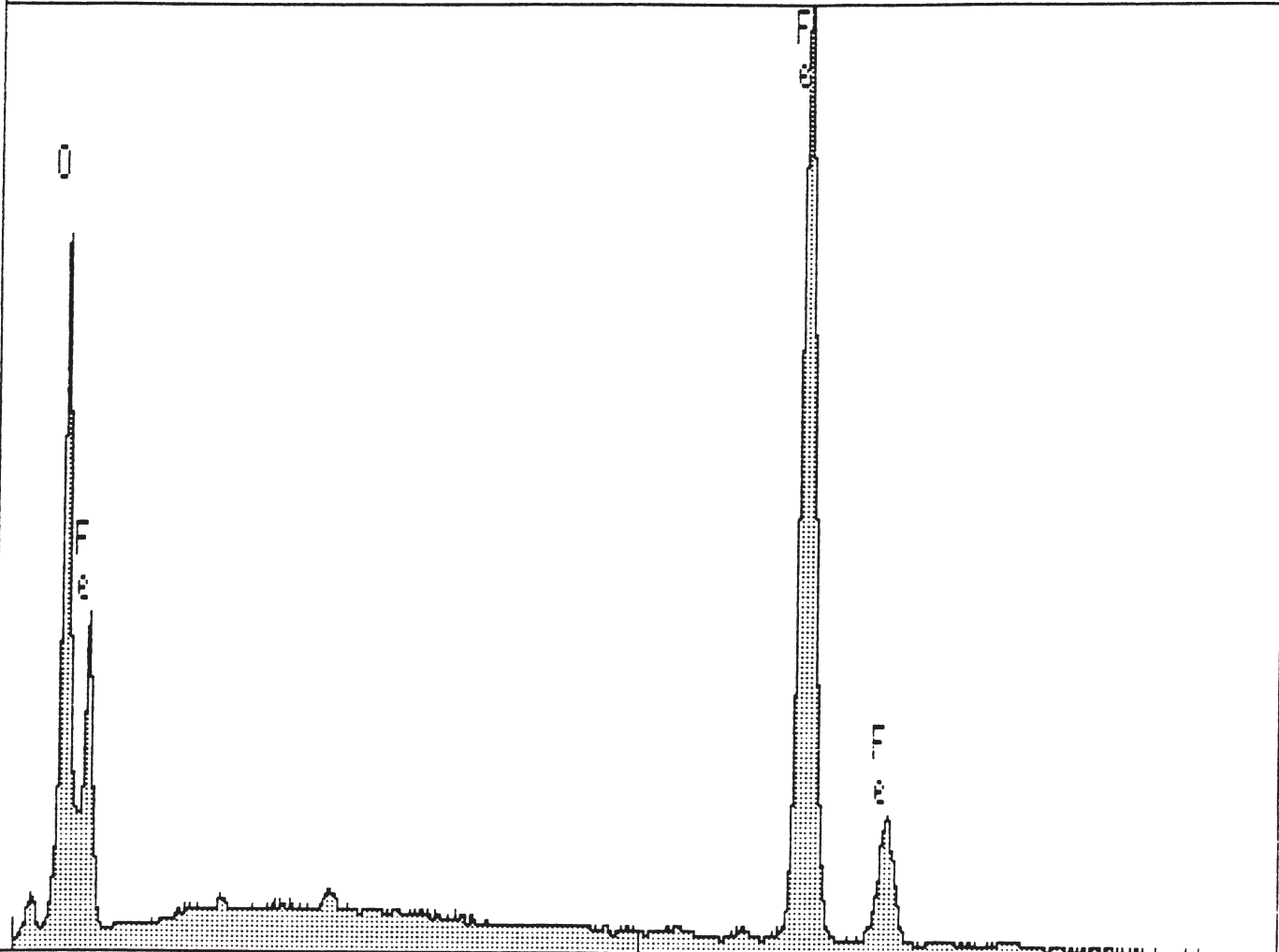
< - .0 5.080 keV 10.2 >
FS= 16K ch 264= 260 cts
MEM1:Cu bear non scale area

X-RAY: 0 - 20 keV
 Live: 100s Preset: 100s Remaining: 0s
 Real: 144s 31% Dead



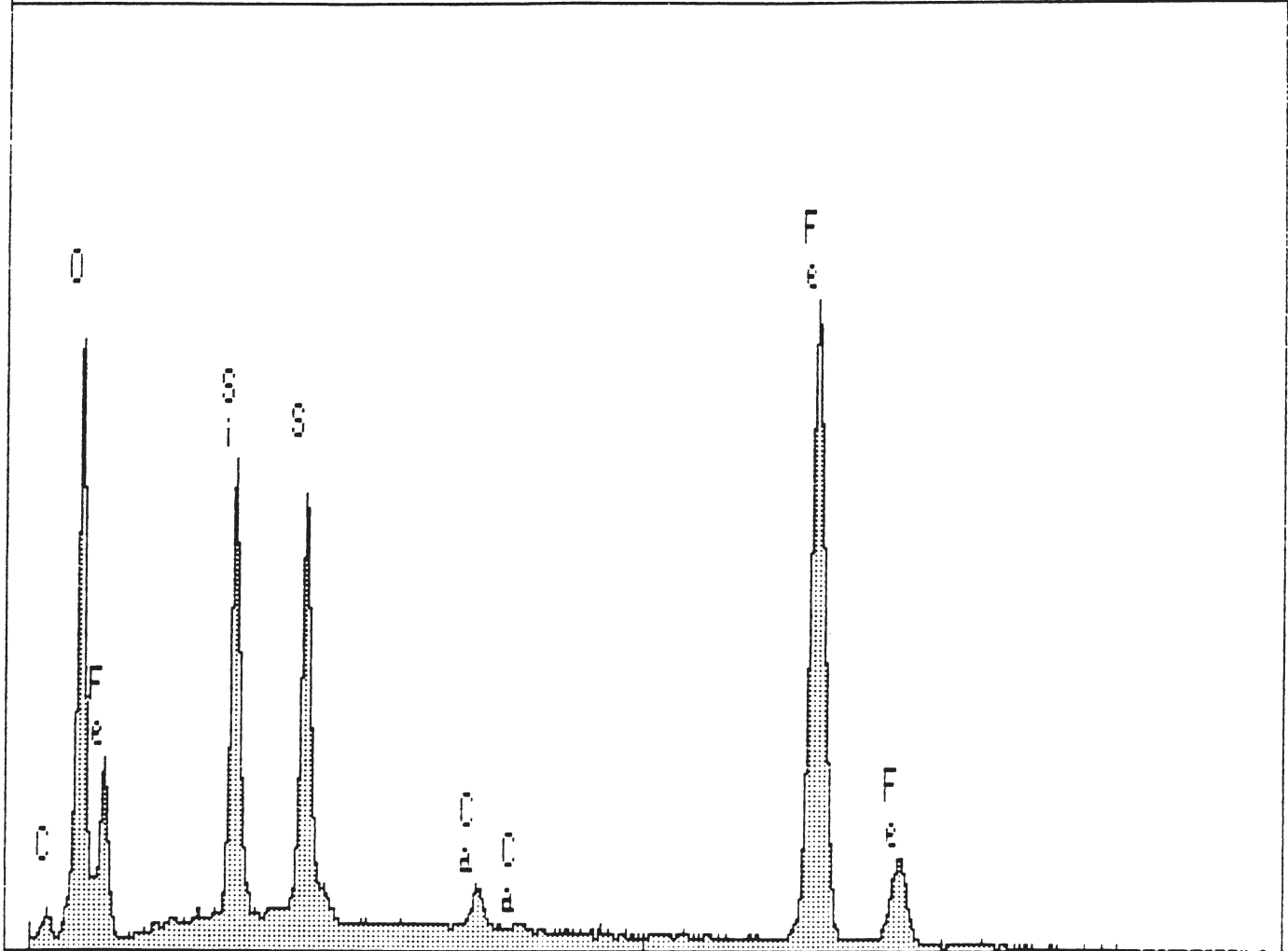
< -.0 5.080 keV 10.2 >
 FS= 16K ch 264= 121 cts
 MEM1:Cu bear scale area xtal

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 165s 39% Dead



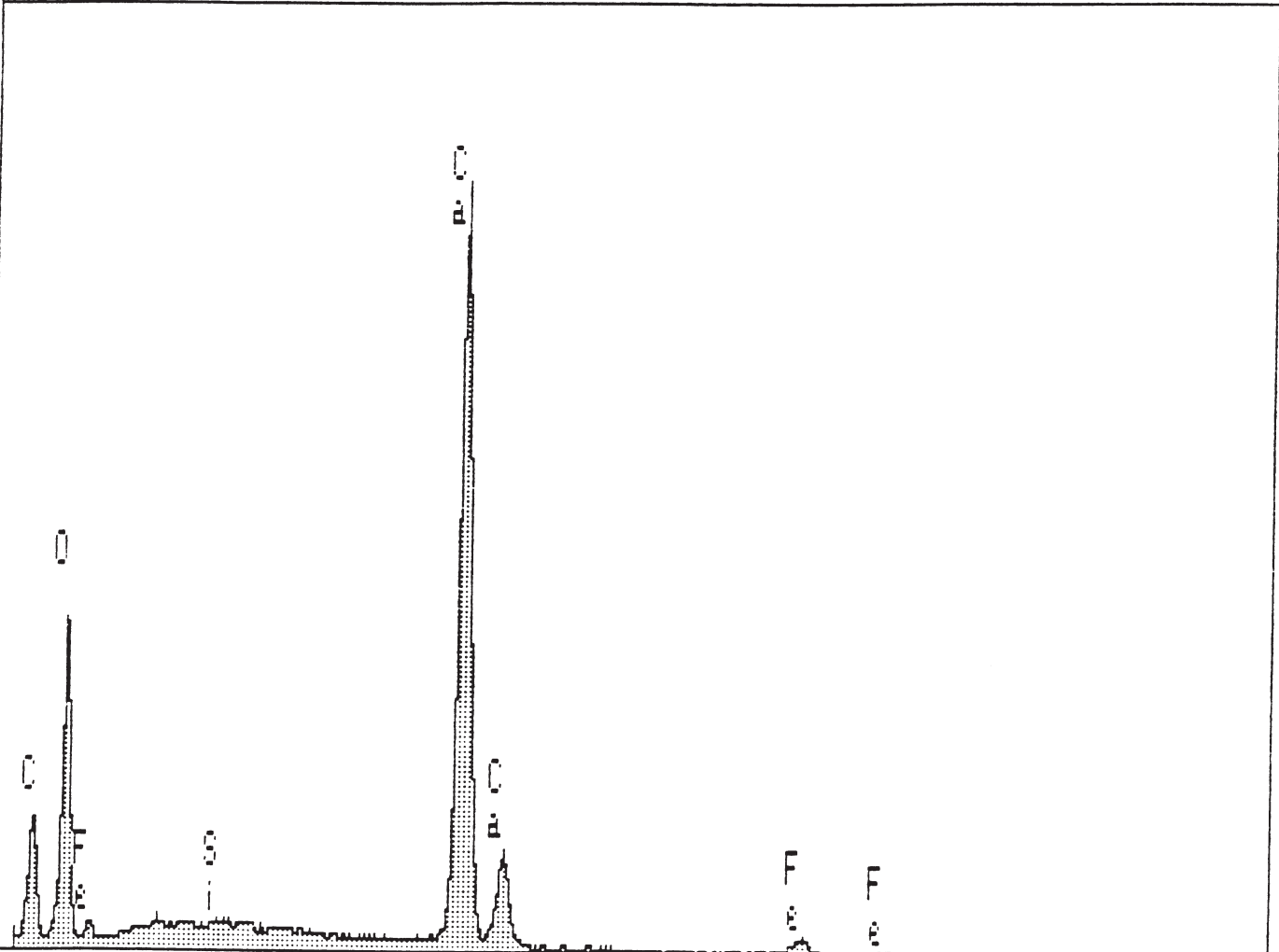
< - .0 5.080 keV 10.2 >
FS= 8K ch 264= 228 cts
MEM1:Corten ref

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 162s 38% Dead



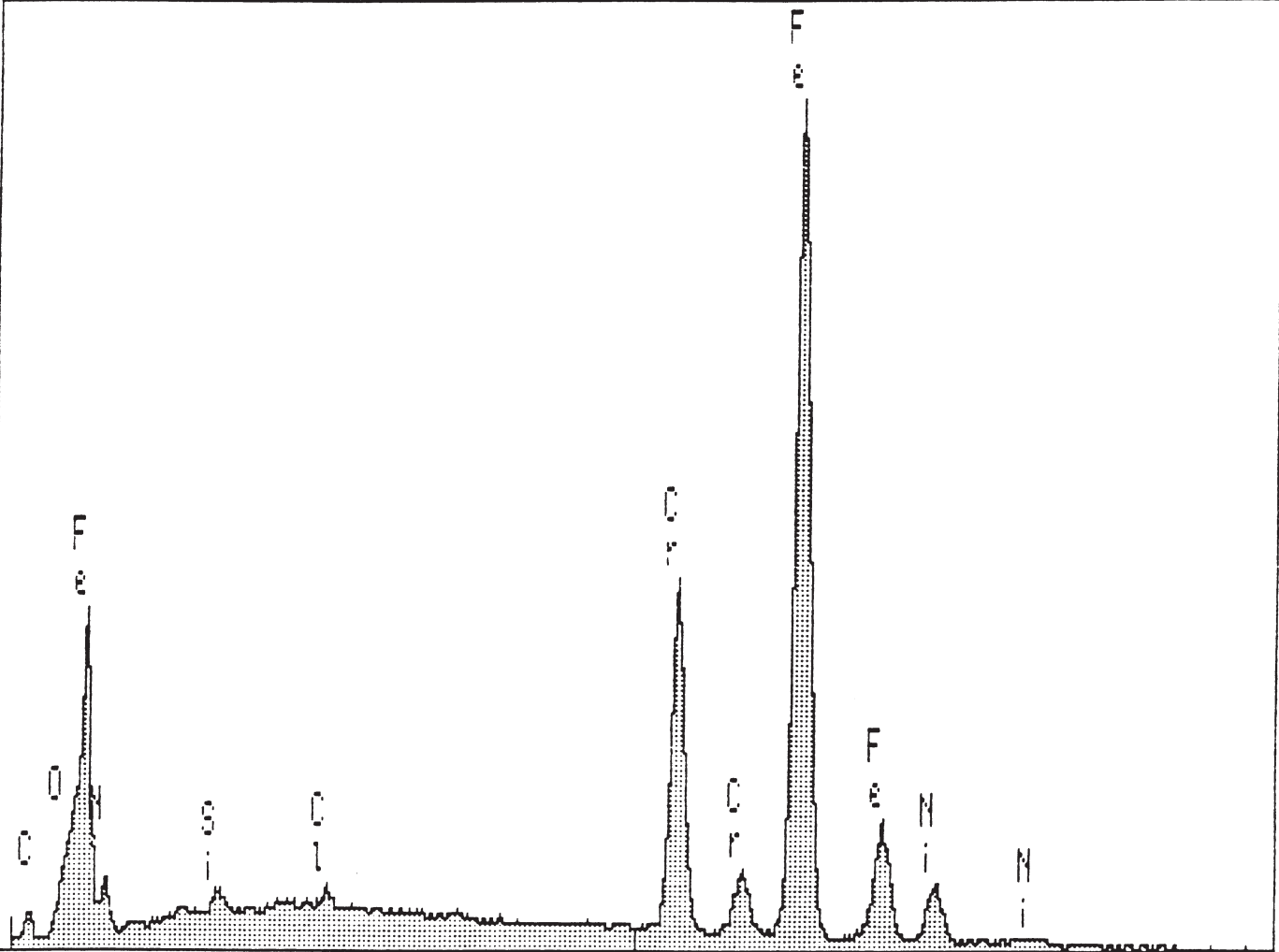
< - .1 5.020 keV 10.1 >
FS= 8K ch 261= 214 cts
MEM1: Corten scale area

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 142s 30% Dead

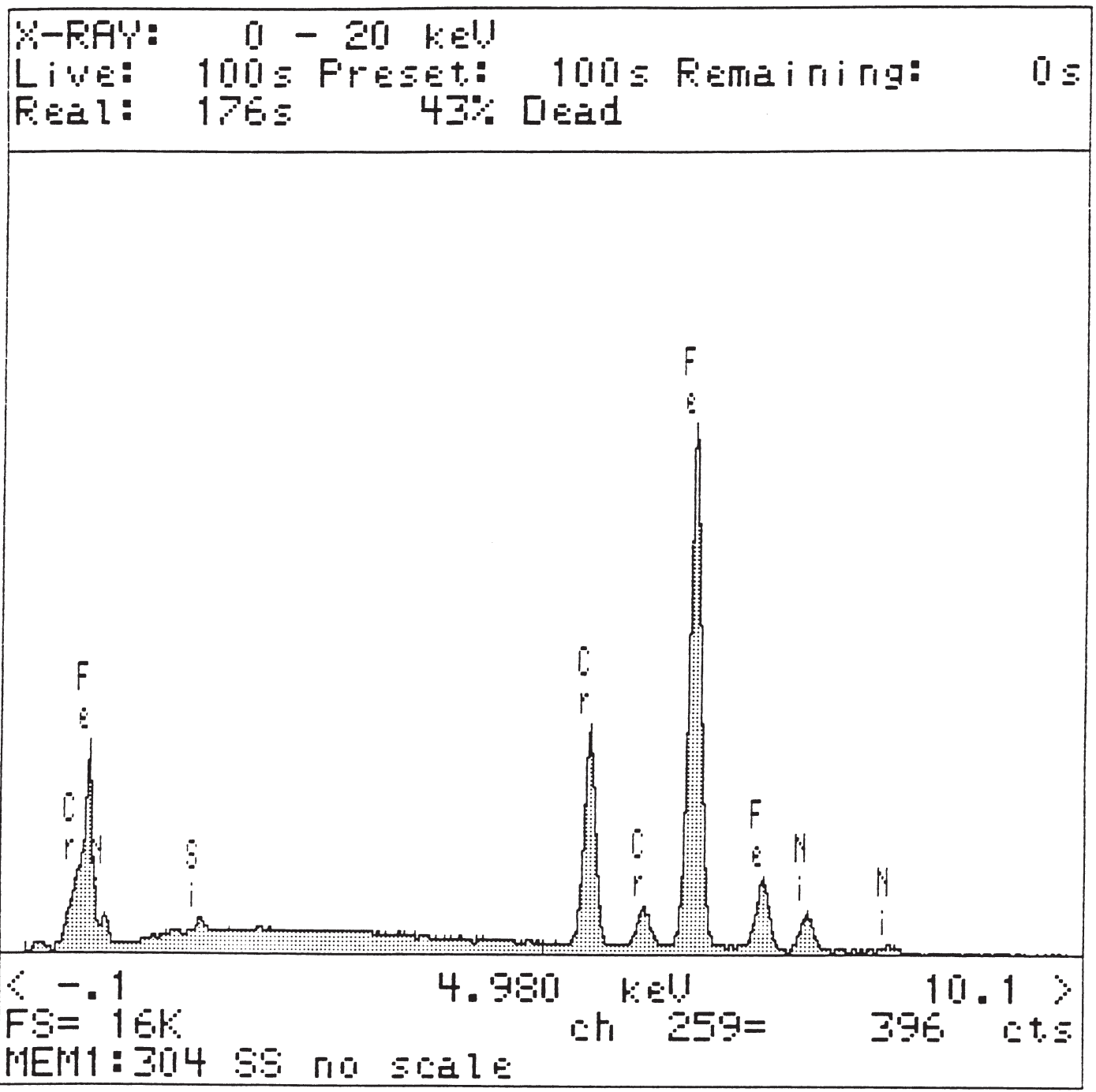


< - .1 5.020 keV 10.1 >
FS= 8K ch 261= 77 cts
MEM1:Corten xtals

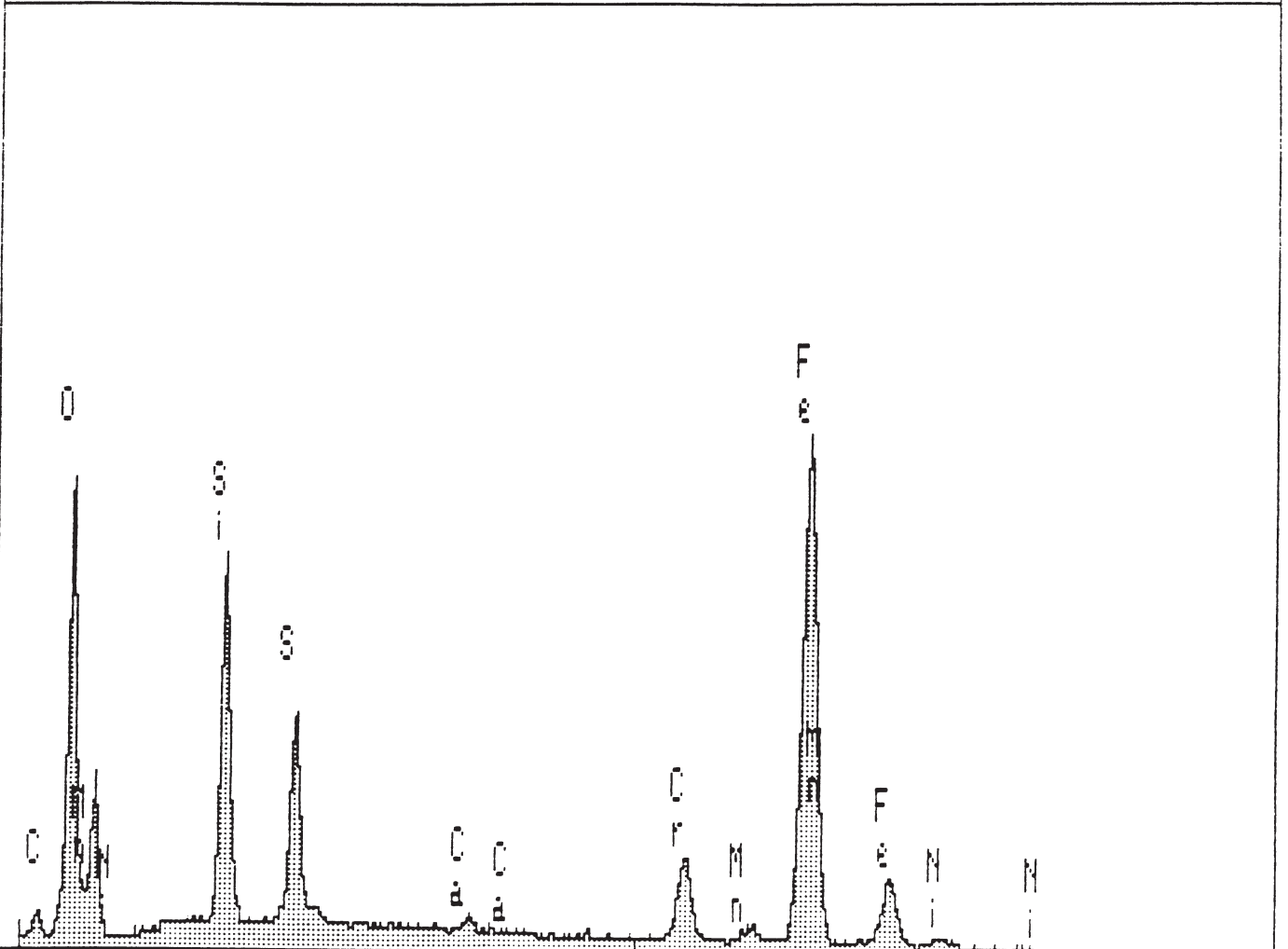
X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 159s 37% Dead



< - .0 5.080 keV 10.2 >
FS= 8K ch 264= 245 cts
MEM1:304 SS ref

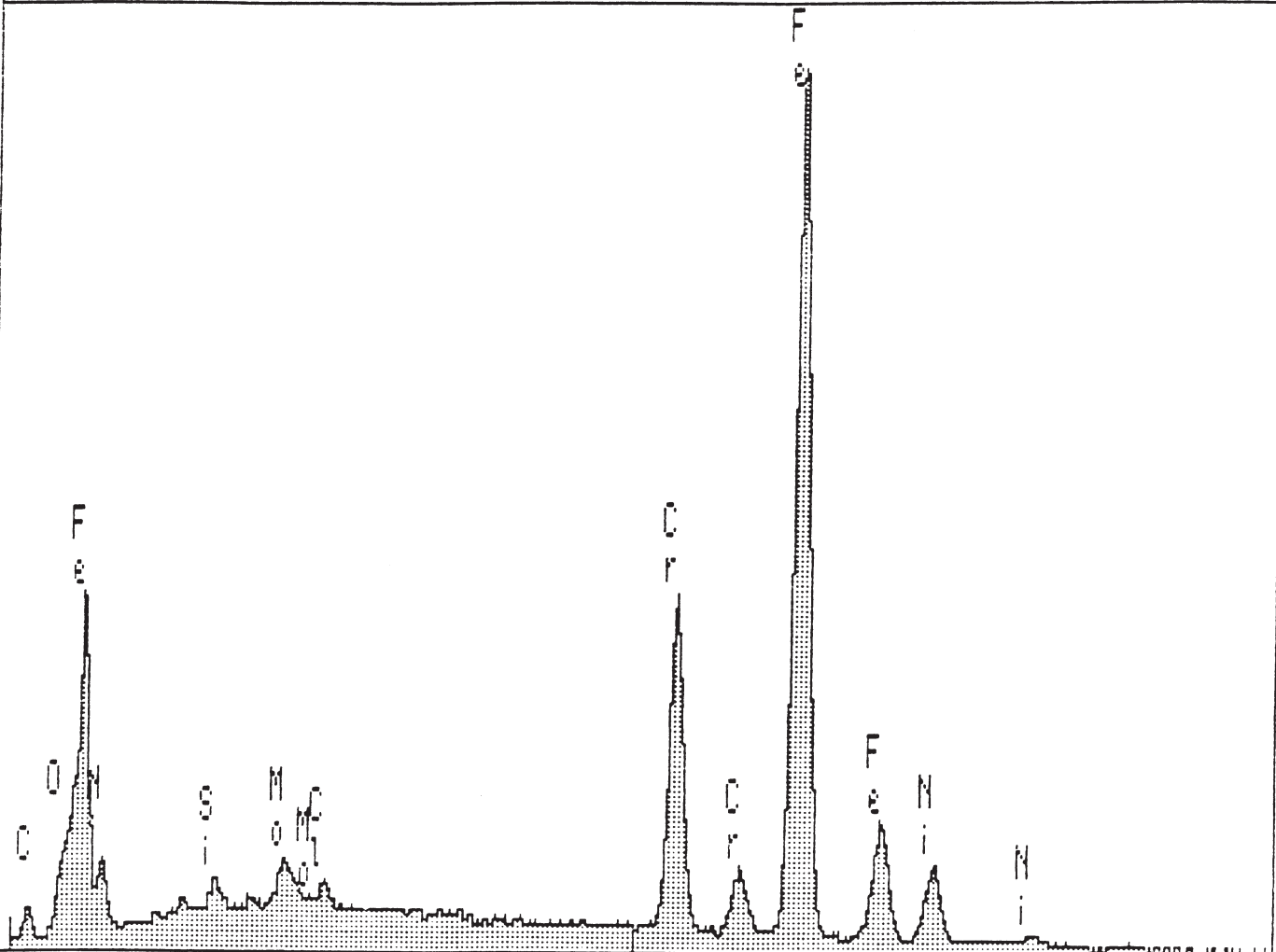


X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 154s 35% Dead



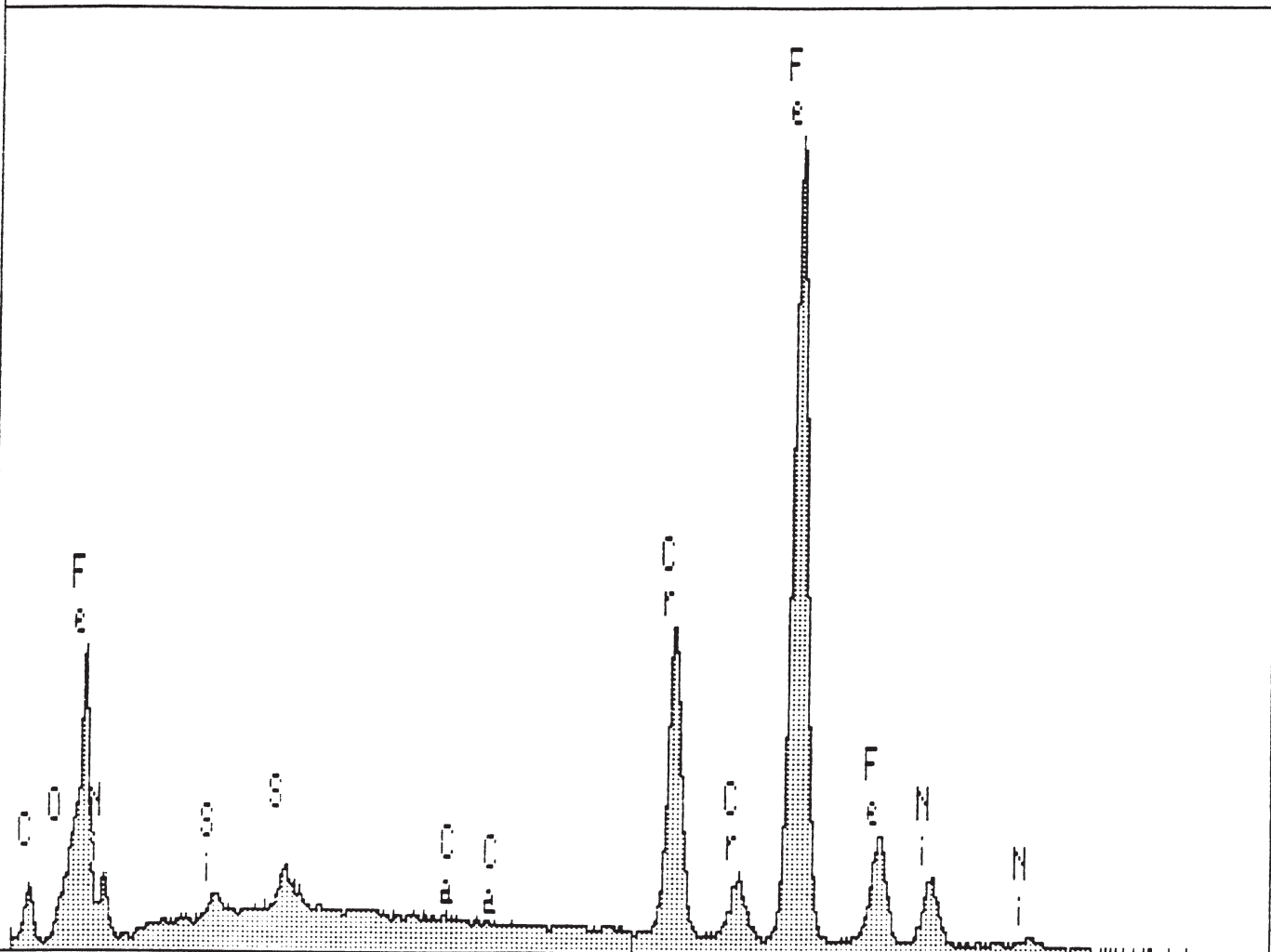
< -0.1 5.020 keV 10.1 >
FS= 8K ch 261= 165 cts
MEM1:304 SS scale

X-RAY: 0 - 20 keV
Live: 100s Preset: 100s Remaining: 0s
Real: 163s 39% Dead



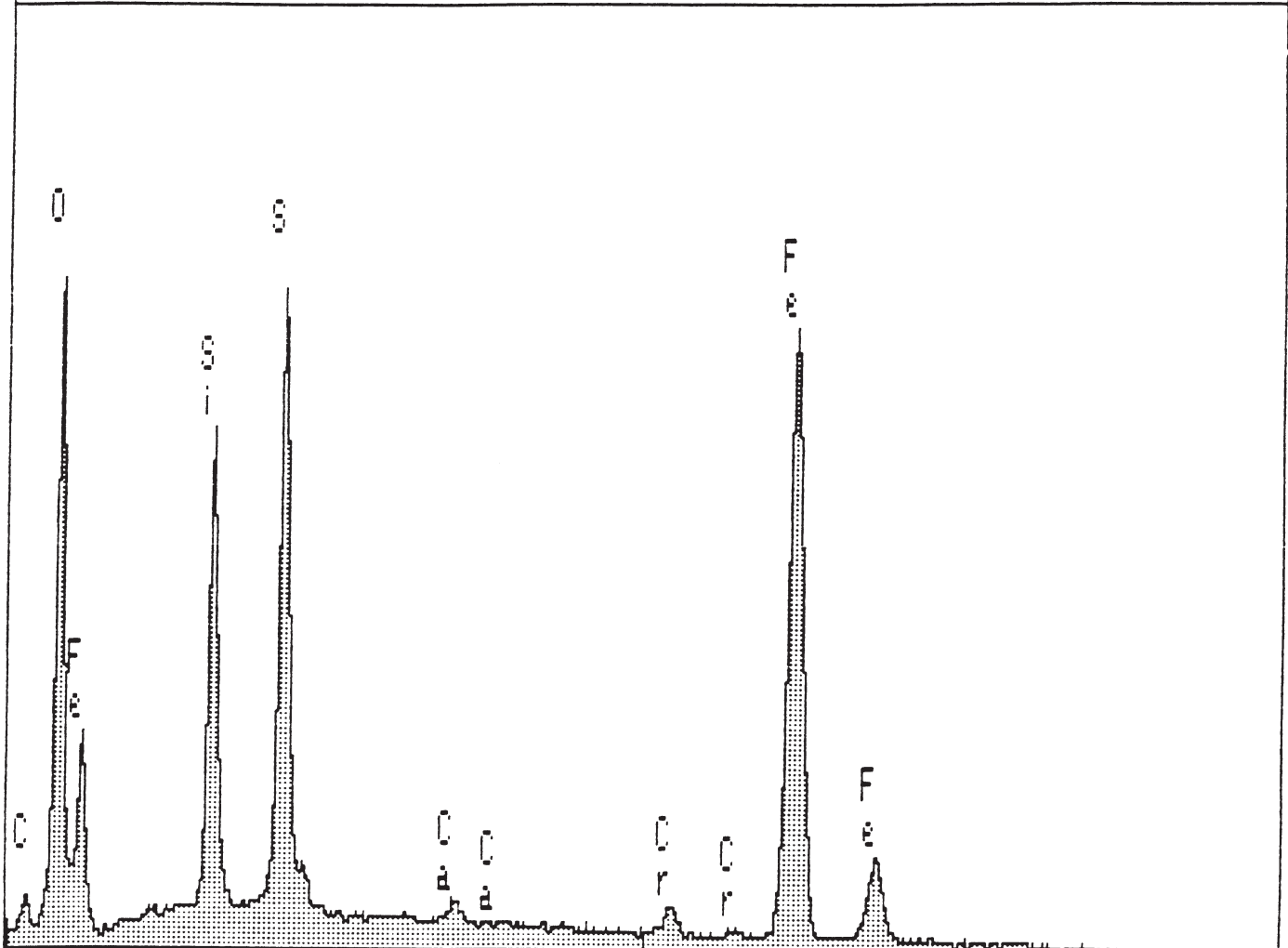
< - .0 5.080 keV 10.2 >
FS= 8K ch 264= 269 cts
MEM1:316 SS ref

X-RAY: 0 - 20 keV
 Live: 100s Preset: 100s Remaining: 0s
 Real: 156s 36% Dead



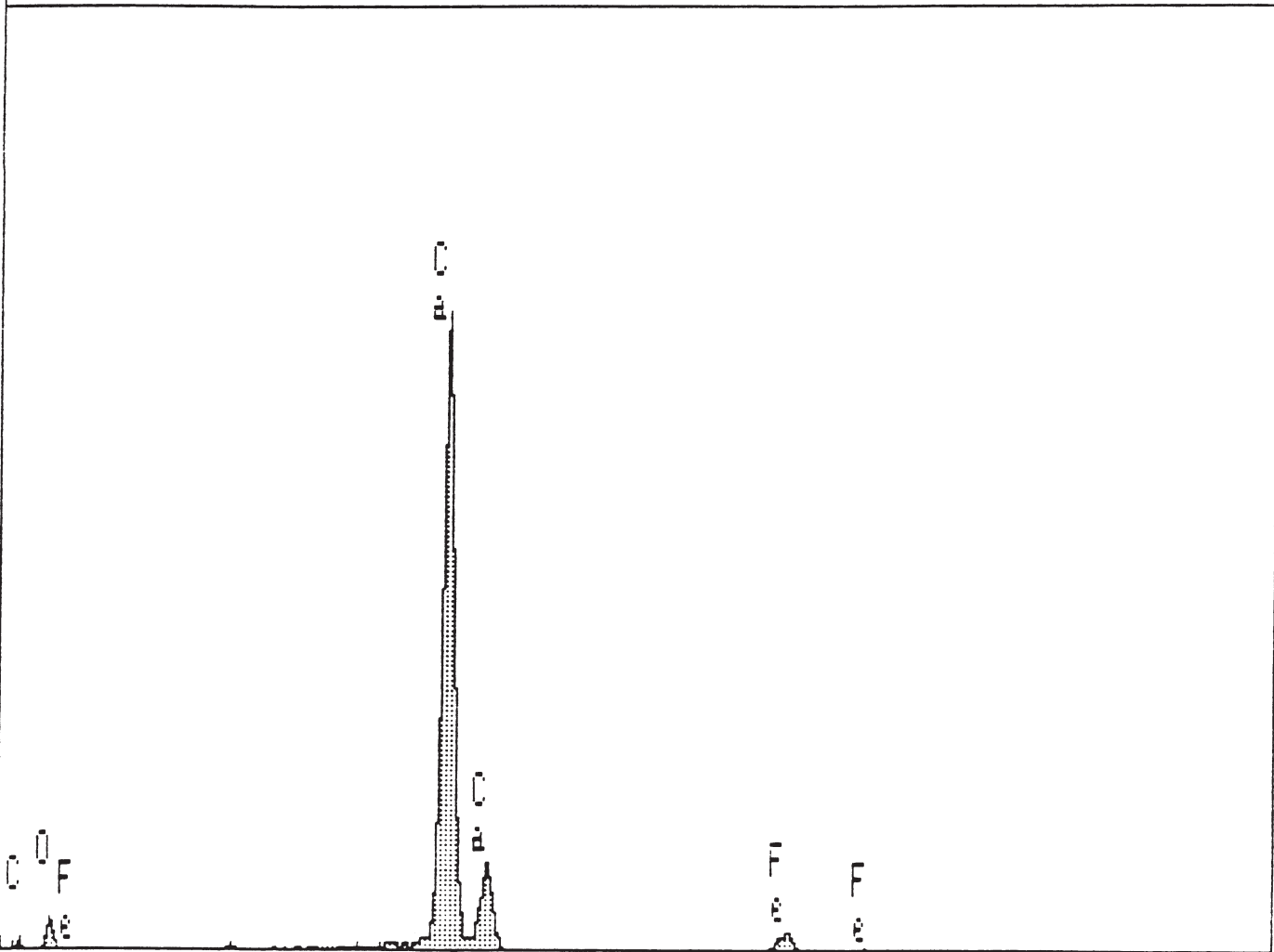
< - .0 5.080 keV 10.2 >
 FS= 8K ch 264= 252 cts
 MEM1:316 SS non scale

X-RAY: 0 - 20 keV
 Live: 100s Preset: 100s Remaining: 0s
 Real: 166s 40% Dead



< .1 5.200 keV 10.3 >
 FS= 8K ch 270= 200 cts
 MEM1:316 SS scale

X-RAY: 0 - 20 keV
 Live: 100s Preset: 100s Remaining: 0s
 Real: 127s 21% Dead



< .1 5.200 keV 10.3 >
 FS= 8K ch 270= 36 cts
 MEM1:316 SS xtal

