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Materials Performance in the Atmospheric Fluidized-bed Cogeneration Air Heater Experiment

by K. Natesan, W. Podolski, D. Y. Wang, F. G. Teats, W. Gerritsen, A. Stewart, and K. Robinson

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MATERIALS PERFORMANCE IN THE ATMOSPHERIC FLUIDIZED-BED COGENERATION AIR HEATER EXPERIMENT

by

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and
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Rockwell International

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MASTER

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ABSTRACT

The Atmospheric Fluidized-Bed Cogeneration Air Heater Experiment (ACAHE) sponsored by the U.S. Department of Energy (DOE) was initiated to assess the performance of various heat-exchanger materials to be used in fluidized-bed combustion air heater systems. Westinghouse Electric Corporation, through subcontracts with Babcock & Wilcox, Foster Wheeler, and ABB Combustion Engineering Systems, prepared specifications and hardware for the ACAHE tests. Argonne National Laboratory contracted with Rockwell International to conduct tests in the DOE atmospheric fluidized-bed combustion facility. This report presents an overview of the project, a description of the facility and the test hardware, the test operating conditions, a summary of the operation, and the results of analyzing specimens from several uncooled and cooled probes exposed in the facility. Extensive microstructural analyses of the base alloys, claddings, coatings, and weldments were performed on specimens exposed in several probes for different lengths of time. Alloy penetration data were determined for several of the materials as a function of specimen orientation and the exposure location in the combustor. Finally, the data were compared with earlier laboratory test data, and the long-term performance of candidate materials for air-heater applications was assessed.

SUMMARY

The Atmospheric Fluidized-Bed Cogeneration Experiment (ACAHE) is part of a research program funded by the U.S. Department of Energy (DOE) to advance the utilization of fluidized-bed combustion (FBC) technologies. It is a follow-up to the Generic Studies of Advanced Fluid-Bed Air Heater Technology and is intended to provide the data base required to commercialize the technology. The project comprises several tasks coordinated between two major contractors, namely, Argonne National Laboratory (ANL) and Westinghouse Electric Corp. During the course of the study, concerns were expressed over attempting to design and build, with commercial warranties, facilities based on the four concepts developed in the Generic Studies project without benefit of previous testing in FBC units. The ACAHE was conducted to assess the performance of various heat-exchanger materials at full commercial scale and thereby increase confidence in the resultant designs of FBC air-heater systems.

The ACAHE was conducted by ANL through a subcontract with Rockwell International (RI). The Energy Technology Engineering Center (ETEC) within the Rocketdyne Division of RI reactivated a

1.8-m x 1.8-m advanced fluidized-bed combustion (AFBC) unit at an RI site in El Segundo, CA. The Westinghouse team, consisting of Babcock & Wilcox (B&W), Foster Wheeler (FW), and ABB Combustion Engineering Systems (ABB/CE), provided test specimens which ETEC installed. The testing at RI required 45 months, beginning in December 1985. A total of 1958 h of coal-fired testing was accumulated.

Test Hardware

Nine types of test articles were exposed to the fluidized-bed environment: (1) previously exposed 304H platens, (2) platens fabricated from new serpentine sections, (3) platens fabricated from existing return bends and new straight sections, (4) cooled ring specimens, (5) a 304H platen section replaced after 1000-h exposure, (6) uncooled tab specimens, (7) uncooled ring specimens, (8) new platen clamps, and (9) uncooled U-bend tubes. The first five types of test article were used to evaluate candidate heat-exchanger tube materials and butt weldments, while the rest were used to evaluate hanger materials and weldments. More than 60 alloys were exposed during the 1958 h of testing. Test articles were visually inspected at regular intervals and removed for further examination.

Thirteen air-cooled specimen probes were installed in various test ports through the combustor casing to test the erosion and corrosion properties of candidate tube materials. Twelve of the probes were in the fluidized bed, and one was located in the convection section, just below the convection section heat exchanger. A valve was installed on each probe to control the flow of cooling air to maintain a particular temperature profile along the probe.

The probes were built up using interlocking rings of various alloys, stacked along the probe body. Each ring was hand lapped to each of the adjacent rings to minimize the leakage of cooling air, to maintain the desired probe temperature profile, and to reduce the possibility of oxygen addition to the bed. Each probe had between 20 and 30 specimen rings and four pairs of thermocouple rings.

Two types of uncooled specimen probes were exposed during AFBC testing: (1) individual tabs of material welded to a central bar of 304H, and (2) specimens that were similar to the cooled ring specimens, but were housed in probes that did not have provisions for cooling air and had only two thermocouples. The final type of test article was an uncooled "U-bend" of tubing. Two of these were placed in ports just above the in-bed heat exchanger.

Test Operation

Illinois No. 6 coal (-4.0 mesh) was used during the experiment. Pfizer high-calcium grit (-8 x 20 mesh), a local limestone, was used for sulfur control. The fluidized bed operated at a temperature of 871°C, a fluidizing velocity of 1.5 m/s, a working fluid outlet temperature of 816°C, and a flue gas oxygen content of 4%. Samples of solids from the bed and gas stream discharge ports were collected every shift for analysis. All separations were in compliance with approved EPA methods.

Results from Materials Analysis

Argonne conducted detailed microstructural analyses on specimens exposed in uncooled and cooled probes from ANL, B&W, and FW during the ACAHE. In addition, penetration depths were measured for several of the materials as a function of specimen orientation, exposure location in the combustor, and time of exposure. These results, together with those reported earlier from a laboratory test program in support of ACAHE, were used to determine the role of key variables that contribute to accelerated corrosion of materials and to assess the long-time materials performance of candidate materials for air-heater applications. Based on the information, a number of conclusions can be drawn:

1. Austenitic stainless steels such as Types 304, 310, and 330 and alloys (e.g., HR 3C, FW 4C, and 8XX) exhibited low depths of penetration after exposure in the ACAHE, as well as an earlier laboratory test under gas cycling conditions and a more severe laboratory test under low oxygen partial pressure (pO_2).

2. Alloys such as HS 188, HS556, HK 40, and 800H exhibited catastrophic corrosion from exposure to a sustained low-pO_2 condition and surface deposits of bed material, based on an earlier 3000-h laboratory test. Even though the test is more severe than what the materials will be subjected to in a typically well run FBC system, the data nevertheless suggest the susceptibility of these materials to accelerated corrosion.

3. Alloys such as HH, HP 50, 253 MA, XM 19, Sanicro 33, HS 556, and HS 188 were found susceptible to unacceptable corrosion when in contact with the bed material.

4. Among the weldments, filler metals 25-35R, 21-33, and 308 exhibited superior corrosion resistance. Filler metals such as Nicro 82, 188, and 25-35 showed acceptable corrosion resistance.

5. Among the coated specimens, aluminized coatings performed poorly. In general, this is because of the difficulty in achieving a crack-free coating rather than exposure to an FBC environment. If cracks were present initially, accelerated oxidation occurred, which considerably diminished the coating integrity.

6. Among the cladding alloys, Type 310 stainless steel on Type 304 stainless steel or on Alloy 800H exhibited superior performance.

7. The results from analyzing specimens in the uncooled probes indicate that the presence of bed material deposit on specimen surfaces leads to significant, and sometimes catastrophic, corrosion degradation of materials at a temperature of ~843°C (1550°F). On the other hand, the same alloys exhibit acceptable corrosion rates in the range of 0.05 to 0.25 mm/yr (2 to 10 mil/yr) when the surfaces were devoid of bed material deposits. (These rates are extrapolated from the 1980-h data based on parabolic kinetics.) In this regard, component material surfaces exposed to a corrosive-erosive environment perform superior to those exposed to corrosive environment alone. The acceptable performance of even Alloy 800 (an alloy that has been shown to undergo substantial corrosion during exposure in other FBC facilities) indicates that the combustion atmosphere in the present test was much more benign than in the other systems and that the operating conditions/procedures, if duplicated in a commercial system, can result in enhanced reliability of the larger system.

8. The corrosion rates for several materials (tested in this program) were in the range of 0.25 to 0.4 mm/yr (10 to 16 mils/yr) for temperatures in the range of 775 to 871°C (1425 to 1600°F). Considering that air tubes are 5 to 6 mm in wall thickness, these rates will lead to a thickness loss of 0.8 to 1.25 mm after 10 years of service in the FBC environment, even with built-in abnormal conditions. This report does not address how adequate the mechanical properties of materials were at elevated temperatures, which is also important in materials selection. However, based on this study, corrosion resistant materials can be applied as a cladding onto a structurally acceptable alloy (i.e., one with sufficient strength at high temperatures) to achieve adequate corrosion resistance and mechanical properties for the air-heater tubes.

I. INTRODUCTION

In 1980 Rocketdyne, a division of Rockwell International, designed, fabricated, and tested an atmospheric fluidized-bed combustor (AFBC) for research on closed-cycle gas turbine cogeneration systems. This coal-fired facility measures 1.8 m x 1.8 m. Test configurations and procedures were developed for extended corrosion/erosion testing, and approximately 1000 h of actual testing was conducted under DOE sponsorship.[1]

In 1985 ANL and Westinghouse Electric Corp. proposed additional materials research in this facility. The project, known as the Atmospheric Fluidized-Bed Cogeneration Air Heater Experiment (ACAHE), is part of a research program funded by DOE to advance the utilization of fluidized-bed combustion technologies. It is a follow-up to the Generic Studies of Advanced Fluid-Bed Air Heater Technology[2] and is intended to provide the data base required to commercialize the technology.

Four different air-heater cogeneration concepts were studied in the Generic Studies project: (1) a fan- or turbine-exhaust-blown, bubbling AFBC, (2) a fan- or turbine-exhaust-blown, circulating AFBC with a separate fluidized-bed heat exchanger, (3) a fan- or turbine-exhaust-blown coal pyrolyzer operated in series with an AFBC (the pyrolysis gas is combusted to raise the turbine inlet temperature), and (4) a bubbling AFBC or coal pyrolyzer/AFBC that is pressurized to 3 to 5 atm by part of the exhaust from a high-pressure turbine, while the remaining exhaust is expanded through a low-pressure turbine. During the course of the study, it was decided that the four concepts should be tested in an FBC unit before attempting to incorporate them into a commercial facility. The ACAHE was conducted to test various heat-exchanger materials at full commercial scale for better resultant designs of FBC air-heater systems.

Before the testing at Rockwell, ANL assessed the information in the literature concerning high-temperature materials performance in FBC environments[3] and conducted bench-scale corrosion studies in simulated FBC environments.[4]

Rockwell's contribution was to reactivate the AFBC facility, to improve its operability characteristics, to fabricate and install test specimens, to report the test data, and to decommission the facility. The test specimens were provided by three Westinghouse subcontractors: Babcock & Wilcox (B&W), Foster Wheeler (FW), and ABB/Combustion Engineering Systems (ABB/CE). The original project scope involved three test phases: 1000 h of coal firing, 50 h of coal/water slurry testing, and 1000 h of natural gas-fired testing. The slurry test and the gas-fired simulation of a circulating fluidized-bed (CFB) boiler were deleted because an adequate simulation of a CFB could not be accomplished in the existing facility. Coal firing was then extended to 2000 h. The project required 45 months, beginning in December 1985. A total of 1958 h of coal-fired testing was accumulated.

The Energy Technology and Engineering Center (ETEC) within Rocketdyne provided engineering designs, fabrication, and project management; and Rockwell International's North American Aviation Operations Division (NAAO) provided the test crews and facility support. The AFBC facility is located at the NAAO Thermodynamics Laboratory at El Segundo, CA (Fig. I-1).

This report contains a summary of the testing at ETEC and the results obtained from the ANL examination of uncooled and cooled specimens exposed for different lengths of time at several locations in the combustor. A comparison of the results of analyses by ANL and the three Westinghouse subcontractors is presented. Details of analyses of other materials specimens are contained in final reports by the Westinghouse team.

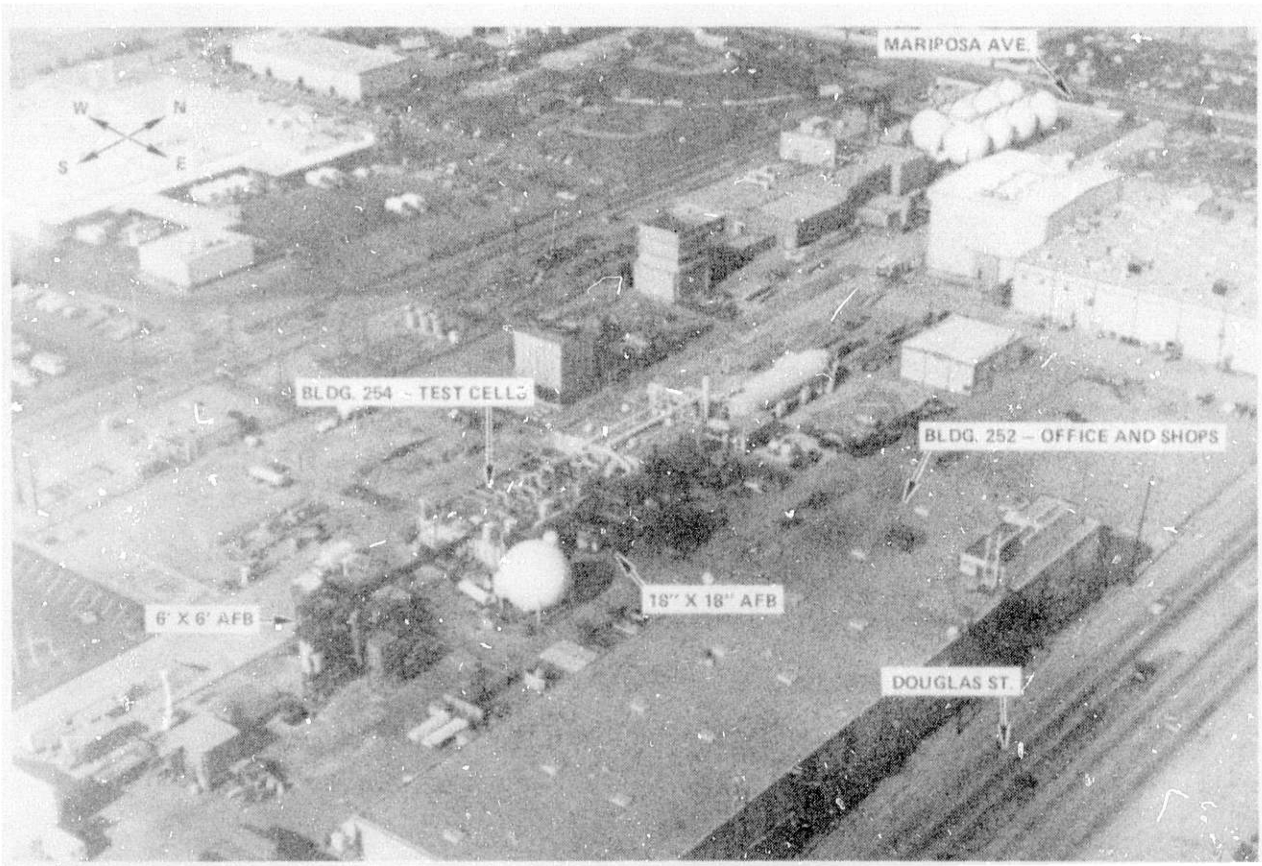


Fig. I-1. Aerial View of NAAO Thermodynamics Laboratory (El Segundo, CA)

II. DESCRIPTION OF THE FACILITY

The 1.8-m x 1.8-m AFBC (Fig. II-1) is an experimental facility to study the technology of metallic heat exchangers. While much work is being done on fluidized-bed combustors for steam-boiler applications, this facility is oriented toward heat-exchanger development with significantly higher metal temperatures than steam-cooled heat exchangers.

The system supports research on hardware and equipment of a size approaching minimum demonstration dimensions. The experimental unit was designed to provide operating data over a wide range of conditions, as summarized in Table II-1.

Table II-1. Range of Test Capability

Superficial Velocity, m/s	0.6 to 2.4
Working-Fluid Outlet Temperature, °C	788 to 843
Excess Air, %	20 to 50
Ca/S Molar Ratio	2 to 4
Ash Recycle	0 to 3 times coal flow rate

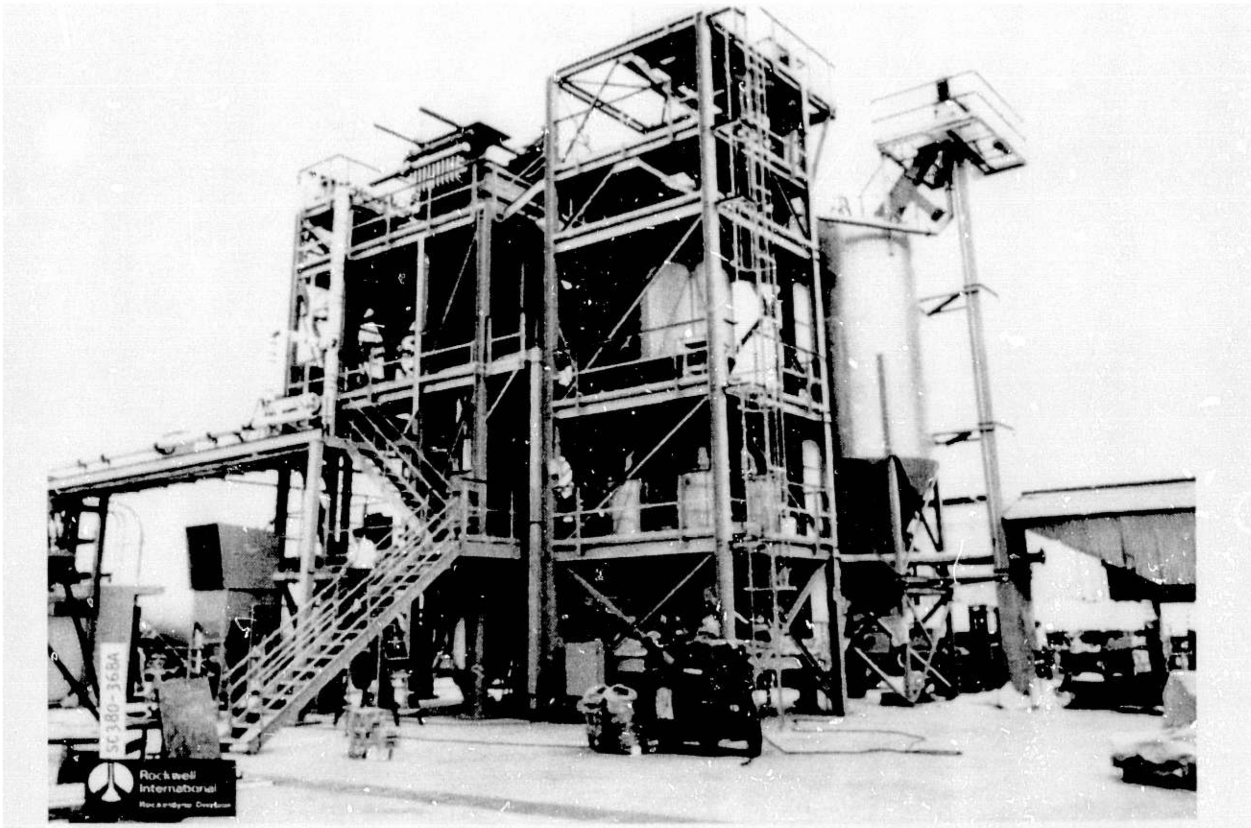


Fig. II-1. Atmospheric Fluidized-Bed Combustion Facility

A simplified schematic is shown in Fig. II-2, which illustrates the key components. The working fluid, air, is supplied from the facility compressor and preheater (not shown) to the top of the combustor tower. The air is heated first in the convection bank; it then flows through the in-bed heat exchanger and, upon leaving the combustor, is discharged to the atmosphere at a temperature of 816°C. Fluidizing air is provided by a forced draft blower and passes through a preheater to exchange heat between the flue gas and fluidizing air. Flue gas leaving the combustor passes through a cyclone separator, the preheater, baghouse, and induced draft fan. The cyclone removes most of the solid particulate, which then can be either disposed of or recycled back into the combustor. The baghouse provides a final cleanup of the flue gases, so the gases discharged are cleaner than the Federal Air Pollution Standards require. The induced draft fan maintains a balanced draft in the freeboard (zone above the fluidized bed) section of the combustor. The solids feed systems are coal, limestone, and fly ash reinjection. Spent solid materials are removed at the bed drain at the combustor bottom.

The experimental unit was designed to address the technical issues related to long-life design for an air-heater application, particularly erosion and corrosion of heater tube materials. The facility and hardware were designed with a great degree of flexibility and range, and the unit can operate for an extended duration. The nominal design parameters are presented in Table II-2. The potential exists for adding turbo machinery to the system.

During the earlier test programs, Rocketdyne identified a number of problems that could be corrected to improve operability of the facility. These problems were presented in a Rocketdyne-published Facility Status Report.[5] The ETEC reviewed the Rocketdyne recommendations and elected to implement some, delete some, and make modifications to simplify facility operation or to meet requirements.

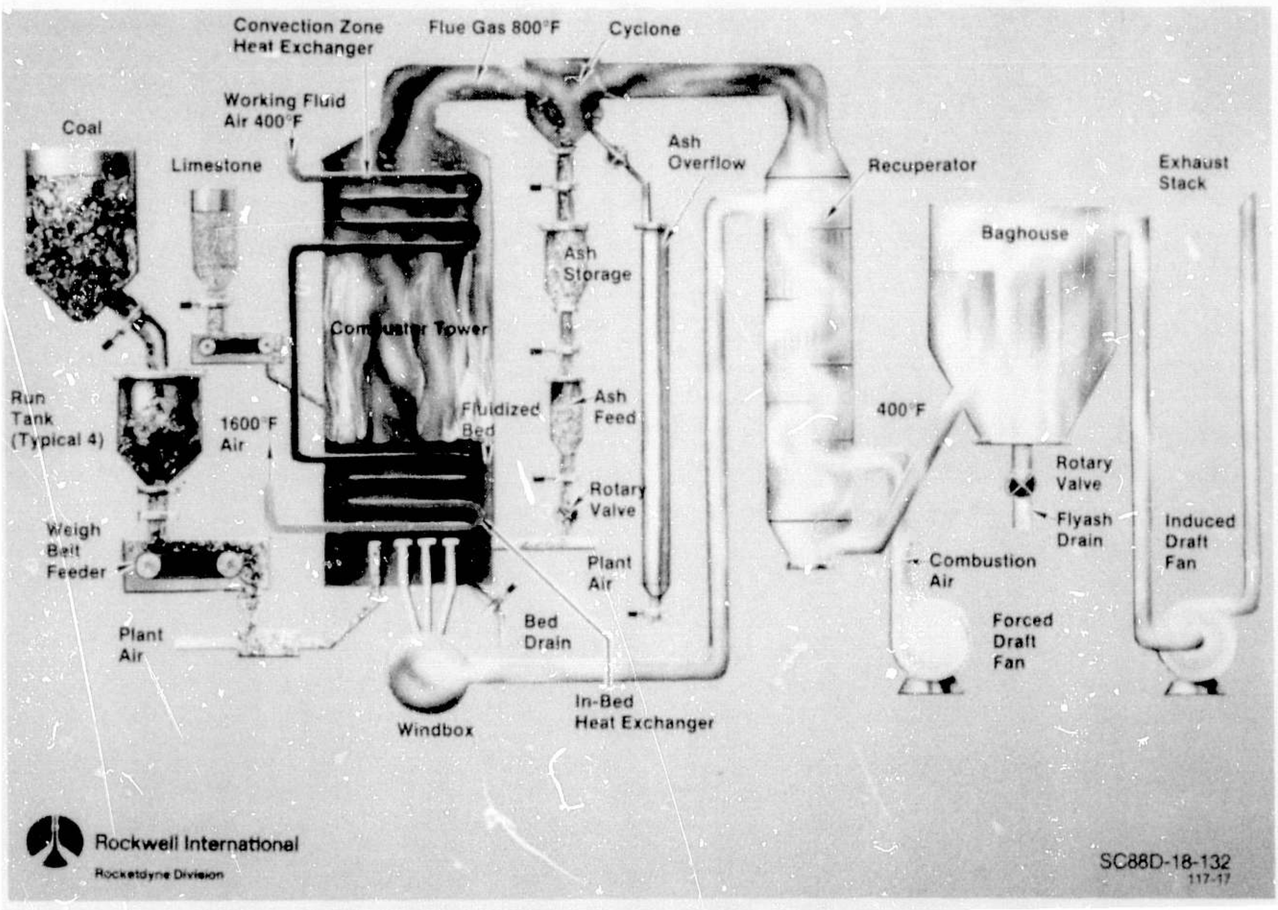


Fig. II-2. Schematic of AFBC Unit

Table II-2. AFBC Nominal Design Parameters

Superficial Velocity, m/s	1.8
Combustion	
Coal Flow Rate, kg/h	636
Air Flow Rate, kg/h	7082
Excess Air, %	25
Bed Temperature, °C	899
Working Fluid (Air)	
Inlet Temperature, °C	232
Exit Temperature, °C	843
Flow Rate, kg/h	18,432
Heat Release, MJ/h	6354

During operation of the combustor, the coal feeding system had been identified as a prime area to improve. The feeders were volumetric, and the feed rates had to be inferred from the measured revolutions per minute of the screw and an estimate of coal bulk density. Direct-reading mass-flow meters were needed to obtain the mass flow instantaneously and to permit closer control of the coal feed rates to the individual coal ports.

A new mass-flow control system was selected to replace the existing volumetric screw feeders. The new system consisted of four weigh belts with four individual mass-flow controllers and a single master controller. Similar units had been used at Rockwell's Combustion Test Facility for feeding various solids, including coarsely milled coal and finely ground coal. The new system allowed coal feed to each quadrant of the combustor air distribution plate to be controlled with precision. The individual controllers are slaved to the master controller to control the total feed rate to the burner. Control of total combustor stoichiometry and simultaneous control of the individual quadrant stoichiometries can be changed easily by the facility operator.

The limestone feed system to the combustor was changed from a vibrating tray feeder to a weigh-belt feeder, similar to the one above for coal. One of the two Rockwell-owned units at the Combustion Test Facility was loaned to NAAO for use on the limestone feed system. Accurate values of instantaneous limestone feed rate and total limestone were continuously available to the operators with the new weigh-belt feed system.

Minor modifications to the limestone loading system were made to facilitate its operation. The horizontal run of the solids-conveying air line was increased to accelerate the solids to a sufficient velocity so that they would not drop out and plug the vertical line.

During the earlier Rocketdyne testing, each quadrant in the fluidized bed was fitted with a different coal-feed port configuration. For this experiment, all ports were identical to provide a more uniform environment in the combustor. The feed-port configuration is shown in Fig. II-3.

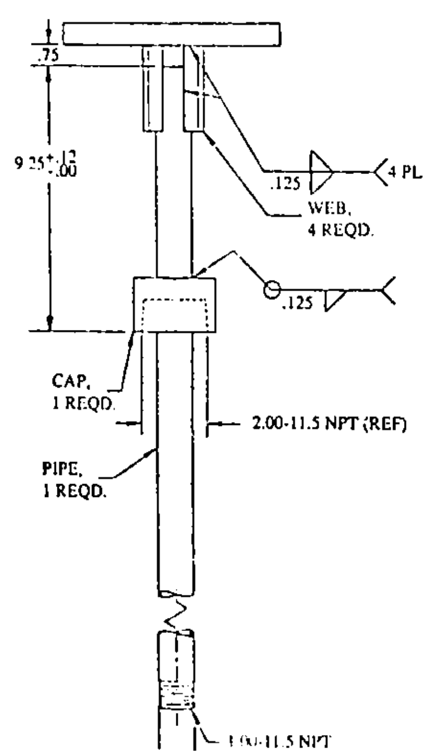


Fig. II-3.

Coal-Feed Port Configuration. (Units for all measurements are in inches. Abbreviations are defined as NPT = National Pipe Thread and PL = Places.)

The ash recycle rotary valve was replaced by a new valve with a floating seal. The existing valve had a rigidly mounted seal, which caused the rotor to bind due to fluctuations of higher temperatures the valve experienced during operation. Also, the vent piping was removed. The ash-injection conveying system was modified, and the line diameter was reduced from three to two inches for more reliable product transport.

The baghouse bags were replaced with 14-ounce Nomex bags that had been heat-treated. They have a "singed" surface which released the fly ash filter cake much more easily. The baghouse pulsers were operated on a timed cycle rather than a manual one, which allowed a large pressure differential to build up. No baghouse problems were observed during operation.

Data acquisition was significantly improved by installing a dedicated system in the AFBC control room. The computer controlled the various displays and recording devices according to input from the operator. A modem was provided so that the system could be accessed remotely for modifying programs or troubleshooting from ETEC offices 40 miles away. The system had 336 channels. In addition, there were five pulse-counter inputs which measured the frequency of the weigh-belt coal and limestone feeders. Data were recorded on disk for temporary storage and recall, and permanent data were recorded on magnetic tape.

III. TEST HARDWARE

In fluidized-bed air-heater applications, heat-exchanger materials must withstand metal temperatures considerably higher than are typical with steam-raising applications. Nine types of test articles were exposed in the fluidized-bed environment: (1) previously exposed 304H platens, (2) platens fabricated from new serpentine sections, (3) platens fabricated using existing return bends and new straight sections, (4) cooled ring specimens, (5) a 304H platen section replaced after 1000 h of exposure, (6) uncooled tab specimens, (7) uncooled ring specimens, (8) new platen clamps, and (9) uncooled U-bend tubes. The first five types of test articles were used to evaluate candidate heat-exchanger tube materials and butt weldments, while the remaining test-article types were used to evaluate hanger materials and weldments. More than 60 alloys were exposed during the 1958 h of testing. Test articles were inspected visually at regular intervals and removed and evaluated.

The in-bed heat exchanger, shown in Fig. III-1, comprised 24 platens. A typical platen is shown in Fig. III-2. Air from the inlet header is carried by a downcomer to the first (lowest) tube. After ten passes through the system, the air exits to the outlet header. The original tube bundle was fabricated from 2-in. (50.8-mm) 304H tubing. The first four rows of tubes had 0.180-in. (4.6-mm) thick walls, while the final six rows had a wall thickness of 0.260 in. (6.6-mm). A transition piece through the combustor casing from the tube bundle to the inlet and outlet headers had a 0.50-in. (12.7-mm) wall thickness. The transition pieces provided vertical support for the tube bundle. Several types of clamps were used to tie the tube bundle together while allowing for thermal expansion. Diagrams of various types of hangers are shown in Fig. III-3.

The existing tube bundle was modified with two types of new tube specimens. The first type consisted of straight-tube sections of various alloys with 3-in. (8-cm) stubs of 304H welded to each end (Fig. III-4). The 304 stubs allowed the bundle fabricator to make only 304-to-304 welds. Existing return bends were used for the five platens that were modified with the straight sections in order to utilize existing hangers where possible.

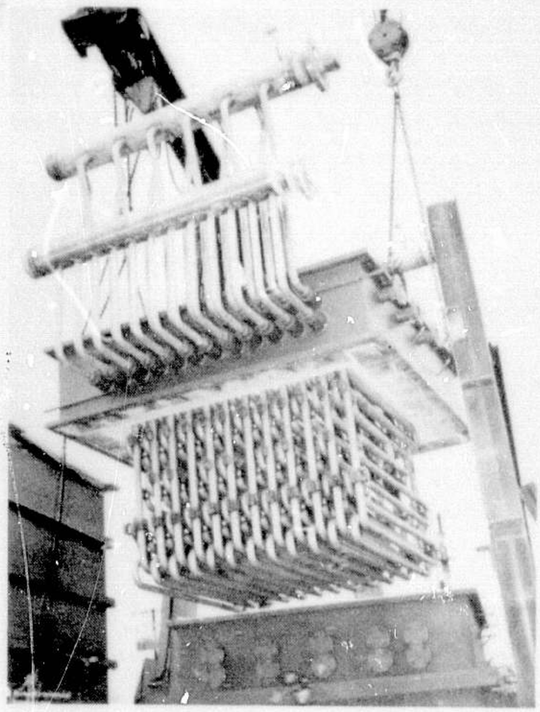


Fig. III-1. In-Bed Heat Exchanger

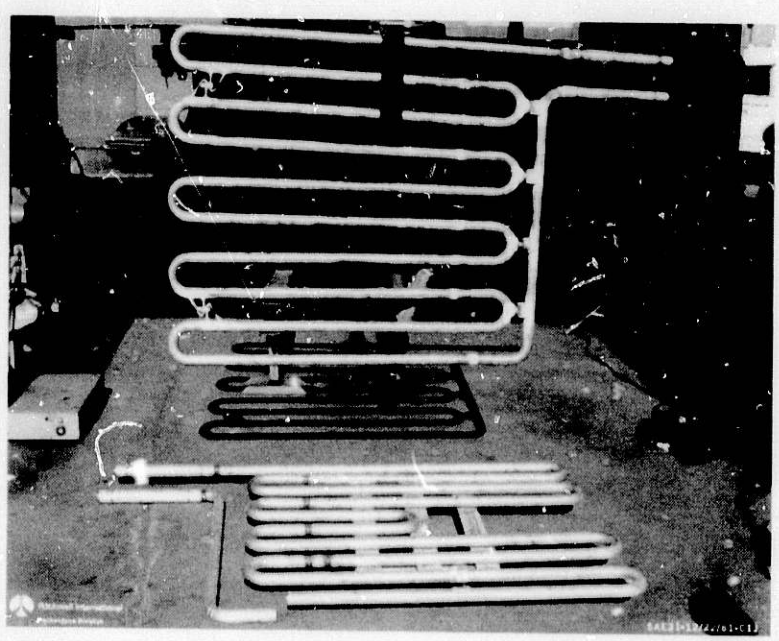


Fig. III-2. Typical Platen

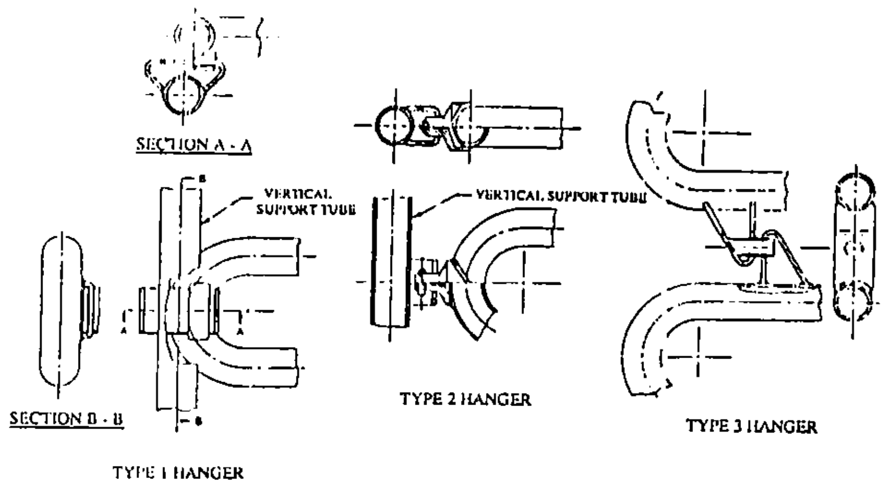


Fig. III-3. Hanger Types

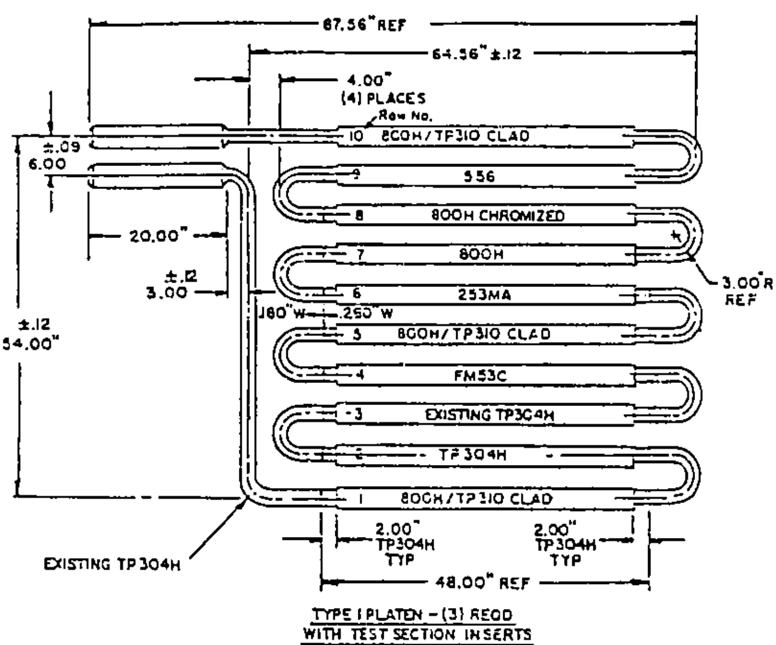


Fig. III-4. Platen with Straight Test Specimens

The second type of heat-exchanger test specimen consisted of replacement platens of new material, including return bends. Seven platens were modified in this way. Hangers cut from the original platens were reused on the new platens, with the exception of 17 clamps, which were replaced with new hangers of a different design (Fig. III-5).

After these changes were made, all welds were liquid-penetrant inspected, and selected welds were radiographed. The tube bundle was hydrostatically tested after its fabrication to ensure its integrity.

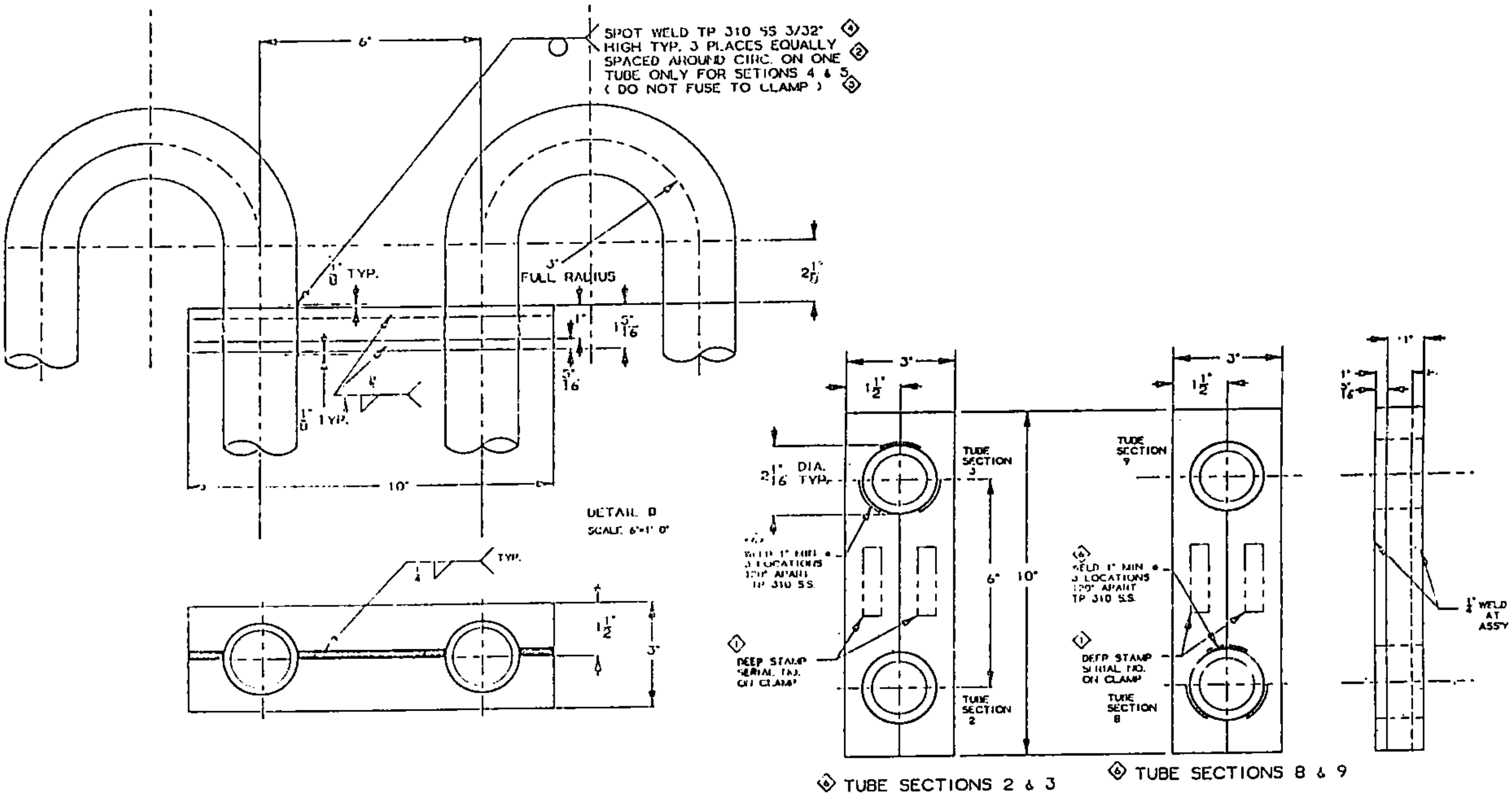


Fig. III-5. Engineering Drawing for Clamp Assembly. (TYP = Typical)

A final modification to the tube bundle was made after approximately 1000 h of testing. Six sections of tubing, three from the uppermost row of platens and three from the lowermost rows, were to be replaced, but because of the difficulty in making satisfactory welds with the limited space available, only two actually were replaced.

Twenty thermocouples were installed on the exterior wall of in-bed heat-exchanger tubes. These thermocouples were destroyed after only a few hours of operation, as expected, but some useful data on metal temperature were obtained.

Thirteen air-cooled specimen probes (Fig. III-6) were installed in various test ports through the combustor casing to test the erosion and corrosion properties of tube materials. Twelve of the probes were in the fluidized bed (as shown in Fig. III-7) and one was located just below the convection-section heat exchanger. A valve was installed on each probe to control the flow of cooling air to maintain a particular temperature profile along the probe. There were five thermocouples installed to monitor temperatures, four located along the probe, and one at the coolant outlet.

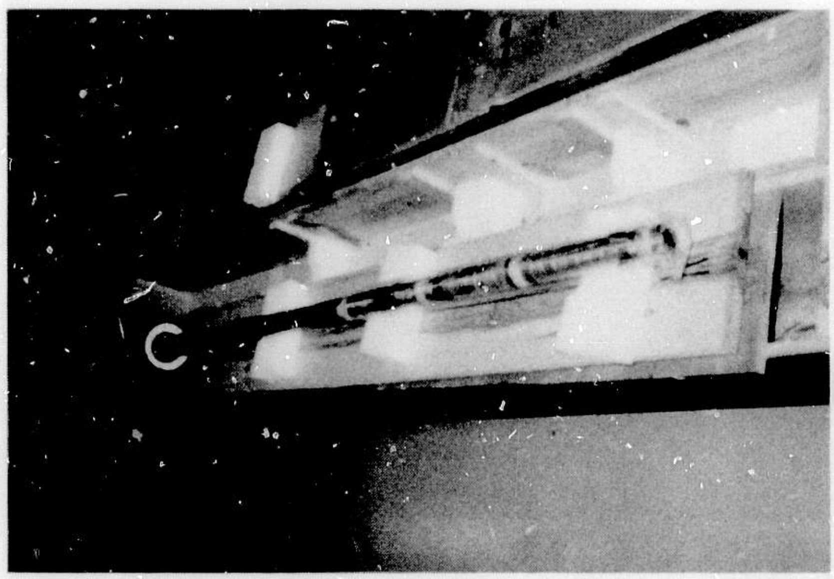


Fig. III-6. Air-Cooled Specimen Probe

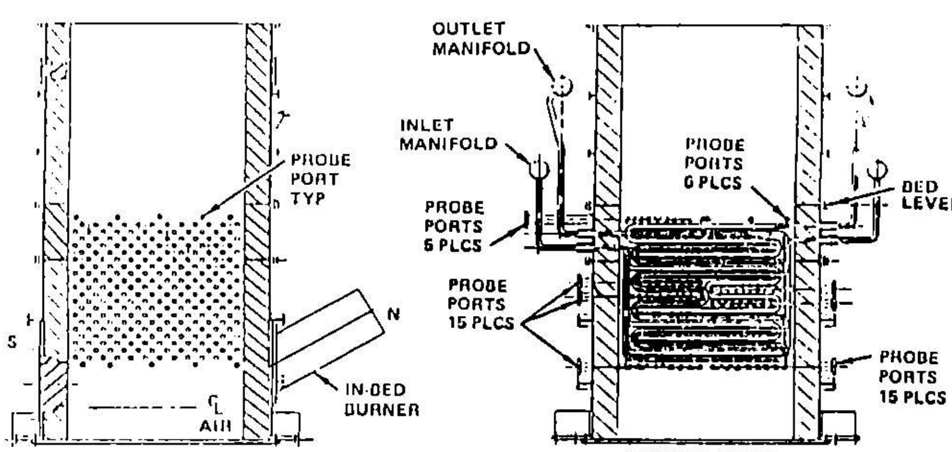


Fig. III-7. Probe Port Locations in the Fluidized Bed

The probes were built from interlocking rings of various alloys that were stacked along the probe body (Fig. III-8). Each ring was hand lapped to its adjacent rings to minimize the leakage of cooling air, to maintain the desired probe temperature profile, and to reduce the possibility of oxygen addition to the bed. Each ring was carefully washed, rinsed, and weighed (to the nearest 0.1 m) prior to assembly onto the probe body. Figure III-9 shows typical cooled-ring specimens. Each probe had between 20 and 30 specimen rings and four pairs of thermocouple rings.

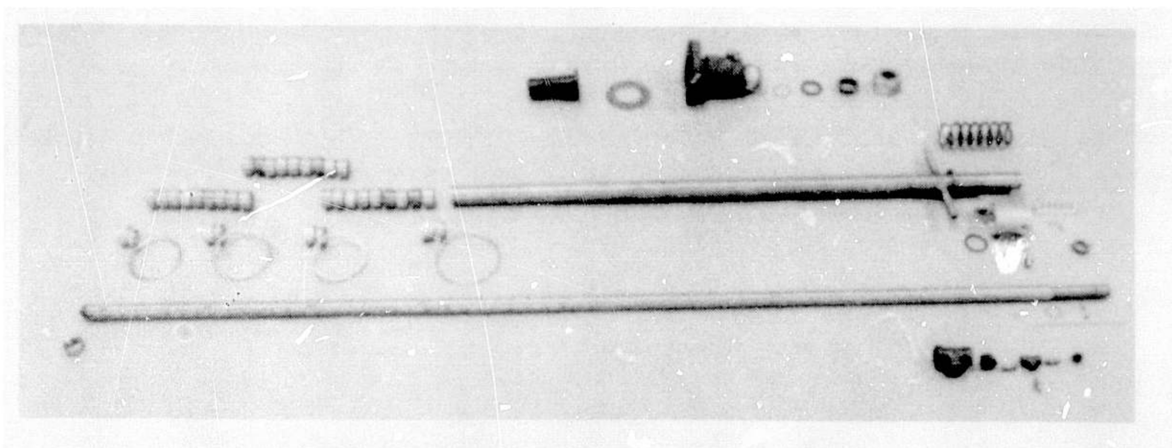


Fig. III-8. Components of the Air-Cooled Probe

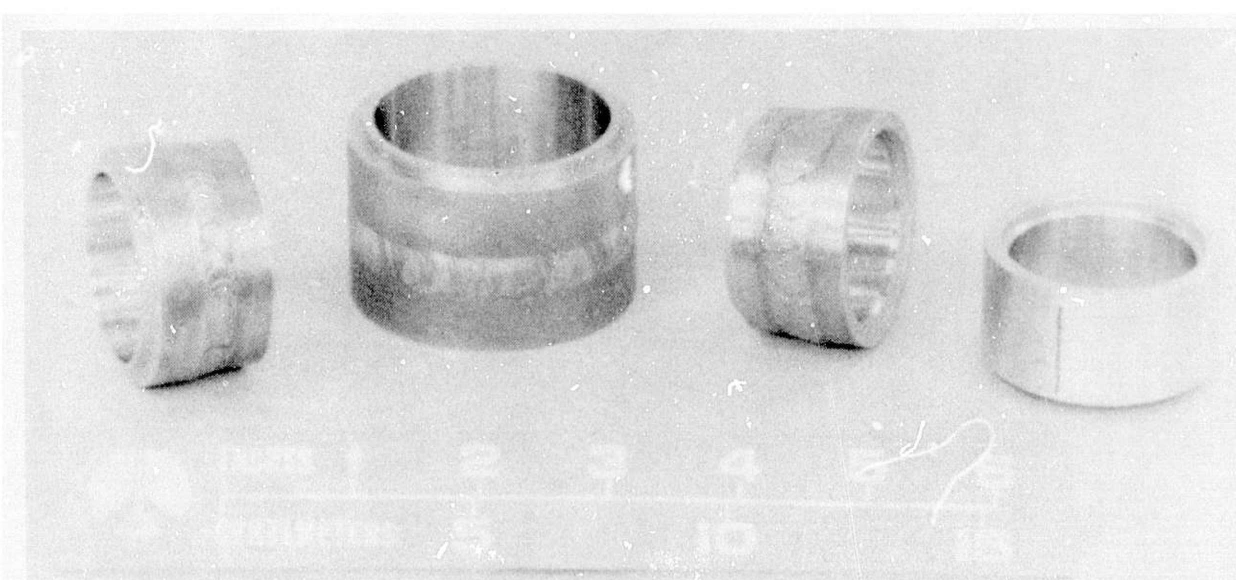


Fig. III-9. Typical Ring Specimens

Two types of uncooled specimen probes were exposed during AFBC testing. These probes were designed to test candidate hanger materials. The first type of probe was the uncooled tab probe, in which individual tabs of material were welded to a central bar of 2-in. (5-cm) 304H. Tabs of each material were welded at the 12, 3, 6, and 9 o'clock positions. In addition, five uncooled tab probes were installed. Figure III-10 shows a typical uncooled tab probe.

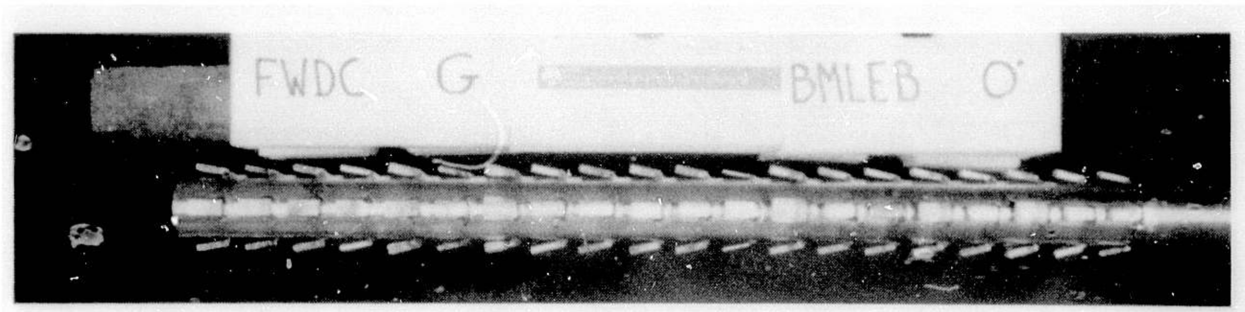


Fig. III-10. Typical Uncooled Tab Probe

The second type of uncooled probe was the uncooled ring probe of which there were three (Fig. III-11). The specimens in these probes were similar to the cooled ring specimens, but the probes did not have provisions for cooling air and had only two thermocouples.

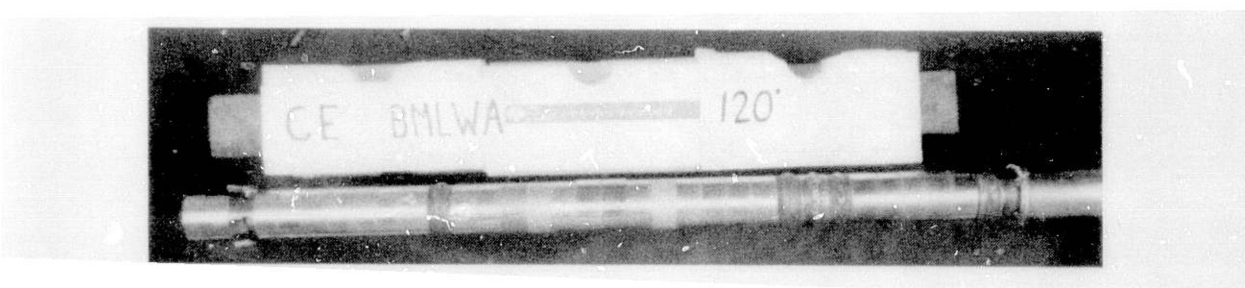


Fig. III-11. Uncooled Ring Probe

The last type of test article was an uncooled U-bend of 2-in. (5-cm) OD tubing. Two of these were placed in ports just above the in-bed heat exchanger. Figure III-12 shows one of these specimens.

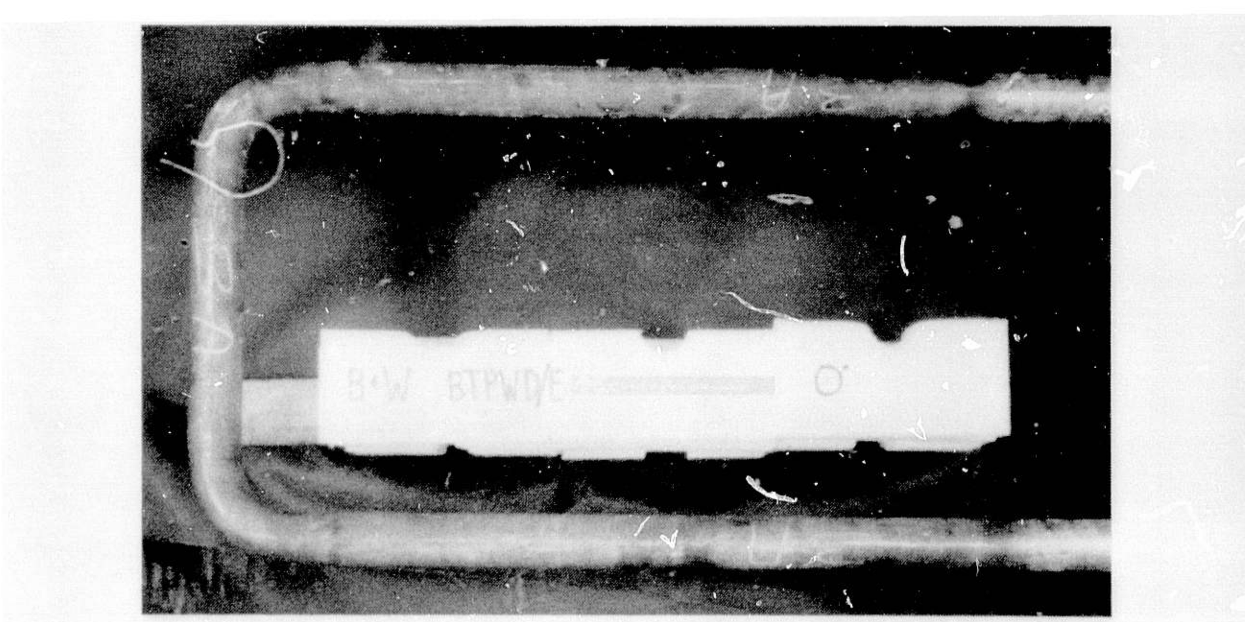


Fig. III-12. Uncooled U-Bend Probe

IV. TEST PLAN

The test duration was planned to be 2000 h, divided in 250-h test segments. Each segment was characterized by a gradual startup to steady-state test conditions, a 250-h hold at test condition, and a gradual shutdown to ambient temperature. Between segments, maintenance and necessary repairs would be performed on the facility and the test specimens would be inspected. The steady-state operating conditions are shown in Table IV-1.

Table IV-1. Steady-State Operating Conditions

Fluidized-Bed Temperature, °C	871 ± 14
Fluidized-Bed Height, m	2.4 +.15-0
Superficial Velocity, m/s	1.5 ± 0.1
Freeboard Pressure, kPa	-101.2 ± 101.2
Working Fluid Outlet Temperature, °C	816 ± 14
Oxygen in Flue Gas, %	4 ± 0.5

Instrumentation was provided in the facility to measure temperatures of the test article and to identify the environment to which the test articles were exposed. All instruments were calibrated to meet the specified accuracies. Measurements were recorded on (1) disk at a rate of one sample per 10 s for on-line data retrieval and plots and (2) magnetic tape at a rate of one sample per 120 s for permanent storage and data manipulation.

The coal used for this experiment was Illinois No. 6 screened to ~4 mesh. Analytical results for coal samples taken before testing are shown in Table IV-2. The sorbent used for sulfur capture was Pfizer high-calcium grit (limestone) (>98% $CaCO_3$) screened through a -8 x 20 mesh.

Table IV-2. Results from Ultimate Analysis of Coal[a]

Component	Percent
Carbon	60.87
Hydrogen	4.18
Nitrogen	1.11
Chlorine	0.1
Sulfur	3.34
Ash	8.86
Oxygen	8.17
Moisture	13.97

[a]One of four samples taken before testing.

Periodic solids sampling was required during test operations. Each shift one-liter samples were taken from the coal, limestone, baghouse fly-ash, and spent-bed material. These samples were periodically analyzed for adherence to feed stock and combustion-product requirements.

The South Coast Air Quality Management District (SCAQMD) requires power-plant operation in compliance with approved EPA methods. The SCAQMD issued an operating permit for coal-fired testing up to 1200 h per year, while continuously monitoring emission concentrations of NO_x, SO_x, CO_2, O_2, CO, and unburned hydrocarbons. The SO_2 emission was limited to 276 ppm at 3% O_2 on a dry basis. Over the course of the program, this limit was easily met. The permit conditions also required daily calibrations of the flue-gas instrumentation system.

The possibility of in-bed heat-exchanger tube leaks was of particular concern because tube leaks can cause severe damage to adjacent tubes. Therefore, ETEC conducted leak tests at 8-h intervals by injecting helium into the working fluid and then sampling the stack effluent for the presence of helium.

During the test segments, oxygen concentrations in the bed were determined using a diagnostic probe which measured partial pressure at various locations within the bed. The probe could penetrate through several ports in the combustor casing via an isolation valve.

To comply with the instrument accuracy requirements, all instruments affecting the key parameters (pressure, pressure differential, and flows) were calibrated between test segments. Additionally, calibrations on the data-acquisition system were performed. No significant shifts in calibration were observed during the course of the test program.

V. TEST OPERATION

All operations were conducted in accordance with a detailed Test Procedure written by Rockwell. The Test Procedure was the controlling document specifying the order in which each subsystem was to be brought on-line. Each subsystem (e.g., plant air, nitrogen purge, burner ignition, and coal-feed system) had its own detailed procedure, which defined proper valve line-up, flow rates, temperatures, etc., to ensure proper and safe system operation. These procedures worked well, and throughout almost 2000 h of testing, no time was lost due to improper setup of plant conditions.

During the initial checkout of the facility, the combustor was preheated in small increments to allow the newly installed refractory to cure. Once curing was completed, the preheat stage commenced. During the earlier Rocketdyne test program, a major problem was the fouling of the convection-section tube bundle with ash deposit. It was determined that moisture generated by the natural gas burners used in the initial heating of the combustor was condensing on the convection-section tubes, and ash material was then adhering to the tubes. To avoid this problem, the procedure for initial heating of the unit called for preheating the combustor with the working fluid. The working fluid was heated by the compressor gas-fired preheater. The forced draft and the induced draft fans were used to distribute the heat through the combustor. Heat-up rates were controlled to less than 55.6°C/h (131°F/h) by adjusting the working-fluid flow rates and the firing rate of the compressor heater. This procedure worked well, and no fouling of the convection bank heat exchanger was observed throughout the test program.

Once the unit reached a temperature of approximately 150°C, 1135 kg of bed material was loaded into the combustor, and two natural gas-fired burners were started to bring the combustor temperature to approximately 482°C (Fig. V-1). The first of these burners, rated at 5295 MJ/h (5 x 10^6 Btu/h), was located in the combustion air duct downstream of the air preheater and upstream of the windbox. The second burner, rated at 2648 MJ/h, fired into the bed directly below the in-bed heat exchanger. Firing rates and working-fluid flows were adjusted to maintain a temperature rise of 55°C/h.

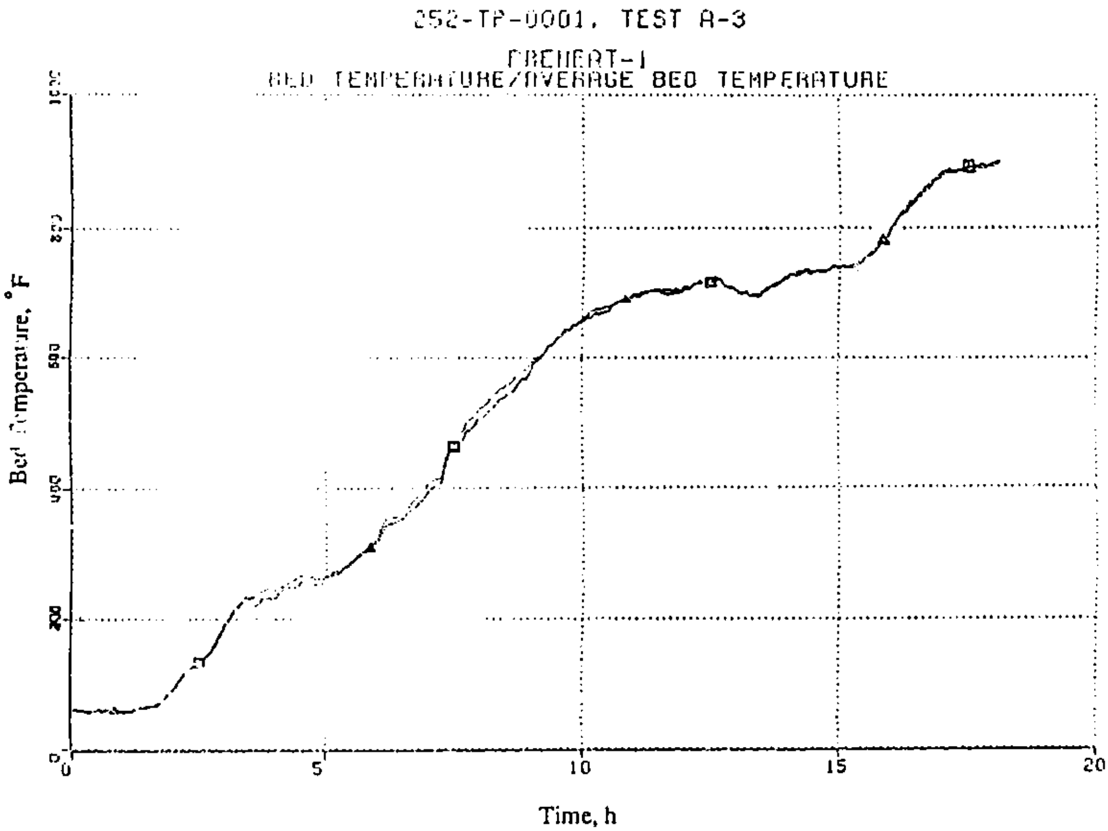


Fig. V-1. Combustor Preheat Stage (two measurements)

At a temperature of 482°C, coal feed into the combustor was initiated at approximately 22.7 kg/h for each of the four coal-feed nozzles. Combustion was verified by observing a rise in flue gas CO_2 and a decrease in O_2. At this point, the gas burners were shut down, and the heat-up rate was controlled by adjusting coal feed and working-fluid flow rates to a final bed temperature of 871°C (Fig. V-2).

As the target temperature of 871°C was approached, the forced draft fan was adjusted to obtain a superficial velocity of approximately 1.5 m/s, and the induced draft fan was set to maintain a freeboard pressure of -101.2 kPa. The coal-feed rate was set to obtain an excess oxygen concentration of 4.0%, while working-fluid flow was adjusted to maintain a bed temperature of 871°C. The bed was then brought to its final height of 2.4 m by the addition of limestone.

Another activity during start-up concerned the cooled specimen probes. Each probe had a specified temperature set point that was maintained by adjusting its cooling air. After the first 1000 h of operation (after segment A-6), the probes were checked for leaks prior to initiating preheat because some of the cooled probes exhibited gaps between the specimens at ambient temperature.

Once the operating conditions had been established, operators adjusted coal feed, combustion air flow, and working-fluid flow to maintain these conditions. When an adequate supply of recycle ash had been accumulated, the ash recycle system was started. The bed was drained about once an hour to maintain the proper bed height (Fig. V-3). During steady-state operation, solid feeds (coal and limestone) and waste streams (fly ash, spent bed material, and recycle ash) were sampled once every 8 h.

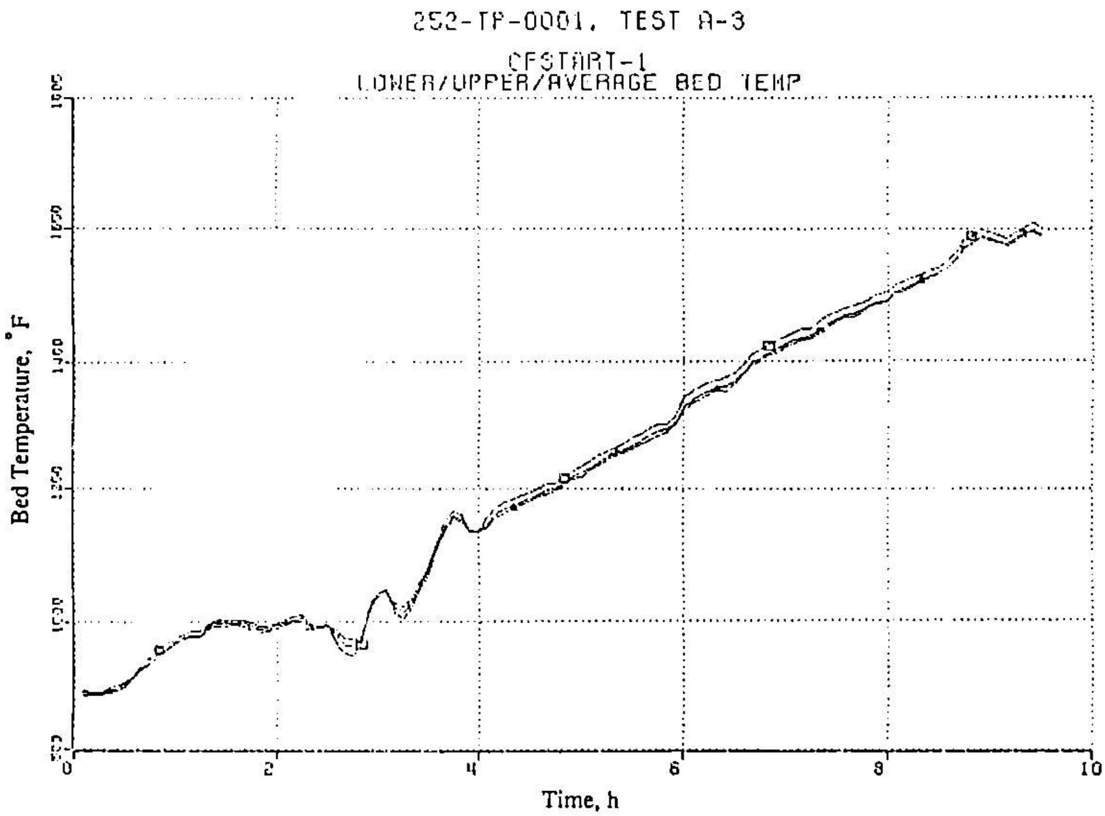


Fig. V-2. Continued Heat-Up Using Coal (three measurements)

Fig. V-3. Bed Drain Operation

A helium leak check of the tube bundle was carried out every 8 h using a mass spectrometer. Helium was injected into the working fluid at various locations, and the flue gas was sampled for traces of helium. No leakage was ever noted.

Data collection and retrieval was a key activity during steady-state operation. Numerous data plots and printouts were made at 8- and 25-h intervals (Appendix A). In addition, special data packages were taken to document plant conditions for periods of special interest, such as during pO_2 probing.

The flue-gas analysis system was calibrated every 24 h during steady-state operation. In addition, after leaks were discovered in the sample line, a portable O_2 meter was used to verify flue-gas oxygen concentrations. This portable meter was used every 8 h.

Two types of upset conditions were anticipated during the operation of the unit. The first type would require setting the plant back to a lower temperature at a controlled rate, while the second would mandate emergency slumping of the bed. Both types of situations occurred several times during the course of testing.

An example of the first type involved a large compressor at the Thermodynamics Laboratory, whose services the AFBC shared. Several times during the test period, competing tests required large volumes of air (usually for short periods of time). When this condition existed, working-fluid flow and coal feed would be reduced at a rate such that the temperature decrease would be limited to 55°C/h, to a setback temperature of 704°C. Once the competing test was finished, coal-feed and working-fluid flow would be increased to return to 871°C at a rate of 55°C/h.

The second type of upset condition required an immediate plant shutdown and slumping of the bed. This type was typically caused by the failure of some major plant component or loss of incoming power and occurred several times during test operations. When this situation occurred, coal feed was immediately stopped. Flue-gas readings were monitored for a rise in O_2 concentration and a decrease in CO_2 concentration to ensure that all carbon was burned from the bed. The working-fluid flow was stopped, to limit the loss of bed temperature, and the forced-draft and induced-draft fans were shut off to slump the bed. If it was determined that the problem could be resolved in a few hours, working fluid was trickled in (if possible) to maintain the temperature of the in-bed heat-exchanger outlet headers. If the shutdown appeared to require long duration, the working-fluid flow shut off to limit heat loss from the bed.

If the problem was corrected and if the bed was still above 482°C, the induced-draft and forced-draft fans were restarted, and coal-feed and working-fluid flows were re-established. Working-fluid and coal-feed flow were set to limit the temperature rise of the coolest part of the system (usually the outlet headers) to 55°C/h.

At the conclusion of a test run, the unit was shut down by essentially reversing the startup procedure. Coal feed was reduced and working-fluid flow adjusted to initiate a temperature decrease of 55°C/h. At 482°C coal feed was stopped, and the duct and in-bed burners were lit and adjusted to continue the temperature decrease. At about 200°C the bed was drained, the burners were shut off, and combustion-air and working-fluid flows were terminated. All supporting systems were shut down to complete the test run.

VI. TEST SUMMARY

Ten test segments were initiated. Their history is summarized in Table VI-1. Checkout and facility shakedown were initiated in February 1988, but were aborted when the working-fluid compressor failed. Facility problems during this interval were minor, related primarily to data acquisition change requests and forced draft fan controller changes. Many project objectives were accomplished, including

Table VI-1. ACAHE Test Summary

Test Segment	Starting Date	Hours in Test Envelope	Comments
Checkout	02-08-88	0	Facility checkout. Approached test envelope, halted due to compressor failure.
A-1	03-03-88	17	Halted due to coal plugging.
A-2	03-30-88	242	Completed test segment. Approximately 70% availability due to intermittent coal plugging.
A-3	05-09-88	252	Better than 99% availability. No significant problems.
A-4	06-01-88	0	Halted due to preheater air duct failure.
A-5	06-11-88	444	Shutdown due to ash recycle line failure.
A-6	08-22-88	0	Halted due to north wall refractory failure.
A-7	09-06-88	27	Measured and calculated oxygen difference.
A-8	09-24-88	300	Failure of limestone weigh-belt feeder.
A-9	11-29-88	346	ID fan bearing & compressor oil pump failure.
A-10	07-22-89	330	Slumped once to avoid August power demand changes. No facility problems.

satisfactory operation of all subsystems during preheat, startup, solids injection, steady-state operation, and shutdown. The operation confirmed adequacy of procedures and compliance with permits. Additionally, it provided an opportunity for training of personnel.

The planned test duration for the first set of test specimens was 1000 h, to be performed in four 250-h test segments. The first test segment began in March, but it was halted after 18 h because wet coal clogged the feed systems. The coal inventory was removed and dried to a moisture content of approximately 10%.

Two hours into the next test period, the bed-drain line failed, requiring an immediate shutdown for repairs. This was the first of many corrosion failures of sensitized stainless steels and carbon steels because of the lack of preservation and the presence of salt air from the ocean nearby. The test was restarted and the first 250-h segment completed. However, the coal-system plugged intermittently (due to wet coal), yielding approximately a 70% availability (see Fig. VI-1).

The coal feeding systems were modified to improve their tolerance to moisture. Figure VI-2 shows the tapered downcomer that replaced a system of bell reducers. The conveying air was replumbed to yield a more even air distribution to the four conveying systems. In addition, coal was dried to approximately 10 to 11% moisture for the remainder of the test program. These changes completely eliminated the wet-coal feed problem.

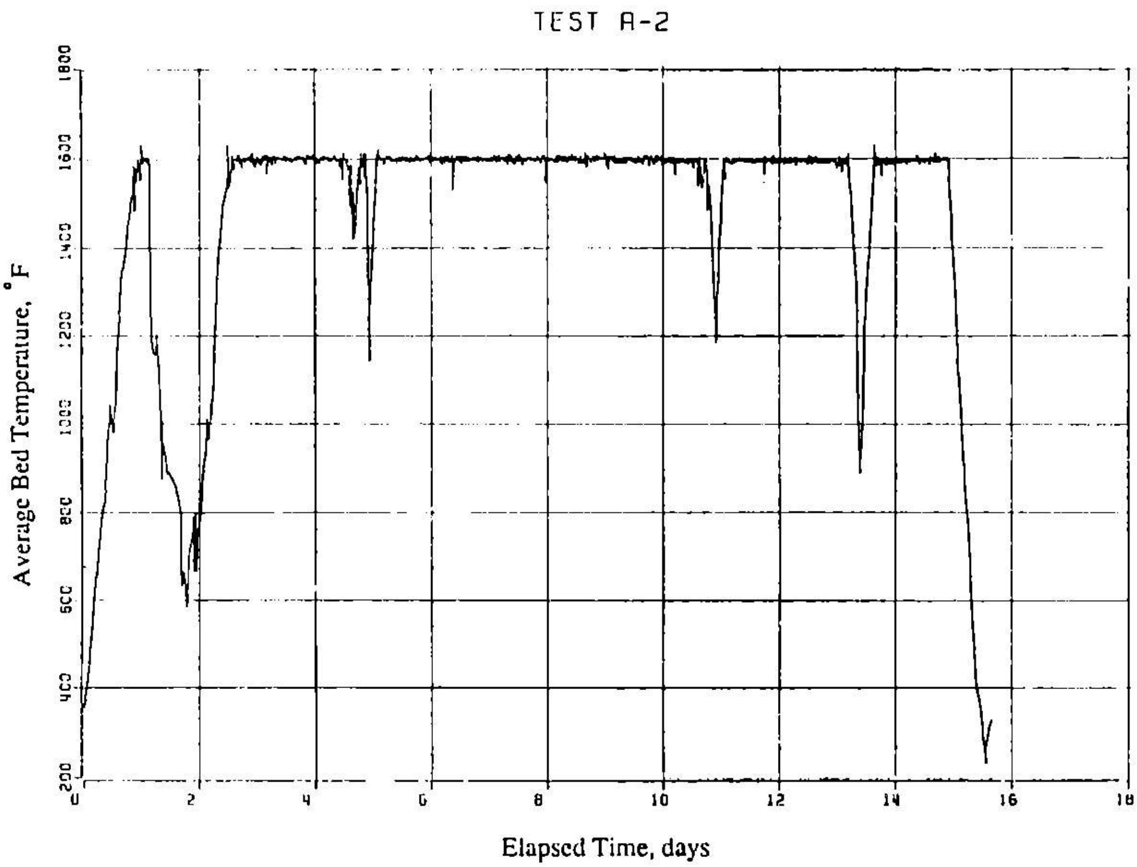


Fig. VI-1. Data Plot for Bed Temperature

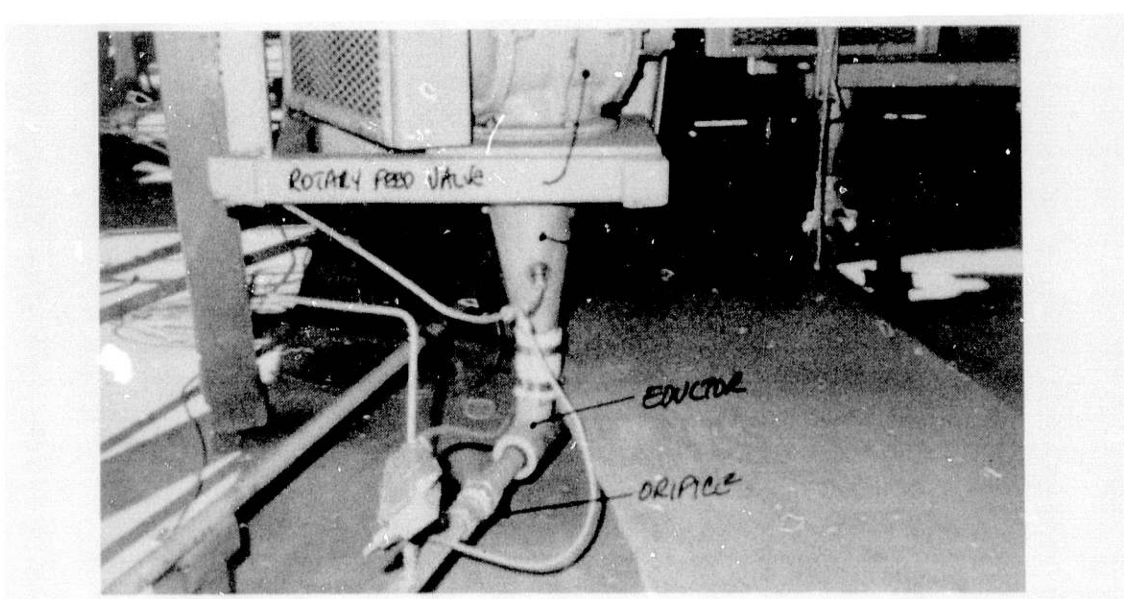


Fig. VI-2. Coal Feeding and Conveying System

The combustor was inspected after Test segment A-3, and no anomalies were noted (Fig. VI-3). One of the ABB/CE probes was found to be approximately 1-in. (25.4-mm) short, causing the first specimen to be inside the refractory (Fig. VI-4). The external thermocouples which had been installed on the tube bundle were gone (Fig. VI-5). This was not unexpected; however, they lasted long enough to provide some external tube temperatures.

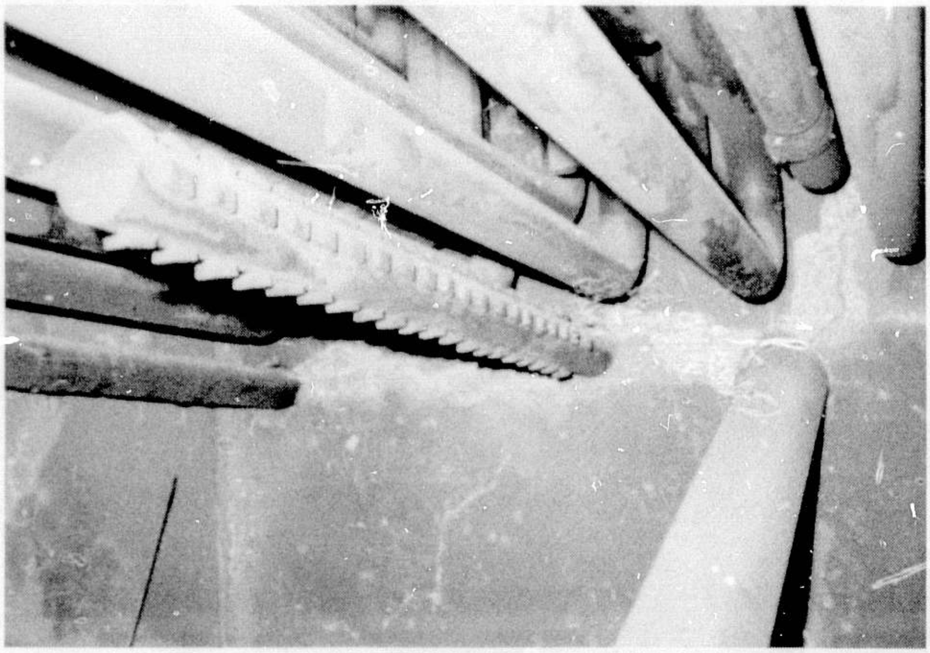


Fig. VI-3. View of Combustor below Tube Bundle

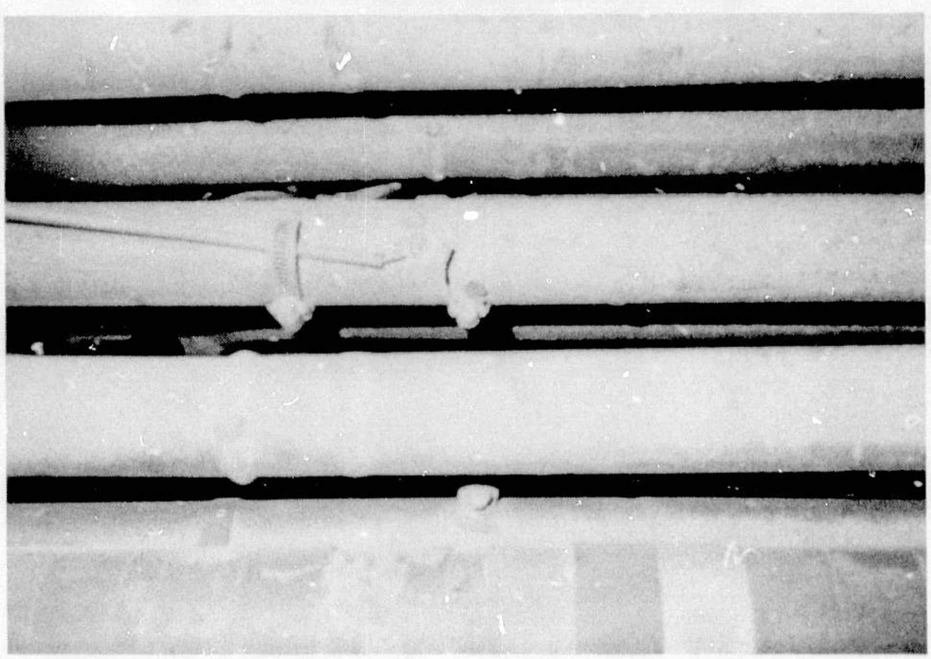


Fig. VI-4. View of Combustor above Tube Bundle and CE Probe

Fig. VI-5. View of Top of Tube Bundle

During this first test segment, 14 pO_2 probings were performed in three ports. A fourth port (BTPWC) was found to be blocked by a misaligned gasket. Probing was found to be very time consuming due to the size of the probe and the congested area (Fig. VI-6). A platform was installed on the west side to provide better access.

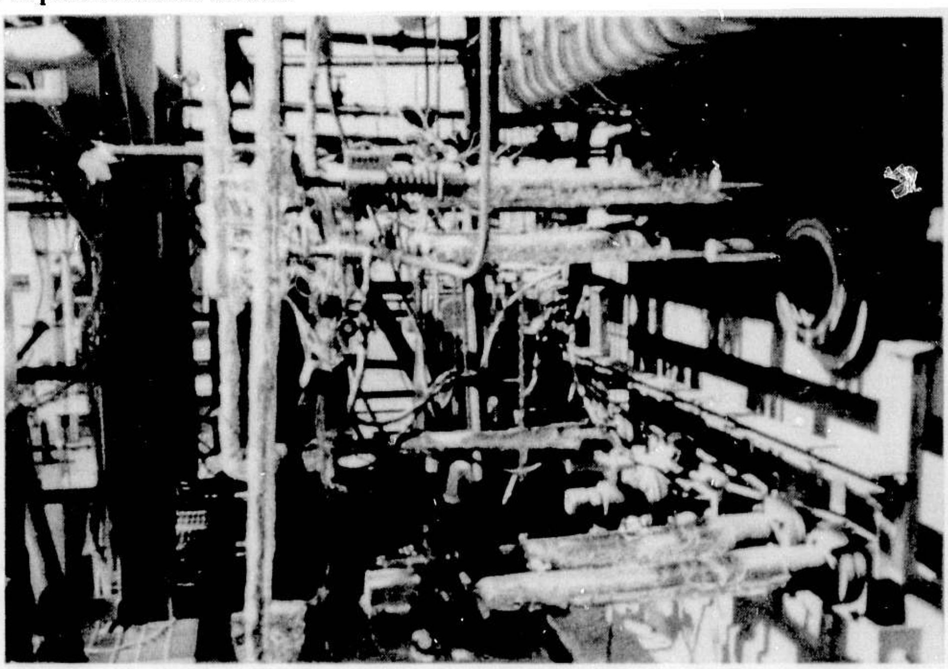


Fig. VI-6. West Side of the Combustor

The next test segment was initiated in early May and completed 250 h of operation virtually trouble free. Excluding startup and shutdown time, the 250 h was accumulated in less than 255 h of elapsed time, achieving better than 99% availability. (Availability compares the number of hours of operation to the number of hours between startup and shutdown.) See Fig. VI-7.

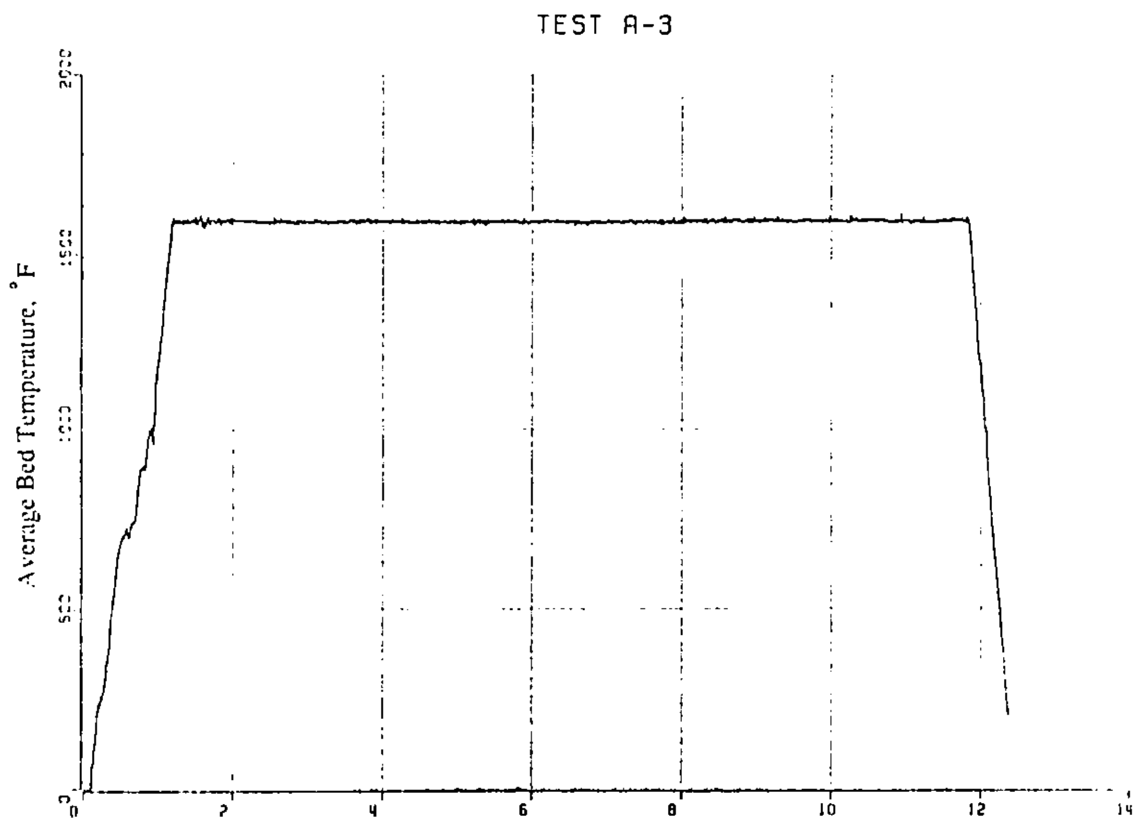


Fig. VI-7. Data Plot for Bed Temperature for Test A-3

Following this segment, the combustor was inspected, and again, no anomalies were observed. Probes BBTED, an uncooled tab probe located in the northeast quadrant below the bed, and BMLWB, a cooled ring probe located in the middle of the bed on the west side, were removed as planned and returned to B&W. The latter probe was substituted for probe BMUWB, located one level higher in the middle of the bed, because it had more operable thermocouples.

During preheat for the next test segment, the combustion air duct failed downstream of the in-line duct heater and caused the test to be aborted. The failure occurred when the system was at about 340°C. The previously installed carbon-steel ducting was found to have wall-material wastage from normal use. About 2 m of duct required replacement. It was replaced with stainless steel to provide higher strength at the elevated temperature that can occur in the immediate vicinity of the duct burner.

The earlier schedule delays, associated costs, and unanticipated peak summertime power surcharges were factors leading to a duration of 500 h for the next test segment. During this run a minor interruption occurred when a substation circuit breaker failed. An ash-recycle transfer line failure caused the test to be stopped at about 450 h. A reference junction failure caused some temperature measurement oscillations, but did not otherwise impair operation.

On June 26, 1988, the control thermocouple on the ANL-supplied cooled probe (BMLEC) began to indicate a rise in temperature. This probe was already supplied with full air flow at the maximum available supply pressure to "run as cool as possible." ETEC attempted to reduce the temperature by supplementing the cooling with high-pressure nitrogen. Although this reduced the temperature, nitrogen consumption was deemed excessive, and it was decided to return to air cooling only and accept the higher temperature operation.

Upon removal of this probe, a leak was discovered in the probe (Fig. VI-8) that severed a dummy probe located directly above it (Fig. VI-9). Extensive examinations of the tube bundle indicated that no damage to the platens had occurred.

Fig. VI-8. ANL Cooled Specimen Probe BMLEC

Fig. VI-9. Dummy Probe BMUEC

Other facility-related problems that occurred during the course of the testing included failures of instruments, auxiliary equipment, combustor casing penetration sleeves, and feed lines, some due to the erosiveness of the materials handled.

A key failure occurred in the flue-gas monitoring system. Air that leaked in through a defective sample line was interpreted to increase the oxygen content in the bed. Over the course of the test operation, the leakage of air into the detector slowly increased. It was not detected, and the operators gradually adjusted coal feed to maintain a constant oxygen concentration. This resulted in an environment that was much more "severe" than specified, meaning that the oxygen concentration was lower than intended and thus there was more potential for corrosion. Calculation of in-bed oxygen concentration based on air-to-coal ratio shows oxygen concentrations as low as approximately 2%.

The flue-gas measurement system was repaired. Besides the measured oxygen concentration, an independent calculated measurement was displayed based on air-to-fuel ratio. Any discrepancy between the two would alert the control room operators to possible problems with the plant on-line data. Oxygen concentration was also checked using a portable detector and indicator on a daily basis.

At this point, four cooled specimen probes, one of which is shown in Fig. VI-10, including the leaking probe described above, were removed and returned to their respective suppliers. In addition, the U-bend test articles and one uncooled tab probe (Fig. VI-11) were removed and returned to B&W.

Fig. VI-10. Cooled Probe BBTWE (FW) at 1000 h

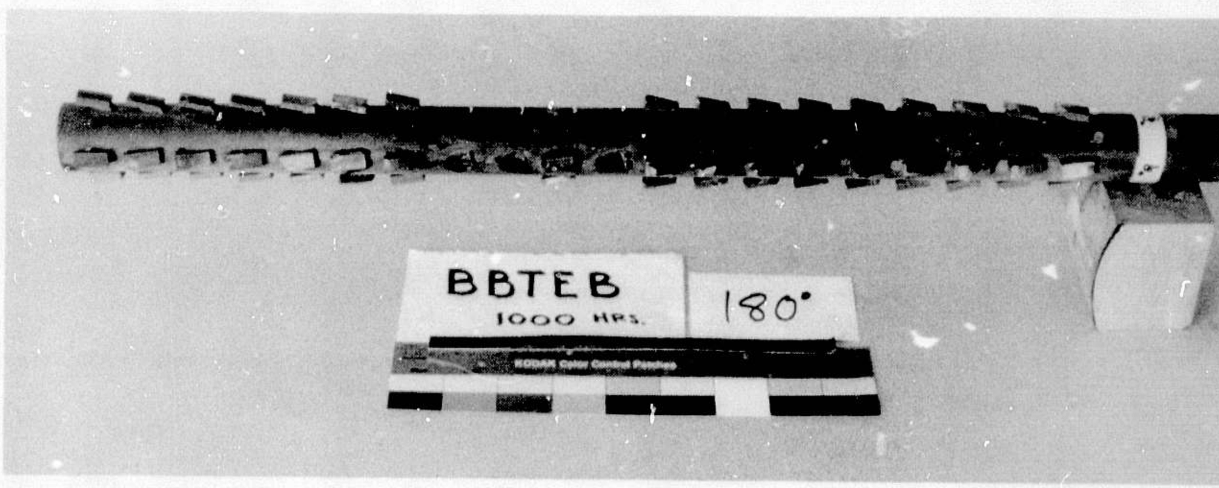


Fig. VI-11. Uncooled Probe BBTEB (B&W) at 1000 h

During startup for A-6, an operator observed discoloration of the combustor casing, which led to the discovery of a hot spot on the combustor wall just above the in-bed burner. Removal of the in-bed burner revealed severe erosion in the refractory near the burner. It was postulated that operating the burner with a slumped bed may have caused the flame to erode the wall over time. The damage was repaired, and the startup procedure was modified to delay operating the burner until the bed was fluidized with a reduced-bed inventory.

Upon resumption of testing, the measured and calculated oxygen concentration parameters failed to agree, and testing was stopped until this problem could be resolved. To this end, ETEC injected helium into the flowing gas stream and measured the dilution downstream using a gas chromatograph. This technique confirmed the absence of leakage and identified some flow-stream measurement errors. The errors were corrected, resulting in good subsequent agreement between the calculated and measured oxygen concentration.

Testing resumed in October. Two test runs (A-8 and -9) were completed before the end of 1988 for a total of 646 h, bringing the cumulative total to 1628 h. Test A-8 was terminated after 300 h, when the limestone feeder failed.

Inspection of the combustion chamber after cooldown revealed some possible erosion on the ABB/CE probe in the convection zone. The probe was removed and, following inspection, reinstalled.

Test A-9 was initiated on November 29 and, following failures of the induced draft fan bearing and the working-fluid compressor oil pump, was terminated on December 24 after accumulating 346 h.

After the holidays, the tube bundle and other specimens within the combustor were inspected. The cooled specimen probes were removed, inspected, photographed, and then reinstalled. No significant anomalies were observed.

Further testing was delayed for approximately six months due to a series of compressor problems. The compressor finally became operational in July 1989, allowing completion of the final test segment on August 7, 1989. Total test time accumulated then was 1958 h.

VII. DISCUSSION OF KEY TEST DATA

Since the objective of the experiment was to identify suitable materials for fluidized-bed applications, key parameters to be controlled within specified limits were identified. These parameters and the specified limits are shown in Table IV-1, and discussed below. An interpretation of the data follows.

A. Fluidized-Bed Temperature

Bed temperature was controlled very closely during the entire test period. Initially the temperature was maintained by adjusting the working-fluid flow using a trim valve in the working-fluid supply line. This required constant vigilance and adjustment. As operators gained experience with the plant's operation, they found that temperature control could be achieved much more easily by adjusting the recycle ash flow.

The fluidized-bed temperature was computed by averaging three bed temperatures. It was noted during testing that one or more of the temperatures would gradually decrease. This was traced to the bending of the thermocouples due to the impact of the bed material. As the tip of the thermocouple approached the tube bundle, its output would approach the temperature of the tube. When this was noted, corrections to the data reduction were made to replace the suspect indication or to change the algorithm for data reduction.

B. Fluidized-Bed Height

The bed height averaged about 2.5 m for the test period. Figure VII-1 shows the oscillations observed during operation, which resulted from bubbles erupting at the bed surface. The operators used a performance printout (Fig. VII-2) which gave the average readings over a 30-min period to determine bed height before draining. No corrections were made to this parameter for the final data package.

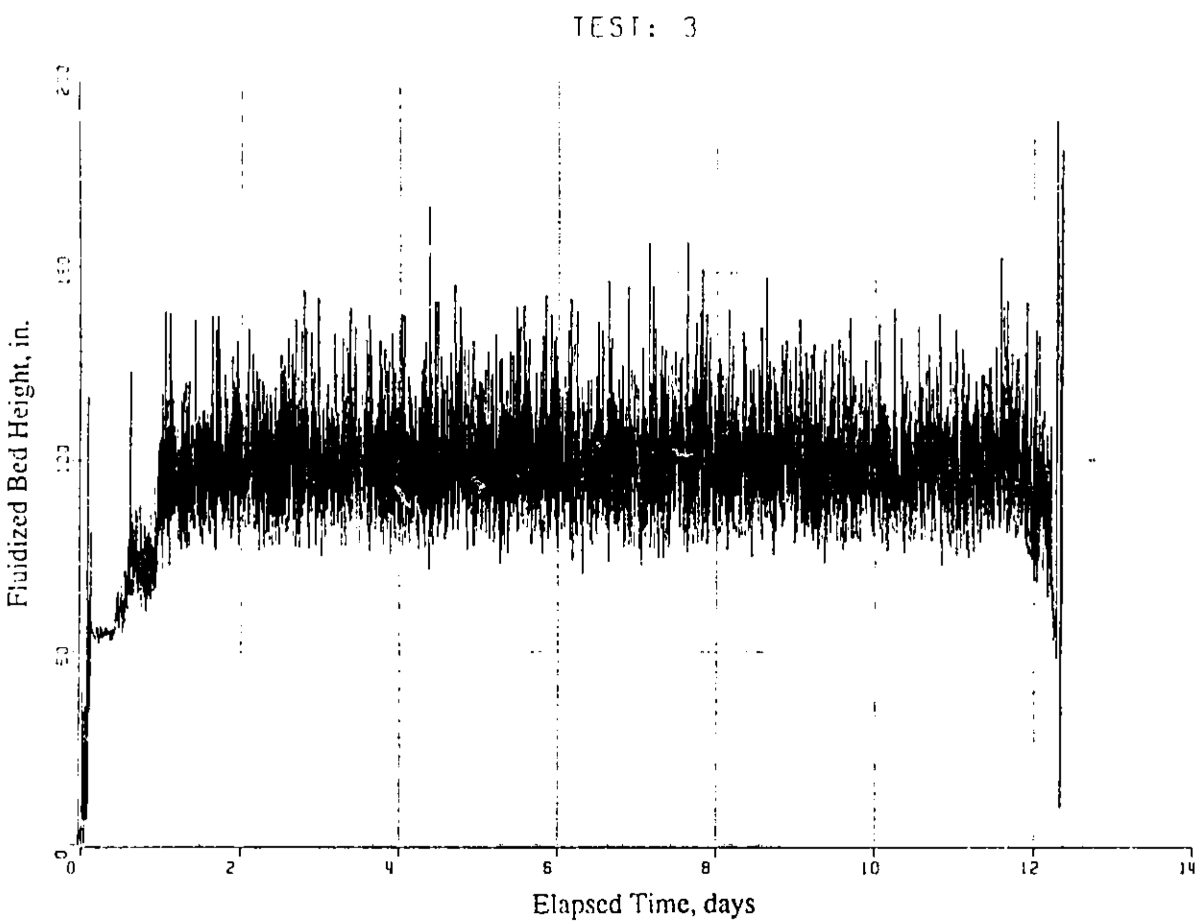


Fig. VII-1. Oscillations of Fluidized-Bed Height

A F B C Test Facility
Performance Printout
252-TP-0001, TEST A-10

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

Page 1 of 3
Time 0: 7:37
Date 8/ 1/89

Tag No.	SEQ#	Description	Value	Units
Fluidized Bed:				
CFDT01	405	Avg. Bed Temp.	1598.	F
FBP12	270	Freeboard Press.	-.6	in H20
CFBV01	407	Superficial Vel.	5.1	fps
CFDH01	406	Bed Height	100.	in
CSC	464	Sulfur Capture	93.5	%
Solid Feed:				
CCFF52T	411	Total Coal Flow	1185.	lb/hr
LSW02	5	Total Limestone Flow	334.	lb/hr
CARF03	427	Ash Recycle Flow	1742.6	lb/hr
Combustion Air:				
CAP04	250	Windbox Press.	.88.	in H20
CAT06	71	Windbox Temp.	570.	F
ART02	66	Ash Recycle Temp.	275.	F
CARF02	434	Ash Recycle Air Flow	866.	lb/hr
CCFF01T	428	Coal Feed Air Flow	2098.	lb/hr
CLSF02	433	Limestone Feed Air Flow	261.	lb/hr
CCAF01	410	Combustion Air Flow	8855.	lb/hr
CCAF01T	409	Total Air Flow	12269.	lb/hr

Tag No.	SEQ#	Description	Value	Units
Working Fluid				
CWFF11	417	Air Flow - East	13840.	lb/hr
CWFF21	418	Air Flow - West	15138.	lb/hr
WFT15	220	East Bed Bank Temp. Out	1498.	F
WFT25	227	West Bed Bank Temp. Out	1497.	F
WFT14	219	East Bed Bank Temp. In	.823.	F
WFT24	226	West Bed Bank Temp. In	806.	F
WFP14	52	East Bed Bank Press. In	38.	Psig
WFP24	57	West Bed Bank Press. In	38.	Psig
Flue Gas:				
CFGF01	412	Total Flue Gas Flow	13355.	lb/hr
FGT01	83	Flue Gas Temp.	702.	F
COMB	10	Comb. Flue Gas Analysis	.1	%
CO	7	CO Flue Gas Analysis	67.	PPM
CO2	8	CO2 Flue Gas Analysis	13.1	%
SO2	14	SO2 Flue Gas Analysis	186.	PPM
NOx	11	NOx Flue Gas Analysis	214.	PPM
O2B	13	O2 Flue Gas Analysis	4.1	%
CO2B	408	Flue Gas Excess Air	35.7	%
CCACO1T	419	Tot. Comb Air/Coal Ratio	10.4	
C-O2+CO2	470	Oxygen + CO2	17.2	%
UK-FLUE	15	Soot Blow, Flue Gas Cal.	68	MV
Heat Balance:				
COIN	444	Heat Input	3485.	Btu/sec
CCOMBEFF	441	Heat Bal. Comb. Eff.	84.7	%

Fig. VII-2. AFBC Performance Printout

C. Superficial Velocity

Superficial velocity is based on the sum of the air flows entering the bed and the generation of the gas produced by the burning coal flowing through the cross-sectional area. Between tests A-7 and A-8, as the result of an investigation of a discrepancy between measured and calculated oxygen concentration in the bed, it was discovered that the venturi in the combustion air supply was actually reading 5.4% lower than indicated. The one installed at the beginning of the program had a range of 0-22.4 kPa (0-90 in. water), while its replacement had a range of 0-4 kPa (0-16 in. water). Both transducers recorded data for the remainder of the test program, although the lower-range unit was used for the calculation of combustion air flow. The transducers tracked consistently and no changes were observed.

D. Working-Fluid Outlet Temperature

These temperatures were controlled very closely, and no significant problems were observed during the test program.

E. Flue-Gas Oxygen Concentration

The most significant technical problem involved the failure of the flue-gas monitoring system. Oxygen was to be controlled at a concentration of 4.0 ± 0.5%. Review of the data by ETEC after the 1000-h testing period revealed an inconsistency between the air-to-fuel ratio and the measured oxygen concentration. The problem was traced to a leaking flue-gas sample line.

Over the course of the test operation, the leakage of air into the line slowly increased. It was not recognized as a leak and the operators gradually adjusted coal feed to maintain a constant oxygen concentration. Calculations of the in-bed oxygen concentration based on the air-to-coal ratio showed oxygen concentrations lower than specified.

Repairs to the flue-gas system were made, verified, and accepted. In addition to the measured oxygen concentration, an independent calculated parameter was displayed. It was decided that for future testing, continuous comparisons of calculated and measured parameters would be made. Testing was not resumed until agreement between the two was achieved.

Satisfactory operation of every element of the air- and coal-flow systems had to be confirmed. To this end, ETEC injected a known quantity of helium into a flowing gas stream, and measured its dilution downstream of the injection point using a gas chromatograph. This not only provided a verification of the flow-system calibrations, but also enabled determination of whether there was in-leakage or out-leakage.

The use of this technique revealed air-flow measurement errors, most notably an approximately 5.4% error in the discharge coefficient of the combustion air venturi and a much higher-than-estimated flow in the limestone-conveying air system. When all the corrections were incorporated, testing was resumed and reasonable agreement in oxygen concentrations was achieved (calculated 3.9% vs. measured 4.1% average for the remainder of the program).

The data tapes for the entire test were corrected using the new coefficients. In-bed oxygen was computed from the calculated parameter based on the air-to-coal ratio. This had been the only option for the early part of the test program where the sample line was leaking. We have great confidence in this parameter, since the coal feed and air flows into the bed were well characterized and continued to agree well for the latter part of the test period.

An alternative method for computing the oxygen in the bed would be to perform a mass balance around the freeboard (area above the bed). This method was proposed, but it could not be done when the sample line was suspected to be leaking. Also, it is unreliable (after the replacement of the sample line) due to uncertainties in the limestone-conveying air measurement. During the helium-dilution tests, the orifice used to determine limestone-conveying air flow had not been installed. This resulted in a much higher than anticipated air flow rate. Based on the results of the helium-dilution tests, an algorithm was developed for computing the flow rate.

The ETEC recommended that the calculated value based on the air-to-coal ratio for the in-bed oxygen concentration be used for the entire 2000 h of testing, as opposed to a mass balance around the freeboard.

VIII. OXYGEN PROBE MEASUREMENTS

To examine the corrosive potential at given locations within the fluidized bed, a special probe was used to obtain *in situ* measurements of fluctuating oxygen concentration. A schematic of the probe is shown in Fig. VIII-1.

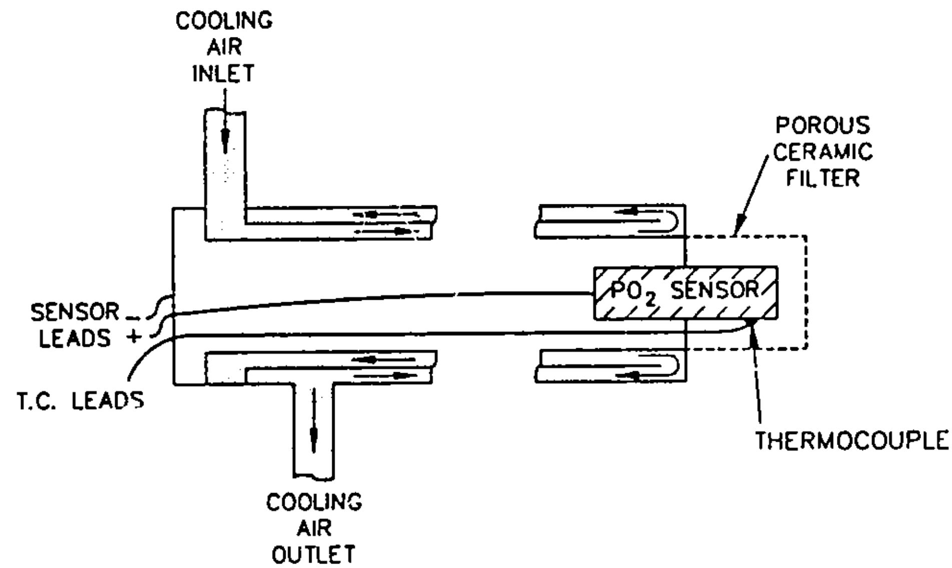


Fig. VIII-1. Schematic of pO_2 Probe

The sensor was placed inside a porous ceramic filter to protect it from damage due to impact by hot-bed particles and also to prevent plugging of the sensor pores. To accomplish the measurement, some of the bed gases are drawn into the filter cavity so that the gases come in contact with the sensor surface. The sensor is a platinum/zirconia (Y_2O_3 stabilized)/platinum galvanic cell designed for high-temperature operation. The sensor used in this experiment was manufactured by Robert Bosch Gmbh (Germany) for use as an automobile exhaust-gas oxygen sensor.

The relationship between cell voltage and partial pressure of oxygen is based on the Nernst equation, which, upon substitution of the proper constants and units, reduces to

$$pO_2 = 0.209 \exp(-83610 \cdot V/T)$$

where pO_2 = partial pressure of oxygen in atmospheres

V = cell voltage in volts

T = cell temperature in degrees Rankine

The pO_2 of the fluidized bed was measured as often as schedule would permit. Over 100 pO_2 probings were carried out during the nearly 2000 h of testing. This measurement required that the probe be inserted through an isolation valve and inserted into the fluidized bed, and that data be taken for one minute. The probe would then be moved 7 cm farther into the bed and measurement again taken for one minute. This process was repeated until the probe was inserted 0.8 m into the bed. Two ports (locations BMUED and BBTED) on the east side of the combustor and three ports (locations BTPWC, BMUWC, and BBTWC) on the west side of the combustor were used for probing. Figures VIII-2 and -3 show locations of the oxygen probes on the east and west sides of the combustor. Also shown in the figures are the locations of the uncooled and cooled probes exposed by ANL, B&W, FW, and ABB/CE.

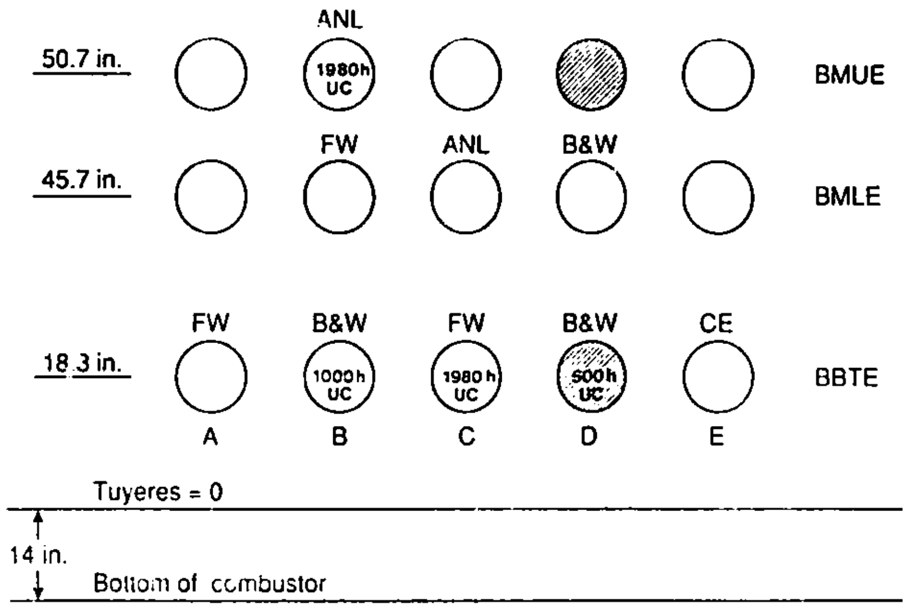


Fig. VIII-2. East-Wall Probe Port Location

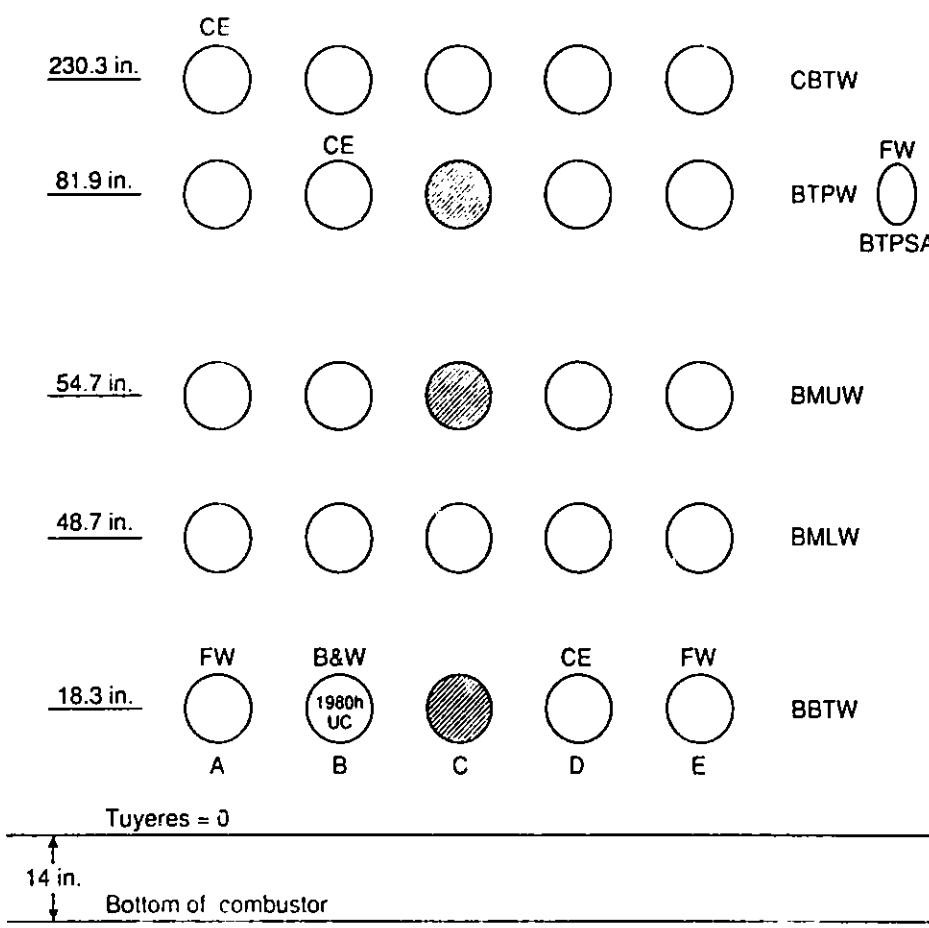


Fig. VIII-3. West-Wall Probe Port Location

Extensive corrosion information developed earlier in laboratory tests under a variety of simulated FBC environments indicated that high-chromium alloys exhibit acceptable corrosion rates when pO_2 in the environment is 10^{-8} atm or higher.[3,6] The corresponding sulfur partial pressures (pS_2) in such environments would be less than 10^{-20} atm (in the temperature range of 800 to 900°C), and the intergranular penetration of sulfur in the substrate alloy is also minimal. When the pO_2 values fall below 10^{-8} atm, the pS_2 values increase, dictated by the $CaO/CaSO_4$-phase stability line.[3,6] As a result, the oxygen-cell measurement data were compiled on the basis of 10^{-8} atm as the value separating oxidation and oxidation/sulfidation regions for the chromia- and alumina-forming materials.* Figures VIII-4 through -8 show the cell data plotted as a percent of total time that the local environment had a pO_2 exceeding 10^{-8} atm, for sensor port locations BMUED, BMUWC, BBTWC, BBTED, and BTPWC, respectively. The figures show the data obtained from both the east and west walls of the combustor and at three different radial distances from the insertion walls of the combustor, namely, between 3 and 12 in., 12 and 24 in., and 25 amd 33 in.

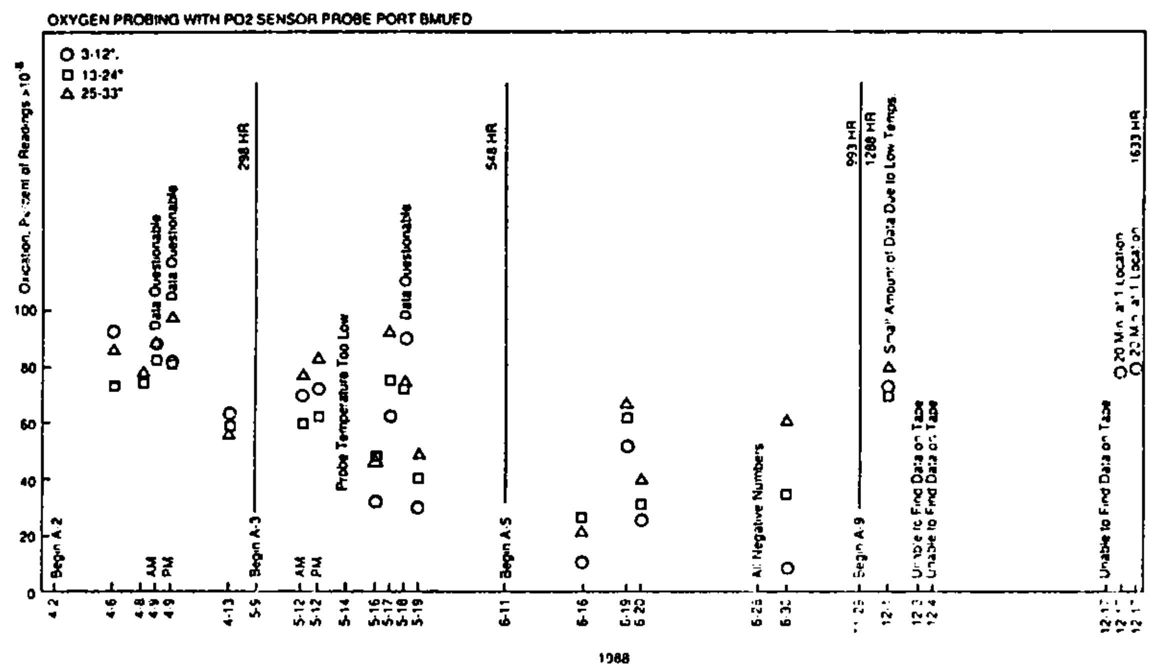


Fig. VIII-4. Oxygen Probe Results from Port BMUED

*Other values of oxygen partial pressure were used by ETEC in the initial processing of the pO_2 data; namely, oxidizing for $pO_2 > 10^{-3}$ atm and reducing for $pO_2 < 10^{-12}$ atm.

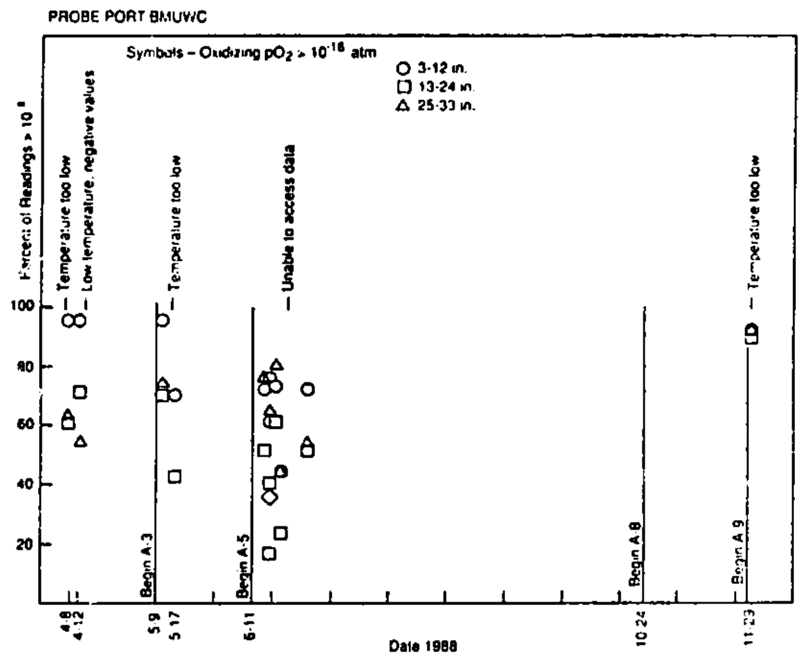


Fig. VIII-5. Oxygen Probe Results from Port BMUWC

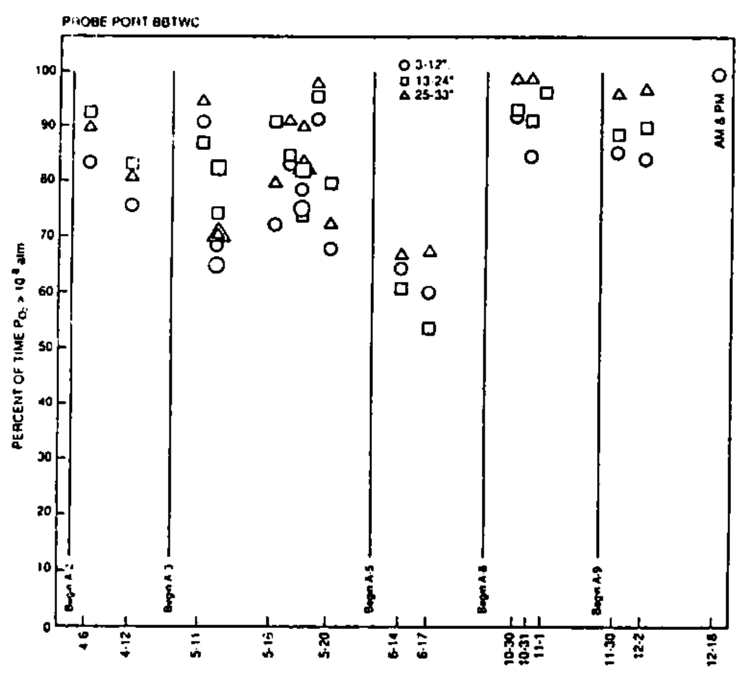


Fig. VIII-6. Oxygen Probe Results from Port BBTWC

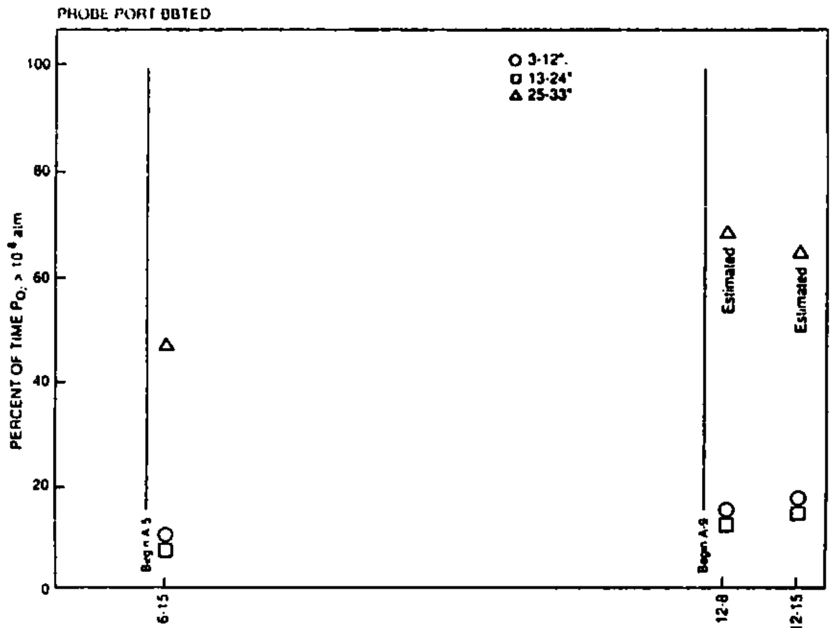


Fig. VIII-7. Oxygen Probe Results from Port BBTED

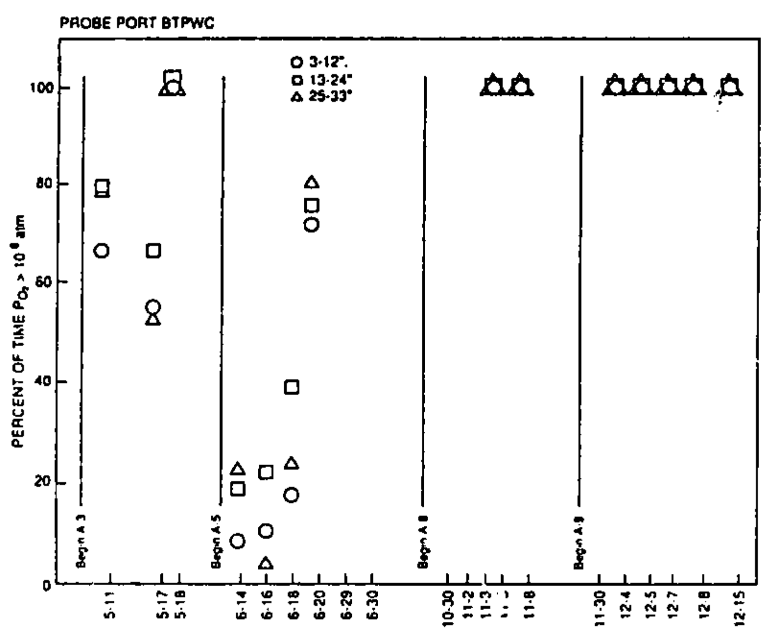


Fig. VIII-8. Oxygen Probe Results from Port BTPWC

The data in Figs. VIII-4 through -7 vary substantially with exposure time and distance from the wall. The data indicate that the pO_2 values were above 10^{-8} atm at port BMUED for an exposure period between ~300 and 500 h for only 25-50% of the time. Further, the data show that the bed essentially operated under reducing conditions for the second 500 h of exposure of the corrosion probes, the time period of June 16-30, 1988 (which spans the second 500 h of exposure of corrosion probes). However, laboratory corrosion test results obtained under gas conditions cycled between oxidizing and reducing showed that exposure for as long as 100 h to a sustained low pO_2 is needed to initiate sulfidation attack of high-Cr alloys in an SO_2-containing combustion environment.[6] The flue-gas sample line developed a leak during the second 500 h of testing, which was interpreted as an insufficient fuel feed rate. During this period, the coal-feed rate was increased to reduce the flue-gas oxygen concentration; this, in effect, decreased the in-bed oxygen concentration, leading to operation under reducing conditions. It can be seen that the oxygen concentrations near the combustor walls were generally lower than in the center of the bed.

IX. CORROSION MECHANISMS

Interactions between materials and the environment in FBCs indicate that structural alloys develop predominantly oxide scales when exposed at elevated temperatures to O_2-SO_2 gas mixtures of combustion atmospheres.[6] Figure IX-1 is a schematic of corrosion scale development and morphological changes that occur in Cr_2O_3-forming alloys. The high-Cr alloys develop porous oxide scales (Fig. IX-1a), and some sulfides are also observed in the inner portions of the scale (near the scale/substrate interface). The sulfides are formed by reactions between substrate elements and sulfur that is released when chromium reacts with SO_2 to form external oxide scale. The porosity of the scale enables SO_2 gas molecules to permeate to the scale/substrate interface (Fig. IX-1b), leading to further oxidation/sulfidation. The released sulfur is transported along the grain boundaries in the metal, leading to internal sulfidation of the alloy (Fig. IX-1c).

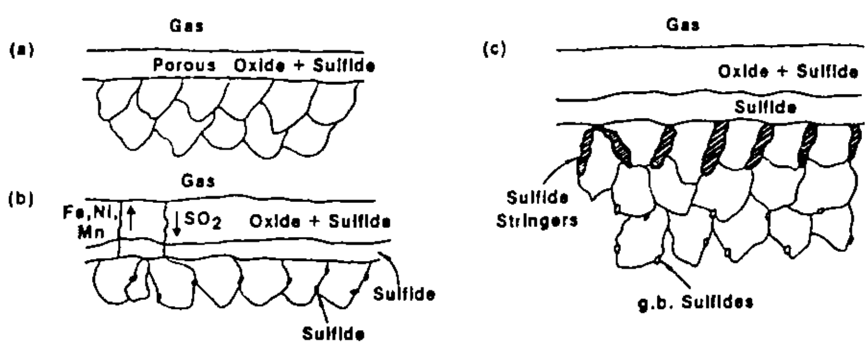


Fig. IX-1. Schematic of Corrosion Scale Development

Extensive corrosion information has also been developed on a variety of structural alloys that were coated with reagent grade $CaSO_4$ and/or $CaSO_4$-CaO mixtures (which make up the spent bed material in FBC systems); however, it is conceivable that in certain locations within the bed, such as coal feedport regions and sections of bed not contacted by combustion air due to fouling/deposit formation, the local gas chemistry may lead to deposits that may contain CaS and/or CaO-CaS mixture.[7] To examine the effect of such changes in deposit chemistry on corrosion of heat-exchanger materials, tests have been conducted at 840°C with Incoloy 800 and Type 310 stainless steel that were coated with CaO/CaS, CaS/$CaSO_4$, CaO/$CaSO_4$, and CaO/CaS/$CaSO_4$ mixtures. Further, 3000-h laboratory corrosion tests were conducted with several candidate heat-exchanger materials in the presence of reagent grade $CaSO_4$ with gas chemistries that simulate the highest sulfur pressure and lowest oxygen pressure (in the vicinity of the CaO-CaS-$CaSO_4$ triple point of the phase stability diagram).[3] In addition, spent-bed materials from two large FBC facilities, the TVA-20MW pilot plant in Paducah, KY, and the IEA/Grimethorpe PFBC facility in the UK, were used as deposits in laboratory corrosion experiments to evaluate the roles of deposit chemistry and gas chemistry in the corrosion performance of structural alloys.[7]

The results from these studies have clearly established that the presence of $CaSO_4$ deposit alone can lead to intergranular sulfidation of high-chromium alloys, even though the external scales are predominantly oxides. The results also showed that low oxygen pressure in the exposure environment can increase the corrosion of bare alloys, as well as those coated with $CaSO_4$ and CaO, at temperatures above 600°C. The gas cycling (oxidizing/sulfidizing) experiment showed that sulfidation can be triggered even in Type 310 stainless steel with a cycle time of 100 h; no sulfidation was noted with a 10-h cycle time. Because the fraction of time spent under low pO_2 conditions was the same in both 100- and 10-h cycle time tests, it was concluded that a sustained exposure (>10 h) to a low pO_2 atmosphere is required for initiation of sulfidation attack of the material. Furthermore, variations in relative time periods for high and low pO_2 during an exposure cycle had almost no effect on the corrosion of alloys coated with either $CaSO_4$ or CaO, if the virgin specimens were exposed to a high pO_2 (similar to flue-gas oxygen pressure) atmosphere at the start of the first cycle.

Generally, acceptable lifetimes for high-Cr alloys exposed to these environments are determined by the magnitude of the depth of internal sulfidation, which is largely determined by the alloy chemistry, temperature, and SO_2 content of the gas phase.[3,7] The alumina-forming alloys, in general, are much more resistant to corrosion in these environments, but their scales are susceptible to spallation. When this occurs, the exposed alloy surface is depleted in aluminum; as a result, reformation of protective oxide scale is impeded, and accelerated sulfidation of the base metal ensues.

X. CORROSION TEST RESULTS

Several alloy specimens that were exposed in the uncooled condition in the Rocketdyne AFBC by ANL, B&W, and FW were analyzed at ANL. These specimens were obtained from the probes BMUED (uncooled probe from ANL); BBTED, BBTEB, BBTWB (uncooled probes from B&W); BBTEC (uncooled probe from FW); and BBTEA (cooled probe from FW). The specimens in the uncooled probes were in flat or coupon form. All the samples in the B&W and FW probes were cut sections of rings and were welded at an angle onto a support rod. The samples obtained from FW included those at 3, 6, 9, and 12 o'clock positions. In the ANL probe, the weldment specimens were welded at an angle (similar to B&W and FW specimens) onto the support rod, while the base-metal specimens were welded so that one side completely contacted the support rod. Figures X-1 through -4 show schematics of probe orientations and specimen surfaces from different probes analyzed at ANL. Table X-1 lists the chemical composition of alloys, weldments, and claddings that were tested in the present program. In addition, some of the specimens were chromized or aluminized prior to exposure in the AFBC facility.

The specimens exposed in ANL and B&W probes were analyzed on both outside (bed side) and inside (support-rod side) surfaces. Since the specimens were welded at an angle to the support rod (see Figs. X-1 and -2), the inside surfaces were exposed to a deposit of bed material which collected between the specimen and the support rod. The outside surfaces were exposed to moving-bed particles in the dynamic bed environment and exhibited very little, if any, deposit material on them. In the specimens in the FW probe, the 12 o'clock position (identified as location "A") probably simulates a region with bed deposit.

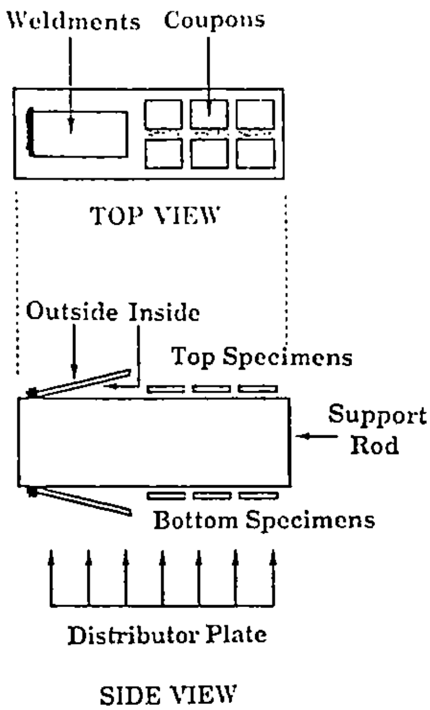


Fig. X-1.

ANL Uncooled Probe

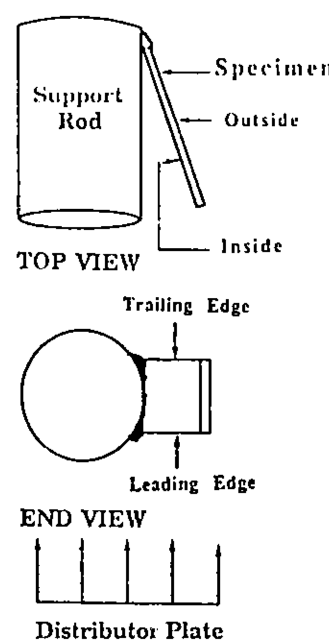


Fig. X-2.

B&W Uncooled Probe

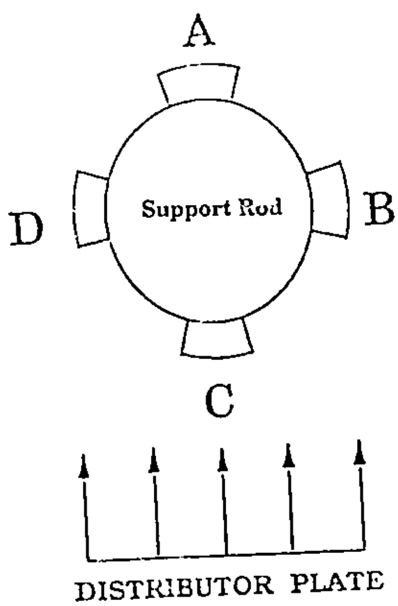


Fig. X-3.

FW Uncooled Probe

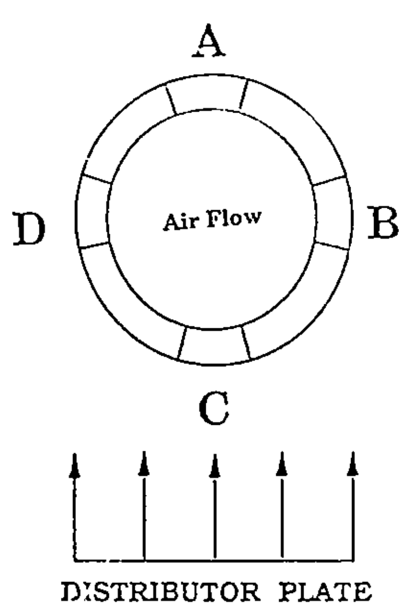


Fig. X-4.

FW Cooled Probe

Table X-1. Chemical Composition (wt%) of Alloys Exposed in Rocketdyne AFBC

Material	C	Cr	Ni	Mn	Si	S	Mo	Al	Fe	Other
304	0.08	18.3	8.10	1.5	0.27	0.018	0.27	---	Bal.[a]	---
800	0.08	20.1	31.7	1.0	0.24	0.006	0.30	0.39	Bal.	Ti 0.31, Cu 0.78
330	0.05	18.6	35.1	1.2	0.92	0.006	0.18	---	Bal.	Nb 0.12
310	0.07	25.0	18.7	1.2	0.64	0.006	---	---	Bal.	
347	0.06	18.9	10.8	1.5	0.58	0.014	---	---	Bal.	Nb + Ta 0.57
333	0.06	25.0	46.2	1.6	0.88	0.002	3.34	---	Bal.	W 3.1, Cu 0.16
188	0.08	23.4	23.3	0.7	0.40	---	0.60	0.22	1.40	Co 35.7, W 14.6
556	0.10	22.0	20.0	1.5	0.4	---	3.00	---	Bal.	Co 20, W 2.5
253MA	0.10	20.7	10.9	0.3	1.80	---	---	---	Bal.	Ce 0.03
HK40	0.40	28.0	20.0	2.0	2.00	---	0.50	---	Bal.	Cu 0.5
HH	0.32	24.6	11.8	0.4	1.99	0.017	0.19	---	Bal.	---
HP 50	0.45	24.3	34.0	0.7	1.73	0.008	0.14	---	Bal.	---
XM 19	0.02	21.2	12.5	5.1	0.39	0.004	2.22	---	Bal.	Nb 0.2, V 0.2
Sanicro 33	0.07	22.1	30.3	4.5	0.13	0.003	---	---	Bal.	Nb 0.9, Ce 0.08
8XX	--	20.2	32.5					3	Bal.	---
FW 4C	0.05	19.5	20.0	4.9	2.60	---	---	1.40	Bal.	---
HR 3C	0.06	24.8	2.0	1.2	0.40	---	---	---	Bal.	Nb 0.48, N 0.25
Ess 1250	0.11	15.4	10.0	6.0	0.59	0.014	0.90	---	Bal.	Nb 0.26, V 0.94
30 CrA	0.06	29.2	49.9	0.2	0.29	0.001	1.89	---	Bal.	Ti 0.17
HR2M	0.02	22.0	14.0	3.0	---	---	1.5	---	Bal.	Nb 0.19
HR6W	0.07	22.8	41.9	1.1	0.18	0.002	---	---	Bal.	Nb 0.17, W 5.47
25/20/3Zr	0.02	24.8	19.8	0.1	---	---	---	---	Bal.	Zr 3.14
25/20/3Nb	0.02	24.0	20.0	0.1	0.3	---	---	---	Bal.	Nb 3.28
Nicro 82[b]	0.02	18.7	Bal.	3.9	0.30	0.003	0.68	0.30	2.74	Nb/Ta 2 .0, Ti 0.1
21/33[b]	0.19	22.2	33.2	1.6	0.35	0.004	---	---	Bal.	Nb/Ta 2.49
25/35[b]	0.41	25.4	34.8	1.9	0.91	0.006	0.3	---	Bal.	N 0.08
25/35R[b]	0.42	26.3	35.3	1.8	1.06	0.05	---	---	Bal.	Nb 1.35
30/50[b]	0.51	28.8	47.6	2.2	1.56	0.009	---	---	Bal.	W 4.61
50/50Nb[b]	0.06	50.0	48.0	1.0	0.60	0.015	---	---	0.80	Nb 1.7

[a]Bal. = balance.
[b]Filler metal in weldments.

A. ANL Probe Specimen

The base-metal specimens in the ANL probe were exposed in the FBC environment for 1980 h. Two sets of specimens were exposed: one set facing the distributor plate and the other facing the top of the bed. Since the base-metal specimens in the ANL probe were welded in contact with the support rod, only the outside surfaces of these specimens were analyzed. In the case of weldment specimens, the top set of specimens was removed after 1000-h exposure, and a new set of specimens was welded onto the support rod and exposed for the last 980 h. The bottom set of weldment specimens was exposed to the bed environment for the entire 1980 h. Both the inside (support-rod side) and outside surfaces of weldment specimens were analyzed.

1. Filler Materials

Chromium provides superior corrosion resistance to materials used in high-temperature, multi-oxidant environments, such as coal gasification and fluidized-bed combustors.[8,9] Because of their high chromium content, several commercial filler materials, including Marathon specialty alloys and other cobalt- and iron-base alloys, were selected for evaluation in the AFBC environment. The results of the post-exposure analyses were used to quantify the relationship between alloy composition and corrosion performance. The detailed microstructural information is presented in Appendix B for three sets of specimens exposed for the first 100 h, last 980 h, and the entire 1980 h.

a. Marathon 21/33

Marathon 21/33, containing 22.2 wt% Cr and 33 wt% Ni, exhibited good corrosion performance in the FBC environment. The specimens developed a predominantly Cr_2O_3 scale that was 2 to 10 μm in thickness. The oxide layer was continuous and uniform. A few internal precipitates, primarily MnS, NbS, and Cr_xS/Cr_2O_3, were observed in the substrate. The depth of internal oxidation/sulfidation was limited to 70 μm for the surface. The specimen surface was covered with a ~2-3 μm layer of bed-deposit material.

b. Marathon 25/35

Marathon 25/35, containing 25 wt% Cr and 35 wt% Ni, exhibited a uniform layer of Cr_2O_3 scale, and the extent of internal attack was blocked largely by the oxide scale. Localized penetration of oxygen and sulfur was observed extending ~40 μm into the substrate. Large discrete particles of SiO_2 formed along the oxide/substrate interface. In addition, a SiO_2 phase was present along the internal Cr_2O_3 phase in the substrate alloy. A few MnS particles, 1-μm dia, were identified ~50 μm from the surface. Very little $CaSO_4$ deposit was observed on both the inside and outside surfaces of the specimens.

c. Marathon 25/35R

Marathon 25/35R, containing 1.35 wt% Nb and 35 wt% Ni, is a Nb-modified version of Marathon 25/35. The corrosion performance of this alloy is rated among the best of all the filler materials exposed in the ETEC facility. The weldment surface was covered with a continuous 3-5 μm thick Cr_2O_3 film that blocked further penetration of oxygen or sulfur into the substrate material. Internal oxidation of chromium in the substrate was not observed. Several isolated MnS particles were scattered in the substrate matrix, but these were inclusions in the weldment and had not developed during exposure to FBC atmosphere.

d. Marathon 30/50

Marathon 30/50, containing 20 wt% Cr and 48 wt% Ni, experienced localized internal oxidation and sulfidation. The samples were covered with a 5-μm $CaSO_4$ deposit. A layer of Cr_2O_3 (without any Fe) scales 5-10 μm thick formed between the sulfate deposit and the substrate alloy. As in Marathon 25/35, massive amounts of SiO_2 were observed beneath the Cr_2O_3 layer and along grain boundaries in the substrate. After 1000 h of exposure, the SiO_2 phase formed a near-continuous film between the Cr_2O_3 and the substrate. The grain boundaries provided fast diffusion paths for oxygen to form additional SiO_2 farther into the substrate material. Scattered Cr_2O_3 phase and MnS particles of submicron size formed in the substrate.

e. Marathon 50/50Nb

Marathon 50/50Nb, which contains 50 wt% Cr, 48 wt% Ni, and 1.75 wt% Nb, developed external scales that comprised a mixture of oxides and sulfides containing iron, calcium, and chromium. A continuous, 10-μm thick layer of Cr_2O_3 scale formed between the external scale and the substrate. Internal penetration by oxidation and sulfidation of chromium exceeded 150-μm deep. X-ray analysis indicated that Cr_2O_3 and Cr_xS were the primary corrosion products.

f. Nicro 82

Nicro 82 is a nickel-base filler metal containing 18.7 wt% Cr. The surface of the weldment was covered with a thick layer of $CaSO_4$. The 5-10 μm thick layer of oxide scales blocked most of the internal penetration of oxygen and sulfur that occurred in other filler materials. This oxide layer consisted of predominantly Cr_2O_3 phase. A large amount of MnO was also detected in this layer. The high nickel content (72 wt%) did not impair the corrosion resistance of Nicro 82, as it did in other high-Ni alloys such as Marathon 30/50 and Marathon 50/50Nb. However, some localized breakdown of the scale resulted in internal oxidation of the alloy. Some of the internal attacks were clearly associated with $CaSO_4$ deposition. Depth of penetration of internal attack ranged between 20 and 70 μm.

g. Haynes 188 Filler Metal

Cobalt-based Haynes 188 experienced little corrosion in the FBC atmosphere. A thin layer of Cr_2O_3 scale formed on the sample surface. Internal sulfidation, primarily Cr_xS, occurred within 50 μm of the surface. Sulfide phases were observed along the grain boundary at ~25-70 μm from the surface. A few SiO_2 particles were observed along the Cr_2O_3/alloy interface.

h. RA 333 Filler Metal

The RA 333 weld specimen, containing 25 wt% Cr and 46 wt% Ni, exhibited a deposit layer of $CaSO_4$ after exposure in FBC environment. The surface scale on the alloy comprised a mixture of iron oxide and calcium oxide. Below this layer was a layer of Cr_2O_3, about 5-10 μm thick. Finally, along the interface between the Cr_2O_3 and the substrate alloy, scattered SiO_2 particles were identified. Both Cr_2O_3 and SiO_2 extended farther into the substrate along grain boundaries; Cr_xS was observed in the substrate matrix in the form of scattered particles of submicron size. The filler metal was highly susceptible to accelerated corrosion in the presence of bed material.

Figure X-5 shows the filler metal penetration data obtained from the weldment specimens exposed for different times in ANL probe BMUEB. The data clearly show that a number of filler metals with acceptable corrosion rates in the range of 0.1 to 0.2 mm/yr can be selected from the tested materials. The results also show that the filler metal selected for application in FBC atmosphere should be impervious to not only the gas atmosphere but also the bed-deposit material. On that basis, filler metals 25-35R, 25-35, and 188 alloys are the most desirable.

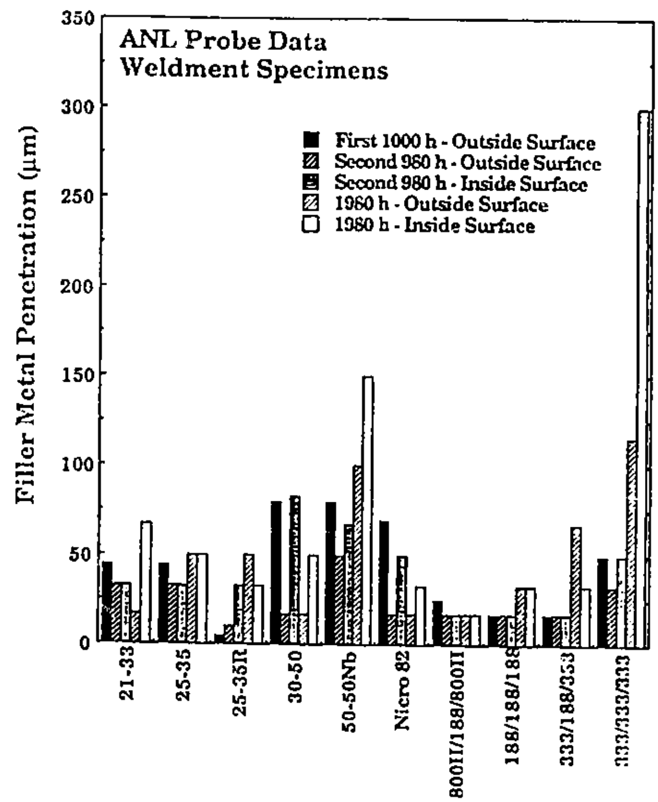


Fig. X-5. Filler Metal Penetration Data from ANL Probe BMUEB

2. Base Metal Alloys

The base metal specimens in the ANL probe were all exposed for 1980 h. Detailed miscrostructural evaluation of various base-metal alloys was conducted, and the SEM photographs of the cross sections of different alloys are given in Appendix B. The specimens on the top of the support rod (identified as "Top Specimens") would have had some accumulation of bed material on them, while those on the bottom of the support rod would have been exposed to particle/gas impingement and essentially would have had no accumulation of bed material. Figure X-6 shows the alloy penetration data for all the base-metal specimens exposed in ANL probe BMUEB. The penetration rates for the alloys ranged between 10 and 160 µm (which translates to 0.02 - 0.34 mm/yr, based on parabolic kinetics) after 1980-h exposure. Alloys such as Type 310 stainless steel, HS 188, and HR 3C exhibited better corrosion resistance than the others. The internal penetration in most of these alloys was predominantly due to oxidation attack, and virtually no sulfur was detected.

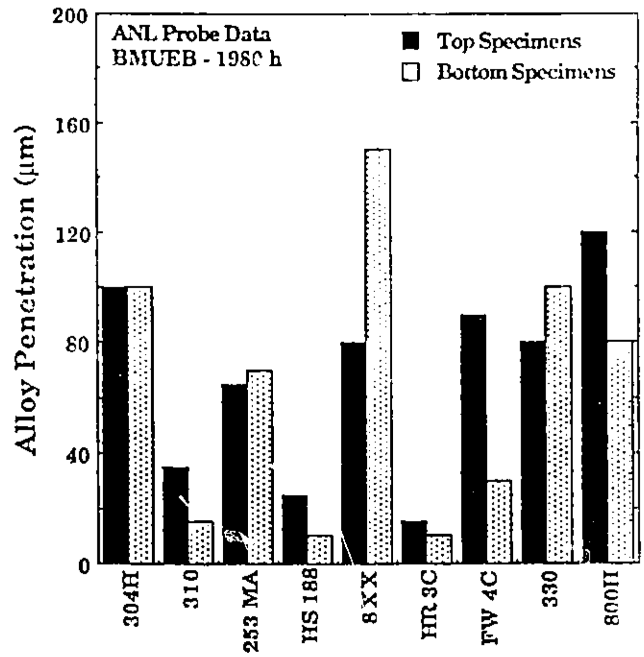


Fig. X-6. Alloy Penetration Data from ANL Probe BMUEB

B. B&W Probe Specimens

The specimens exposed in the uncooled probes of B&W were flat. The probes identified as BBTED, BBTEB, and BBTWB were exposed for 500, 1000, and 1980 h at different locations in the combustor (see Figs. VIII-2 and -3). Cross sections of specimens from these probes were examined using SEM equipped with an energy dispersive X-ray analyzer and an electron microprobe. The purpose of these analyses was to identify the morphological features of corrosion product phases in the scale layers and to determine the thickness of scales and depths of intergranular penetration, if any, of the substrate material. The specimens obtained by ANL were exposed at the 9 o'clock position on the B&W probes. Four different surfaces (see Fig. X-2), namely, outside (bed side), inside (support-rod side), leading edge, and trailing edge, were examined on the specimens exposed for 500 and 1000 h. The leading-edge surface was exposed to the coal/air-flow direction while the trailing edge was exposed by the flow. Only the inside and outside surfaces of the specimens were analyzed for the BBTWB probe exposed for 1980 h. Detailed miscrostructural evaluation of various specimens from the three B&W probes is given in Appendices C, D, and E.

Figures X-7 to -9 show the penetration depth data for different surfaces on alloys exposed in B&W probes for 500, 1000, and 1980 h. In general, the data show that the penetration was much less on the outer surfaces of the alloy specimens when compared with those on the inside surfaces, which were exposed to deposits of bed material. This is especially true for the specimens exposed for 1980 h. The penetration on the outer surfaces for all the alloys was in a range of 3-110 μm. The penetration depths for the leading- and trailing-edge surfaces were essentially in the same range. On the other hand, penetrations on the inside surfaces of all the specimens (except Types 304 and 310 stainless steel) ranged between 630 and 3000 μm (which translates to 1.3 and 6.3 mm/yr, based on parabolic kinetics). The inside surfaces of stainless steels exhibited a maximum of 90 μm (equivalent to 0.02 mm/yr).

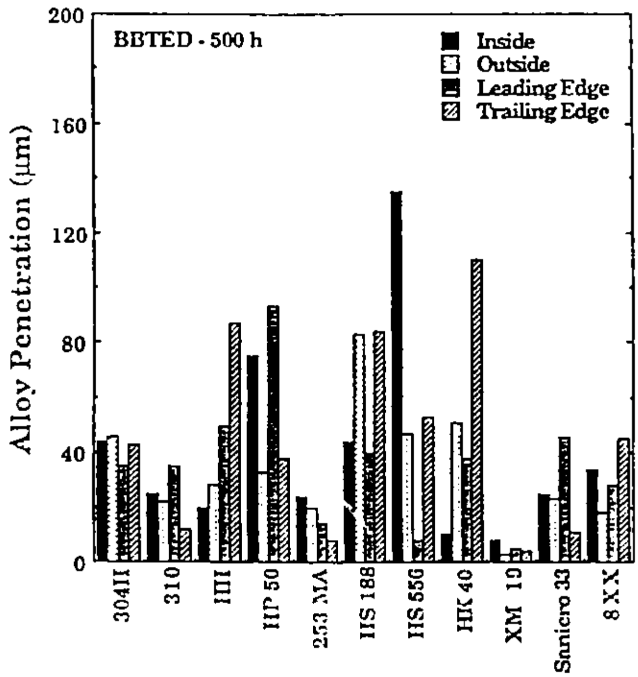
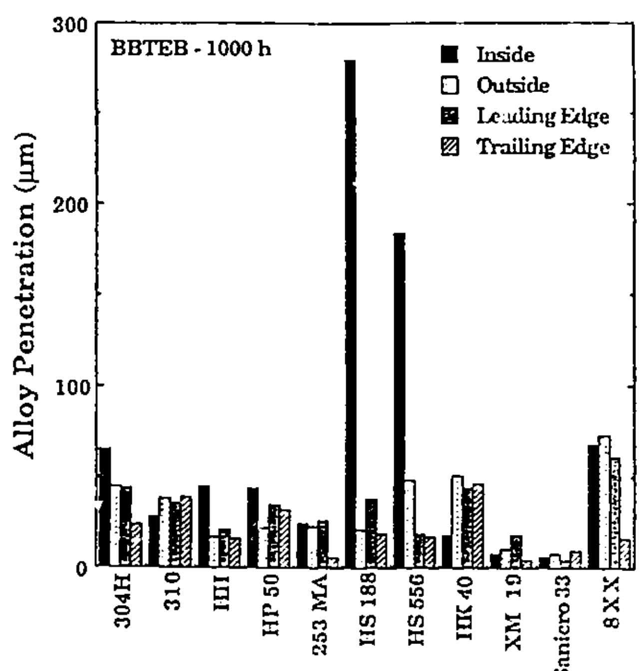


Fig. X-7.

Penetration Data for Alloy Surfaces Exposed for 500 Hours in B&W Probe BBTED

Fig. X-8.

Penetration Data for Alloy Surfaces Exposed for 1000 Hours in B&W Probe BBTEB



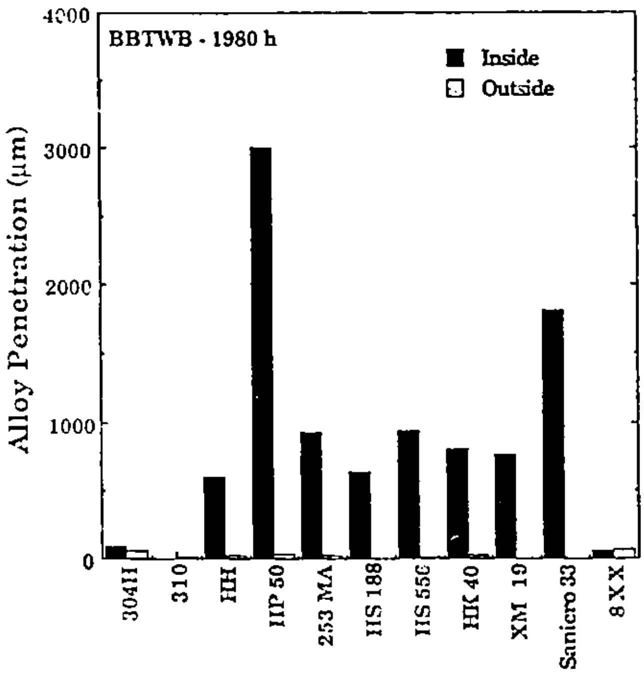


Fig. X-9.

Penetration Data for Alloy Surfaces Exposed for 1980 Hours in B&W Probe BBTWB

Figures X-10 to -12 show the effect of exposure time in the range of 500 to 1980 h on the alloy penetration depth for the outside, inside, leading edge, and trailing edge, respectively. The data for the outside, leading-, and trailing-edge surfaces do not show any trend with an increase in exposure time; however, the penetration depths for these surfaces are fairly small, and any variation in the penetration data with exposure time can be considered to be within the scatter of the data. Further, the lack of trend

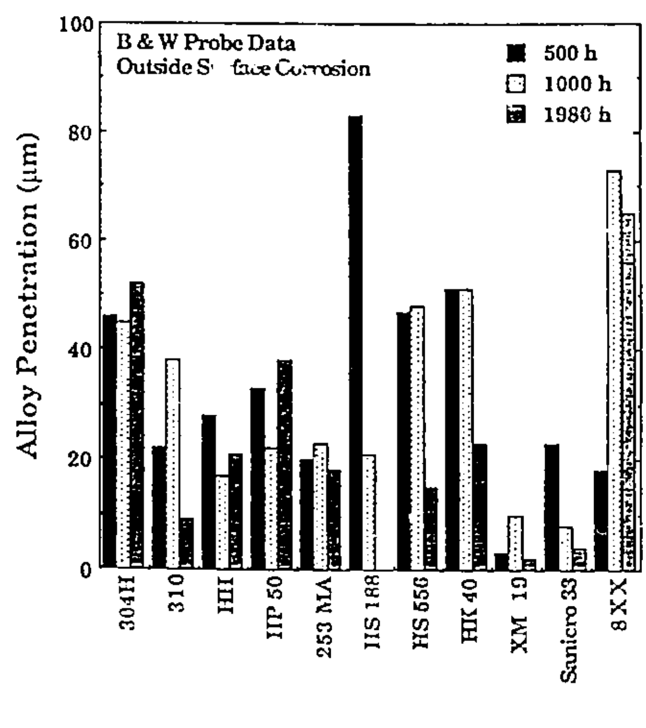


Fig. X-10.

Outside Surface Penetration of Alloys at 500, 1000, and 1980 Hours

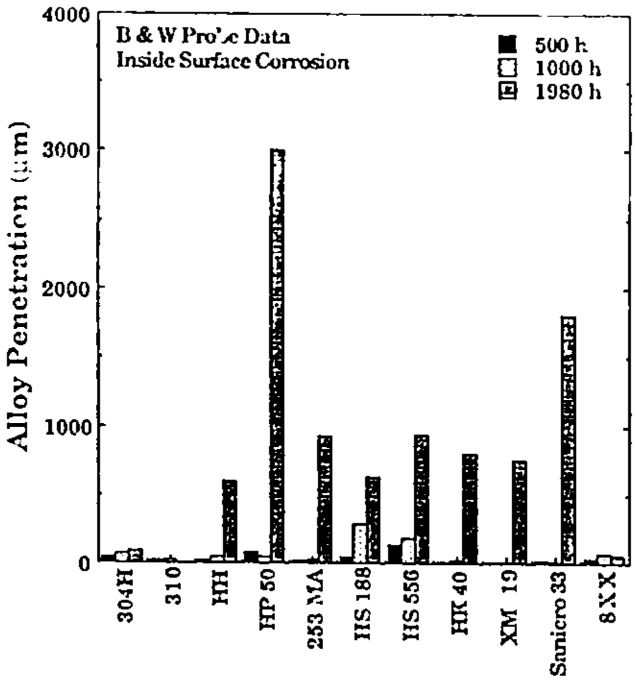


Fig. X-11.

Inside Surface Penetration of Alloys at 500, 1000, and 1980 Hours

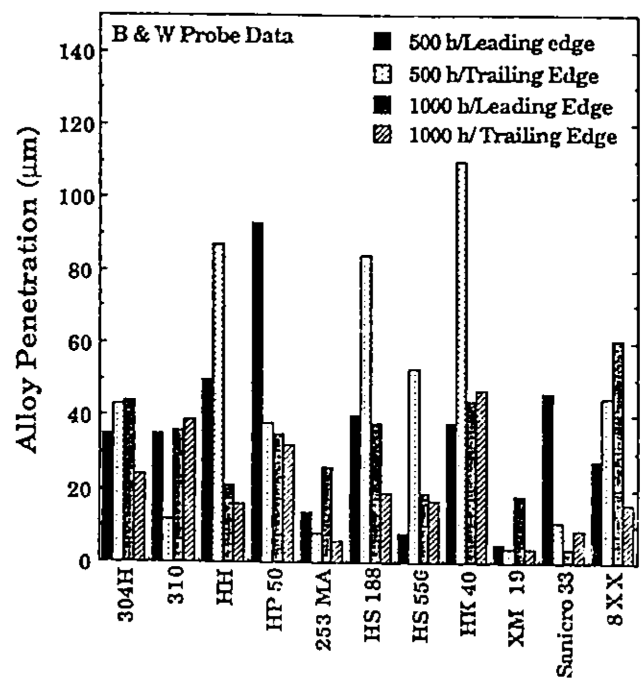


Fig. X-12.

Alloy Penetration on the Leading and Trailing Edges at 500 and 1000 Hours

may also be due to the fact that the probes were exposed in different locations within the combustor, and the local chemistry around the probes/specimens could have been different. Also, during the second 500 h of the run, the combustor environment was maintained in a much more reducing condition (due to pressure tap malfunction), which also would have contributed to the lack of trend in the data. On the other hand, the effect of exposure time on the penetration of inside (in contact with bed-deposit material) surfaces of alloy specimens is dramatic and exemplifies the susceptibility of several alloys to deposit-induced corrosion. Most of the high-Cr alloys (except Types 304 and 310 stainless steel and 8XX) exhibited penetrations in the range of 700 to 1000 μm (1.5 to 2.0 mm/yr, based on parabolic kinetics) after 1980-h exposure. The alloys such as HP 50 and Sanicro 33 exhibited catastrophic corrosion after 1980-h exposure.

C. FW Uncooled Probe Specimens

The specimens obtained from FW were exposed for 1980 h in the uncooled probe BBTEC. These specimens were exposed in the combustor at the same elevation (distance from the air distributor plate) as the specimens in the B&W probes BBTED, BBTEB, and BBTWB. The specimens were in the form of cut sections of rings and were attached to the support rod at 12, 3, 6, and 9 o'clock positions (identified as locations A, B, C, and D in Fig. X-3). The specimens in location C in the underside of the bed are exposed to environments similar to outside surfaces of specimens in B&W probe BBTWB and the bottom row of specimens in ANL probe BMUEB. Microstructural details on various specimens in the FW probe are presented in Appendix F.

Figure X-13 shows the penetration depth data for alloys and coatings exposed in the FW probe BBTEC for 1980 h. The results indicate that the coated specimens exhibited less corrosion resistance than the corresponding base metals. The penetration in all of the samples was dominated by oxidation and very little, if any, sulfur was detected. Figure X-14 shows a comparison of data for alloys (exposed under similar conditions) common to the probes exposed by the three organizations. The penetration rates for the alloys ranged between 5 and 10 μm (0.01- and 0.21-mm/yr, based on parabolic kinetics) after 1980-h exposure to the FBC environment. Figure X-15 shows a comparison of penetration data for common alloys exposed in location A of FW probe and the top row of specimens in the ANL probe.

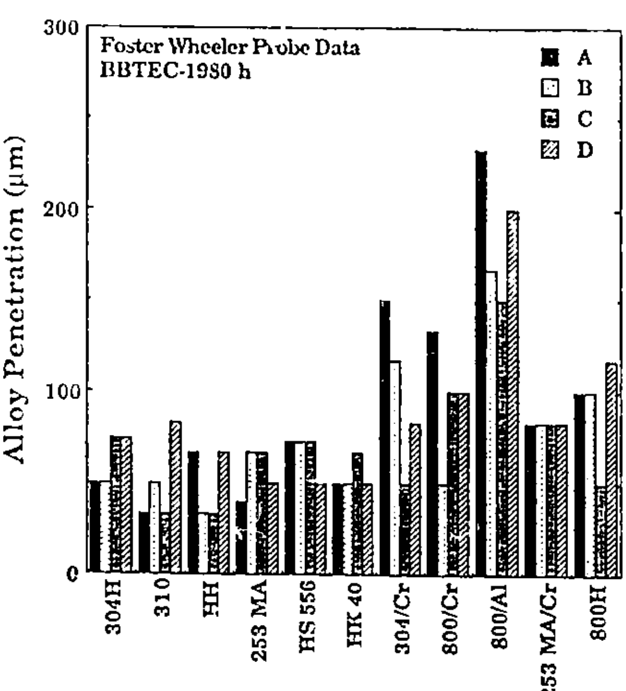


Fig. X-13.

Alloy Penetration for Samples Exposed 1980 Hours in FW Probe BBTEC

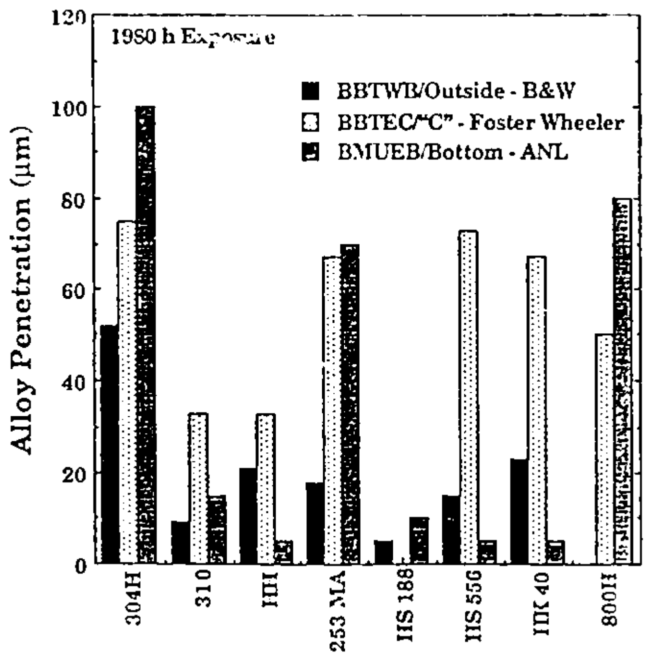


Fig. X-14.

Comparison of B&W, FW, and ANL Penetration Data

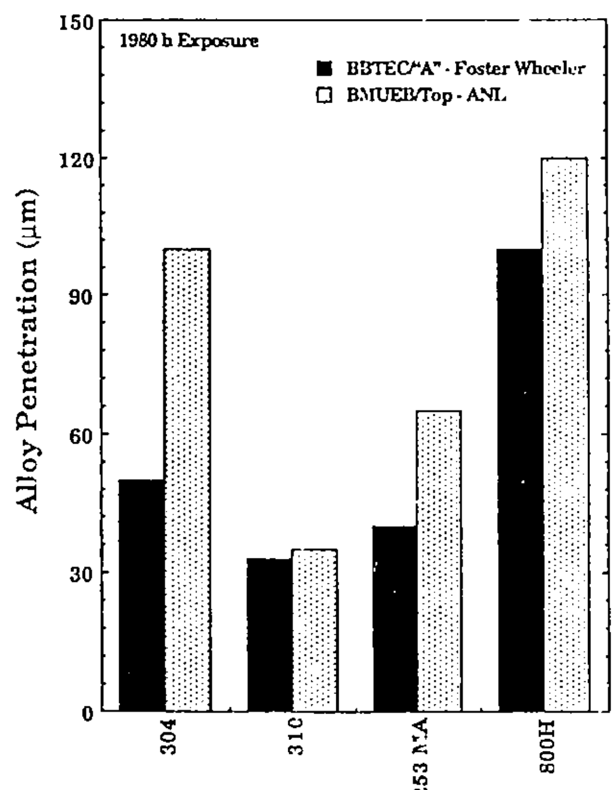


Fig. X-15.

Comparison of FW and ANL Penetration Data for Top Specimens

The specimens obtained from B&W probes were exposed in the 9 o'clock position, and data from these could not be included in this comparison. The similarity of penetration depths in Fig. X-15 indicates that the probe exposure elevation [18.3 in. (46.5 cm) for FW probe vs. 50.7 in. (129 cm) for ANL probe] had negligible effect on the corrosion process.

D. FW Cooled Probe Specimens

Specimens from one FW cooled probe, identified as BBTEA, were analyzed. The exposure temperatures ranged between 774 and 843°C (1425 and 1550°F) for the specimens in this probe. The specimens were exposed for 1980 h at an elevation of 18.3 in. (46.5 cm) from the air distributor plate (see Fig. X-13). Among the specimens, the uncoated specimens were exposed at the lower end of the temperature range, while the coated specimens experienced higher temperatures. The clad and weldment specimens were exposed in the middle of the temperature range. Details on the microstructural analyses of these specimens are presented in Appendix G. Figure X-16 shows the alloy penetration depth data for the alloys, claddings, coatings, and weldments exposed in BBTEA probe. The higher penetration depth for some of the chromized and aluminized specimens is due to internal penetration of coating layer, primarily via oxidation mode, and no sulfur being present. The data also show that a number of alloys, claddings, and weldments performed with adequate corrosion resistance for 1980 h.

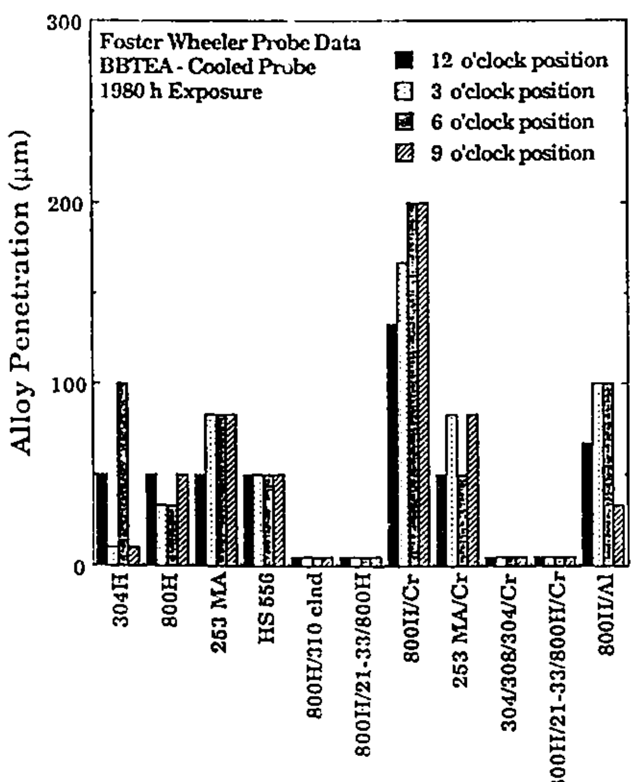


Fig. X-16.

Penetration Data for FW Probe BBTEA Exposed for 1980 Hours

XI. COMPARISON WITH EARLIER TEST DATA

Recently, a laboratory test program was conducted to evaluate the corrosion behavior of several metallic alloys, coatings, claddings, and weldments in support of the atmospheric fluidized-bed air heater experiment.[3] The program involved six tests, five of which were conducted at a metal temperature of 871°C (1600°F), while the last one was performed at a metal temperature of 635°C (1175°F). Three of the tests were conducted under simulated bubbling-bed conditions, while in others circulating fluid-bed conditions were maintained. Reagent grade $CaSO_4$ and ash from a circulating fluid-bed system were used as the deposit materials to simulate the bubbling- and circulating-fluid beds, respectively, in the laboratory test program.

Two of the bubbling-bed simulation tests were of 3000-h (Test A2) and 2000-h (Test C) durations, and the data from these tests are relevant for comparison with in-bed test data. In Test A2, the specimens were exposed in a sustained manner for 3000 h at a temperature of 871°C in a low-pO_2 environment, simulating the worst possible combustion environment anticipated in FBC systems. The oxygen and sulfur partial pressures during the exposure were maintained at 3×10^{-12} and $\sim 10^{-7}$ atm, respectively, at a gas temperature of 900°C. The gas environment in Test C was cycled between a high-pO_2 mixture ($pO_2 \sim 10^{-3}$ atm) and a low-pO_2 mixture ($pO_2 \sim 3 \times 10^{-12}$ atm) every 100 h. The pS_2 values corresponding to the high- and low-pO_2 gas mixtures were $\sim 10^{-28}$ and 10^{-7} atm, respectively.

Figure XI-1 shows the corrosion rates calculated for several candidate alloys exposed in Tests A2 and C, as well as in the ETEC AFBC tests. The data included in this figure incorporate information developed at ANL from all the specimens (from ANL, B&W, and FW probes) analyzed. The ETEC test data in this figure are differentiated as to whether or not the specimens were covered with the bed material. The data show that some of the alloys (such as 800H, HK 40, HS 188, and HS 556) are susceptible to catastrophic corrosion when subjected to a sustained low-pO_2 and relatively high-pS_2 environment (dictated by the boundary between CaO and $CaSO_4$ phases). The next worst environment from the materials corrosion point of view is one in which bed deposit material is present. Of the alloys exposed to a bed deposit in the ETEC exposure, HP 50 and Sanicro 33 exhibited 4- to 6-mm/yr corrosion,

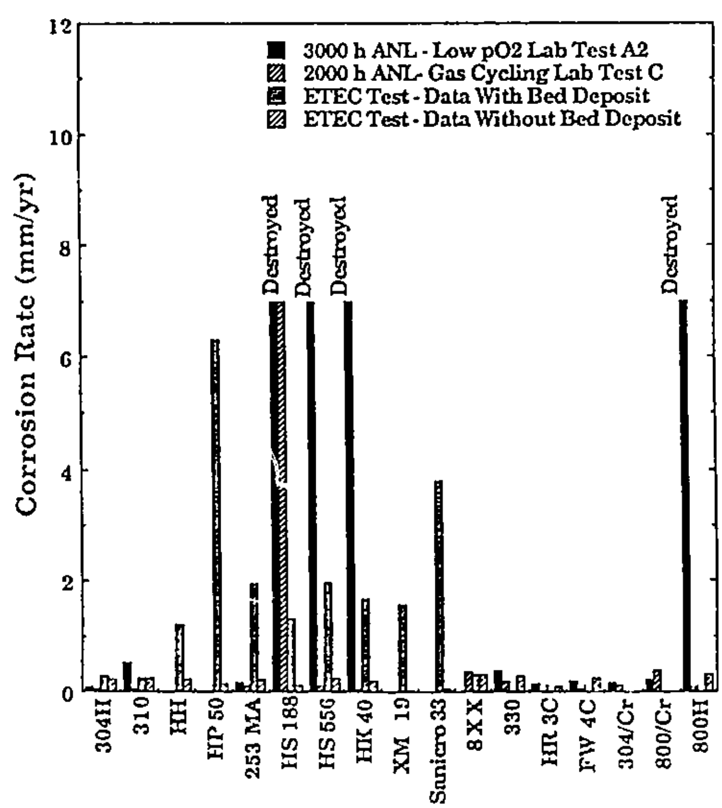


Fig. XI-1. Corrosion Rates for ANL Tests A-2 and C and ETEC Tests while 253 MA, HS 556, HS 188, XM 19, and HK 40 exhibited ~2 mm/yr corrosion rate. It should be noted that FBC systems will probably not experience a sustained low-pO_2 atmosphere for thousands of hours; the materials corrosion data obtained in Test A2 may be overly pessimistic, and selection of materials based on this test data will be highly conservative.

Figure XI-2 shows the results plotted without the data from Test A2. The gas-cycling data showed that the alloys, in general, can tolerate the oxidizing/reducing environments as long as the alloys are exposed to oxidizing condition in the startup cycle. Only Alloy HS 188 exhibited high corrosion, which manifested as internal oxidation of the alloy. The results also show that a number of structural alloys (such as Types 304 and 310 stainless steel, HR 3C, FW 4C, 8XX, and 330) and some of the chromized coatings performed well under all the environmental conditions used in different tests. The corrosion rates for these materials were in the range of 0.25 to 0.4 mm/yr (0.25 to 4 mm/yr) for temperatures in the range of 775 to 871°C (1425 to 1600°F). In the case of air tubes with 5 to 6 mm wall thickness, the above corrosion rates will lead to a thickness loss of 0.8 to 1.25 mm after 10 years of service in the FBC environment. Since abnormal conditions (e.g., the low-pO_2 condition during the second 500 h of the present test at ETEC) are anticipated during the operation of an FBC system, the material selected for the air tubes should possess adequate corrosion resistance, even under the perceived abnormal conditions. Another aspect of importance in materials selection, which this report does not address, is the adequacy of mechanical properties of materials at elevated temperatures. However, based on this study, corrosion resistant materials can be applied as a cladding onto structurally acceptable alloy (e.g., Type 310 stainless steel clad on Type 304 stainless steel, Alloy 800, or HR 3C) to achieve adequate corrosion resistance and other mechanical properties for the air-heater tubes.

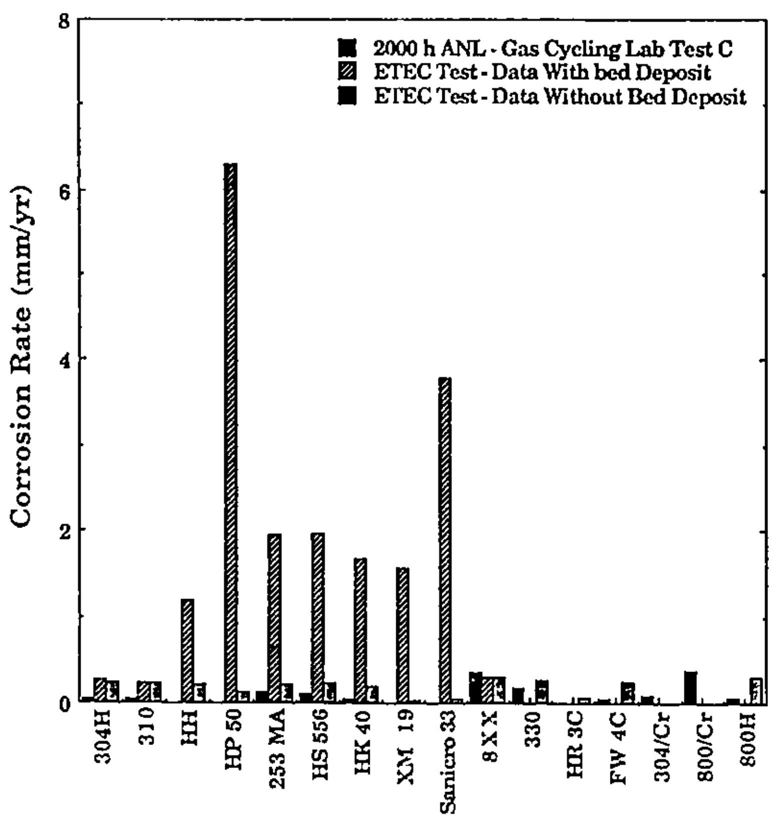


Fig. XI-2. Corrosion Rates for ANL Test C and ETEC Tests

XII. CONCLUSIONS

Detailed microstructural analyses were conducted at ANL on specimens exposed in uncooled and cooled probes by ANL, B&W, and FW during the ACAHE. In addition, information was developed on penetration depths for several of the materials as a function of specimen orientation, exposure location in the combustor, and time of exposure. These results, together with those reported earlier from a laboratory test program in support of ACAHE, are used to determine the role of key variables that contribute to accelerated corrosion of materials and assess the long-time performance of candidate materials for air-heater applications. Based on the information, a number of conclusions can be drawn:

1. Austenitic stainless steels such as Types 304, 310, and 330 and alloys such as HR 3C, FW 4C, and 8XX exhibited low depths of penetration after exposure in the AFBC facility, as well as a laboratory test under gas-cycling conditions and a more severe laboratory test under low-pO_2 conditions.

2. Alloys such as HS 188, HS556, HK 40, and 800H exhibited catastrophic corrosion in the presence of sustained low-pO_2 condition and deposit material, based on a 3000-h laboratory test. Even though the test is more severe than what the materials will be subjected to in a typical well-run FBC system, the data nevertheless suggest the susceptibility of these materials to accelerated corrosion.

3. Alloys such as HH, HP 50, 253 MA, XM 19, Sanicro 33, HS 556, and HS 188 were found susceptible to unacceptable corrosion when in contact with the bed material.

4. Among the weldments, filler metals 25-35R, 21-33, and 308 exhibited superior corrosion resistance. Filler metals Nicro 82, 188, and 25-35 showed acceptable corrosion resistance.

5. Among the coated specimens analyzed at ANL, the performance of aluminized coatings was poor. In general, this is more due to difficulty in the development of crack-free coating than to exposure in the FBC environment. However, the cracked regions, if present initially, exhibited accelerated oxidation and the coating integrity declined.

6. Among the cladding alloys, Type 310 stainless steel on Type 304 stainless steel or Alloy 800H exhibited superior performance.

7. The results obtained from an analysis of the specimens in the uncooled probes indicate that the presence of bed-material deposit on the specimen surfaces leads to significant, sometimes catastrophic, corrosion of materials at a temperature of ~845°C. On the other hand, the same alloys exhibit acceptable corrosion rates, in the range of 0.05 to 0.25 mm/yr (extrapolated from the 1980 h data based on parabolic kinetics), when the surfaces are devoid of bed-material deposits. In this regard, component material surfaces exposed to a corrosive-erosive environment perform superior to those exposed to a corrosive environment alone. The acceptable performance of even Alloy 800 (an alloy that has been shown to undergo substantial corrosion after exposures in other FBC facilities) indicates that the combustion atmosphere in the present test was much more benign than in the other systems, and that the operating conditions/procedures, if duplicated in a commercial system, can result in enhanced reliability of the larger system.

8. The corrosion rates for several materials tested in this program were in the range of 0.25 to 0.4 mm/yr (10 to 16 mils/yr) for temperatures in the range of 775 to 871°C (1425 to

1600°F). In the case of air tubes with 5 to 6 mm wall thickness, the above corrosion rates will lead to a thickness loss of 0.8 to 1.25 mm after 10 years of service in the FBC environment, even with a period of abnormal conditions, as experienced in this test. Another aspect of importance in materials selection, which this report does not address, is the adequacy of mechanical properties of materials at elevated temperatures. However, based on this study, corrosion resistant materials can be applied as a cladding onto structurally acceptable alloys (e.g., Type 310 stainless steel clad on Type 304 stainless steel, Alloy 800, or HR 3C) to achieve adequate corrosion resistance and mechanical properties for the air-heater tubes.

ACKNOWLEDGMENTS

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APPENDIX A.

SAMPLE DATA PACKAGE

A F B C Test Facility
Performance Printout
252-TP-0001, TEST A-10

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

Page 1 of 3
Time 0: 7:37
Date 8/ 1/89

Fluidized Bed:

Tag No.	SEQ#	Description	Value	Units
CFBT01	405	Avg. Bed Temp.	1598.	F
FBP12	270	Freeboard Press.	-.6	in H2O
CFBV01	407	Superficial Vel.	5.1	fps
CFBH01	406	Bed Height	100.	in
CSC	464	Sulfur Capture	93.5	%

Solid Feed:

Tag No.	SEQ#	Description	Value	Units
CCFF52T	411	Total Coal Flow	1185.	lb/hr
LSW02	5	Total Limestone Flow	334.	lb/hr
CARF03	427	Ash Recycle Flow	1742.6	lb/hr

Combustion Air:

Tag No.	SEQ#	Description	Value	Units
CAP04	250	Windbox Press.	.88.	in H2O
CAT06	71	Windbox Temp.	570.	F
ART02	66	Ash Recycle Temp.	275.	F
CARF02	434	Ash Recycle Air Flow	866.	lb/hr
CCFF01T	428	Coal Feed Air Flow	2098.	lb/hr
CLSF02	433	Limestone Feed Air Flow	261.	lb/hr
CCAF01	410	Combustion Air Flow	8855.	lb/hr
CCAF01T	409	Total Air Flow	12289.	lb/hr

Working Fluid

Tag No.	SEQ#	Description	Value	Units
CWFF11	417	Air Flow - East	15840.	lb/hr
CWFF21	418	Air Flow - West	15138.	lb/hr
WFT15	220	East Bed Bank Temp. Out	1498.	F
WFT25	227	West Bed Bank Temp. Out	1497.	F
WFT14	219	East Bed Bank Temp. In	823.	F
WFT24	226	West Bed Bank Temp. In	806.	F
WFP14	52	East Bed Bank Press. In	38.	Psig
WFP24	57	West Bed Bank Press. In	38.	Psig

Flue Gas:

Tag No.	SEQ#	Description	Value	Units
CFGF01	412	Total Flue Gas Flow	13355.	lb/hr
FGT01	83	Flue Gas Temp.	702.	F
COMB	10	Comb. Flue Gas Analysis	.1	%
CO	7	CO Flue Gas Analysis	67.	PPM
CO2	8	CO2 Flue Gas Analysis	13.1	%
SO2	14	SO2 Flue Gas Analysis	186.	PPM
NOx	11	NOx Flue Gas Analysis	214.	PPM
O23	13	O2 Flue Gas Analysis	4.1	%
CO2B	408	Flue Gas Excess Air	35.7	%
CCACO1T	419	Tot. Comb Air/Coal Ratio	10.4	
C-O2+CO2	470	Oxygen + CO2	17.2	%
UK-FLUE	15	Soot Blow, Flue Gas Cal.	66	MV

Heat Balance:

Tag No.	SEQ#	Description	Value	Units
COIN	444	Heat Input	3465.	Btu/sec
CCOMBEFF	441	Heat Bal. Comb. Eff.	84.7	%

A F B C Test Facility
Cooled Probe Temperature Profiles
252-TP-0001, TEST A-10

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

Page 1 of 1
Time 0: 8: 2
Date 8/ 1/89

T/C Location	BBTEA	BBTEE	BBTWA	BBTWE	BMLEC
2-inch (Tip)	663.	1531.	1075.		
13-inch	918.	1480.	612.		
24-inch	1264.	1413.	948.		
34-inch (Wall)	889.	1232.	726.		
Coolant Out	788.	790.	640.		

	BMLED	BMLWB	BMLWC	BMUWB
2-inch (Tip)	9999.		1006.	
13-inch	1129.		614.	
24-inch	926.		7253.	
34-inch (Wall)	9759.		1065.	
Coolant Out	742.		763.	

	BMUWD	BTPWB	BTPSA	CBTWA
2-inch (Tip)	*****		9571.	1291.
13-inch	1224.		1432.	1215.
24-inch	4325.		1027.	9999.
34-inch (Wall)	-133.		-496.	*****
Coolant Out	677.		773.	579.

A F B C Test Facility
Fluidized Bed Temperature Profile
252-TP-0001, TEST A-10

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

Time 0: 8: 8
Date 8/ 1/89

Tube Bundle:

T/C Location	Platen 2	Platen 4	Platen 5	Platen 6	Platen 8	Platen 10	Platen 11	Platen 12
Outlt	1454.	1477.		1468.	1469.	1437.		1467.

	Platen 14	Platen 16	Platen 17	Platen 18	Platen 20	Platen 21	Platen 22	Platen 24
Outlet	1467.	1497.		1492.	1462.		1509.	1466.

Fluidized Bed:

T/C Elev.	Bed Temp.
5.7-inch	1575.
27.7-inch	1602.
51.7-inch	1597.
75.4-inch	1597.
103.1-inch	1544.
229.3-inch	1469.

Working Fluid:

T/C Location.	Air Temp
Bed Bank Outlet-E	1498.
Bed Bank Outlet-W	1497.
Bed Bank Inlet-E	823.
Bed Bank Inlet-W	806.

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 289 Samples

Test Facility 252
Statistical Printout Only
PERFORMANCE PRINTOUT

Page 1
Time 0:16:26
Date 8/ 1/89

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
406	CFBH01	FLUIDIZED BED HEIGHT	INCHES	100.00	13.57	73.06	141.15
413	CCAC01	IN-BED COMB AIR TO COAL RATIO	RATIO	10.15	.10	9.86	10.47
470	C-02+C02	OXYGEN PLUS CARBON DIOXIDE	PERCENT	17.16	1.52	.02	20.68
83	FGT01	FLUE GAS SYSTEM-CYCLONE INLET TEMP	DEG F	702.28	10.08	680.22	723.05
84	FGT02	FLUE GAS SYSTEM-CYCLONE OUTLET TEMP	DEG F	689.92	9.18	669.05	707.65
274	FGP01	FLUE GAS SYSTEM-CYCLONE INLET PRESSURE	IN W.G.	-.96	.78	-3.02	1.68
275	FGP02	FLUE GAS SYSTEM-CYCLONE OUTLET PRESSURE	IN W.G.	-3.26	.20	-3.82	-2.53
85	FGT03	FLUE GAS SYSTEM-AIR HEATER OUTLET TEMP	DEG F	396.81	5.00	381.53	410.20
276	FGP03	FLUE GAS SYSTEM-AIR HEATER OUTLET PR	IN W.G.	-5.94	1.23	-7.66	-3.34
69	CAT03	COMB AIR-AIR HEATER OUTLET TEMPERATURE	DEG F	601.52	8.00	583.59	619.09
248	CAP02	COMB AIR-AIR HEATER IN PRESSURE	IN W.G.	1.43	.43	-.20	2.62
249	CAP03	COMB AIR-AIR HEATER OUT PRESSURE	IN W.G.	90.99	1.65	86.74	95.98
68	CAT01	COMB AIR-VENTURI U/S TEMPERATURE	DEG F	177.82	3.74	169.66	185.19
246	CAD01	COMB AIR-VENTURI DELTA PRESSURE	IN W.G.	4.82	.24	4.17	5.45
247	CAP01	COMB AIR-VENTURI U/S PRESSURE	IN W.G.	89.36	1.44	85.84	93.00
49	WFD11	AIR WORKING FLUID-ORIFICE DELTA PR EAST	IN W.G.	76.28	3.10	64.23	79.80
50	WFD21	AIR WORKING FLUID-ORIFICE DELTA PR WEST	IN W.G.	69.97	3.89	57.91	74.42
313	WFP11	AIR WORKING FLUID-ORIFICE U/S PR EAST	PSIG	271.28	1.03	263.69	273.45
54	WFP21	AIR WORKING FLUID ORIFICE U/S PR WEST	PSIG	270.91	1.07	263.30	273.56
251	CFP12	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #1	PSIG	29.77	0.00	29.77	29.77
253	CFP22	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #2	PSIG	36.44	0.00	36.44	36.44
257	CFP32	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #3	PSIG	29.59	0.00	29.59	29.59
259	CFP42	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #4	PSIG	31.17	.08	31.17	31.17
243	ARP02	ASH RECYCLE SYSTEM-INJECTION PRESSURE	PSIG	62.63	.32	61.30	63.52
51	WFP12	AIR WORKING FLUID-CONV BANK IN PR EAST	PSIG	43.10	1.06	39.26	44.75
79	WFP13	AIR WORKING FLUID CONV BANK OUT PR EAST	PSIG	39.95	1.12	36.26	41.74
217	WFT12	AIR WORKING FLUID-CONV BANK IN TEMP EAST	DEG F	364.56	1.53	360.85	368.95
218	WFT13	AIR WORKING FLUID-CONV BNK OUT TEMP EAST	DEG F	842.11	6.62	828.61	860.78
55	WFP22	AIR WORKING FLUID-CONV BANK IN PR WEST	PSIG	40.27	1.38	35.55	42.11
56	WFP23	AIR WORKING FLUID-CONV BANK OUT PR WEST	PSIG	36.79	1.30	32.62	38.59
222	WFT22	AIR WORKING FLUID-CONV BANK IN TEMP WEST	DEG F	362.38	2.80	356.35	367.15
225	WFT23	AIR WORKING FLUID-CONV BNK OUT TEMP WEST	DEG F	830.03	8.43	809.95	853.17
406	CFBH01	FLUIDIZED BED HEIGHT	INCHES	100.00	13.57	73.06	141.15
413	CCAC01	IN-BED COMB AIR TO COAL RATIO	RATIO	10.15	.10	9.86	10.47
470	C-02+C02	OXYGEN PLUS CARBON DIOXIDE	PERCENT	17.16	1.52	.02	20.68
83	FGT01	FLUE GAS SYSTEM-CYCLONE INLET TEMP	DEG F	702.28	10.08	680.22	723.05
84	FGT02	FLUE GAS SYSTEM-CYCLONE OUTLET TEMP	DEG F	689.92	9.18	669.05	707.65
274	FGP01	FLUE GAS SYSTEM-CYCLONE INLET PRESSURE	IN W.G.	-.96	.78	-3.02	1.68
275	FGP02	FLUE GAS SYSTEM-CYCLONE OUTLET PRESSURE	IN W.G.	-3.26	.20	-3.82	-2.53

Test Facility 252
Statistical Printout Only
PERFORMANCE PRINTOUT

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 289 Samples

Page 2
Time 0:16:39
Date 8/ 1/89

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
85	FGT03	FLUE GAS SYSTEM-AIR HEATER OUTLET TEMP	DEG F	396.81	5.00	381.53	410.20
276	FGP03	FLUE GAS SYSTEM-AIR HEATER OUTLET PR	IN W.G.	-5.94	1.23	-7.66	-3.34
69	CAT03	COMB AIR-AIR HEATER OUTLET TEMPERATURE	DEG F	601.52	8.00	583.59	619.09
248	CAP02	COMB AIR-AIR HEATER IN PRESSURE	IN W.G.	1.43	.43	-.20	2.62
249	CAP03	COMB AIR-AIR HEATER OUT PRESSURE	IN W.G.	90.99	1.65	86.74	95.90
68	CAT01	COMB AIR-VENTURI U/S TEMPERATURE	DEG F	177.82	3.74	169.66	185.19
246	CAD01	COMB AIR-VENTURI DELTA PRESSURE	IN W.G.	4.82	.24	4.17	5.45
247	CAP01	COMB AIR-VENTURI U/S PRESSURE	IN W.G.	89.36	1.44	85.84	93.00
49	WFD11	AIR WORKING FLUID-ORIFICE DELTA PR EAST	IN W.G.	76.28	3.10	64.23	79.80
50	WFD21	AIR WORKING FLUID-ORIFICE DELTA PR WEST	IN W.G.	69.97	3.89	57.91	74.42
313	WFP11	AIR WORKING FLUID-ORIFICE U/S PR EAST	PSIG	271.28	1.03	263.69	273.45
54	WFP21	AIR WORKING FLUID ORIFICE U/S PR WEST	PSIG	270.91	1.07	263.30	273.56
251	CFP12	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #1	PSIG	29.77	0.00	29.77	29.77
253	CFP22	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #2	PSIG	36.44	0.00	36.44	36.44
257	CFP32	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #3	PSIG	29.59	0.00	29.59	29.59
259	CFP42	COAL SYSTEM-EDUCTOR UP-STREAM PRESS #4	PSIG	31.17	.08	31.17	31.17
243	ARP02	ASH RECYCLE SYSTEM-INJECTION PRESSURE	PSIG	62.63	.32	61.30	63.52
51	WFP12	AIR WORKING FLUID-CONV BANK IN PR EAST	PSIG	43.10	1.06	39.26	44.75
79	WFP13	AIR WORKING FLUID CONV BANK OUT PR EAST	PSIG	39.95	1.12	36.26	41.74
217	WFT12	AIR WORKING FLUID-CONV BANK IN TEMP EAST	DEG F	364.56	1.53	360.85	368.95
218	WFT13	AIR WORKING FLUID-CONV BNK OUT TEMP EAST	DEG F	842.11	6.62	828.61	860.78
55	WFP22	AIR WORKING FLUID-CONV BANK IN PR WEST	PSIG	40.27	1.38	35.55	42.11
56	WFP23	AIR WORKING FLUID-CONV BANK OUT PR WEST	PSIG.	36.79	1.30	32.62	38.59
222	WFT22	AIR WORKING FLUID-CONV BANK IN TEMP WEST	DEG F	362.38	2.80	356.35	367.15
225	WFT23	AIR WORKING FLUID-CONV BNK OUT TEMP WEST	DEG F	830.03	8.43	809.95	853.17

Test Facility 252

From: 7/31/89 at 0: 0: 0	Statistical Printout Only	Page 1
To : 8/ 1/89 at 0: 0: 0	TEST ARTICLE AND RELATED FACILITY DATA TO AID	Time 0:20: 0
Avg. of 289 Samples	TEST OPERATIONS (TARFD)	Date 8/ 1/89

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
83	FGT01	FLUE GAS SYSTEM-CYCLONE INLET TEMP	DEG F	702.28	10.08	680.22	723.05
84	FGT02	FLUE GAS SYSTEM-CYCLONE OUTLET TEMP	DEG F	689.92	9.18	669.05	707.65
274	FGP01	FLUE GAS SYSTEM-CYCLONE INLET PRESSURE	IN W.G.	-.96	.78	-3.02	1.68
275	FGP02	FLUE GAS SYSTEM-CYCLONE OUTLET PRESSURE	IN W.G.	-3.26	.20	-3.82	-2.53
85	FGT03	FLUE GAS SYSTEM-AIR HEATER OUTLET TEMP	DEG F	396.81	5.00	381.53	410.20
276	FGP03	FLUE GAS SYSTEM-AIR HEATER OUTLET PR	IN W.G.	-5.94	1.23	-7.66	-3.34
69	CAT03	COMB AIR-AIR HEATER OUTLET TEMPERATURE	DEG F	601.52	8.00	583.59	619.09
248	CAP02	COMB AIR-AIR HEATER IN PRESSURE	IN W.G.	1.43	.43	-.20	2.62
249	CAP03	COMB AIR-AIR HEATER OUT PRESSURE	IN W.G.	90.99	1.65	86.74	95.98
68	CAT01	COMB AIR-VENTURI U/S TEMPERATURE	DEG F	177.82	3.74	169.66	185.19
9	CAD01A	AUX COMB AIR-VENTURI DELTA PRESSURE	IN W.C.	4.60	.11	4.30	4.89
50	WFD21	AIR WORKING FLUID-ORIFICE DELTA PR WEST	IN W.G.	69.97	3.89	57.91	74.42
49	WFD11	AIR WORKING FLUID-ORIFICE DELTA PR EAST	IN W.G.	76.28	3.10	64.23	79.80
16	CAP01A	AUX COMB AIR-VENTURI U/S PR	IN W.C.	91.05	2.49	83.61	107.23
310	CFP01	COAL SYSTEM-AIR SUPPLY PRESSURE	PSIG	96.34	.42	94.69	97.59
243	ARP02	ASH RECYCLE SYSTEM-INJECTION PRESSURE	PSIG	62.63	.32	61.30	63.52
313	WFP11	AIR WORKING FLUID-ORIFICE U/S PR EAST	PSIG	271.28	1.03	263.69	273.45
54	WFP21	AIR WORKING FLUID ORIFICE U/S PR WEST	PSIG	270.91	1.07	263.30	273.56
217	WFT12	AIR WORKING FLUID-CONV BANK IN TEMP EAST	DEG F	364.56	1.53	360.85	368.95
222	WFT22	AIR WORKING FLUID-CONV BANK IN TEMP WEST	DEG F	362.38	2.80	356.35	367.15
218	WFT13	AIR WORKING FLUID-CONV BNK OUT TEMP EAST	DEG F	842.11	6.62	828.61	860.78
225	WFT23	AIR WORKING FLUID-CONV BNK OUT TEMP WEST	DEG F	830.03	8.43	809.95	853.17
51	WFP12	AIR WORKING FLUID-CONV BANK IN PR EAST	PSIG,	43.10	1.06	39.26	44.75
55	WFP22	AIR WORKING FLUID-CONV BANK IN PR WEST	PSIG	40.27	1.38	35.55	42.11
79	WFP13	AIR WORKING FLUID CONV BANK OUT PR EAST	PSIG	39.95	1.12	36.26	41.74
56	WFP23	AIR WORKING FLUID-CONV BANK OUT PR WEST	PSIG	36.79	1.30	32.62	38.59
480	CFG02	FLUE GAS O2 CALC FROM A/F RATIO	PERCENT	4.03	.17	3.51	4.54
481	CRO2FG	RATIO OF O2 TO CALC FG O2	RATIO	1.01	.29	.02	5.27
83	FGT01	FLUE GAS SYSTEM-CYCLONE INLET TEMP	DEG F	702.28	10.08	680.22	723.05
84	FGT02	FLUE GAS SYSTEM-CYCLONE OUTLET TEMP	DEG F	689.92	9.18	669.05	707.65
274	FGP01	FLUE GAS SYSTEM-CYCLONE INLET PRESSURE	IN W.G.	-.96	.78	-3.02	1.68
275	FGP02	FLUE GAS SYSTEM-CYCLONE OUTLET PRESSURE	IN W.G.	-3.26	.20	-3.82	-2.53
85	FGT03	FLUE GAS SYSTEM-AIR HEATER OUTLET TEMP	DEG F	396.81	5.00	381.53	410.20
276	FGP03	FLUE GAS SYSTEM-AIR HEATER OUTLET PR	IN W.G.	-5.94	1.23	-7.66	-3.34
69	CAT03	COMB AIR-AIR HEATER OUTLET TEMPERATURE	DEG F	601.52	8.00	583.59	619.09
248	CAP02	COMB AIR-AIR HEATER IN PRESSURE	IN W.G.	1.43	.43	-.20	2.62
249	CAP03	COMB AIR-AIR HEATER OUT PRESSURE	IN W.G.	90.99	1.65	86.74	95.98
68	CAT01	COMB AIR-VENTURI U/S TEMPERATURE	DEG F	177.82	3.74	169.66	185.19
9	CAD01A	AUX COMB AIR-VENTURI DELTA PRESSURE	IN W.C.	4.60	.11	4.30	4.89

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 289 Samples

Test Facility 252
Statistical Printout Only
TEST ARTICLE AND RELATED FACILITY DATA TO AID
TEST OPERATIONS (TARFD)

Page 2
Time 0:20:.0
Date 8/ 1/89

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
50	WFD21	AIR WORKING FLUID-ORIFICE DELTA PR WEST	IN W.G.	69.97	3.89	57.91	74.42
49	WFD11	AIR WORKING FLUID-ORIFICE DELTA PR EAST	IN W.G.	76.28	3.10	64.23	79.80
16	CAP01A	AUX COMB AIR-VENTURI U/S PR	IN W.C.	91.05	2.49	83.61	107.23
310	CFP01	COAL SYSTEM-AIR SUPPLY PRESSURE	PSIG	96.34	.12	94.69	97.59
243	ARP02	ASH RECYCLE SYSTEM-INJECTION PRESSURE	PSIG	62.63	.32	61.30	63.52
313	WFP11	AIR WORKING FLUID-ORIFICE U/S PR EAST	PSIG	271.28	1.03	263.69	273.45
54	WFP21	AIR WORKING FLUID ORIFICE U/S PR WEST	PSIG	270.91	1.07	263.30	273.56
217	WFT12	AIR WORKING FLUID-CONV BANK IN TEMP EAST	DEG F	364.56	1.53	360.85	368.95
222	WFT22	AIR WORKING FLUID-CONV BANK IN TEMP WEST	DEG F	362.38	2.80	356.35	367.15
218	WFT13	AIR WORKING FLUID-CONV BNK OUT TEMP EAST	DEG F	842.11	6.62	828.61	860.78
225	WFT23	AIR WORKING FLUID-CONV BNK OUT TEMP WEST	DEG F	830.03	8.43	809.95	853.17
51	WFP12	AIR WORKING FLUID-CONV BANK IN PR EAST	PSIG	43.10	1.06	39.26	44.75
55	WFP22	AIR WORKING FLUID-CONV BANK IN PR WEST	PSIG	40.27	1.38	35.55	42.11
79	WFP13	AIR WORKING FLUID CONV BANK OUT PR EAST	PSIG	39.95	1.12	36.26	41.74
56	WFP23	AIR WORKING FLUID-CONV BANK OUT PR WEST	PSIG	36.79	1.30	32.62	38.59
480	CFG02	FLUE GAS O2 CALC FROM A/F RATIO	PERCENT	4.03	.17	3.51	4.54
481	CRO2FG	RATIO OF O2 TO CALC FG O2	RATIO	1.01	.29	.02	5.27

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Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

Page 10
Time 0:28:49
Date 8/ 1/89

From 7/31/89 at 0:0[illegible]
To [illegible]

FOR INFORMATION
WILL NOT BE [illegible] AND MAY
BE CHANGED WITHOUT NOTICE

MO/DY/YR	HR:MN:SC MS	[illegible]T01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89	0: 2:14.290	1596.55	826.914	1499.03	809.948	1499.03	5.08969	3.97684	10.3372
7/31/89	0: 7:14.700	1595.36	824.371	1498.15	808.250	1496.39	5.10517	3.85510	10.3379
7/31/89	0:12:14.370	1595.96	827.762	1495.51	809.948	1496.39	5.16340	3.97684	10.5406
7/31/89	0:17:14.610	1595.96	825.219	1494.64	809.948	1495.51	5.16630	4.00727	10.5300
7/31/89	0:22:14.250	1596.85	825.219	1495.51	809.099	1496.39	5.16251	3.88553	10.5338
7/31/89	0:27:14.290	1597.14	823.523	1495.51	809.099	1497.27	5.12362	4.10872	10.4312
7/31/89	0:32:14.250	1595.66	824.371	1494.64	809.099	1495.51	5.15709	3.70292	10.5029
7/31/89	0:37:14.270	1597.14	825.219	1495.51	809.099	1495.51	5.14241	4.04785	10.4953
7/31/89	0:42:14.250	1595.96	822.675	1495.51	808.250	1495.51	5.11961	4.06814	10.4903
7/31/89	0:47:14.640	1595.36	822.675	1497.27	808.250	1497.27	5.11722	4.02756	10.4908
7/31/89	0:52:14.260	1594.77	821.827	1494.64	805.703	1493.76	5.09024	4.09858	10.3827
7/31/89	0:57:14.610	1593.29	824.371	1497.27	806.552	1493.76	5.10348	4.23046	10.4483
7/31/89	1: 2:14.250	1595.07	822.675	1495.51	806.552	1495.51	5.16478	4.09858	10.5529
7/31/89	1: 7:14.400	1595.66	822.675	1497.27	805.703	1493.76	5.14425	4.21017	10.5364
7/31/89	1:12:14.290	1595.96	821.827	1495.51	805.703	1492.88	5.12336	4.30148	10.4664
7/31/89	1:17:14.290	1595.66	820.130	1494.64	805.703	1493.76	5.06856	4.00727	10.3993
7/31/89	1:22:14.290	1595.96	820.130	1494.64	805.703	1495.51	5.09806	4.22032	10.4448
7/31/89	1:27:14.290	1596.25	822.675	1497.27	805.703	1493.76	5.11663	4.57539	10.4821
7/31/89	1:32:14.880	1595.96	820.130	1497.27	804.854	1495.51	5.11444	4.11887	10.4440
7/31/89	1:37:14.290	1596.85	821.827	1495.51	807.401	1497.27	5.11781	4.23046	10.4505
7/31/89	1:42:14.290	1595.66	819.282	1495.51	805.703	1495.51	5.08689	3.98698	10.4059
7/31/89	1:47:14.290	1598.03	819.282	1497.27	807.401	1494.64	5.15282	4.11887	10.5074
7/31/89	1:52:14.620	1597.74	820.979	1497.27	806.552	1494.64	5.10763	3.81452	10.3901
7/31/89	1:57:14.290	1599.52	819.282	1499.03	807.401	1496.39	5.12220	3.97684	10.5032
7/31/89	2: 2:14.290	1597.14	819.282	1497.27	804.854	1497.27	5.10888	3.96669	10.4559
7/31/89	2: 7:14.290	1598.03	820.979	1495.51	805.703	1495.51	5.14005	4.00727	10.4796
7/31/89	2:12:14.290	1595.96	819.282	1497.27	804.854	1495.51	5.09181	3.95655	10.4463
7/31/89	2:17:14.540	1597.44	820.979	1495.51	803.155	1495.51	5.11085	3.92611	10.4524
7/31/89	2:22:14.290	1595.96	819.282	1497.27	805.703	1496.39	5.11410	4.14930	10.4447
7/31/89	2:27:14.290	1596.85	819.282	1495.51	804.854	1497.27	5.08624	4.07829	10.4136
7/31/89	2:32:14.290	1599.52	820.979	1496.39	805.703	1495.51	5.10159	3.85510	10.4396
7/31/89	2:37:14.380	1598.63	820.979	1498.15	805.703	1499.03	5.09492	3.95655	10.3935
7/31/89	2:42:14.650	1596.55	816.737	1497.27	803.155	1496.39	5.06794	3.93626	10.3467
7/31/89	2:47:14.290	1597.14	818.434	1498.15	803.155	1496.39	5.10531	4.00727	10.3985
7/31/89	2:52:14.510	1596.55	818.434	1496.39	804.854	1496.39	5.07613	4.02756	10.3717

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0

Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

Page 11
Time 0:29: 5
Date 8/ 1/89

MO/D	HR:MN:S	CFAV01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCACO1T SEQ# 419 RATIO
7/31/89	2:57:14.480	1598.03	820.979	1496.39	805.703	1496.39	5.10756	3.92611	10.4591
7/31/89	3: 2:14.510	1597.74	820.130	1496.39	805.703	1496.39	5.11703	3.83481	10.4146
7/31/89	3: 7:14.630	1598.33	820.979	1498.15	804.854	1495.51	5.06544	3.91597	10.3662
7/31/89	3:12:14.640	1601.00	818.434	1496.39	805.703	1498.15	5.07089	3.82466	10.3612
7/31/89	3:17:14.530	1599.81	820.130	1499.03	805.703	1499.03	5.12130	3.80437	10.4308
7/31/89	3:22:14.520	1597.74	820.979	1499.03	805.703	1496.39	5.08943	4.08843	10.3729
7/31/89	3:27:14.530	1599.22	820.979	1499.03	805.703	1498.15	5.10830	3.72321	10.4153
7/31/89	3:32:14.520	1600.70	821.827	1499.03	806.552	1497.27	5.14456	3.81452	10.4931
7/31/89	3:37:14.590	1602.19	821.827	1498.15	805.703	1499.03	5.19244	3.86524	10.5706
7/31/89	3:42:14.560	1601.30	821.827	1499.91	805.703	1499.03	5.12198	3.82466	10.3985
7/31/89	3:47:14.550	1603.08	822.675	1500.78	806.552	1499.91	5.15095	3.78408	10.4902
7/31/89	3:52:14.290	1599.81	823.523	1499.03	808.250	1499.91	5.14605	3.81452	10.4730
7/31/89	3:57:14.530	1601.00	822.675	1499.03	806.552	1499.03	5.13913	3.86524	10.4736
7/31/89	4: 2:14.290	1600.11	823.523	1498.15	809.099	1499.03	5.12225	4.05800	10.4398
7/31/89	4: 7:14.290	1599.52	825.219	1499.03	809.099	1498.15	5.18522	3.95655	10.5581
7/31/89	4:12:14.290	1599.81	826.067	1499.91	810.797	1499.91	5.19951	3.68263	10.5306
7/31/89	4:17:14.540	1602.78	827.762	1501.66	810.797	1499.03	5.12328	3.65220	10.3888
7/31/89	4:22:14.290	1601.89	826.914	1500.78	811.646	1501.66	5.11220	4.09858	10.3946
7/31/89	4:27:14 290	1600.70	826.067	1502.54	809.948	1499.91	5.13687	3.91597	10.5000
7/31/89	4:32:14.290	1601.00	827.762	1499.91	810.797	1500.78	5.12921	3.98698	10.4571
7/31/89	4:37:14.290	1599.81	823.523	1499.03	809.099	1499.91	5.20426	3.88553	10.5605
7/31/89	4:42:14.250	1599.81	825.219	1500.78	809.948	1499.91	5.21958	3.98698	10.6253
7/31/89	4:47:14.520	1599.52	824.371	1499.03	809.099	1496.39	5.15729	3.78408	10.4758
7/31/89	4:52:14.650	1598.33	825.219	1499.03	810.797	1500.78	5.09820	3.66234	10.3772
7/31/89	4:57:14.580	1600.41	825.219	1500.78	809.099	1499.03	5.13855	3.96669	10.4713
7/31/89	5: 2:14.640	1601.89	823.523	1499.91	809.948	1499.91	5.12303	3.60147	10.4325
7/31/89	5: 7:14.610	1602.19	825.219	1502.54	809.948	1501.66	5.15178	3.96669	10.4568
7/31/89	5:12:14.390	1602.78	824.371	1501.66	810.797	1502.54	5.11654	3.93626	10.3702
7/31/89	5:17:14.620	1601.30	825.219	1502.54	810.797	1501.66	5.14337	3.81452	10.4723
7/31/89	5:22:14.280	1599.52	824.371	1500.78	808.250	1498.15	5.18037	3.86524	10.5181
7/31/89	5:27:14.500	1598.63	825.219	1499.03	809.948	1499.03	5.16422	4.02756	10.4681
7/31/89	5:32:14.280	1598.63	824.371	1499.91	809.948	1499.03	5.11231	3.95655	10.3960
7/31/89	5:37:14.510	1597.14	823.523	1499.91	809.099	1498.15	5.13570	3.88553	10.4499
7/31/89	5:42:14.280	1597.74	822.675	1498.15	809.099	1496.39	5.10735	4.02756	10.4373
7/31/89	5:47:14.640	1598.33	822.675	1499.03	807.401	1498.15	5.14991	3.92611	10.4822

From [illegible]
To [illegible]
[illegible] MAY
BE CHANGED WITHOUT NOTICE

Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

Page 12
Time 0:29:21
Date 8/ 1/89

MO/DY/YR	HR:MN:SC.MS	CFDT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89	5:52:14.530	1598.63	820.979	1498.15	806.552	1498.15	5.09264	3.57104	10.3527
7/31/89	5:57:14.400	1602.19	822.675	1499.03	807.401	1498.15	5.13066	3.76379	10.4291
7/31/89	6: 2:14.280	1601.00	822.675	1500.78	809.099	1499.03	5.12433	3.83481	10.3785
7/31/89	6: 7:14.630	1601.00	822.675	1500.79	808.250	1499.03	5.09343	3.71307	10.3557
7/31/89	6:12:14.520	1598.92	822.675	1500.78	806.552	1496.39	5.11765	3.95655	10.4089
7/31/89	6:17:14.290	1598.63	821.827	1499.03	805.703	1499.03	5.01835	3.90582	10.2181
7/31/89	6:22:14.290	1599.22	820.979	1499.03	805.703	1496.39	5.15019	3.88553	10.4982
7/31/89	6:27:14.290	1599.22	822.675	1498.15	808.250	1498.15	5.17102	4.08843	10.5002
7/31/89	6:32:14.290	1598.63	824.371	1500.78	809.099	1499.03	5.10728	3.89568	10.3552
7/31/89	6:37:14.290	1599.81	824.371	1499.03	809.099	1499.03	5.14848	3.85510	10.4540
7/31/89	6:42:14.490	1601.89	822.675	1499.03	809.099	1499.91	5.18566	4.08843	10.5900
7/31/89	6:47:14.520	1601.89	823.523	1500.78	809.099	1499.03	5.12126	3.82466	10.3767
7/31/89	6:52:14.290	1601.89	823.523	1499.91	808.250	1499.91	5.17069	3.80437	10.4754
7/31/89	6:57:14.620	1599.52	824.371	1501.66	808.250	1499.03	5.10616	3.74350	10.3208
7/31/99	7: 2:14.550	1600.70	823.523	1499.91	809.099	1499.91	5.17360	3.93626	10.4882
7/31/89	7: 7:14.290	1597.74	824.371	1500.78	809.099	1499.03	5.14636	3.63191	10.4797
7/31/89	7:12:14.290	1598.92	822.675	1498.15	809.948	1498.15	5.15053	4.00727	10.5025
7/31/89	7:17:14.620	1597.74	821.827	1499.91	806.552	1499.03	5.10186	3.97684	10.4012
7/31/89	7:22:14.550	1597.14	822.675	1498.15	809.099	1496.39	5.10208	3.93626	10.3725
7/31/89	7:27:14.290	1599.52	821.827	1496.39	806.552	1496.39	5.13118	3.85510	10.4243
7/31/89	7:32:14.580	1599.22	821.827	1500.78	808.250	1496.39	5.05622	3.91597	10.2677
7/31/89	7:37:14.630	1601.59	822.675	1500.78	809.099	1499.03	5.05269	3.73336	10.2562
7/31/89	7:42:14.620	1603.97	823.523	1500.78	808.250	1499.03	5.11172	3.62176	10.3600
7/31/89	7:47:14.290	1601.89	824.371	1501.66	810.797	1499.03	5.13372	3.45944	10.4591
7/31/89	7:52:14.290	1603.67	824.371	1502.54	810.797	1500.78	5.15159	3.48988	10.5599
7/31/89	7:57:14.290	1604.86	826.067	1502.54	809.948	1501.66	5.14725	3.35799	10.6629
7/31/89	8: 2:14.420	1598.03	825.219	1501.66	809.948	1499.91	5.10819	4.08843	10.5640
7/31/89	8: 7:14.290	1598.03	824.371	1498.15	810.797	1499.03	5.09808	4.07829	10.5486
7/31/89	8:12:14.290	1596.55	820.979	1498.15	806.552	1496.39	5.12312	4.20003	10.6083
7/31/89	8:17:14.490	1594.18	820.979	1496.39	805.703	1495.51	5.08131	4.20003	10.5154
7/31/89	8:22:14.290	1596.55	818.434	1496.39	804.854	1497.27	5.06236	4.00727	10.4614
7/31/89	8:27:14.290	1597.44	818.434	1497.27	803.155	1494.64	5.06742	3.92611	10.3651
7/31/89	8:32:14.290	1596.55	817.586	1496.39	803.155	1497.27	5.09347	3.93626	10.4688
7/31/89	8:37:14.290	1597.14	817.586	1496.39	804.854	1497.27	5.18824	4.21017	10.6916
7/31/89	8:42:14.510	1596.55	818.434	1497.27	803.155	1495.51	5.14172	4.27104,	10.5370

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Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

MO/DY/YR	HR:MN:SC.MS	CFBT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89	8:47:14.290	1596.55	818.434	1496.39	804.854	1495.51	5.12660	4.14930	10.5517
7/31/89	8:52:14.680	1598.63	818.434	1496.39	804.854	1497.27	5.14512	3.91597	10.4644
7/31/89	8:57:14.400	1597.74	820.979	1497.27	805.703	1494.64	5.09592	4.02756	10.3660
7/31/89	9: 2:14.640	1598.33	819.282	1496.39	804.854	1496.39	5.12724	4.07829	10.4233
7/31/89	9: 7:14.640	1598.92	820.130	1496.39	807.401	1495.51	5.08482	4.27104	10.3358
7/31/89	9:12:14.600	1599.52	821.827	1500.78	806.250	1497.27	5.13433	3.88553	10.4315
7/31/89	9:17:14.640	1598.92	820.130	1496.39	805.703	1498.15	5.12097	4.08843	10.5308
7/31/89	9:22:14.630	1599.81	820.130	1499.03	804.854	1496.39	5.07778	4.35220	10.4194
7/31/89	9:27:14.640	1598.03	819.282	1500.78	803.155	1496.39	5.11371	4.10872	10.4898
7/31/89	9:32:14.520	1598.33	820.130	1499.03	804.854	1496.39	5.07722	3.87539	10.4170
7/31/89	9:37:14.650	1597.74	818.434	1496.39	804.004	1496.39	5.03408	3.93626	10.3246
7/31/89	9:42:14.690	1597.14	818.434	1497.27	805.703	1495.51	5.00063	3.75365	10.2581
7/31/89	9:47:14.510	1597.44	818.434	1496.39	803.155	1497.27	5.10479	3.88553	10.4870
7/31/89	9:52:14.640	1601.59	819.282	1500.78	803.155	1498.15	5.06807	3.69278	10.3680
7/31/89	9:57:14.380	1600.11	819.282	1499.91	804.854	1499.03	5.07666	3.83481	10.4283
7/31/89	10: 2:14.600	1600.11	819.282	1499.91	804.854	1499.03	5.09622	3.75365	10.4661
7/31/89	10: 7:14.620	1600.70	816.737	1499.03	803.155	1498.15	4.99289	3.76379	10.2278
7/31/89	10:12:14.600	1600.70	817.586	1500.78	803.155	1500.78	5.08694	3.72321	10.4229
7/31/89	10:17:14.640	1598.33	816.737	1499.03	802.306	1498.15	5.03664	3.83481	10.3100
7/31/89	10:22:14.610	1598.63	817.586	1499.03	802.306	1496.39	5.02847	3.77394	10.2973
7/31/89	10:27:14.520	1598.63	816.737	1496.39	803.155	1497.27	5.02773	3.63191	10.3166
7/31/89	10:32:14.430	1598.33	819.282	1498.15	803.155	1499.03	5.00916	3.59133	10.2547
7/31/89	10:37:14.640	1600.41	816.737	1496.39	804.004	1499.03	5.04433	3.73336	10.3505
7/31/89	10:42:14.290	1598.33	815.040	1499.03	803.155	1496.39	5.03987	3.61162	10.3442
7/31/89	10:47:14.600	1596.55	815.889	1500.78	800.607	1498.15	4.96996	3.54060	10.1711
7/31/89	10:52:14.650	1597.74	815.040	1499.03	798.058	1496.39	4.99020	3.77394	10.3052
7/31/89	10:57:14.520	1596.25	813.343	1495.51	798.907	1496.39	4.99967	3.57104	10.3122
7/31/89	11: 2:14.380	1596.25	915.889	1497.27	798.058	1495.51	5.01720	3.60147	10.3542
7/31/89	11: 7:14.590	1597.14	814.192	1497.27	797.208	1494.64	5.02305	3.69278	10.3694
7/31/89	11:12:14.610	1598.92	815.040	1496.39	798.058	1496.39	5.00512	3.72321	10.3180
7/31/89	11:17:14.640	1598.63	815.889	1499.03	799.757	1496.39	5.09519	3.63191	10.4708
7/31/89	11:22:14.600	1598.63	916.737	1499.03	798.907	1496.39	5.02073	3.90582	10.3702
7/31/89	11:27:14.610	1597.14	817.586	1497.27	798.058	1494.64	5.03729	3.86524	10.4155
7/31/89	11:32:14.560	1597.74	813.343	1497.27	798.058	1494.64	5.00191	4.14930	10.3385
7/31/89	11:37:14.640	1596.85	815.040	1494.64	800.607	1494.64	4.98026	3.93626	10.3043

From: 7/31/89 at 0: 0: 0
To 8/ 1/89 at 0: 0: 0 MAY
BE CHANGED WITHOUT NOTICE

Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

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Time 0:29:53
Date 8/ 1/89

MO/DY/YR HR:MN:SC.MS	CFBT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89 11:42:14.290	1595.07	815.889	1497.27	798.058	1493.76	5.03218	3.90582	10.3794
7/31/89 11:47:14.620	1596.85	815.040	1494.64	797.206	1493.76	5.03854	3.98698	10.3985
7/31/89 11:52:14.510	1595.36	816.737	1494.64	796.358	1495.51	5.03682	3.70292	10.3923
7/31/89 11:57:14.510	1597.44	815.889	1497.27	798.907	1495.51	5.00113	3.64205	10.3017
7/31/89 12: 2:14.610	1598.03	817.586	1498.15	796.358	1495.51	5.00856	3.46959	10.3297
7/31/89 12: 7:14.530	1597.74	815.889	1497.27	796.358	1493.76	5.01435	3.75365	10.3610
7/31/89 12:12:14.600	1596.25	815.040	1494.64	796.358	1493.76	5.00501	3.98698	10.3377
7/31/89 12:17:14.500	1595.96	814.192	1494.64	795.509	1492.00	4.98757	3.81452	10.2953
7/31/89 12:22:14.610	1596.55	814.192	1494.64	793.809	1492.00	5.03271	3.78408	10.3775
7/31/89 12:27:14.620	1596.85	811.646	1492.88	793.809	1493.76	5.02501	3.67249	10.3714
7/31/89 12:32:14.520	1596.25	814.192	1492.88	794.659	1491.12	5.01611	3.81452	10.3645
7/31/89 12:37:14.540	1593.29	812.494	1493.76	794.659	1490.25	4.98059	3.84495	10.2952
7/31/89 12:42:14.480	1595.66	812.494	1494.64	792.109	1492.00	5.00707	3.47973	10.2984
7/31/89 12:47:14.650	1596.85	811.646	1494.64	793.809	1491.12	5.02167	3.83481	10.3859
7/31/89 12:52:14.610	1595.07	810.797	1494.64	792.109	1489.37	5.02579	3.72321	10.4061
7/31/89 12:57:14.520	1594.77	811.646	1492.88	792.109	1490.25	4.99619	3.87539	10.3535
7/31/89 13: 2:14.600	1594.18	812.494	1493.76	791.258	1488.49	4.99416	3.92611	10.3330
7/31/89 13: 7:14.620	1595.66	811.646	1493.76	791.258	1491.12	4.97354	3.83481	10.2835
7/31/89 13:12:14.640	1594.18	811.646	1494.64	792.109	1491.12	5.00049	3.84495	10.3290
7/31/89 13:17:14.640	1596.25	812.494	1494.64	794.659	1492.00	5.03961	3.76379	10.4044
7/31/89 13:22:14.630	1598.33	815.040	1497.27	792.959	1492.88	5.04176	3.62176	10.3943
7/31/89 13:27:14.290	1599.52	813.343	1496.39	795.509	1493.76	5.04643	3.76379	10.3649
7/31/89 13:32:14.640	1599.52	815.889	1497.27	794.659	1493.76	4.98164	3.79423	10.2657
7/31/89 13:37:14.640	1598.03	813.343	1497.27	793.809	1492.88	5.01983	4.04785	10.3844
7/31/89 13:42:14.290	1595.36	814.192	1497.27	792.109	1491.12	4.99565	3.87539	10.3233
7/31/89 13:47:14.290	1593.88	814.192	1492.88	792.109	1491.12	4.96758	3.89568	10.2725
7/31/89 13:52:14.290	1592.40	812.494	1493.76	791.258	1491.12	4.96644	3.84495	10.2896
7/31/89 13:57:14.590	1593.29	812.494	1492.88	793.809	1491.12	5.06369	3.98698	10.4743
7/31/89 14: 2:14.540	1592.40	814.192	1493.76	794.659	1488.49	5.05412	3.75365	10.4359
7/31/89 14: 7:14.630	1595.07	813.343	1493.76	793.809	1489.37	5.04546	3.72321	10.4323
7/31/89 14:12:14.660	1592.99	815.040	1493.76	795.509	1489.37	5.01382	3.85510	10.3330
7/31/89 14:17:14.600	1593.58	815.040	1493.76	795.509	1487.61	5.01444	4.03771	10.3775
7/31/89 14:22:14.640	1592.10	815.040	1491.12	793.809	1488.49	5.03465	4.00727	10.4114
7/31/89 14:27:14.600	1592.99	815.889	1493.76	798.058	1490.25	5.03374	3.78408	10.4003
7/31/89 14:32:14.290	1597.44	816.737	1495.51	803.155	1492.28	5.02659	3.82466	10.3943

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0

Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

Time 0:30: 9
Date 8/ 1/89

MO/DY/YR HR:MN:SC.MS	CFBT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89 14:37:14.530	1601.30	818.434	1497.27	806.552	1497.27	5.03789	3.66234	10.3806
7/31/89 14:42:14.640	1603.97	821.827	1499.91	808.250	1499.03	5.12289	3.57104	10.4884
7/31/89 14:47:14.650	1603.38	824.371	1502.54	812.494	1499.91	5.05787	3.56089	10.3655
7/31/89 14:52:14.290	1603.08	826.067	1501.66	813.343	1501.66	5.05008	3.57104	10.2954
7/31/89 14:57:14.660	1606.13	829.457	1504.30	815.889	1503.42	5.07641	3.48988	10.3456
7/31/89 15: 2:14.510	1604.86	832.000	1505.18	813.343	1503.42	5.02579	3.76379	10.3229
7/31/89 15: 7:14.630	1601.89	832.000	1503.42	809.948	1499.91	5.06016	3.72321	10.3533
7/31/89 15:12:14.670	1600.70	832.000	1503.42	808.250	1499.91	5.04870	3.61162	10.3430
7/31/89 15:17:14.640	1600.41	831.152	1502.54	807.401	1499.03	5.05204	3.59133	10.3606
7/31/89 15:22:14.500	1601.30	827.762	1499.91	804.004	1499.03	4.97480	3.35799	10.1831
7/31/89 15:27:14.480	1598.03	826.067	1499.03	802.306	1495.51	5.05601	3.47973	10.3572
7/31/89 15:32:14.610	1596.84	824.371	1499.03	801.456	1496.39	5.02368	3.63191	10.3403
7/31/89 15:37:14.380	1594.18	822.675	1495.51	798.058	1493.76	5.01964	3.87539	10.3725
7/31/89 15:42:14.640	1591.80	822.675	1494.64	796.358	1491.12	4.98737	3.99713	10.3180
7/31/89 15:47:14.640	1592.10	820.130	1492.88	796.358	1490.25	5.00416	3.91597	10.3415
7/31/89 15:52:14.620	1593.88	817.586	1492.88	793.809	1490.25	4.97532	4.02756	10.3232
7/31/89 15:57:14.290	1592.10	813.343	1492.00	791.258	1488.49	4.97601	3.95655	10.3352
7/31/89 16: 2:14.380	1591.80	811.646	1492.88	790.408	1488.49	4.99483	4.18988	10.3699
7/31/89 16: 7:14.600	1589.73	812.494	1489.37	786.157	1487.61	4.97829	4.44351	10.4047
7/31/89 16:12:14.510	1587.06	811.646	1489.37	789.558	1486.74	4.96744	4.22032	10.3572
7/31/89 16:17:14.390	1587.06	814.192	1489.37	794.659	1486.74	4.98910	4.86960	10.3727
7/31/89 16:22:14.540	1588.84	816.737	1489.37	798.058	1485.86	5.02351	4.34206	10.4689
7/31/89 16:27:14.540	1593.29	818.434	1493.76	805.703	1490.25	5.00226	4.16959	10.3887
7/31/89 16:32:14.290	1595.66	821.827	1492.00	809.099	1492.00	4.98162	4.51452	10.2865
7/31/89 16:37:14.550	1600.11	823.523	1497.27	811.646	1495.51	5.01778	4.29133	10.3799
7/31/89 16:42:14.290	1599.81	826.067	1500.78	815.889	1498.15	5.04335	4.26090	10.4507
7/31/89 16:47:14.290	1596.85	827.762	1498.15	817.586	1496.39	5.01719	4.43336	10.3858
7/31/89 16:52:14.290	1598.92	827.762	1496.39	817.586	1499.03	5.07920	4.11887	10.5140
7/31/89 16:57:14.710	1597.44	829.457	1500.78	818.434	1498.15	5.00497	4.18988	10.3393
7/31/89 17: 2:14.290	1601.59	828.610	1499.91	818.434	1499.03	4.98091	4.04785	10.2832
7/31/89 17: 7:14.620	1602.19	830.305	1501.66	821.827	1500.78	5.03036	4.11887	10.3775
7/31/89 17:12:14.610	1601.00	832.000	1501.66	820.130	1499.91	5.01227	4.22032	10.2968
7/31/89 17:17:14.610	1603.37	831.152	1501.66	820.130	1500.78	5.02066	3.77394	10.3379
7/31/89 17:22:14.640	1603.97	834.542	1502.54	822.675	1501.66	5.05377	4.10872	10.4009
7/31/89 17:27:14.650	1605.45	836.236	1506.06	823.523	1505.18	5.08596	3.74350	10.3997

From 7/31/89 at ... To ... /89 at ... MAY
BE CHANGED WITHOUT NOTICE

Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

Time 0:30:25
Date 8/ 1/89

MO/DY/YR HR:MN:SC.MS	CFBT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89 17:32:14.400	1605.16	841.319	1506.06	827.762	1502.54	5.09863	3.89568	10.4672
7/31/89 17:37:14.590	1601.30	839.625	1506.06	824.371	1500.78	5.03593	4.05800	10.3464
7/31/89 17:42:14.290	1601.30	838.778	1503.42	822.675	1500.78	5.06847	3.93626	10.4104
7/31/89 17:47:14.590	1600.70	837.931	1502.54	817.586	1499.91	5.00774	4.29133	10.2874
7/31/89 17:52:14.700	1601.00	837.931	1500.78	816.737	1501.66	5.06454	3.97684	10.3695
7/31/89 17:57:14.290	1600.70	837.084	1502.54	819.282	1499.91	5.08820	4.03771	10.3905
7/31/89 18: 2:14.290	1602.19	841.319	1502.54	819.282	1499.91	5.11454	4.12901	10.4866
7/31/89 18: 7:14.630	1596.55	837.084	1501.66	821.827	1500.78	5.00163	3.78408	10.2936
7/31/89 18:12:14.530	1599.22	837.084	1501.66	819.282	1499.91	5.03865	3.92611	10.3833
7/31/89 18:17:14.510	1599.52	835.389	1499.91	820.979	1499.91	5.03824	4.17974	10.3666
7/31/89 18:22:14.610	1599.81	835.389	1499.91	817.586	1498.15	5.08285	4.27104	10.4705
7/31/89 18:27:14.530	1598.33	835.389	1499.03	817.586	1498.15	5.04179	4.32177	10.3989
7/31/89 18:32:14.650	1598.03	832.000	1498.15	815.889	1498.15	4.99297	4.53481	10.3665
7/31/89 18:37:14.510	1596.25	831.152	1499.03	812.494	1497.27	5.01036	4.49423	10.3833
7/31/89 18:42:14.540	1595.96	829.457	1496.39	812.494	1497.27	5.00914	4.52467	10.3827
7/31/89 18:47:14.540	1597.44	827.762	1497.27	809.948	1498.15	4.99660	4.62612	10.3077
7/31/89 18:52:14.510	1598.33	826.067	1496.39	809.099	1497.27	5.05912	4.46380	10.3922
7/31/89 18:57:14.610	1599.81	826.067	1499.03	809.099	1498.15	5.06725	4.22032	10.3862
7/31/89 19: 2:14.630	1599.22	825.219	1499.03	809.948	1499.03	5.04006	4.49423	10.3654
7/31/89 19: 7:14.620	1598.92	825.219	1499.03	809.099	1499.03	5.03250	4.27104	10.3788
7/31/89 19:12:14.640	1597.74	826.067	1499.03	809.099	1496.39	4.98631	4.55510	10.2710
7/31/89 19:17:14.580	1600.11	825.219	1499.03	809.948	1499.91	4.97902	4.26090	10.2313
7/31/89 19:22:14.380	1598.33	826.067	1499.91	810.797	1500.78	4.98326	4.39278	10.2547
7/31/89 19:27:14.610	1599.81	827.762	1499.91	808.250	1499.91	4.96172	4.22032	10.1960
7/31/89 19:32:14.530	1602.48	827.762	1499.91	809.099	1499.03	5.02944	4.28119	10.3274
7/31/89 19:37:14.290	1602.78	827.762	1501.66	811.646	1501.66	5.03797	4.39278	10.3373
7/31/89 19:42:14.680	1599.52	827.762	1499.91	810.797	1499.91	5.04631	4.32177	10.3824
7/31/89 19:47:14.620	1598.63	828.610	1499.91	812.494	1502.54	5.03412	4.69713	10.3993
7/31/89 19:52:14.560	1598.33	828.610	1498.15	812.494	1500.78	5.05244	4.58554	10.3130
7/31/89 19:57:14.630	1600.70	828.610	1499.03	813.343	1500.78	5.03790	4.58554	10.2609
7/31/89 20: 2:14.670	1600.70	828.610	1500.78	813.343	1500.78	5.06426	4.43336	10.3380
7/31/89 20: 7:14.680	1601.00	829.457	1500.78	817.586	1502.54	5.06296	4.25075	10.2885
7/31/89 20:12:14.650	1602.48	831.152	1500.78	815.889	1500.78	5.07837	4.41307	10.3510
7/31/89 20:17:14.710	1599.22	831.152	1500.78	816.737	1499.91	5.12951	4.33191	10.4689
7/31/89 20:22:14.360	1598.63	830.305	1501.66	815.889	1500.78	5.06161	4.39278	10.3445

From: 7/31/89 at [illegible]
To: 8/ 1/89 at 0: 0: 0

Test Facility 252
Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

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Time 0:30:45
Date 8/ 1/89

MO/DY/YR HR:MN:SC.MS	CFBT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCACO1T SEQ# 419 RATIO
7/31/89 20:27:14.280	1599.22	831.152	1500.78	815.040	1502.54	5.03187	4.56525	10.2536
7/31/89 20:32:14.300	1598.63	830.305	1499.91	813.343	1499.03	5.04935	4.20119	10.2179
7/31/89 20:37:14.520	1599.22	831.152	1499.91	815.889	1500.78	5.06668	4.29133	10.2597
7/31/89 20:42:14.420	1599.22	832.847	1501.66	815.889	1499.91	5.06988	4.34206	10.2673
7/31/89 20:47:14.290	1602.19	831.152	1502.54	817.586	1502.54	5.07242	4.16959	10.2749
7/31/89 20:52:14.610	1603.67	832.847	1502.54	818.434	1503.42	5.11095	3.74350	10.2619
7/31/89 20:57:14.620	1602.70	834.542	1502.54	820.979	1505.18	5.10205	4.11887	10.2417
7/31/89 21: 2:14.430	1601.89	834.542	1501.66	820.130	1501.66	5.07721	4.09858	10.1942
7/31/89 21: 7:14.540	1600.70	836.236	1503.42	816.737	1502.54	5.02290	4.31162	10.0709
7/31/89 21:12:14.550	1599.22	835.389	1499.91	815.889	1499.03	5.07744	4.02756	10.2131
7/31/89 21:17:14.290	1601.30	832.847	1501.66	812.494	1501.66	5.05713	4.25075	10.2048
7/31/89 21:22:14.520	1601.00	830.305	1501.66	808.250	1499.91	5.02879	4.33191	10.1337
7/31/89 21:27:14.500	1599.22	828.610	1500.78	804.854	1499.03	5.01740	4.31162	10.1393
7/31/89 21:32:14.630	1598.33	824.371	1499.03	801.456	1496.39	5.01522	4.33191	10.1198
7/31/89 21:37:14.640	1596.85	820.979	1499.03	798.907	1499.03	5.04428	4.32177	10.2253
7/31/89 21:42:14.550	1599.52	819.282	1499.03	796.358	1495.51	5.05048	4.62612	10.2188
7/31/89 21:47:14.520	1598.63	822.675	1499.03	798.058	1499.03	5.10817	4.40293	10.3528
7/31/89 21:52:14.610	1598.03	822.675	1498.15	798.058	1497.27	5.06308	4.41307	10.2617
7/31/89 21:57:14.520	1599.52	823.523	1499.03	799.757	1497.27	5.04828	4.46380	10.1964
7/31/89 22: 2:14.290	1599.52	826.067	1500.78	801.456	1498.15	5.09136	4.44351	10.3094
7/31/89 22: 7:14.290	1599.81	824.371	1499.03	798.907	1496.39	5.07384	4.45365	10.2889
7/31/89 22:12:14.290	1596.55	822.675	1499.03	799.757	1497.27	5.05824	4.35220	10.2627
7/31/89 22:17:14.290	1597.74	824.371	1498.15	798.907	1496.39	5.08066	4.56525	10.3309
7/31/89 22:22:14.550	1598.63	822.675	1496.39	798.058	1496.39	5.05273	4.60583	10.2600
7/31/89 22:27:14.610	1598.63	821.827	1499.03	798.058	1497.27	5.05755	4.49423	10.2596
7/31/89 22:32:14.400	1599.22	822.675	1498.15	798.058	1496.39	5.09300	4.23046	10.3028
7/31/89 22:37:14.610	1598.92	822.675	1500.78	798.058	1496.39	5.06069	.060866	10.2410
7/31/89 22:42:14.560	1597.14	822.675	1498.15	798.058	1495.51	5.06951	20.7465	10.3199
7/31/89 22:47:14.530	1599.22	821.827	1498.15	796.358	1496.39	5.06414	.11159	10.2959
7/31/89 22:52:14.620	1599.22	821.827	1497.27	796.358	1496.39	5.08532	9.92180	10.3379
7/31/89 22:57:14.510	1597.44	820.979	1498.15	795.509	1495.51	5.06235	4.13916	10.2589
7/31/89 23: 2:14.290	1598.63	820.979	1499.03	797.208	1496.39	5.03477	4.00727	10.2020
7/31/89 23: 7:14.640	1598.03	821.827	1499.03	796.358	1497.27	5.06239	4.14930	10.3089
7/31/89 23:12:14.640	1598.33	821.827	1497.27	796.358	1496.39	5.06423	4.48409	10.2329
7/31/89 23:17:14.620	1598.92	821.827	1500.78	796.358	1499.03	5.05636	4.33191	10.2069

Test Facility 252

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0

Parameter Printout
KEY PARAMETER LIST WAT (PAGE 19)

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Time 0:31: 3
Date 8/ 1/89

MO/DY/YR HR:MN:SC.MS	CFBT01 SEQ# 405 DEG F	WFT14 SEQ# 219 DEG F	WFT15 SEQ# 220 DEG F	WFT24 SEQ# 226 DEG F	WFT25 SEQ# 227 DEG F	CFBV01 SEQ# 407 FT/SEC	O2B SEQ# 13 PERCENT	CCAC01T SEQ# 419 RATIO
7/31/89 23:22:14.470	1598.92	824.371	1499.03	797.208	1495.51	5.00302	4.44351	10.1008
7/31/89 23:27:14.490	1597.14	824.371	1496.39	797.208	1495.51	5.00828	4.11837	10.1760
7/31/89 23:32:14.290	1597.74	821.827	1500.78	794.659	1494.64	4.97761	4.53481	10.0851
7/31/89 23:32:35.160	1598.63	820.130	1498.15	797.208	1497.27	5.00548	4.25075	10.1635
7/31/89 23:37:35.130	1598.63	820.979	1497.27	797.208	1495.51	5.05361	4.39278	10.2800
7/31/89 23:42:35.130	1595.66	820.979	1496.39	794.659	1497.27	5.01507	4.45365	10.1732
7/31/89 23:47:35.130	1596.25	823.523	1495.51	797.208	1493.76	5.00946	4.34206	10.1855
7/31/89 23:52:35.130	1596.25	826.067	1497.27	795.509	1493.76	5.01359	4.33264	10.1809
7/31/89 23:57:35.130	1597.44	826.067	1497.27	796.358	1494.64	5.08546	4.22032	10.3435

A F B C Test Facility
Test Article And Related Facility Data
252-TP-0001, TEST A-10

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
66	ART02	ASH RECYCLE SYSTEM-INJECTION TEMPERATURE	DEG F	274.58	24.90	209.47	348.24
470	C-O2+CO2	OXYGEN PLUS CARBON DIOXIDE	PERCENT	17.16	1.53	.02	20.68
250	CAP04	COMB AIR-WINDBOX PRESSURE	IN W.G.	87.64	1.23	84.40	90.80
415	CARC01	ASH RECYCLE / COAL RATIO	RATIO	1.47	.90	0.00	9.02
427	CARF03	ASH RECYCLE FLOW	LBS/HR	1742.55	1070.35	0.00	10856.01
434	CARF02	ASH RECYCLE CONVEYING AIR FLOW	LBS/HR	866.06	3.93	851.19	876.03
71	CAT06	COMB AIR-WINDBOX TEMPERATURE	DEG F	569.73	7.95	551.40	586.19
466	CBBPF	BED BURNER PURGE AIR FLOW	LBS/HR	209.48	3.25	187.49	213.33
413	CCAC01	IN-BED COMB AIR TO COAL RATIO	RATIO	10.15	.10	9.86	10.47
419	CCAC01T	TOTAL COMBUSTION AIR/COAL RATIO	RATIO	10.37	.10	10.07	10.69
409	CCAF01T	TOTAL COMBUSTION AIR FLOW	LBS/HR	12289.29	135.91	11949.90	12642.78
410	CCAF01	COMBUSTION AIR FLOW	LBS/HR	8854.54	125.98	8534.59	9198.17
465	CCAS	CALCIUM-TO SULFUR MOLAR RATIO	RATIO	2.59	.11	2.37	2.80
411	CCFF52T	TOTAL COAL FLOW	LBS/HR	1184.57	9.95	1163.10	1203.35
428	CCFF01T	TOTAL COAL CONVEYING AIR FLOW	LBS/HR	2098.43	16.44	2044.47	2126.65
429	CCFF12	COAL CONVEYING AIR FLOW #1	LBS/HR	524.61	4.11	511.12	531.66
441	CCOMBEFF	HEAT BALANCE COMBUSTION EFFICIENCY	PERCENT	84.65	1.50	80.59	90.97
406	CFBH01	FLUIDIZED BED HEIGHT	INCHES	100.01	13.60	73.06	141.15
405	CFBT01	AVERAGE BED TEMPERATURE	DEG F	1598.36	0.00	1587.06	1608.13
407	CFBV01	SUPERFICIAL VELOCITY	FT/SEC	5.07	.06	4.96	5.22
412	CFGF01	TOTAL FLUE GAS FLOW	LBS/HR	13355.39	140.95	13006.05	13713.67
1	CFW12	#1 COAL SYSTEM COAL FEEDRATE	LBS/HR	295.57	2.44	290.72	303.49
2	CFW22	#2 COAL SYSTEM COAL FEEDRATE	LBS/HR	295.40	2.40	289.76	300.40
3	CFW32	#3 COAL SYSTEM COAL FEEDRATE	LBS/HR	296.91	2.46	291.72	301.57
4	CFW42	#4 COAL SYSTEM COAL FEEDRATE	LBS/HR	296.69	2.52	290.56	301.47
414	CLSC01	LIMESTONE / COAL RATIO	RATIO	.28	.01	.26	.30
433	CLSF02	LIMESTONE&WINDOW&MISC PURGE FLOW	LBS/HR	260.78	1.38	258.77	265.85
469	CNOX	NOX-CORRECTED TO 3% OXYGEN	PPM	226.88	33.95	.11	451.71
7	CO	FLUE GAS CO CONCENTRATION	PPM	67.35	32.75	.66	552.30
8	CO2	FLUE GAS CO2 CONCENTRATION	PERCENT	13.10	1.59	-.07	13.94
408	CO2B	EXCESS AIR	PERCENT	35.67	230.38	.23	3931.26
10	COMB	FLUE GAS COMB CONCENTRATION	PERCENT	.12	.03	.00	.33
450	CQAR	ASH RECYCLE HEAT LOSS	BTU/SEC	50.44	32.45	0.00	321.06
451	CQCWAD	COMBUSTION AIR WINDBOX DUCT HEAT LOSS	BTU/SEC	19.36	1.02	16.95	22.14
462	CQFLXE	WORKING FLUID BED BANK EAST HEAT FLUX	B/FT2-SC	2.09	.05	1.96	2.16
463	CQFLXW	WORKING FLUID BED BANK WEST HEAT FLUX	B/FT2-SC	2.05	.07	1.84	2.13
444	CQIN	SYSTEM HEAT INPUT	BTU/SEC	3484.89	30.69	3421.38	3544.07

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
448	CQSTACK	STACK EXHAUST HEAT LOSS	BTU/SEC	266.69	5.49	249.77	279.83
445	CQWFE	WORKING FLUID EAST HEAT REMOVAL	BTU/SEC	1246.08	23.79	1169.49	1278.61
446	CQWFW	WORKING FLUID WEST HEAT REMOVAL	BTU/SEC	1187.40	32.25	1082.94	1227.53
460	CQWFBEE	WORKING FLUID BED BANK EAST HEAT REMOVAL	BTU/SEC	765.79	18.01	716.22	792.05
461	CQWFBBW	WORKING FLUID BED BANK WEST HEAT REMOVAL	BTU/SEC	748.51	24.74	672.96	781.16
464	CSC	SULFUR CAPTURE	PERCENT	93.48	1.57	88.95	99.75
468	CSO2	SO2-CORRECTED TO 3% OXYGEN	PPM	200.66	60.88	12.54	834.55
416	CWFF01	TOTAL WORKING FLUID FLOW	LBS/HR	30978.04	610.13	29325.75	31562.06
417	CWFF11	AIR WORKING FLUID FLOW EAST	LBS/HR	15840.41	308.70	14911.18	16212.25
418	CWFF21	AIR WORKING FLUID FLOW WEST	LBS/HR	15137.63	418.90	13820.24	15611.76
442	CSYSEFF	OVERALL BED BNK HEAT EXCH EFFICIENCY	PERCENT	69.83	1.36	66.72	72.48
261	FBP01	FLUID BED-BED PRESSURE (5.7")	IN W.G.	77.35	2.06	71.51	83.34
262	FBP02	FLUID BED-BED PRESSURE (17.1")	IN W.G.	66.04	3.28	55.46	74.38
263	FBP03	FLUID BED-BED PRESSURE (29.7")	IN W.G.	55.80	3.91	45.74	66.59
264	FBP04	FLUID BED-BED PRESSURE (41.7")	IN W.G.	45.59	4.45	28.48	56.75
265	FBP05	FLUID BED-BED PRESSURE (53.7")	IN W.G.	36.90	5.69	21.76	51.84
266	FBP06	FLUID BED-BED PRESSURE (65.9")	IN W.G.	25.64	5.78	9.93	41.43
267	FBP07	FLUID BED-BED PRESSURE (77.9")	IN W.G.	15.28	3.61	6.91	26.71
268	FBP08	FLUID BED-BED PRESSURE (90.1")	IN W.G.	2.26	1.96	-1.35	12.21
269	FBP09	FLUID BED-BED PRESSURE (102".1)	IN W.G.	-.05	.71	-2.26	2.13
270	FBP12	FLUID BED-FREEBOARD PRESSURE (230.3")	IN W.G.	-.58	.14	-1.07	-.26
73	FBT01	FLUID BED-BED TEMPERATURE (5.7")	DEG F	1575.28	5.15	1558.98	1584.69
74	FBT02	FLUID BED-BED TEMPERATURE (27.7")	DEG F	1601.67	4.27	1590.91	1611.40
75	FBT03	FLUID BED-BED TEMPERATURE (51.7")	DEG F	1596.63	0.00	1583.81	1606.94
76	FBT04	FLUID BED-BED TEMPERATURE (75.4")	DEG F	1596.77	1.67	1584.69	1606.05
77	FBT05	FLUID BED-LOWER FREEBOARD TEMP (103.1")	DEG F	1544.35	4.67	1527.18	1558.09
78	FBT06	FLUID BED-UPPER FREEBOARD TEMP (229.3")	DEG F	1468.62	8.11	1448.41	1493.76
83	FGT01	FLUE GAS SYSTEM-CYCLONE INLET TEMP	DEG F	702.32	10.07	680.22	723.05
90	LST01	LIMESTONE & BED MATERIAL LINE TEMP	DEG F	91.41	4.97	82.71	105.62
5	LSW02	LIMESTONE FEEDRATE	LBS/HR	333.65	12.23	309.00	364.67
97	MPT05	MATERIAL PROBE-BBTEA COOLANT OUTLET TEMP	DEG F	788.20	3.78	777.65	796.36
190	MPT06A	MATERIAL PROBE-BBTEA SPECIMEN TEMP (2")	DEG F	867.98	28.24	828.61	930.87
98	MPT06B	MATERIAL PROBE-SPECIMEN BBTEA TEMP (13")	DEG F	918.31	103.64	809.95	1168.31
99	MPT06C	MATERIAL PROBE-SPECIMEN BBTEA TEMP (24")	DEG F	1263.59	50.93	1155.57	1379.81
100	MPT06D	MATERIAL PROBE-SPECIMEN BBTEA TEMP (34")	DEG F	889.15	20.02	819.28	935.94
102	MPT15	MATERIAL PROBE-BBTEE COOLANT OUTLET TEMP	DEG F	789.54	1.84	785.31	793.81
103	MPT16A	MATERIAL PROBE-BBTEE SPECIMEN TEMP (2")	DEG F	1530.91	2.27	1520.13	1540.41

A F B C Test Facility

Test Article And Related Facility Data

252-TP-0001, TEST A-10

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

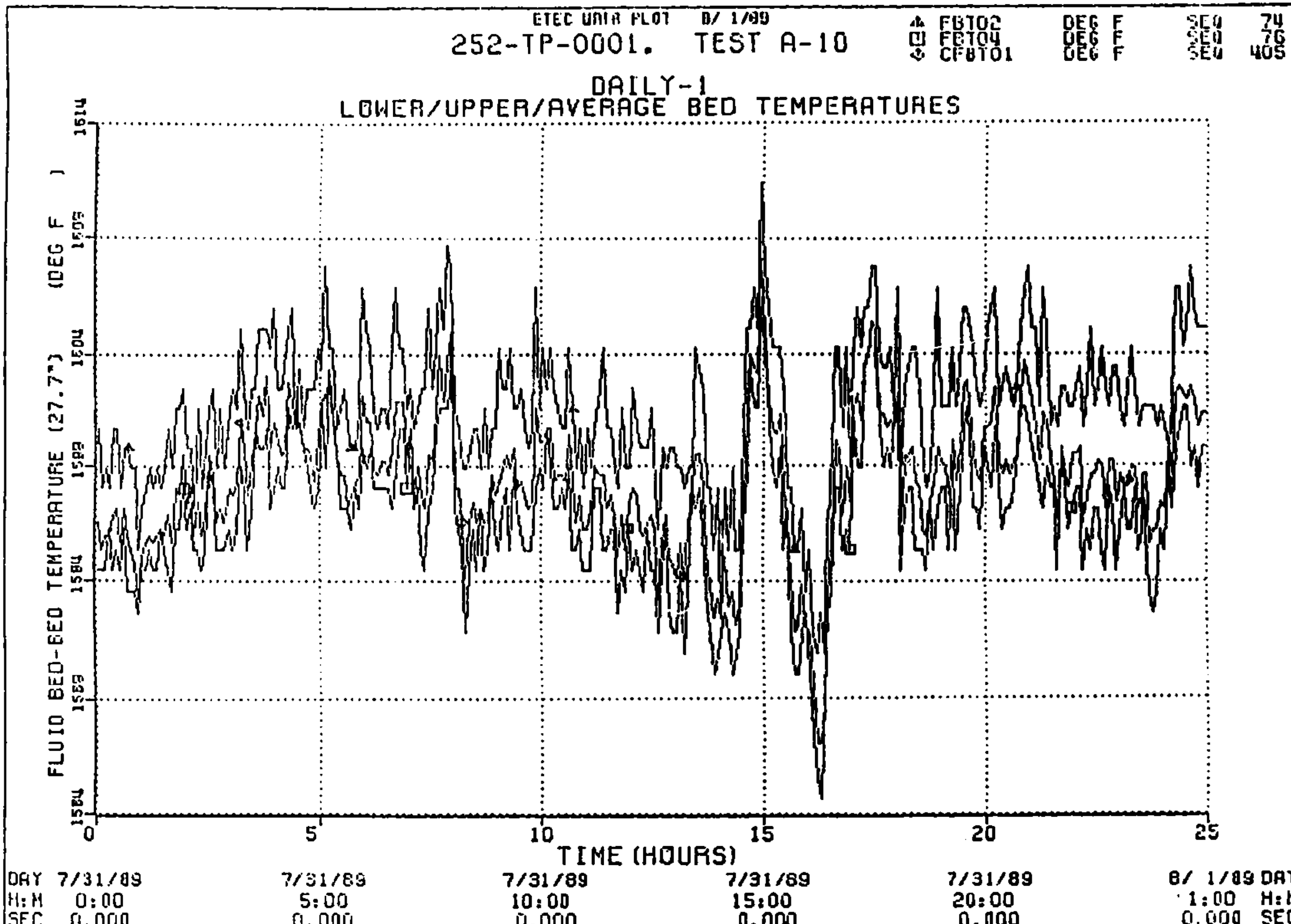
Time 0: 8:36
Date 8/ 1/89

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Max.mum
104	MPT16B	MATERIAL PROBE-BBTEE SPECIMEN TEMP (13")	DEG F	1479.52	1.67	1466.59	1489.37
105	MPT16C	MATERIAL PROBE-BBTEE SPECIMEN TEMP (24")	DEG F	1412.78	3.83	1400.49	1423.03
106	MPT16D	MATERIAL PROBE-BBTEE SPECIMEN TEMP (34")	DEG F	1232.47	3.24	1218.57	1242.53
108	MPT25	MATERIAL PROBE-BBTWA COOLANT OUTLET TEMP	DEG F	640.24	6.79	626.86	651.85
109	MPT26A	MATERIAL PROBE-BBTWA SPECIMEN TEMP (2")	DEG F	1075.33	28.72	1028.90	1210.04
110	MPT26B	MATERIAL PROBE-BBTWA SPECIMEN TEMP (13")	DEG F	612.14	29.43	543.55	660.46
113	MPT26C	MATERIAL PROBE-BBTWA SPECIMEN TEMP (24")	DEG F	948.29	32.85	707.96	978.25
114	MPT26D	MATERIAL PROBE-BBTWA SPECIMEN TEMP (34")	DEG F	726.43	34.30	644.10	839.62
122	MPT45	MATERIAL PROBE-BMLED COOLANT OUTLET TEMP	DEG F	741.75	2.23	734.16	747.82
123	MPT46A	MATERIAL PROBE-BMLED SPECIMEN TEMP (2")	DEG F	9999.00	0.00	9999.00	9999.00
124	MPT46B	MATERIAL PROBE-BMLED SPECIMEN TEMP (13")	DEG F	1129.38	9.61	1109.87	1155.57
125	MPT46C	MATERIAL PROBE-BMLED SPECIMEN TEMP (24")	DEG F	925.85	67.65	772.54	1048.29
129	MPT46D	MATERIAL PROBE-BMLED SPECIMEN TEMP (34")	DEG F	9759.23	1421.67	992.60	9999.00
137	MPT65	MATERIAL PROBE-BMLWC COOLANT OUTLET TEMP	DEG F	763.17	2.60	754.65	769.99
138	MPT66A	MATERIAL PROBE-BMLWC SPECIMEN TEMP (2")	DEG F	1005.90	51.90	886.14	1138.63
139	MPT66B	MATERIAL PROBE-BMLWC SPECIMEN TEMP (13")	DEG F	614.13	242.41	202.52	1062.63
140	MPT66C	MATERIAL PROBE-BMLWC SPECIMEN TEMP (24")	DEG F	7252.68	3890.74	1606.94	9999.00
141	MPT66D	MATERIAL PROBE-BMLWC SPECIMEN TEMP (34")	DEG F	1064.89	33.93	1020.46	1197.23
151	MPT85	MATERIAL PROBE-BMUWD COOLANT OUTLET TEMP	DEG F	677.09	7.97	659.60	691.37
152	MPT86A	MATERIAL PROBE-BMUWD SPECIMEN TEMP (2")	DEG F	-7935.41	4117.80	-9999.00	473.30
153	MPT86B	MATERIAL PROBE-BMUWD SPECIMEN TEMP (13")	DEG F	1223.60	17.91	1188.71	1254.50
154	MPT86C	MATERIAL PROBE-BMUWD SPECIMEN TEMP (24")	DEG F	4325.40	4292.54	430.72	9999.00
155	MPT86D	MATERIAL PROBE-BMUWD SPECIMEN TEMP (34")	DEG F	-133.36	42.66	-224.89	-53.16
164	MPTA5	MATERIAL PROBE-BTPSA COOLANT OUTLET TEMP	DEG F	772.72	3.39	762.32	781.90
165	MPTA6A	MATERIAL PROBE-BTPSA SPECIMEN TEMP (2")	DEG F	9571.20	1828.19	1685.84	9999.00
166	MPTA6B	MATERIAL PTOBE-BTPSA SPECIMEN TEMP (13")	DEG F	1432.15	7.66	1407.42	1450.19
167	MPTA6C	MATERIAL PROBE-BTPSA SPECIMEN TEMP (24")	DEG F	1026.93	27.37	963.91	1079.50
168	MPTA6D	MATERIAL PROBE-BTPSA SPECIMEN TEMP (34")	DEG F	-496.15	3070.19	-9999.00	987.54
181	MPTD5	MATERIAL PROBE-CBTWA COOLANT OUTLET TEMP	DEG F	579.99	6.04	566.21	591.39
182	MPTD6A	MATERIAL PROBE-CBTWA SPECIMEN TEMP (2")	DEG F	1290.73	6.84	1275.92	.312.81
183	MPTD6B	MATERIAL PROBE-CBTWA SPECIMEN TEMP (13")	DEG F	1215.01	7.72	1197.23	1235.67
184	MPTD6C	MATERIAL PROBE-CBTWA SPECIMEN TEMP (24")	DEG F	9999.00	0.00	9999.00	9999.00
185	MPTD6D	MATERIAL PROBE-CBTWA SPECIMEN TEMP (34")	DEG F	-9999.00	0.00	-9999.00	-9999.00
169	MPTE6A	MATERIAL PROBE-BBTWD SPECIMN TEMP (WALL)	DEG F	6605.52	4334.31	248.90	9999.00
170	MPTE6B	MATERIAL PROBE-BBTWD SPECINEN TEMP (TIP)	DEG F	1258.72	4.54	1248.52	1264.78
171	MPTF6A	MATERIAL PROBE-BMLWA SPECIMN TEMP (WALL)	DEG F	1653.06	101.83	1339.41	1861.41
172	MPTF6B	MATERIAL PROBE-BMLWA SPECIMEN TEMP (TIP)	DEG F	1566.84	4.32	1555.44	1574.93

From: 7/31/89 at 0: 0: 0
To : 8/ 1/89 at 0: 0: 0
Avg. of 288 Samples

Time 0: 8:48
Date 8/ 1/89

SEQ#	Tag No.	Description	Units	Mean	Std. Dev	Minimum	Maximum
173	MPTG6A	MATERIAL PROBE-BTPNC SPECIMN TEMP (WALL)	DEG F	1295.53	146.27	932.56	1535.12
174	MPTG6B	MATERIAL PROBE-BTPNC SPECIMN TEMP (TIP)	DEG F	1567.06	4.63	1556.32	1574.04
11	NOX	FLUE GAS NOX CONCENTRATION	PPM	214.26	34.45	.10	524.60
12	02A	FLUE GAS OXYGEN CONCENTRATION	PERCENT	3.43	1.11	-.56	19.75
13	02B	FLUE GAS 02 CONCENTRATION (GROSS)	PERCENT	4.06	1.13	.06	20.75
14	SO2	FLUE GAS SO2 CONCENTRATION	PPM	186.44	45.48	7.16	317.67
52	WFP14	AIR WORKING FLUID-BED BANK IN PR EAST	PSIG	37.91	.93	35.06	39.07
53	WFP15	AIR WORKING FLUID-BED BANK OUT PR EAST	PSIG	9.96	.45	8.53	10.53
57	WFP24	AIR WORKING FLUID-BED BANK IN PR WEST	PSIG	37.58	1.27	33.66	38.92
58	WFP25	AIR WORKING FLUID-BED BANK OUT PR WEST	PSIG	9.29	.53	7.65	9.94
219	WFT14	AIR WORKING FLUID-BED BANK IN TEMP EAST	DEG F	822.67	6.24	810.80	841.32
220	WFT15	AIR WORKING FLUID-BED BANK OUT TEMP EAST	DEG F	1498.25	2.44	1489.37	1506.06
226	WFT24	AIR WORKING FLUID-BED BANK IN TEMP WEST	DEG F	805.56	7.79	786.16	827.76
227	WFT25	AIR WORKING FLUID-BED BANK OUT TEMP WEST	DEG F	1496.94	3.93	1485.86	1505.18
228	WFT26	AIR WORKING FLUID-OUTLET TUBE #2	DEG F	1454.49	3.51	1444.03	1463.96
229	WFT27	AIR WORKING FLUID-OUTLET TUBE #4	DEG F	1477.11	3.02	1463.09	1484.98
230	WFT28	AIR WORKING FLUID-OUTLET TUBE #6	DEG F	1467.85	5.34	1455.49	1477.09
231	WFT29	AIR WORKING FLUID-OUTLET TUBE #8	DEG F	1469.47	5.34	1457.23	1477.97
232	WFT30	AIR WORKING FLUID-OUTLET TUBE #10	DEG F	1436.53	10.80	1403.95	1449.27
233	WFT31	AIR WORKING FLUID-OUTLET TUBE #12	DEG F	1467.49	5.77	1455.49	1477.09
234	WFT32	AIR WORKING FLUID-OUTLET TUBE #14	DEG F	1466.61	9.77	1436.12	1479.72
235	WFT33	AIR WORKING FLUID-OUTLET TUBE #16	DEG F	1496.53	4.08	1479.72	1503.42
236	WFT34	AIR WORKING FLUID-OUTLET TUBE #18	DEG F	1491.53	4.03	1480.60	1503.42
237	WFT35	AIR WORKING FLUID-OUTLET TUBE #20	DEG F	1461.74	12.35	1429.99	1477.97
212	WFT36	AIR WORKING FLUID-OUTLET TUBE #22	DEG F	1508.67	3.78	1499.03	1516.61
213	WFT37	AIR WORKING FLUID-OUTLET TUBE #24	DEG F	1465.56	6.30	1451.05	1481.48
15	UK-FLUE	EVENT CHANNEL -SOOT BLOW-FLUE GAS CAL	MILVOLTS	67.73	220.34	10.00	1750.00
480	CFG02	FLUE GAS 02 CALC FROM A/F RATIO	PERCENT	4.03	.17	3.51	4.54
481	CR02FG	RATIO OF 02 TO CALC FG 02	RATIO	1.01	.29	.02	5.27
483	CINBD02	IN BED 02 CALC FROM A/F RATIO	PERCENT	3.66	.18	3.12	4.19
484	CR02INBD	RATIO OF 02 TO CALC IN BED C2	RATIO	1.11	.33	.02	5.81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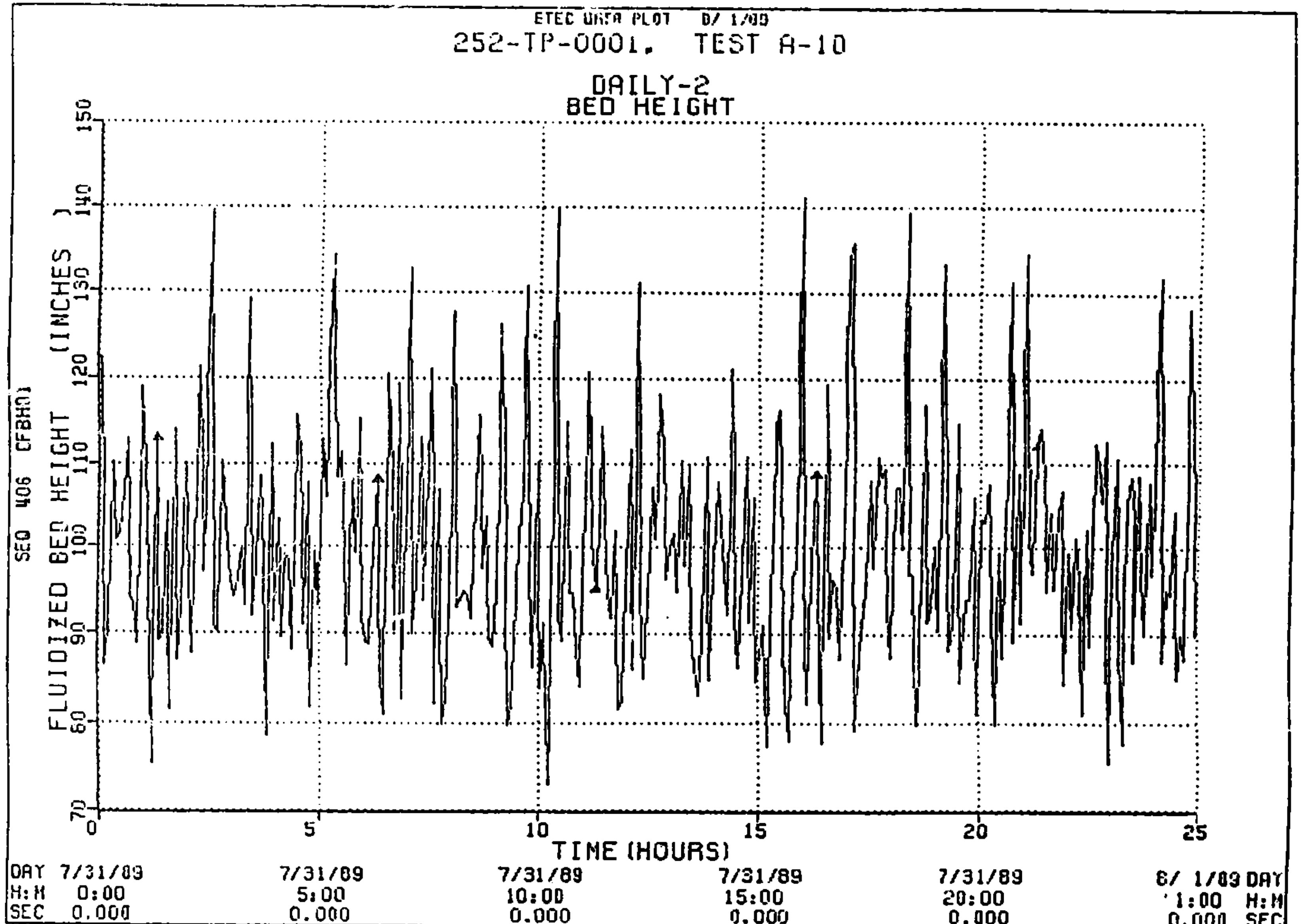
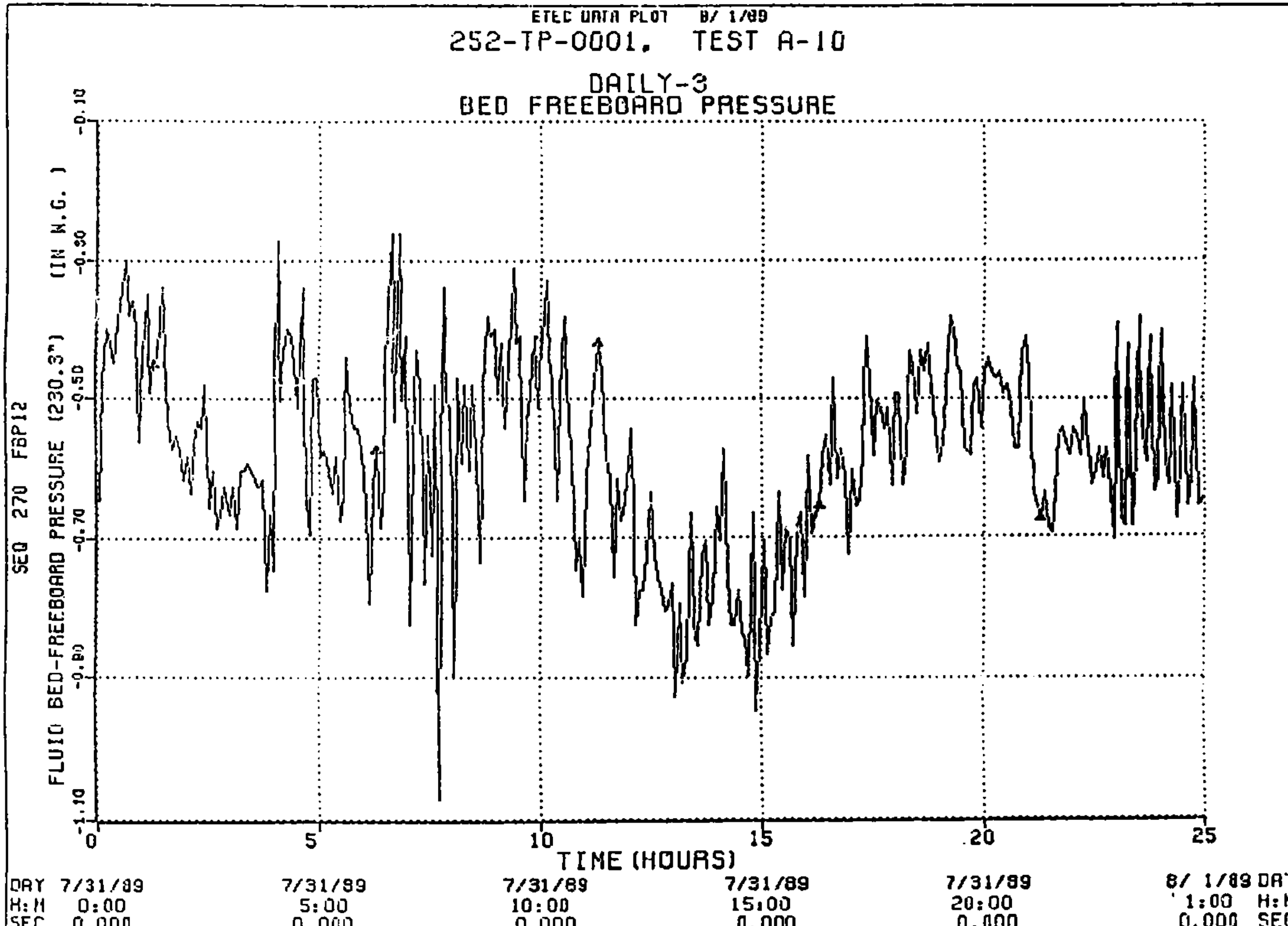
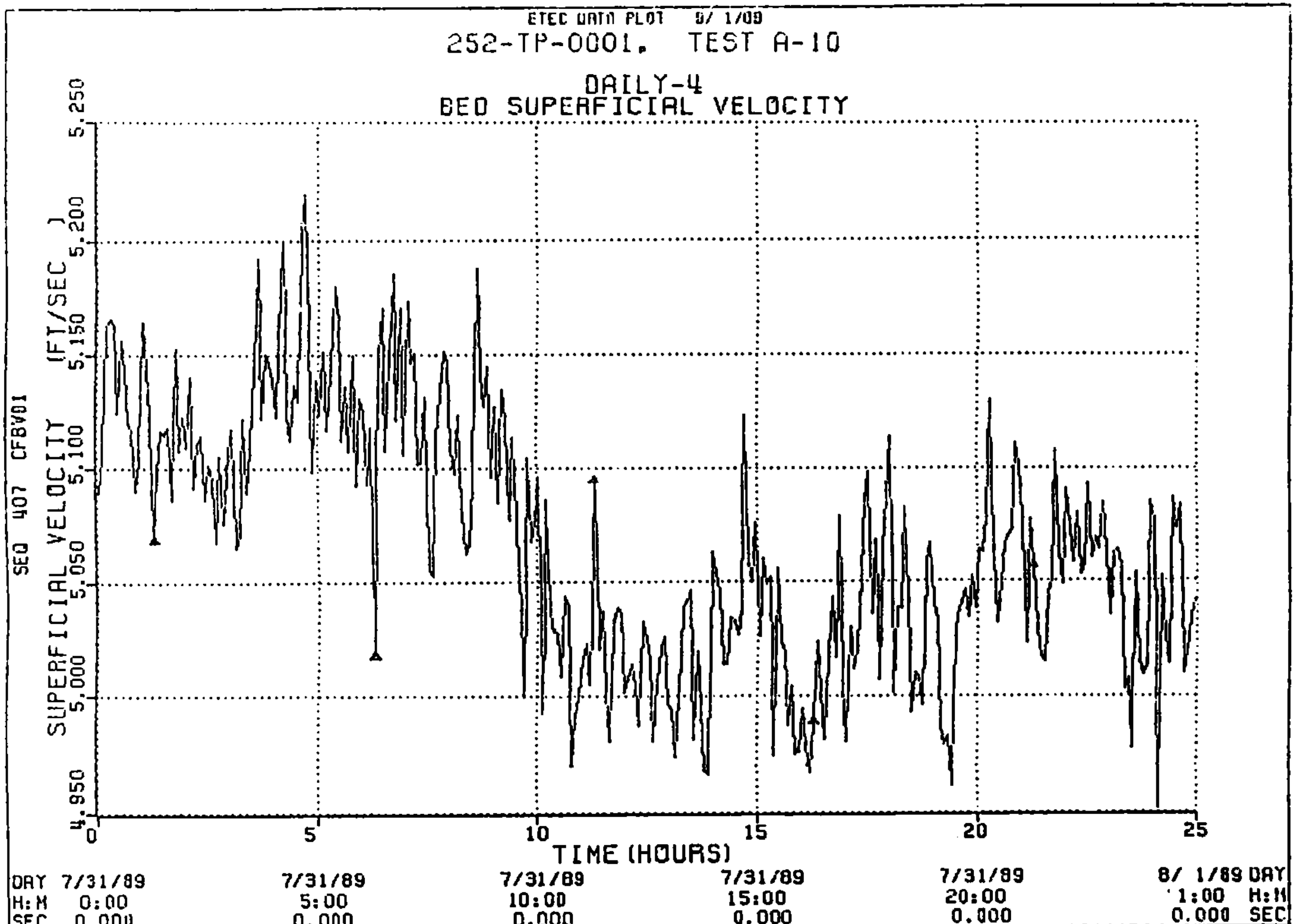
252-TP-0001. TEST A-10
FBT02 DEG F SEQ 74
FBT04 DEG F SEQ 76
CFBT01 DEG F SEQ 405
DAILY-1
LOWER/UPPER/AVERAGE BED TEMPERATURES
FLUID BED-BED TEMPERATURE (27.7") (DEG F)
TIME (HOURS)
0
5
10
15
20
25
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

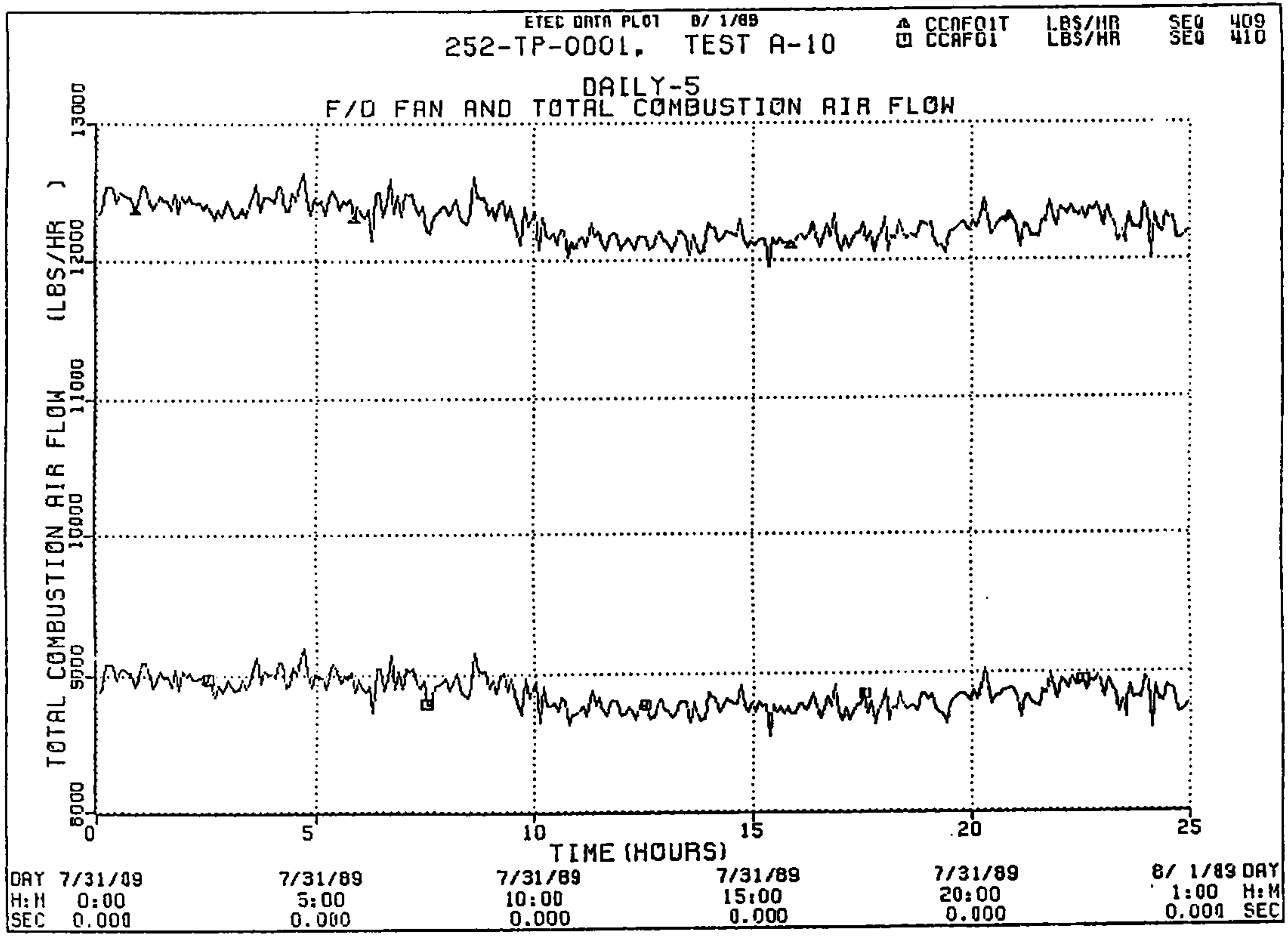


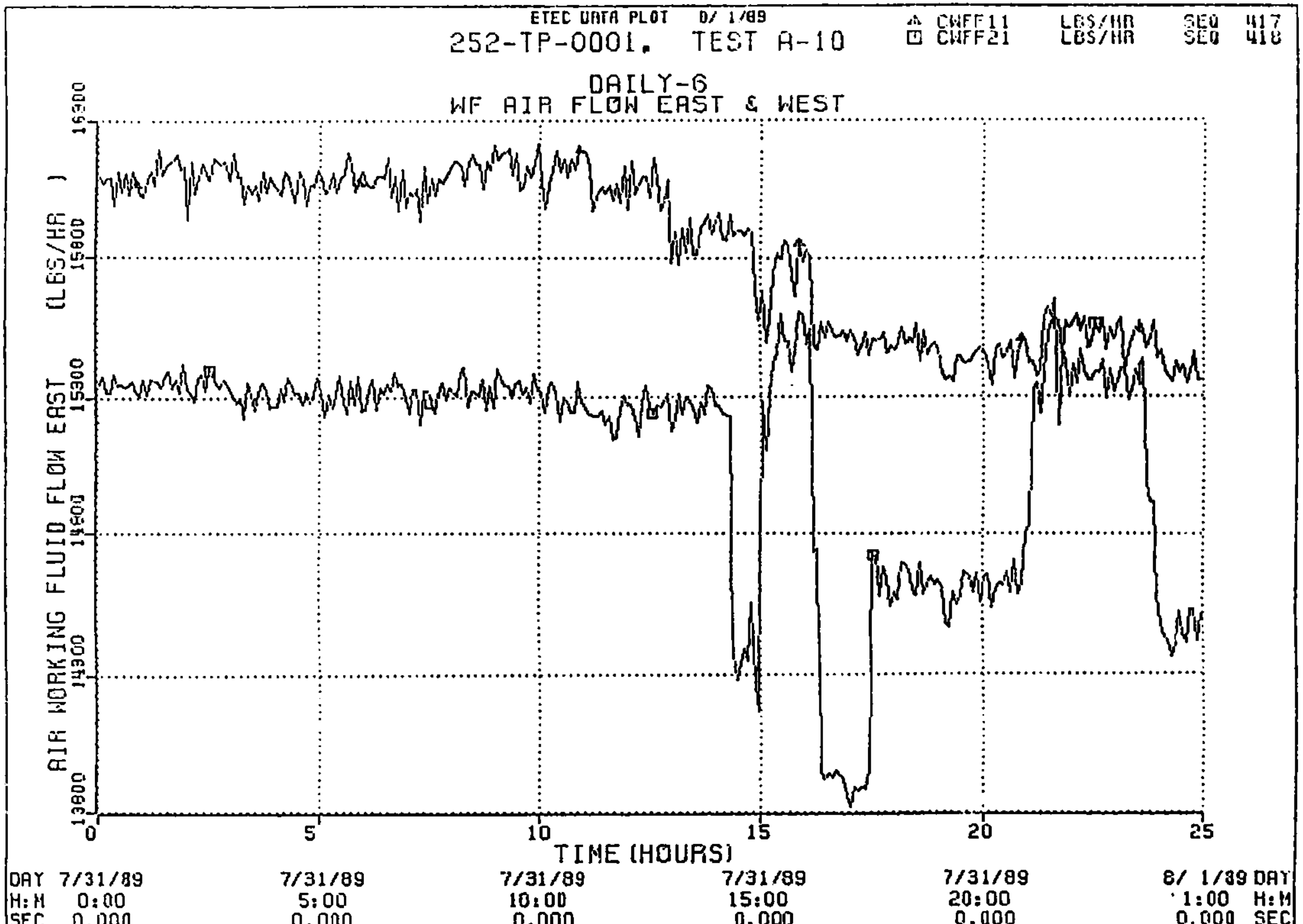
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-2
BED HEIGHT
SEQ 406 CFBHA)
FLUIDIZED BED HEIGHT (INCHES)
150
140
130
120
110
100
90
80
70
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
DAILY-3
BED FREEBOARD PRESSURE
SEQ 270 FBP12
FLUID BED-FREEBOARD PRESSURE (230.3") (IN W.G.)
-0.10
-0.30
-0.50
-0.70
-0.90
-1.10
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

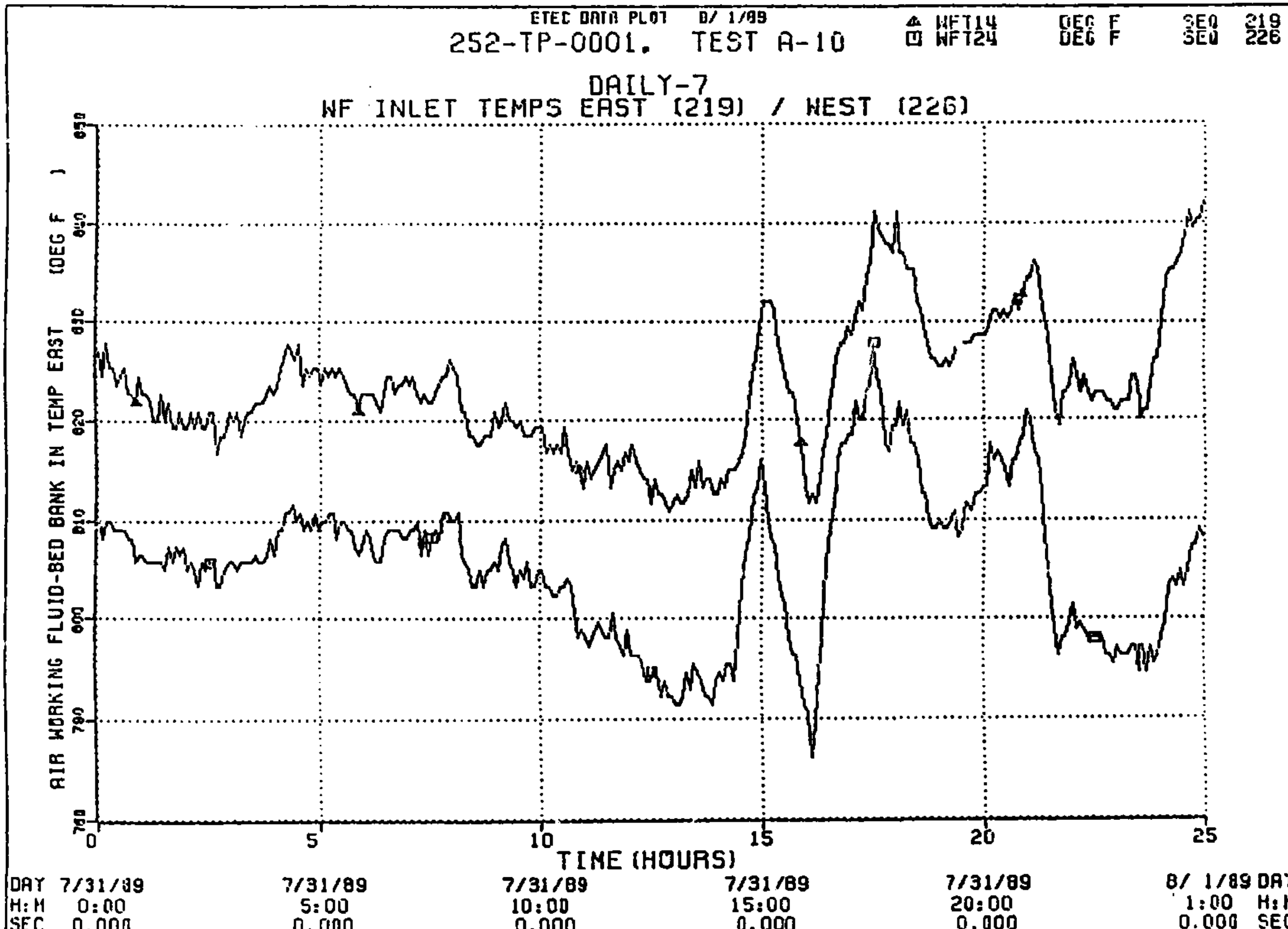


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
DAILY-4
BED SUPERFICIAL VELOCITY
SEQ 407 CFBV01
SUPERFICIAL VELOCITY (FT/SEC)
5.250
5.200
5.150
5.100
5.050
5.000
4.950
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

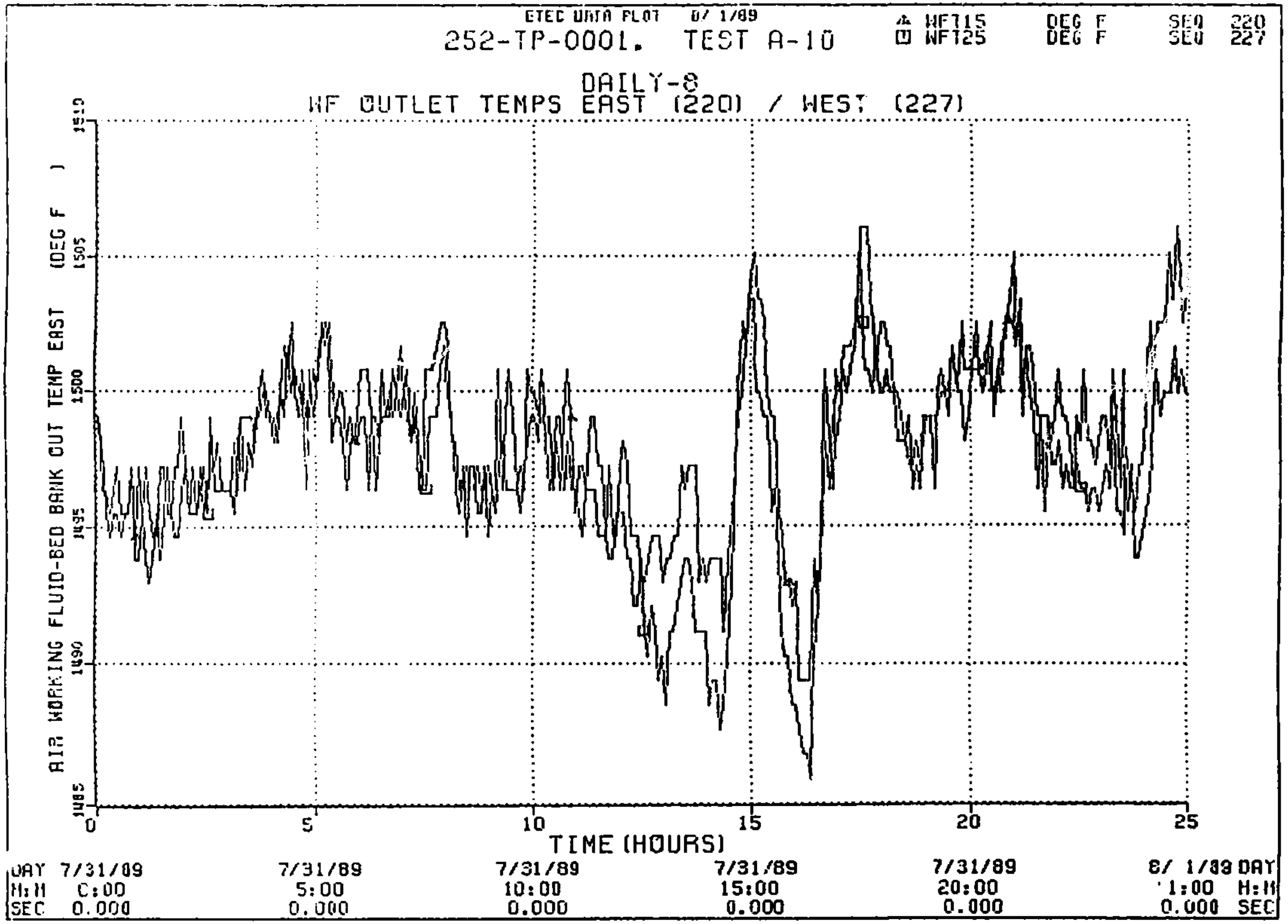

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
△ CCAF01T LBS/HR SEQ 409
⊡ CCAF01 LBS/HR SEQ 410
DAILY-5
F/D FAN AND TOTAL COMBUSTION AIR FLOW
TOTAL COMBUSTION AIR FLOW (LBS/HR)
13000
12000
11000
10000
9000
8000
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC



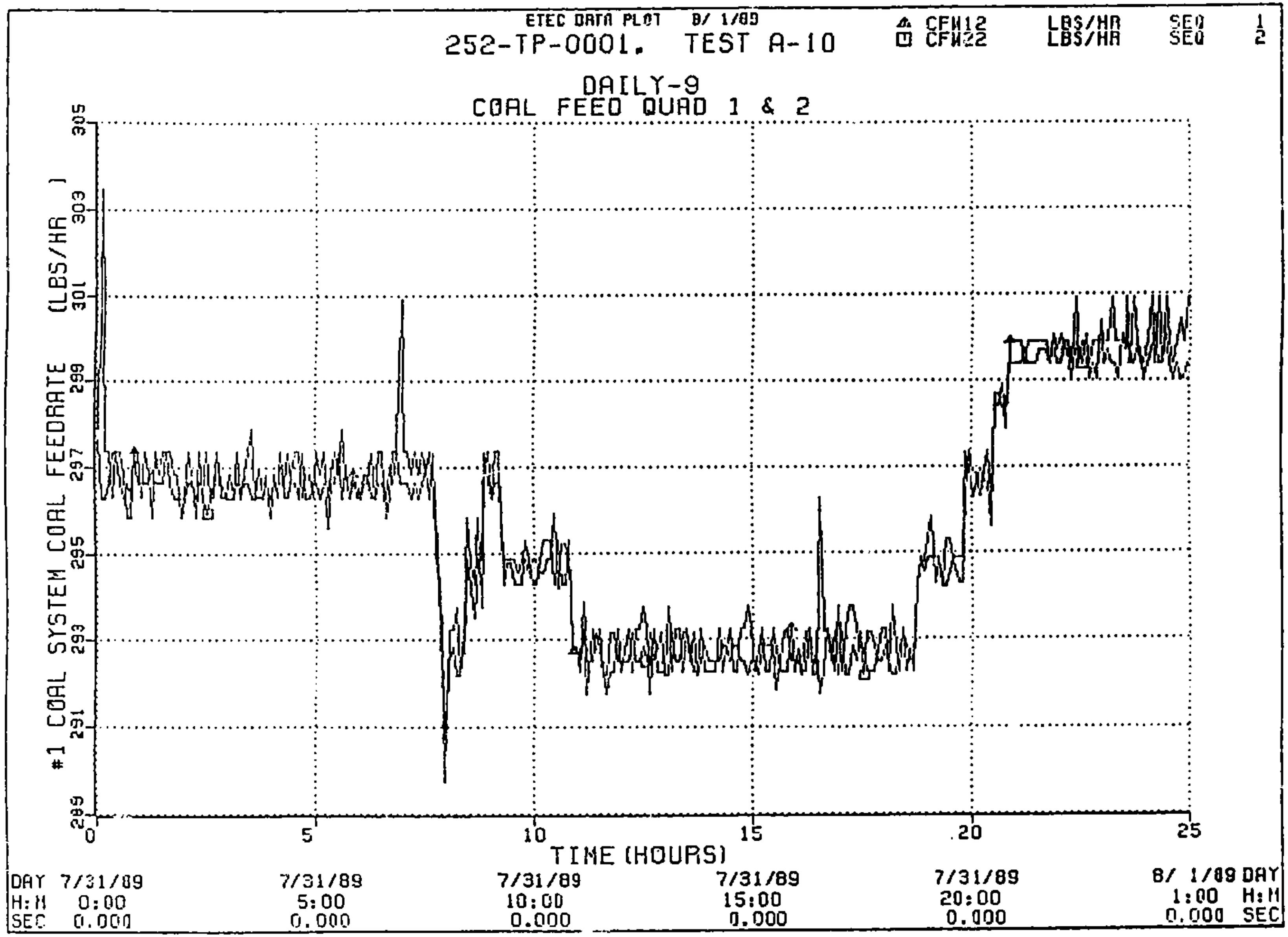
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
CWFF11 LBS/HR SEQ 417
CWFF21 LBS/HR SEQ 418
DAILY-6
WF AIR FLOW EAST & WEST
AIR WORKING FLUID FLOW EAST (LBS/HR)
16300
15800
15300
14800
14300
13800
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC



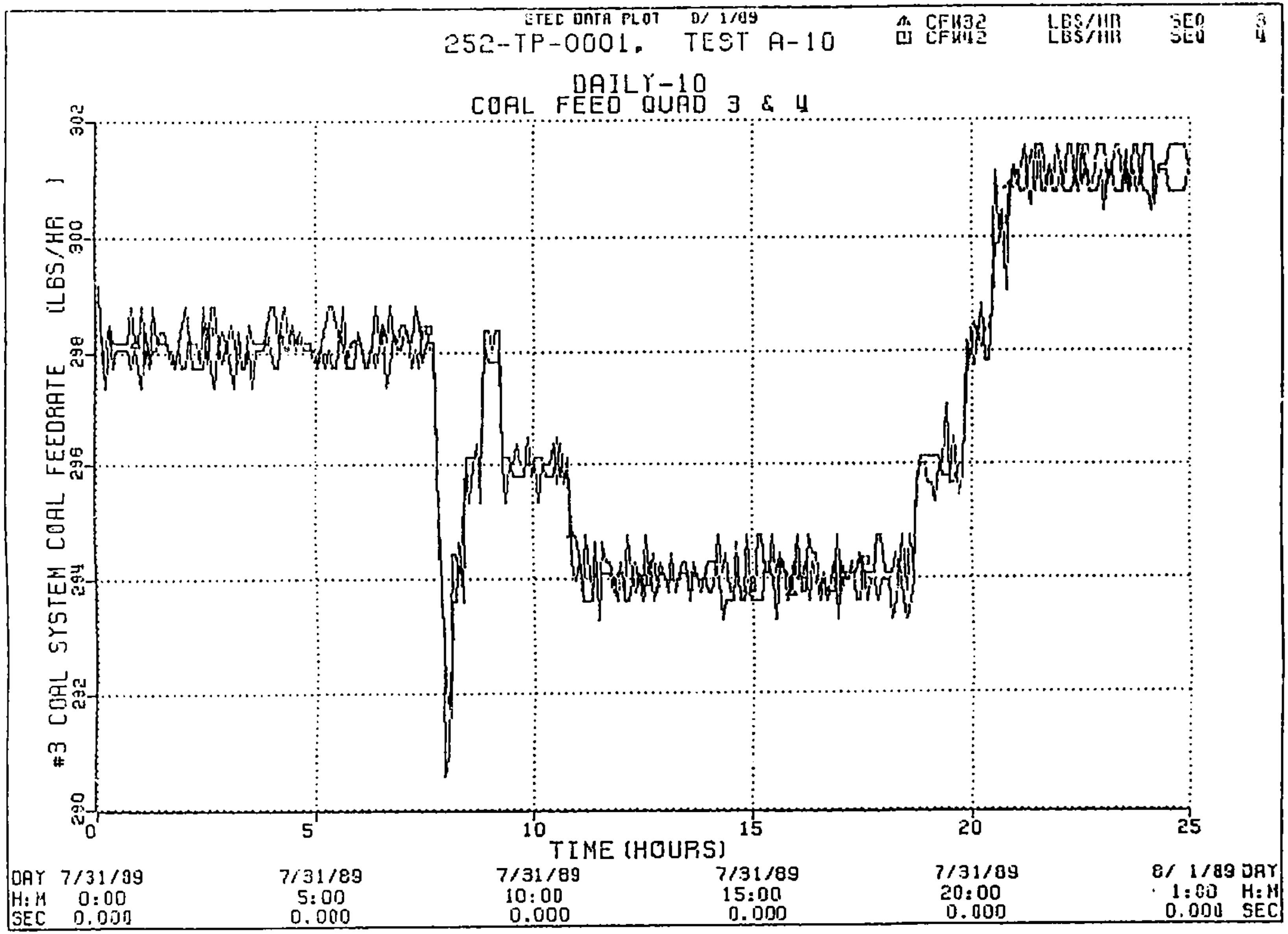
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
▲ WFT14 DEG F SEQ 219
□ WFT24 DEG F SEQ 226
DAILY-7
WF INLET TEMPS EAST (219) / WEST (226)
AIR WORKING FLUID-BED BANK IN TEMP EAST (DEG F)
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

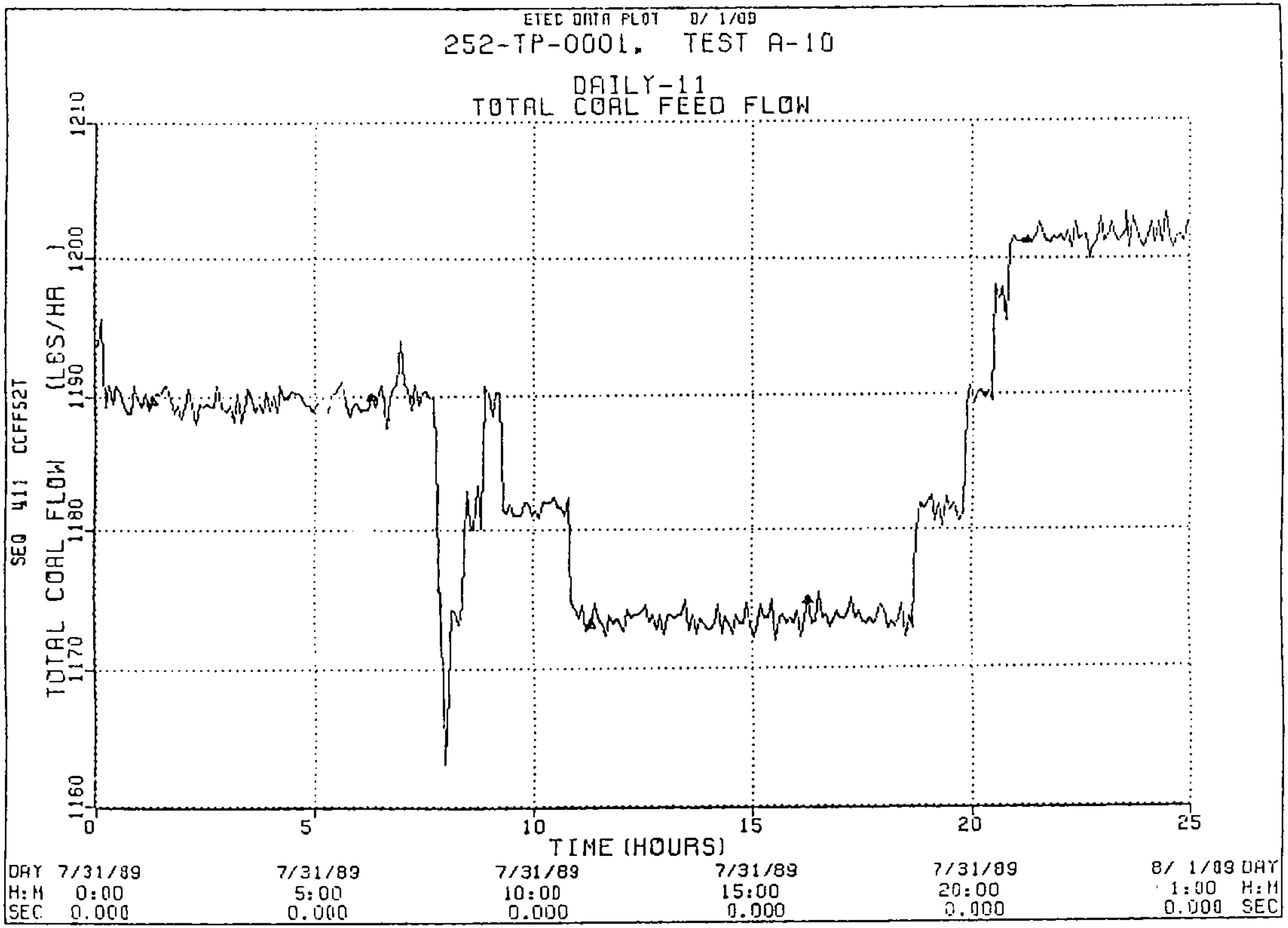


ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
WFT15 DEG F SEQ 220
WFT25 DEG F SEQ 227
DAILY-8
WF OUTLET TEMPS EAST (220) / WEST (227)
AIR WORKING FLUID-BED BANK OUT TEMP EAST (DEG F)
1510
1505
1500
1495
1490
1485
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC



ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-9
COAL FEED QUAD 1 & 2
CFW12 LBS/HR SEQ 1
CFW22 LBS/HR SEQ 2
#1 COAL SYSTEM COAL FEEDRATE (LBS/HR)
289
291
293
295
297
299
301
303
305
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
CFW32 LBS/HR SEQ 3
CFW42 LBS/HR SEQ 4
DAILY-10
COAL FEED QUAD 3 & 4
#3 COAL SYSTEM COAL FEEDRATE (LBS/HR)
302
300
298
296
294
292
290
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
DAILY-11
TOTAL COAL FEED FLOW
SEQ 411 CCFF52T
TOTAL COAL FLOW (LBS/HR)
1210
1200
1190
1180
1170
1160
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
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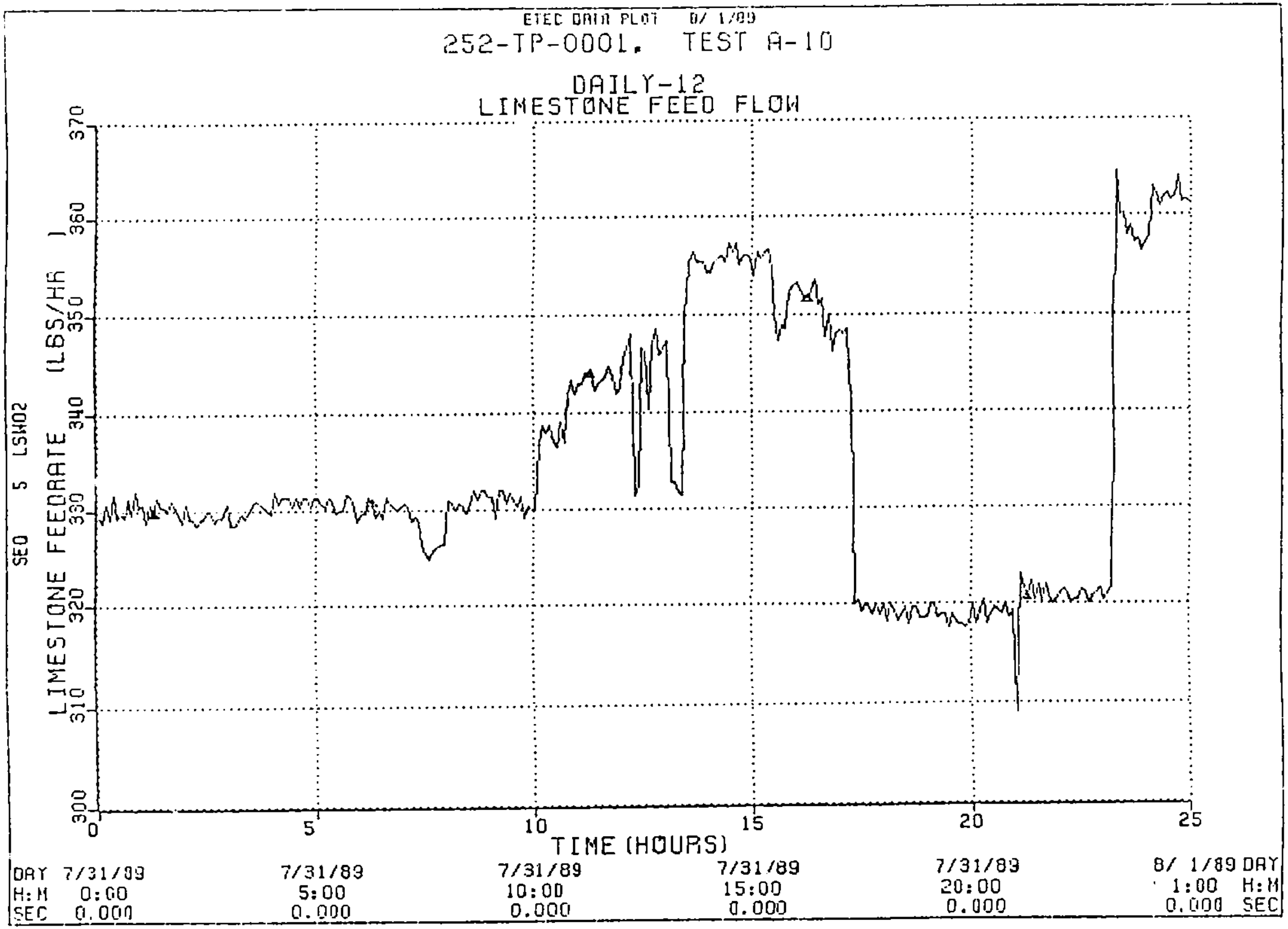
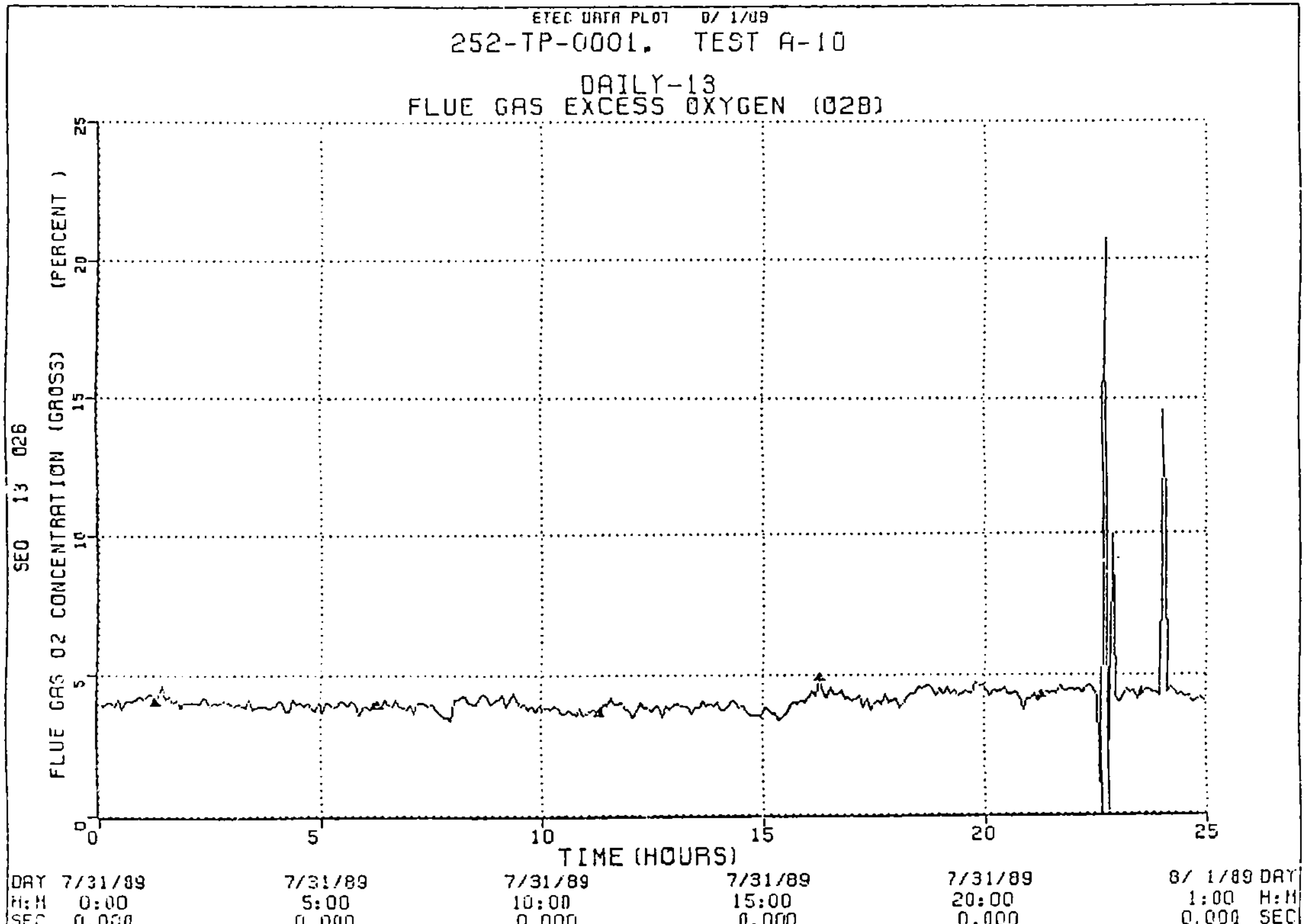
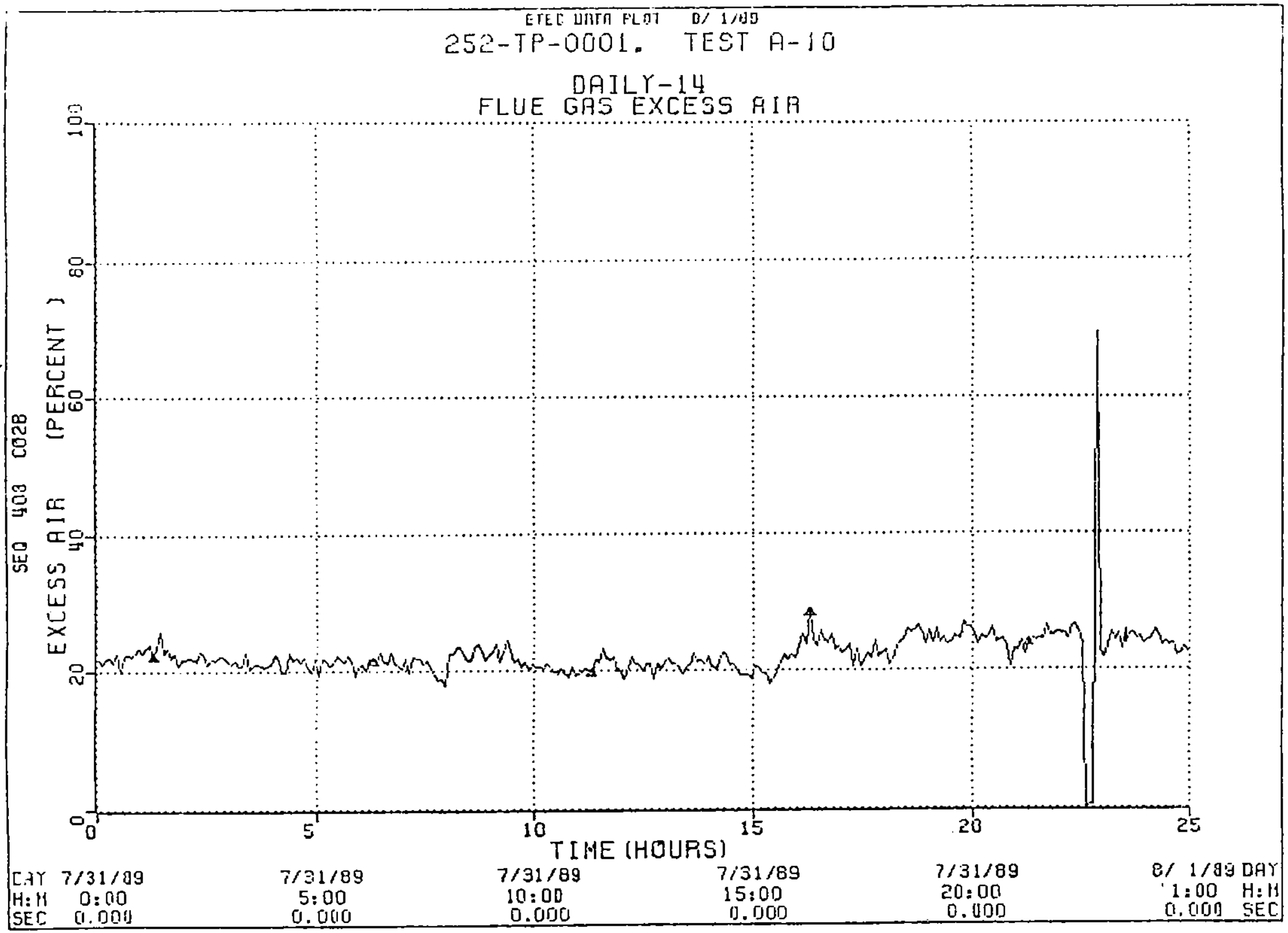
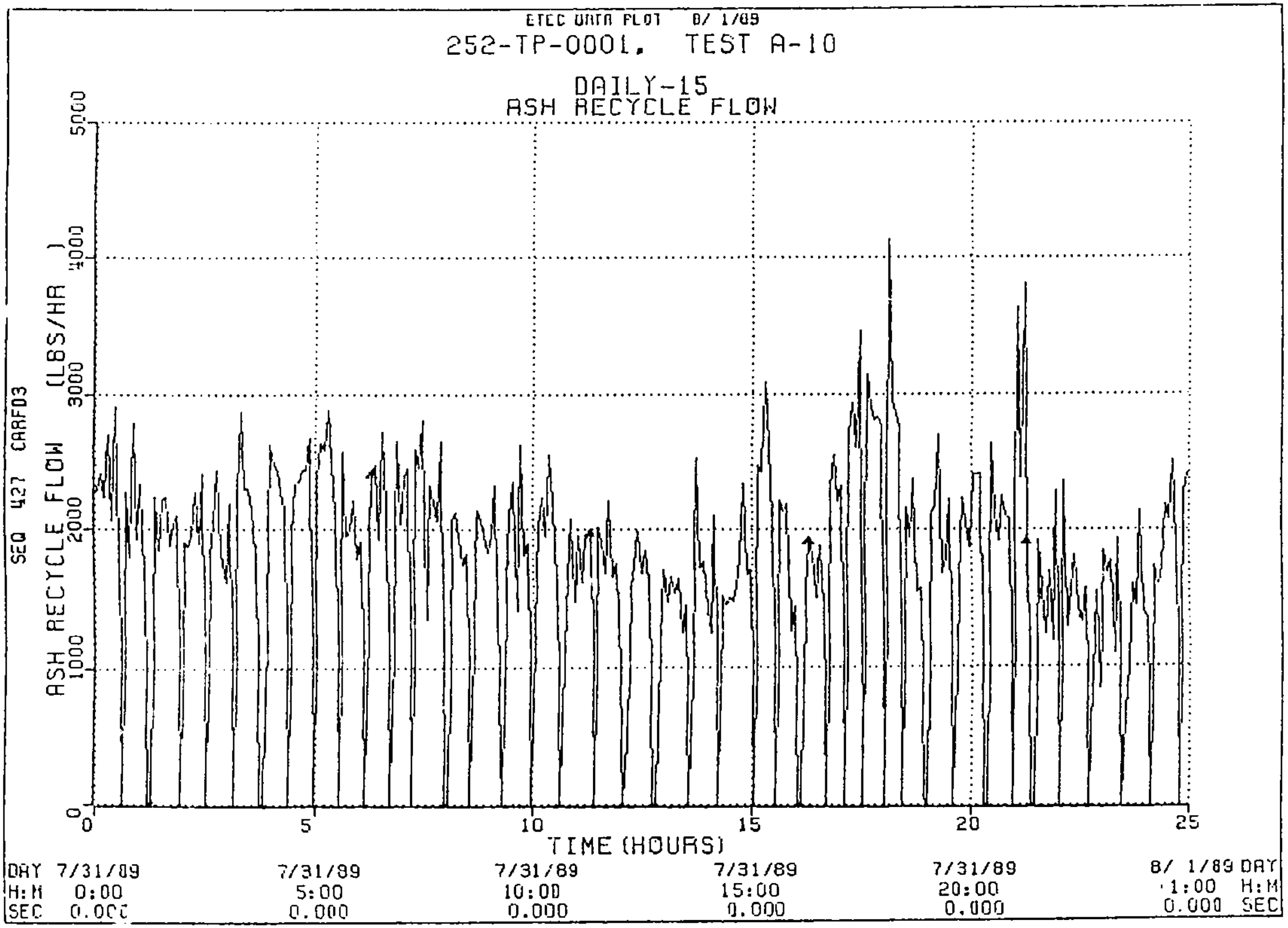

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-12
LIMESTONE FEED FLOW
SEQ 5 LSW02
LIMESTONE FEEDRATE (LBS/HR)
300
310
320
330
340
350
360
370
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

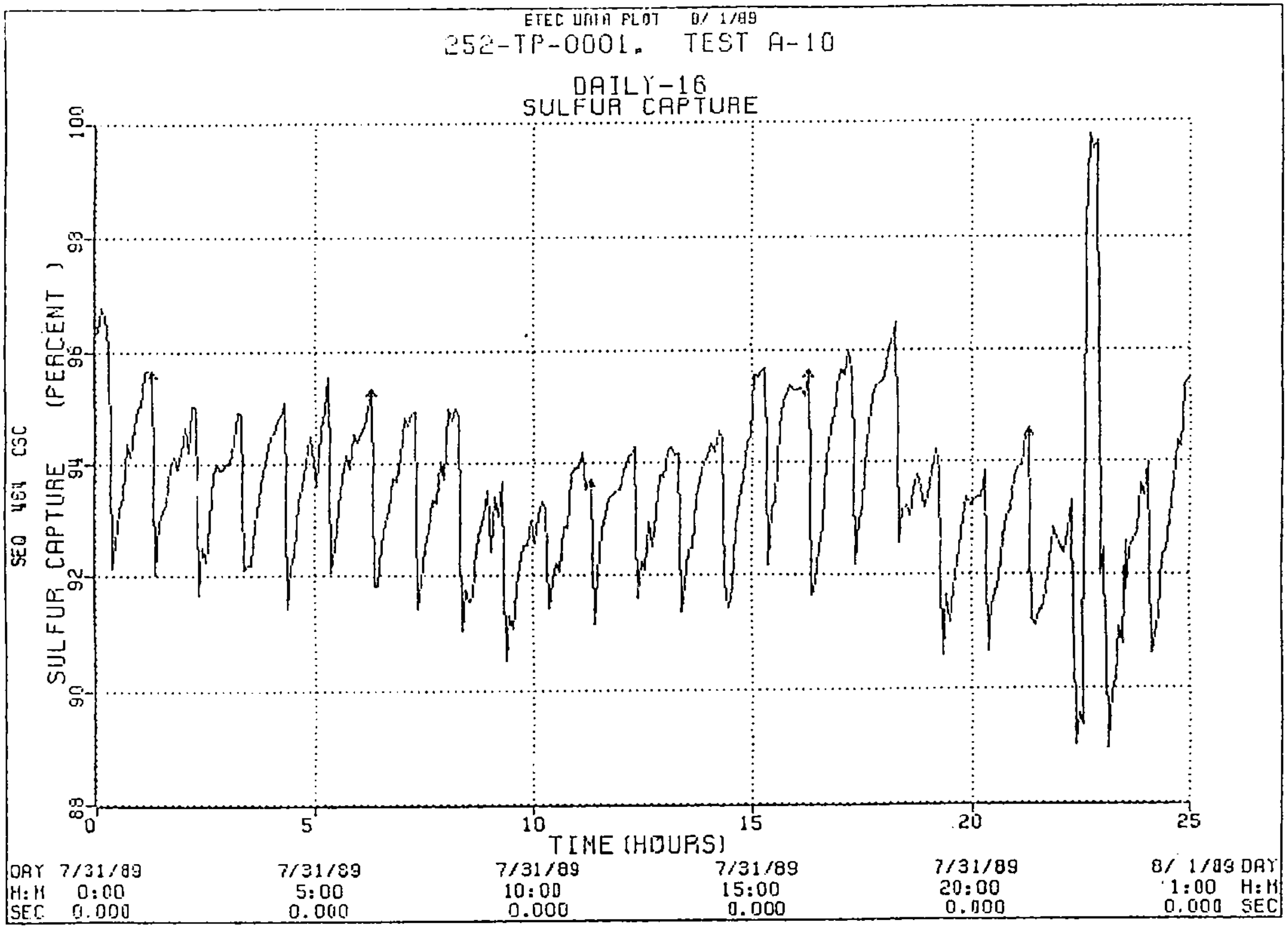

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-13
FLUE GAS EXCESS OXYGEN (O2B)
SEQ 13 O26
FLUE GAS O2 CONCENTRATION (GROSS) (PERCENT)
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

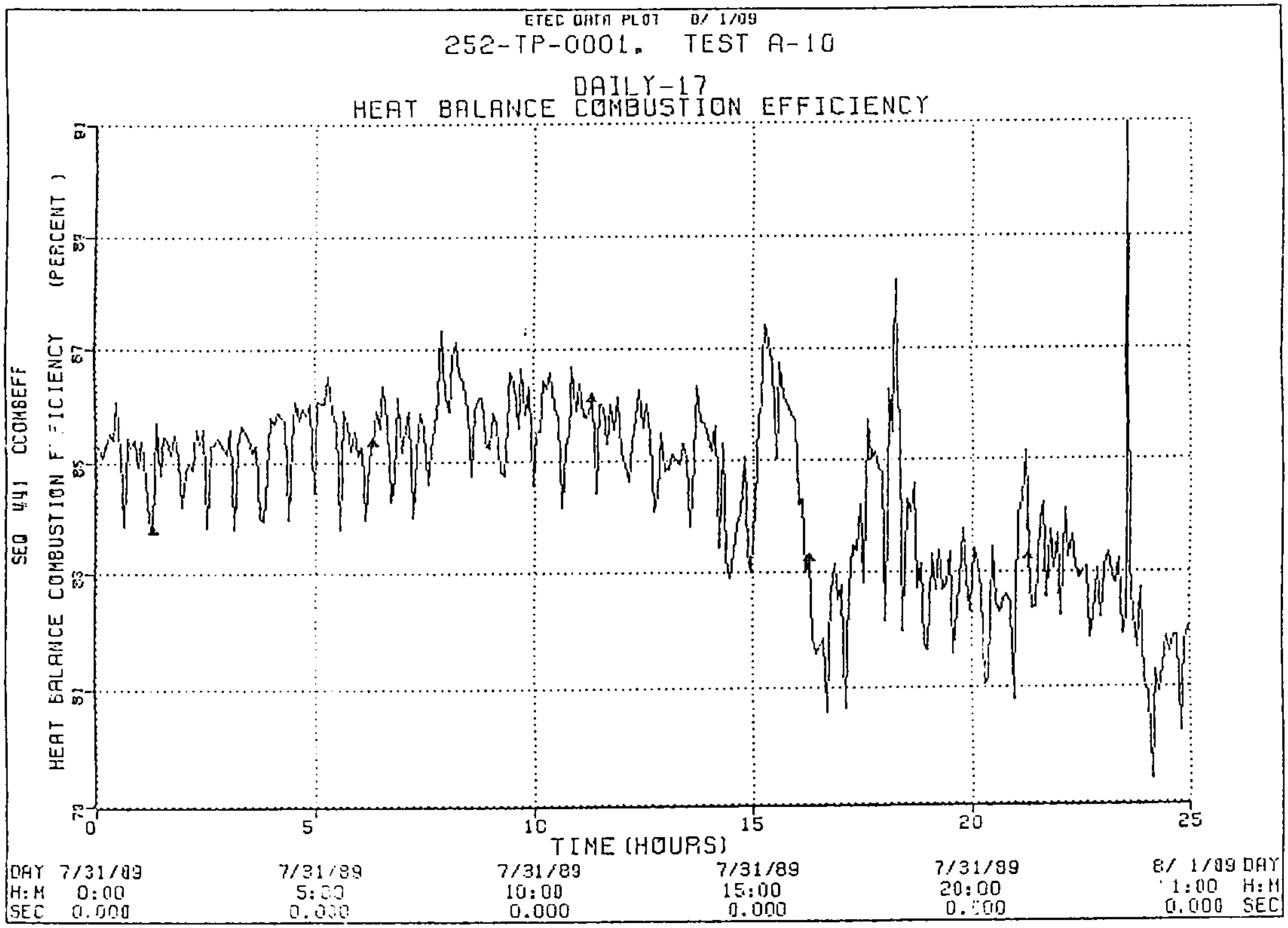


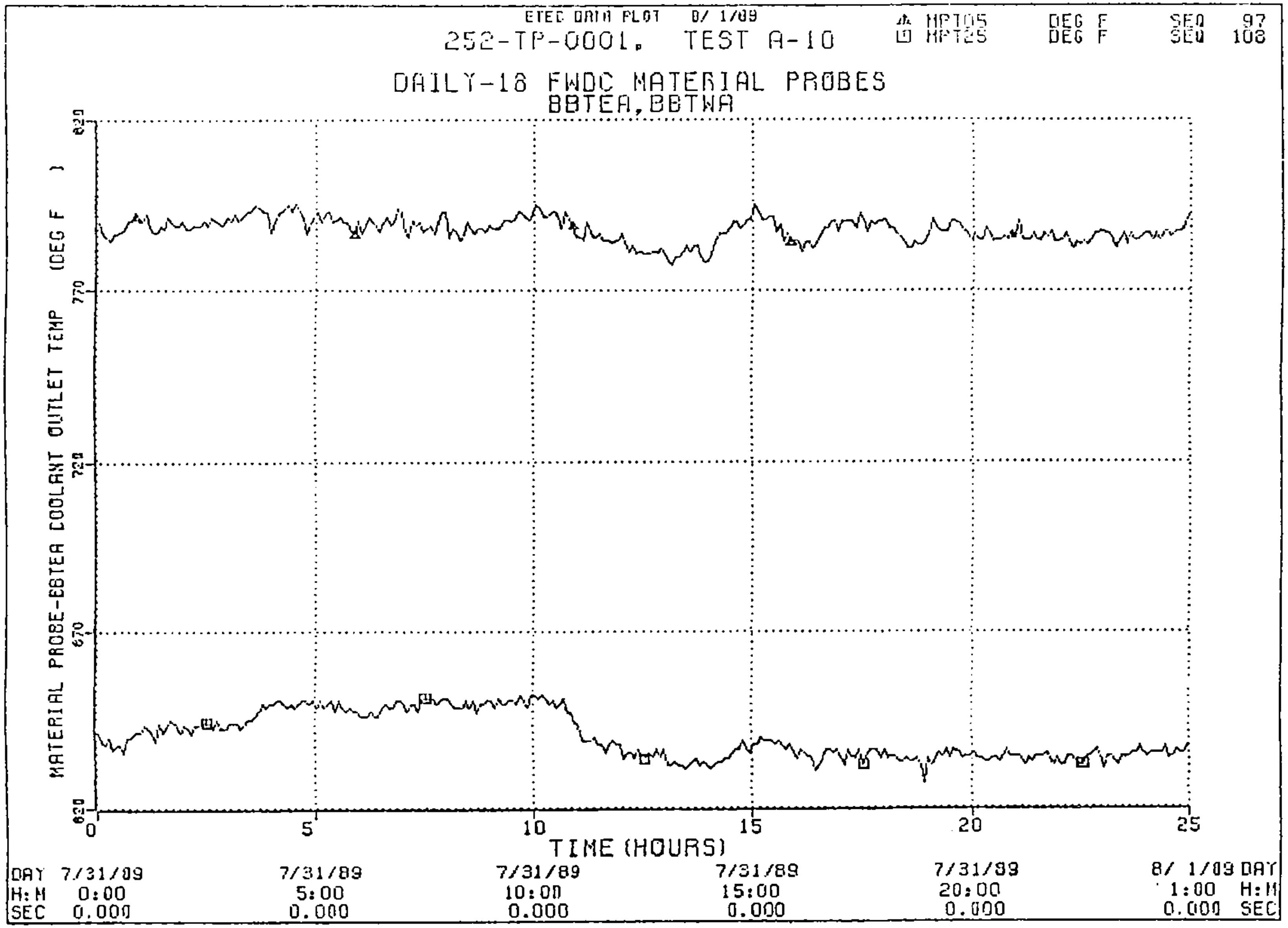
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-14
FLUE GAS EXCESS AIR
SEQ 403 C028
EXCESS AIR (PERCENT)
0
20
40
60
80
100
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

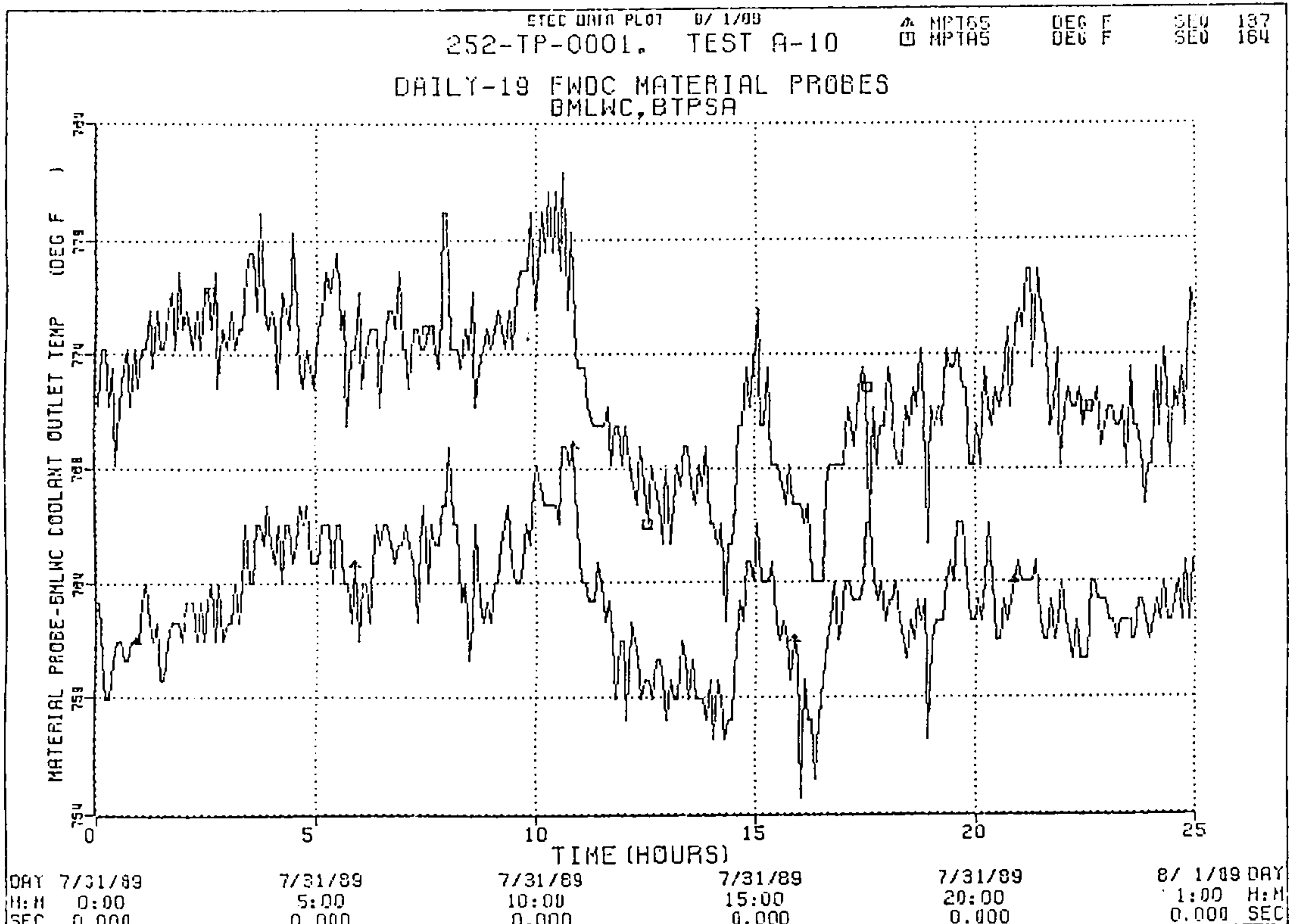


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
DAILY-15
ASH RECYCLE FLOW
SEQ 427 CARF03
ASH RECYCLE FLOW (LBS/HR)
0
1000
2000
3000
4000
5000
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

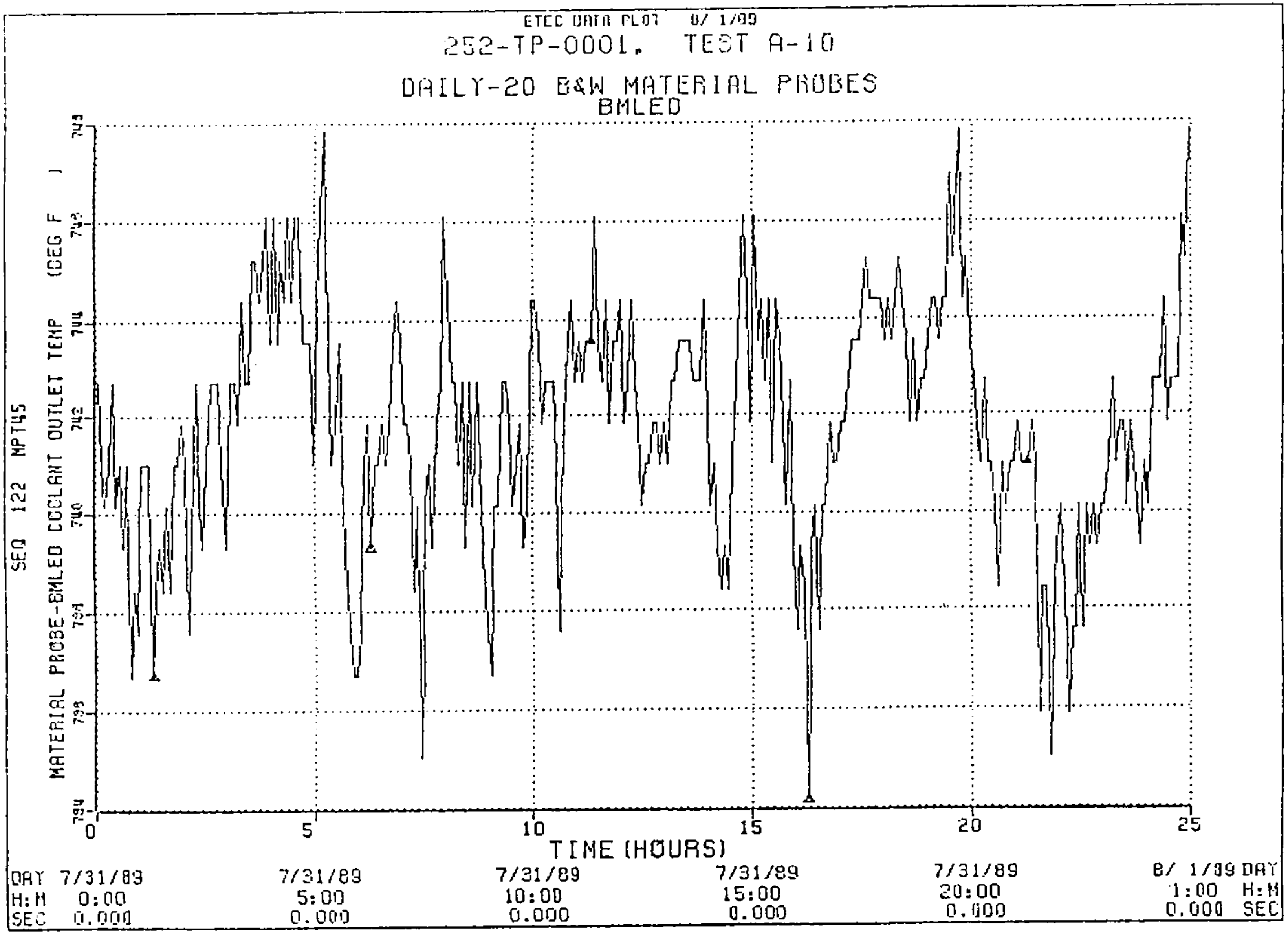

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-16
SULFUR CAPTURE
SEQ 464 CSC
SULFUR CAPTURE (PERCENT)
100
98
96
94
92
90
88
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

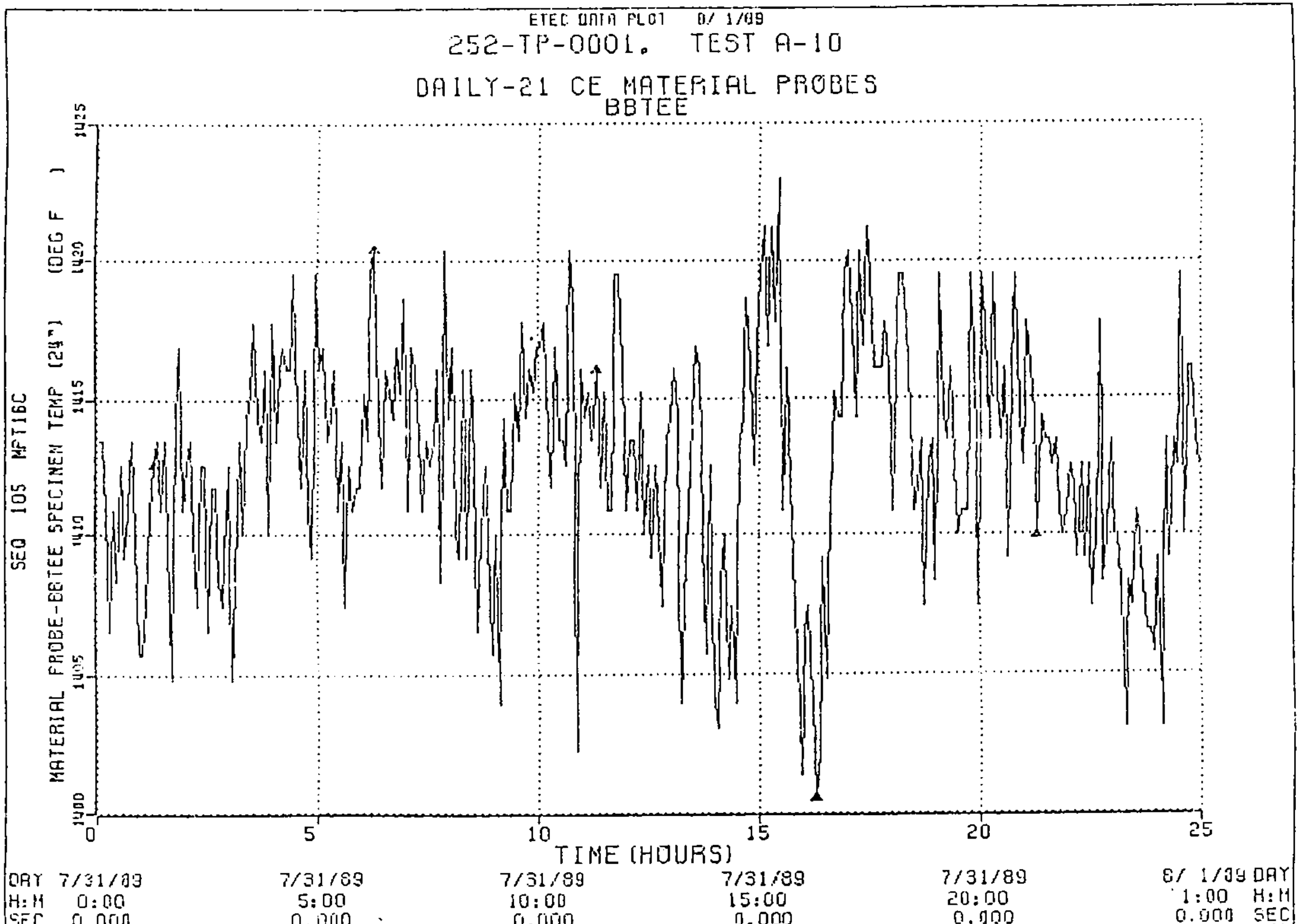

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-17
HEAT BALANCE COMBUSTION EFFICIENCY
SEQ 441 CCOMBEFF
HEAT BALANCE COMBUSTION EFFICIENCY (PERCENT)
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
MPT05 DEG F SEQ 97
MPT25 DEG F SEQ 108
DAILY-18 FWDC MATERIAL PROBES
BBTEA,BBTWA
MATERIAL PROBE-BBTEA COOLANT OUTLET TEMP (DEG F)
820
770
720
670
620
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

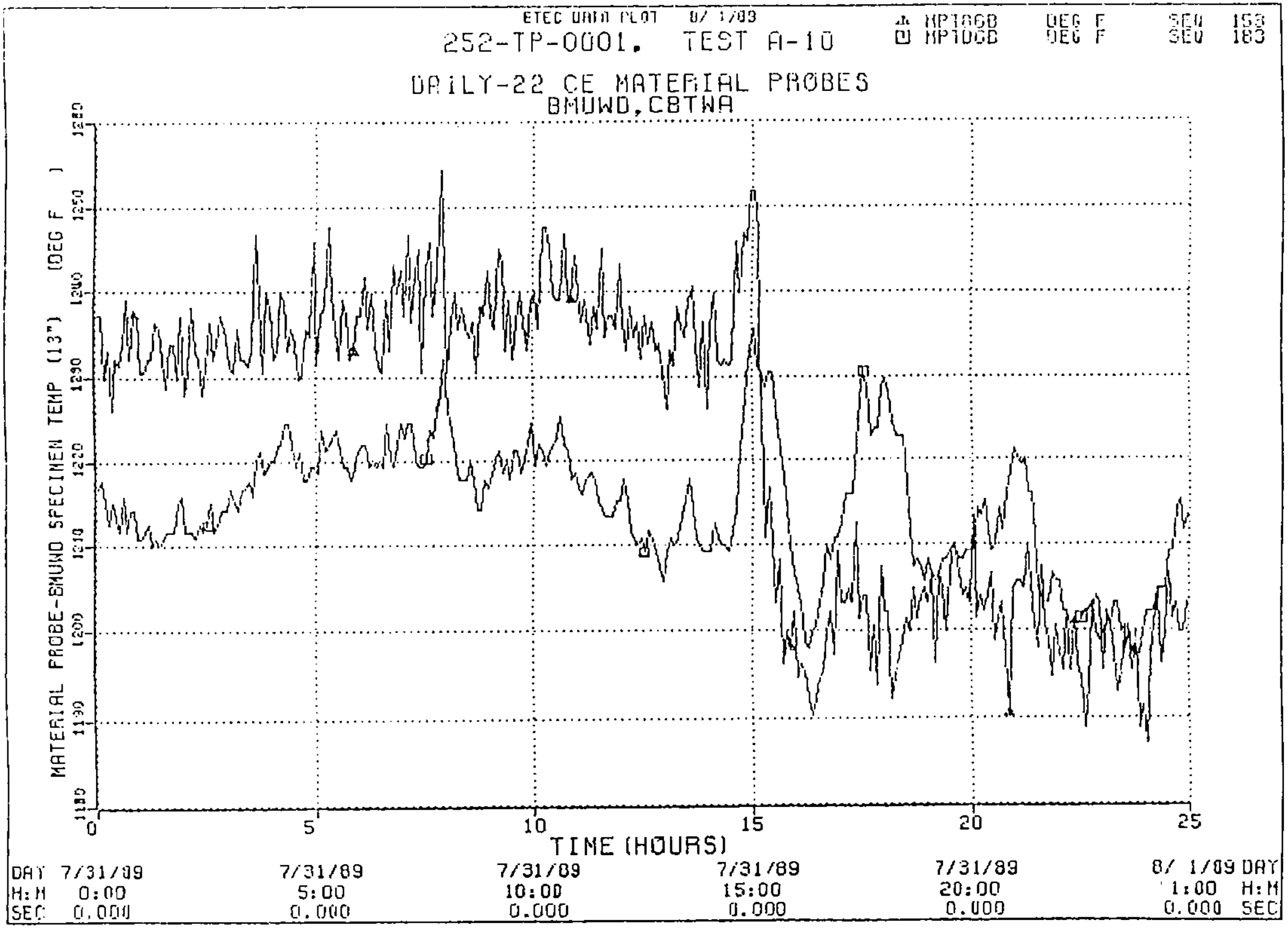


ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
MPT65 DEG F SEQ 137
MPTA5 DEG F SEQ 164
DAILY-19 FWDC MATERIAL PROBES
BMLWC,BTPSA
MATERIAL PROBE-BMLWC COOLANT OUTLET TEMP (DEG F)
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

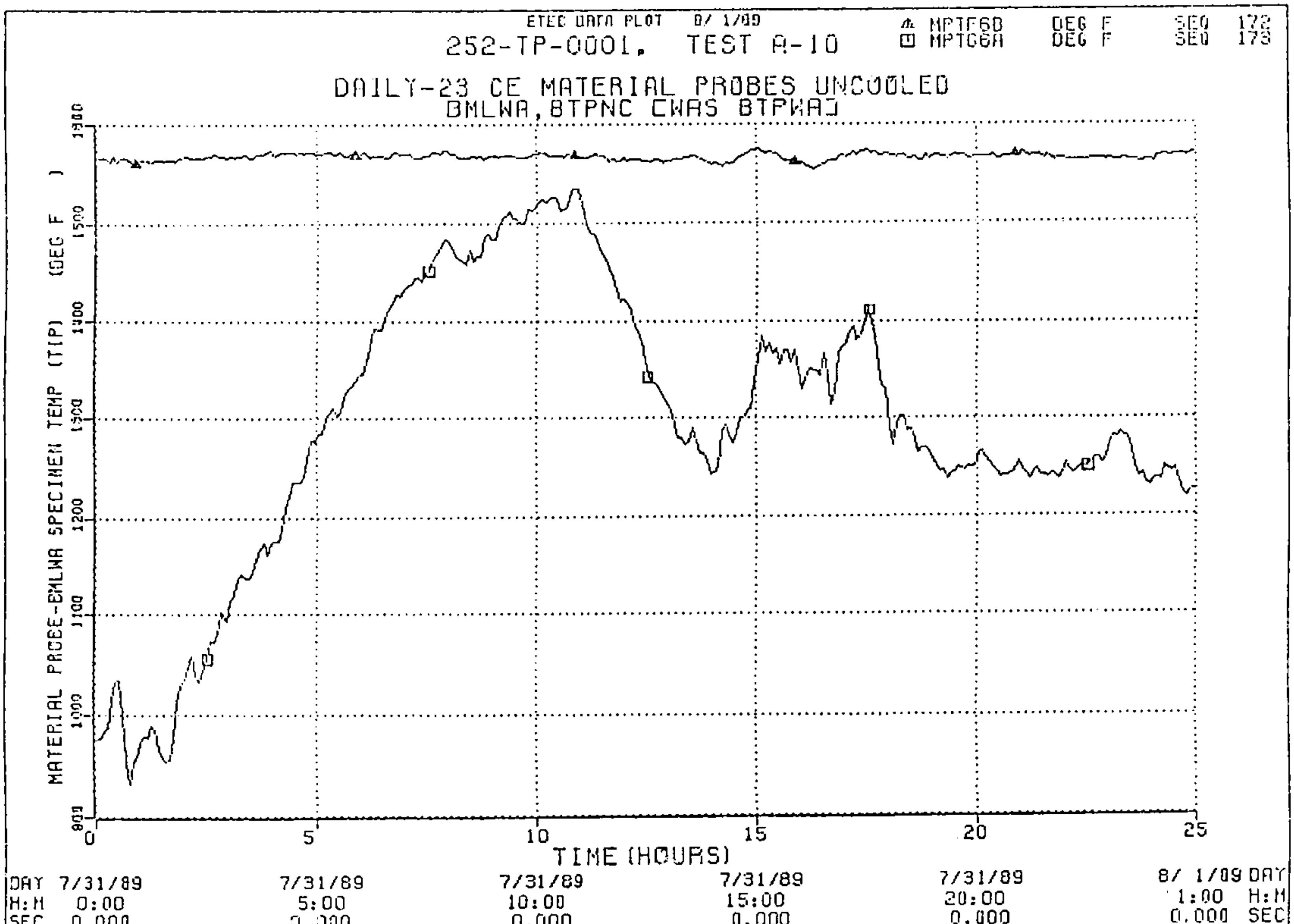

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-20 B&W MATERIAL PROBES
BMLED
SEQ 122 MPT45
MATERIAL PROBE-BMLED COOLANT OUTLET TEMP (DEG F)
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC



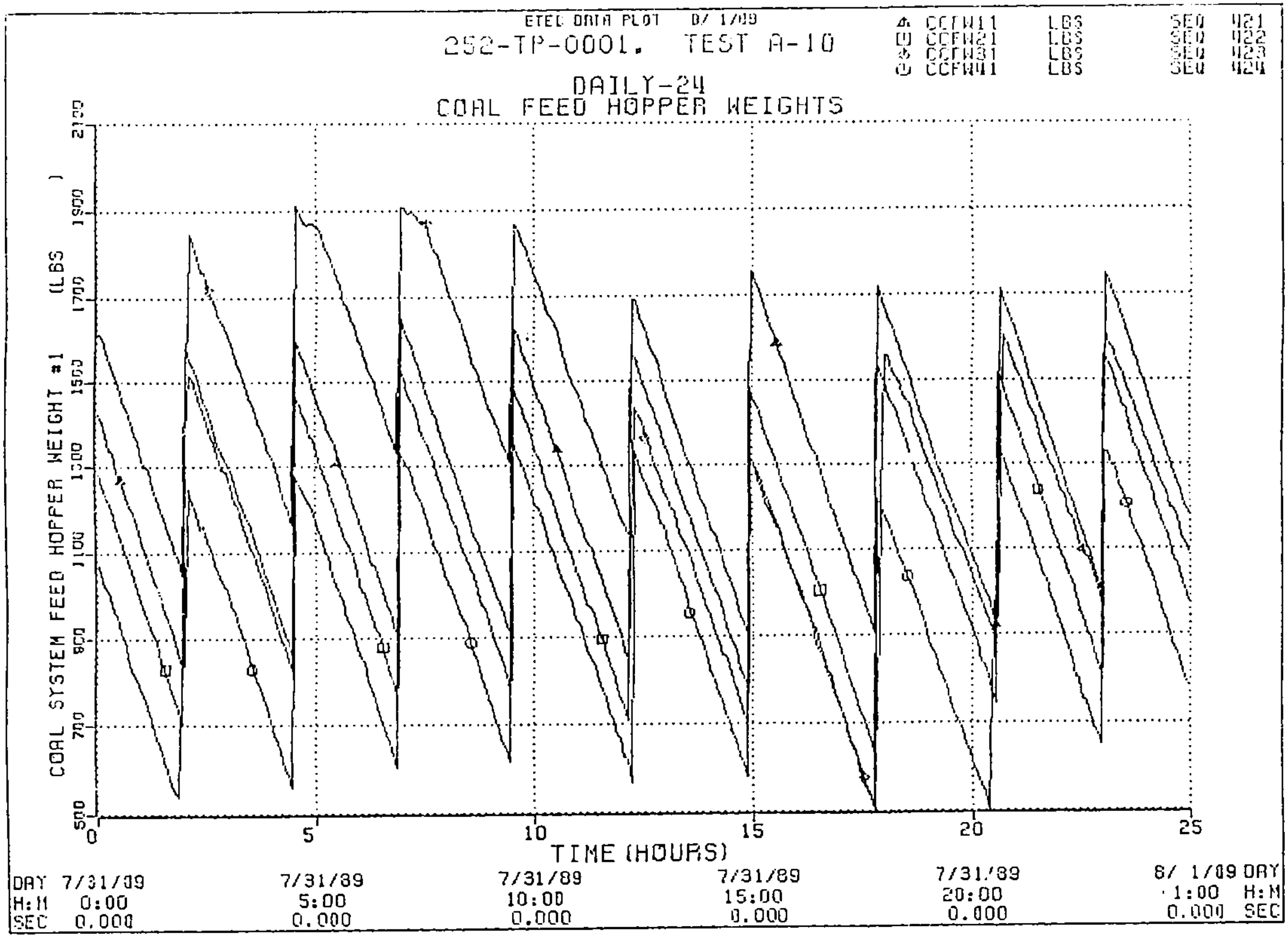
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-21 CE MATERIAL PROBES
BBTEE
SEQ 105 MFT16C
MATERIAL PROBE-BBTEE SPECIMEN TEMP (24") (DEG F)
1425
1420
1415
1410
1405
1400
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

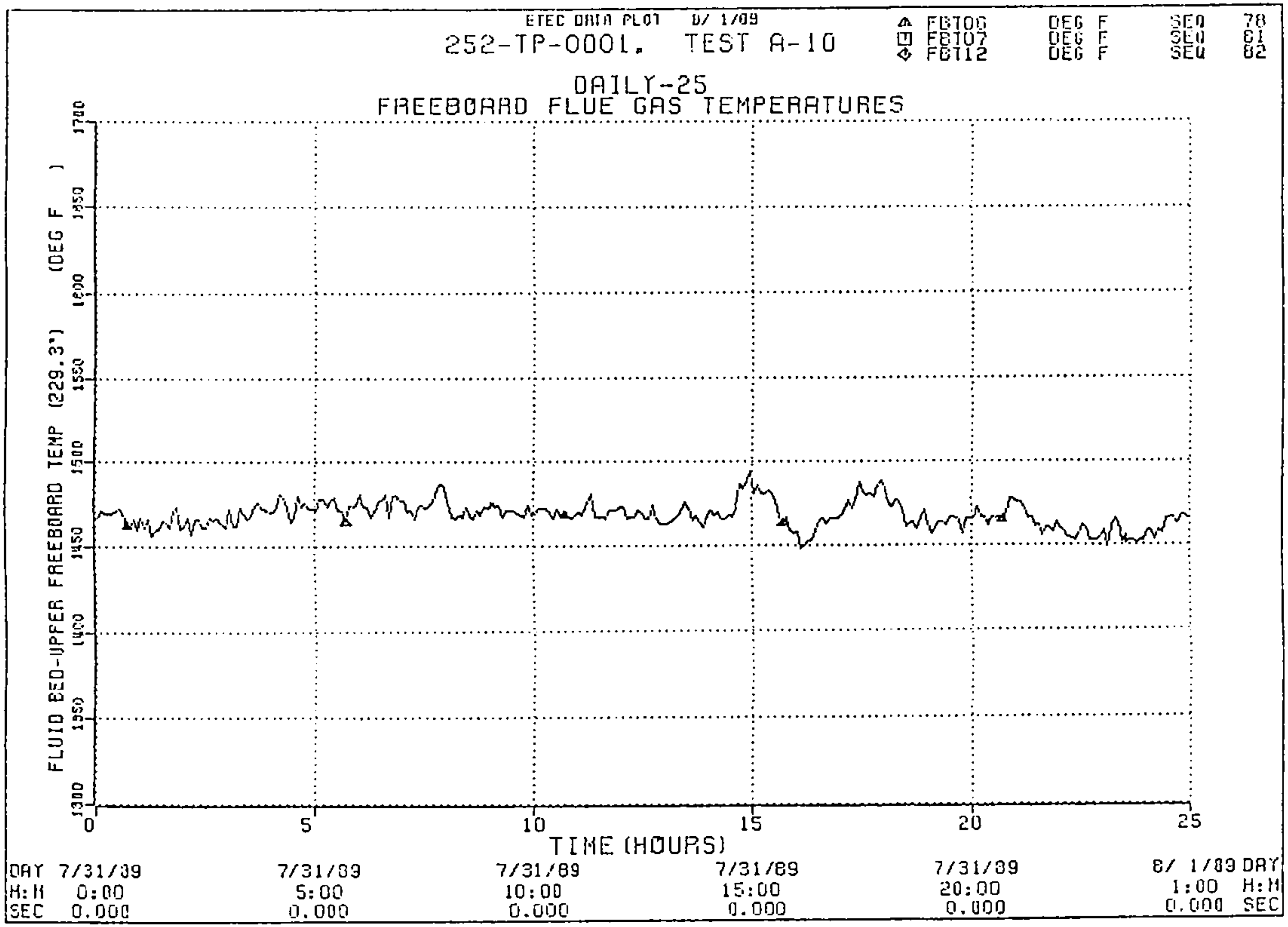


ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
MP106B DEG F SEQ 153
MP106B DEG F SEQ 183
DAILY-22 CE MATERIAL PROBES
BMUWD,CBTWA
MATERIAL PROBE-BMUWD SPECIMEN TEMP (13") (DEG F)
1180
1190
1200
1210
1220
1230
1240
1250
1260
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

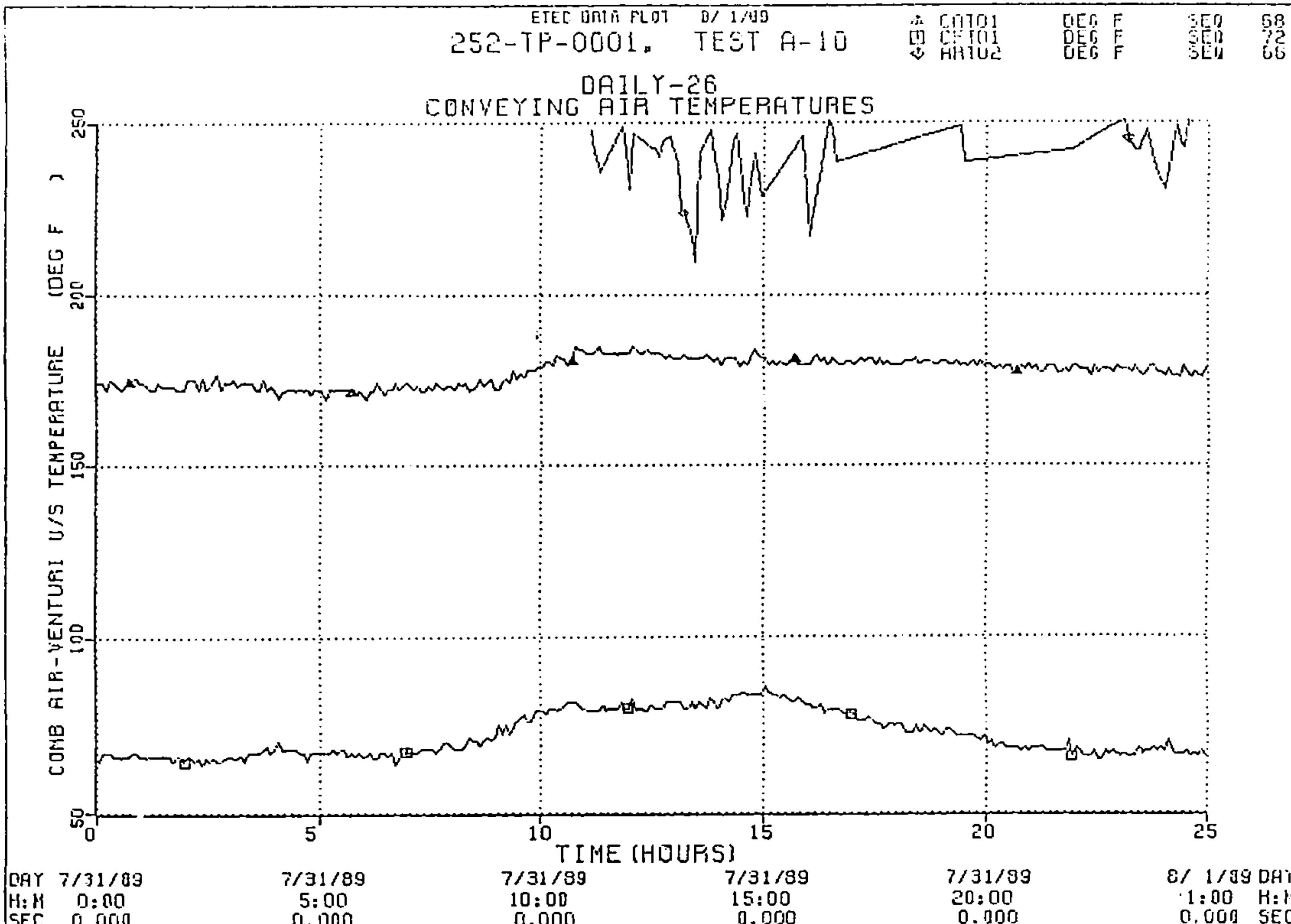


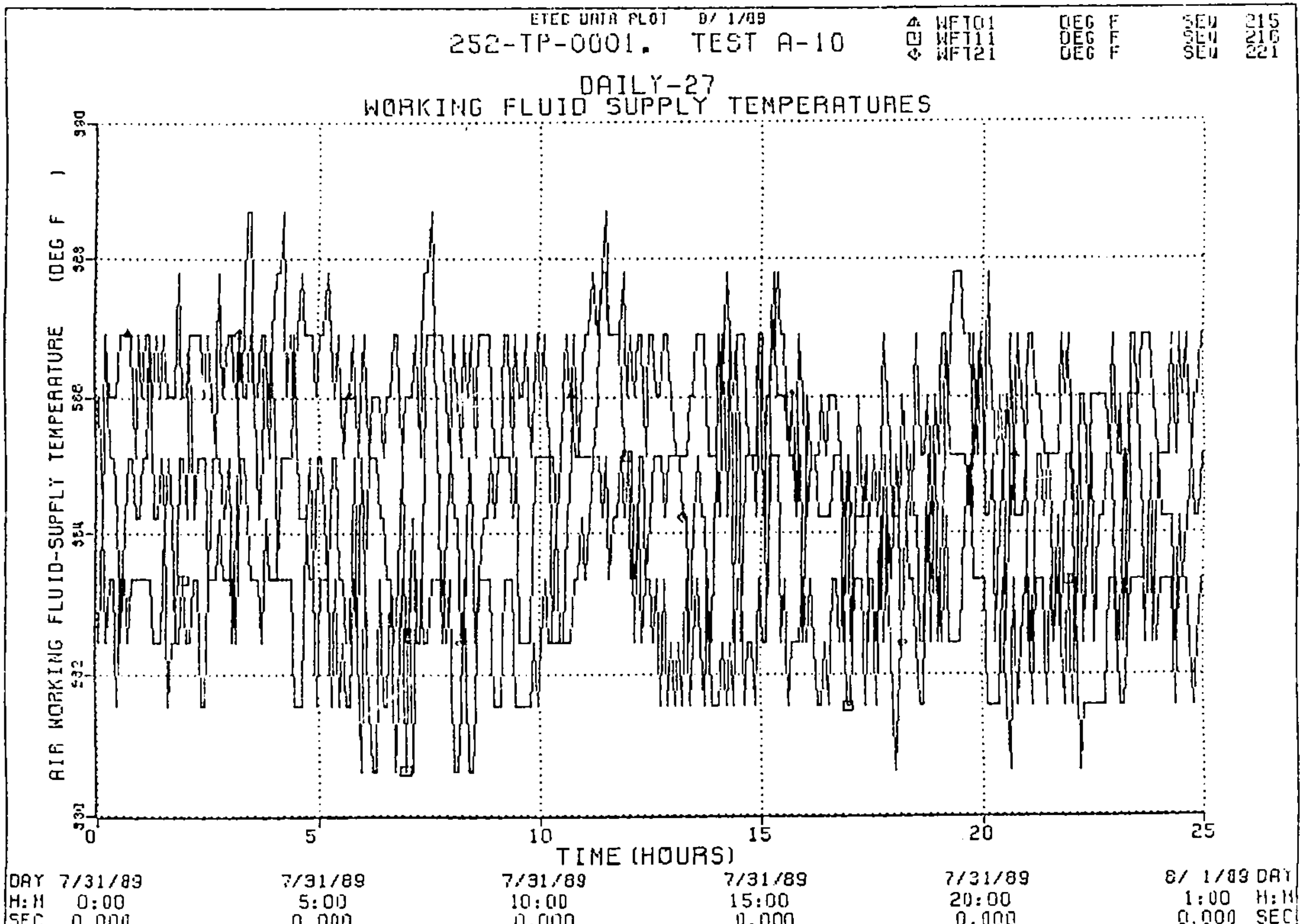
ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
MPTF6D DEG F SEQ 172
MPTG6A DEG F SEQ 173
DAILY-23 CE MATERIAL PROBES UNCOOLED
BMLWA, BTPNC CWAS BTPWA]
MATERIAL PROBE-BMLWA SPECIMEN TEMP (TIP) (DEG F)
1000
1100
1200
1500
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

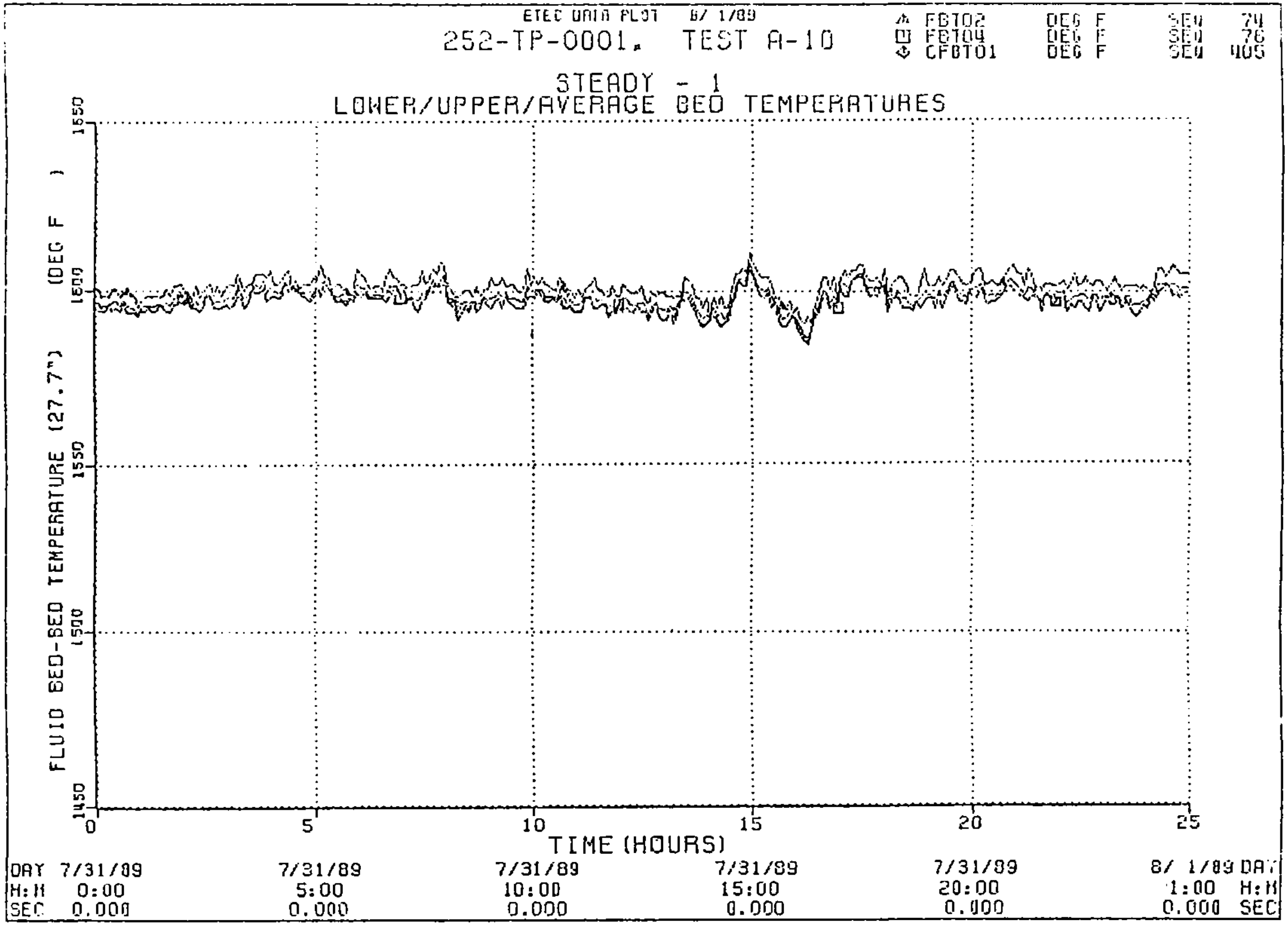

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
CCFW11 LBS SEQ 421
CCFW21 LBS SEQ 422
CCFW31 LBS SEQ 423
CCFW41 LBS SEQ 424
DAILY-24
COAL FEED HOPPER WEIGHTS
COAL SYSTEM FEED HOPPER WEIGHT #1 (LBS)
2100
1900
1700
1500
1300
1100
900
700
500
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

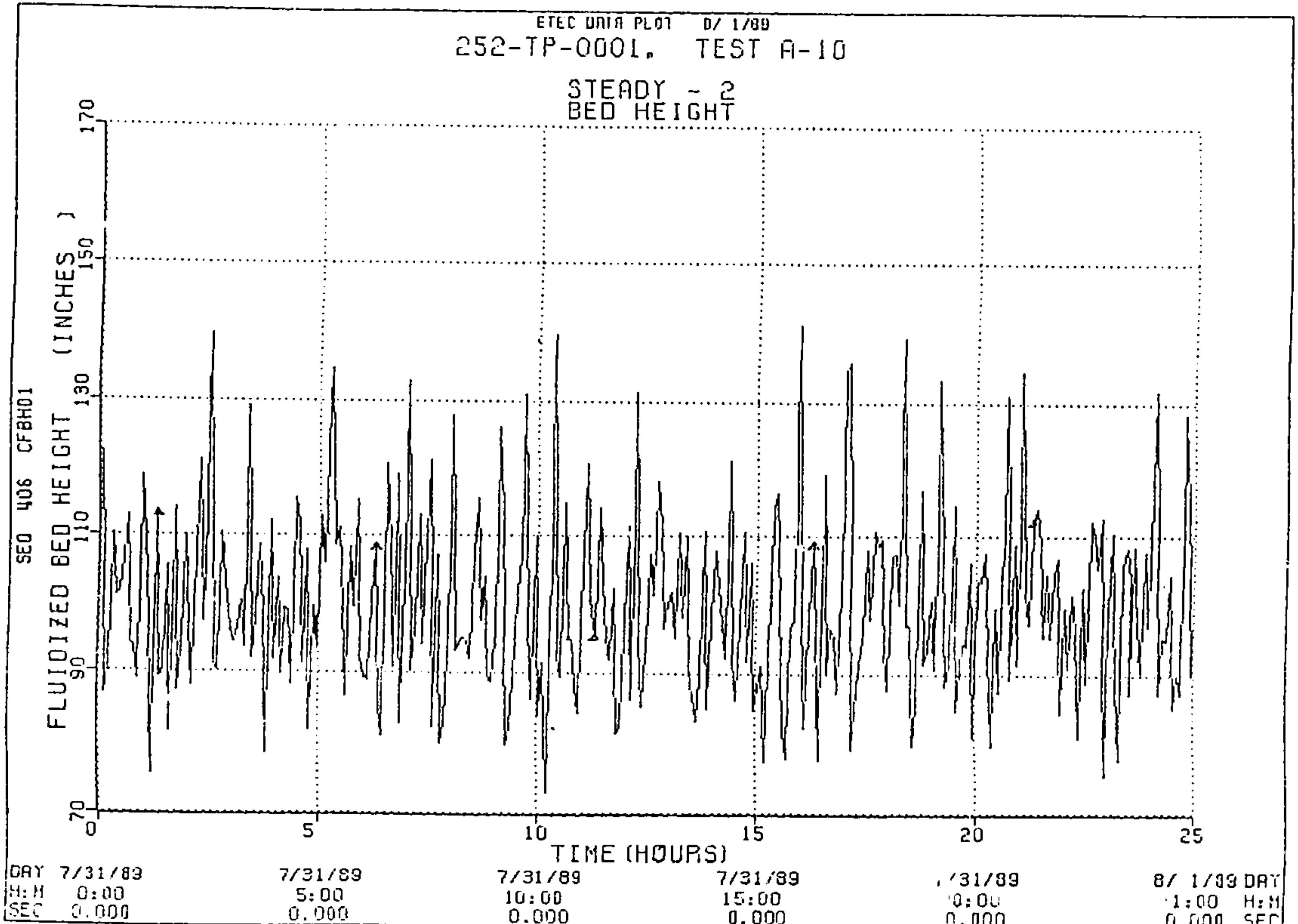


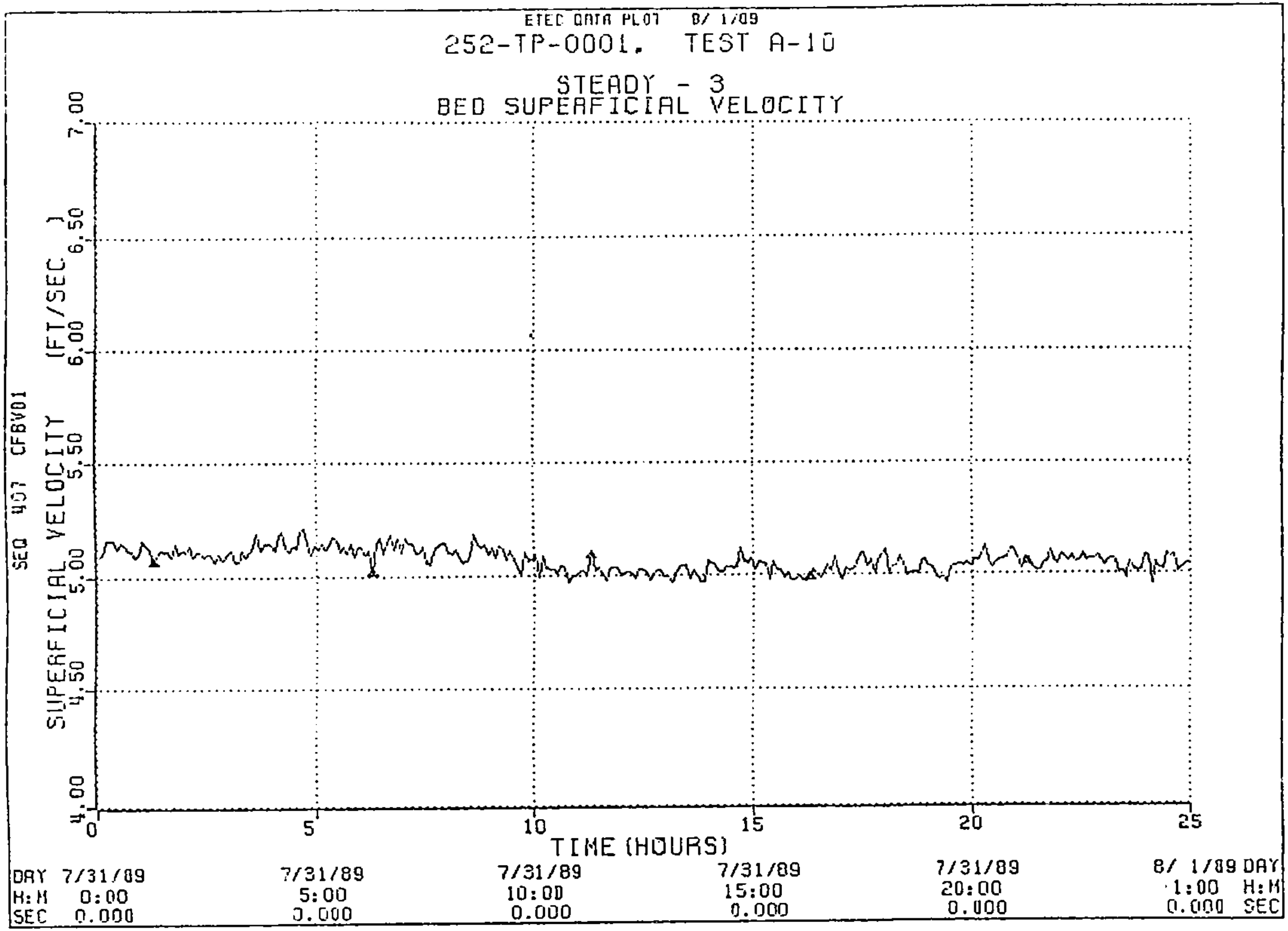
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
FBT06 DEG F SEQ 78
FBT07 DEG F SEQ 81
FBT12 DEG F SEQ 82
DAILY-25
FREEBOARD FLUE GAS TEMPERATURES
FLUID BED-UPPER FREEBOARD TEMP (229.3") (DEG F)
1700
1650
1600
1550
1500
1450
1400
1350
1300
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
DAILY-26
CONVEYING AIR TEMPERATURES
DEG F
DEG F
DEG F
SEQ 68
SEQ 72
SEQ 66
COMB AIR-VENTURI U/S TEMPERATURE (DEG F)
250
200
150
100
50
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

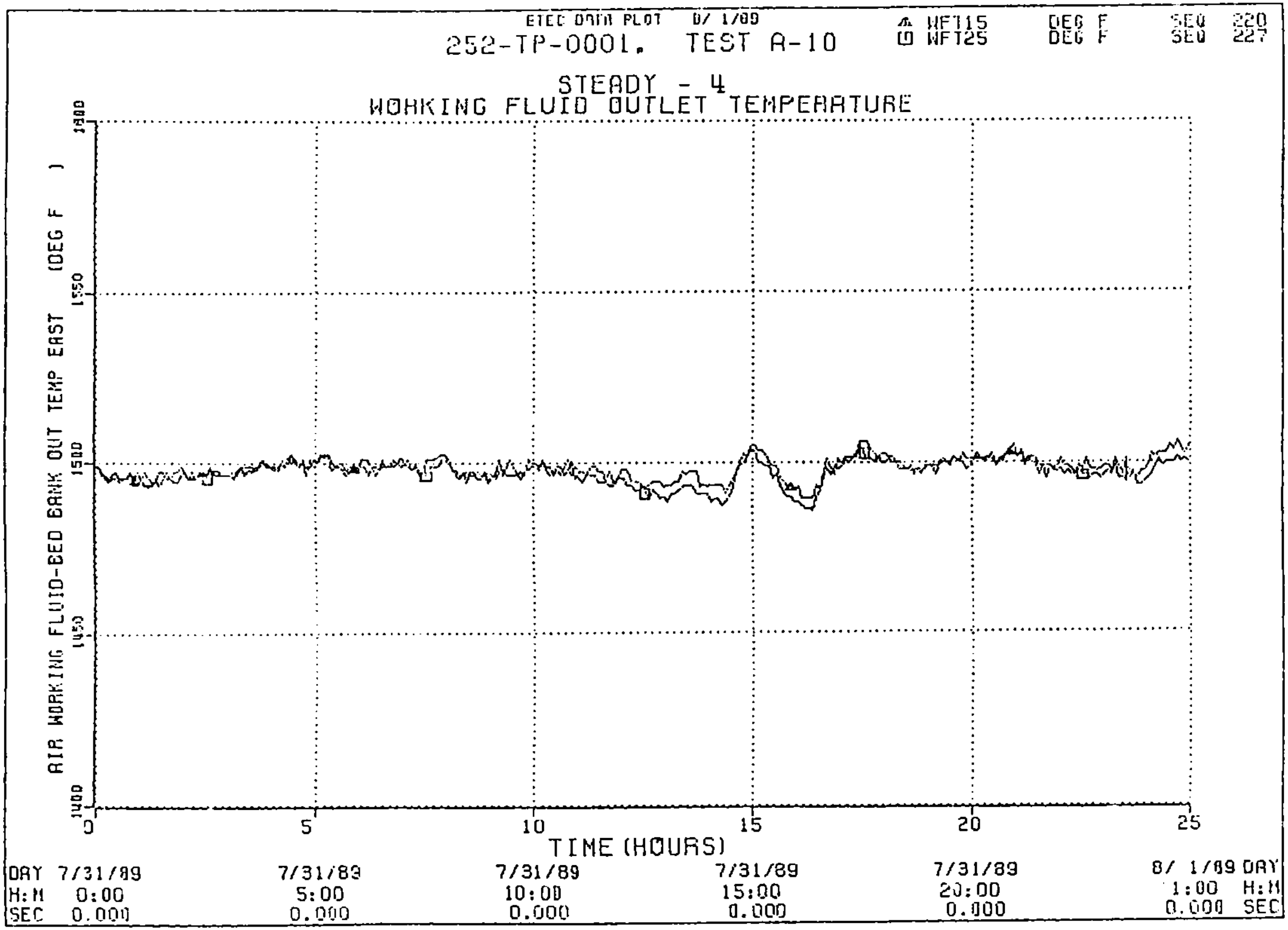

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
WFT01 DEG F SEQ 215
WFT11 DEG F SEQ 216
WFT21 DEG F SEQ 221
DAILY-27
WORKING FLUID SUPPLY TEMPERATURES
AIR WORKING FLUID-SUPPLY TEMPERATURE (DEG F)
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

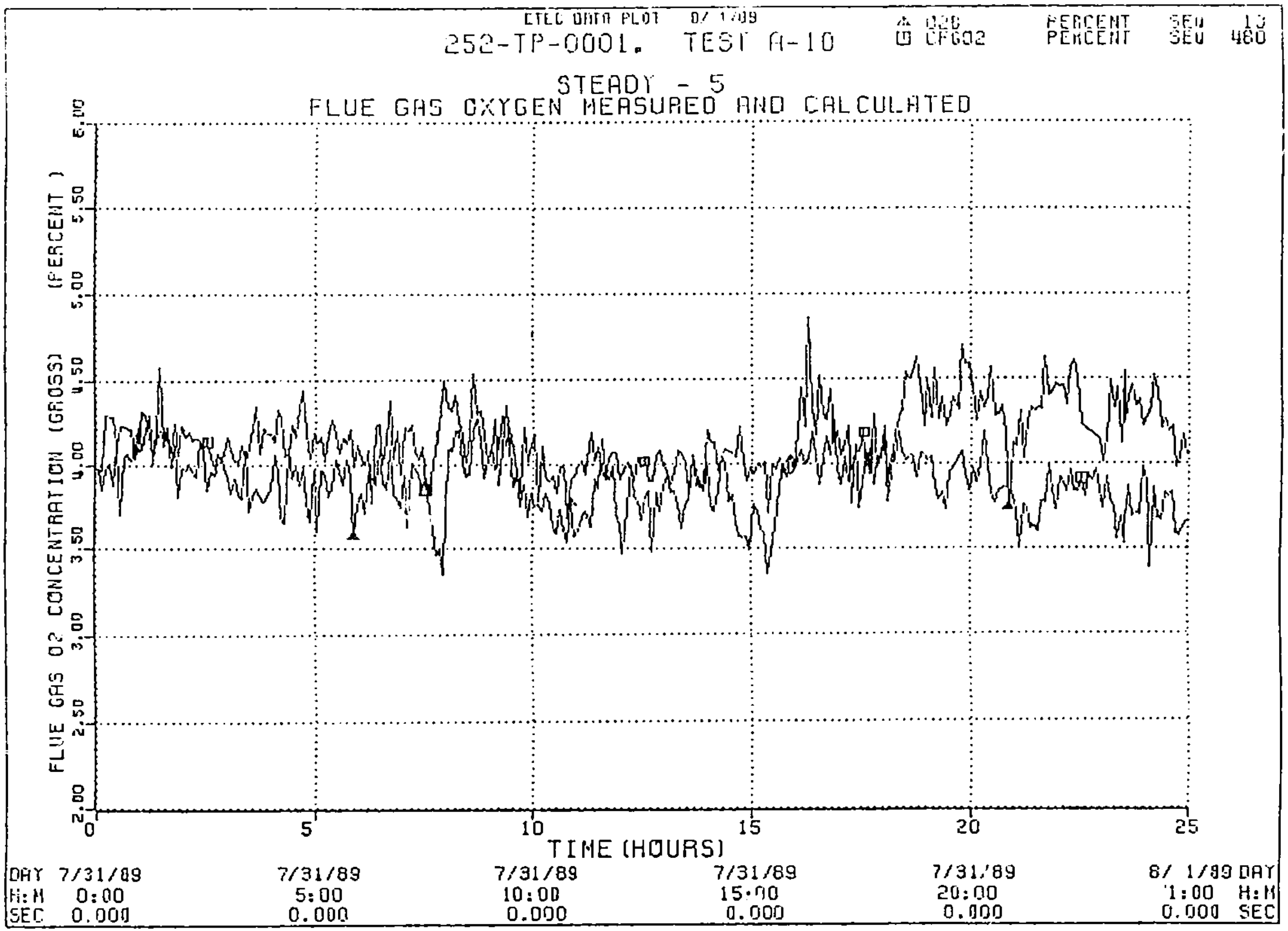

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
FBT02 DEG F
FBT04 DEG F
CFBT01 DEG F
STEADY - 1
LOWER/UPPER/AVERAGE BED TEMPERATURES
FLUID BED-BED TEMPERATURE (27.7") (DEG F)
1650
1600
1550
1500
1450
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

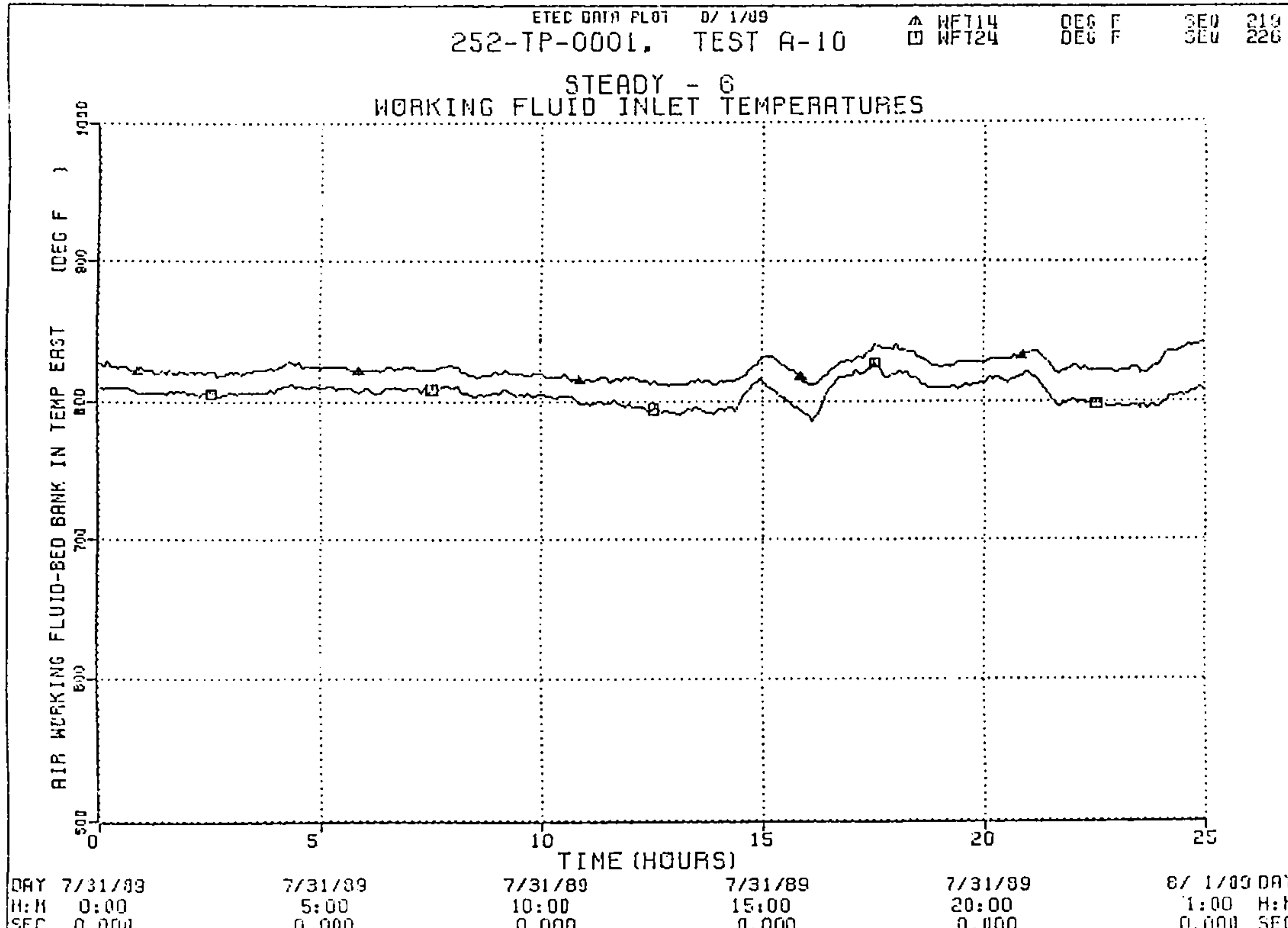

ETEC DATA PLOT 0/ 1/89
252-TP-0001, TEST A-10
STEADY - 2
BED HEIGHT
SEQ 406 CFBH01
FLUIDIZED BED HEIGHT (INCHES)
170
150
130
110
90
70
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
0.000
8/ 1/89 DAY
H:M
0.000 SEC

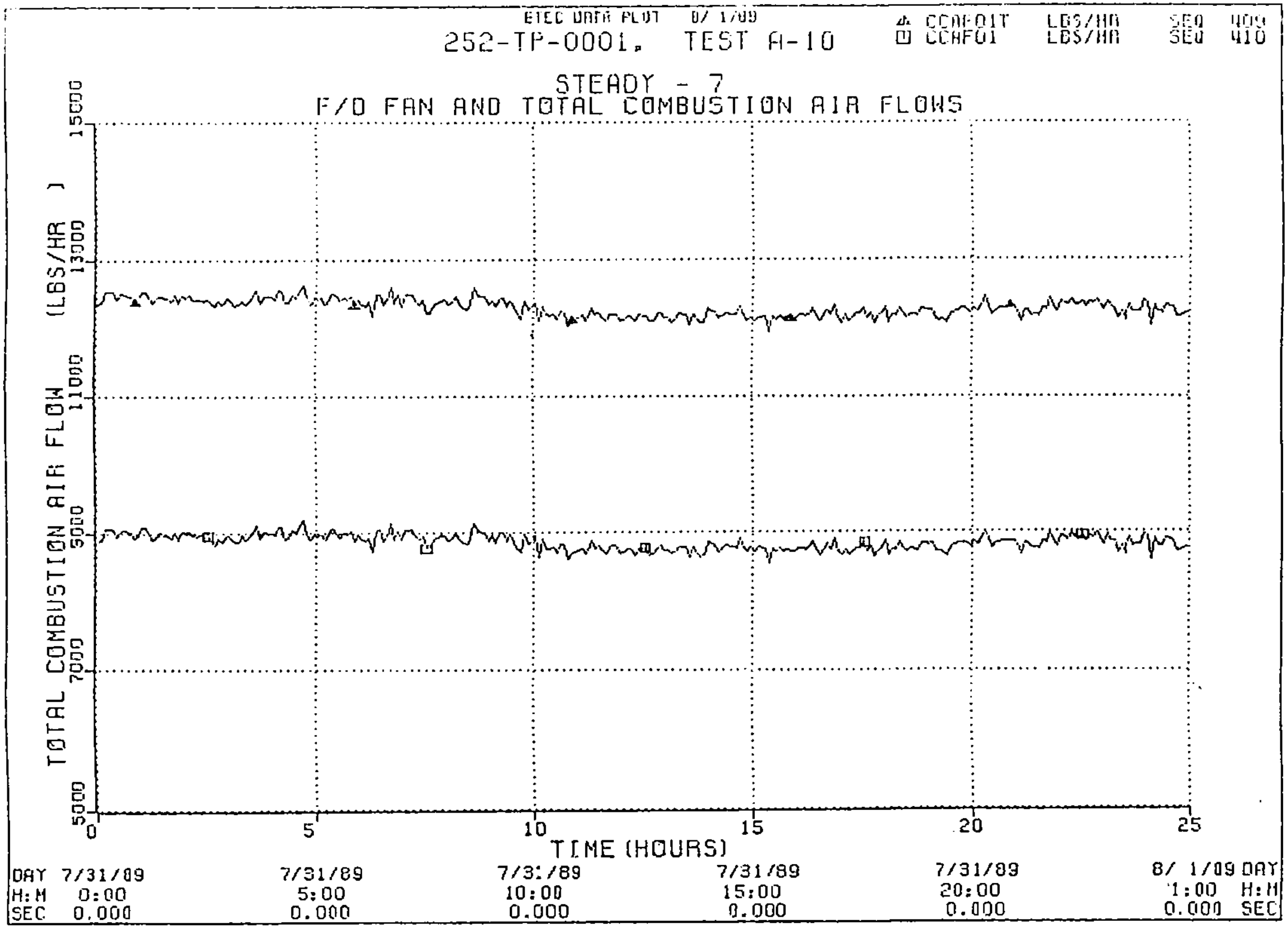


ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
STEADY - 3
BED SUPERFICIAL VELOCITY
SEQ 407 CFBV01
SUPERFICIAL VELOCITY (FT/SEC)
4.00
4.50
5.00
5.50
6.00
6.50
7.00
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

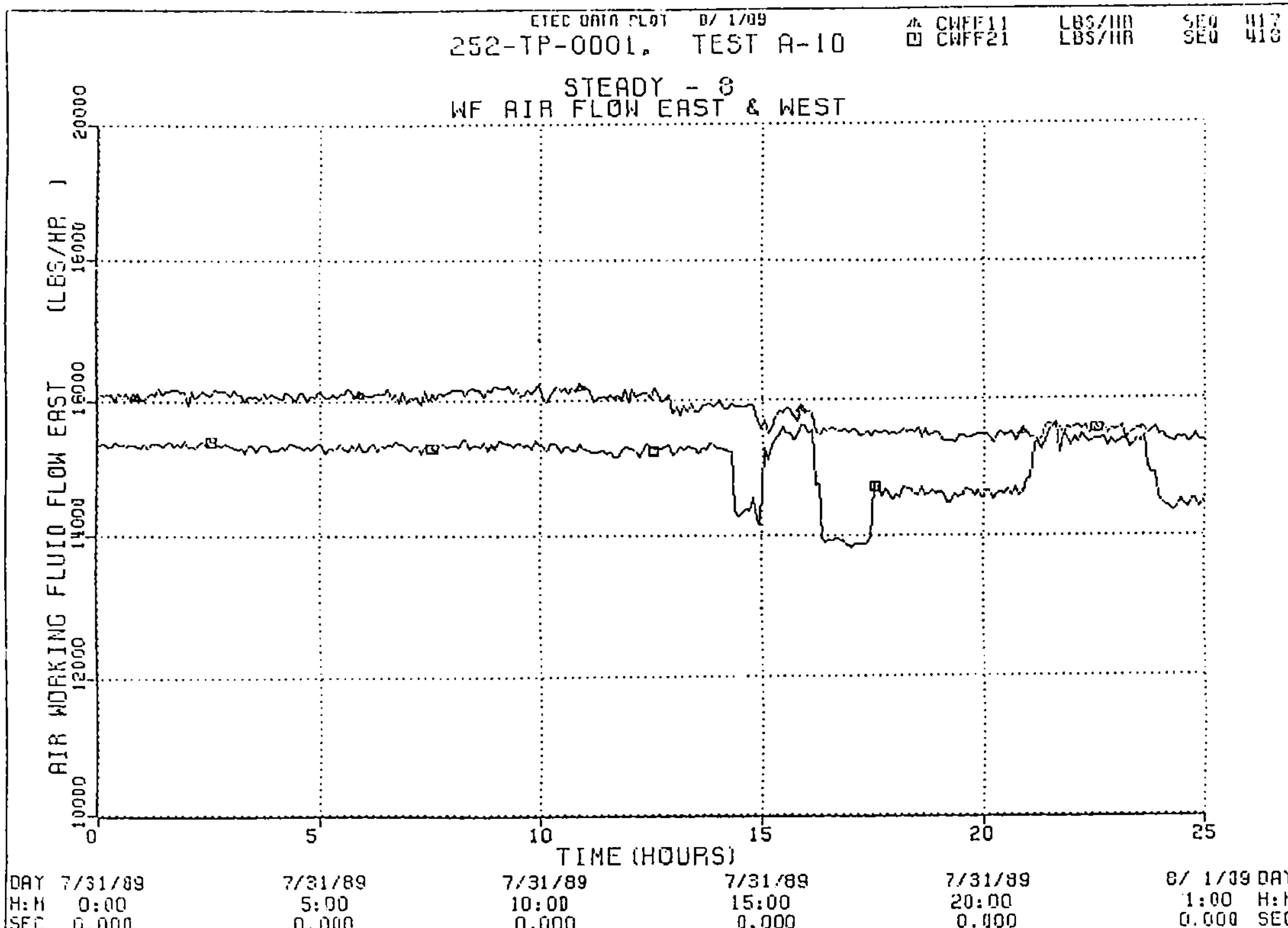

ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
WFT15 DEG F SEQ 220
WFT25 DEG F SEQ 227
STEADY - 4
WORKING FLUID OUTLET TEMPERATURE
AIR WORKING FLUID-BED BANK OUT TEMP EAST (DEG F)
1600
1550
1500
1450
1400
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC


ETEC DATA PLOT
252-TP-0001. TEST A-10
O2B PERCENT SEQ 13
CFGO2 PERCENT SEQ 460
STEADY - 5
FLUE GAS OXYGEN MEASURED AND CALCULATED
FLUE GAS O2 CONCENTRATION (GROSS) (PERCENT)
2.00
2.50
3.00
3.50
4.00
4.50
5.00
5.50
6.00
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

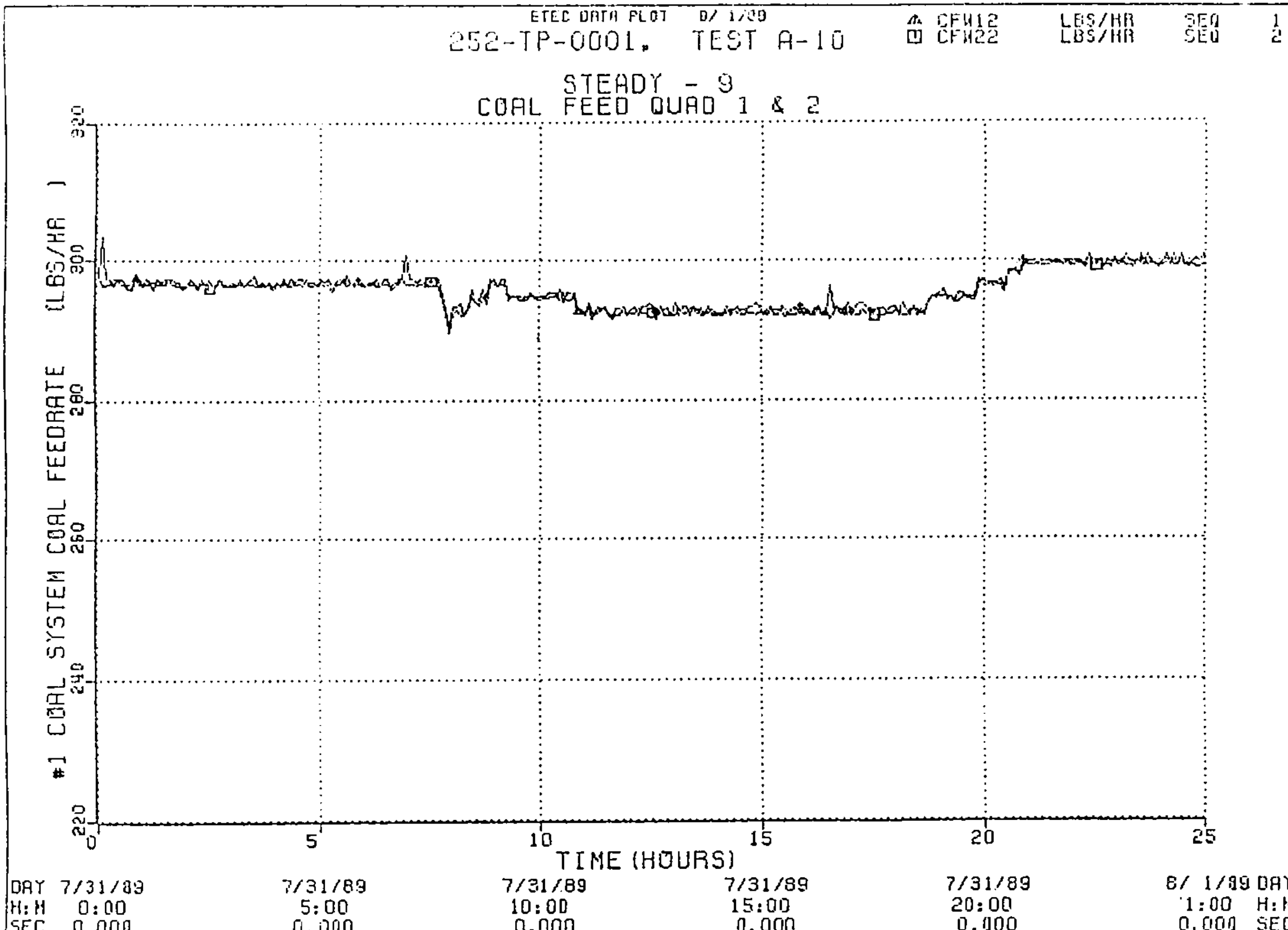

ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
▲ WFT14 DEG F SEQ 219
⊡ WFT24 DEG F SEQ 226
STEADY - 6
WORKING FLUID INLET TEMPERATURES
AIR WORKING FLUID-BED BANK IN TEMP EAST (DEG F)
1000
900
800
700
600
500
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

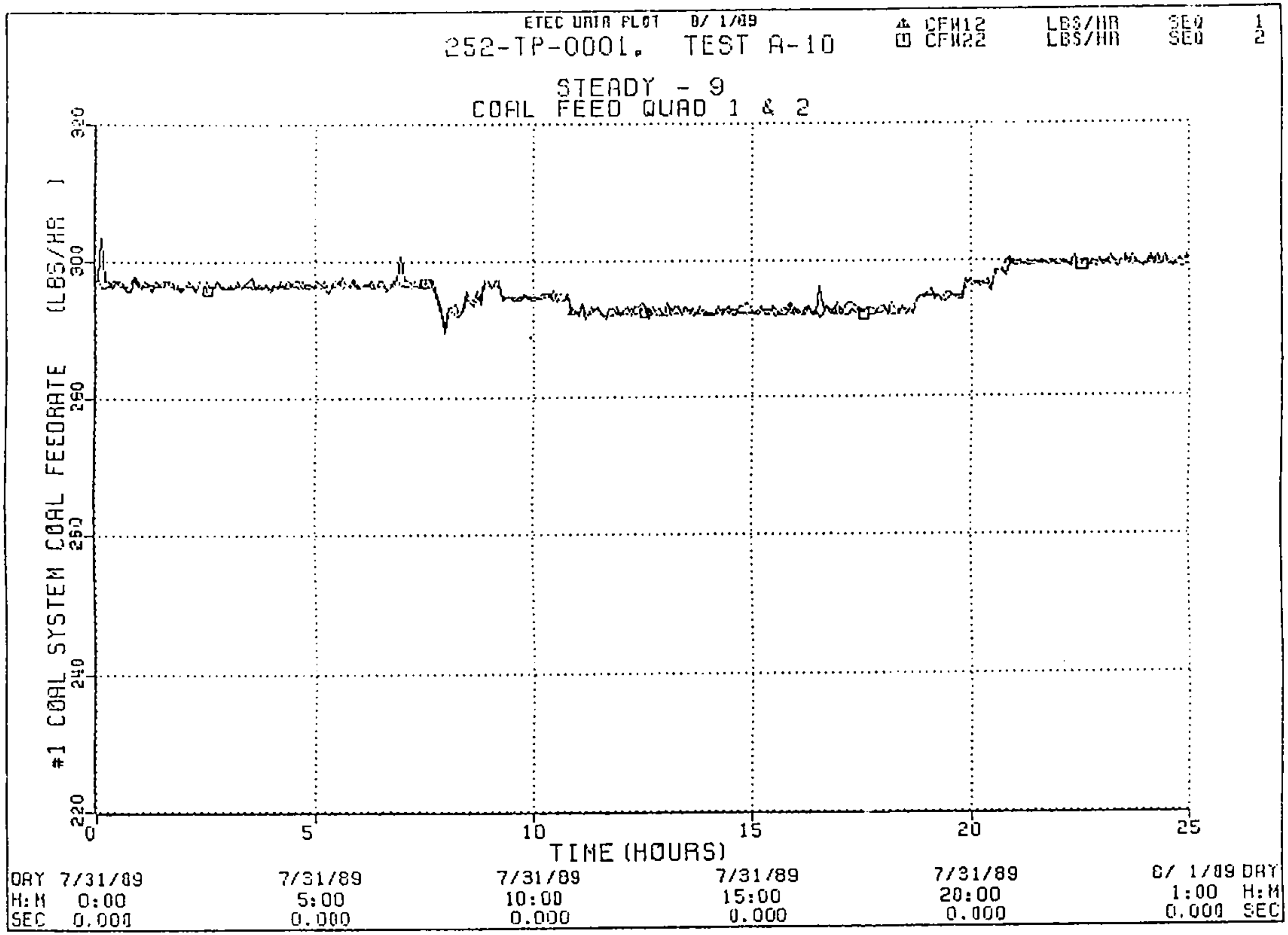


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
CCAF01T LBS/HR SEQ 409
CCAF01 LBS/HR SEQ 410
STEADY - 7
F/D FAN AND TOTAL COMBUSTION AIR FLOWS
TOTAL COMBUSTION AIR FLOW (LBS/HR)
15000
13000
11000
9000
7000
5000
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC

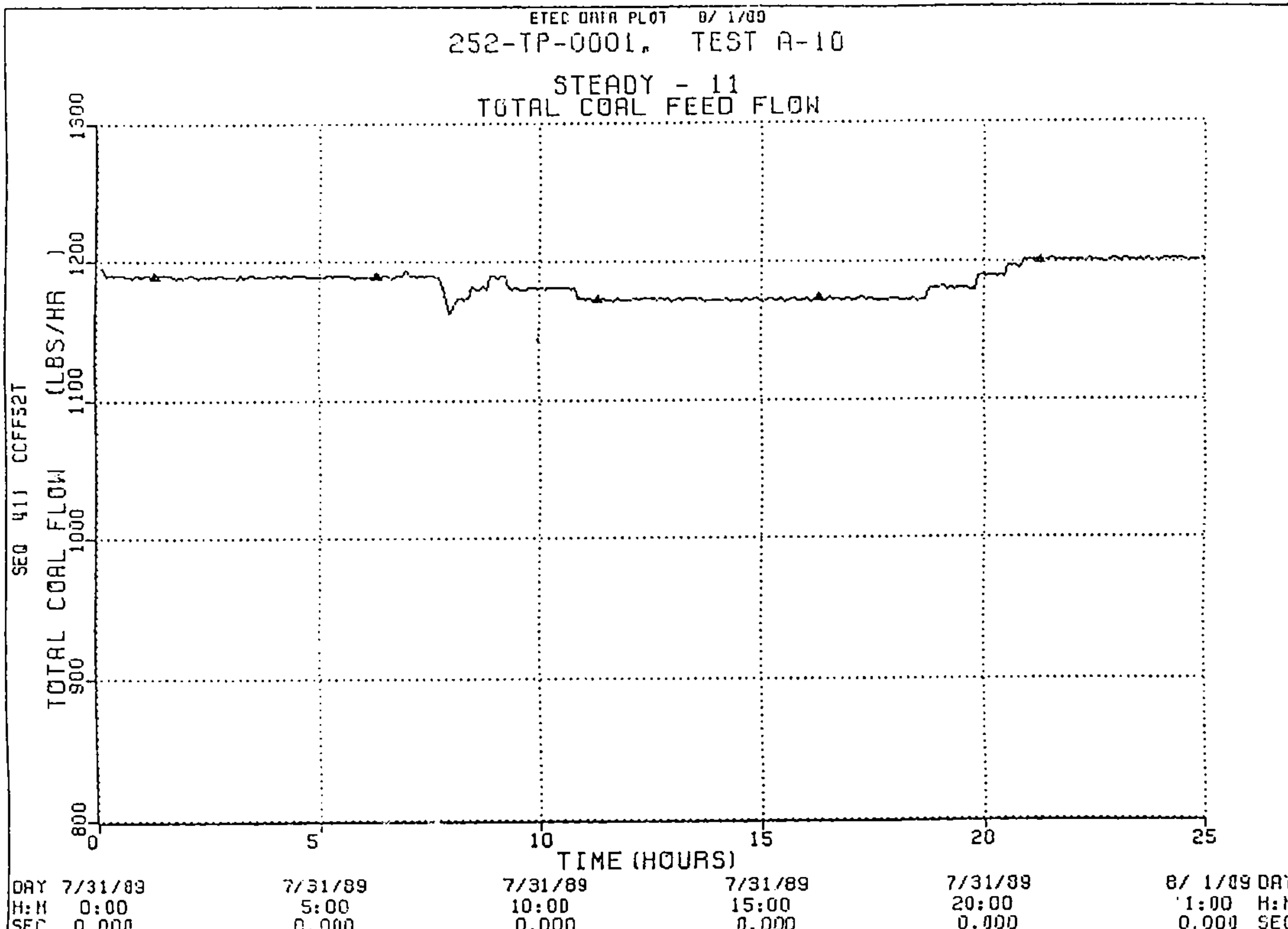


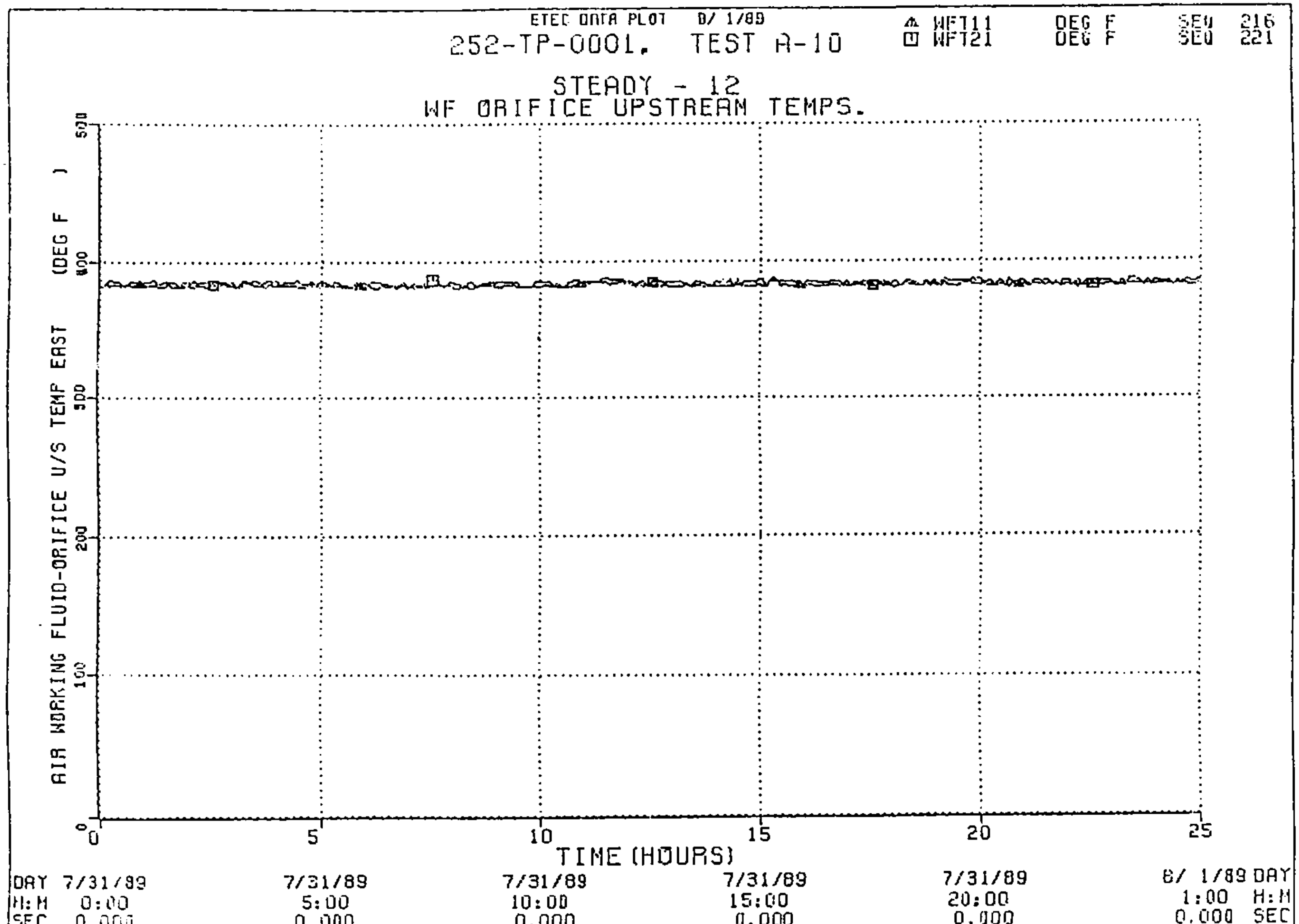
ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
STEADY - 8
WF AIR FLOW EAST & WEST
△ CWFF11 LBS/HR SEQ 417
□ CWFF21 LBS/HR SEQ 418
AIR WORKING FLUID FLOW EAST (LBS/HR)
10000
12000
14000
16000
18000
20000
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

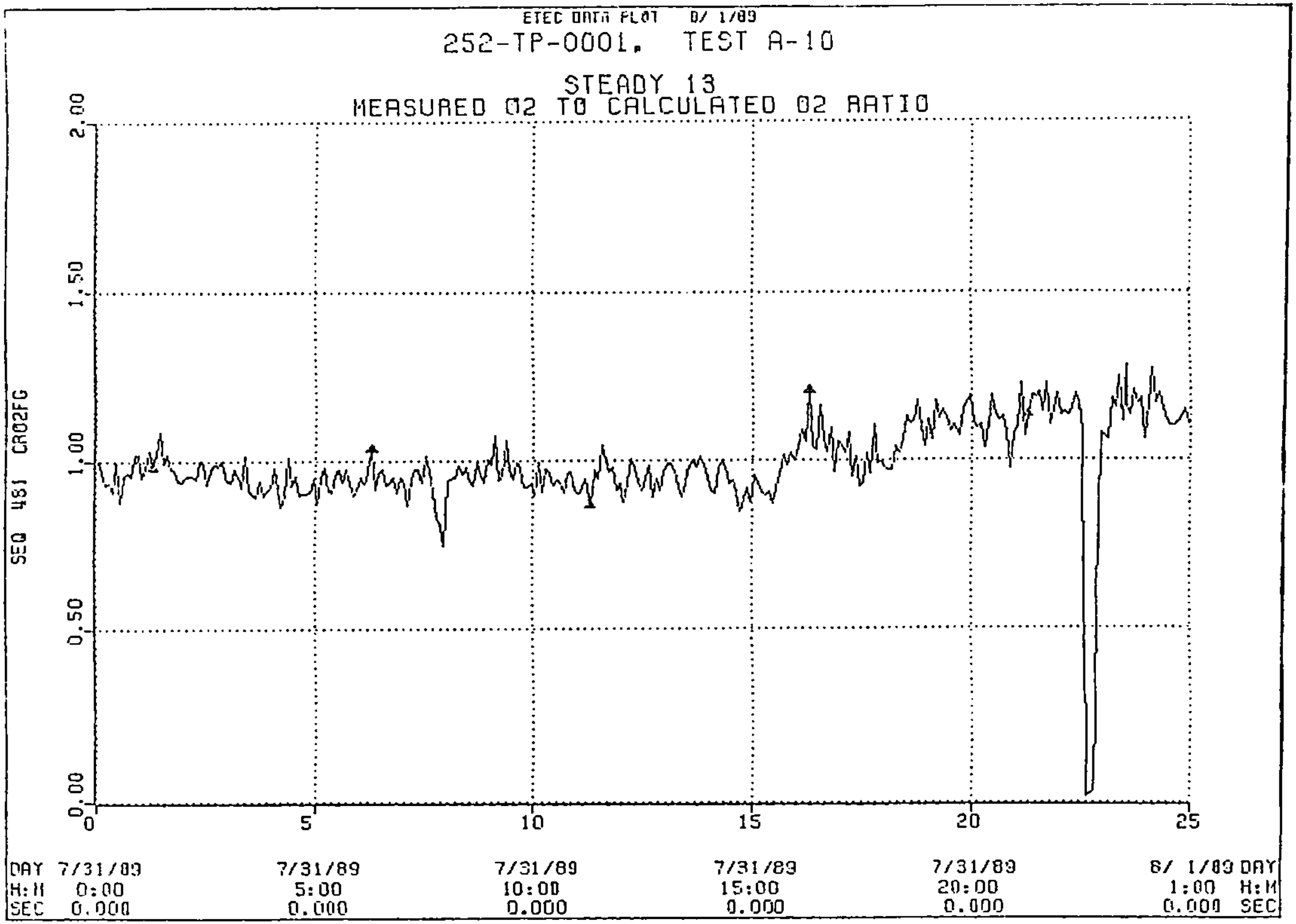

ETEC DATA PLOT
252-TP-0001, TEST A-10
CFW12 LBS/HR SEQ 1
CFW22 LBS/HR SEQ 2
STEADY - 9
COAL FEED QUAD 1 & 2
#1 COAL SYSTEM COAL FEEDRATE (LBS/HR)
320
300
280
260
240
220
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC



ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
CFM12 LBS/HR SEQ 1
CFM22 LBS/HR SEQ 2
STEADY - 9
COAL FEED QUAD 1 & 2
#1 COAL SYSTEM COAL FEEDRATE (LBS/HR)
320
300
280
260
240
220
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89
H:M 0:00
SEC 0.000
7/31/89
5:00
0.000
7/31/89
10:00
0.000
7/31/89
15:00
0.000
7/31/89
20:00
0.000
8/ 1/89 DAY
1:00 H:M
0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
STEADY - 11
TOTAL COAL FEED FLOW
SEQ 411 CCFF52T
TOTAL COAL FLOW (LBS/HR)
1300
1200
1100
1000
900
800
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC


ETEC DATA PLOT 8/ 1/89
252-TP-0001. TEST A-10
△ WFT11 DEG F SEQ 216
□ WFT21 DEG F SEQ 221
STEADY - 12
WF ORIFICE UPSTREAM TEMPS.
AIR WORKING FLUID-ORIFICE U/S TEMP EAST (DEG F)
500
400
300
200
100
0
0
5
10
15
20
25
TIME (HOURS)
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

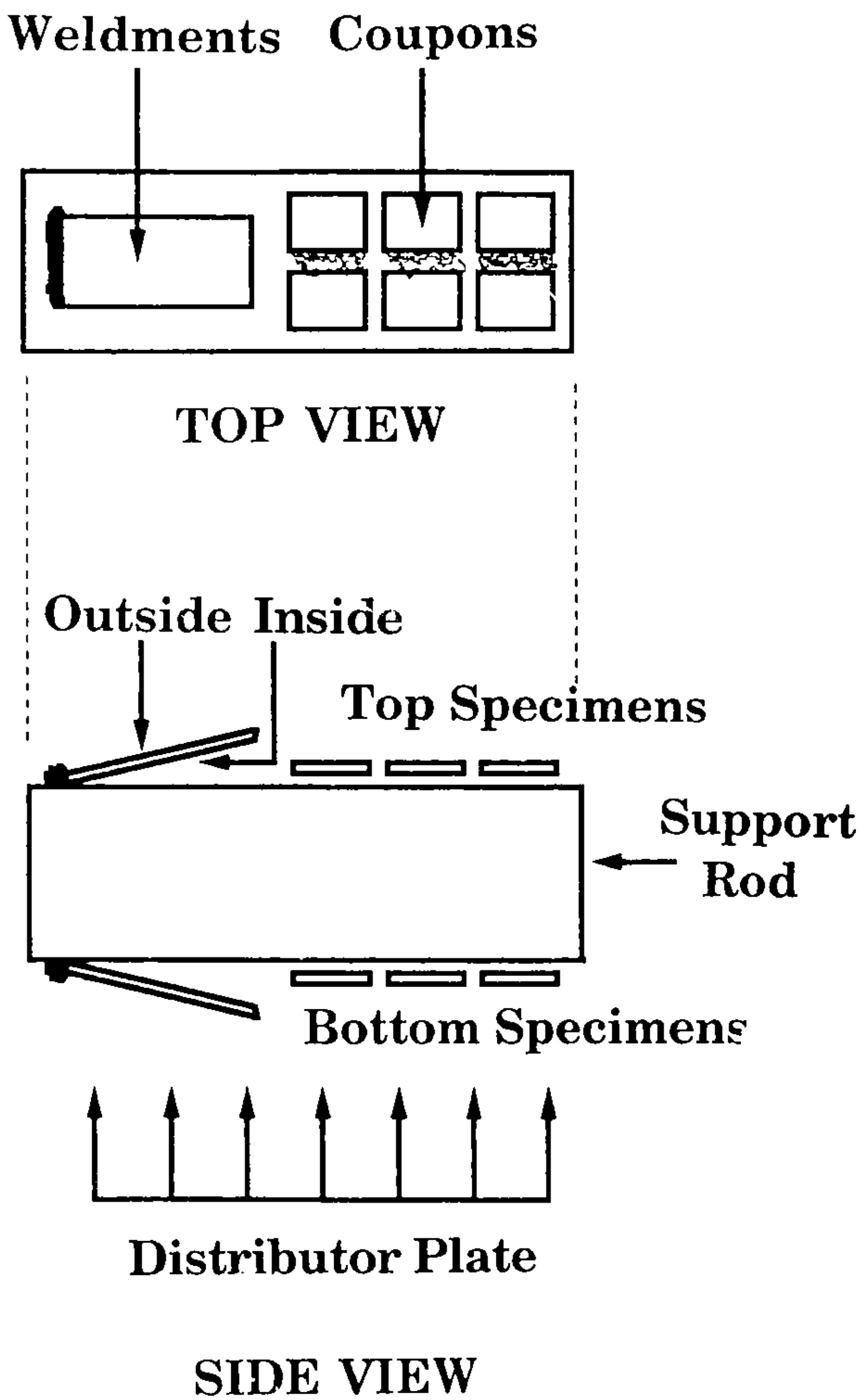


ETEC DATA PLOT 8/ 1/89
252-TP-0001, TEST A-10
STEADY 13
MEASURED O2 TO CALCULATED O2 RATIO
SEQ 481 CRO2FG
2.00
1.50
1.00
0.50
0.00
0
5
10
15
20
25
DAY 7/31/89 7/31/89 7/31/89 7/31/89 7/31/89 8/ 1/89 DAY
H:M 0:00 5:00 10:00 15:00 20:00 1:00 H:M
SEC 0.000 0.000 0.000 0.000 0.000 0.000 SEC

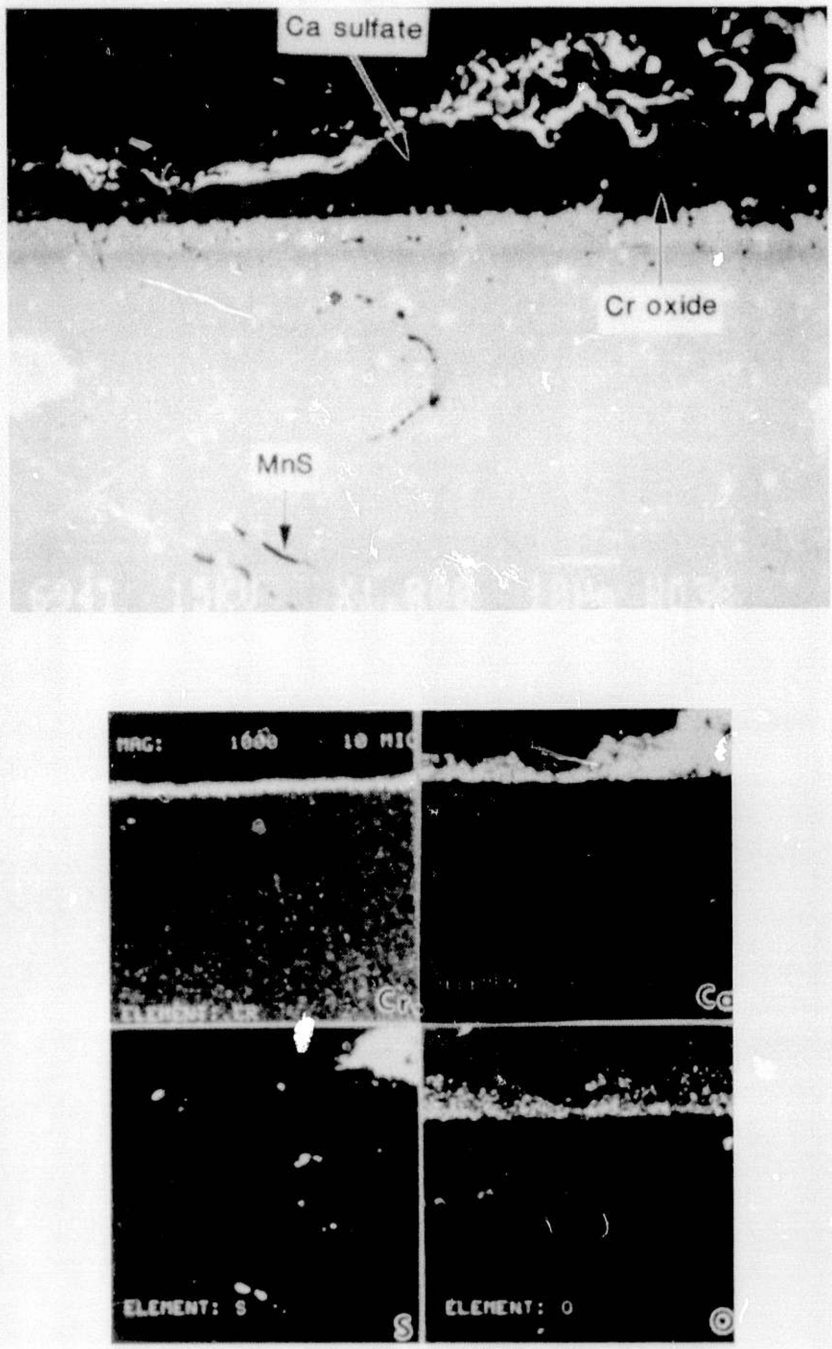
APPENDIX B.

MICROSTRUCTURES OF SPECIMENS FROM ANL PROBE BMUEB

PROBE ID:	**BMUEB**
TYPE OF PROBE:	**Uncooled**
EXPOSURE TIME:	**1000 and 1980 h**
ORGANIZATION:	**Argonne National Laboratory**

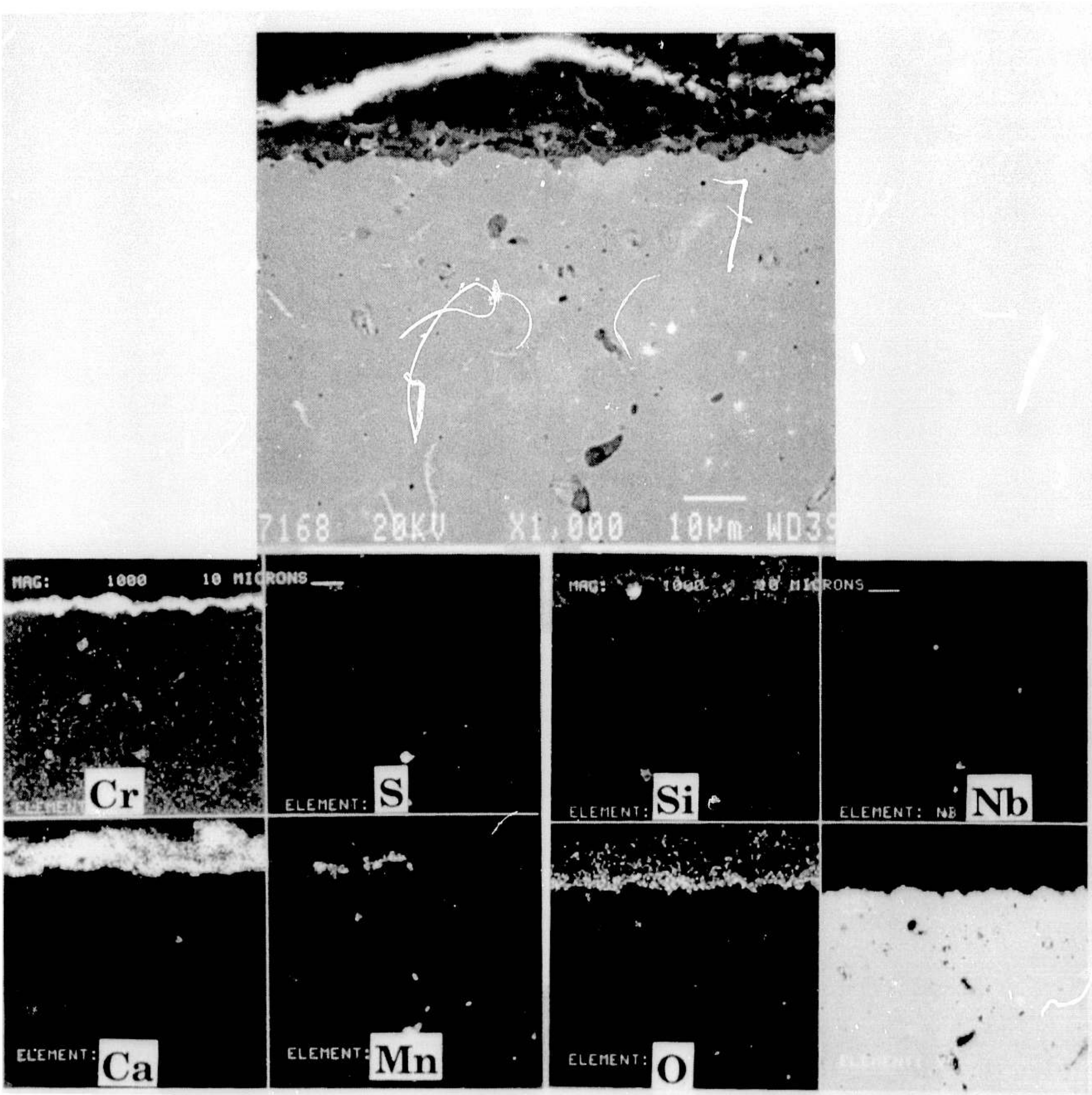


ANL Uncooled Probe BMUEB



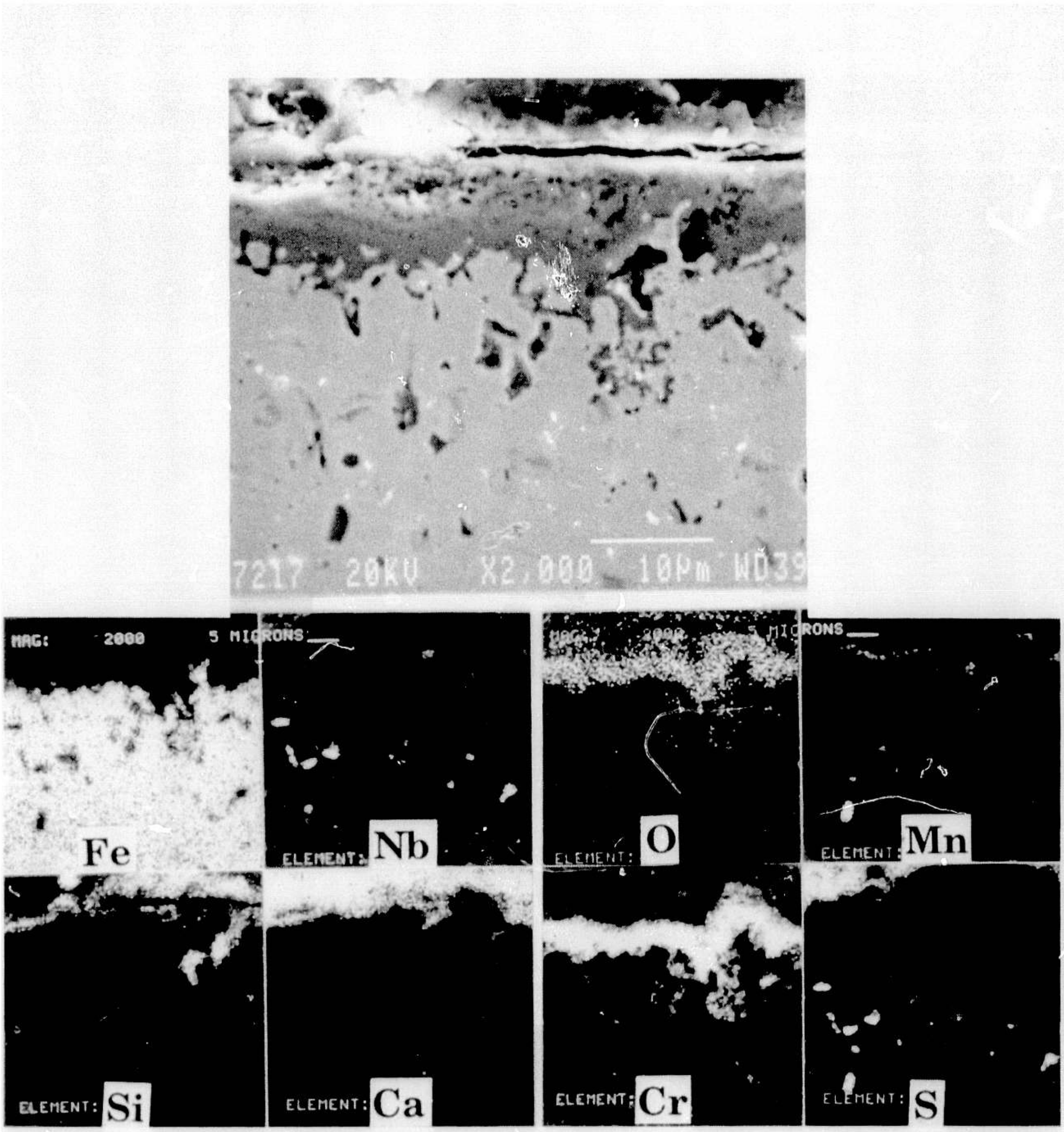
Alloy 800

SEM Micrograph and X-ray Mapping of Alloy 800 Exposed for 1000 h



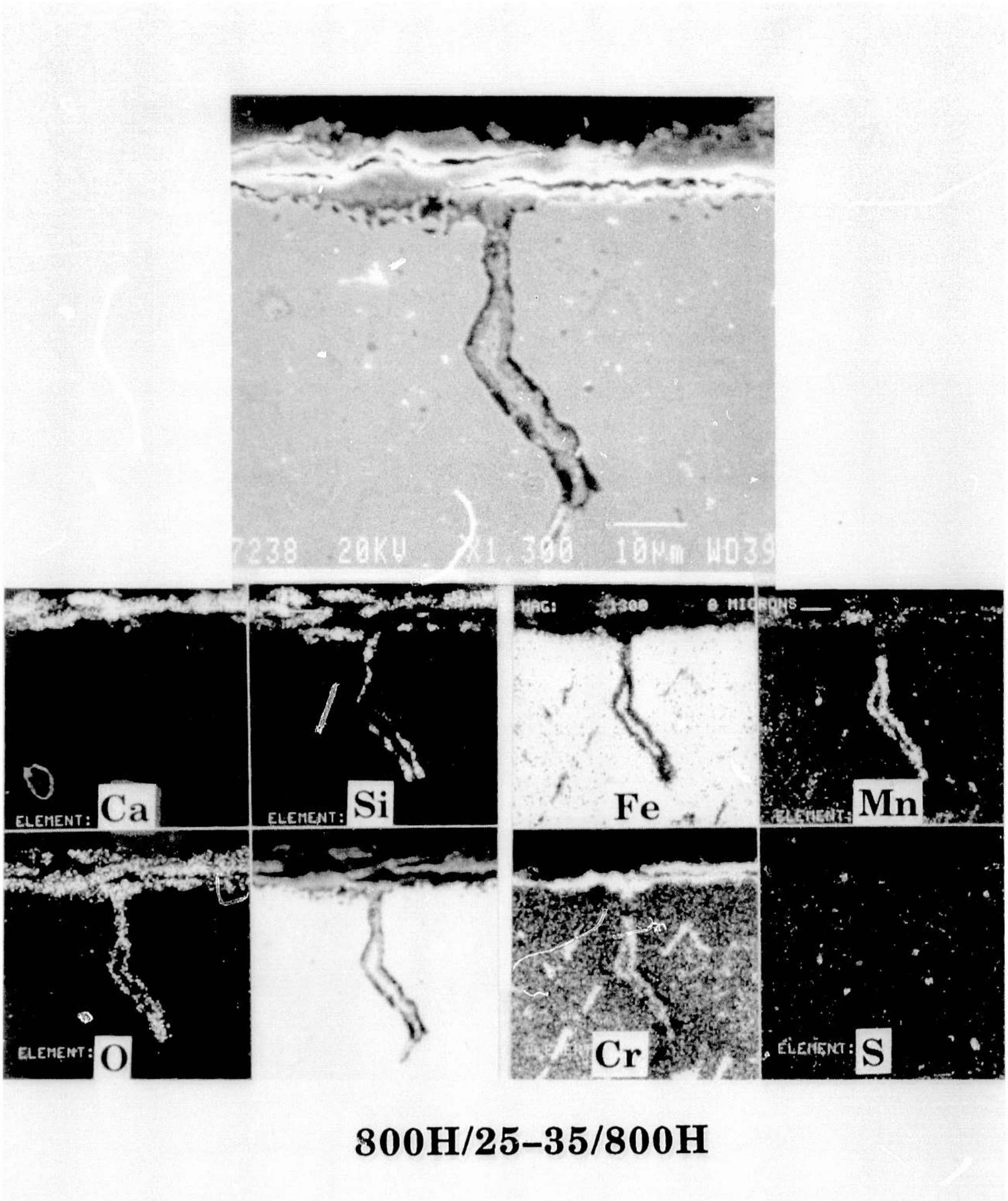
800H/Nicro 82/800H

SEM Micrograph and X-ray Mapping of 800H/Nicro 82/800H
Weldment after 1000 h Exposure

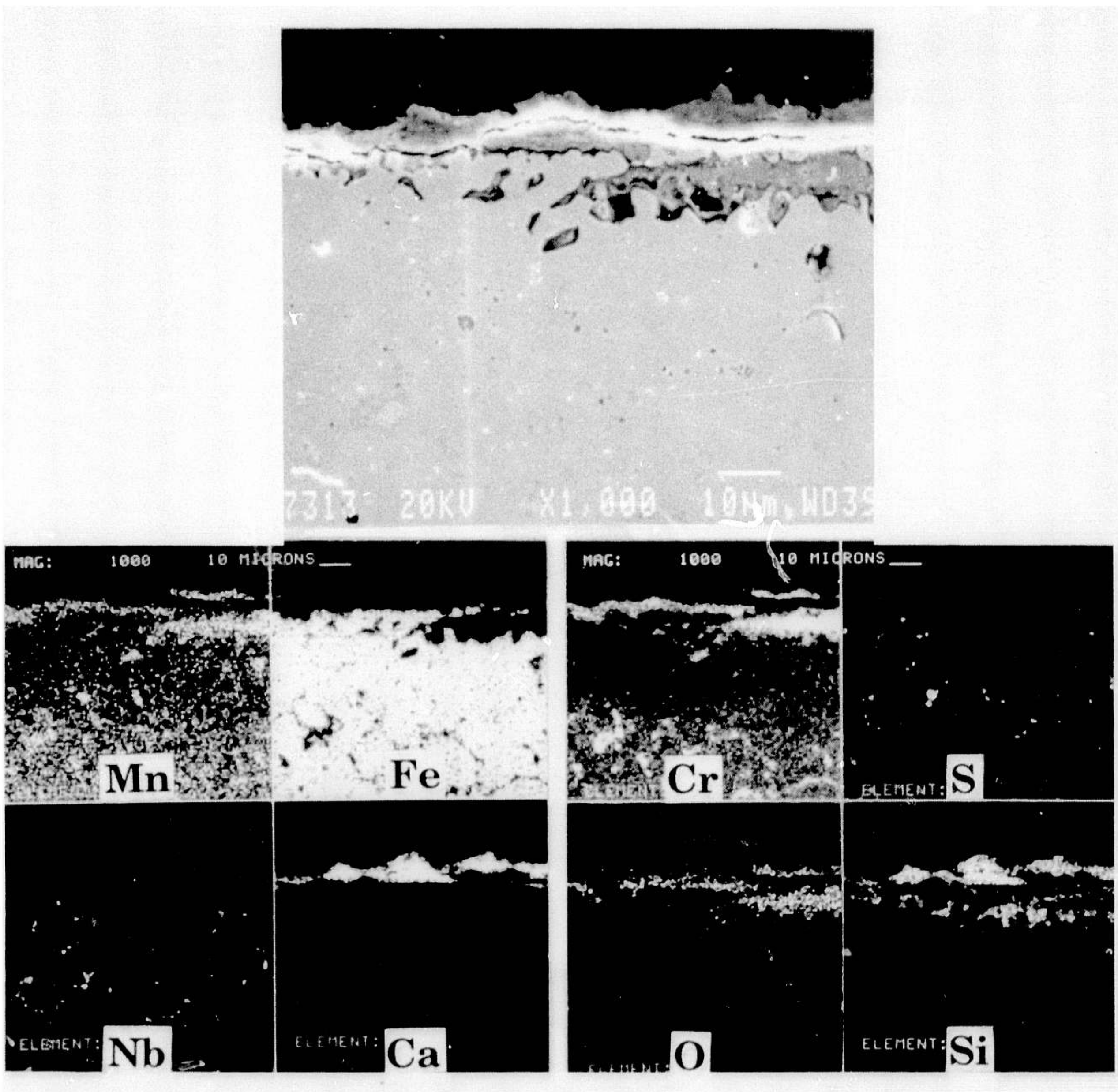


800H/21–33/800H

SEM Micrograph and X-ray Mapping of 21-33 Weldment after 1000 h Exposure

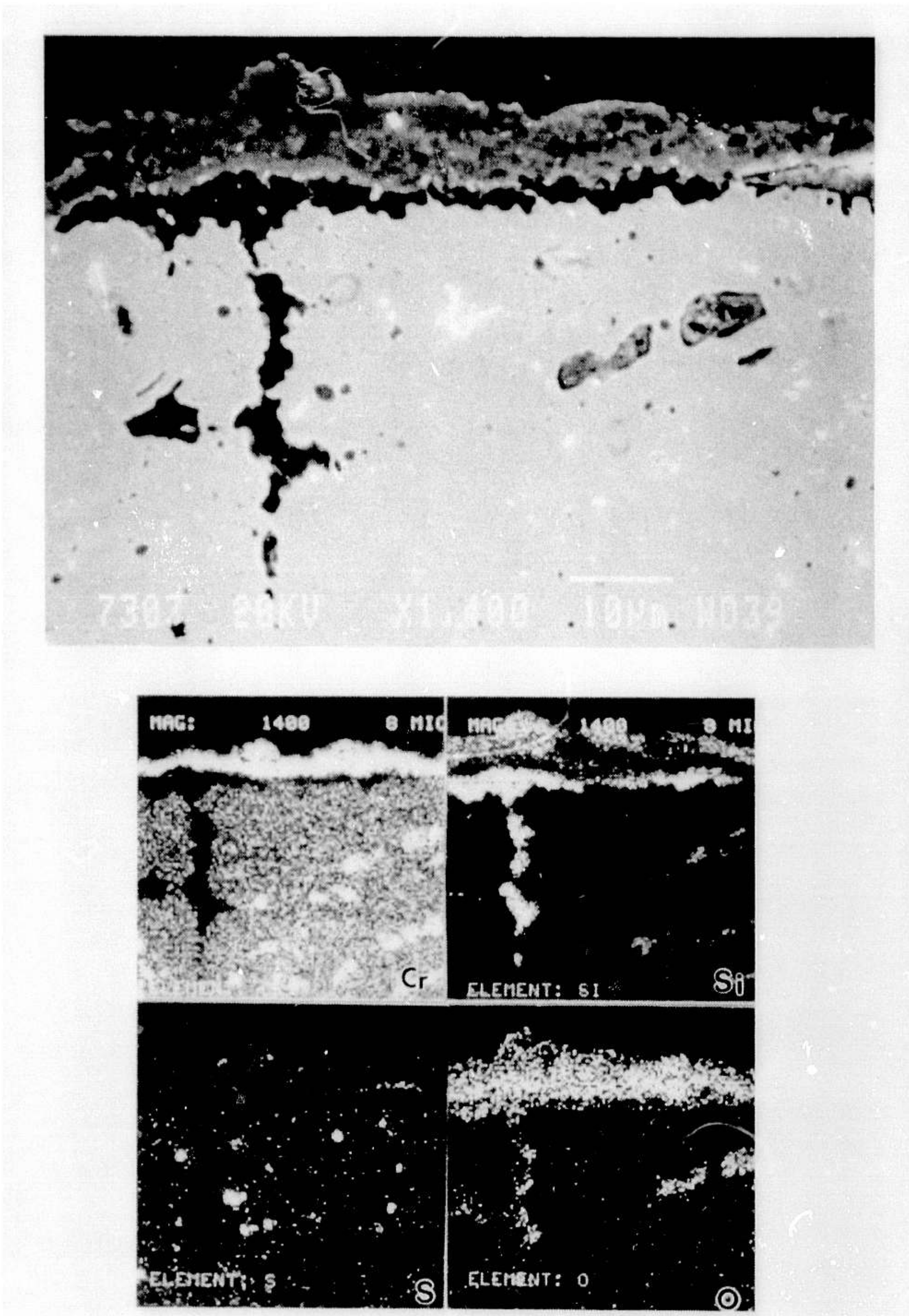


SEM Micrograph and X-ray Mapping of 25-35 Weldment after 1000 h Exposure



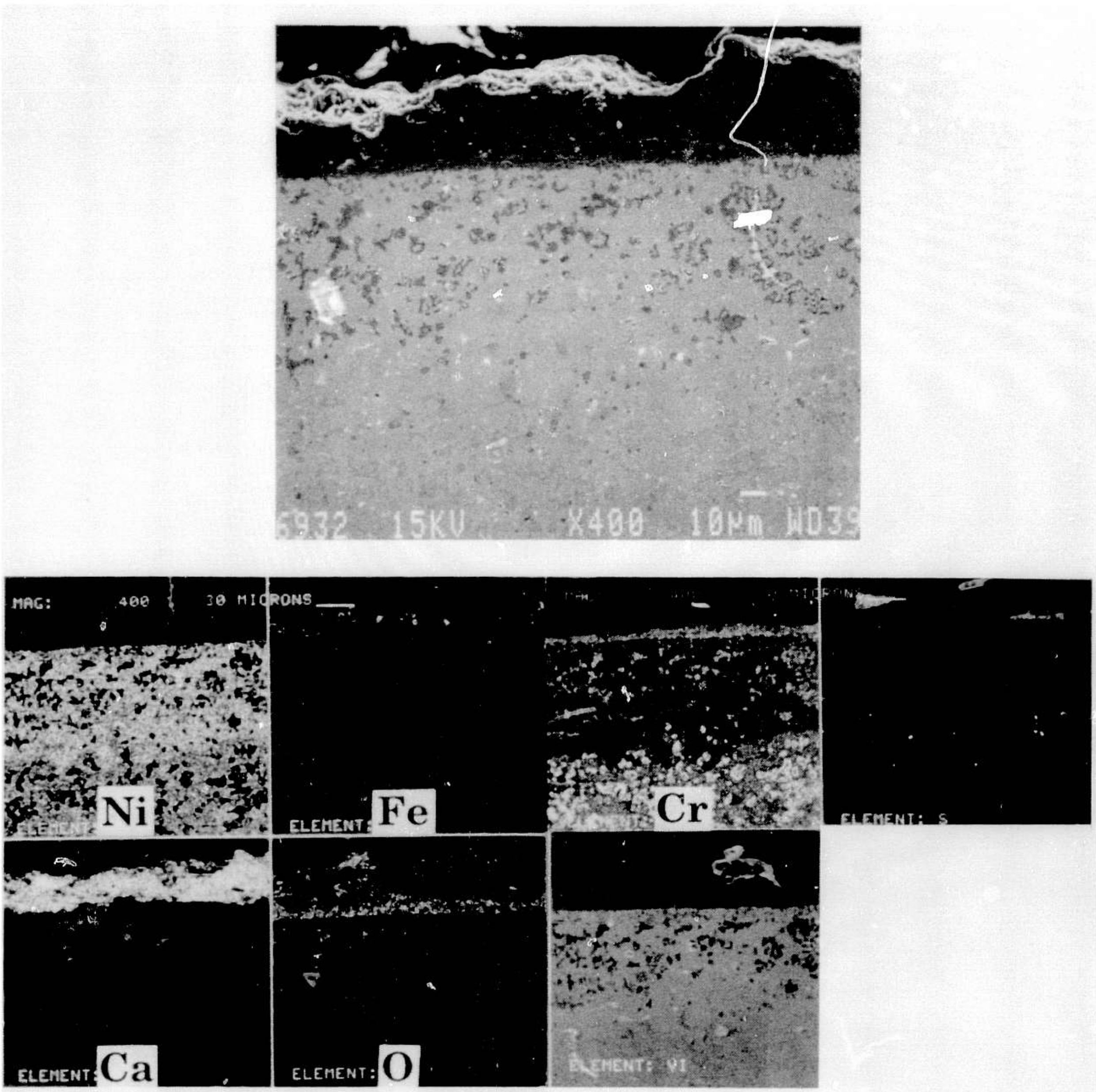
800H/25-35R/800H

SEM Micrograph and X-ray Mapping of 25-35R Weldment after 1000 h Exposure



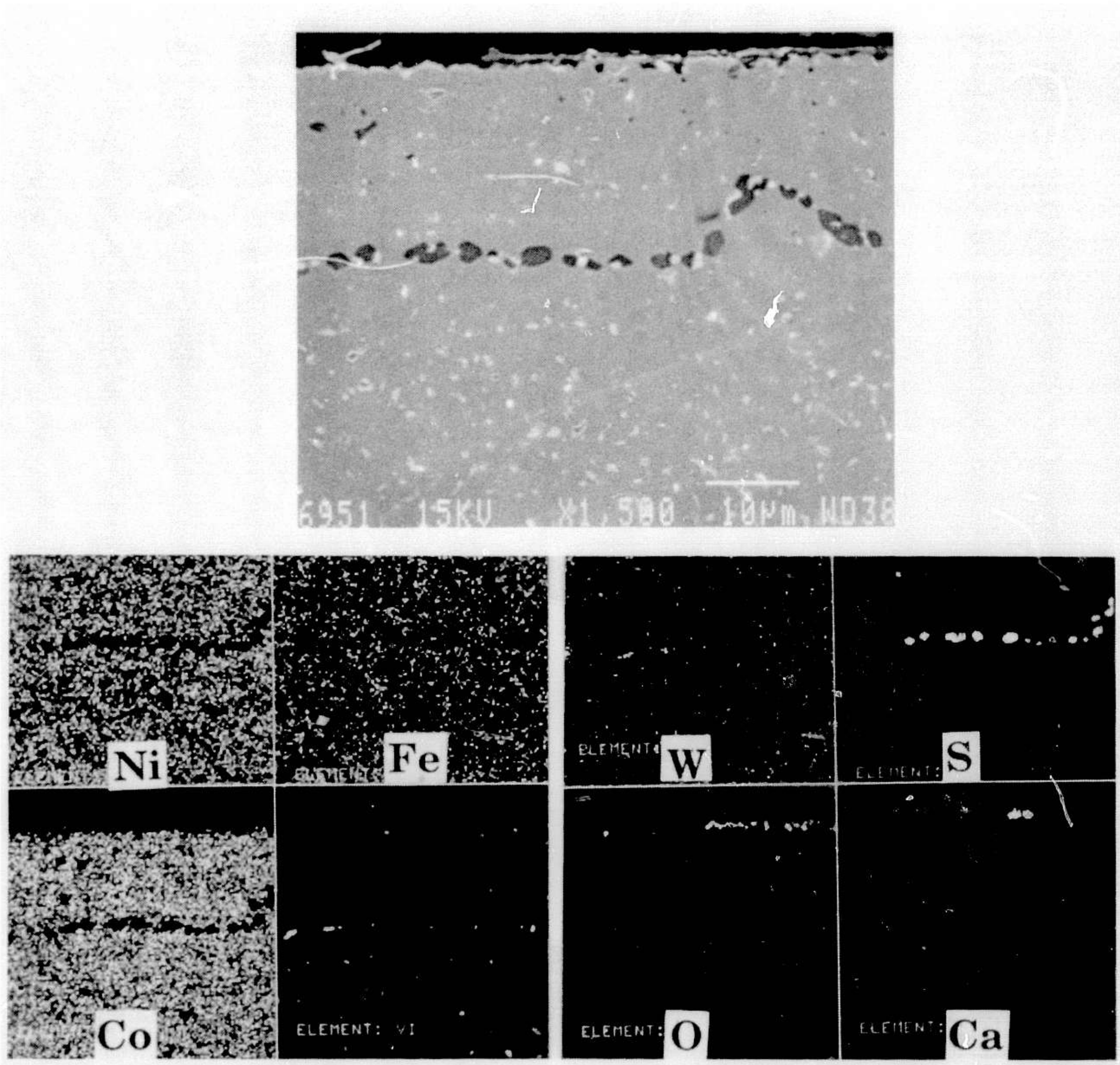
800H/30–50/800H

SEM Micrograph and X-ray Mapping of 30-50 Weldment after 1000 h Exposure



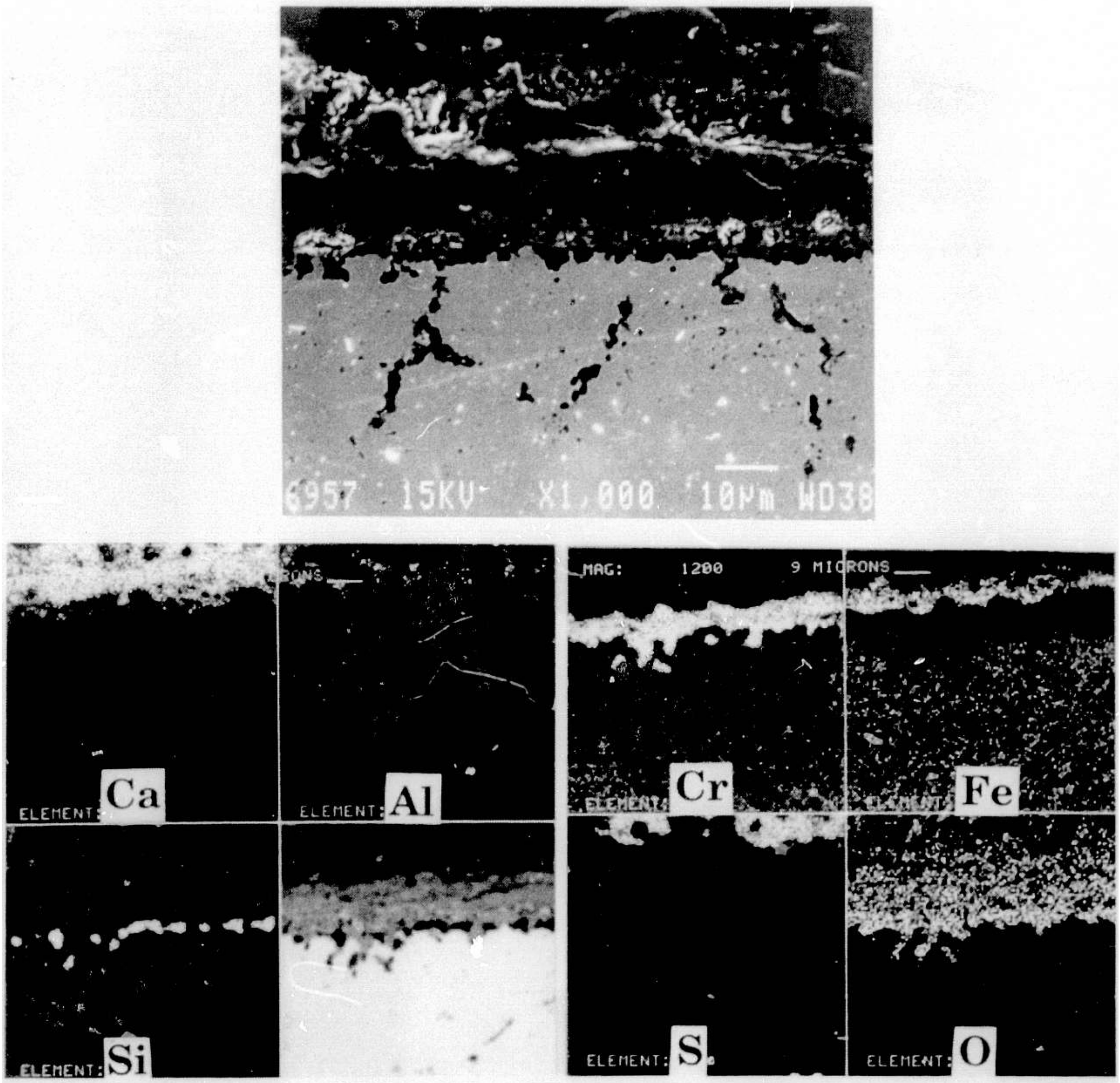
800H/50–50 Nb/800H

SEM Micrograph and X-ray Mapping of 50-50 Nb after 1000 h Exposure



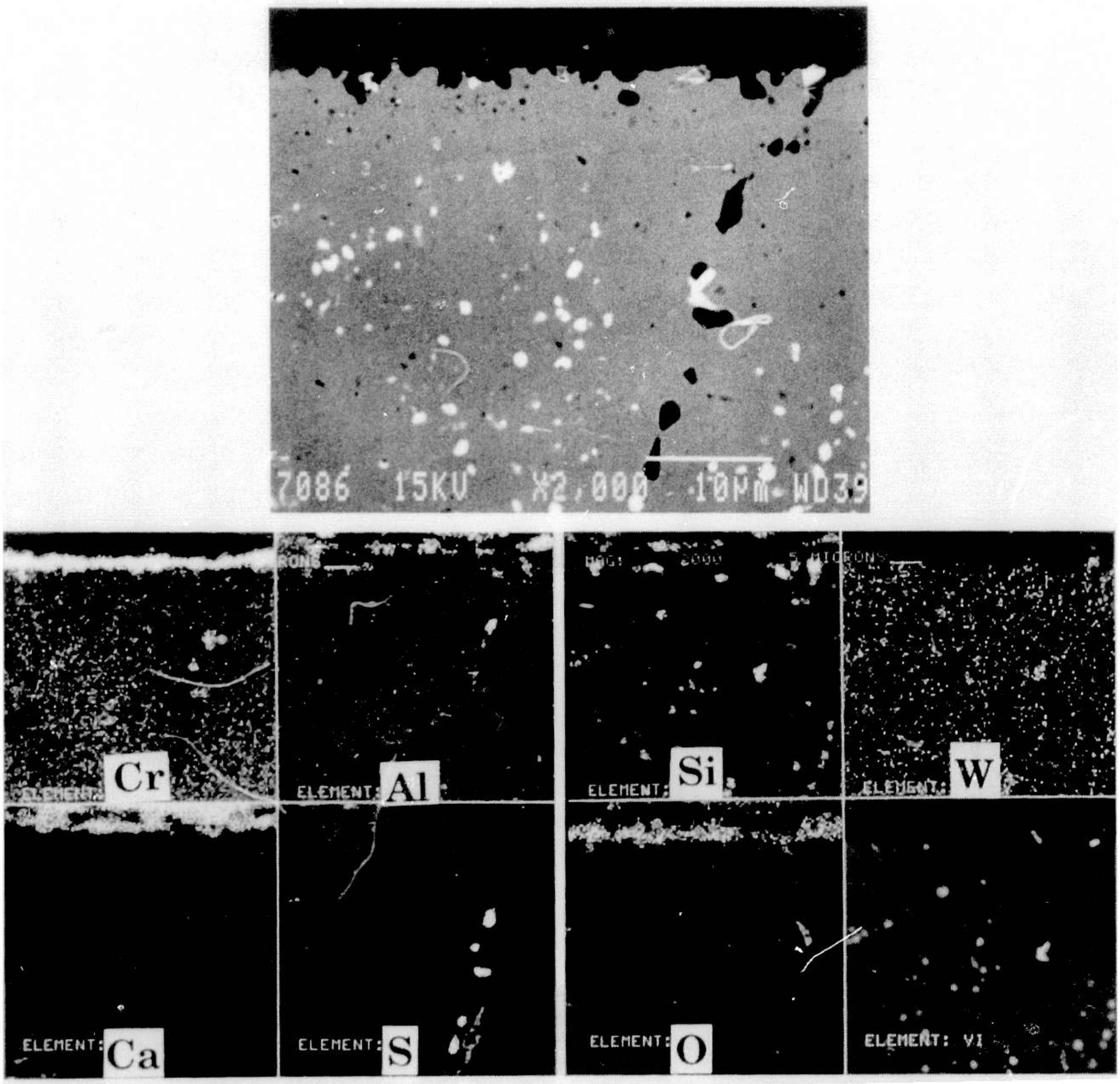
800H/188/800H

SEM Micrograph and X-ray Mapping of 188 Weldment after 1000 h Exposure



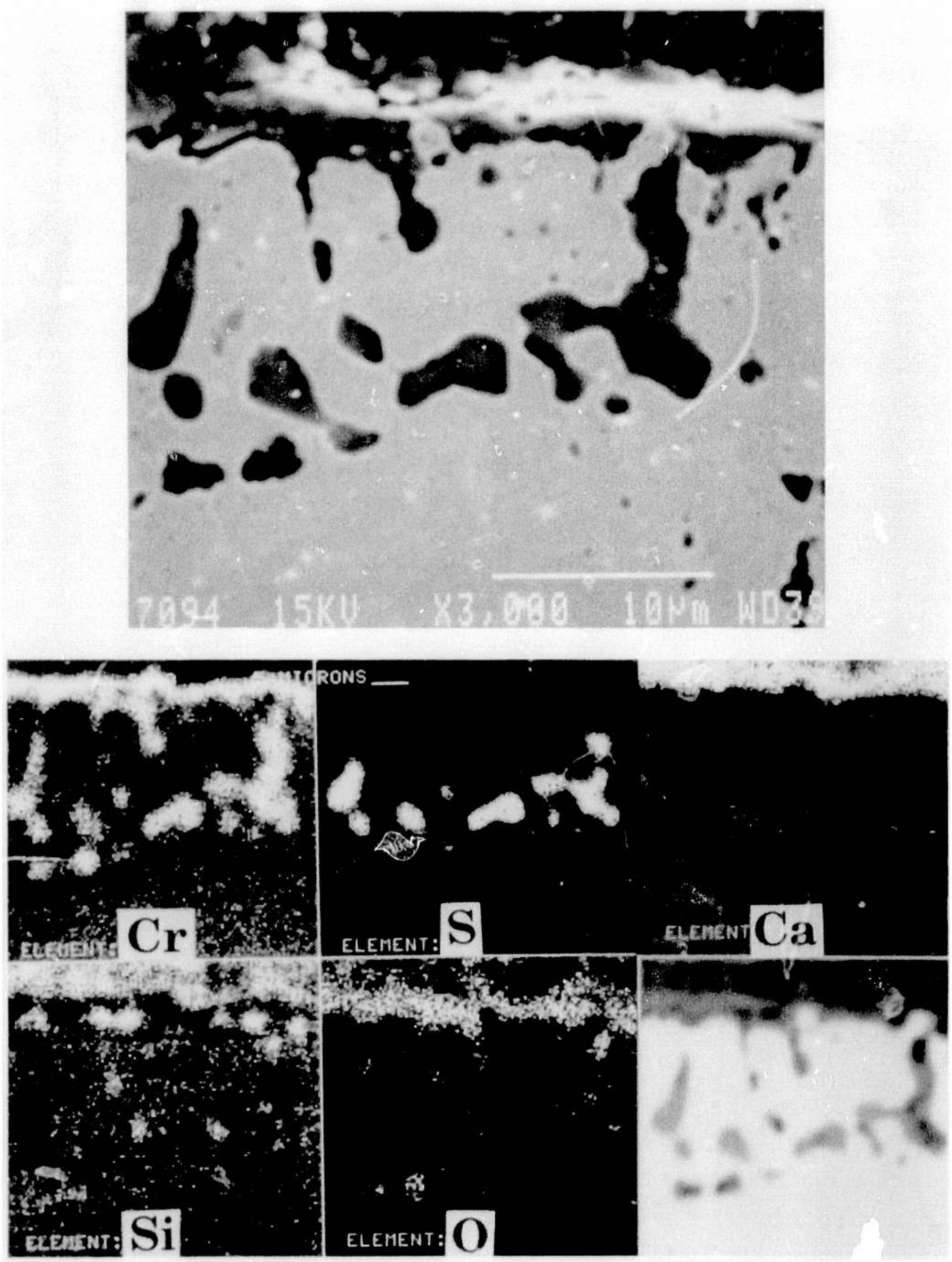
RA 333/RA 333/RA 333

SEM Micrograph and X-ray Mapping of RA 333 Weldment after 1000 h Exposure



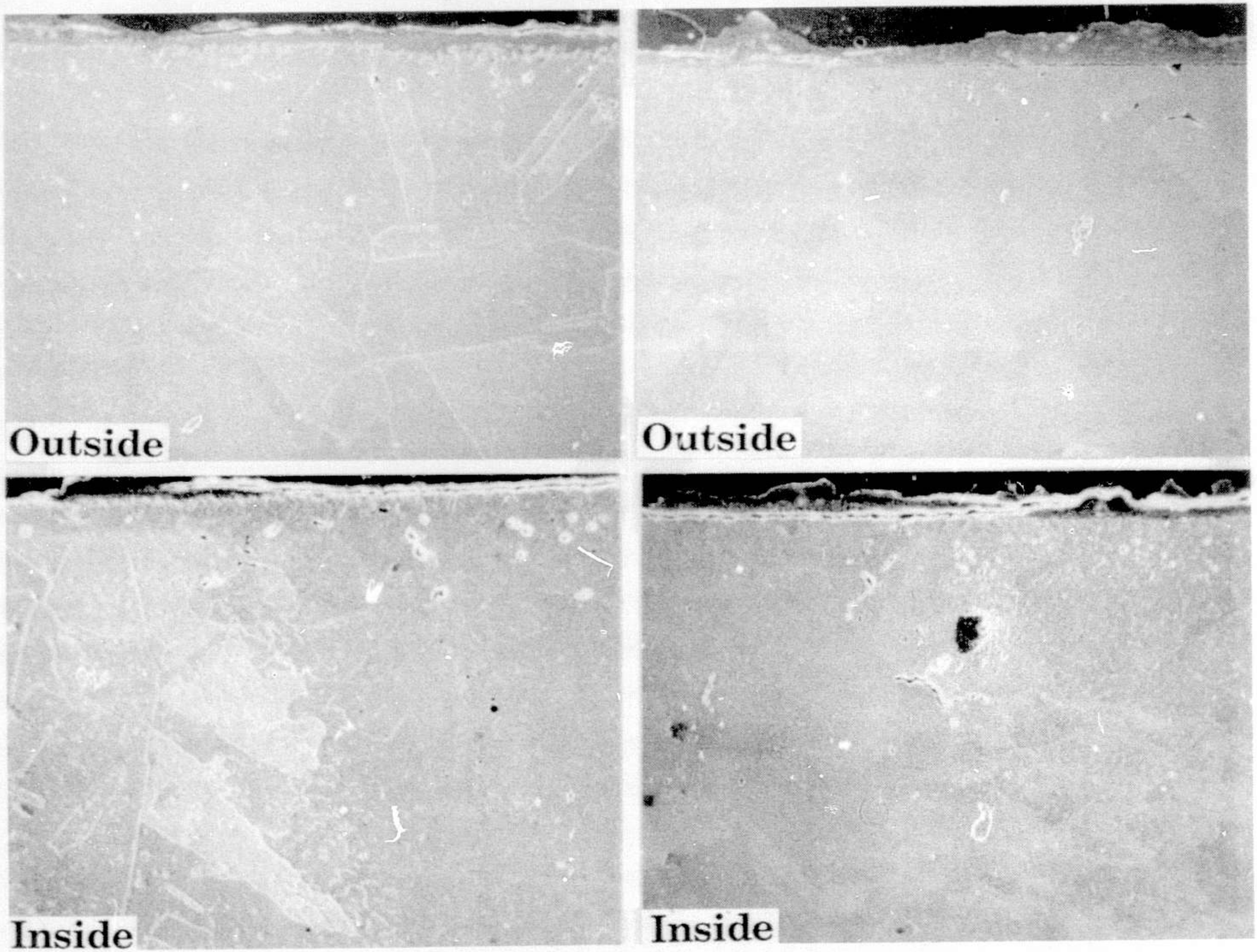
RA 333/188/RA 333

SEM Micrograph and X-ray Mapping of RA 333/188/RA 333
Weldment after 1000 h Exposure



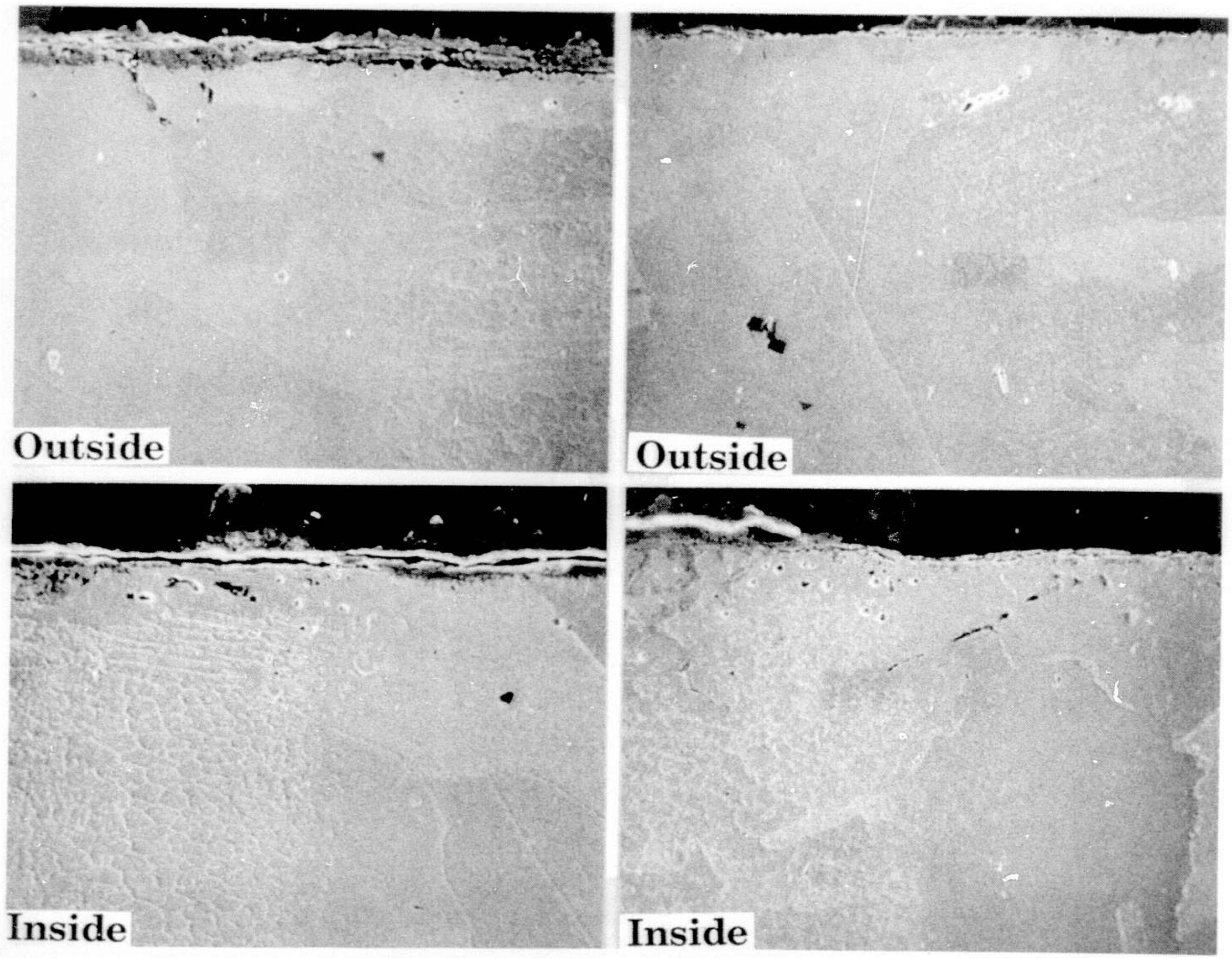
188/188/188

SEM Micrograph and X-ray Mapping of 188 Weldment after 1000 h Exposure



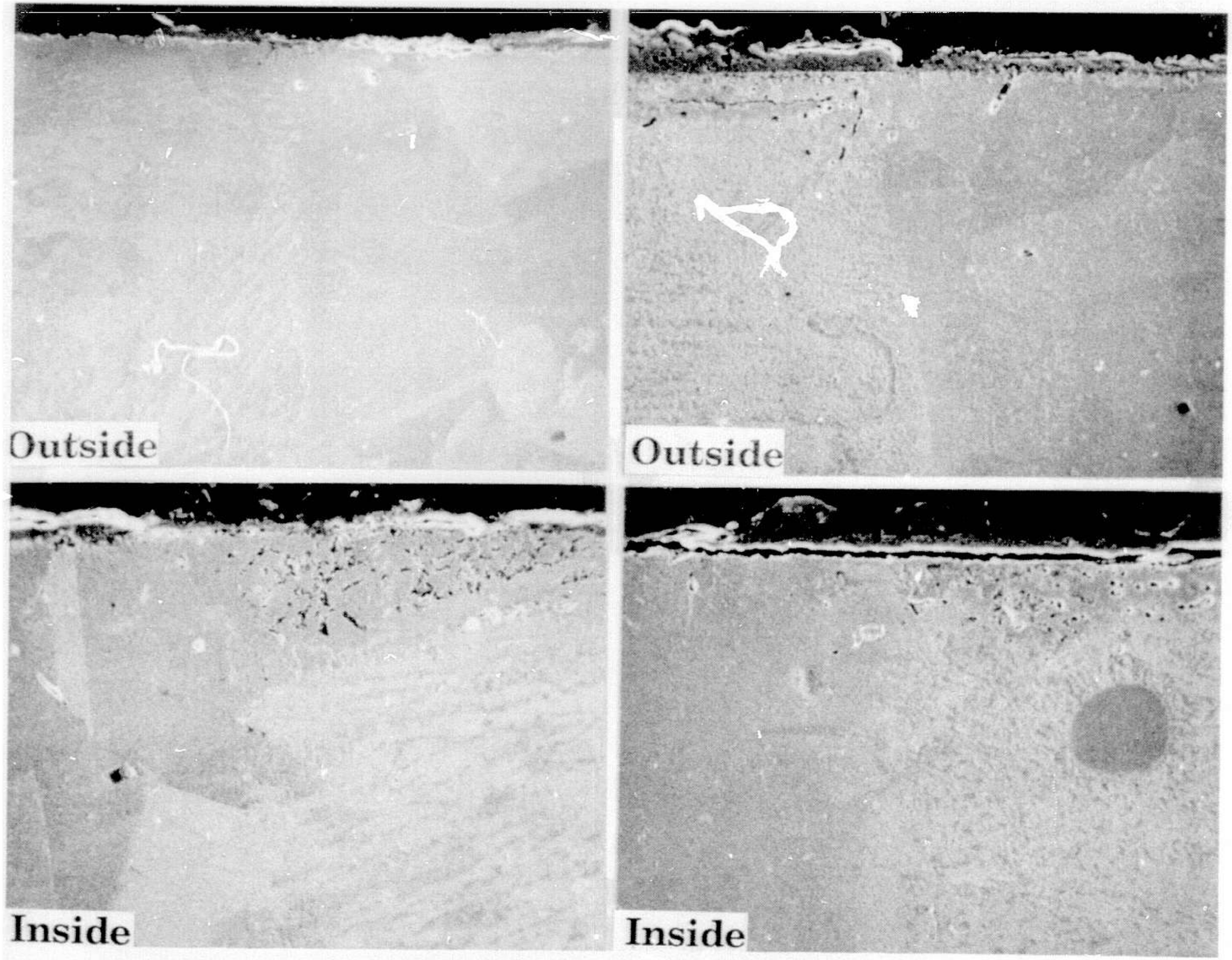
800H/Nicro 82/800H **800H/21–33/800H**

SEM Micrographs of Cross Sections of Nicro 82 and 21-33 Weldments after the Last 980 h Exposure



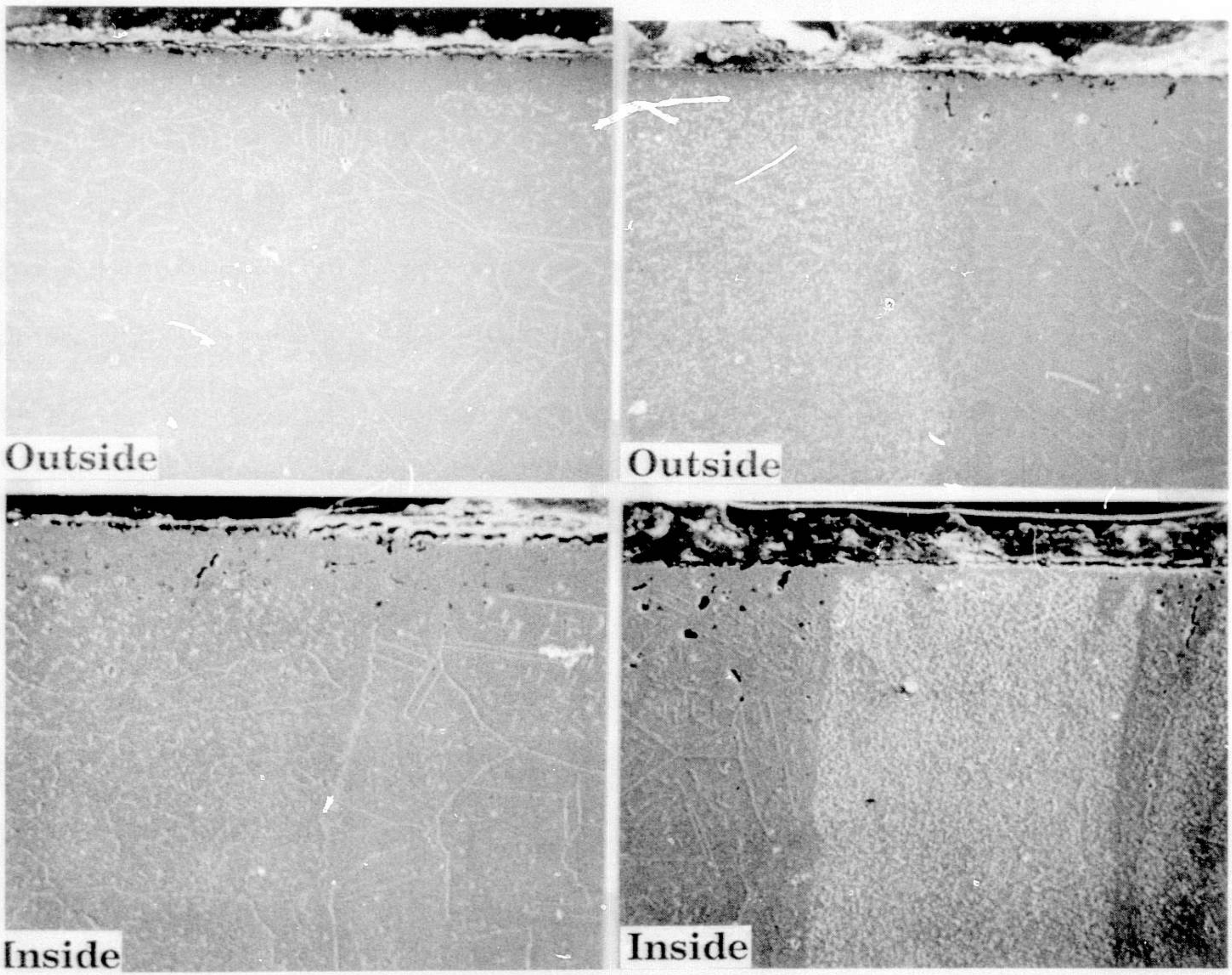
800H/25–35/800H **800H/25–35R/800H**

SEM Micrographs of Cross Sections of 25-35 and 25-35R Weldments after the Last 980 h Exposure



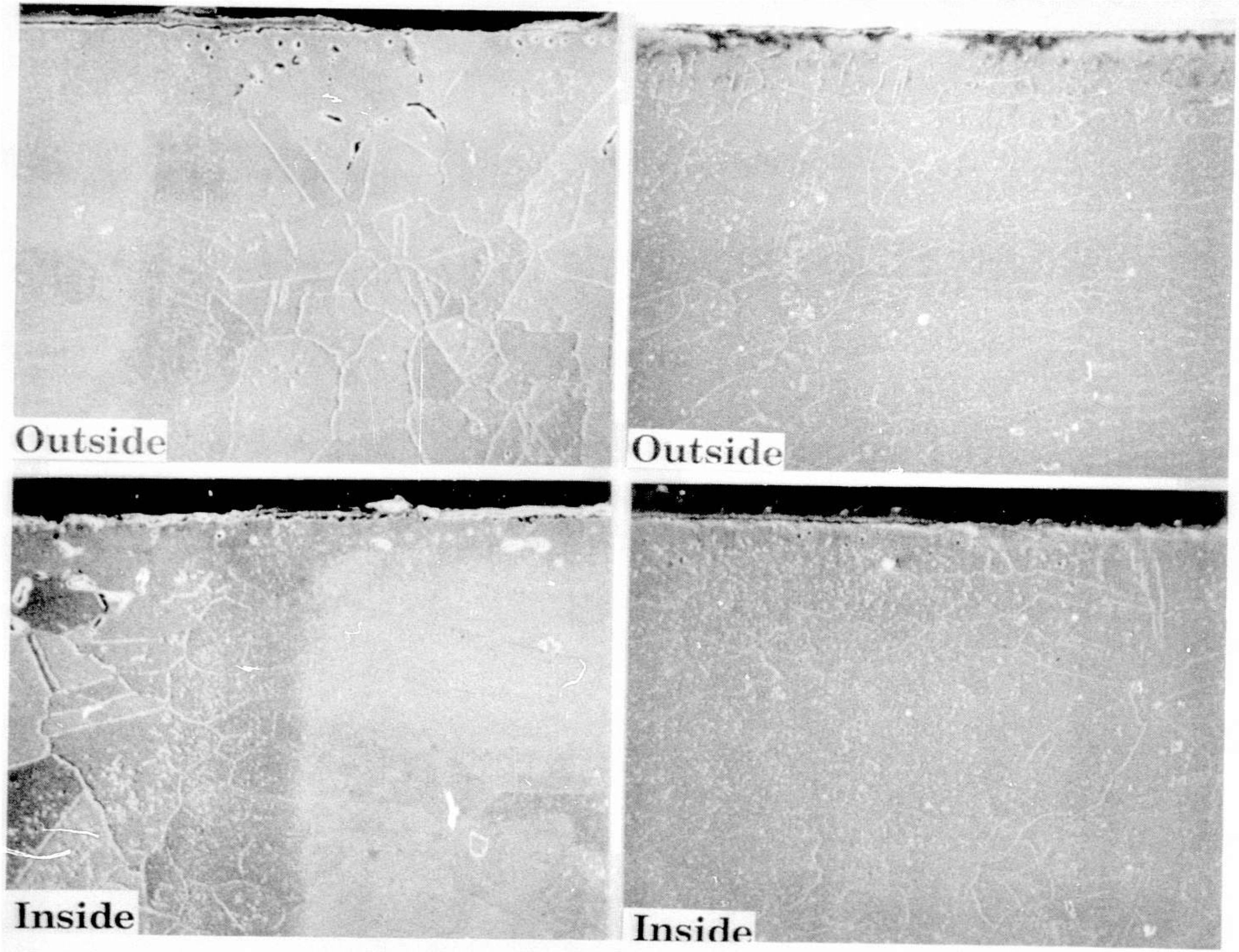
800H/30–50/800H **800H/50–50 Nb/800H**

SEM Micrographs of Cross Sections of 30-50 and 50-50 Nb Weldments after the Last 980 h Exposure



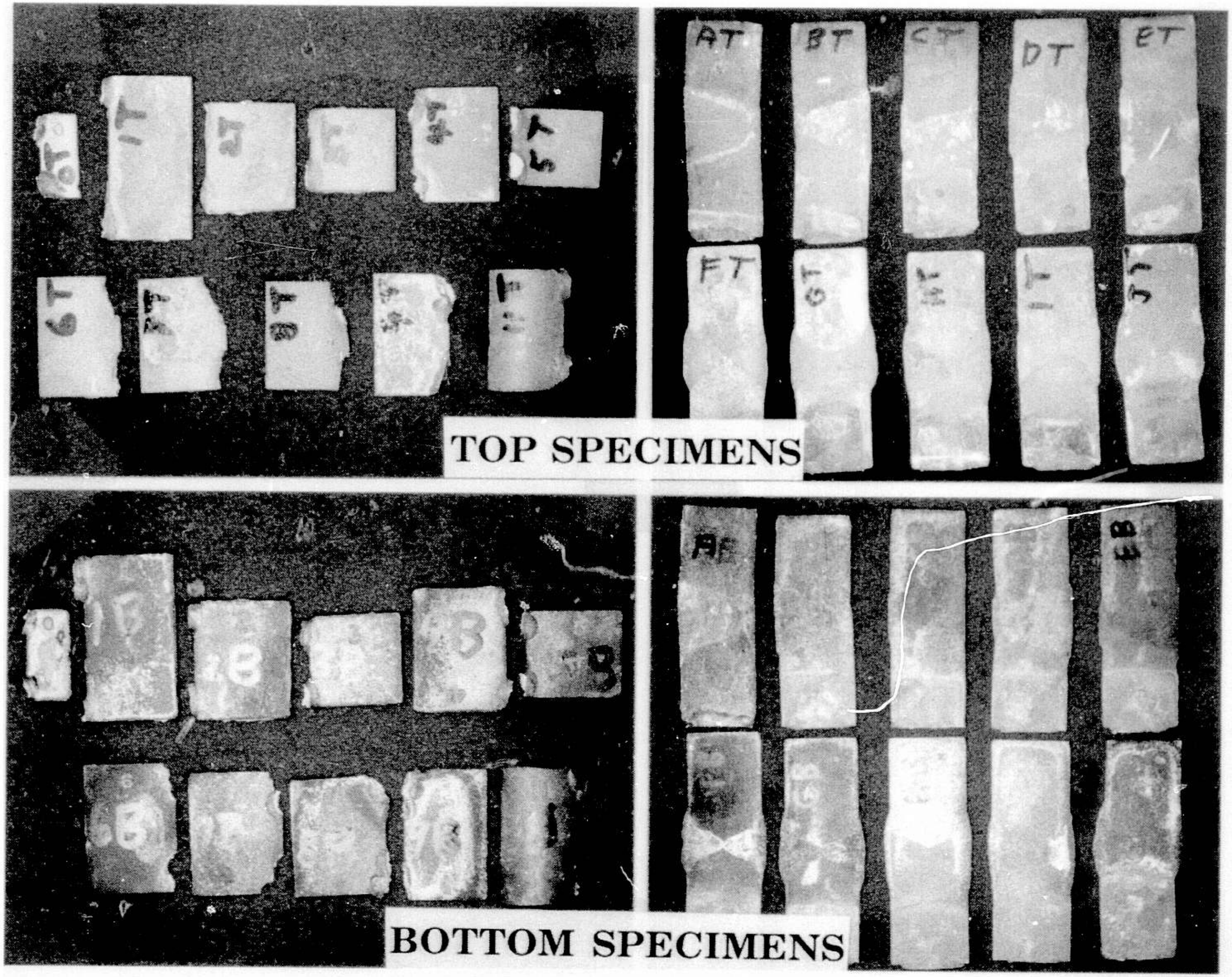
RA 333/RA 333/RA 333 **RA 333/188/RA 333**

SEM Micrographs of Cross Sections of RA 333 and 188 Weldments after the Last 980 h Exposure

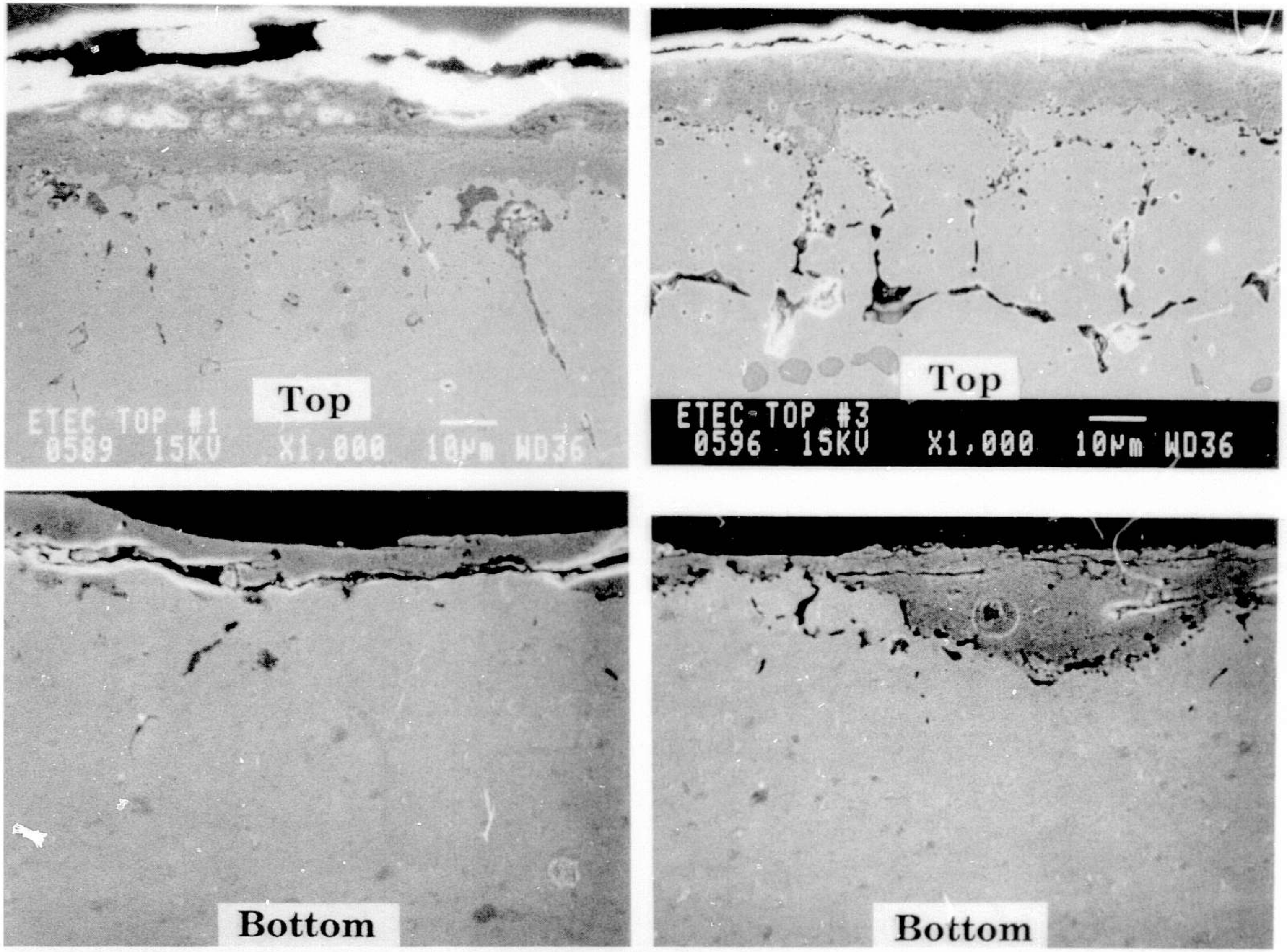


800H/188/800H **188/188/188**

SEM Micrographs of Cross Sections of 800H/188/800H and 188/188/188 Weldments after the Last 980 h Exposure

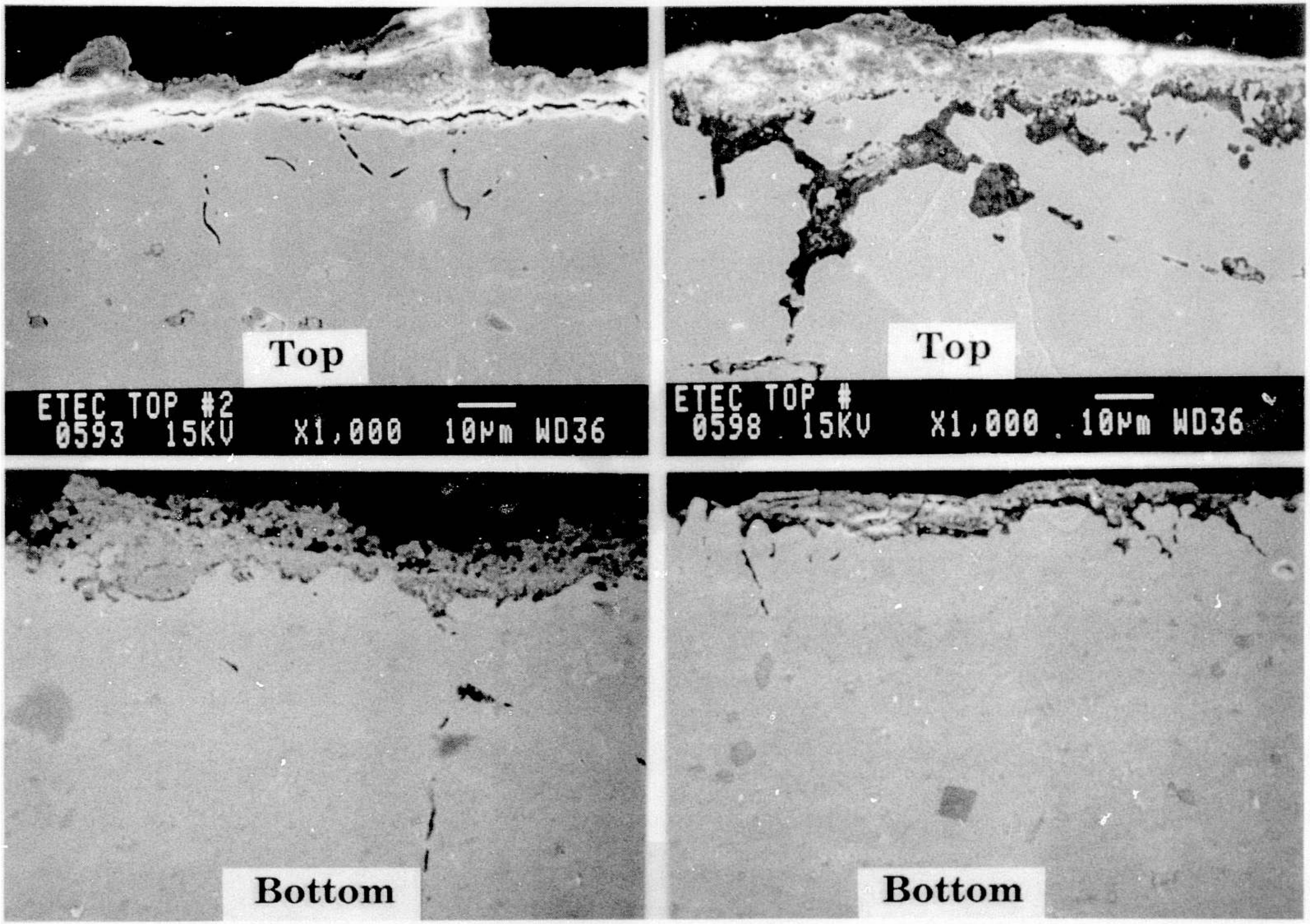


Microphotographs of Base Metal and Weldment Specimens after 1980 h Exposure in ANL Probe



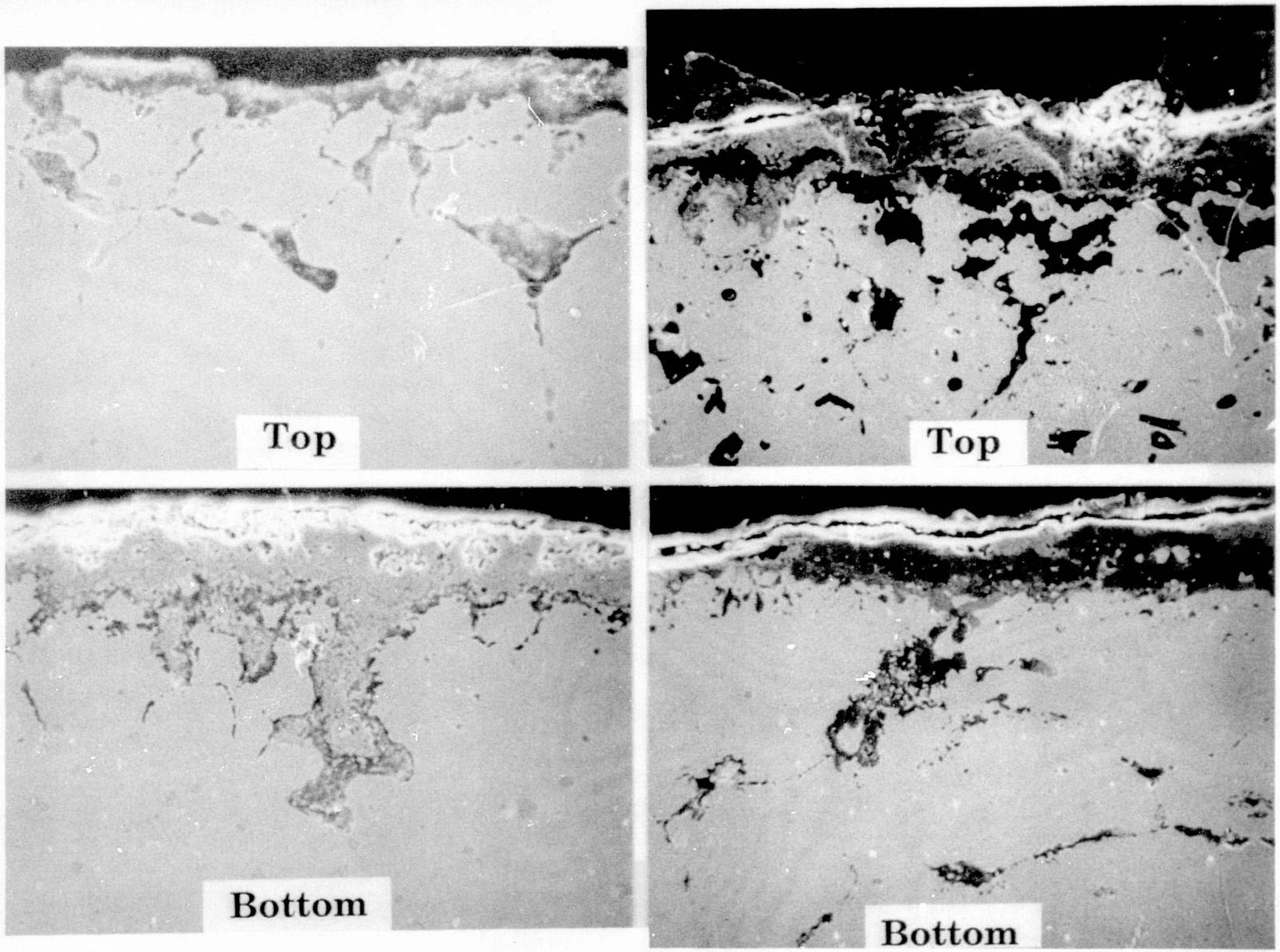
Alloy 800 **304 SS**

SEM Photographs of Cross Sections of Alloy 800 and 304 SS after 1980 h Exposure



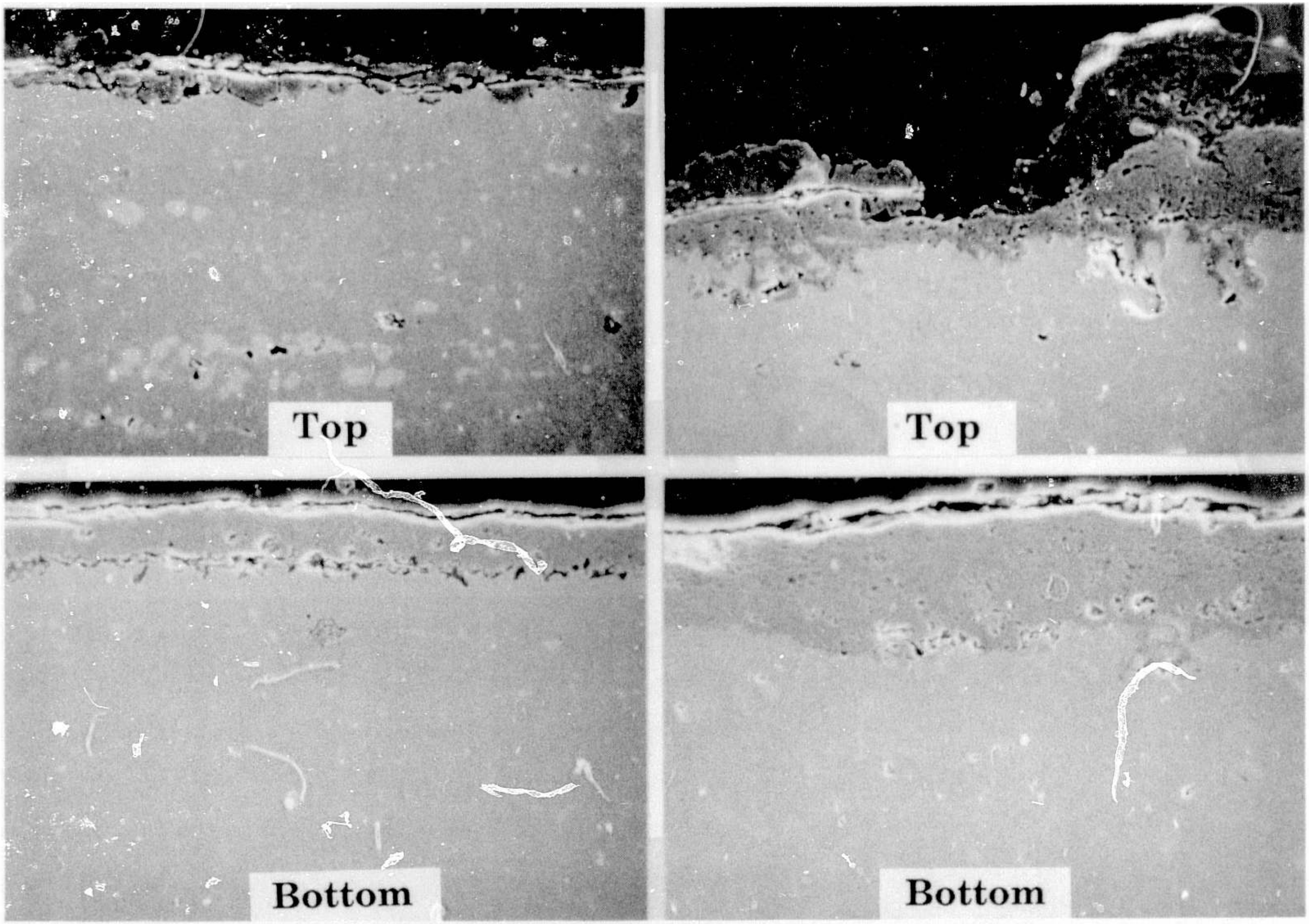
310 SS **330**

SEM Photographs of Cross Sections of Alloys 310 and 330 after 1980 h Exposure



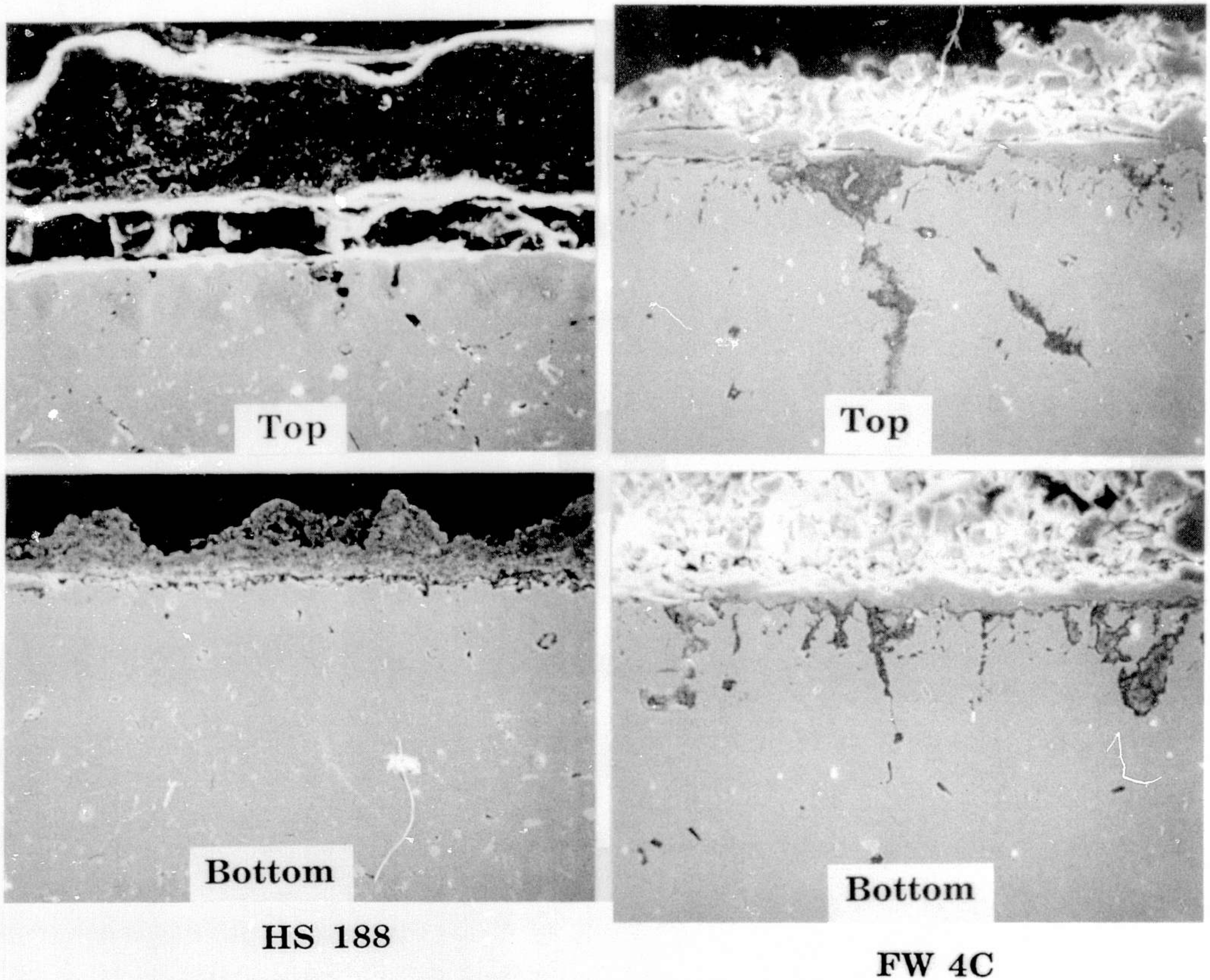
253 MA **8XX**

SEM Photographs of Cross Sections of Alloys 253 MA and 8XX after 1980 h Exposure

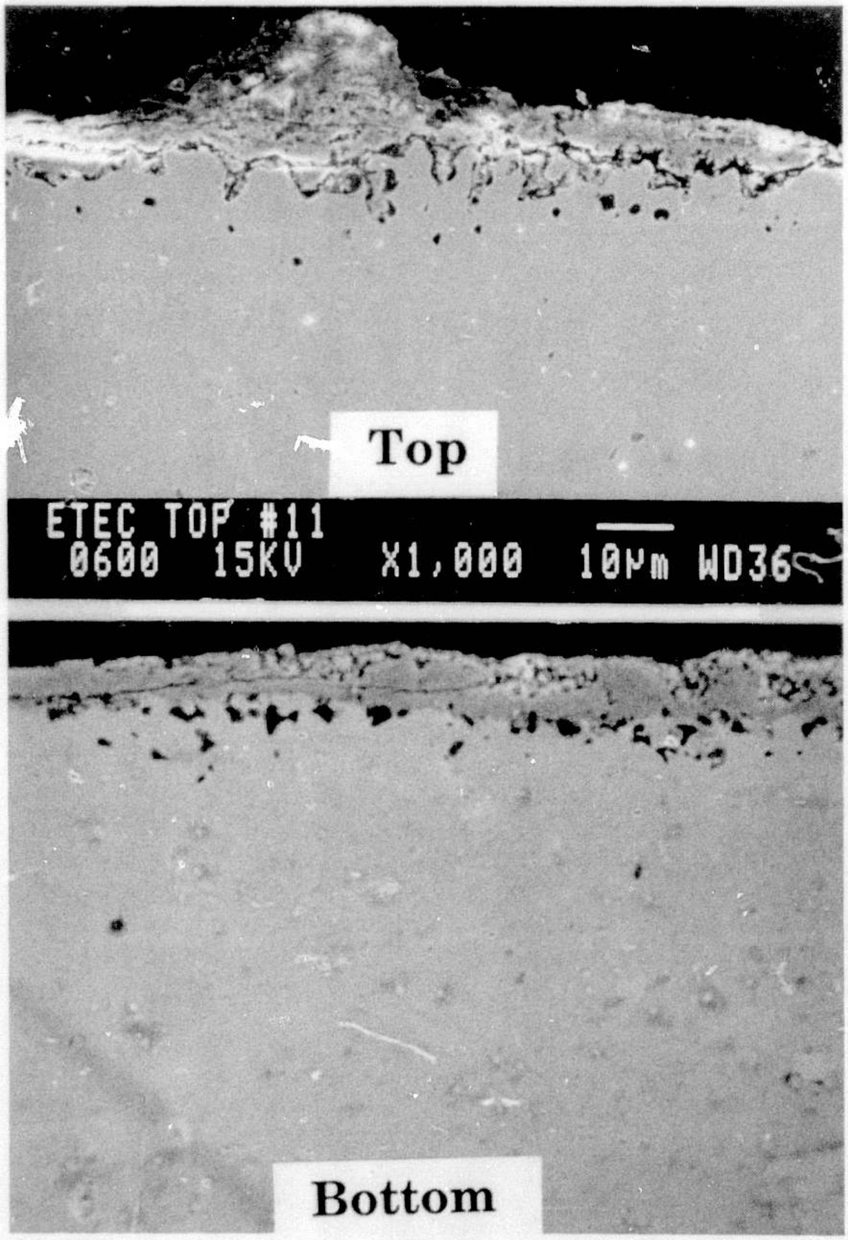


Fe–25Cr–20Ni–3Nb **Fe–25Cr–20Ni–3Zr**

SEM Photographs of Cross Sections of Alloys Fe-25Cr-20Ni-3Nb and Fe-25Cr-20Ni-3Zr after 1980 h Exposure

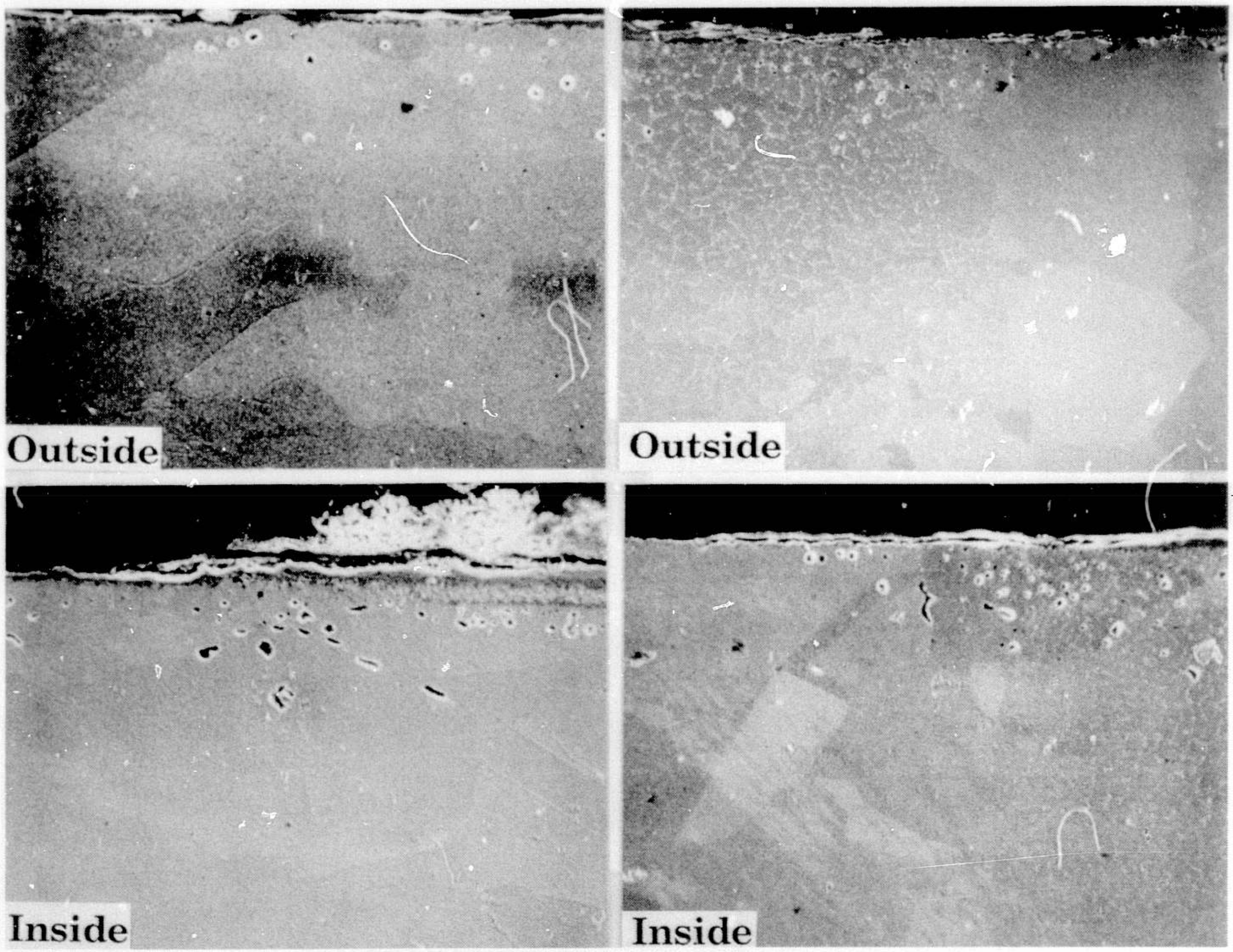


SEM Photographs of Cross Sections of Alloys 188 and FW 4C after 1980 h Exposure



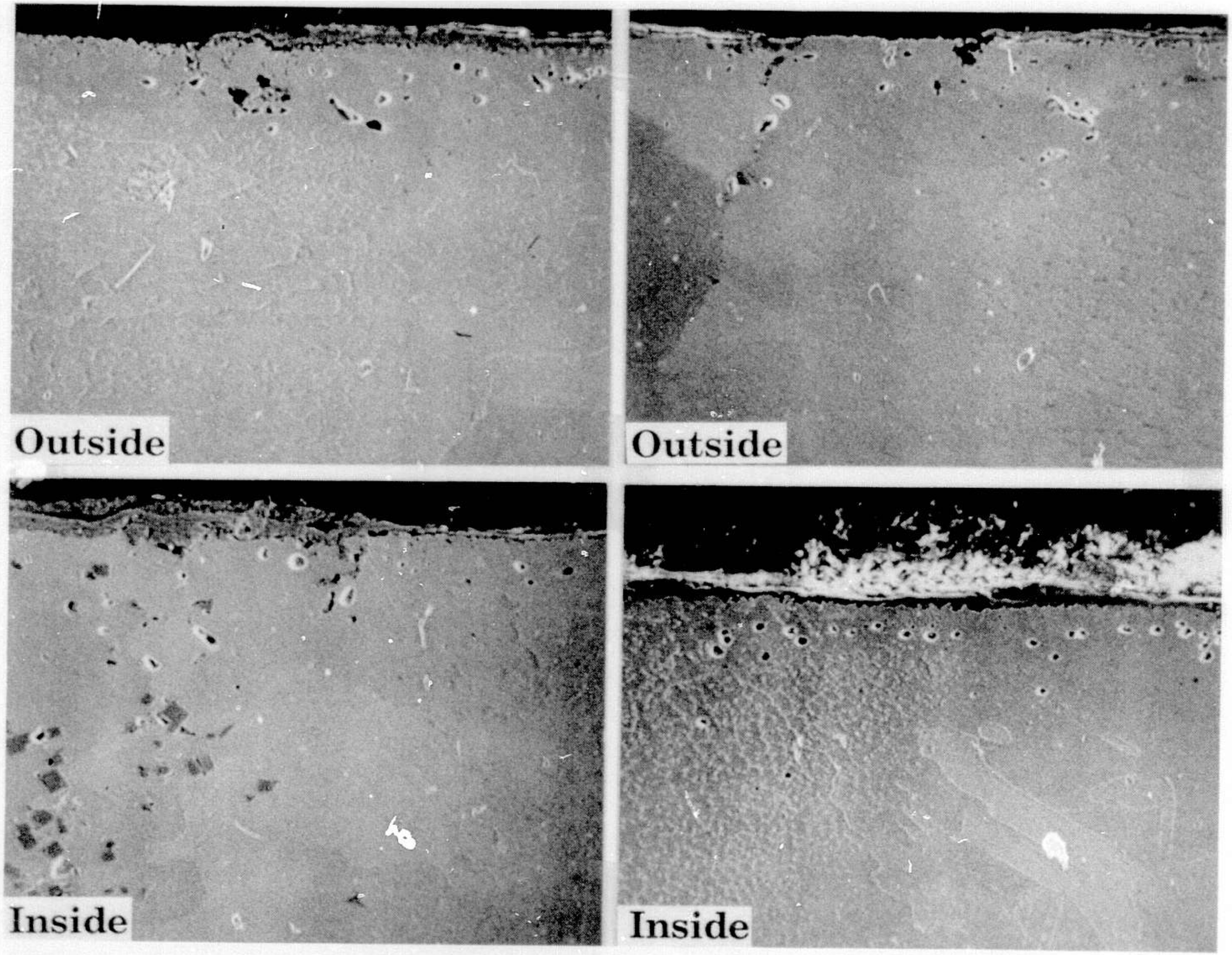
HR 3C

SEM Photographs of Cross Sections of Alloy HR 3C after 1980 h Exposure



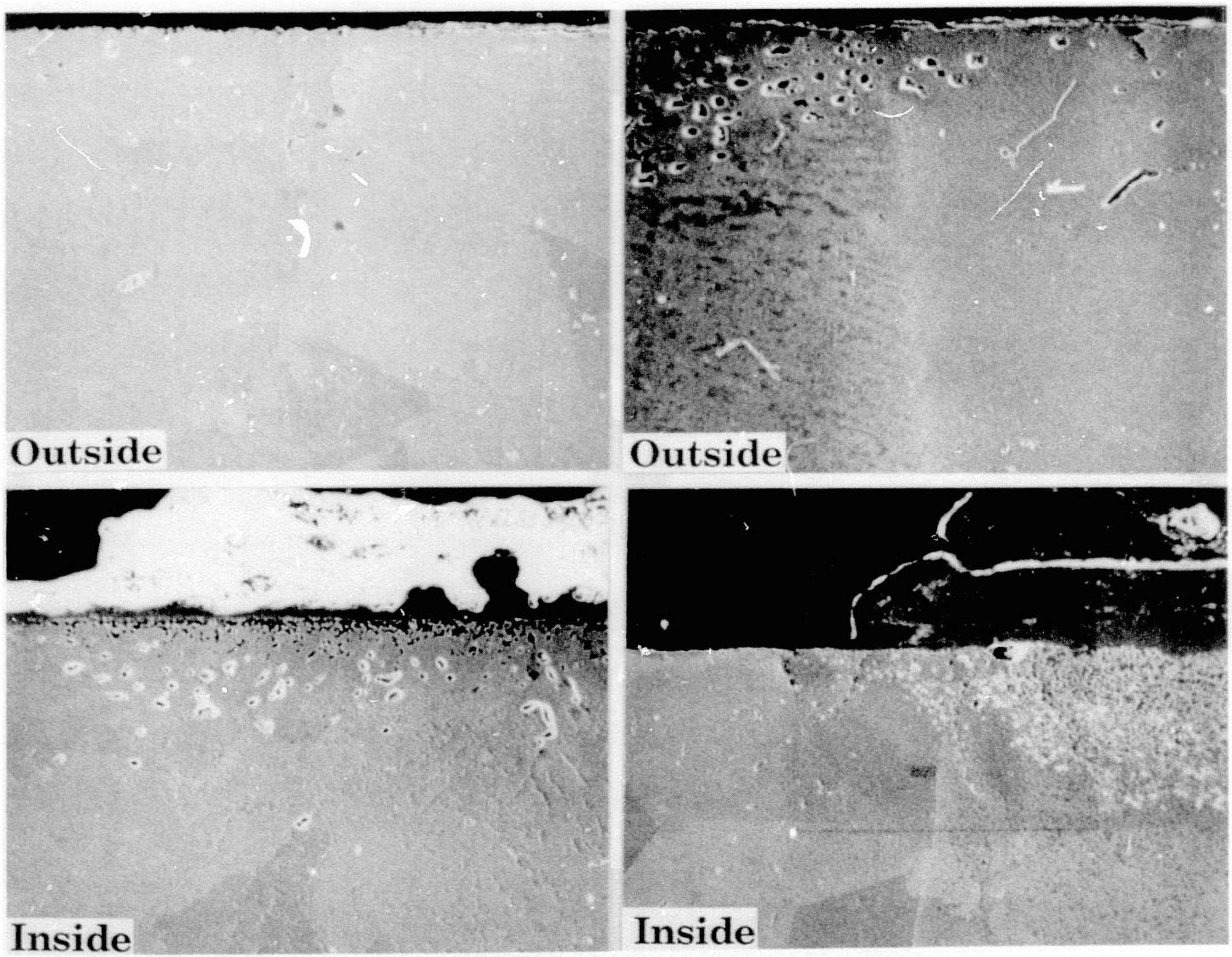
800H/Nicro 82/800H **800H/21–33/800H**

SEM Photographs of Cross Sections of Nicro 82 and 21-33 Weldments after 1980 h Exposure



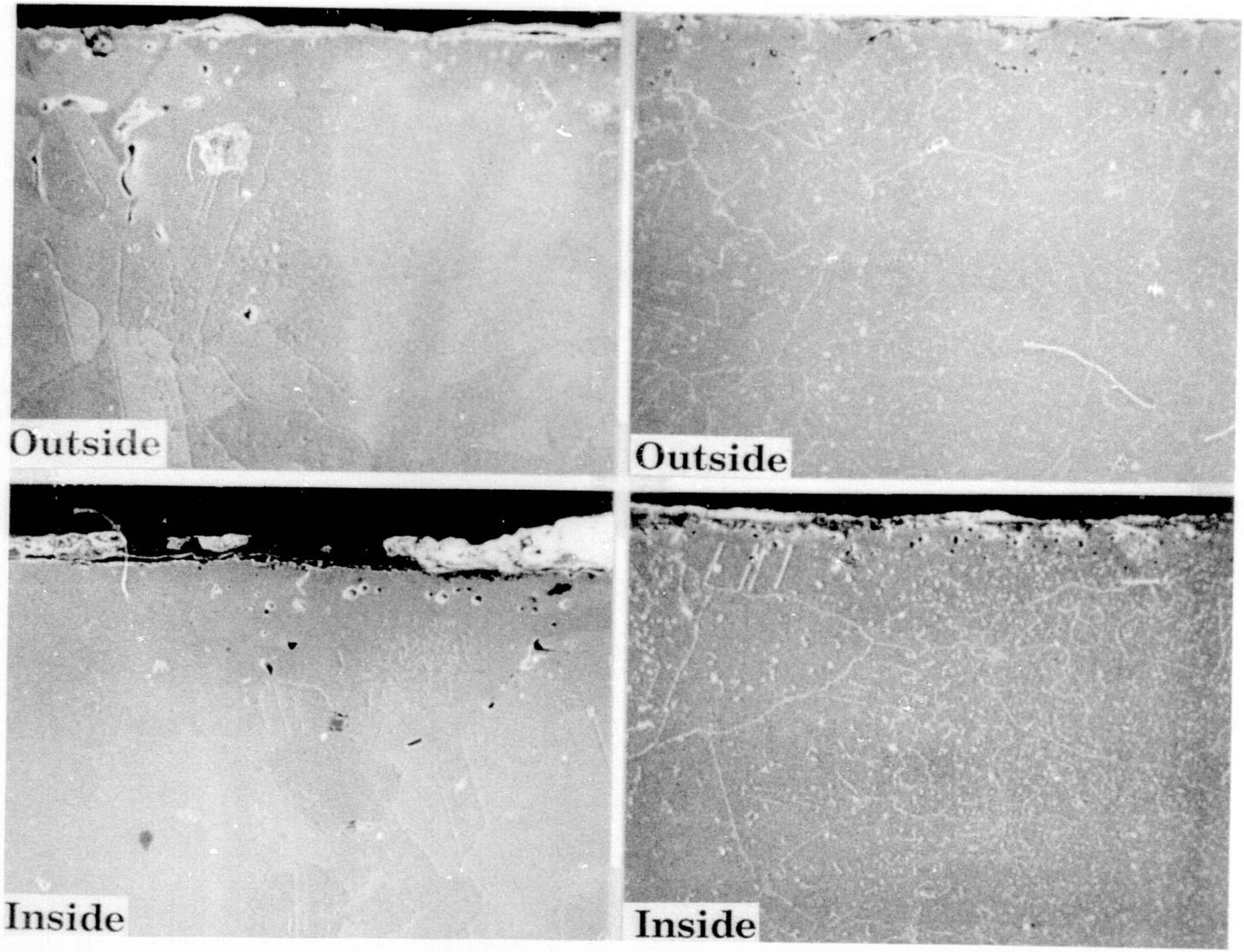
800H/25–35/800H **800H/25–35R/800H**

SEM Photographs of Cross Sections of 25-35 and 25-35R after 1980 h Exposure



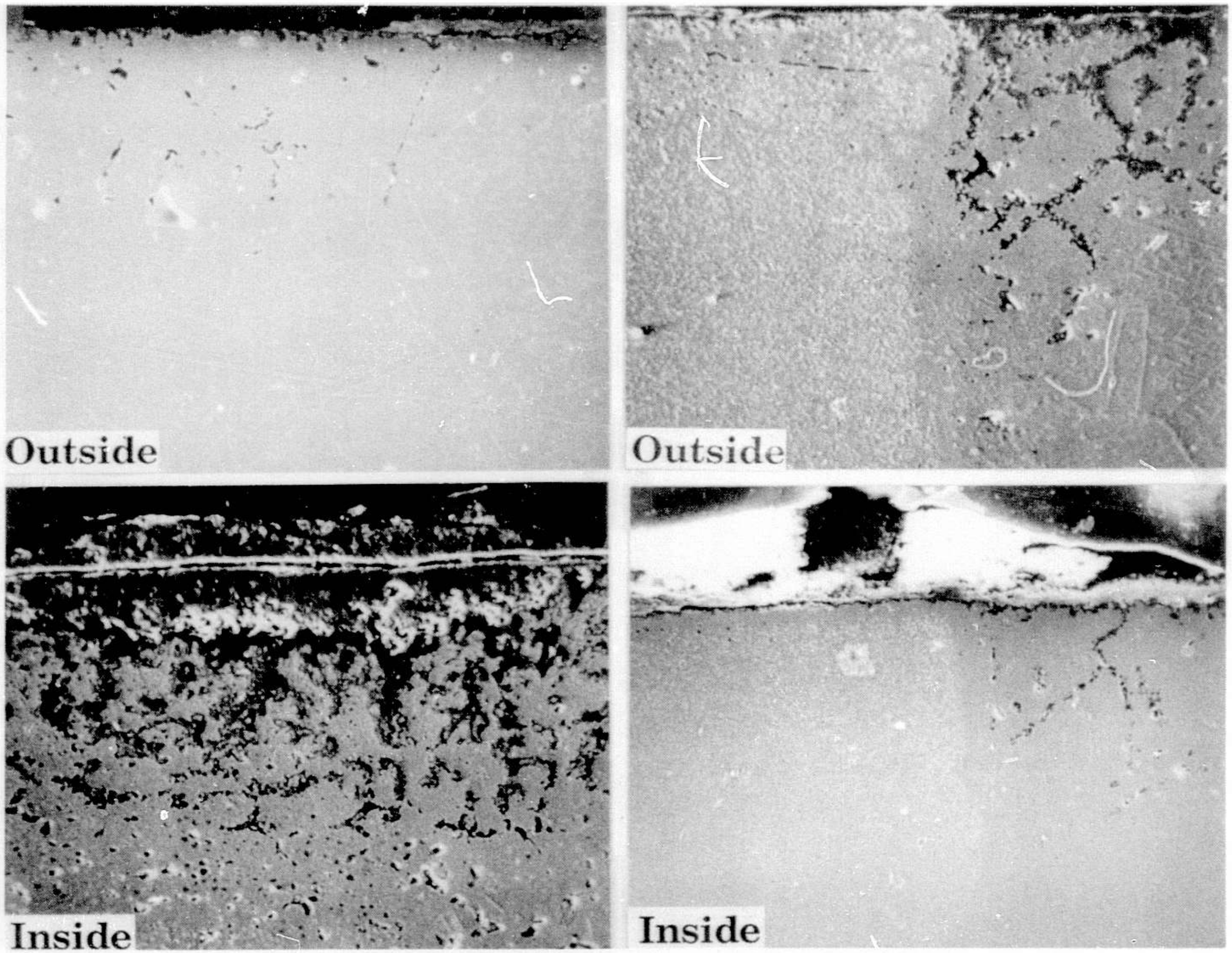
800H/30–50/800H **800H/50–50 Nb/800H**

SEM Photographs of Cross Sections of 30-50 and 50-50 Nb Weldments after 1980 h Exposure



800H/188/800H **188/188/188**

SEM Photographs of Cross Sections of 800H/188/800H and 188/188/188 Weldments after 1980 h Exposure



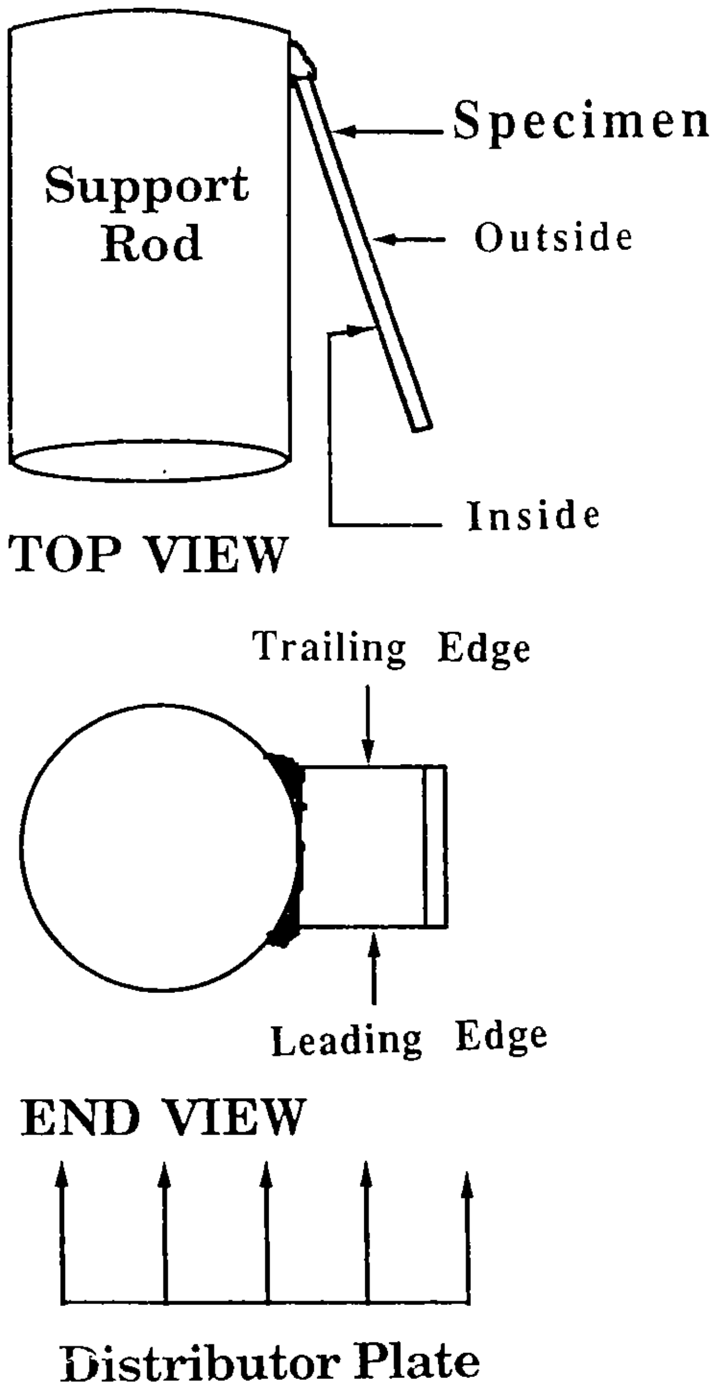
RA 333/RA 333/RA 333 **RA 333/188/RA 333**

SEM Photographs of Cross Sections of RA 333 and 188 Weldments after 1980 h Exposure

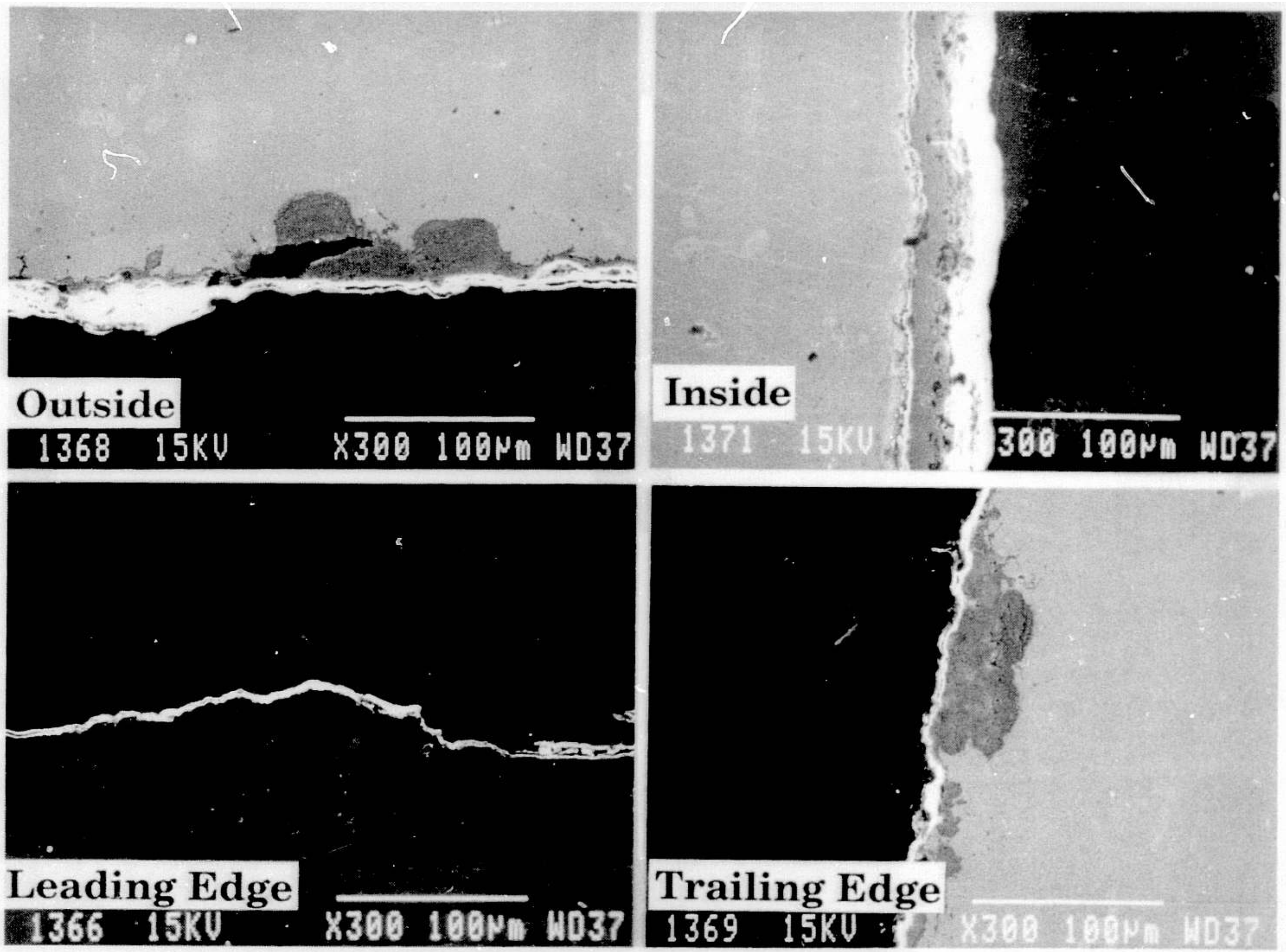
APPENDIX C.

MICROSTRUCTURES OF SPECIMENS FROM B&W PROBE BBTED

PROBE ID:	**BBTED**
TYPE OF PROBE:	**Uncooled**
EXPOSURE TIME:	**500 h**
ORGANIZATION:	**Babcock and Wilcox**

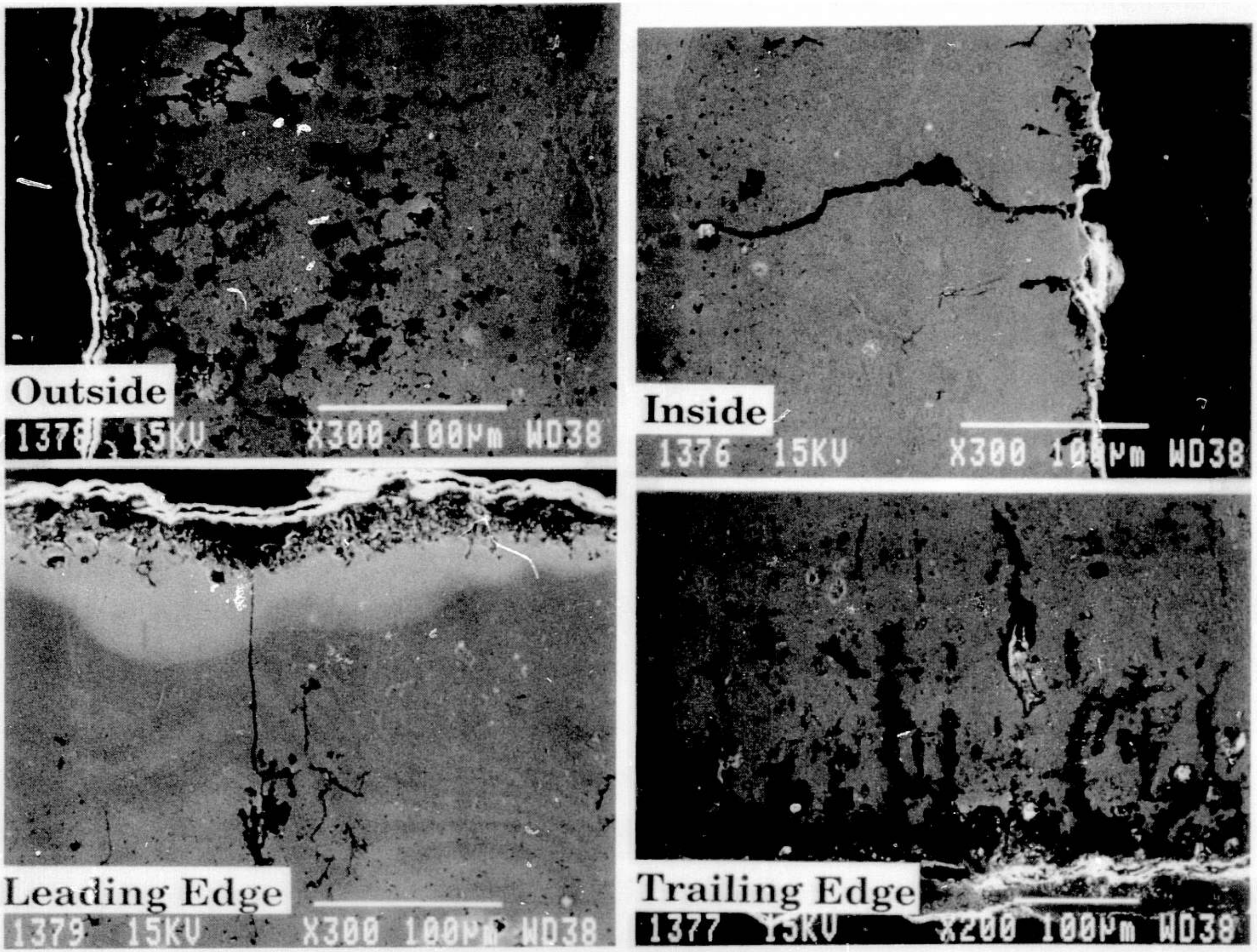


B&W Uncooled Probe BBTED



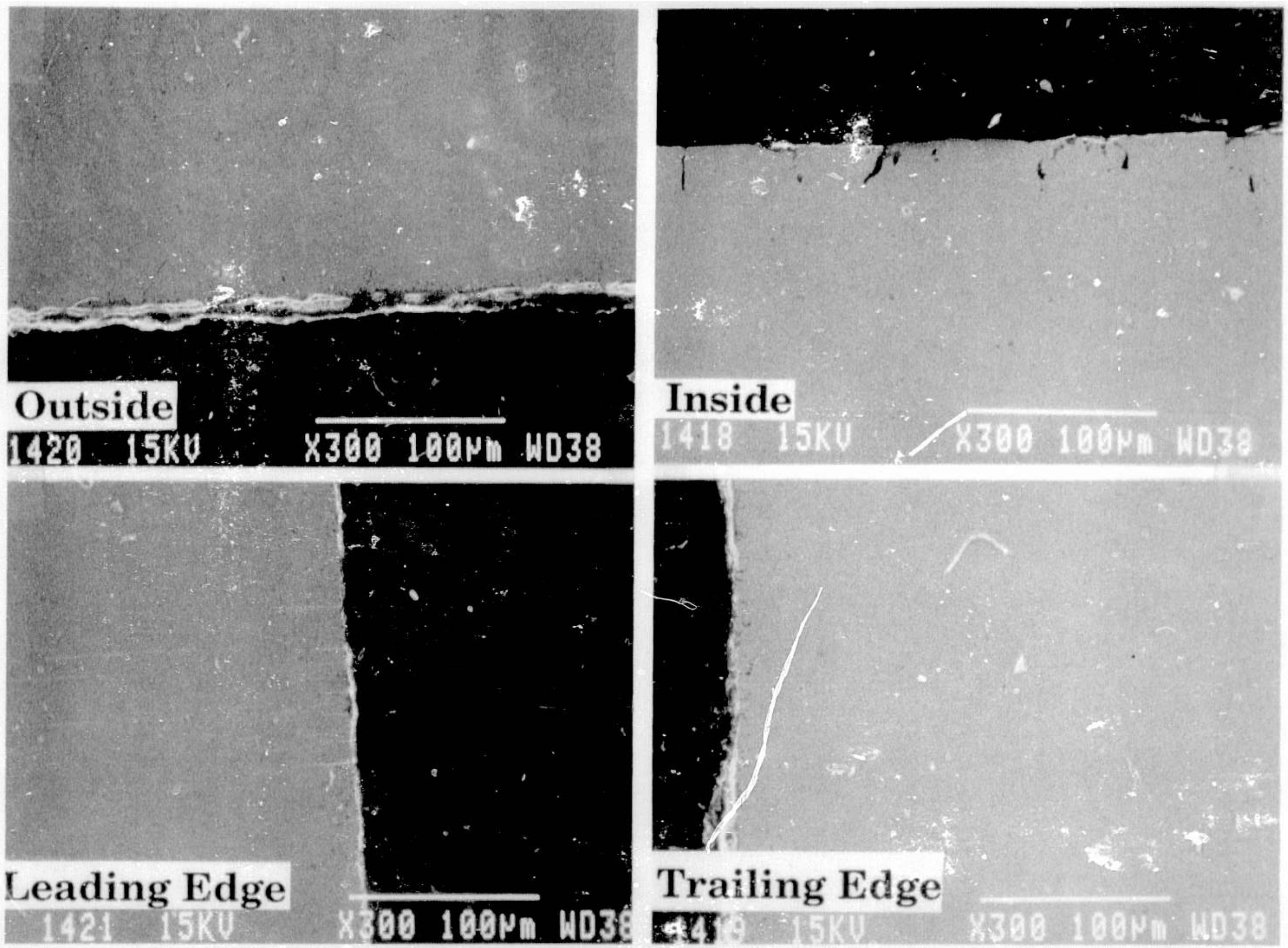
304H SS

SEM Micrographs of 304 Stainless Steel after 500 h Exposure



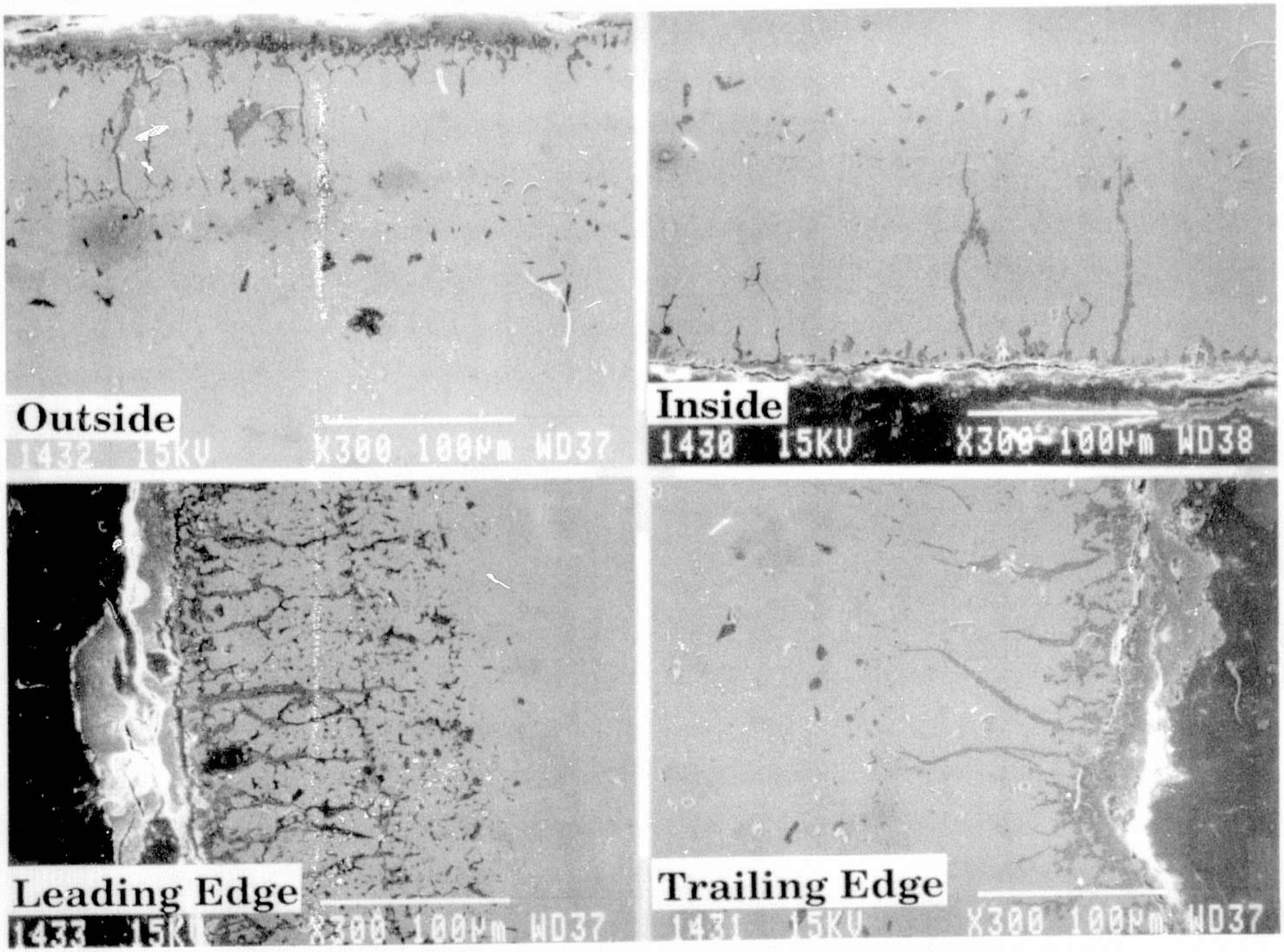
304H/Al

SEM Micrographs of Aluminized 304 Stainless Steel after 500 h Exposure



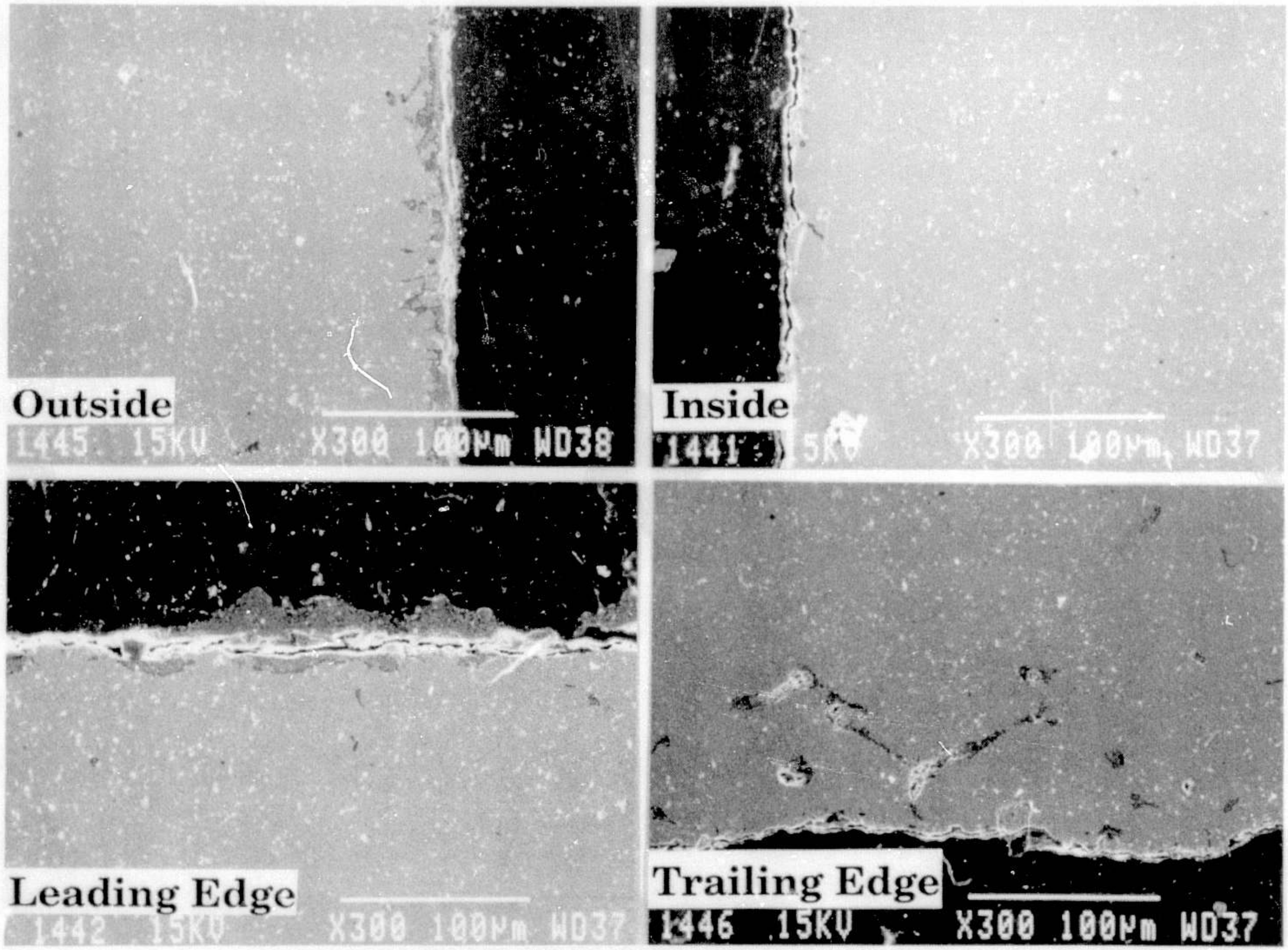
310 SS

SEM Micrographs of 310 Stainless Steel after 500 h Exposure



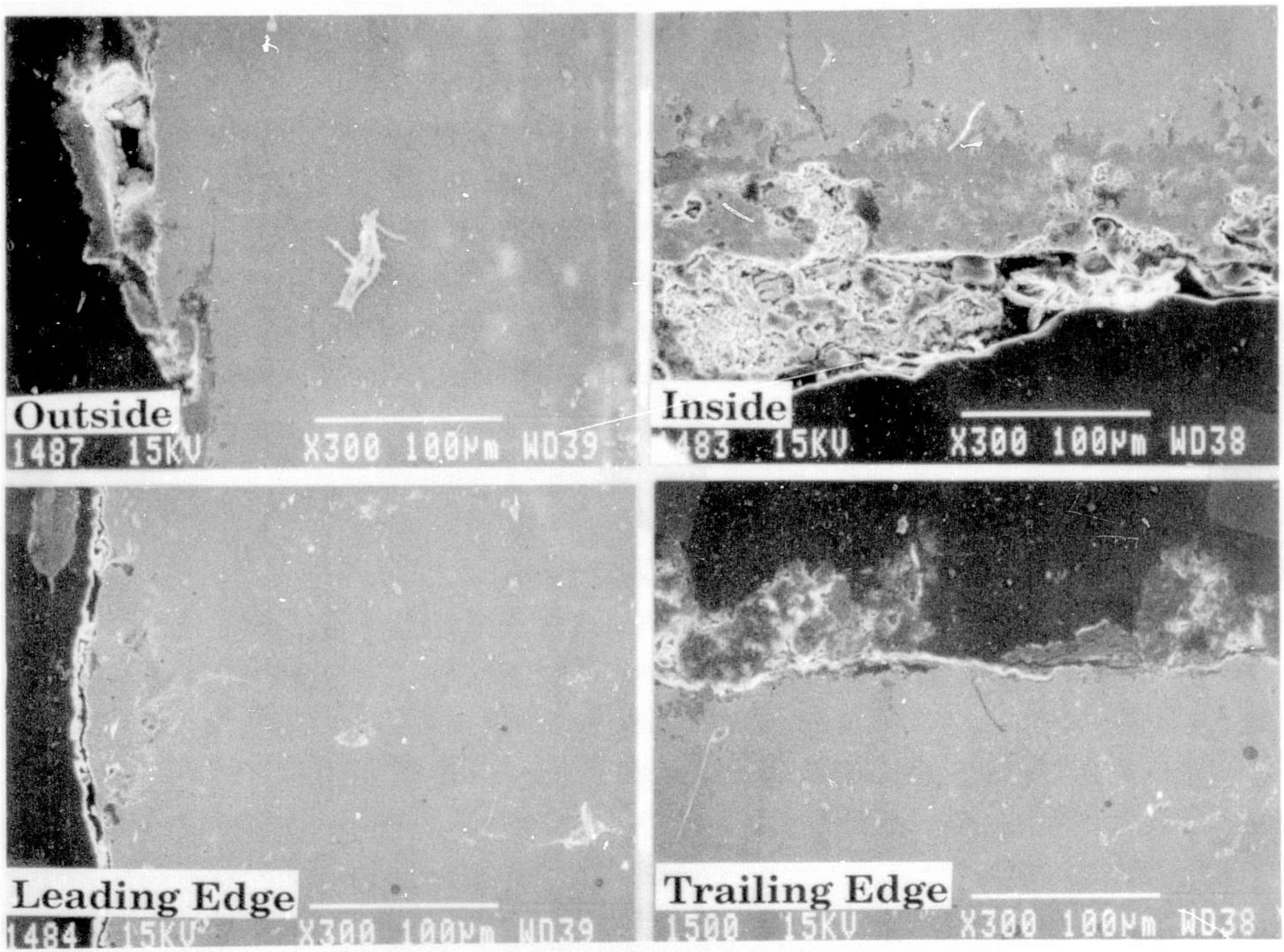
310/Al

SEM Micrographs of Aluminized 310 Stainless Steel after 500 h Exposure



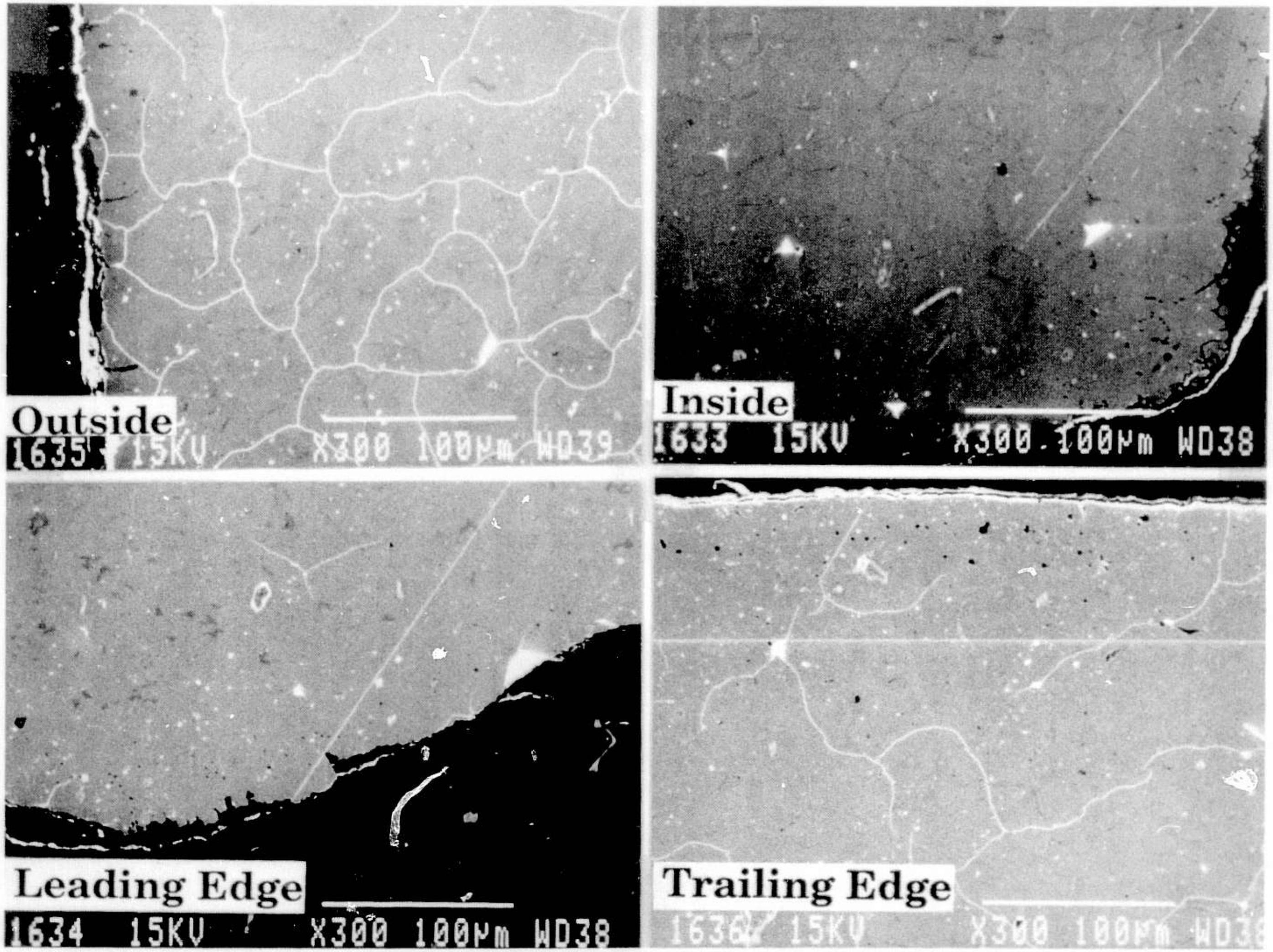
HH

SEM Micrographs of HH after 500 h Exposure



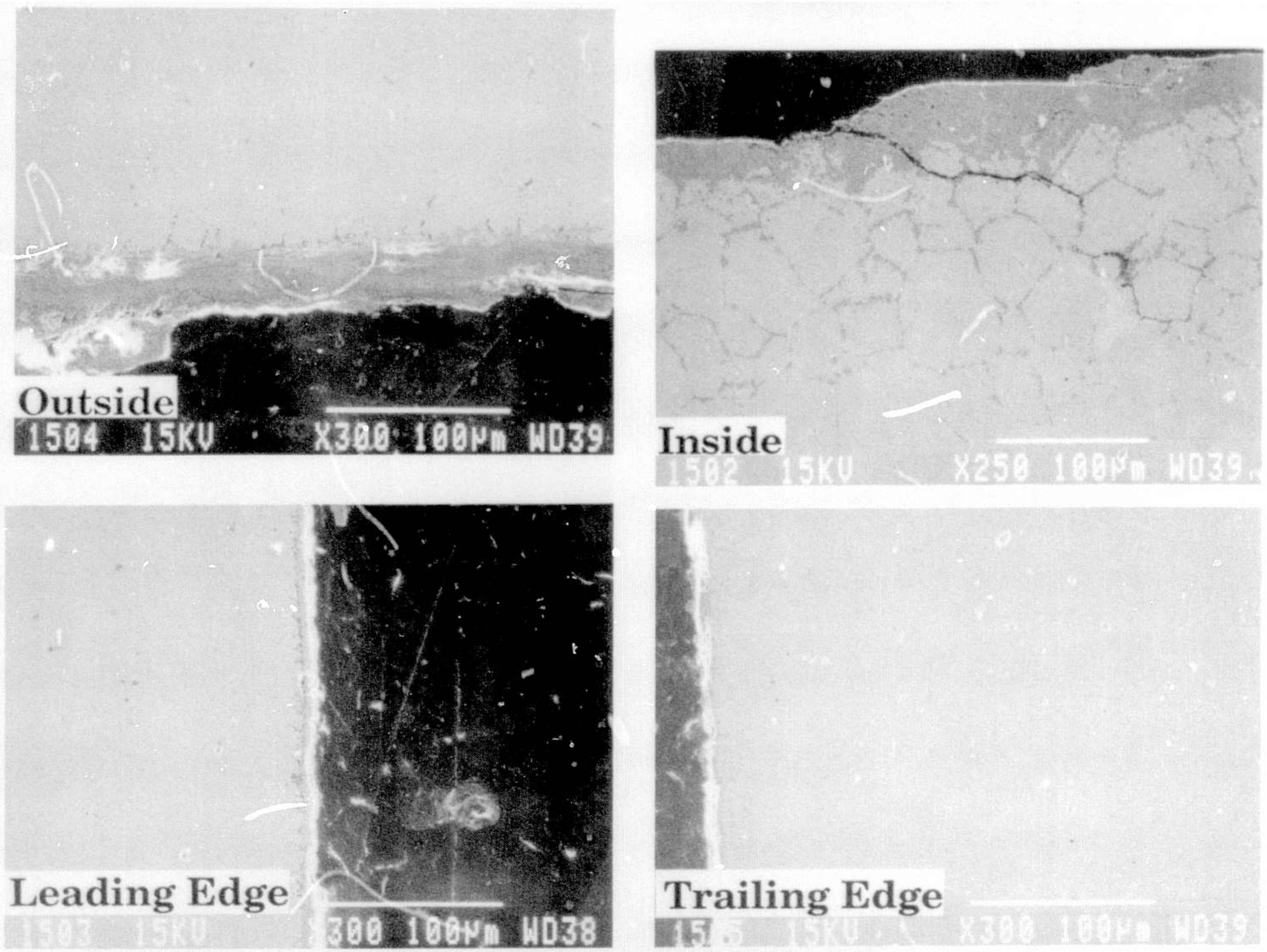
HP 50

SEM Micrographs of HP 50 after 500 h Exposure



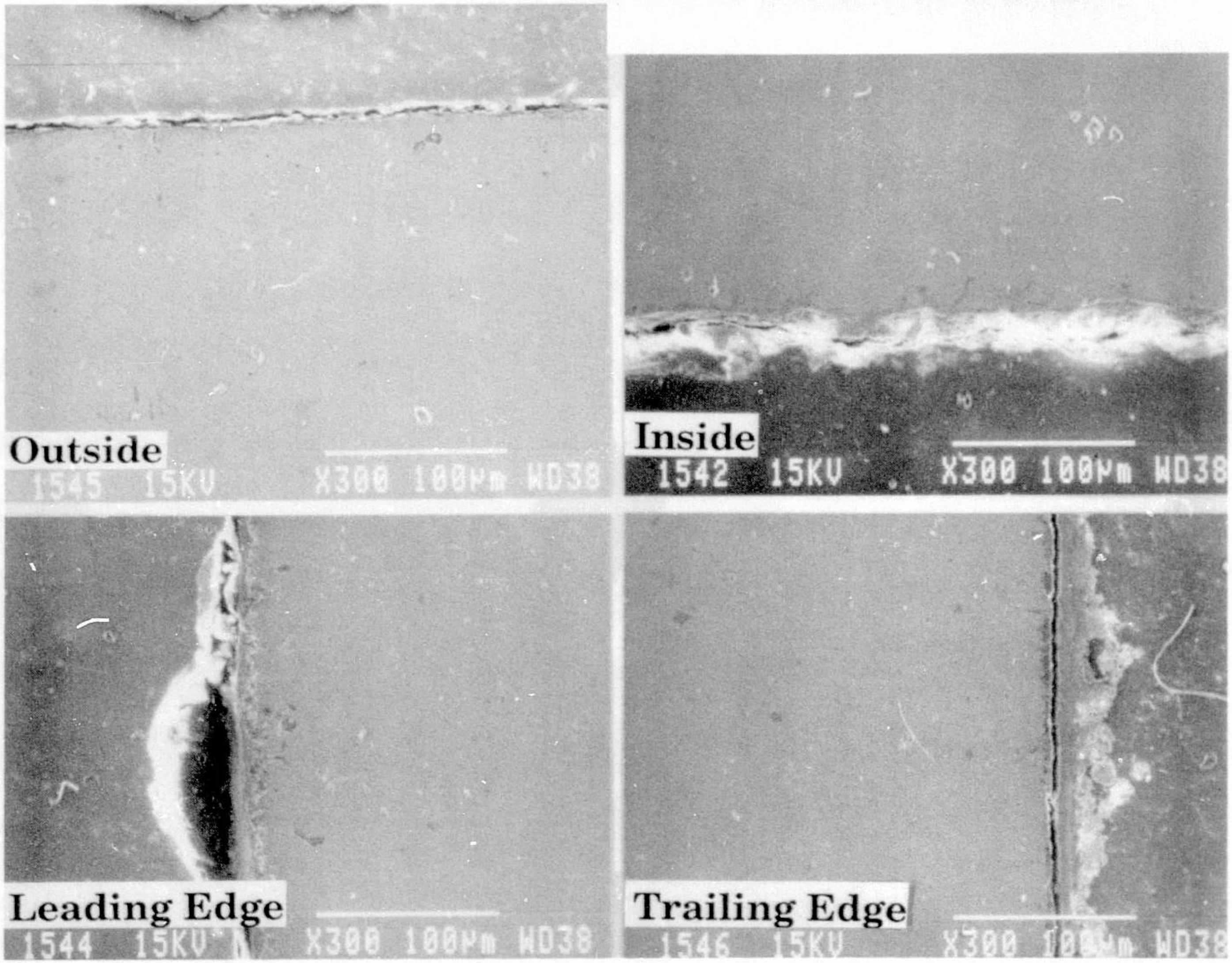
253 MA

SEM Micrographs of 253 MA after 500 h Exposure



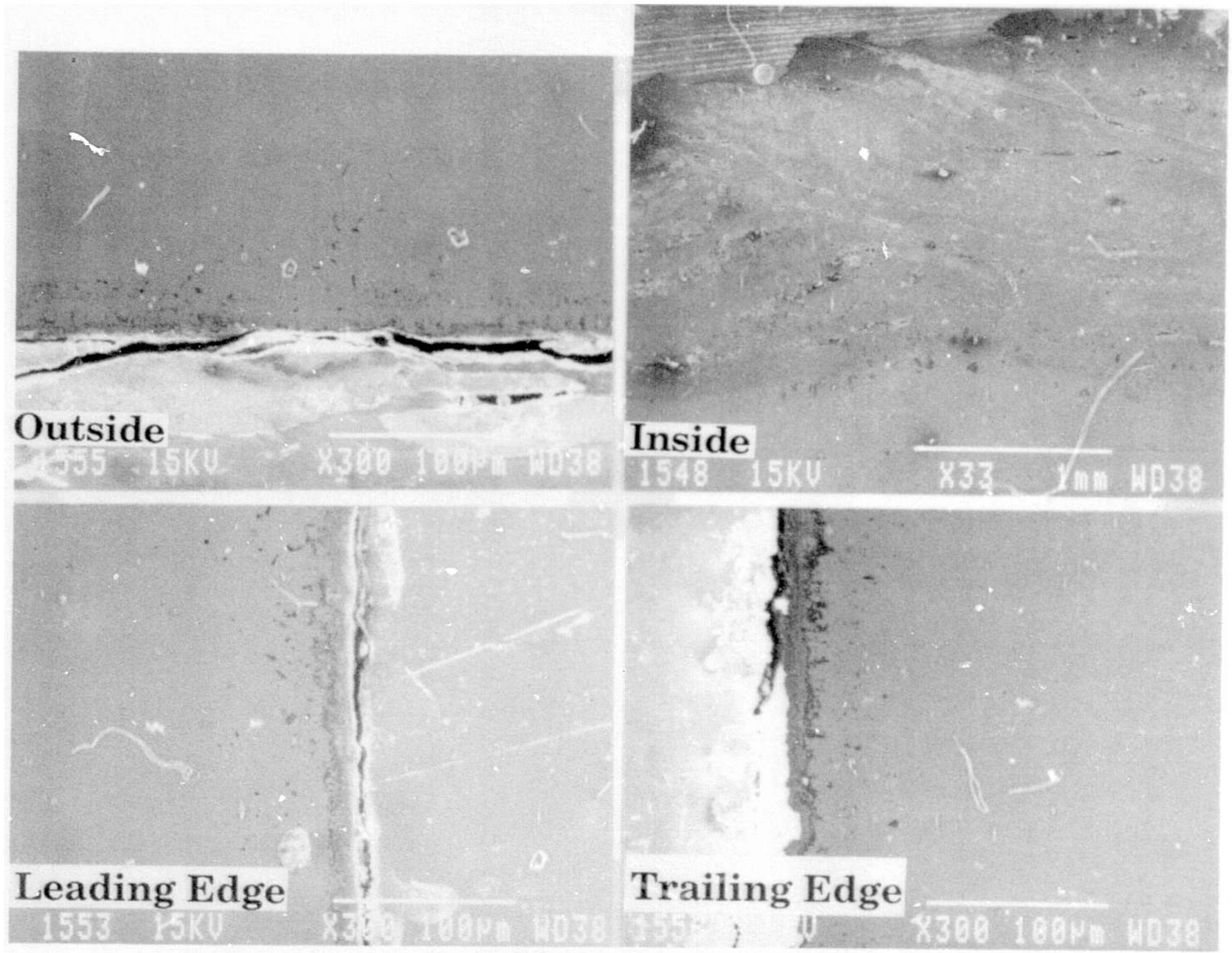
304/310

SEM Micrographs of 310-Clad 304 Stainless Steel after 500 h Exposure Near the Bed Walls



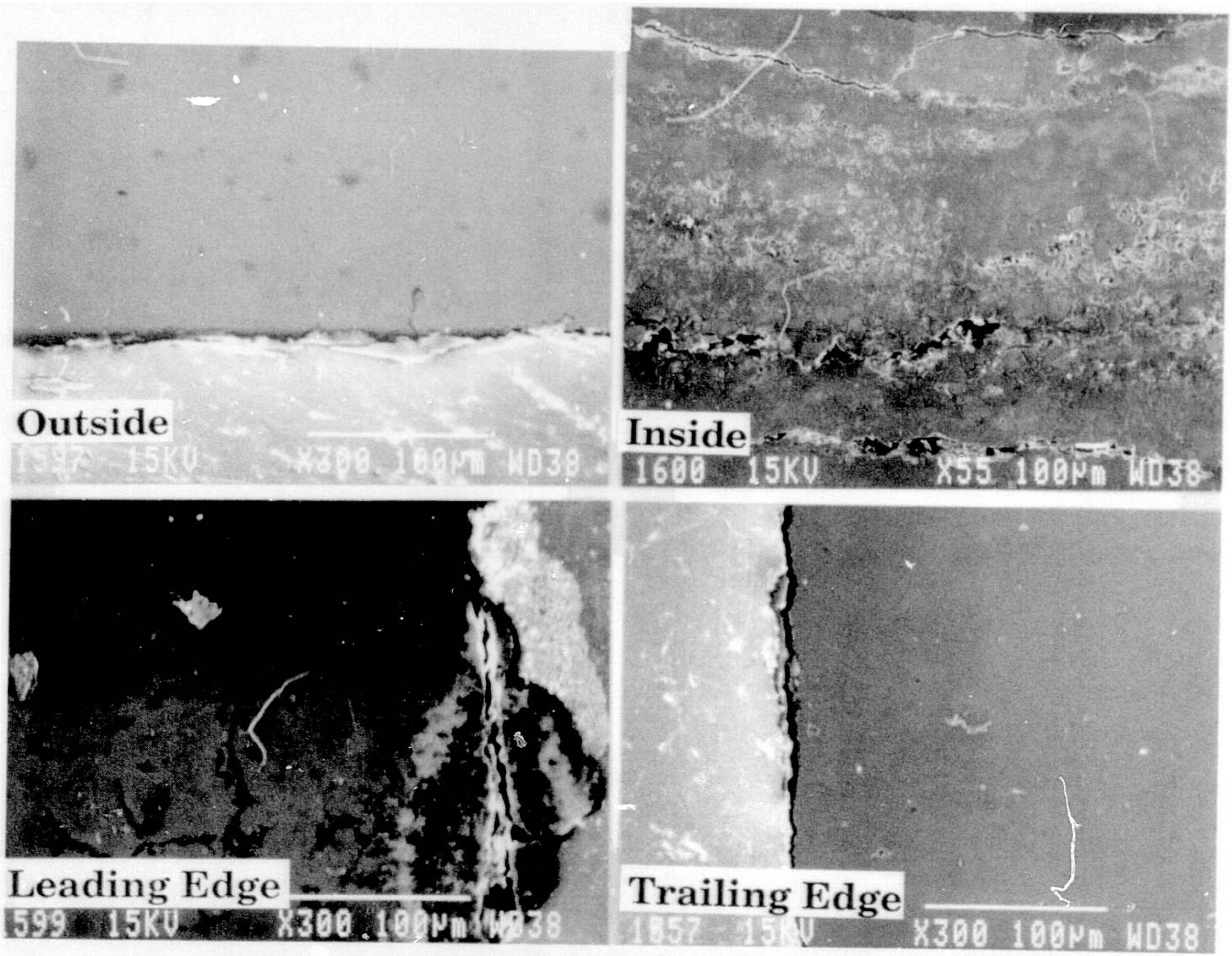
800H/310

SEM Micrographs of 310-Clad 800H Alloy after 500 h Exposure Near the Bed Walls



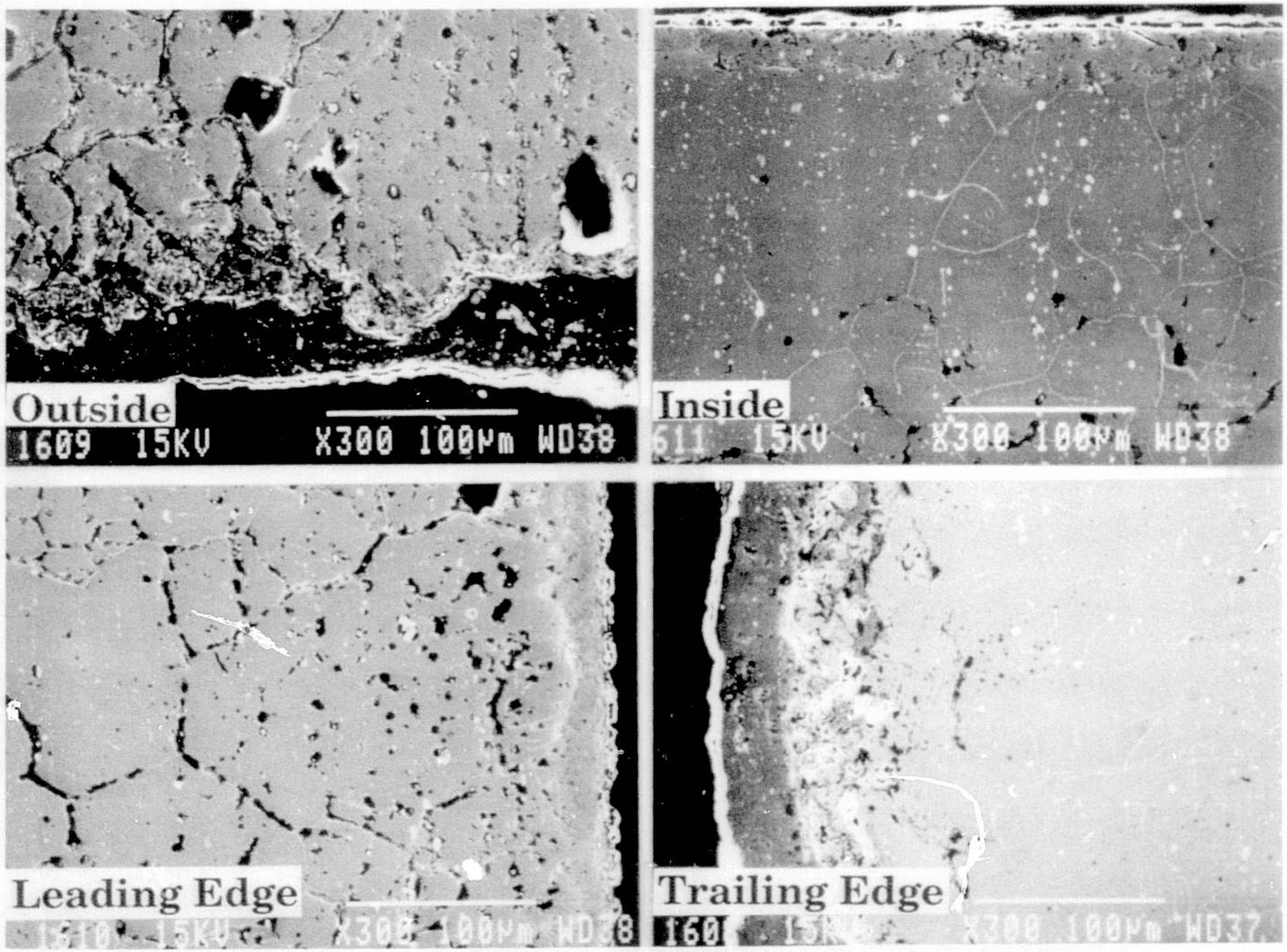
800H/8XX

SEM Micrographs of 8XX-Clad 800H after 500 h Exposure



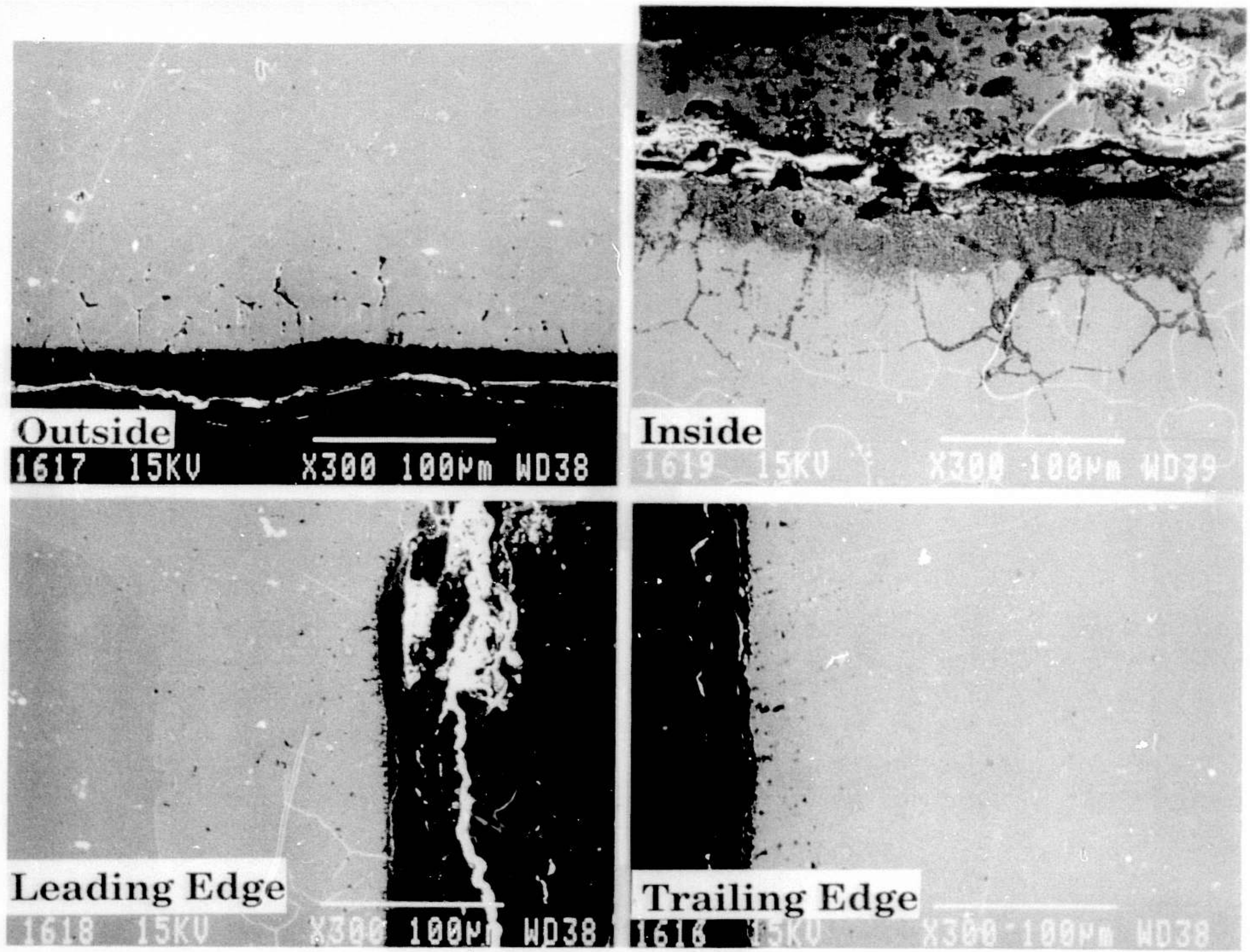
RA 330

SEM Micrographs of RA 330 after 500 h Exposure



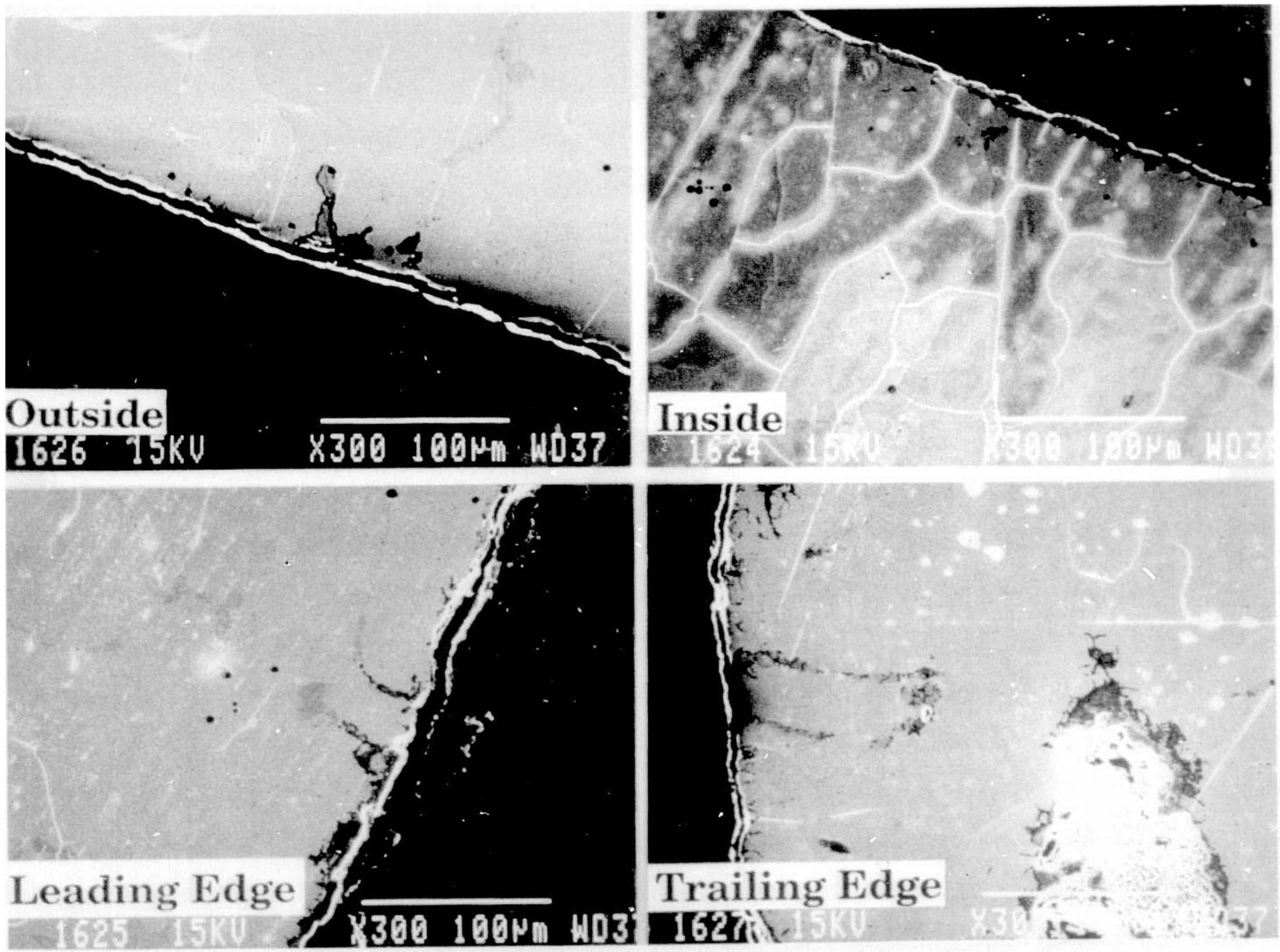
HS 188

SEM Micrographs of HS 188 after 500 h Exposure



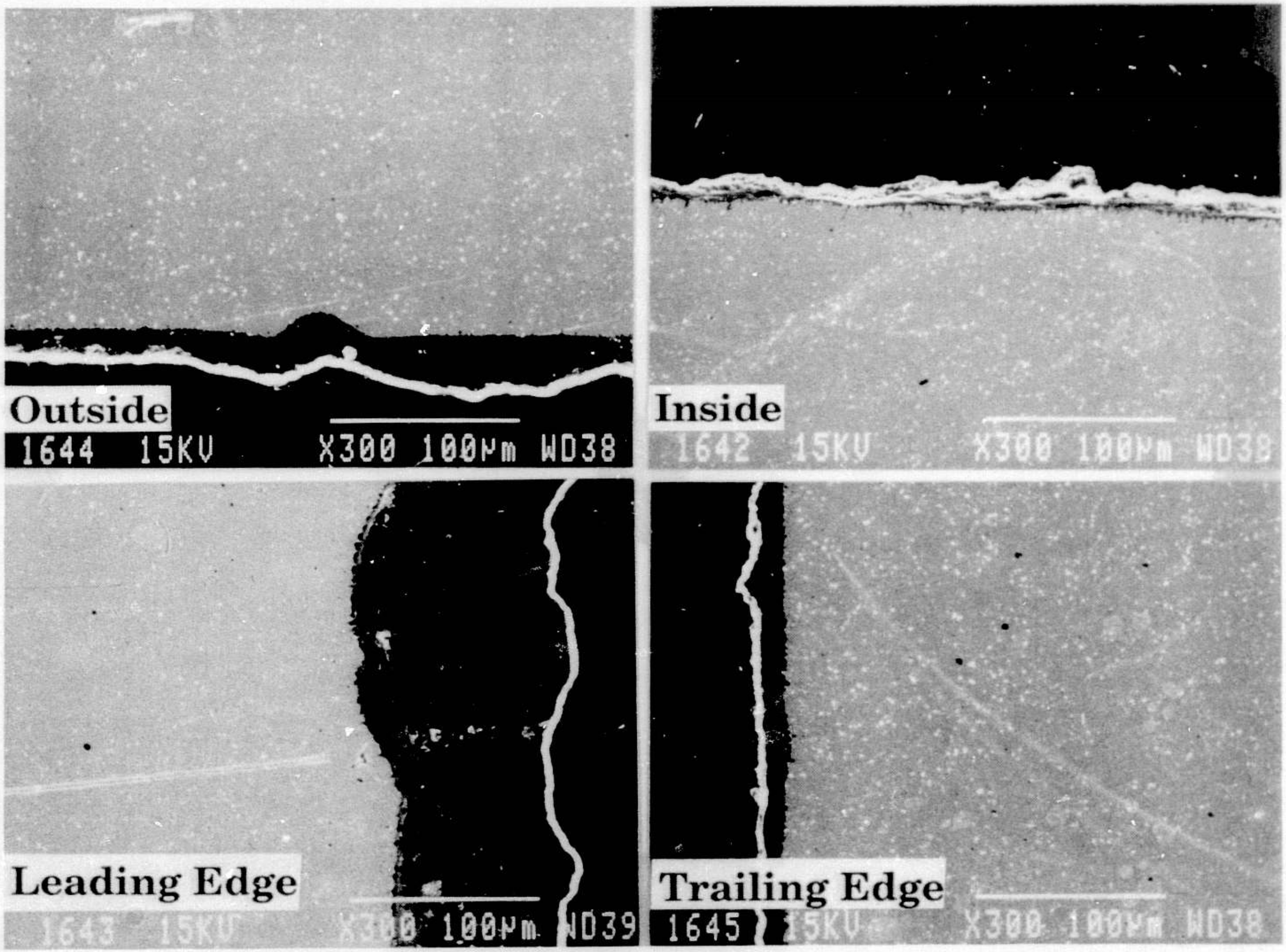
HS 556

SEM Micrographs of HS 556 after 500 h Exposure



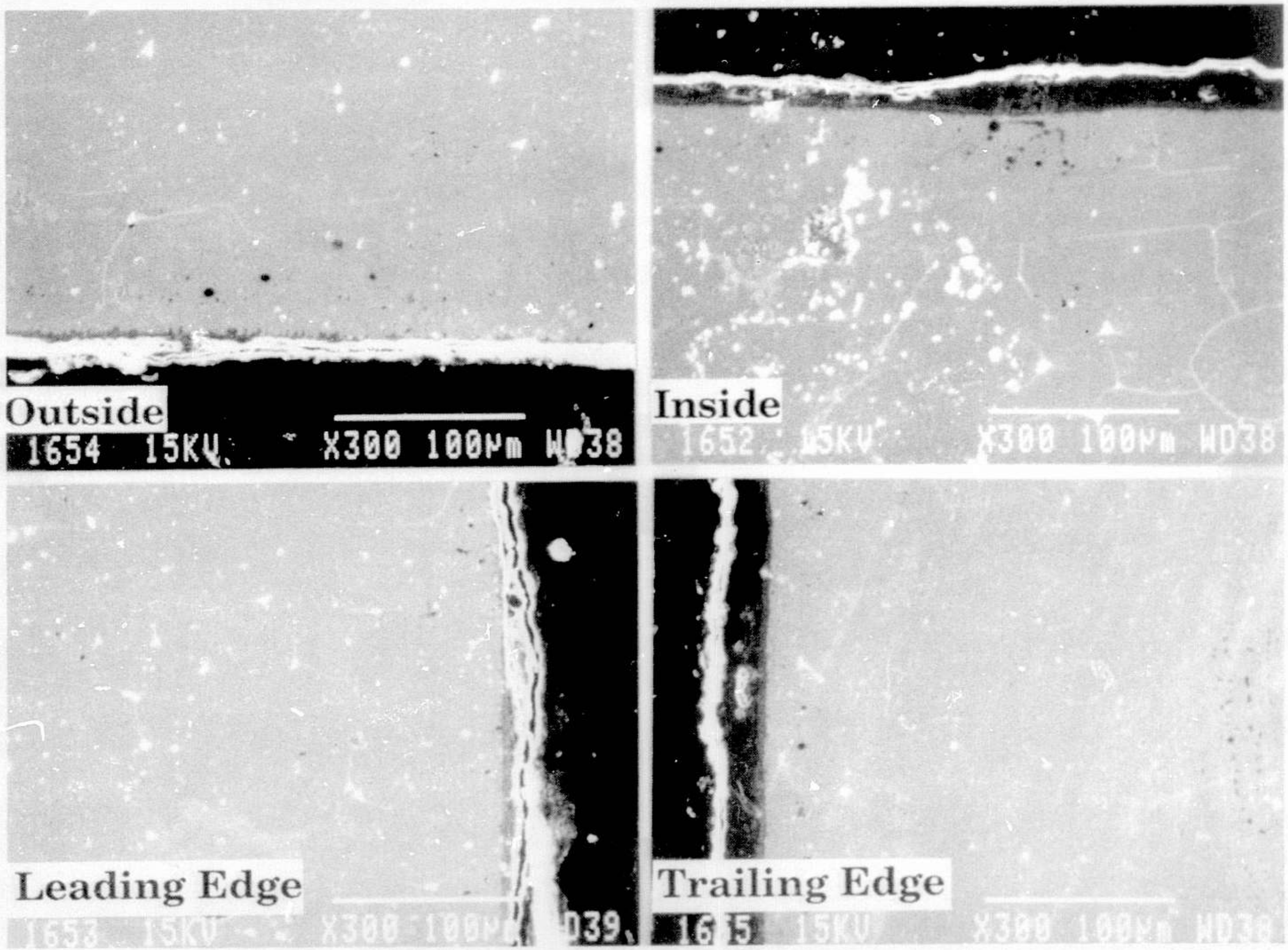
HK 40

SEM Micrographs of HK 40 after 500 h Exposure



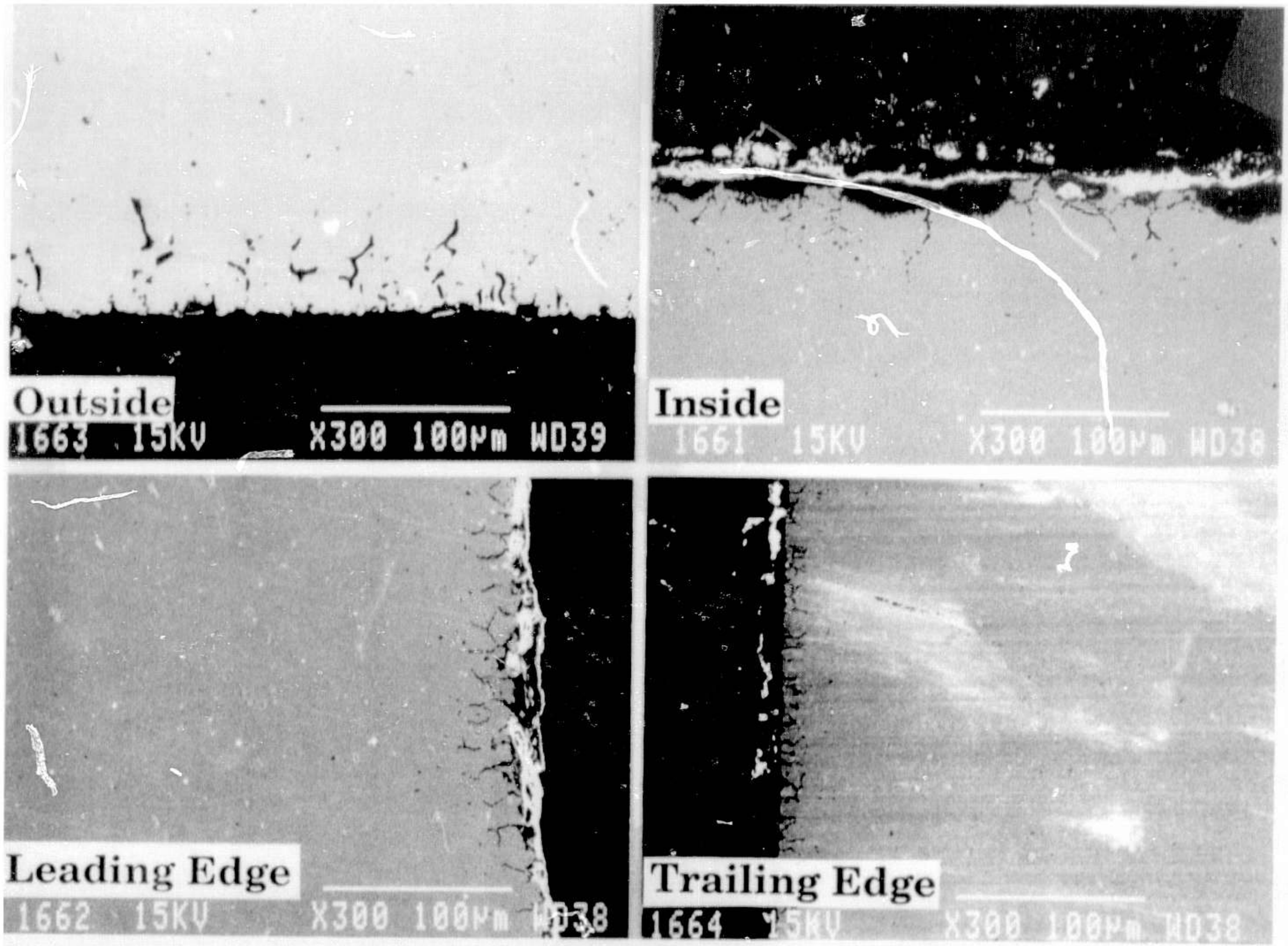
XM 19

SEM Micrographs of XM 19 after 500 h Exposure



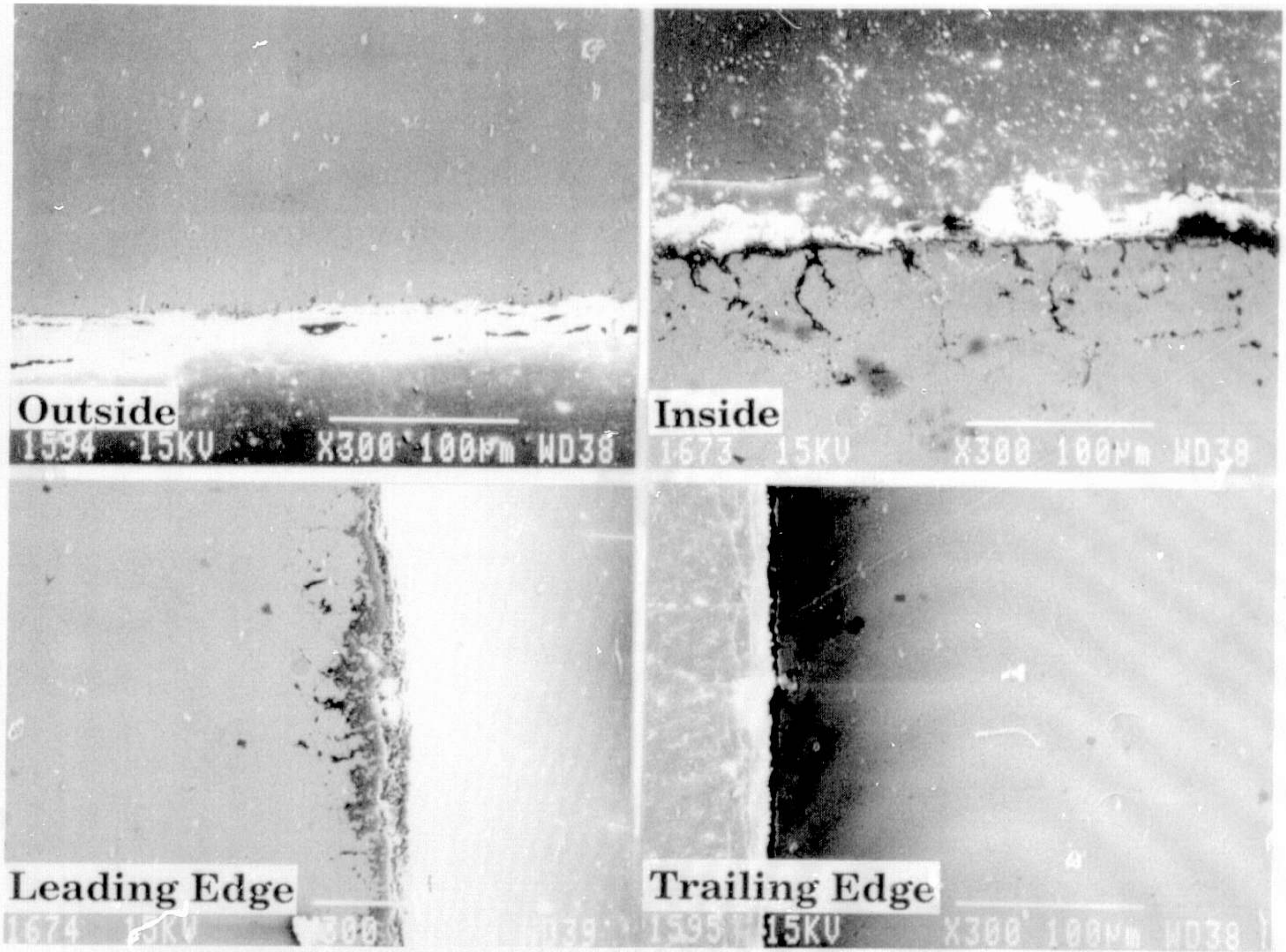
SANICRO 33

SEM Micrographs of Sanicro 33 after 500 h Exposure



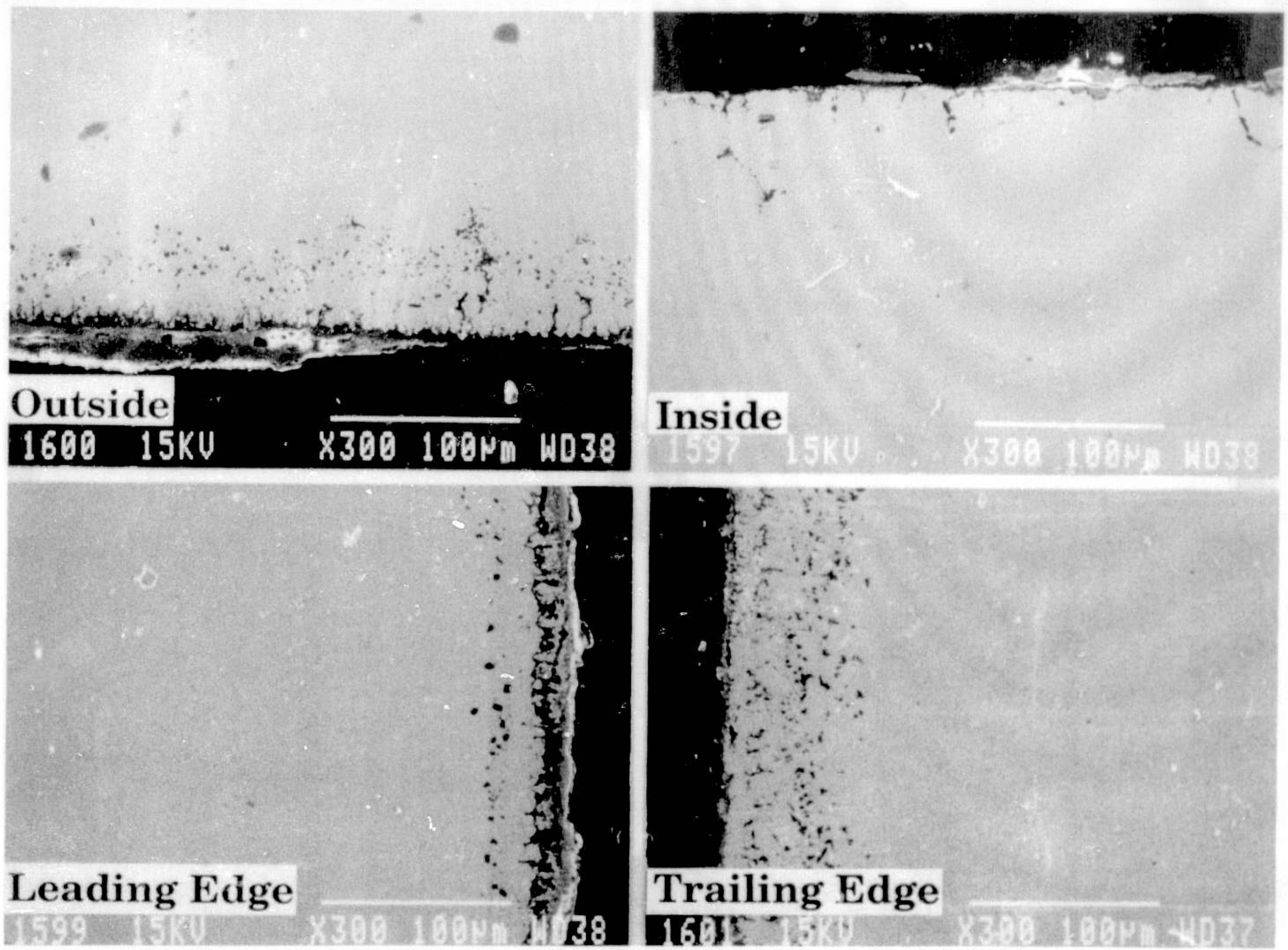
304/310

SEM Micrographs of 310-Clad 304 Stainless Steel after
500 h Exposure Near the Center of the Bed



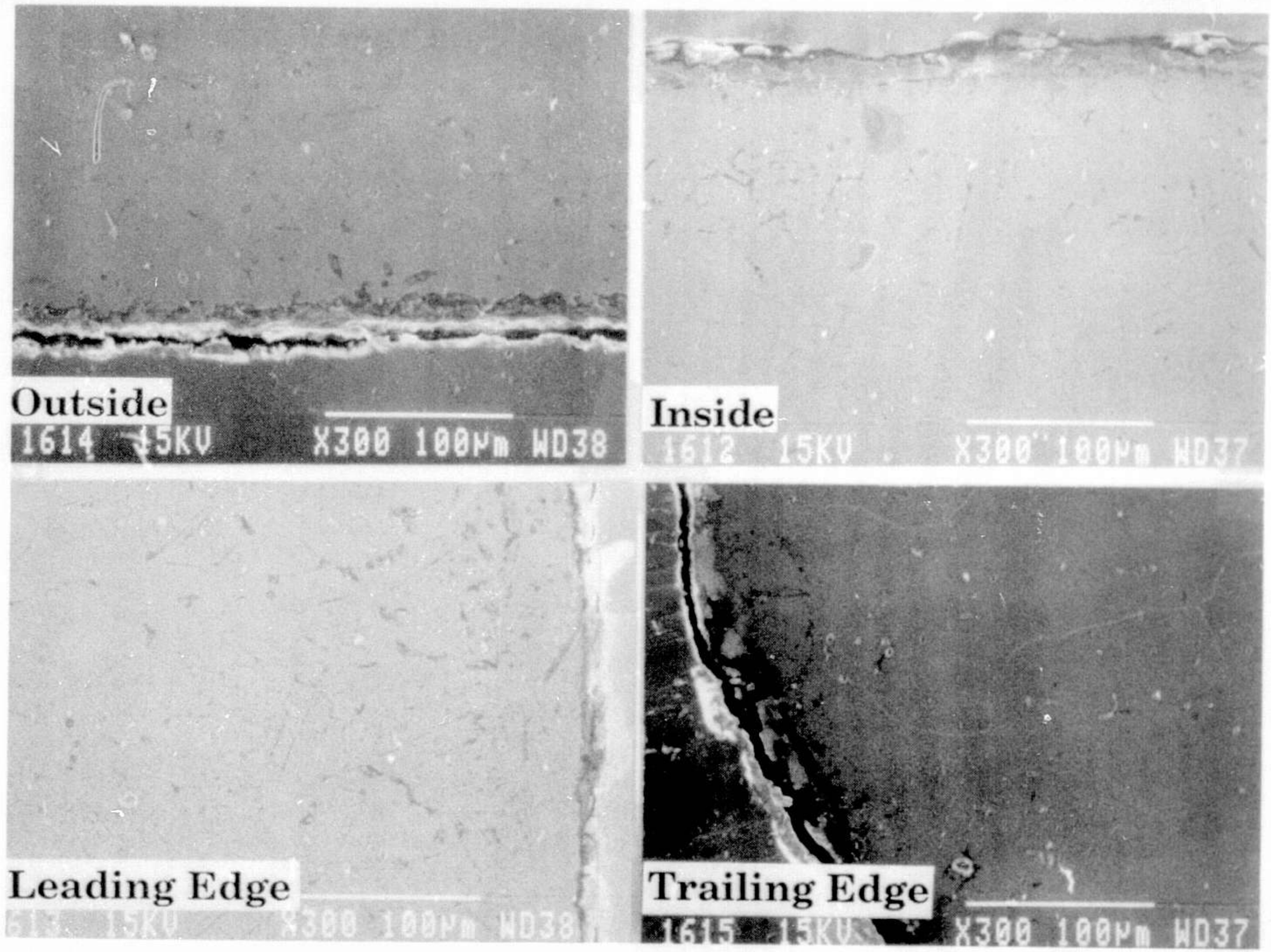
800H/310

SEM Micrographs of 310-Clad 800H Alloy after
500 h Exposure Near the Center of the Bed



800H/8XX

SEM Micrographs of 8XX-Clad 800H after 500 h Exposure



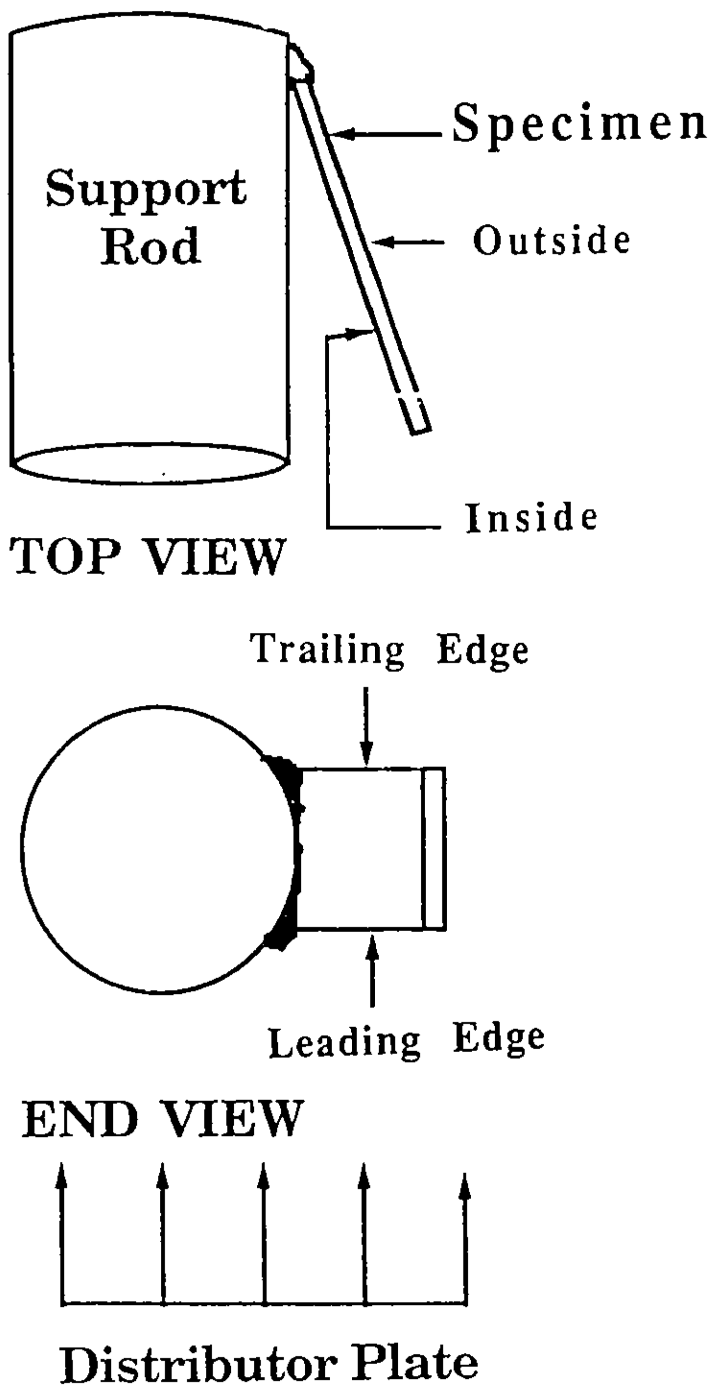
8XX

SEM Micrographs of 8XX after 500 h Exposure

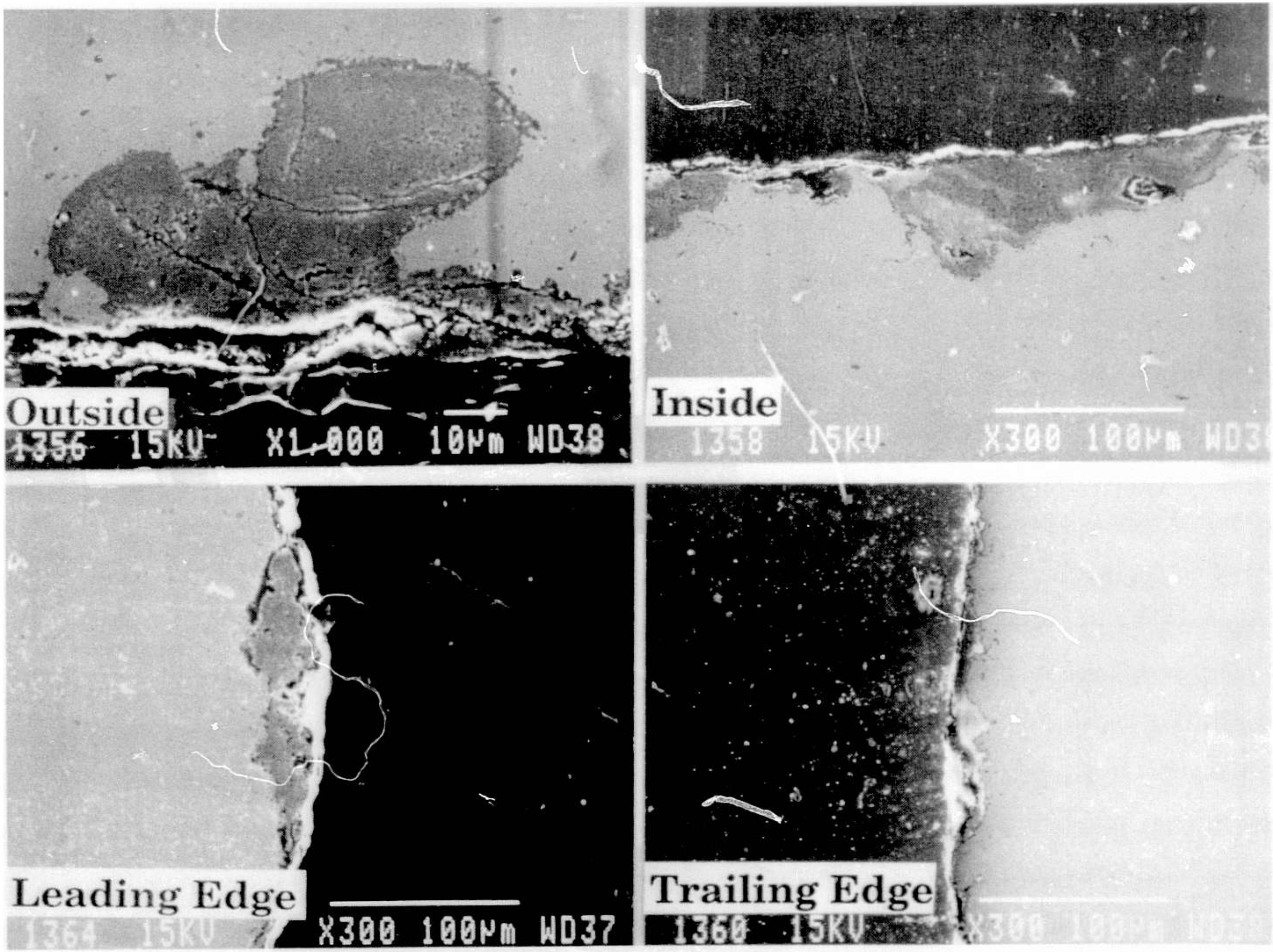
APPENDIX D.

MICROSTRUCTURES OF SPECIMENS FROM B&W PROBE BBTEB

PROBE ID:	**BBTEB**
TYPE OF PROBE:	**Uncooled**
EXPOSURE TIME:	**1000 h**
ORGANIZATION:	**Babcock and Wilcox**

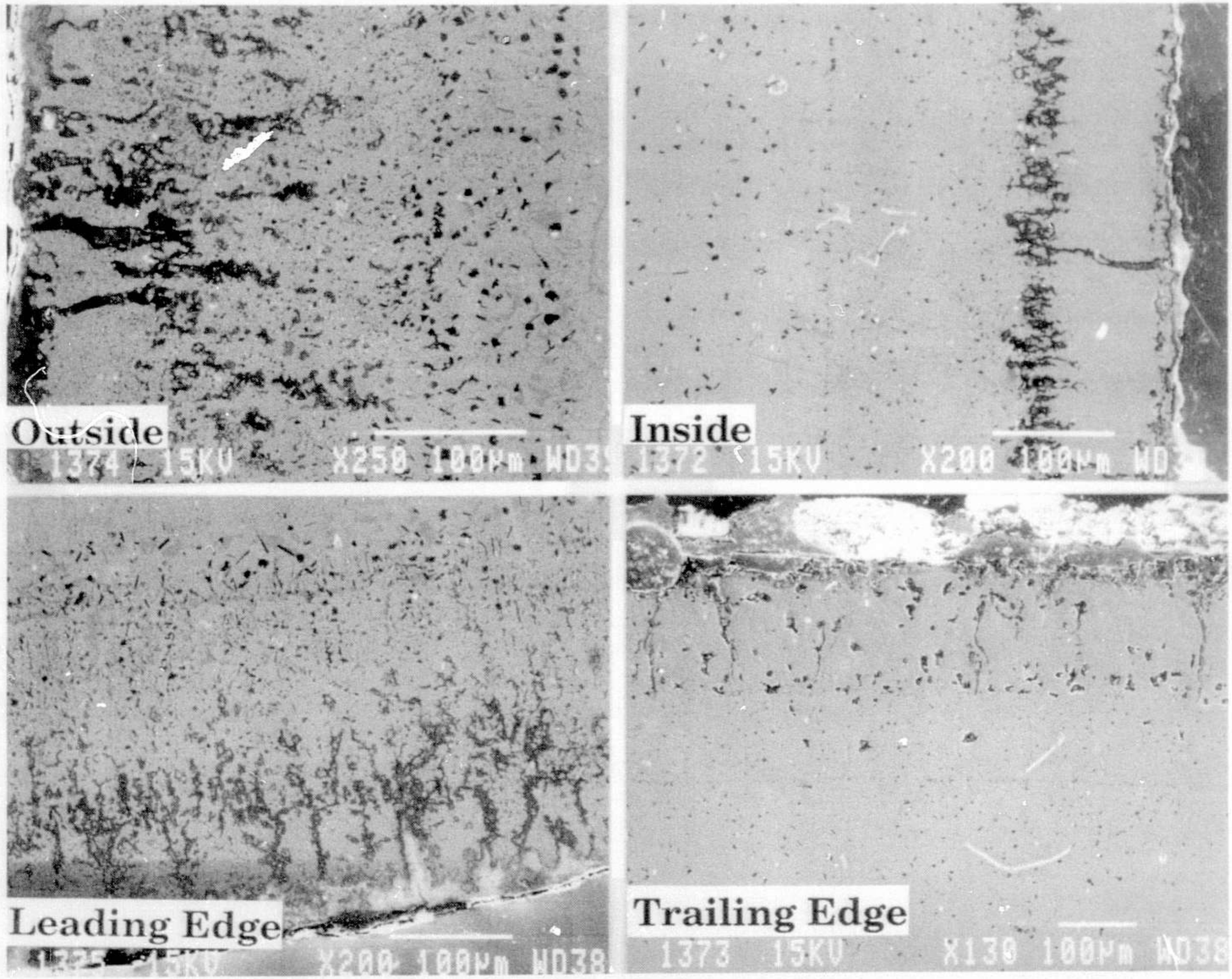


B&W Uncooled Probe BBTEB



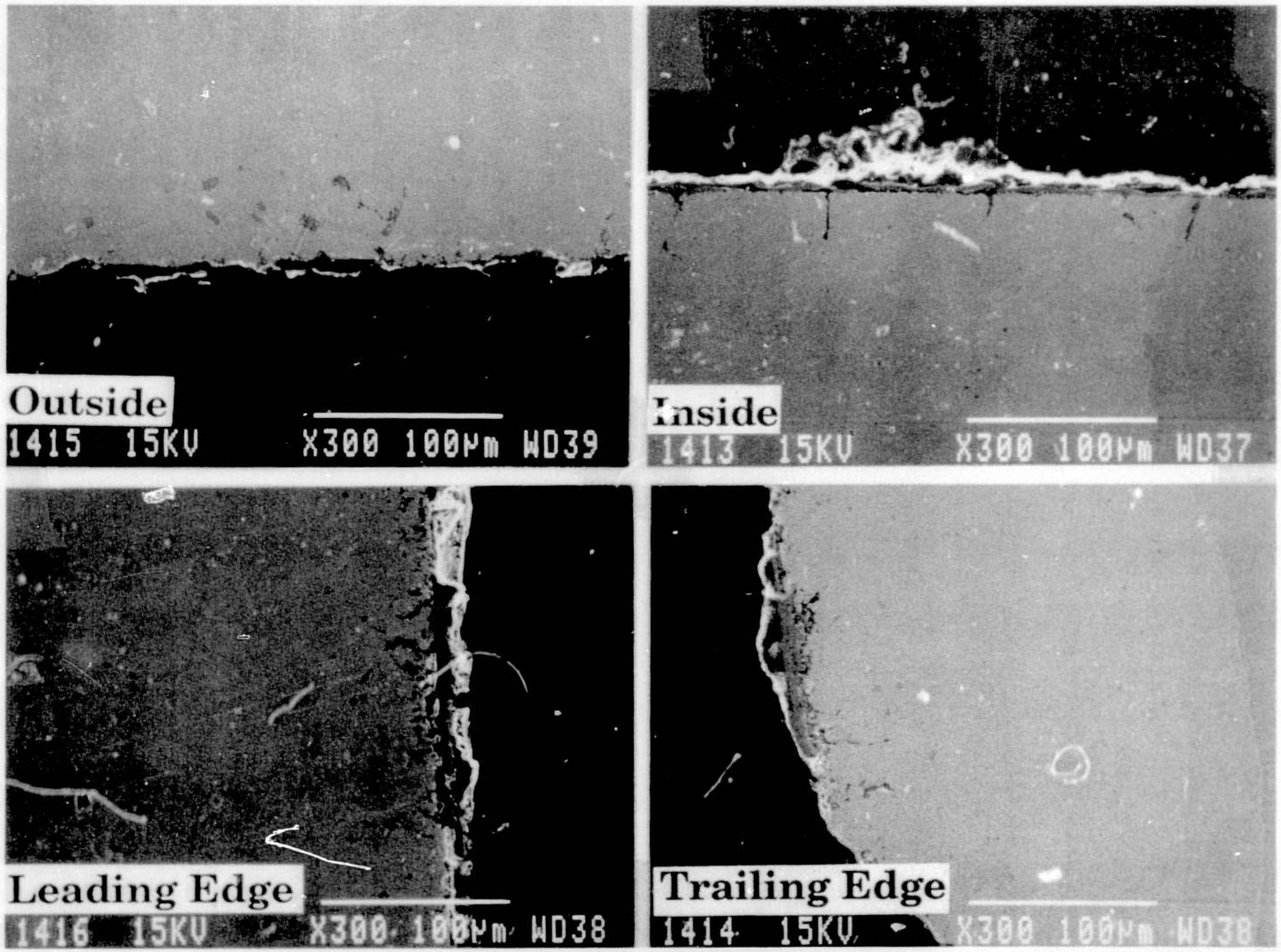
304H SS

SEM Micrographs of 304 Stainless Steel after 1000 h Exposure



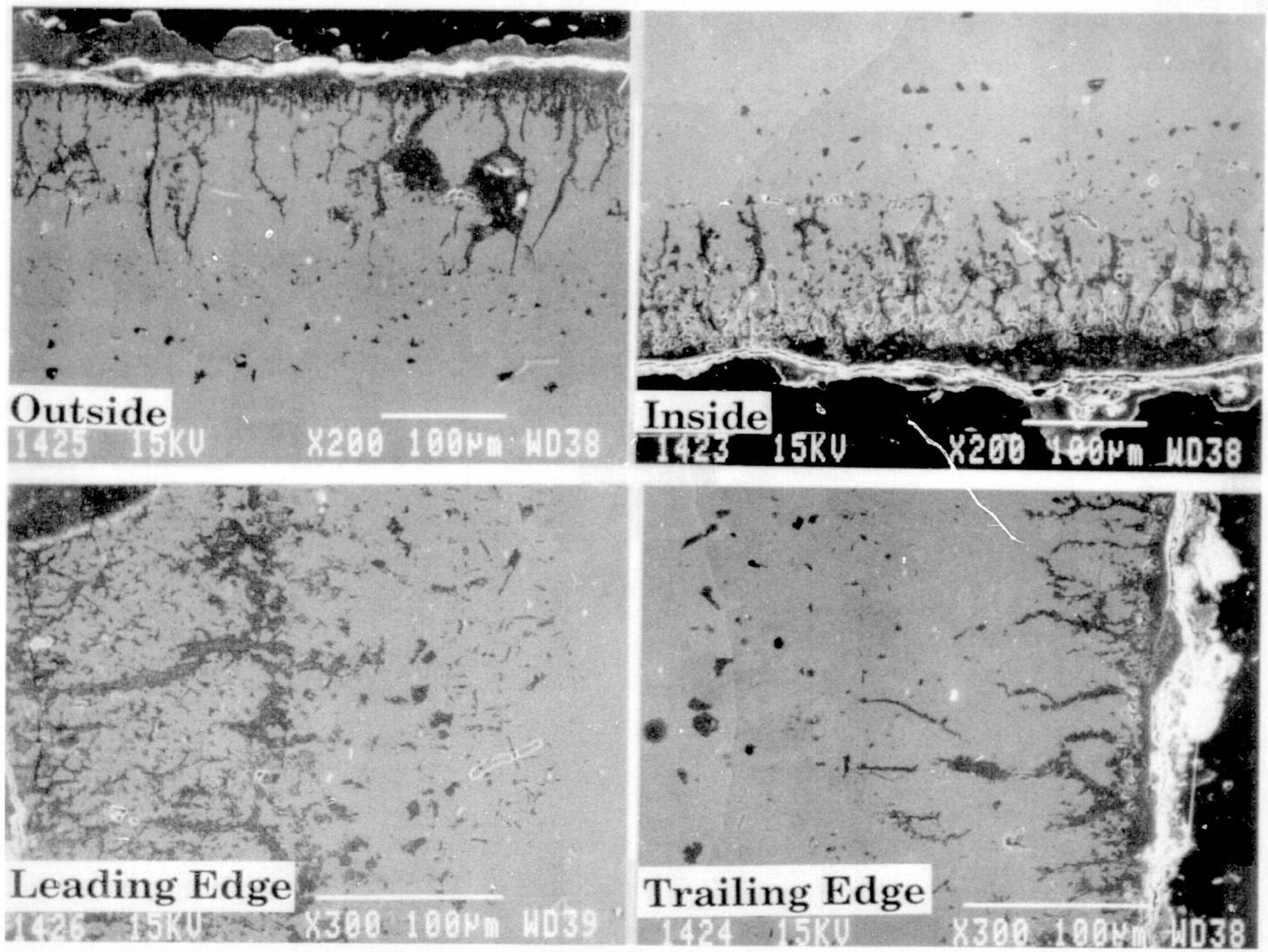
304H/Al

SEM Micrographs of Aluminized 304 Stainless Steel after 1000 h Exposure



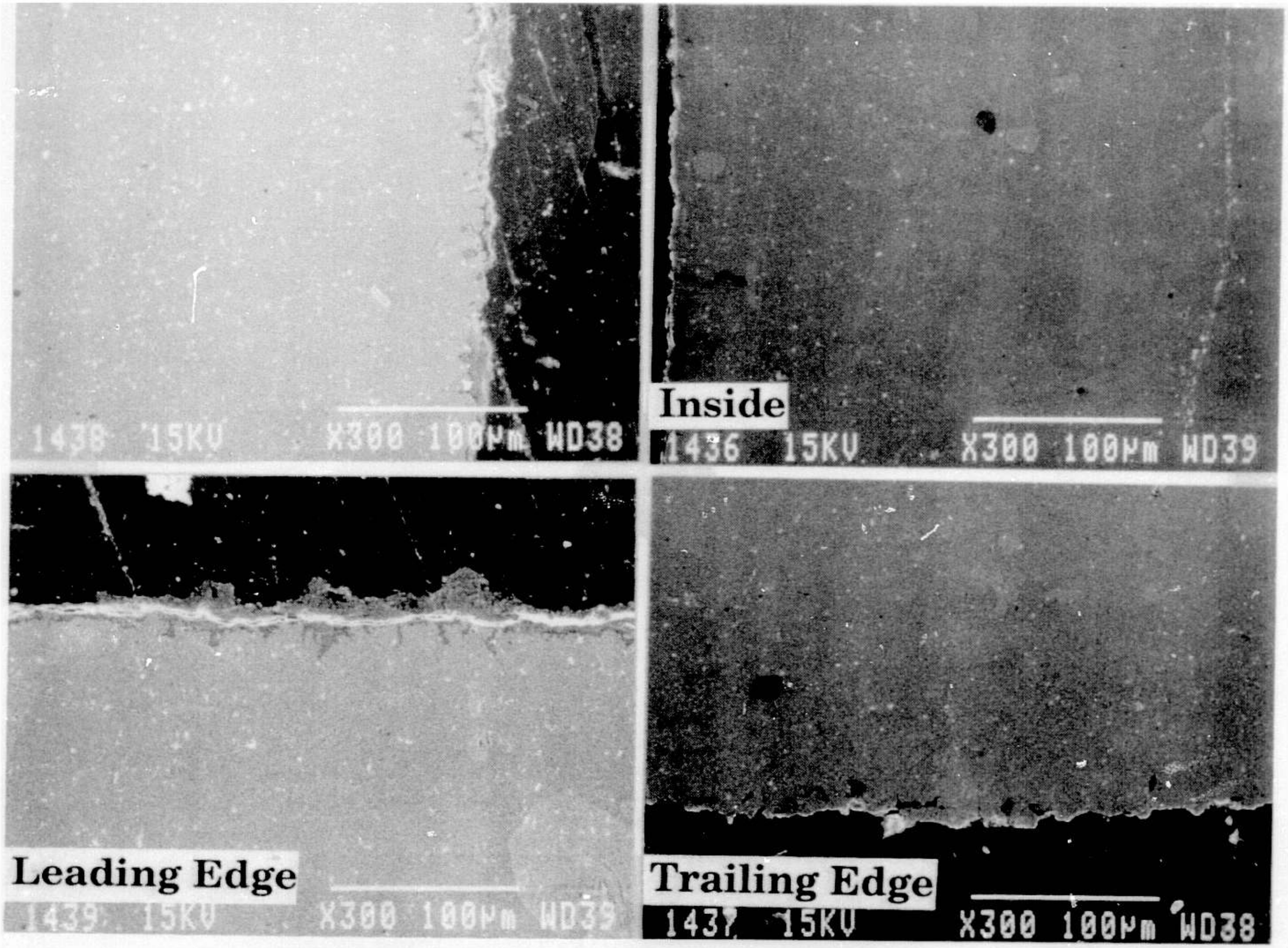
310 SS

SEM Micrographs of 310 Stainless Steel after 1000 h Exposure



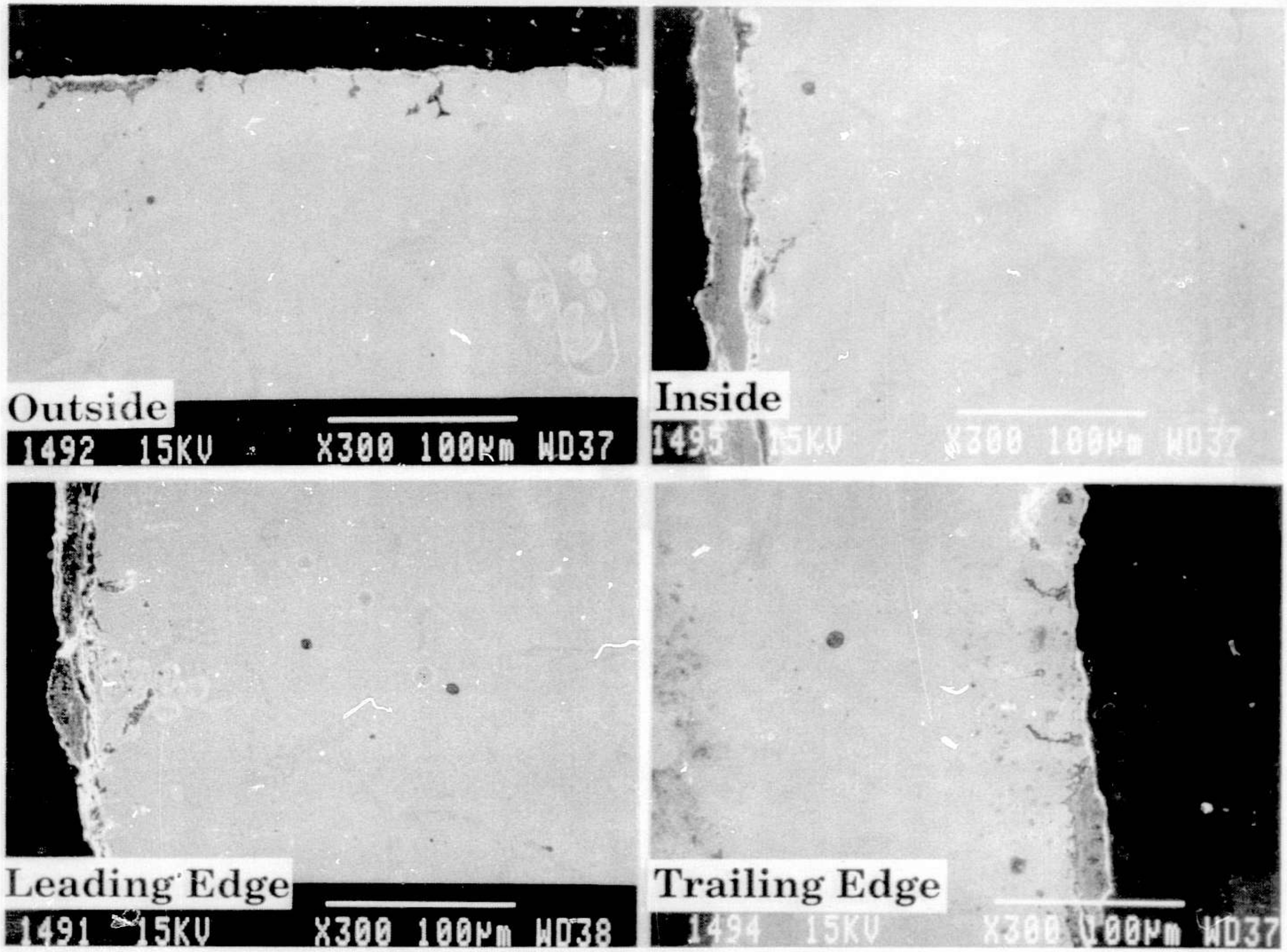
310/Al

SEM Micrographs of Aluminized 310 Stainless Steel after 1000 h Exposure



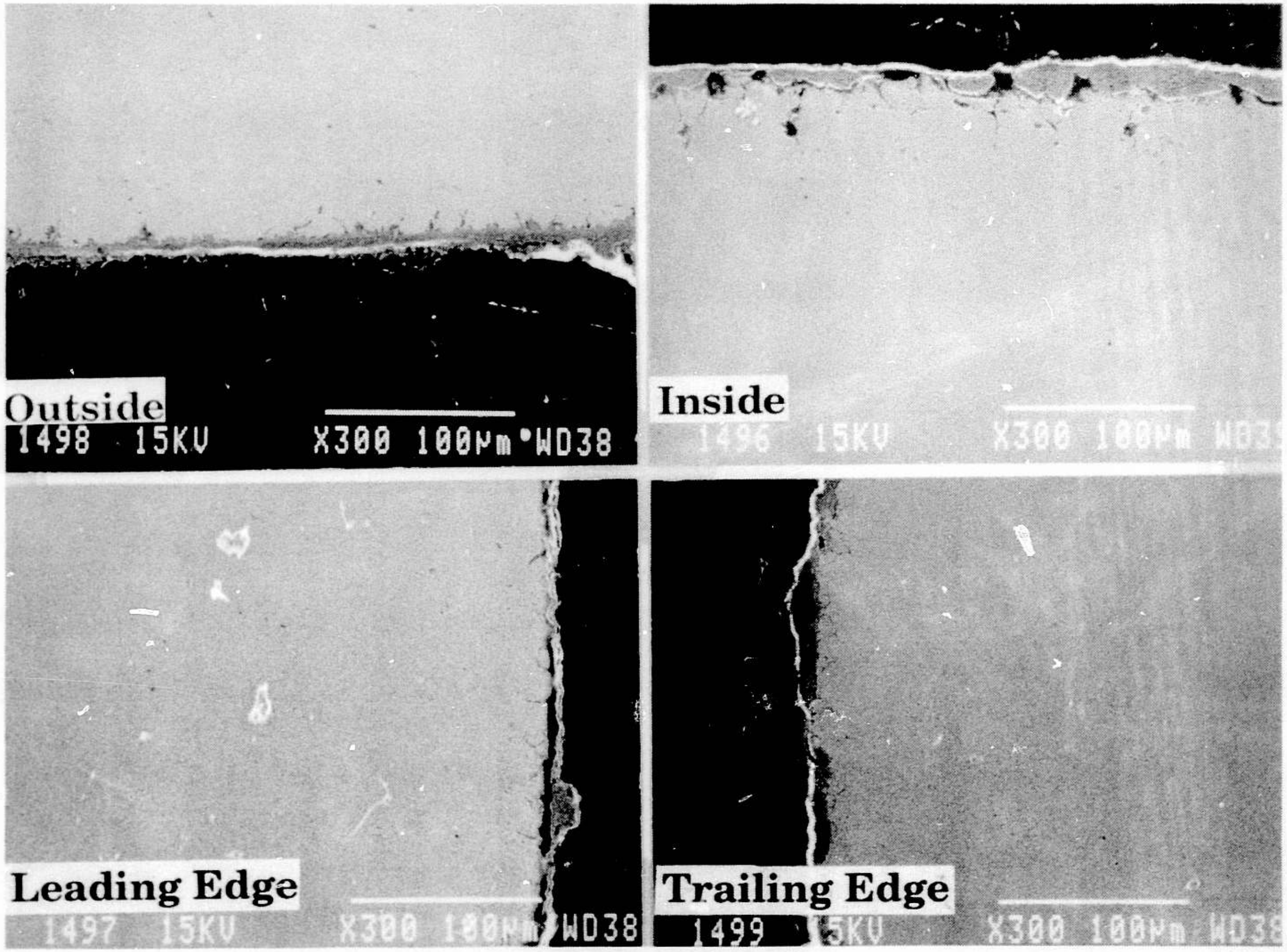
HH

SEM Micrographs of HH after 1000 h Exposure



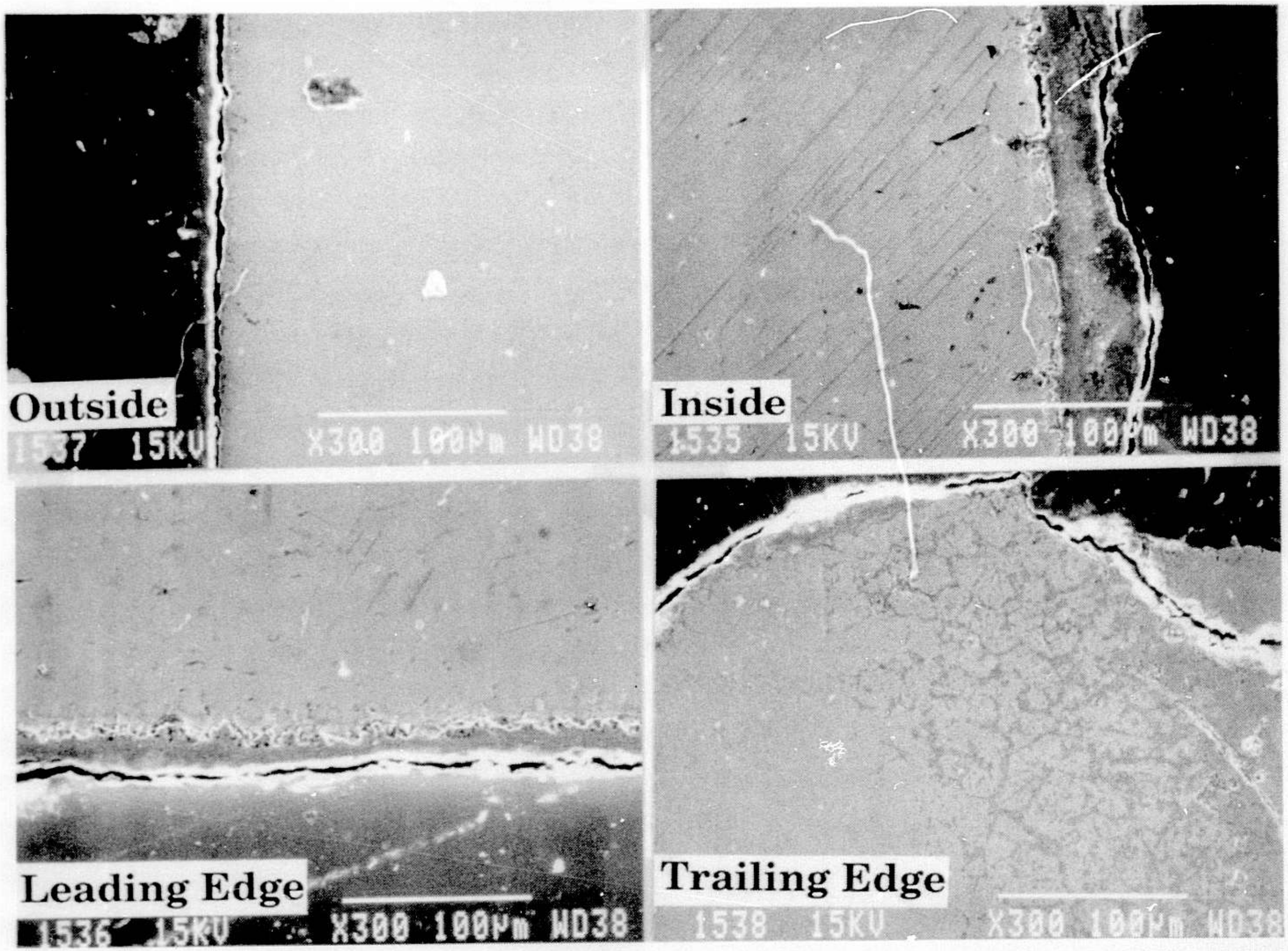
HP 50

SEM Micrographs of HP 50 after 1000 h Exposure



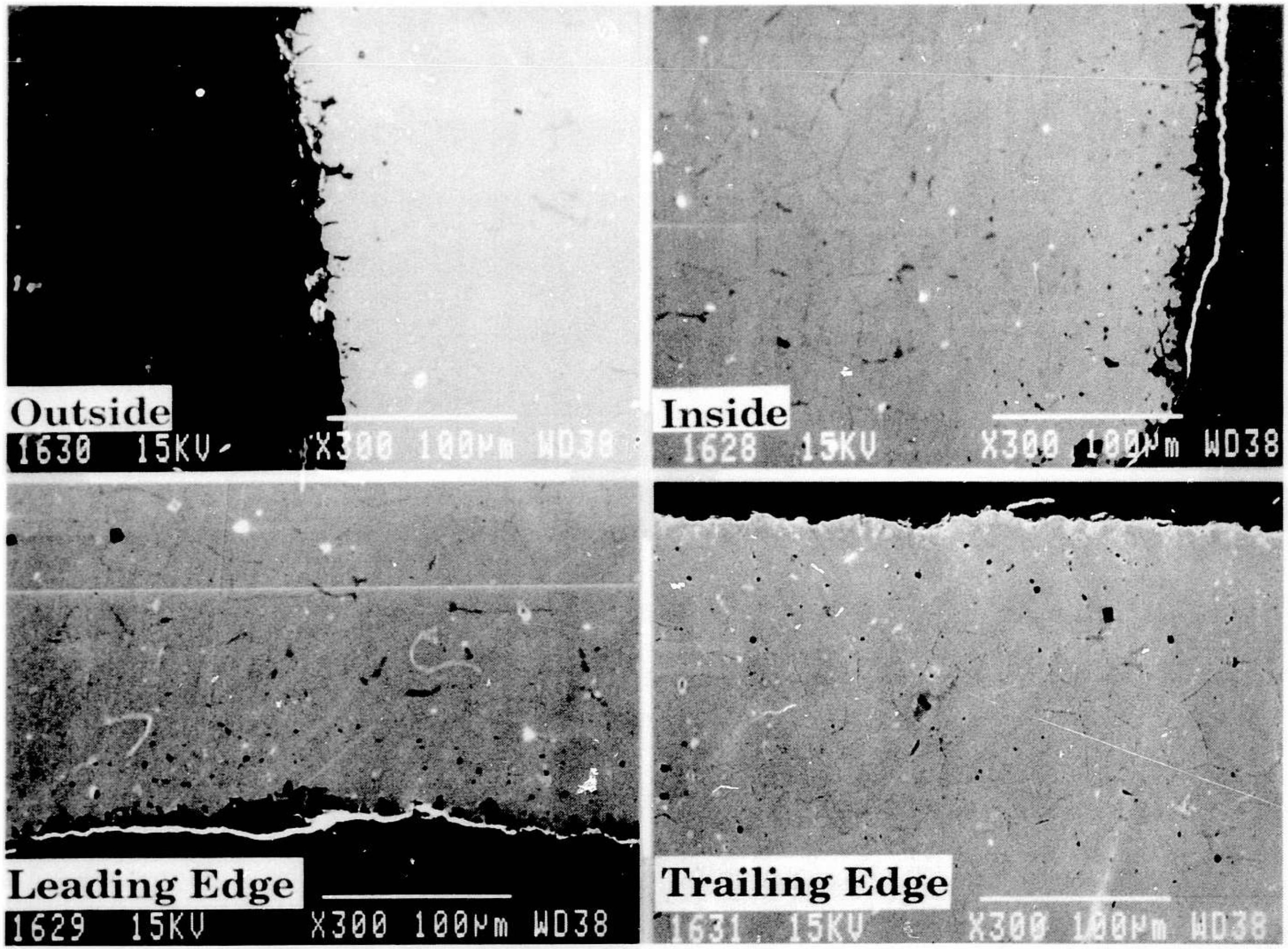
304/310

SEM Micrographs of 310-Clad 304 Stainless Steel after 1000 h Exposure Near the Bed Wall



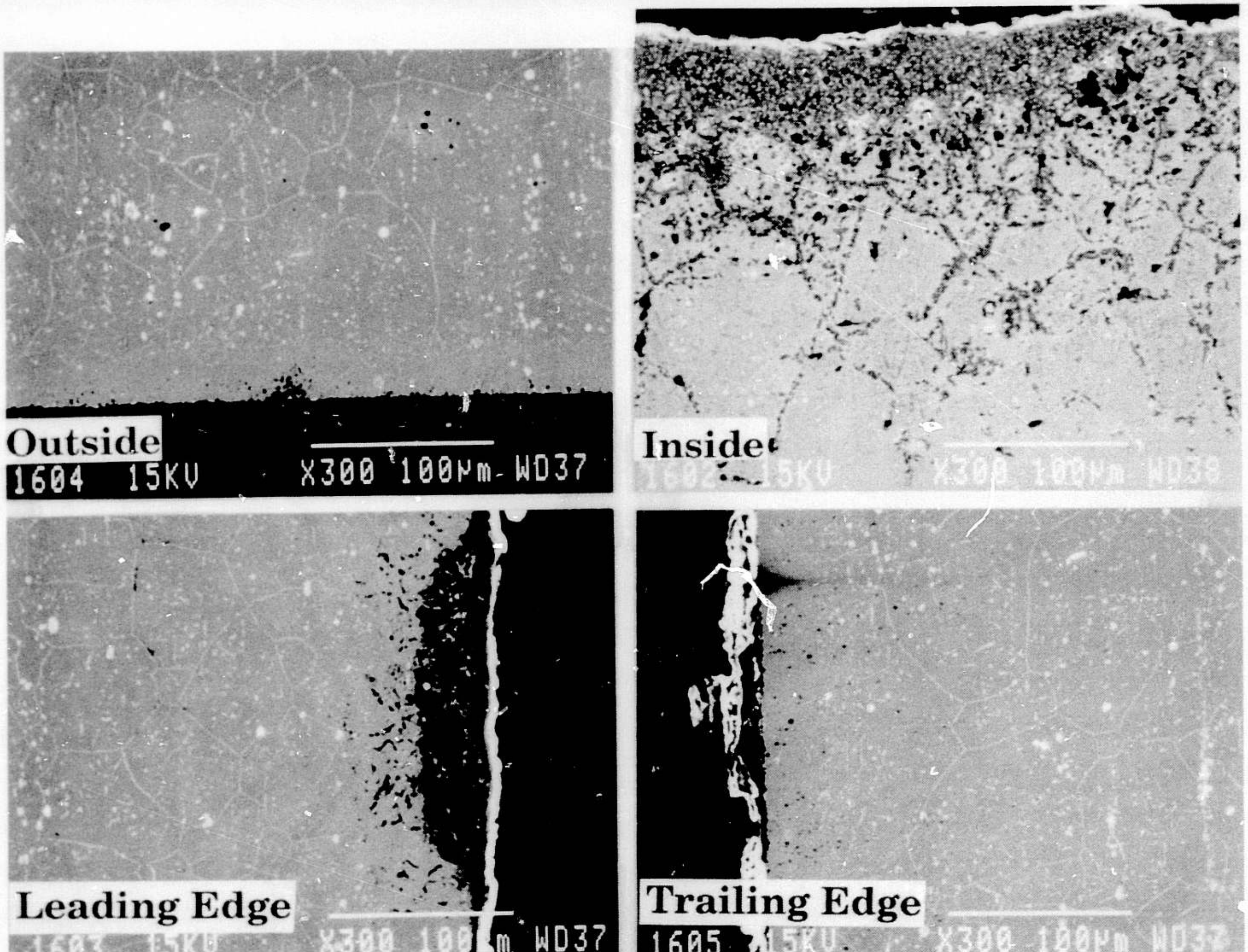
800H/310

SEM Micrographs of 310-Clad 800H after 1000 h Exposure



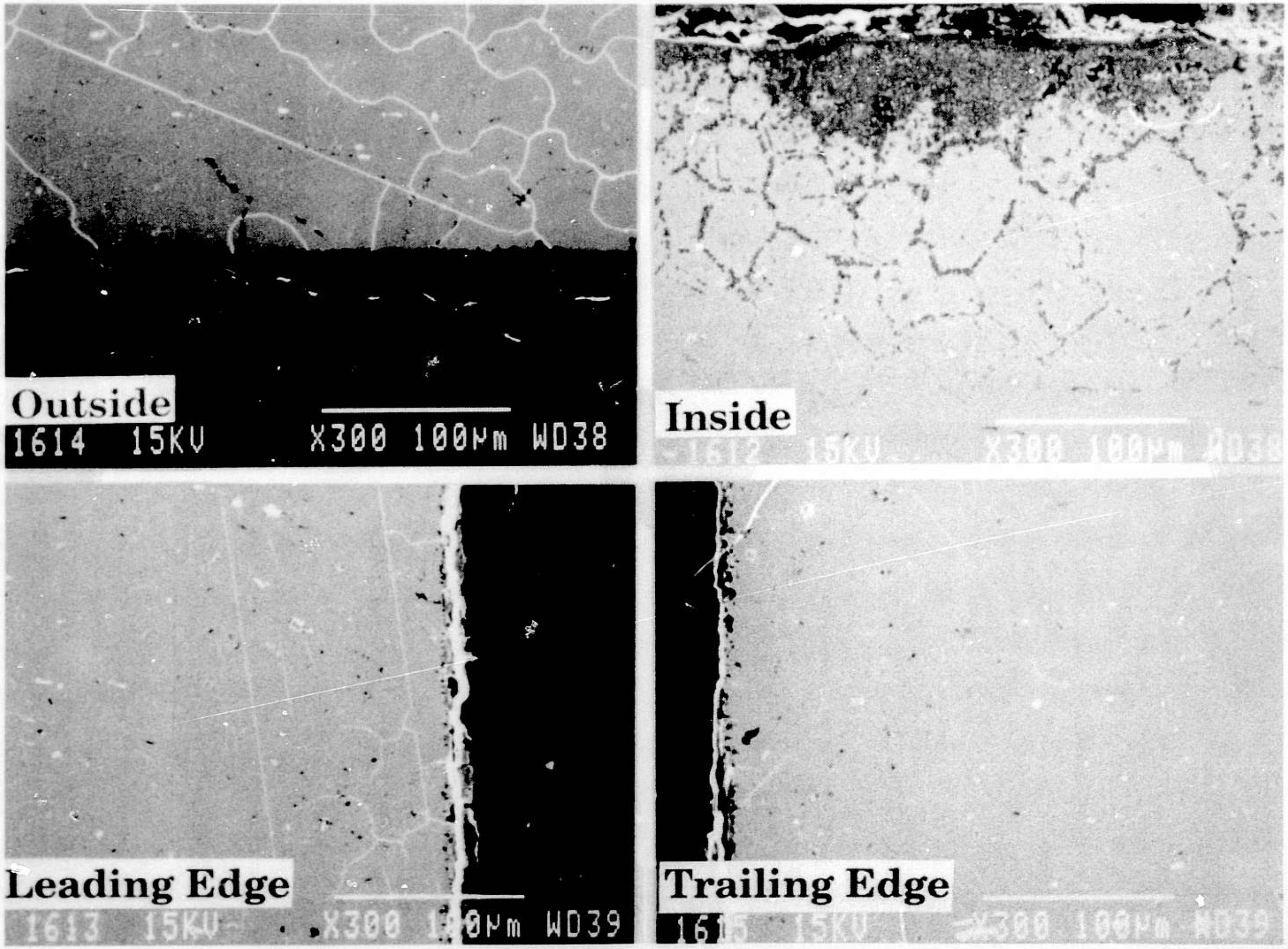
253 MA

SEM Micrographs of 253 MA after 1000 h Exposure



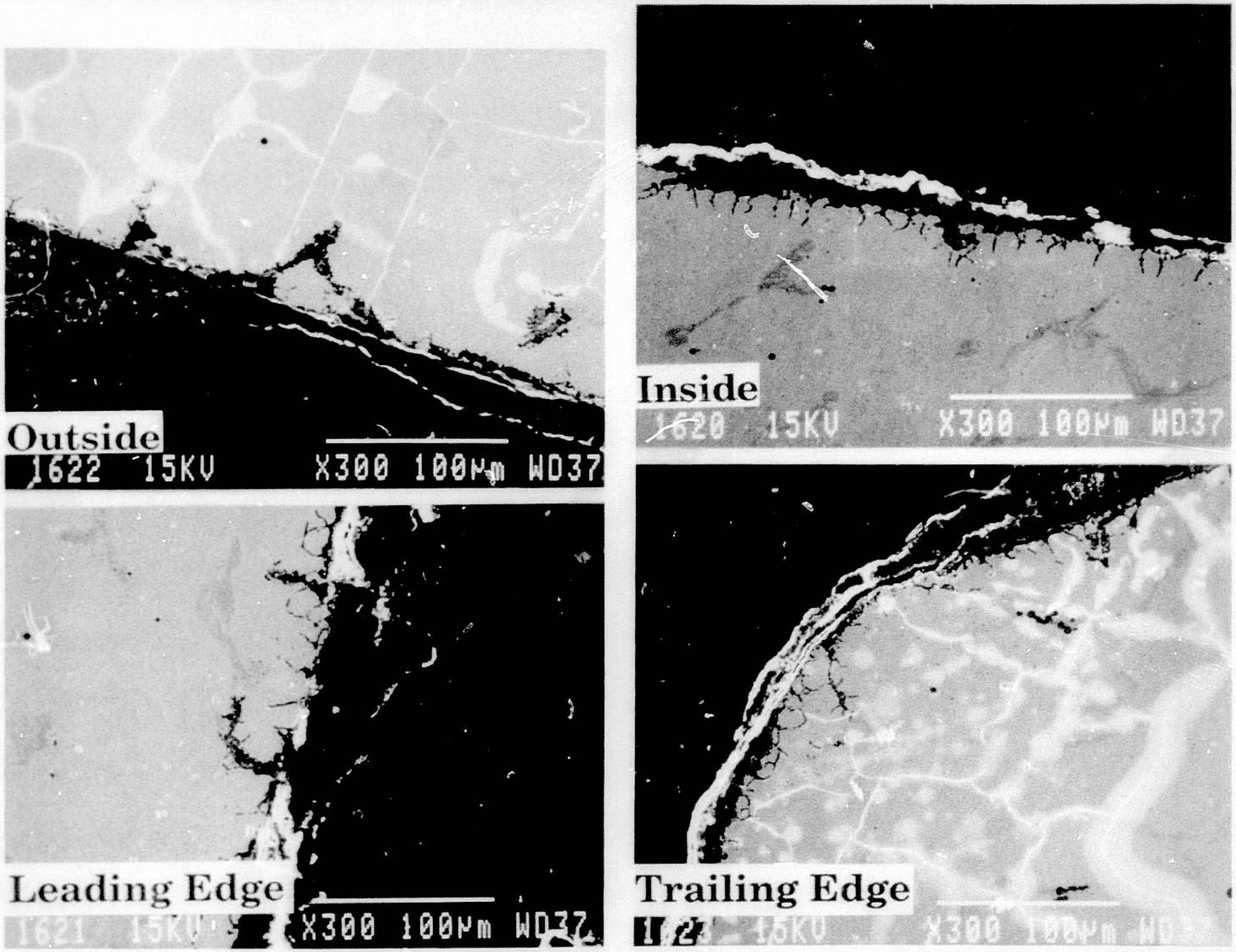
HS 188

SEM Micrographs of HS 188 after 1000 h Exposure



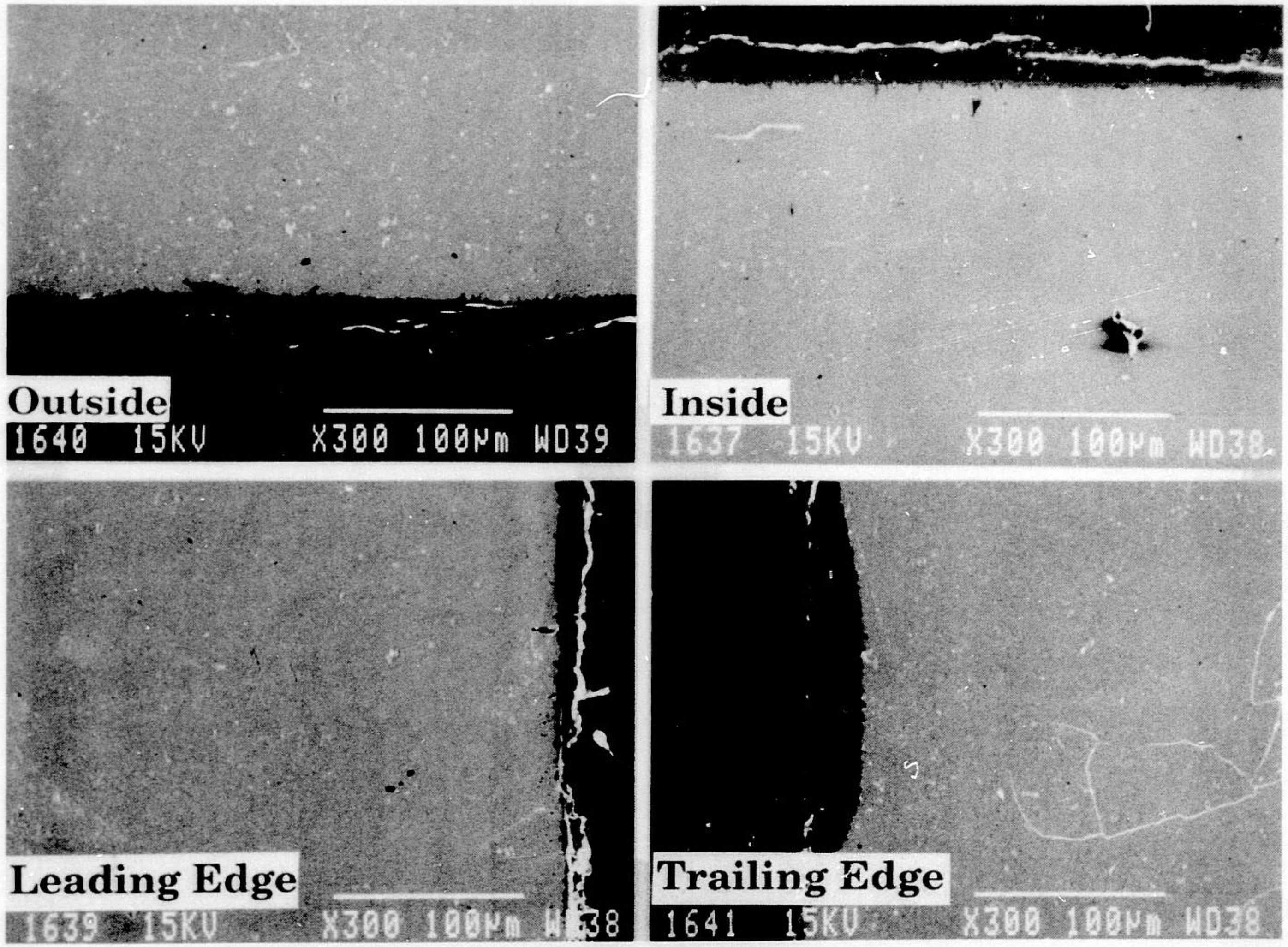
HS 556

SEM Micrographs of HS 556 after 1000 h Exposure



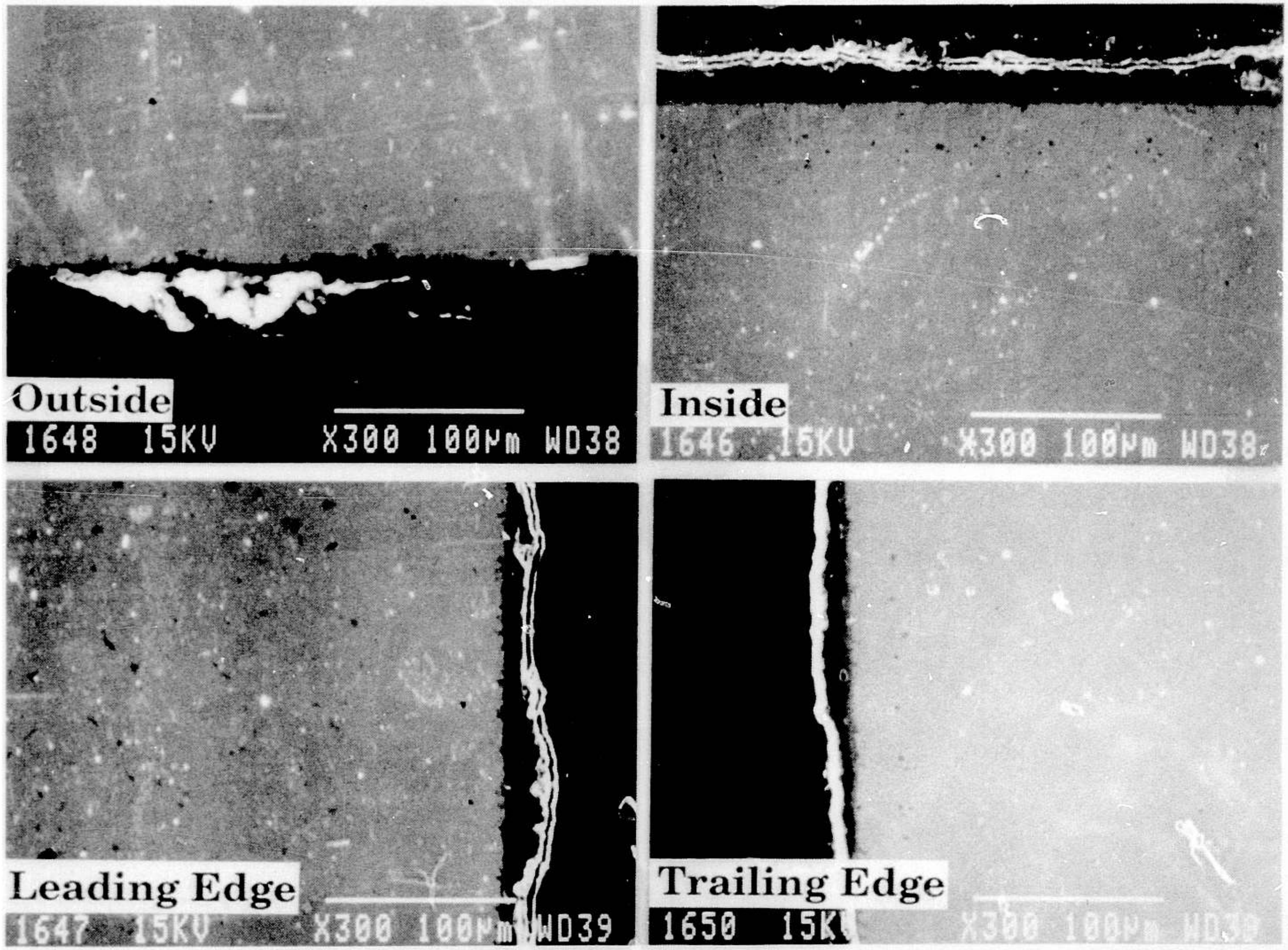
HK 40

SEM Micrographs of HK 40 after 1000 h Exposure



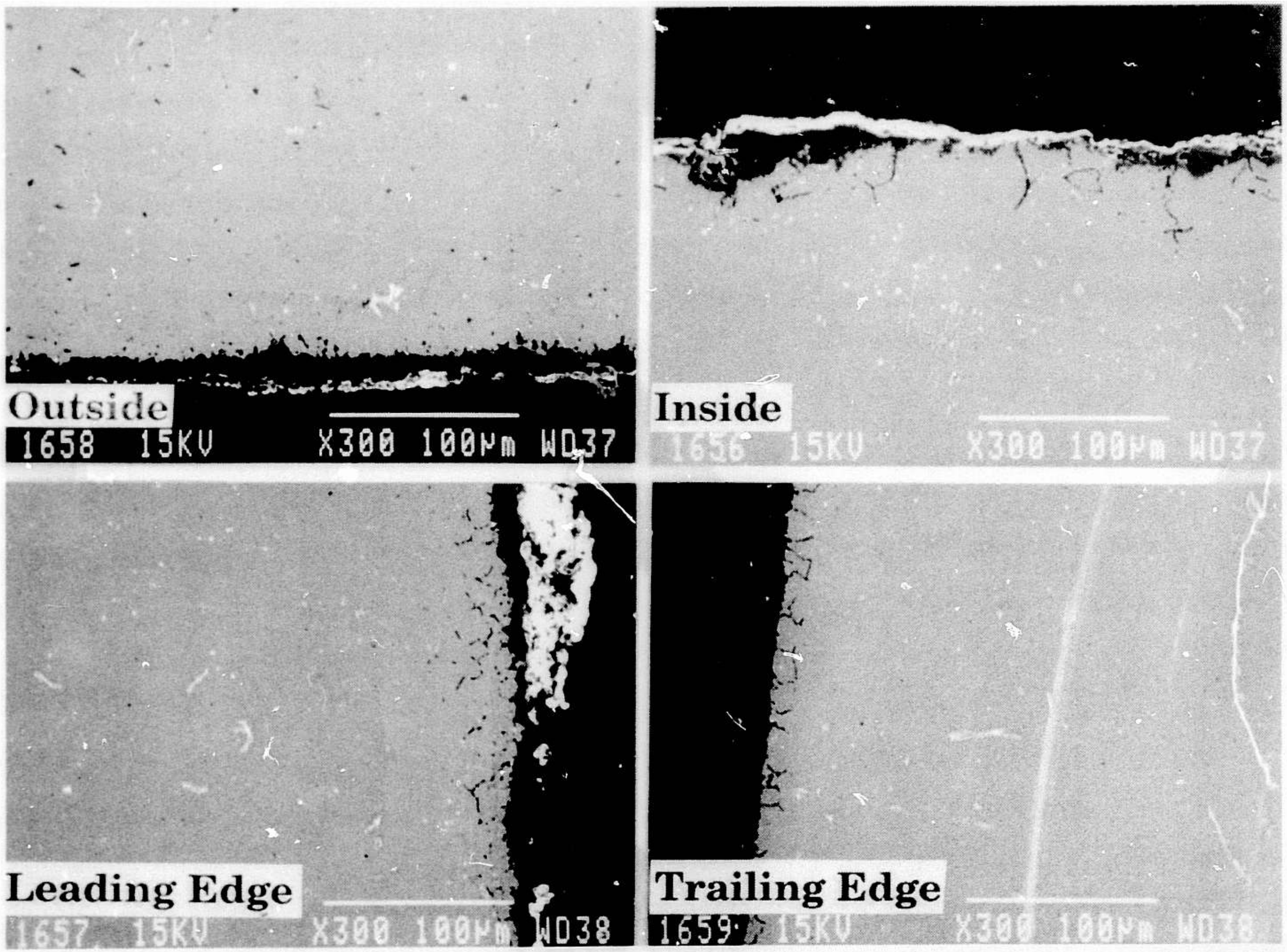
XM 19

SEM Micrographs of XM 19 after 1000 h Exposure



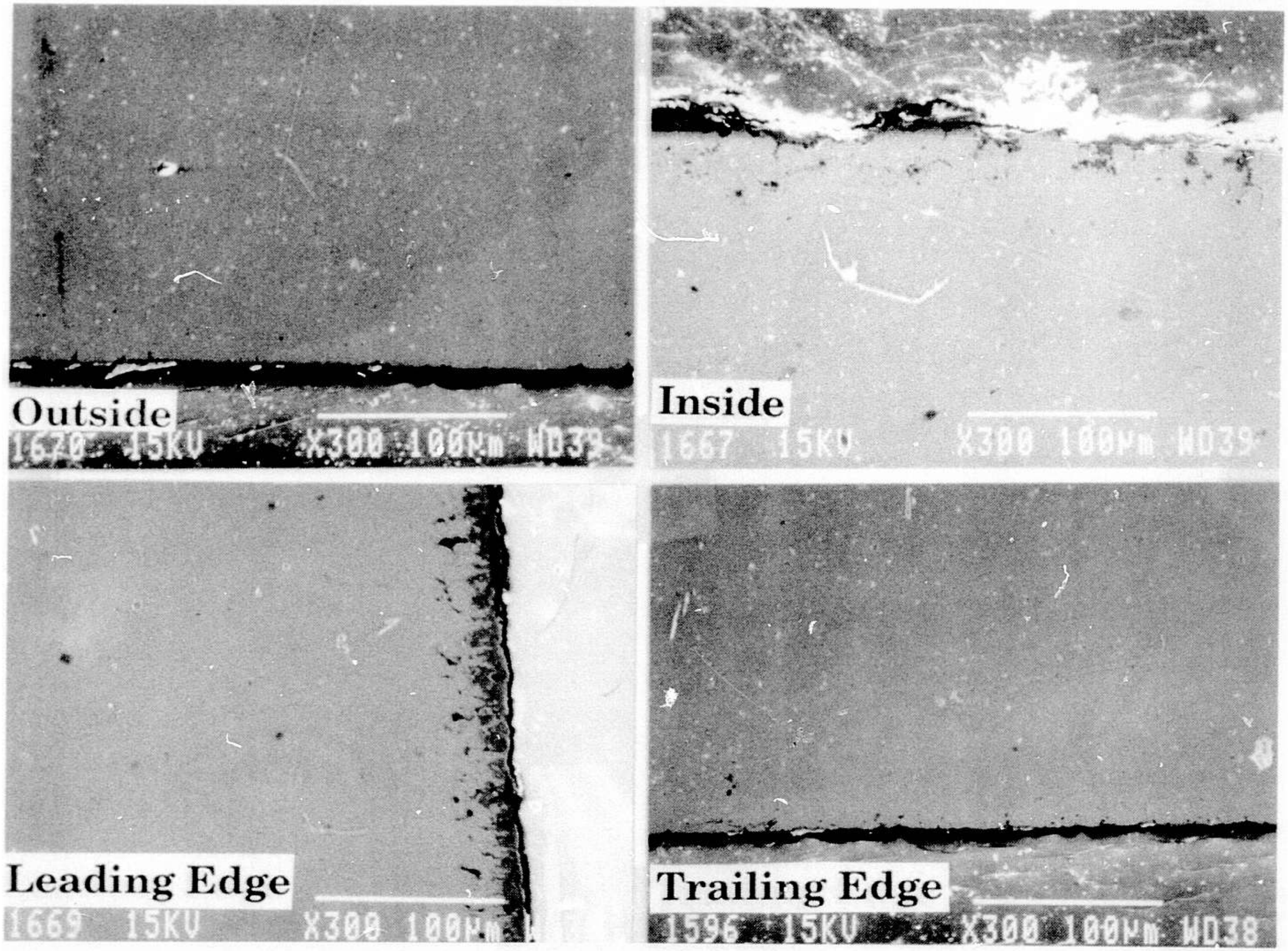
SANICRO 33

SEM Micrographs of Sanicro 33 after 1000 h Exposure



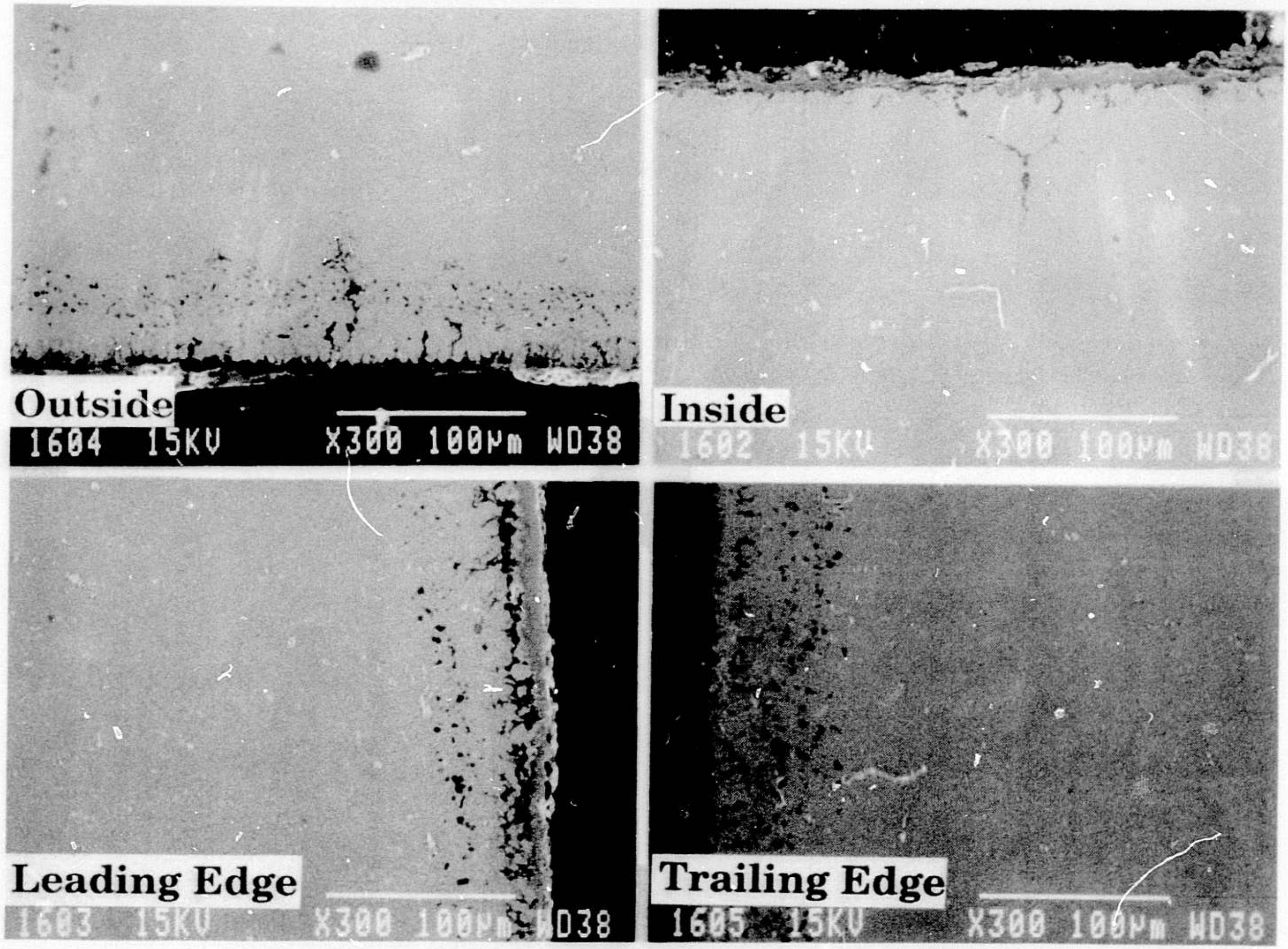
304/310

SEM Micrographs of 310-Clad 304 Stainless Steel after 1000 h Exposure Near the Center of the Bed



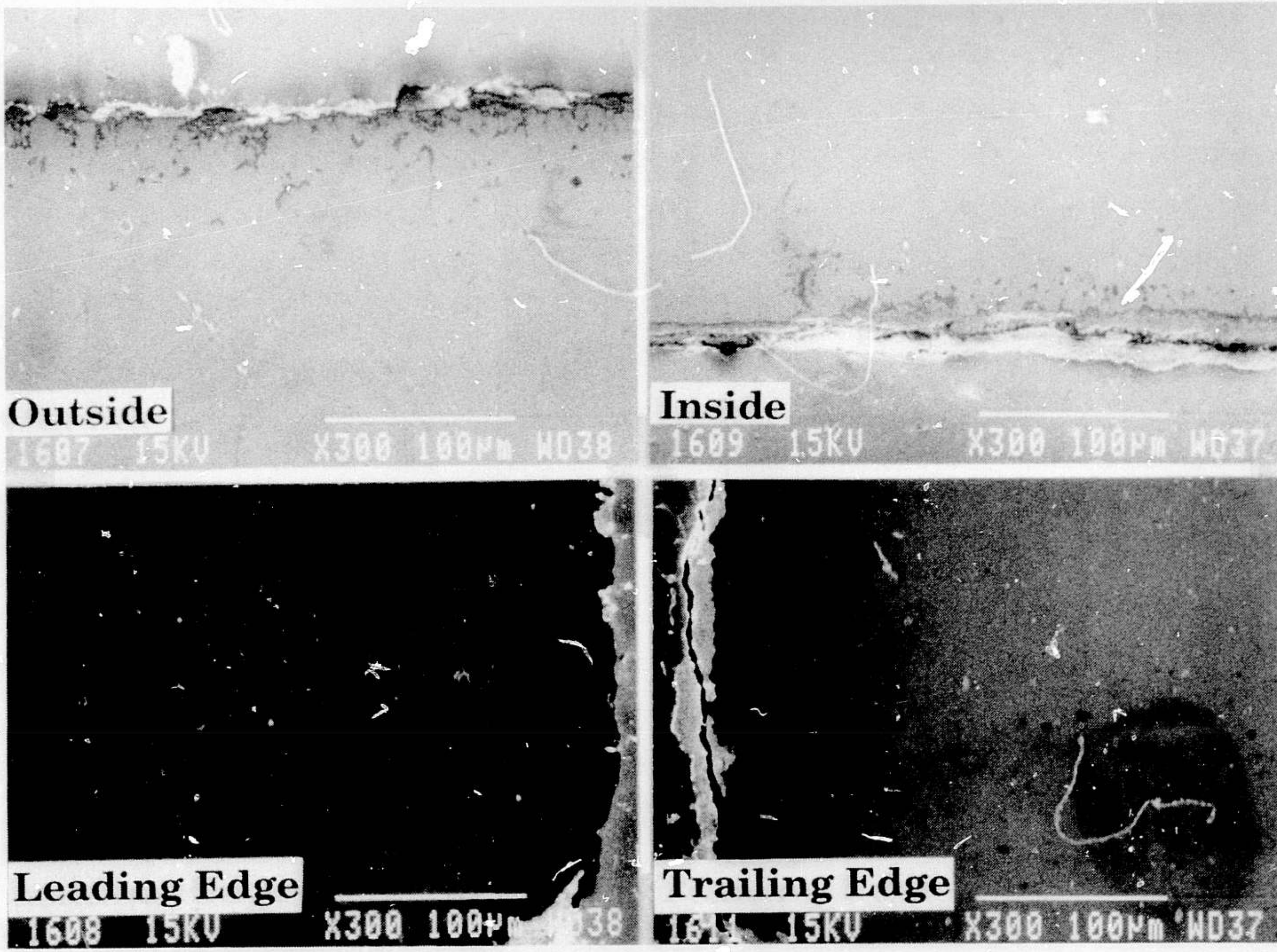
800H/310

SEM Micrographs of 310-Clad 800H after 1000 h Exposure



800H/8XX

SEM Micrographs of 8XX-Clad 800H after 1000 h Exposure



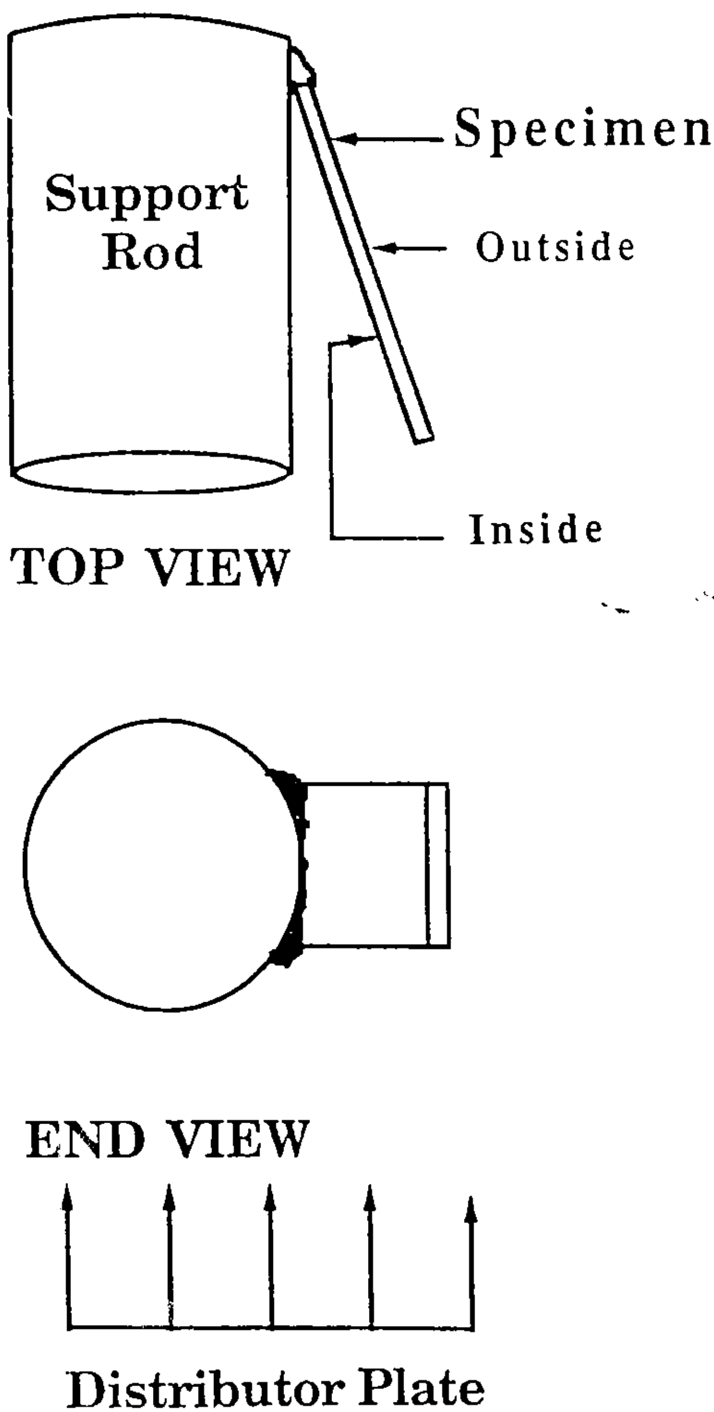
8XX

SEM Micrographs of 8XX after 1000 h Exposure

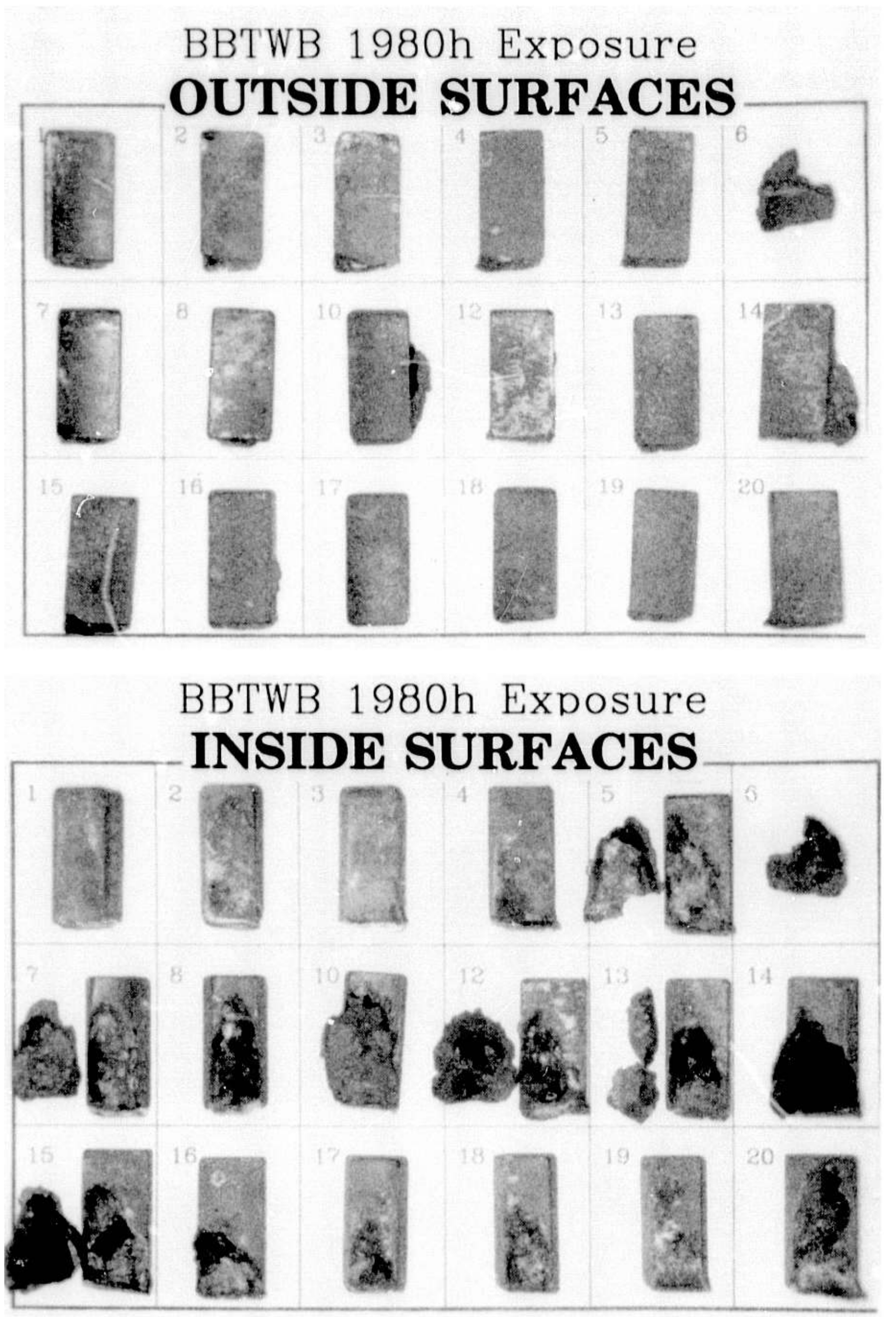
APPENDIX E.

MICROSTRUCTURES OF SPECIMENS FROM B&W PROBE BBTWB

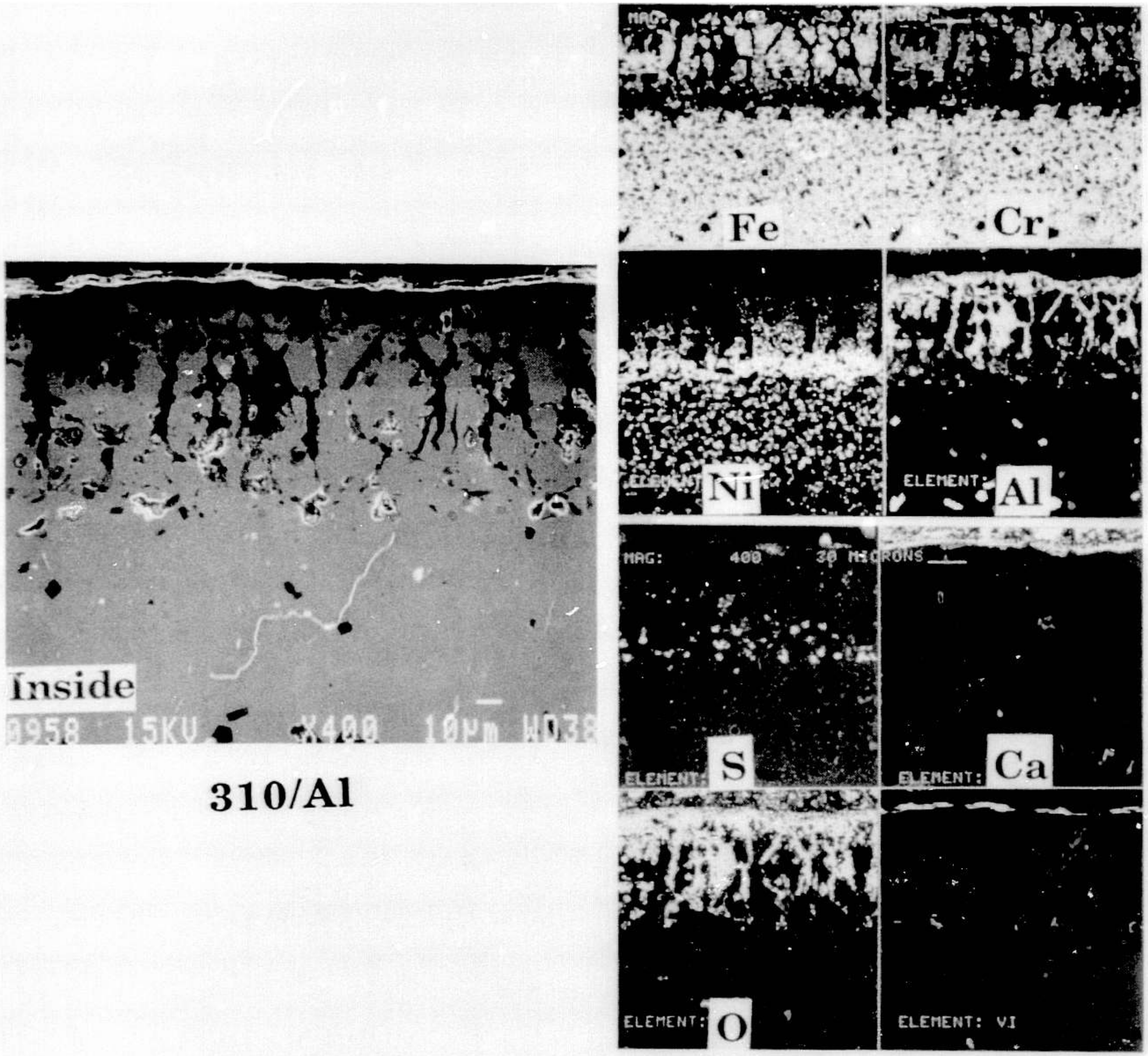
PROBE ID:	**BBTWB**
TYPE OF PROBE:	**Uncooled**
EXPOSURE TIME:	**1980 h**
ORGANIZATION:	**Babcock and Wilcox**



B&W Uncooled Probe BBTWB

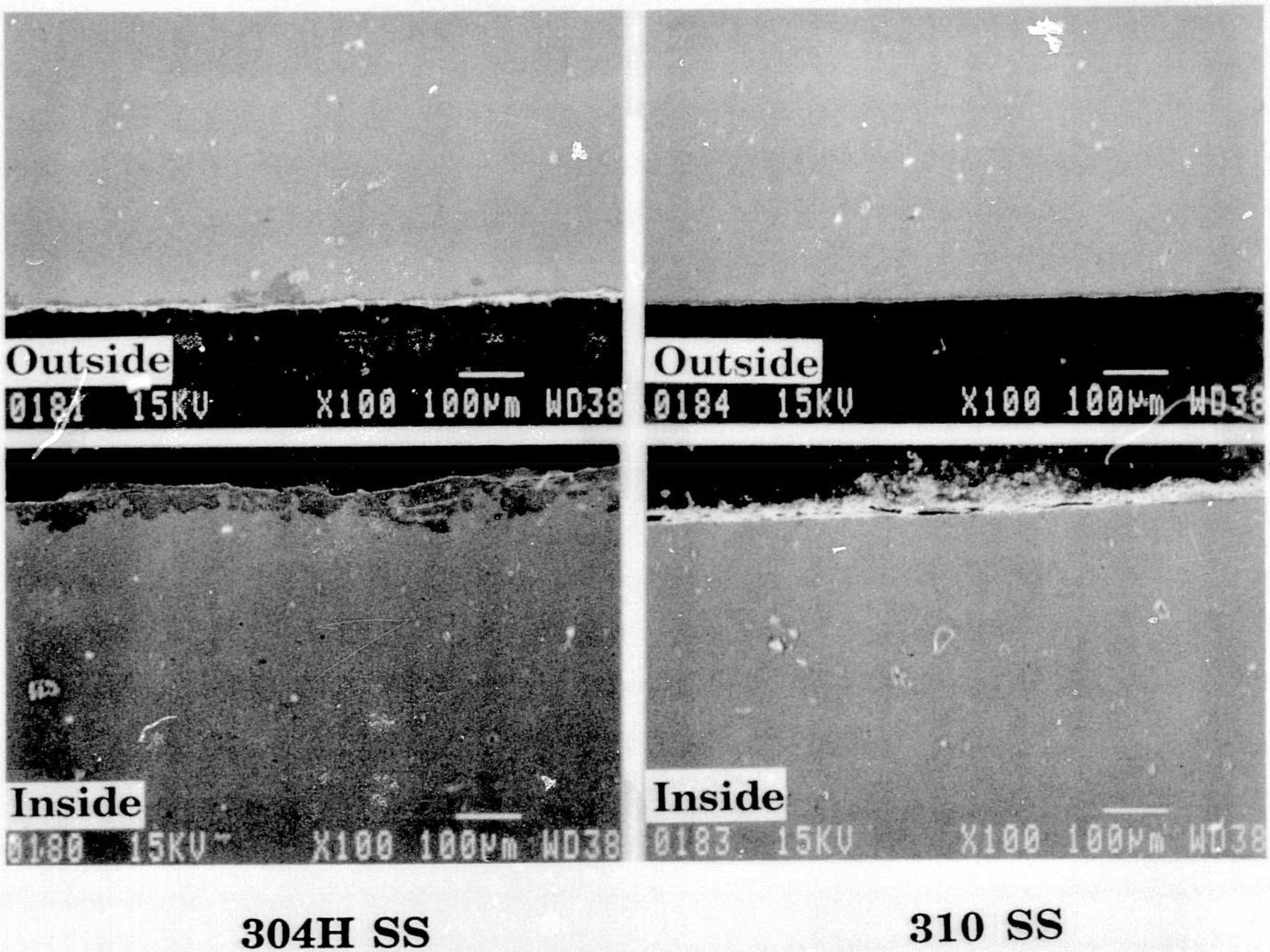


Macrophotographs of Specimens from B&W Probe BBTWB

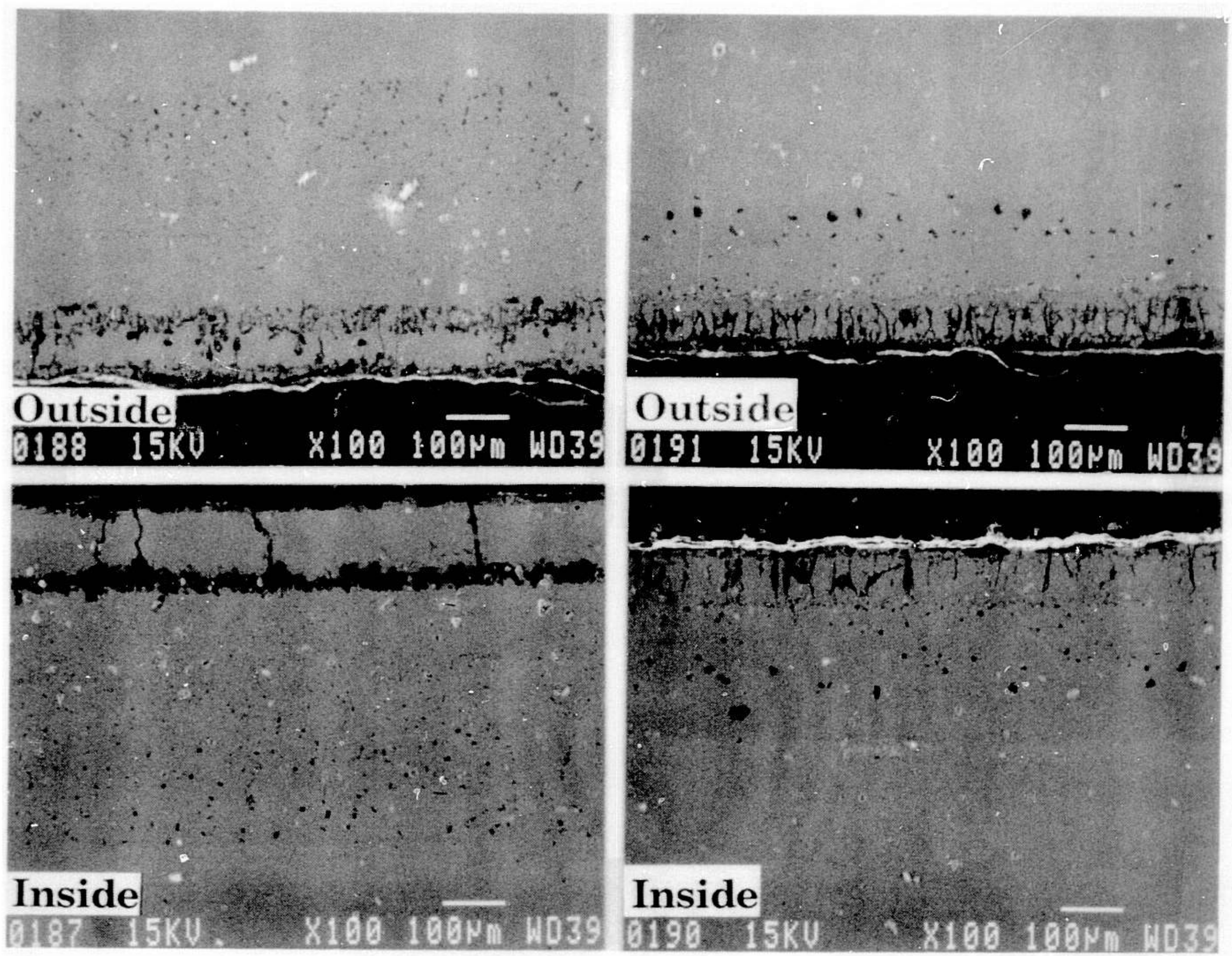


310/Al

SEM Micrographs and X-ray Mapping of Aluminized 310 Stainless Steel after 1980 h Exposure

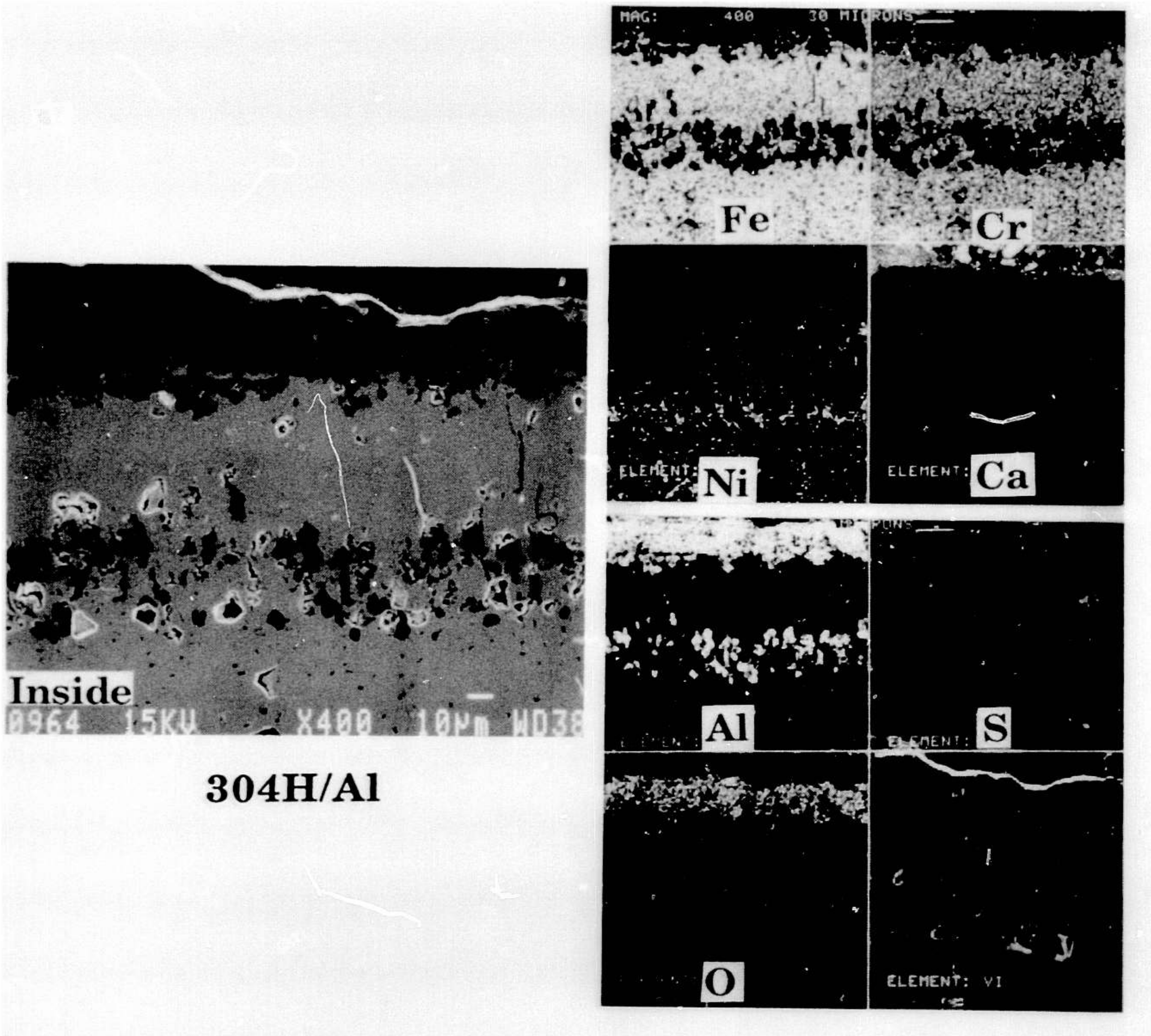


SEM Micrographs of 304 and 310 Stainless Steel after 1980 h Exposure

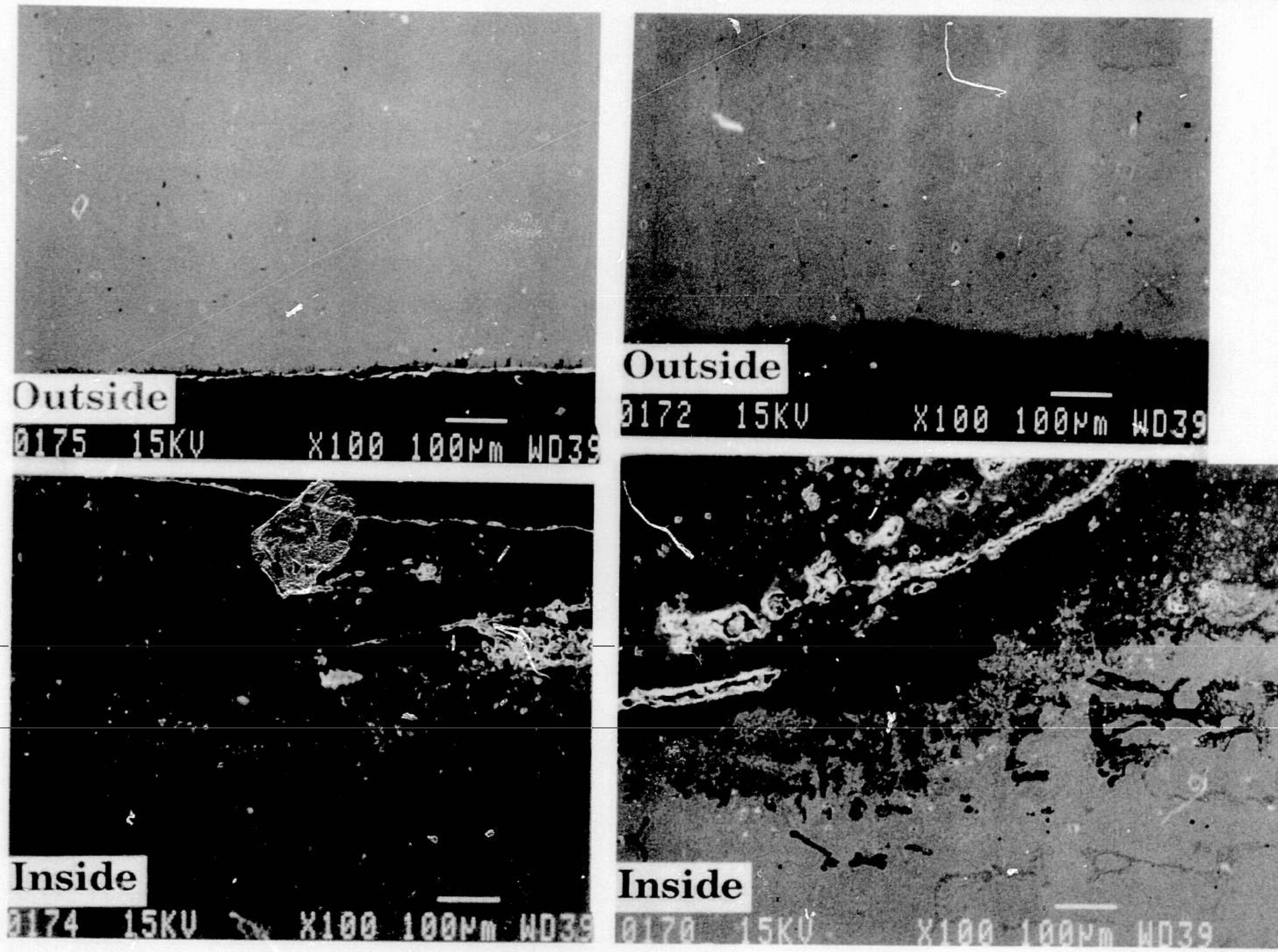


304H/Al **310/Al**

SEM Micrographs of Aluminized 304 and 310 Stainless Steels after 1980 h Exposure

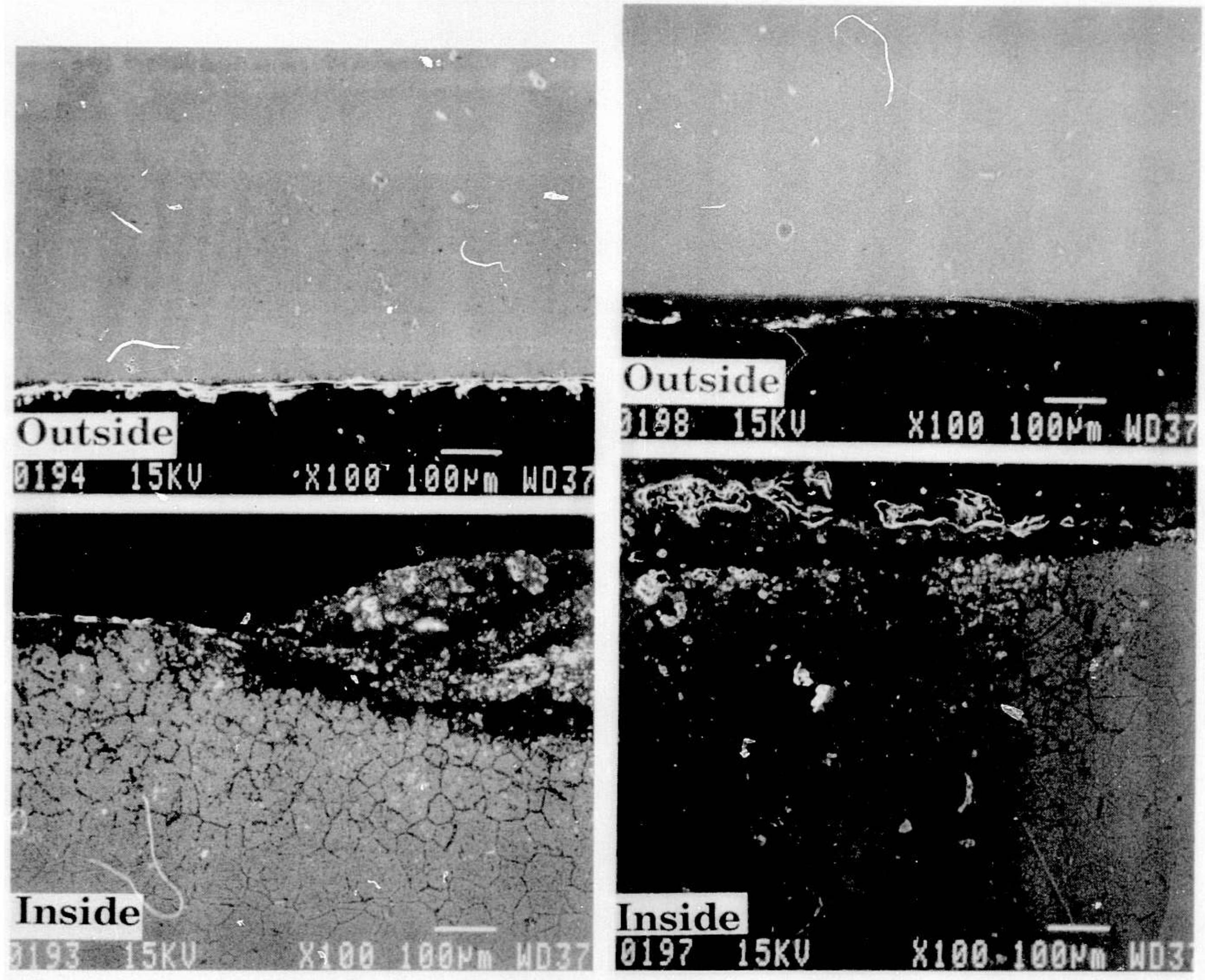


SEM Micrograph and X-ray Mapping of Aluminized 304 Stainless Steel after 1980 h Exposure



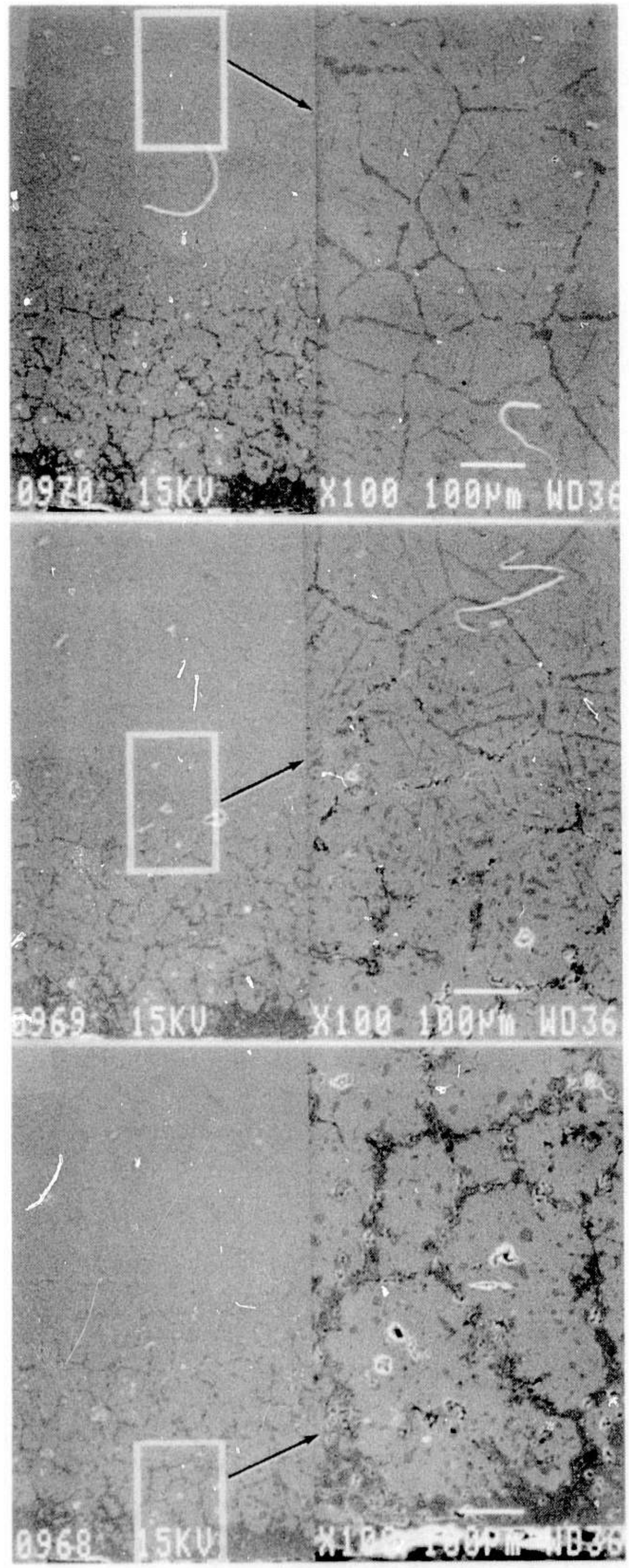
HH **HP 50**

SEM Micrographs of HH and HP 50 after 1980 h Exposure



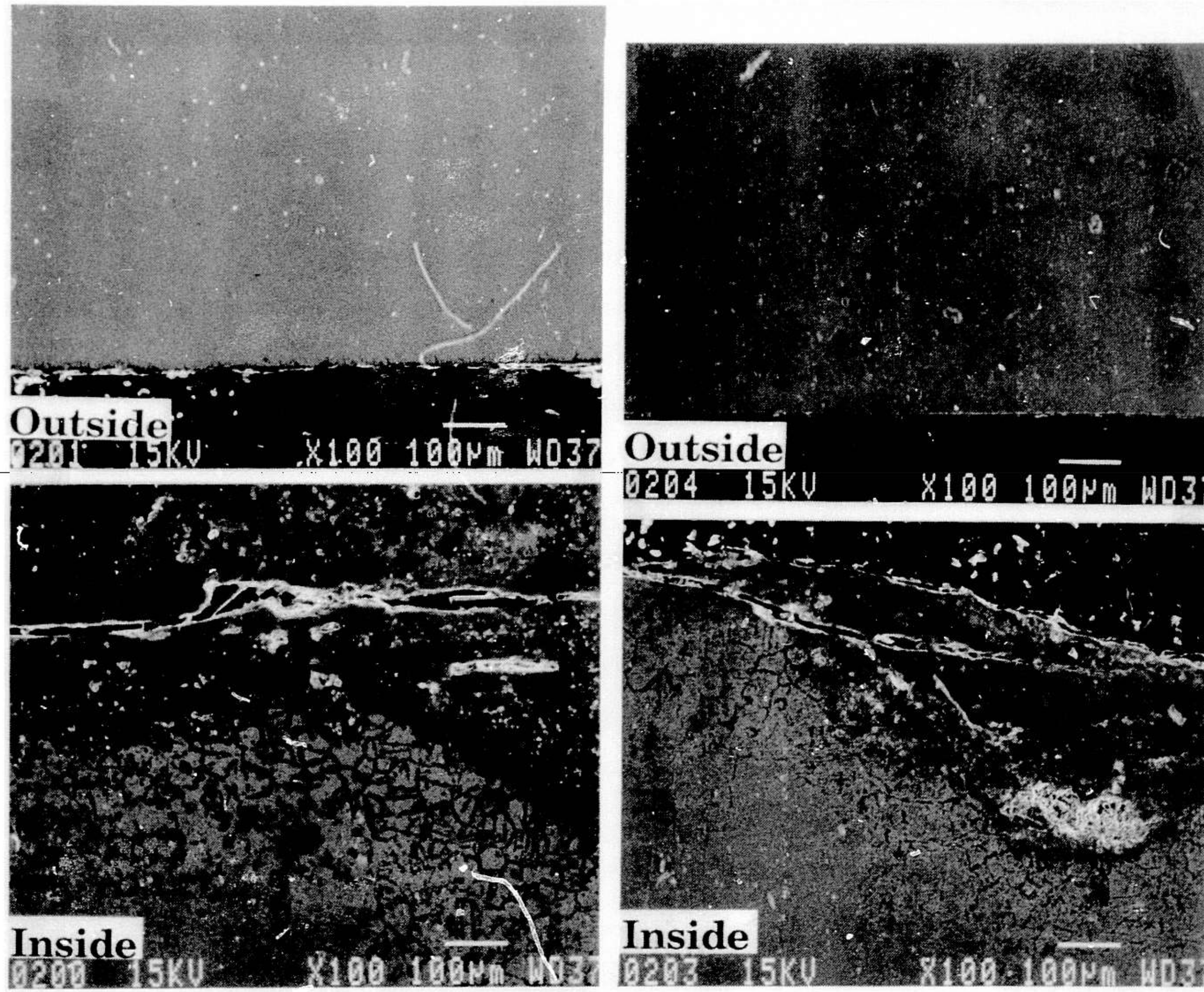
304/310 **800H/310**

SEM Micrographs of 310-Clad Alloys after 1980 h Exposure Near the Bed Walls



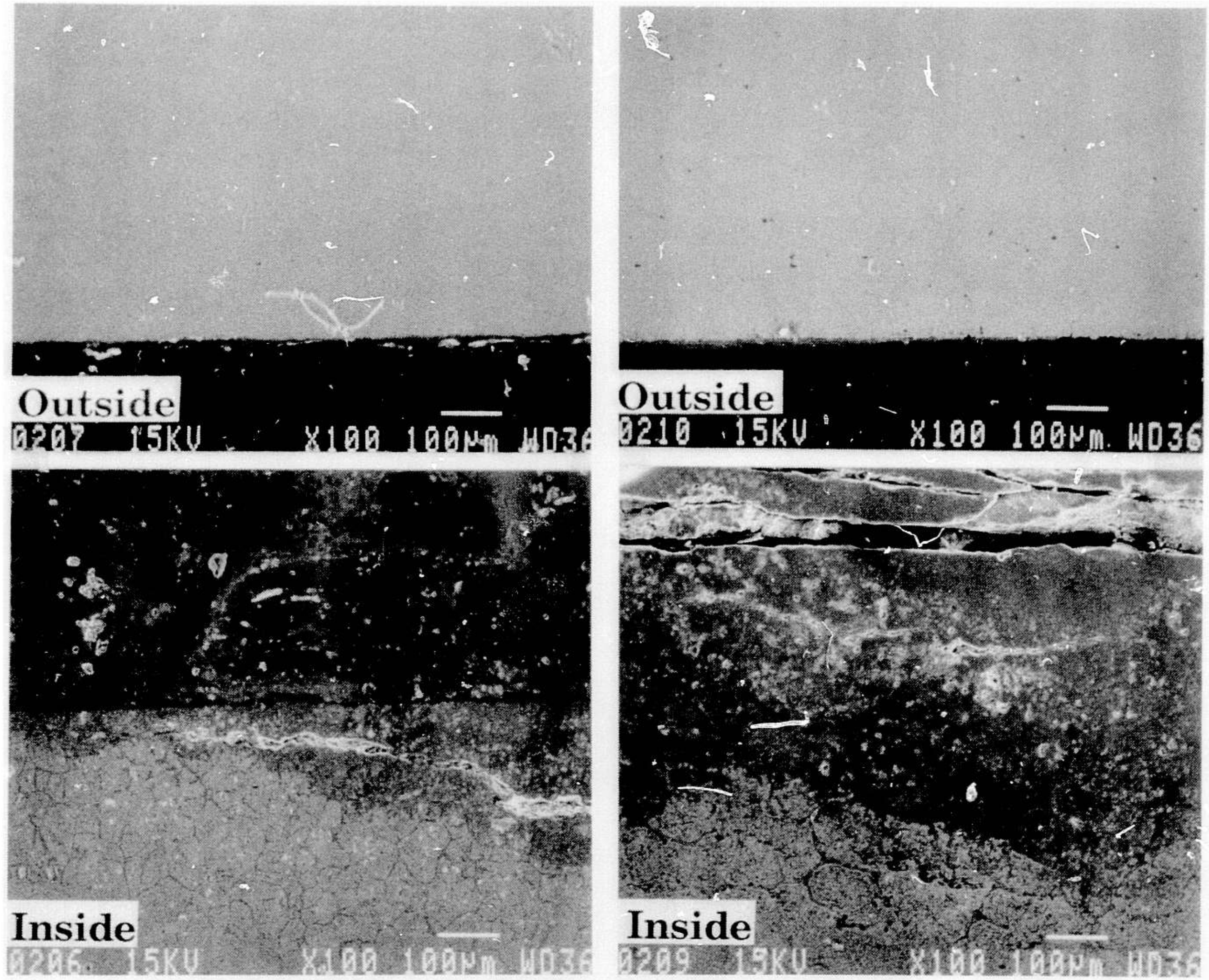
304/310

SEM Micrographs of Different Regions of 310-Clad
304 Stainless Steel after 1980 h Exposure



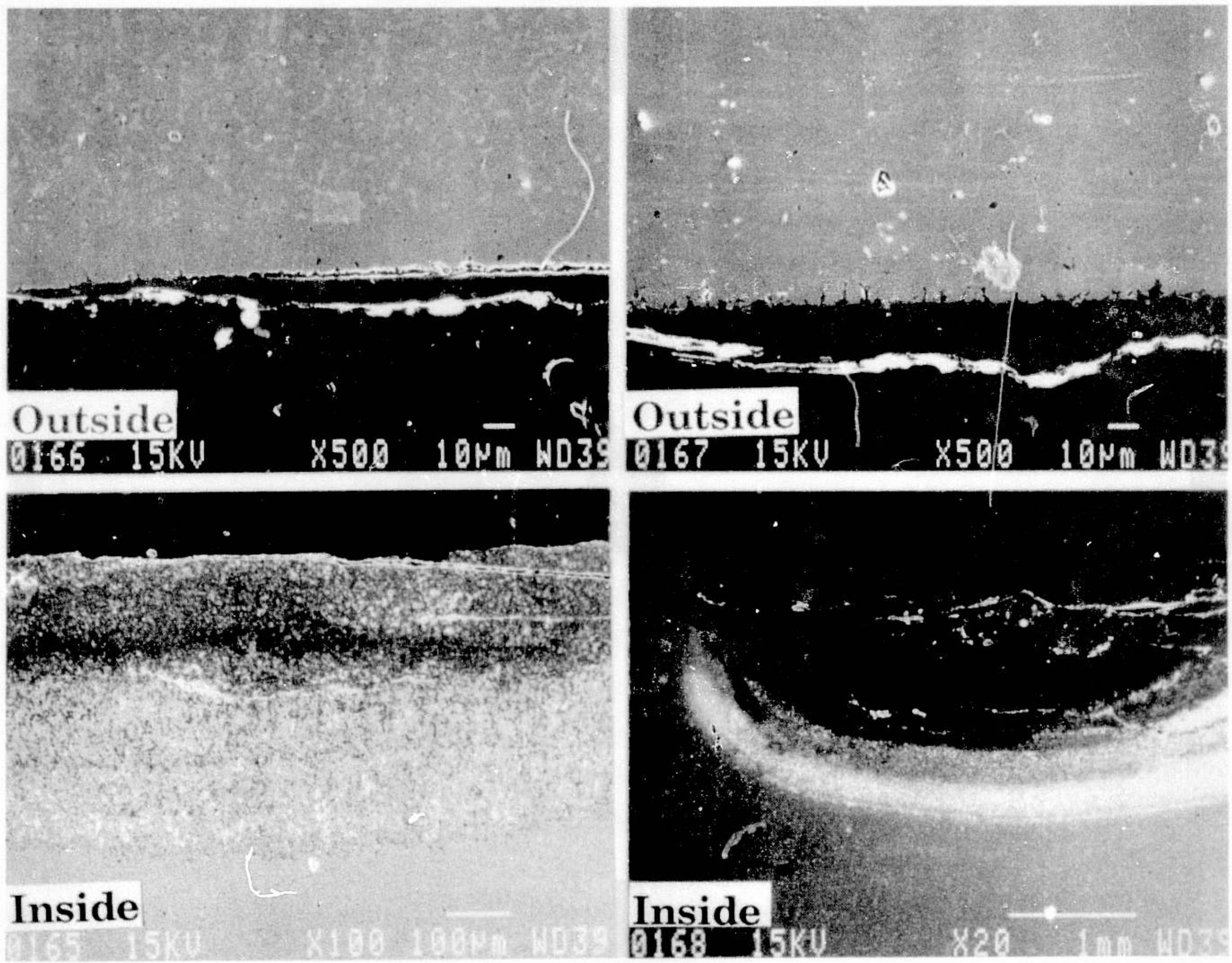
253 MA **HS 188**

SEM Micrographs of 253 MA and 188 after 1980 h Exposure



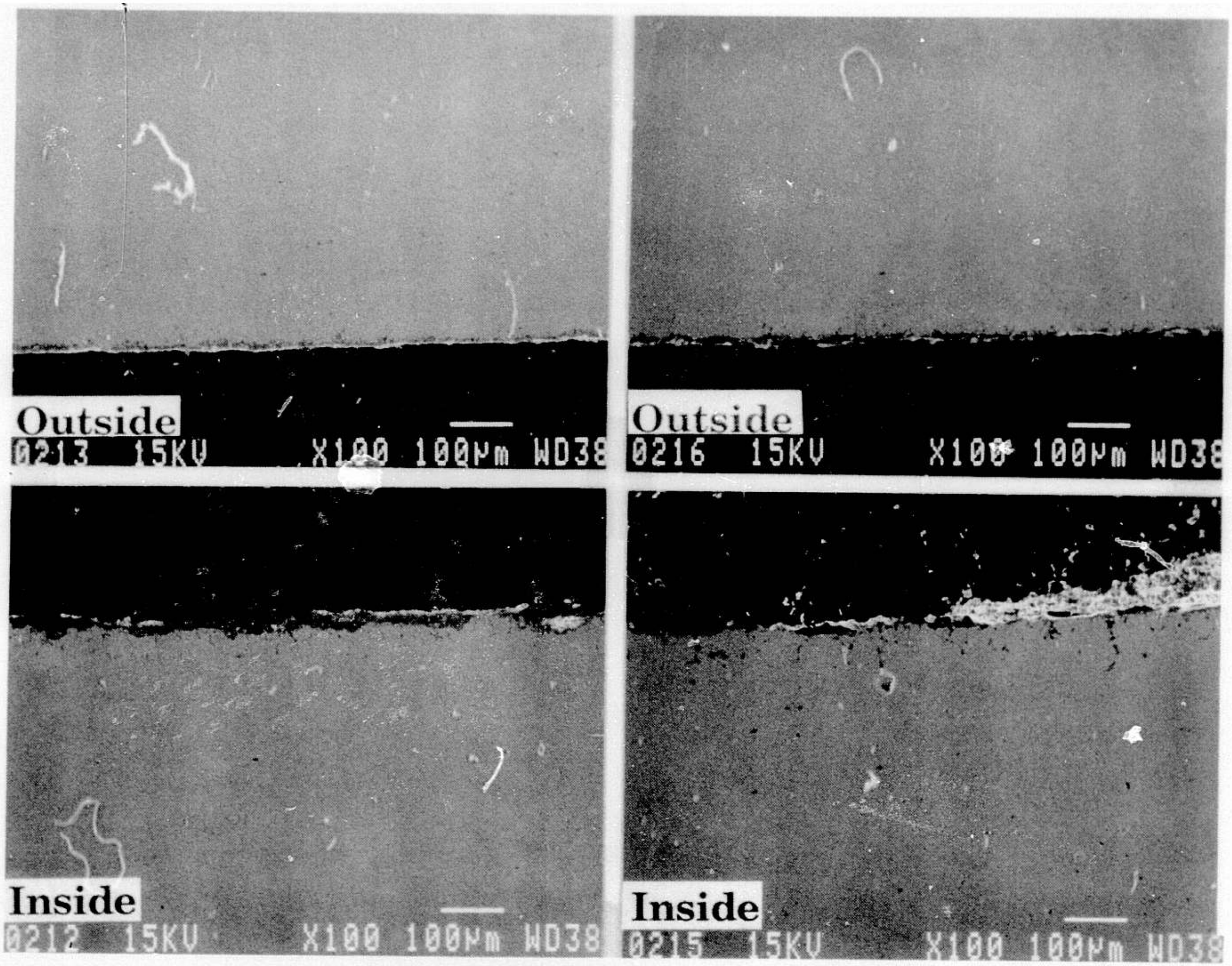
HS 556 **HK 40**

SEM Micrographs of HS 556 and HK 40 after 1980 h Exposure



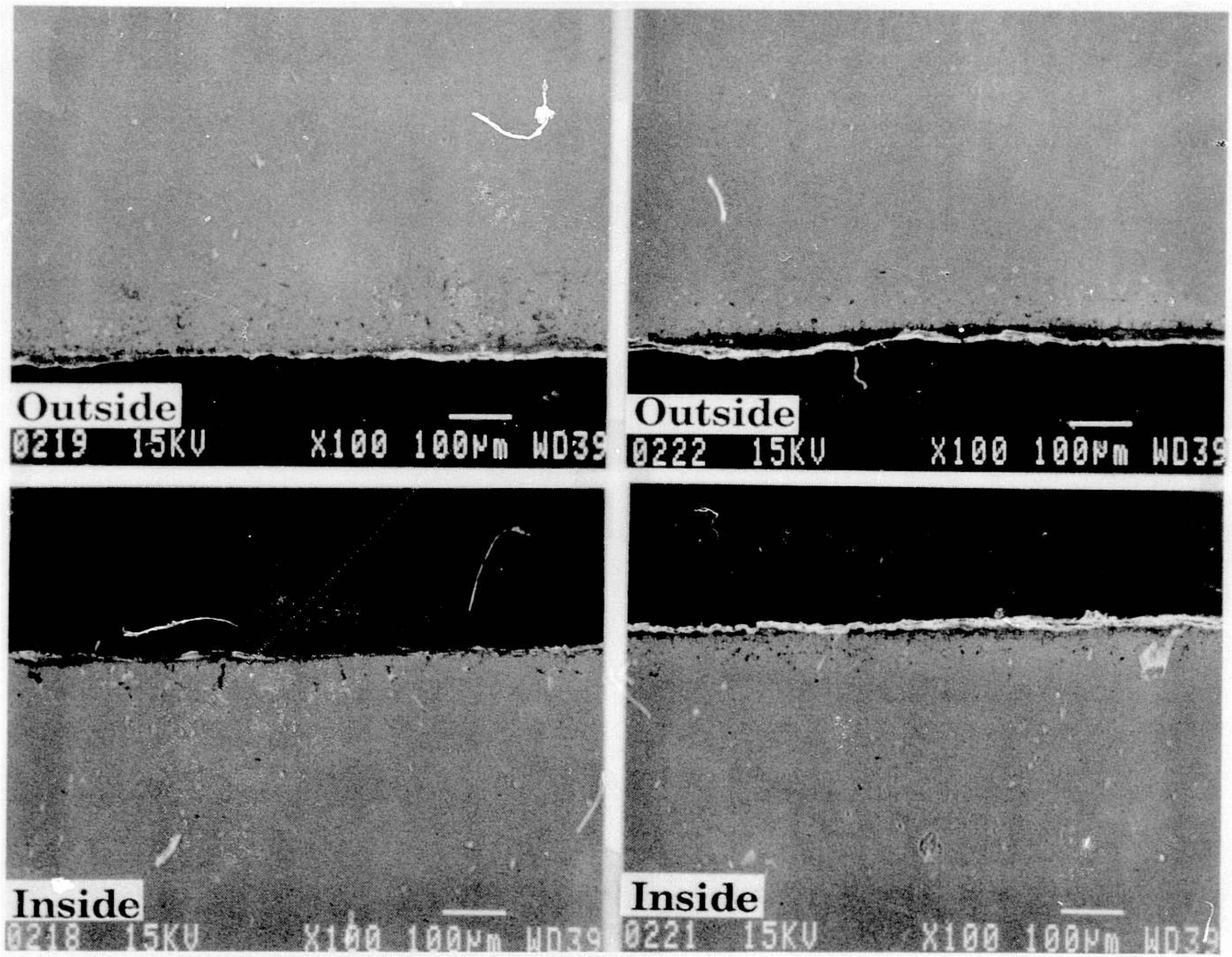
XM 19 **SANICRO 33**

SEM Micrographs of XM 19 and Sanicro 33 after 1980 h Exposure



304/310 **800H/310**

SEM Micrographs of 310-Clad Alloys after 1980 h Exposure Near the Center of the Bed



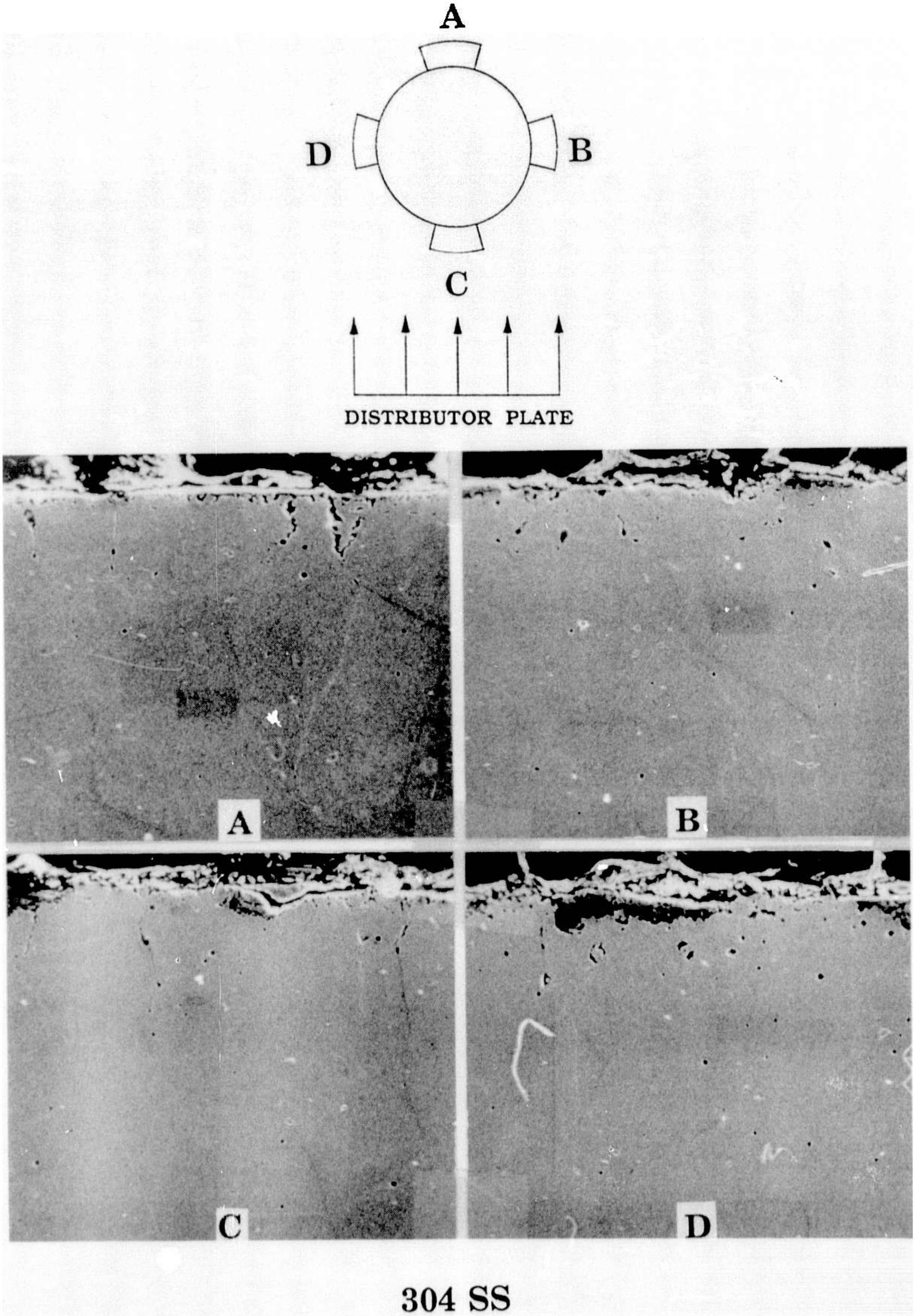
800H/8XX **8XX**

SEM Micrographs of 8XX-Clad 800H and 8XX after 1980 h Exposure

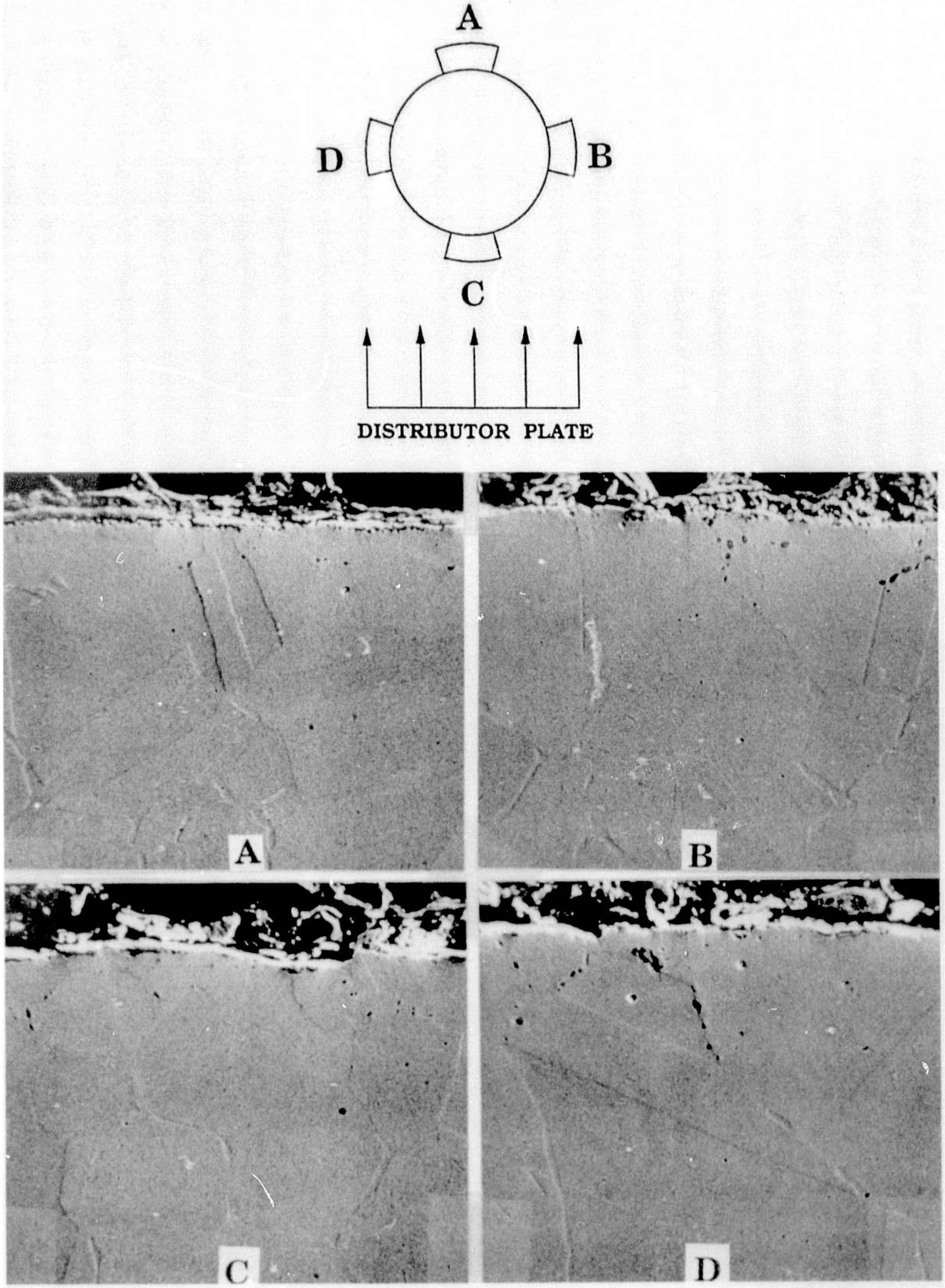
APPENDIX F.

MICROSTRUCTURES OF SPECIMENS FROM FW PROBE BBTEC

PROBE ID:	**BBTEC**
TYPE OF PROBE:	**Uncooled**
EXPOSURE TIME:	**1980 h**
ORGANIZATION:	**Foster Wheeler**

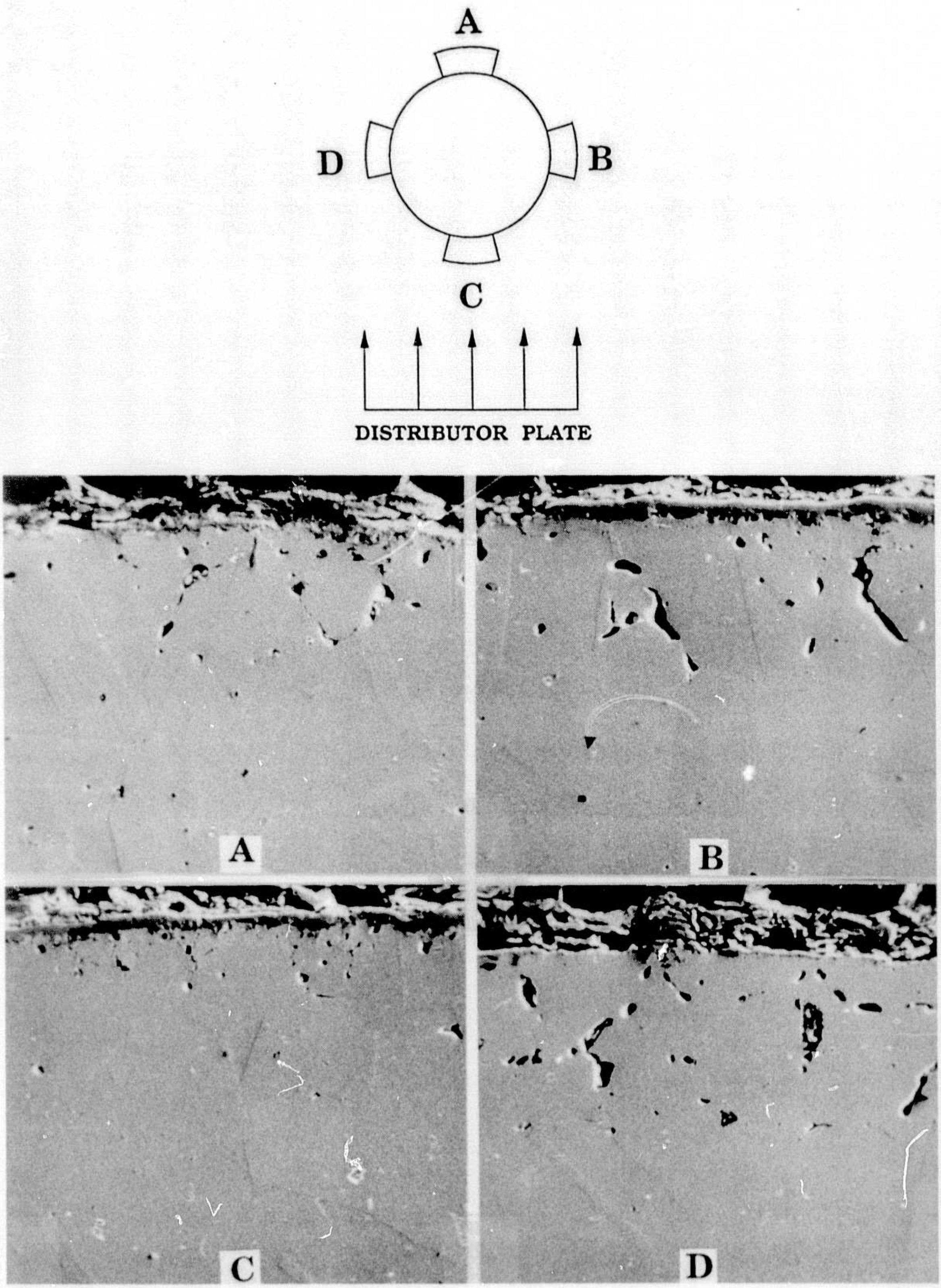


SEM Micrographs of 304 Stainless Steel after 1980 h Exposure



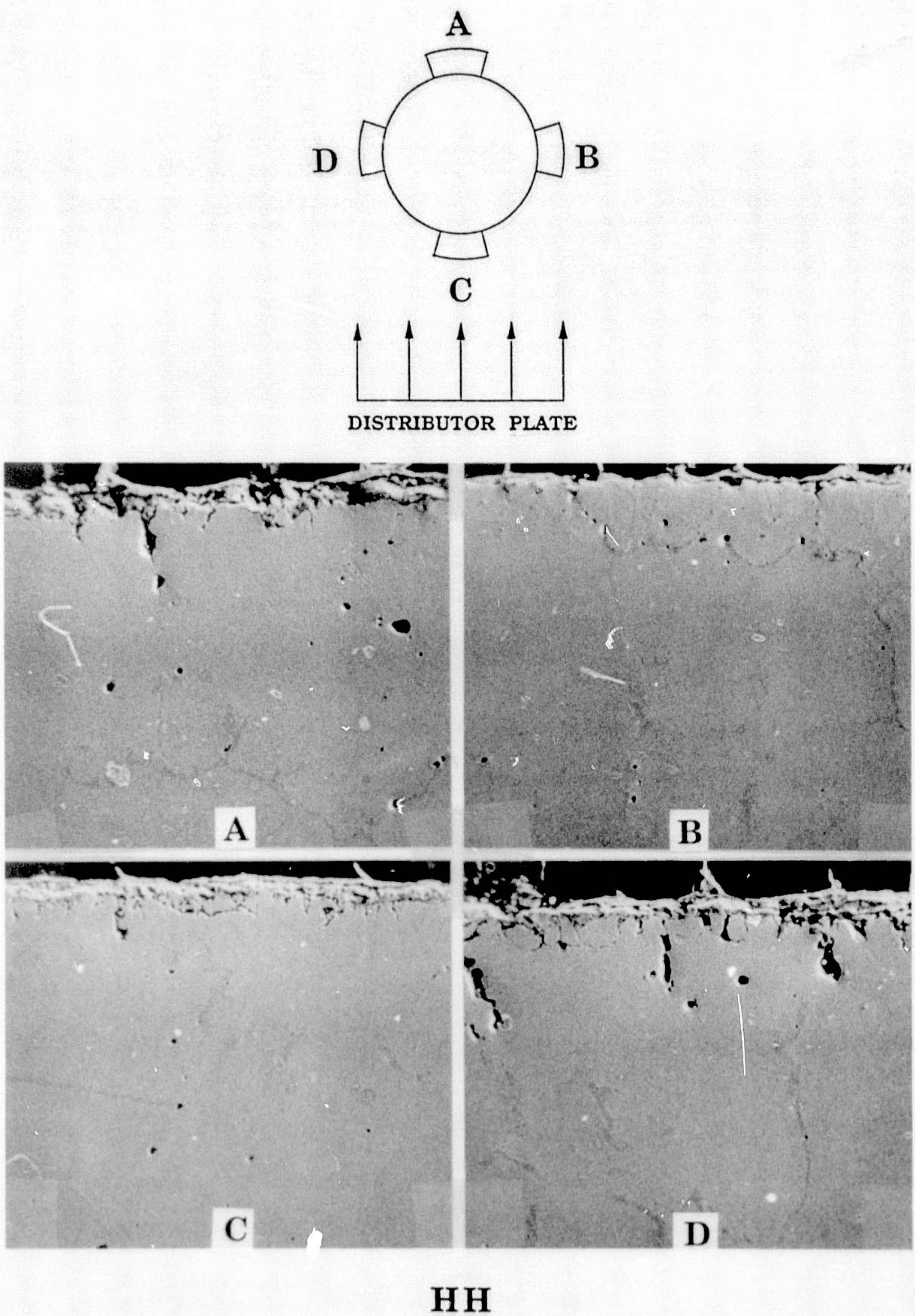
310 SS

SEM Micrographs of 310 Stainless Steel after 1980 h Exposure

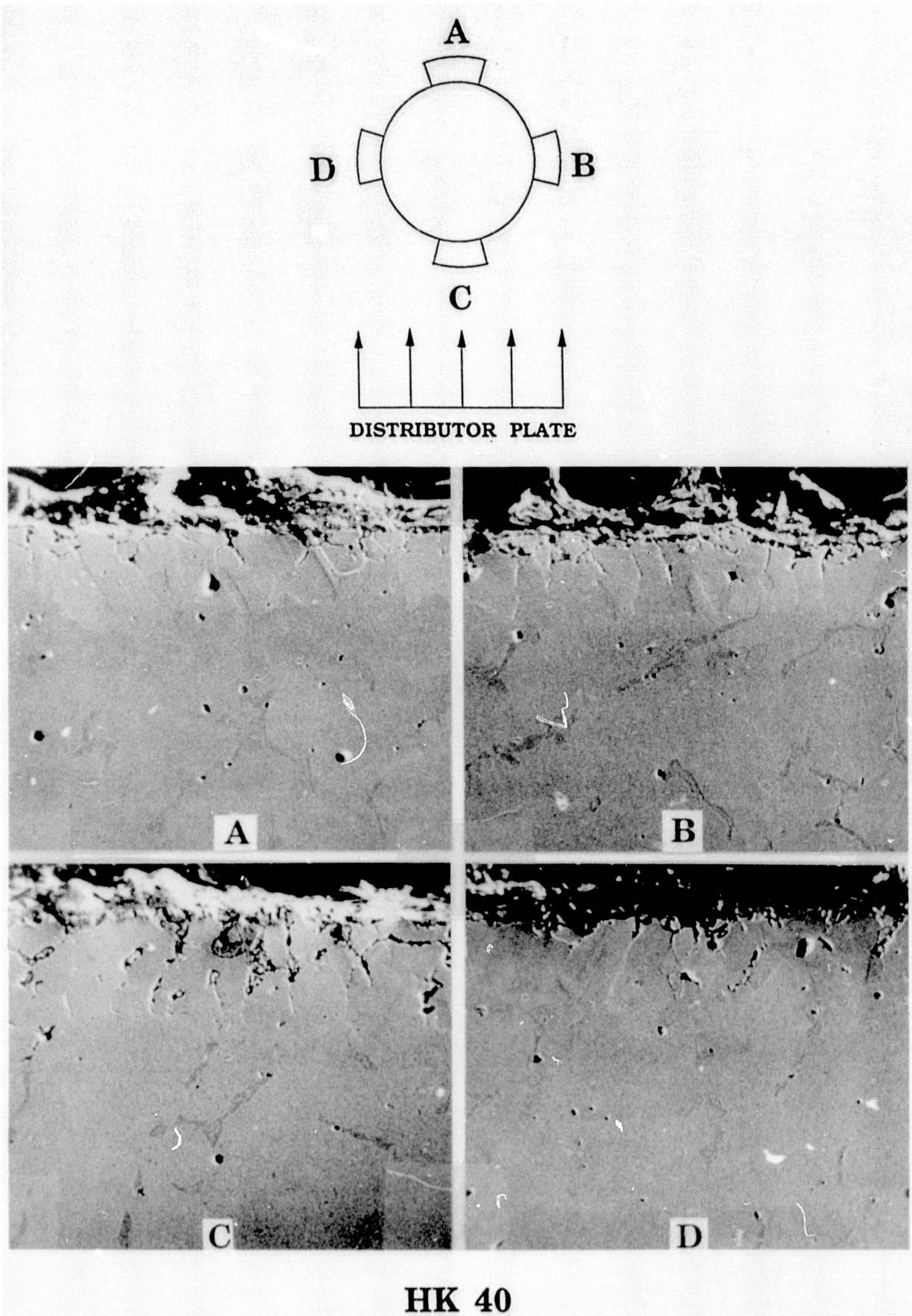


Alloy 800

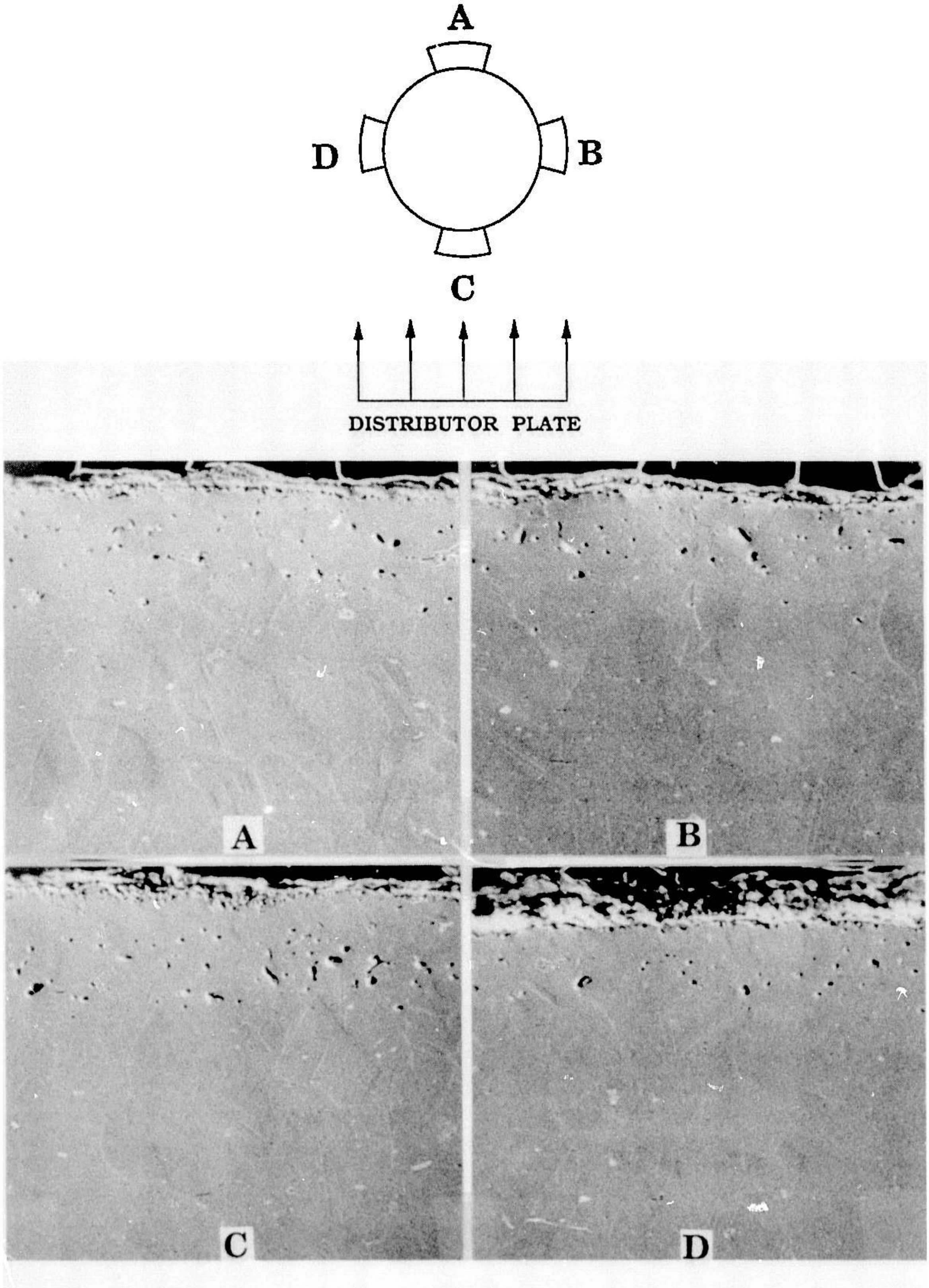
SEM Micrographs of Alloy 800 after 1980 h Exposure



SEM Micrographs of HH after 1980 h Exposure

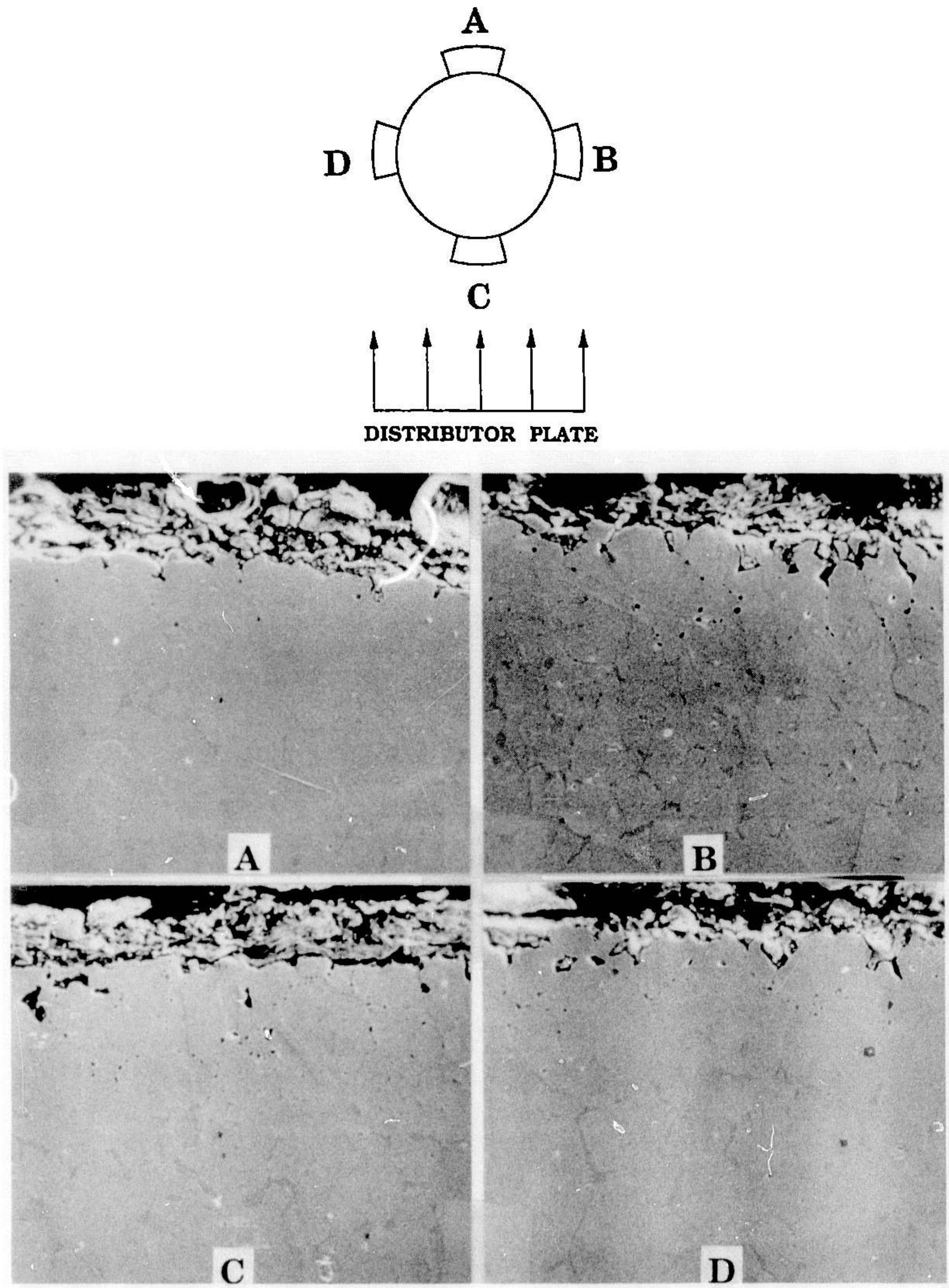


SEM Micrographs of HK 40 after 1980 h Exposure



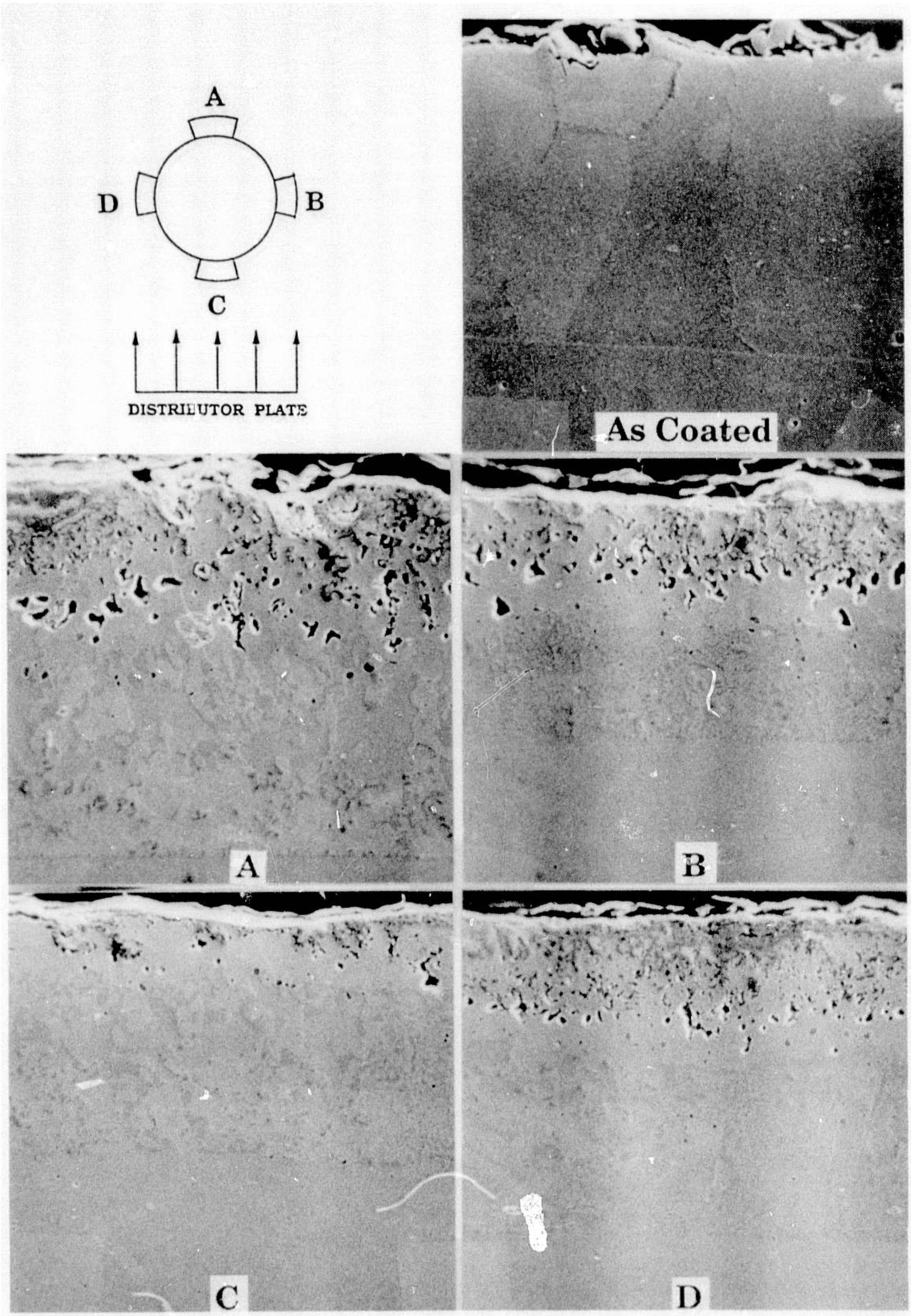
556

SEM Micrographs of Alloy 556 after 1980 h Exposure



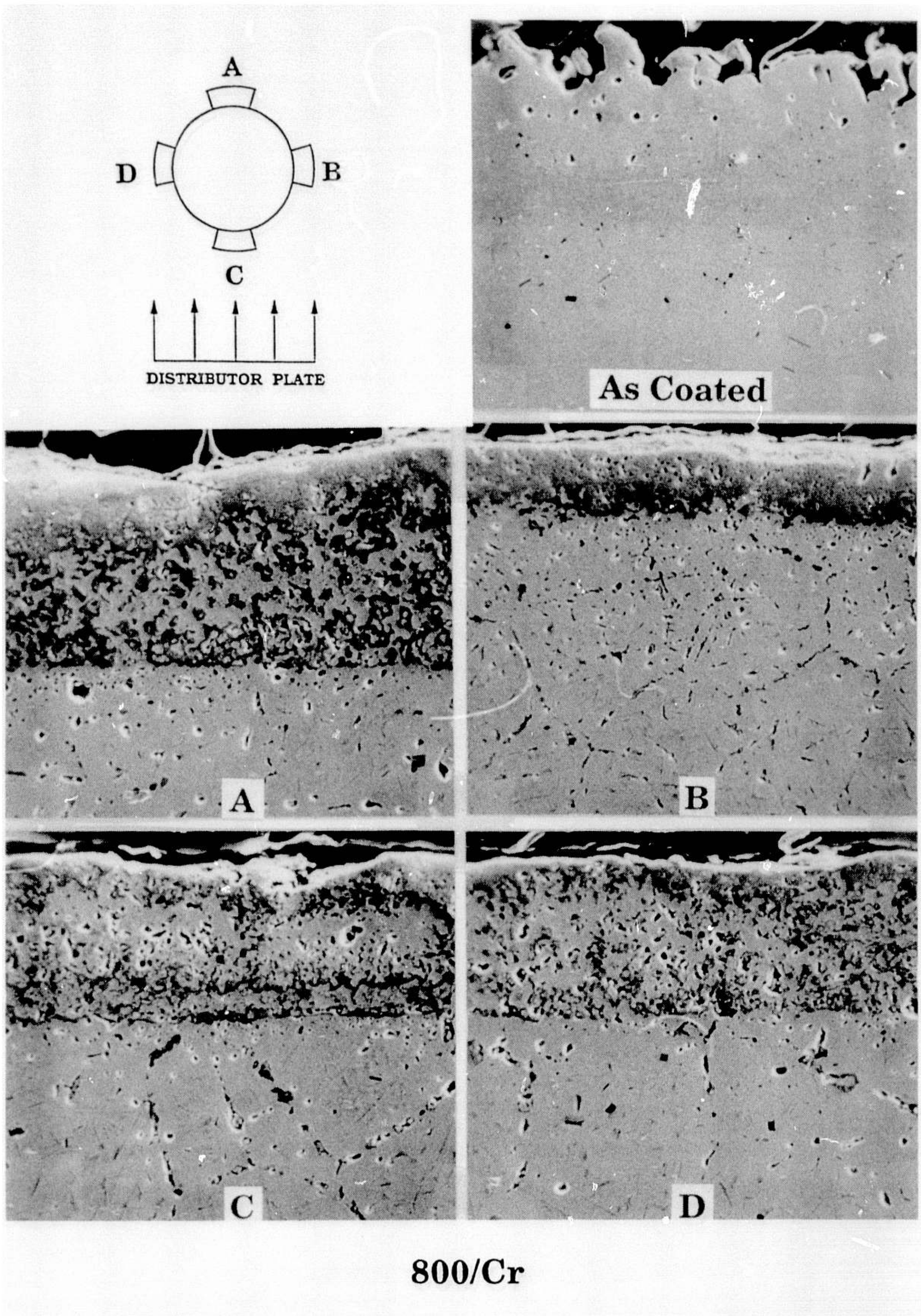
253 MA

SEM Micrographs of 253 MA after 1980 h Exposure

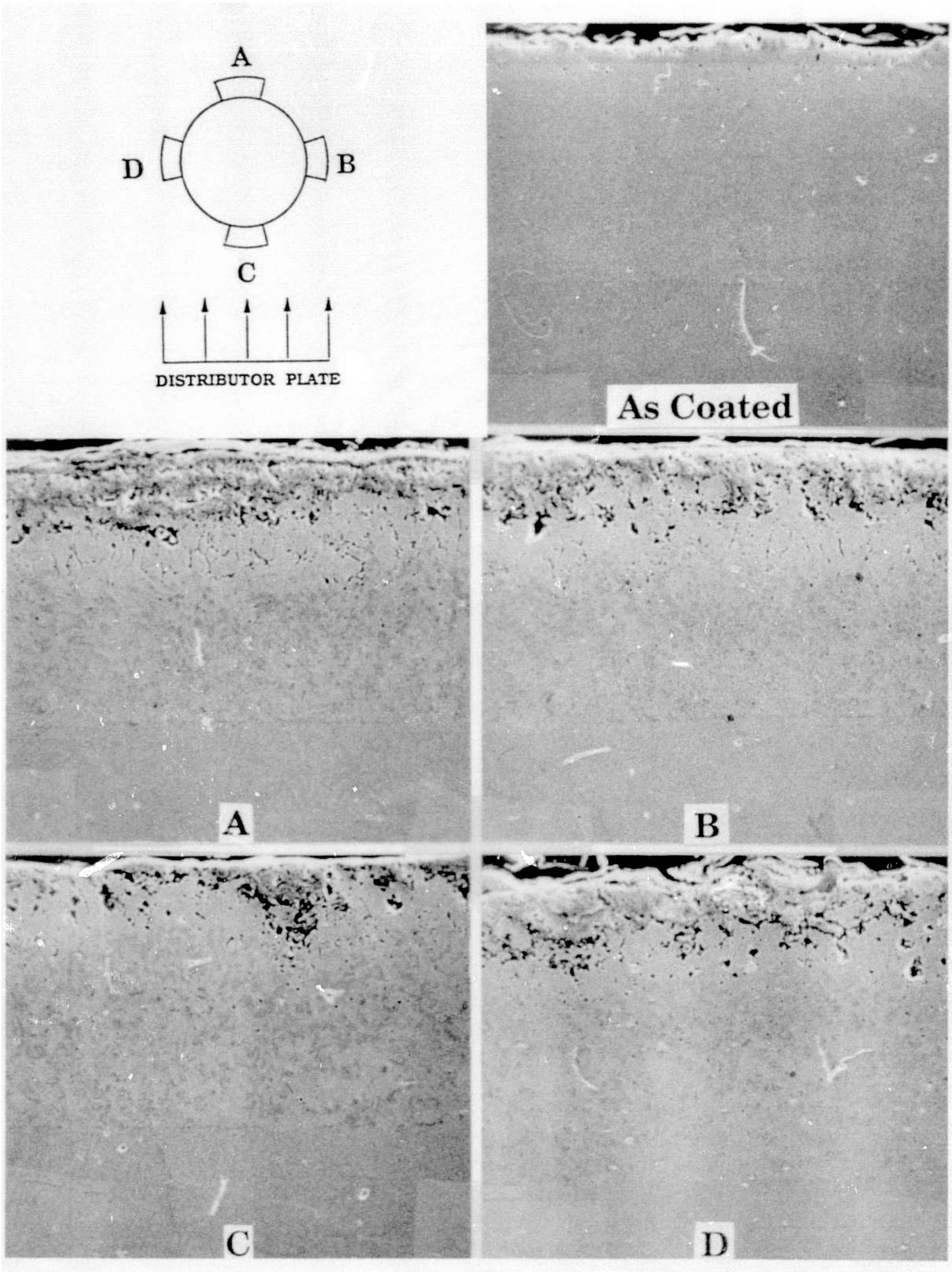


304/Cr

SEM Micrographs of Chromized 304 Stainless Steel after 1980 h Exposure

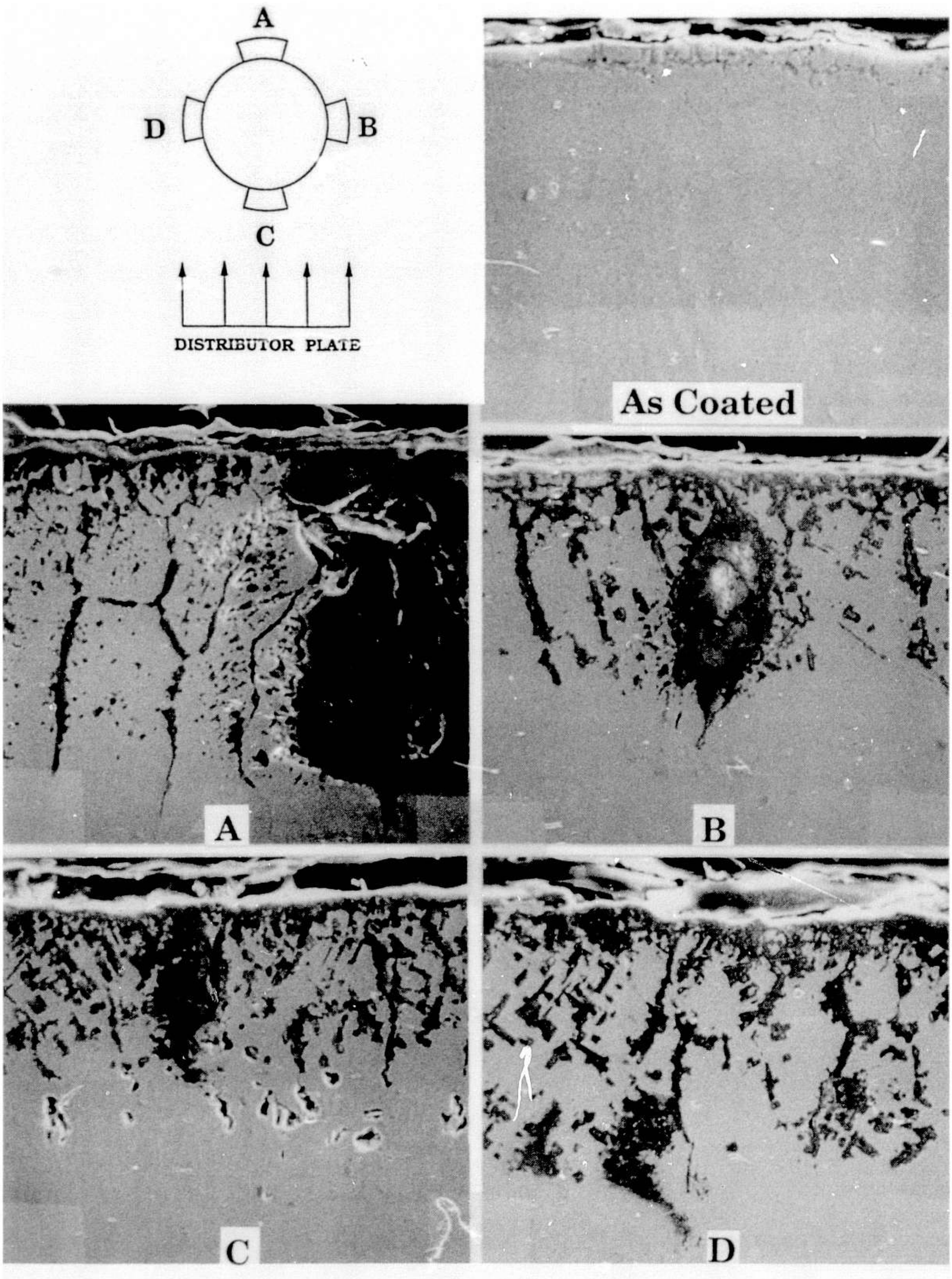


SEM Micrographs of Chromized 800 after 1980 h Exposure



253 MA/Cr

SEM Micrographs of Chromized 253 MA after 1980 h Exposure



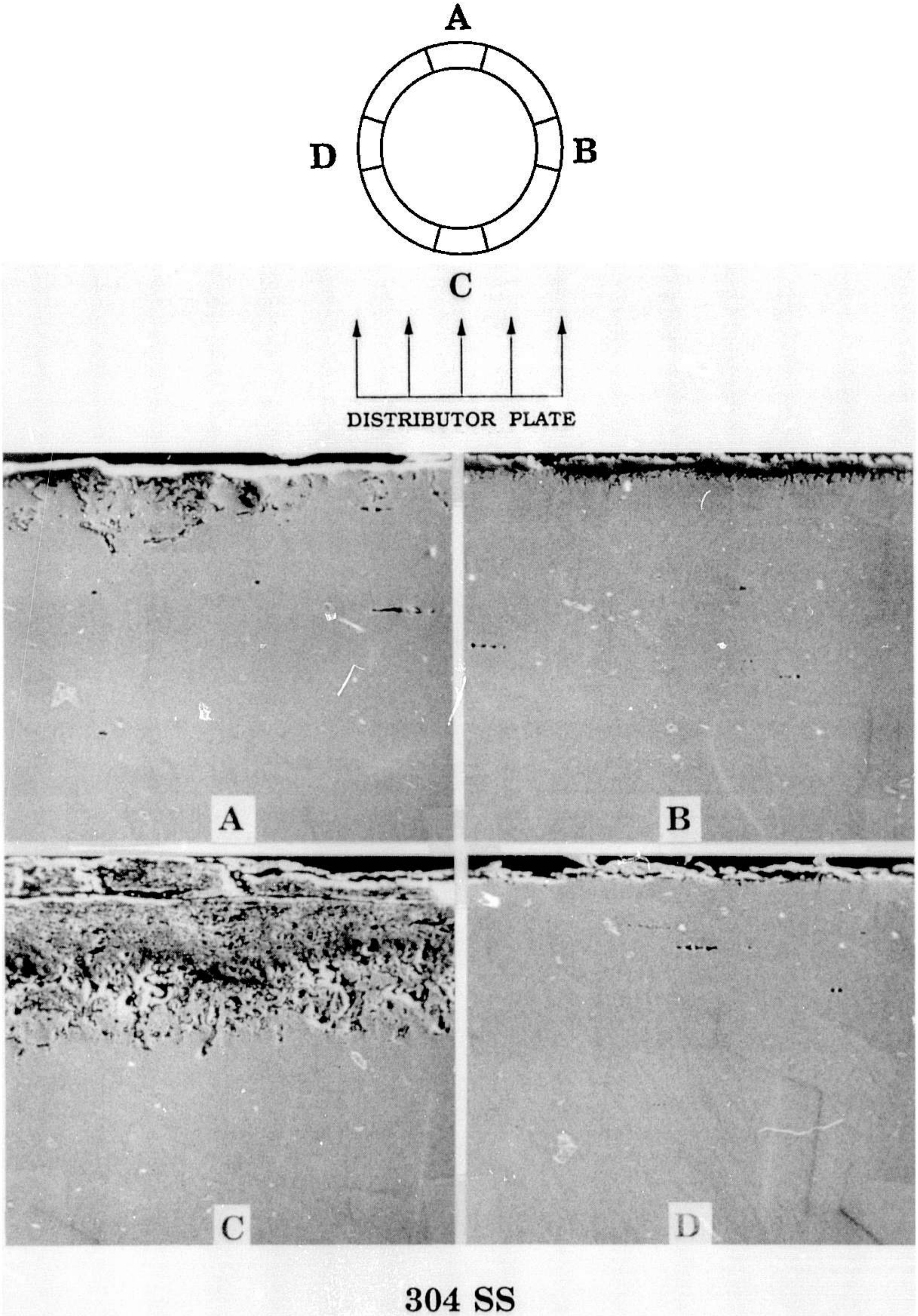
800/Al

SEM Micrographs of Aluminized 800 after 1980 h Exposure

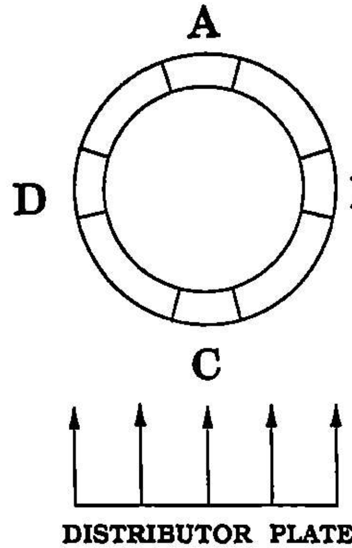
APPENDIX G.

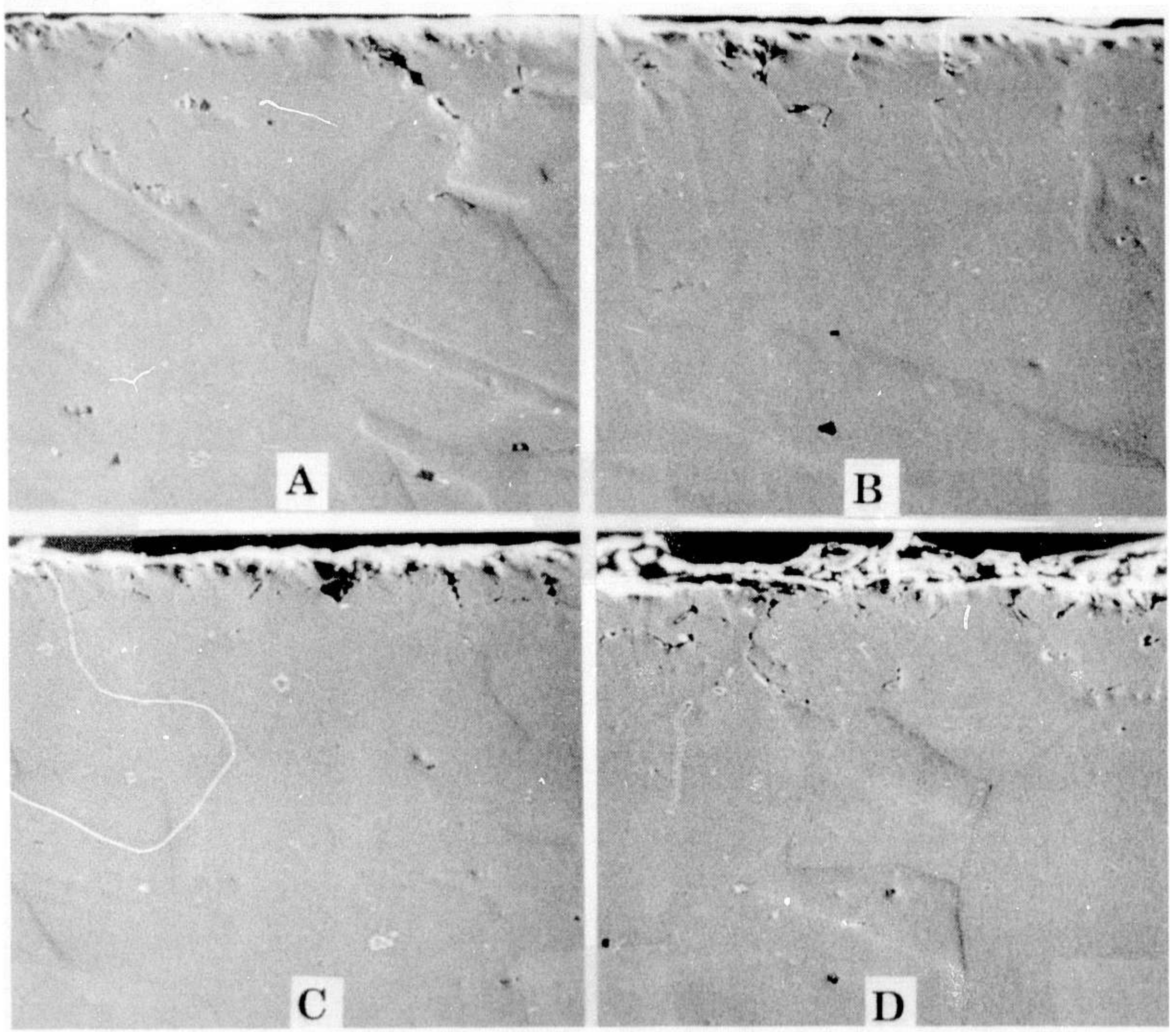
MICROSTRUCTURES OF SPECIMENS FROM FW PROBE BBTEA

PROBE ID:	**BBTEA**
TYPE OF PROBE:	**Cooled**
EXPOSURE TIME:	**1980 h**
ORGANIZATION:	**Foster Wheeler**



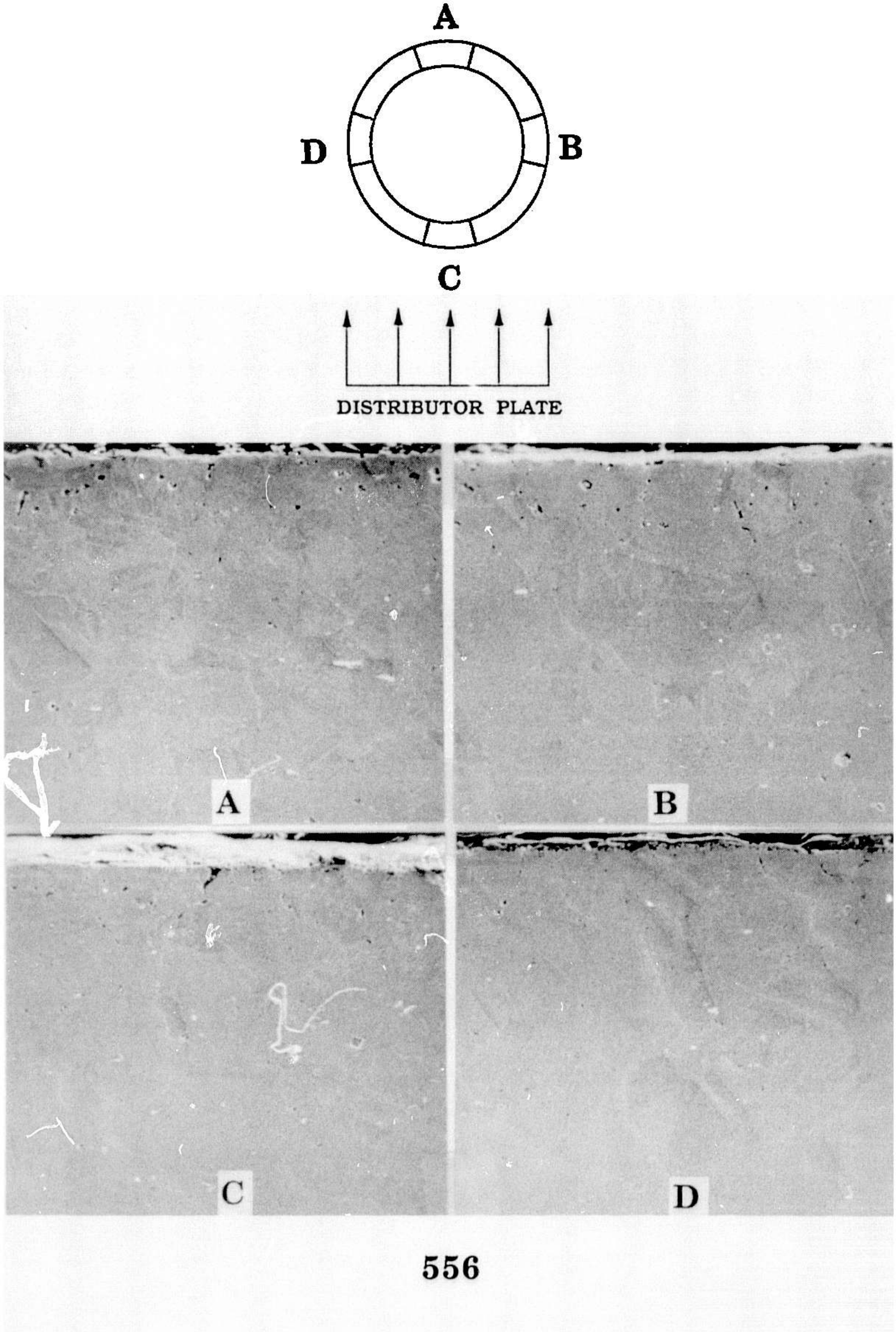
SEM Micrographs of 304 Stainless Steel after 1980 h Exposure



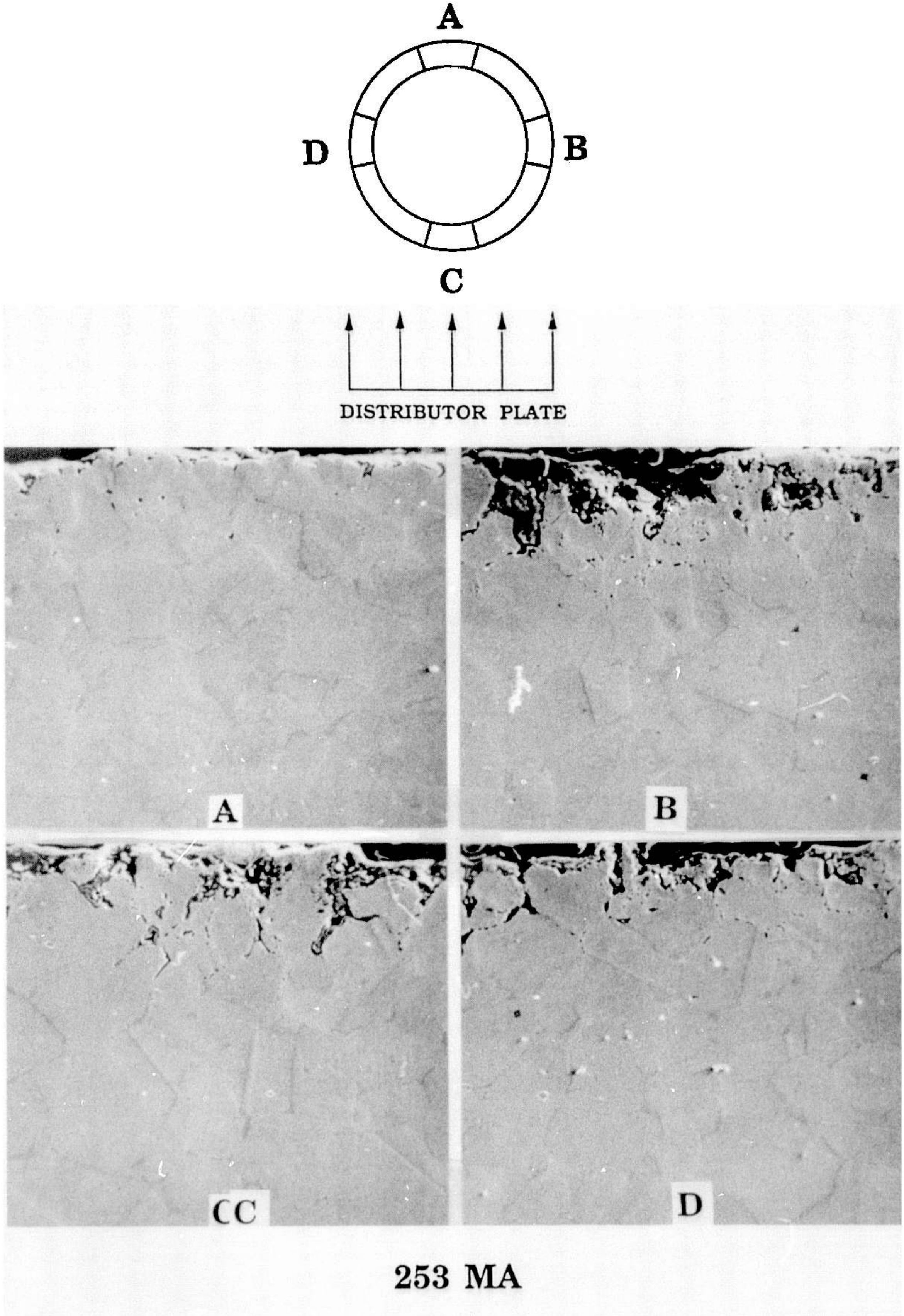


Alloy 800

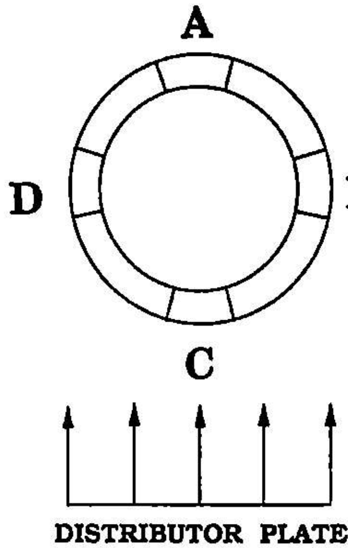
SEM Micrographs of Alloy 800 after 1980 h Exposure

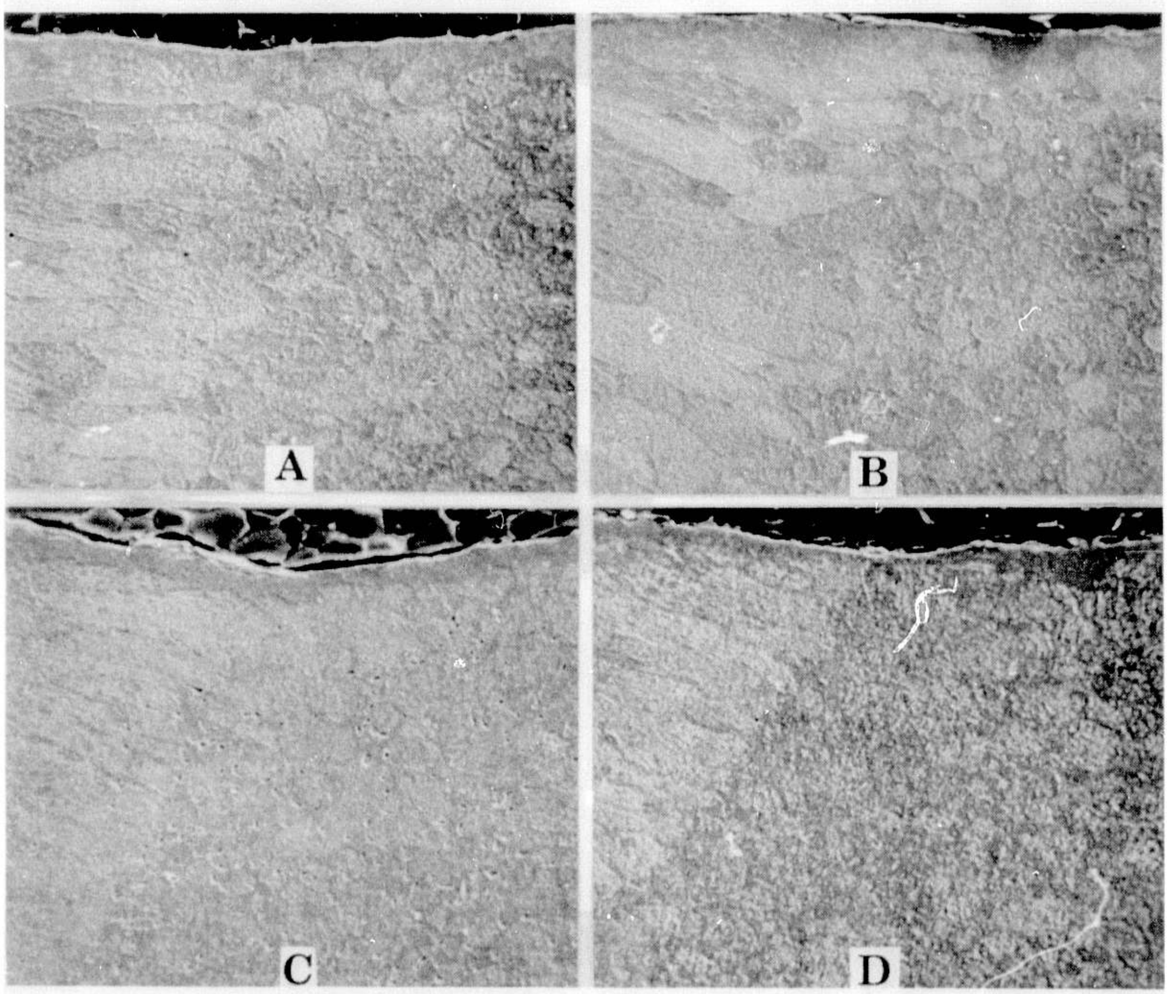


SEM Micrographs of 556 after 1980 h Exposure



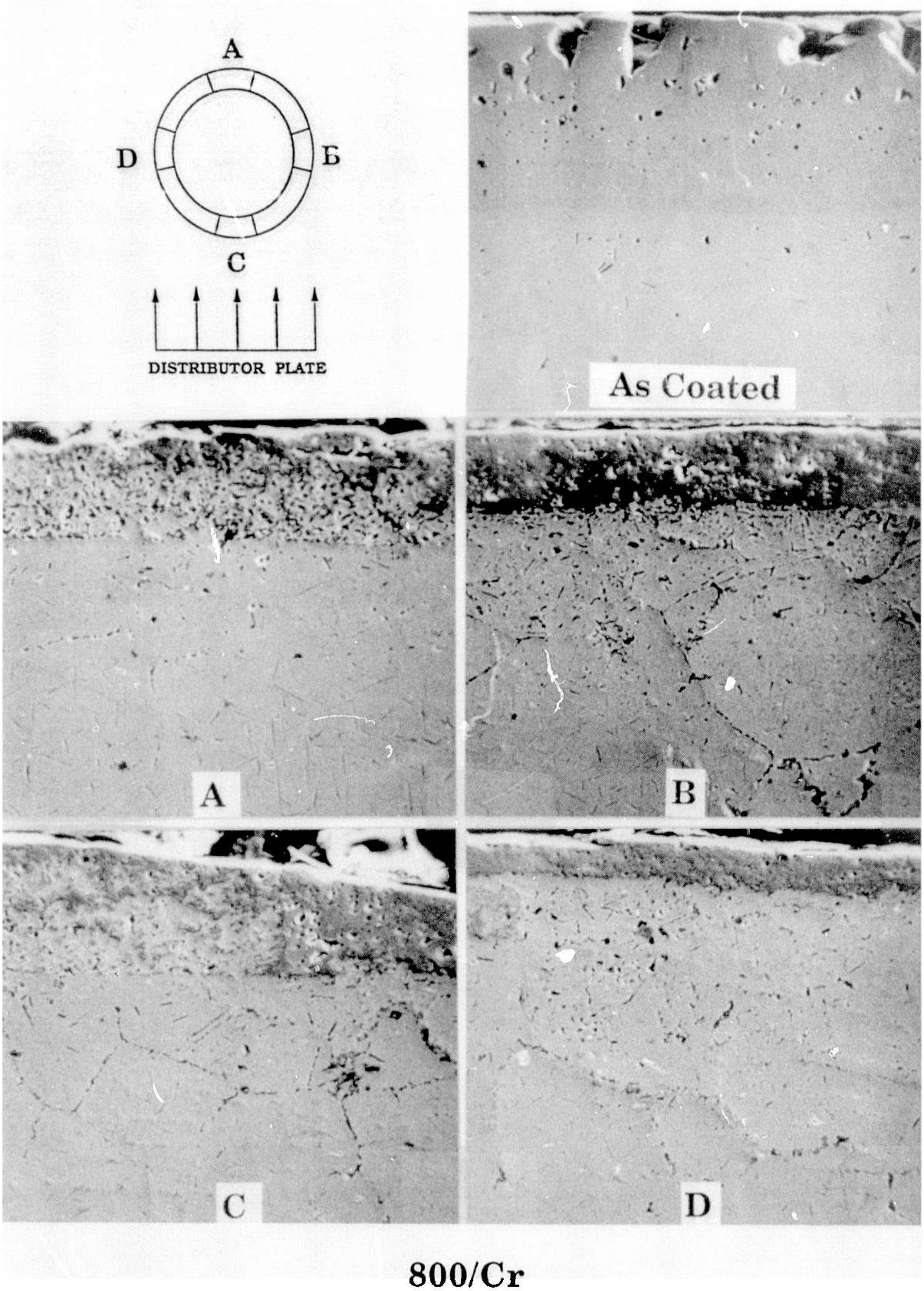
SEM Micrographs of 253 MA after 1980 h Exposure



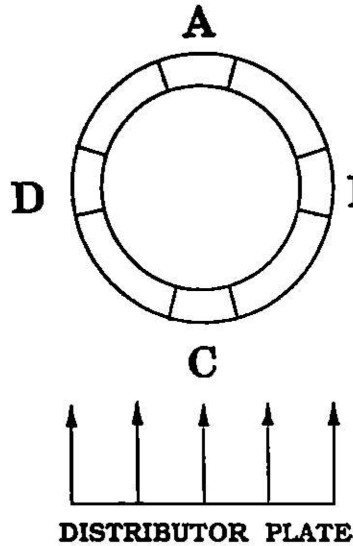


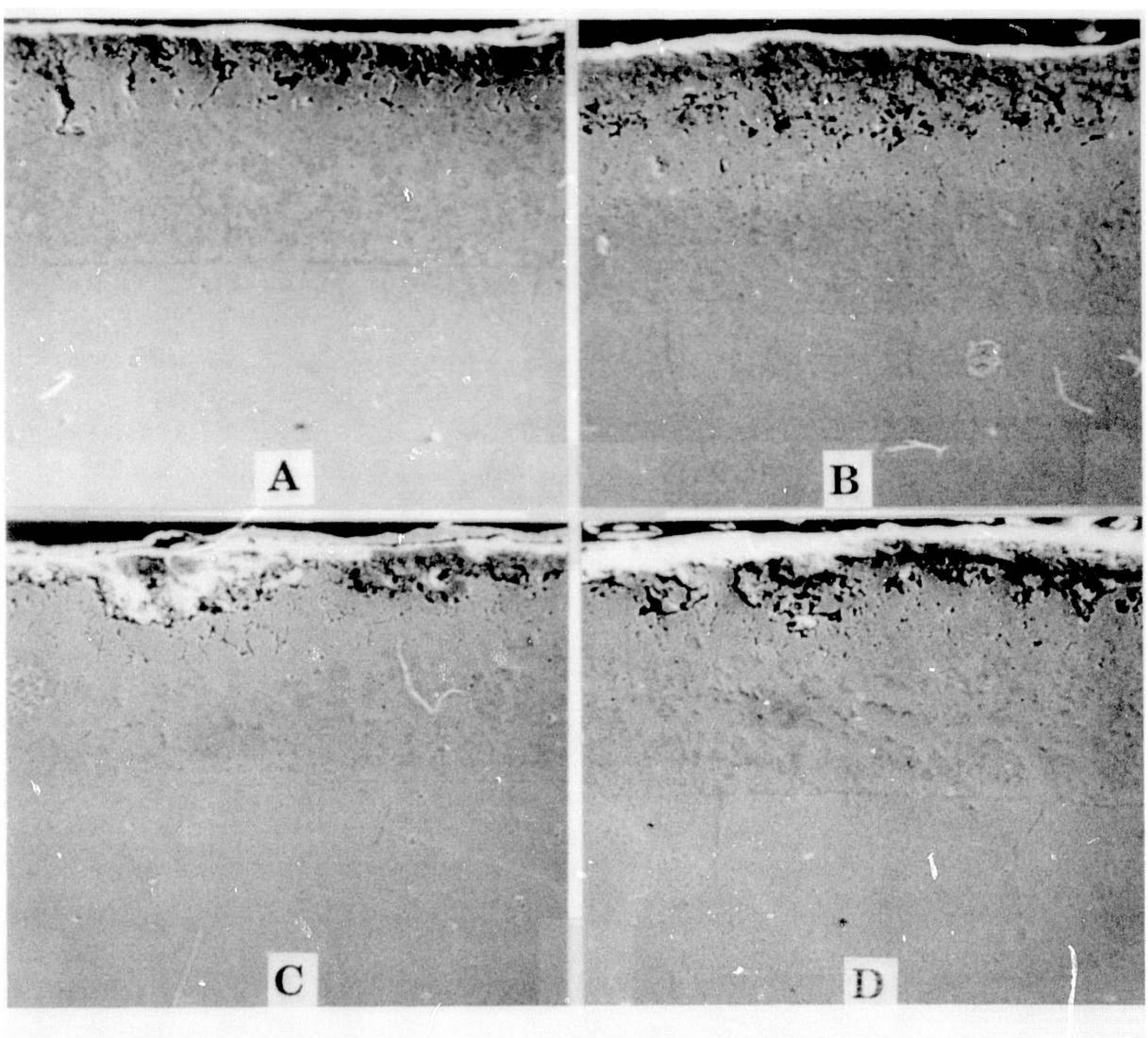
800H/310 Clad

SEM Micrographs of 310-Clad 800H after 1980 h Exposure



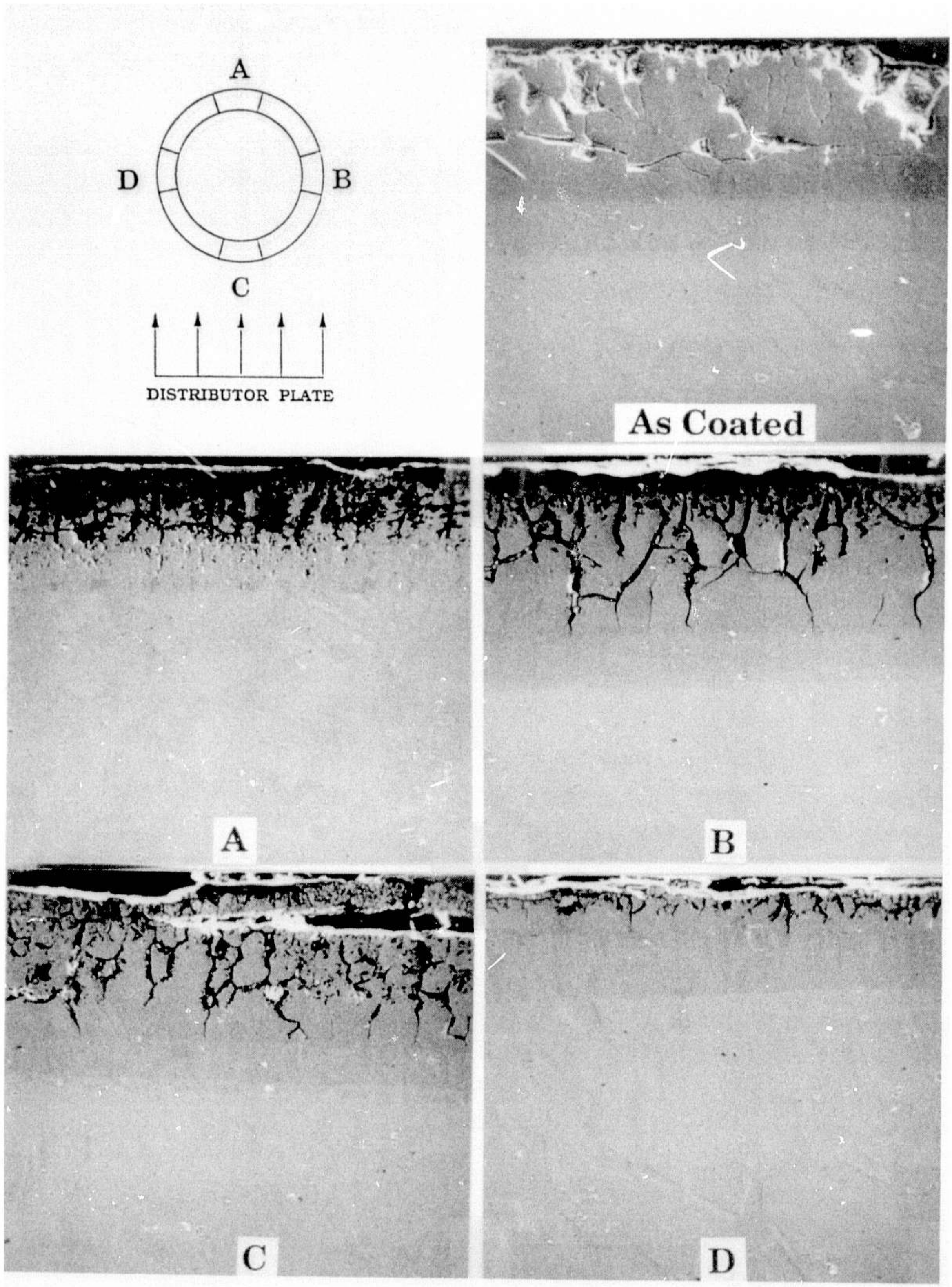
SEM Micrographs of Chromized 800 after 1980 h Exposure





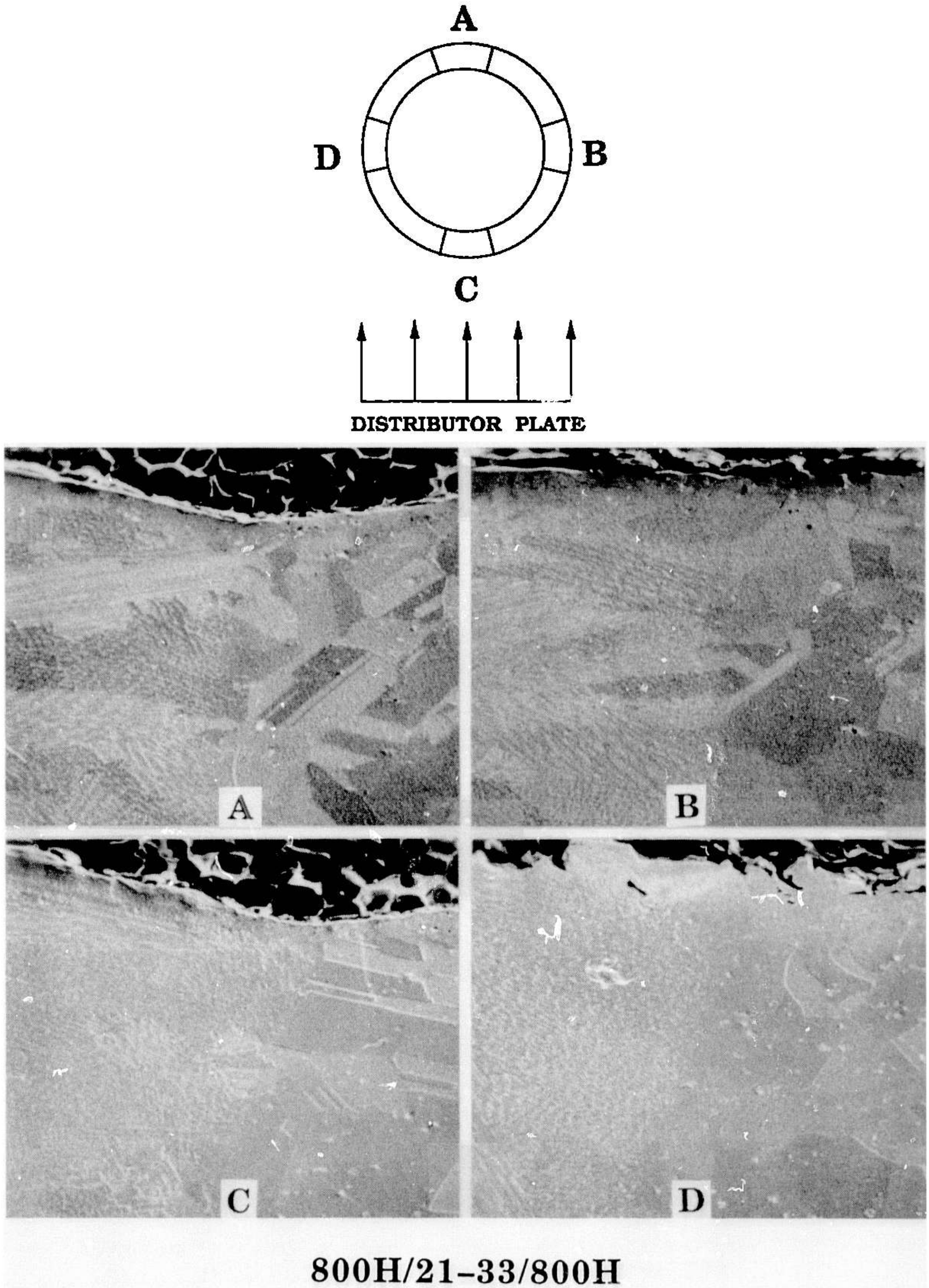
253 MA/Cr

SEM Micrographs of Chromized 253 MA after 1980 h Exposure

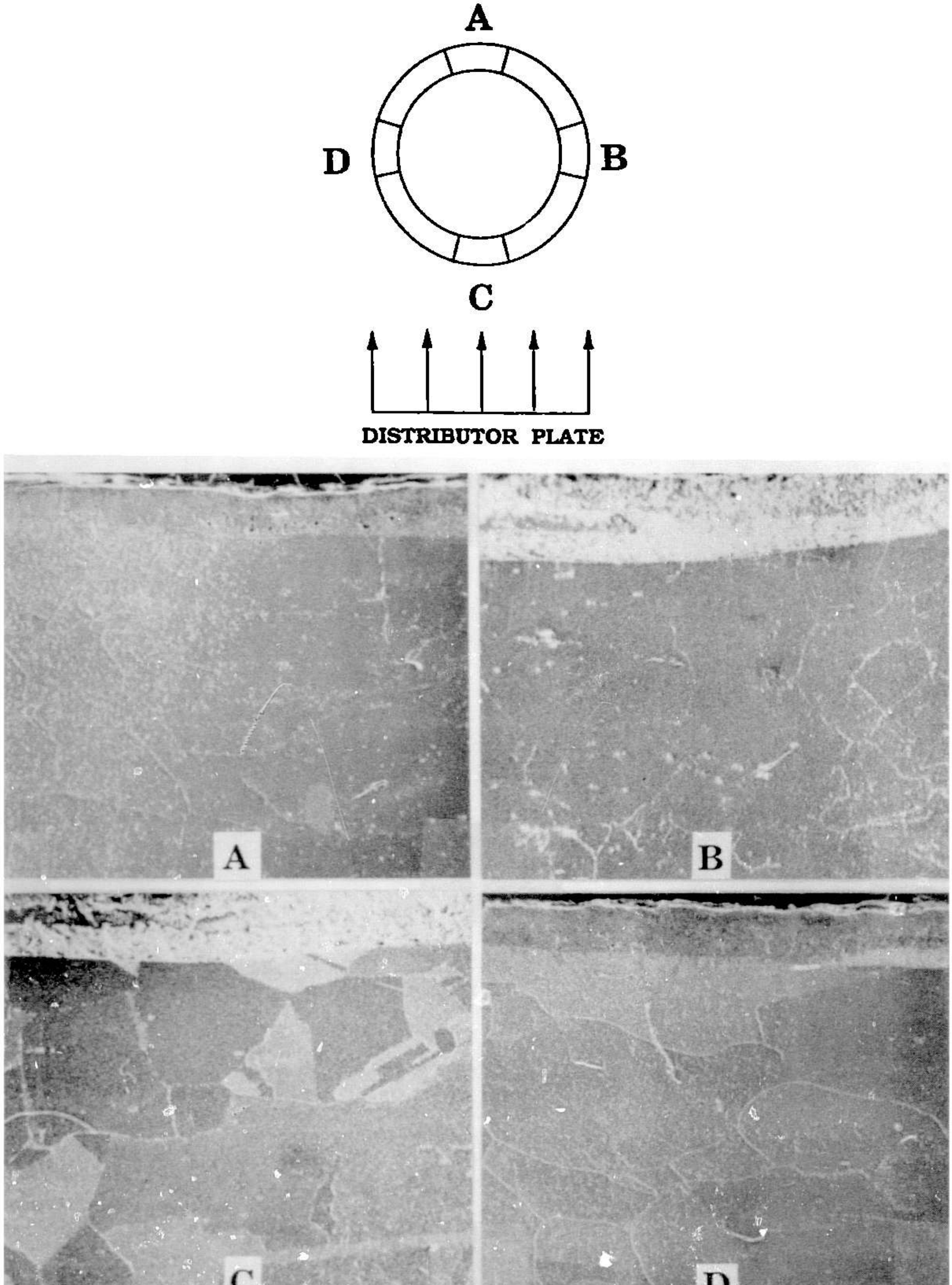


800H/Al

SEM Micrographs of Aluminized 800 after 1980 h Exposure

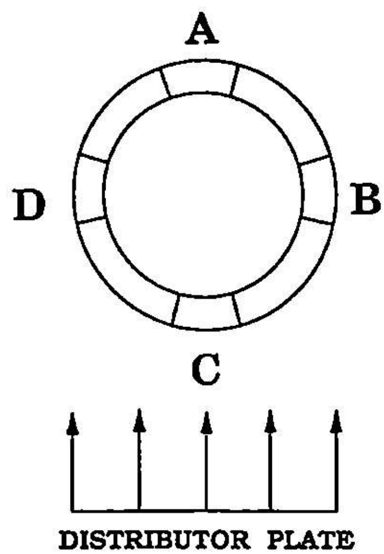


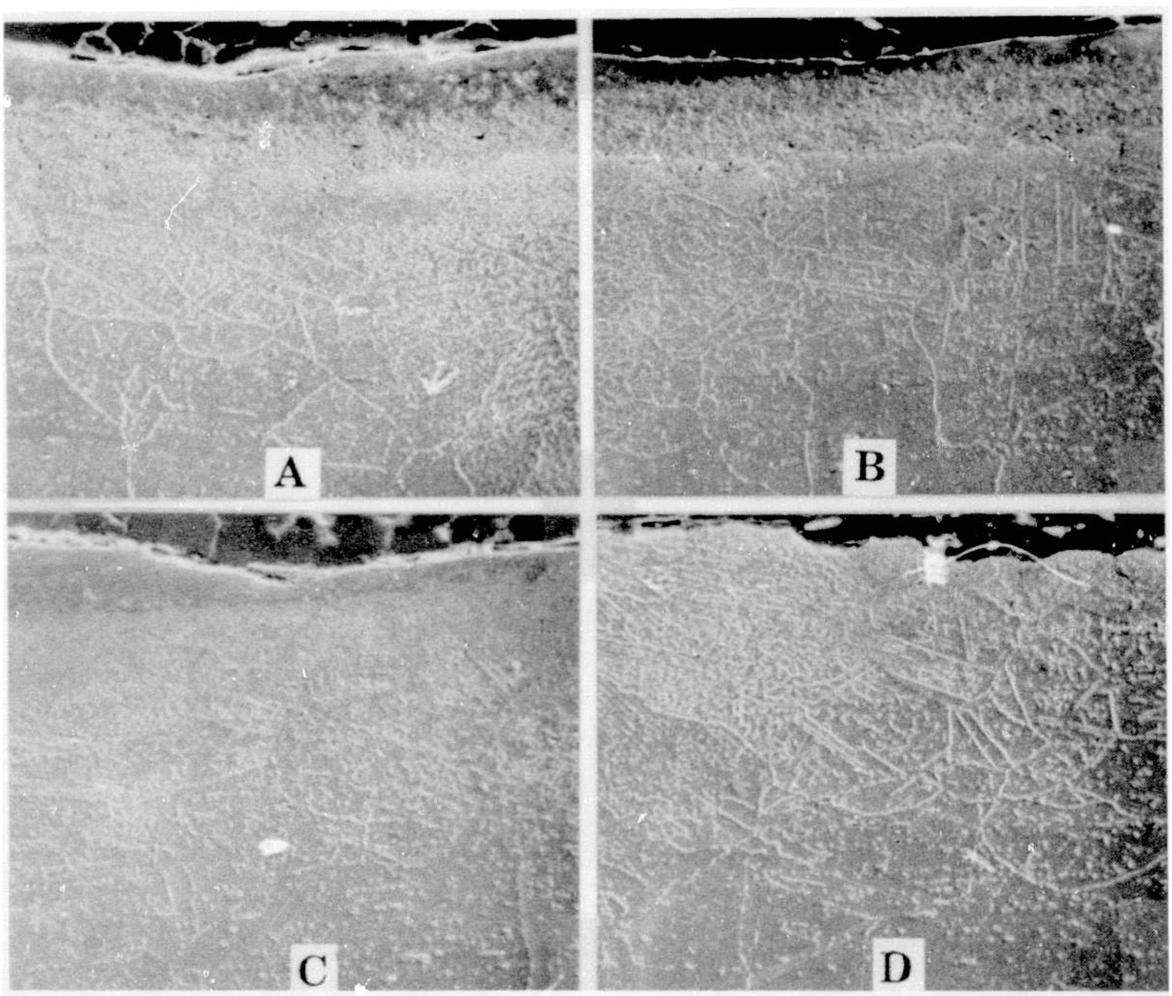
SEM Micrographs of 21-33 Weldments after 1980 h Exposure



Chromized (304/308/304)

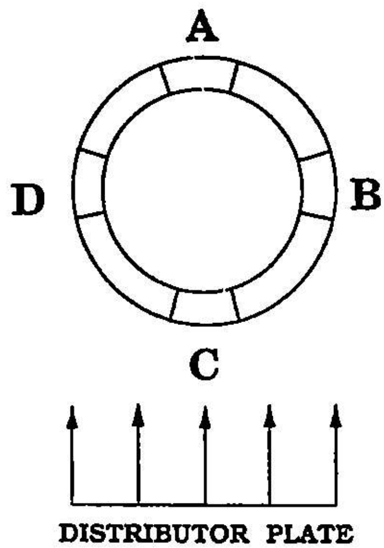
SEM Micrographs of Chromized 308 Weldment after 1980 h Exposure

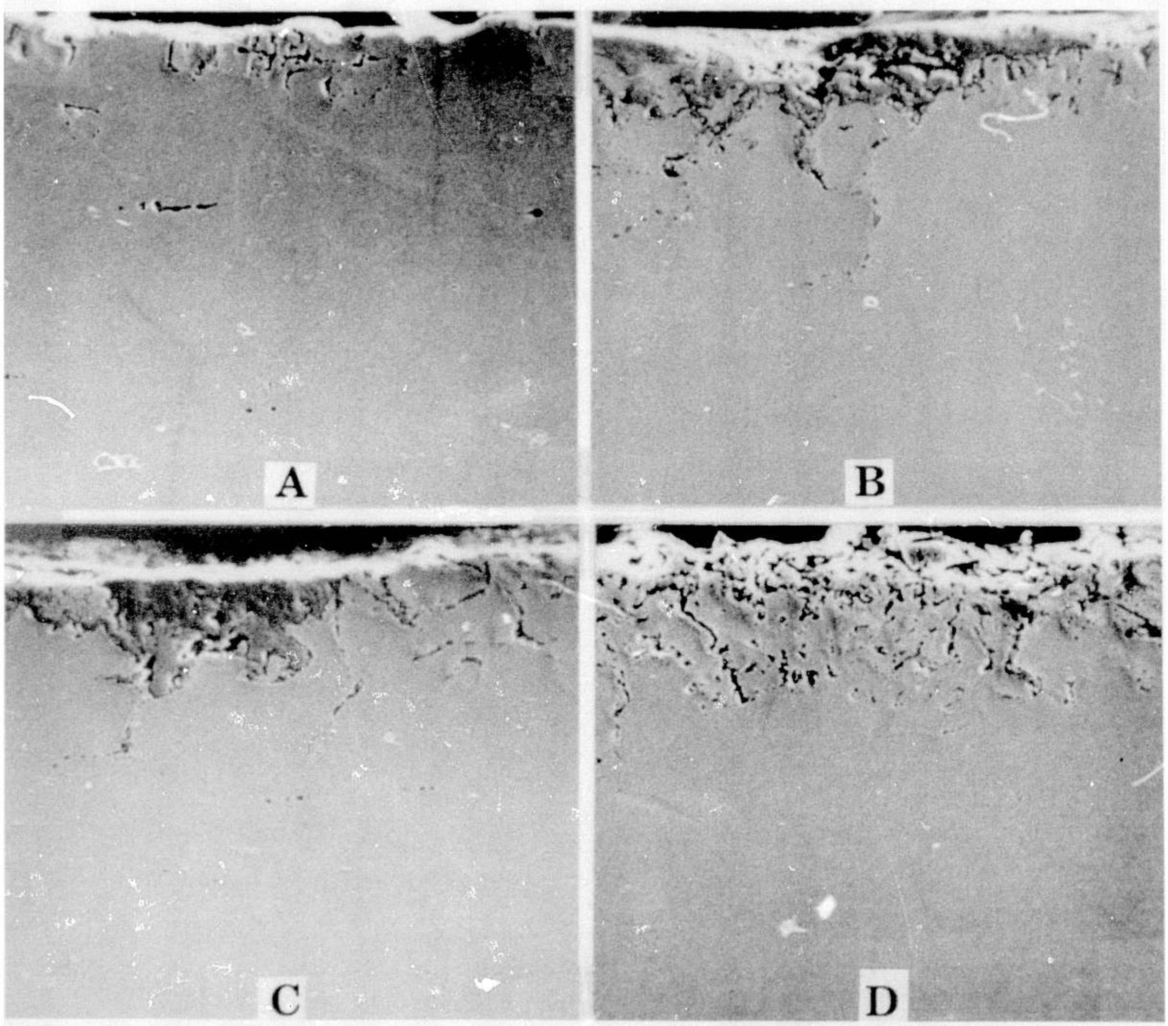




Chromized (800H/21–33/800H)

SEM Micrographs of Chromized 21-33 Weldment after 1980 h Exposure





304H Platen insert in Row 2 of Platen 3

SEM Micrographs of 304H Platen Insert in Row 2 of Platen 3 after 1980 h Exposure

Distribution for ANL-91/4

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