

PICKERING UNIT 1 CHEMICAL CLEANING

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ABSTRACT

The secondary sides of all 12 boilers at Pickering Unit 1 were chemically cleaned in 1994 by the team of Ontario Hydro, B&W International (Cambridge, Ontario) and B&W Nuclear Technologies (Lynchburg, Virginia). A multi-step EPRI/SGOG process was employed in a similar manner to previous cleanings at Units 5 and 6 in 1992 and 1993, respectively. A major innovation with the Unit 1 cleaning was the incorporation of a crevice cleaning step, the first time this had been done on Ontario Hydro plants. In addition, six boilers were cleaned in parallel compared to three at a time in previous Pickering cleanings. This significantly reduced cleaning time. A total of 6,770 kg of sludge was removed through direct chemical dissolution. It consisted of 66% iron/nickel oxides and 28% copper metal. A total of 1,600,000 L (420,000 US gallons) of liquid waste was produced. It was processed through the spent solvent treatment facility located at the Bruce Nuclear Power Development site. Visual inspection performed after the cleaning indicated that the crevices between the boiler tubes and the tube support structure were completely clear of deposit and the general condition of the tubing and lattice bars appeared to be in "as new" condition.

1. PROJECT OVERVIEW

All 12 boilers of the Pickering Nuclear Division Unit 1 (PND-1) reactor were chemically cleaned in the period October 19 to December 2 1994. The cleaning operation was performed in two stages with six boilers (one bank) of the 12 being cleaned simultaneously in each stage. The first stage (the west bank) took 17 days to complete - October 19 to November 4. The second stage (the east bank) took 12 days -

November 21 to December 2. These times represent periods when chemicals were actually in the boilers. They do not include equipment setup, testing dismantling, etc.

Chemical cleaning was performed to remove secondary side deposits that had built up over 22 years of operation. These deposits are thought to be concentrating impurities such as sulphur and chlorides which were causing under-deposit corrosion (pitting) of the Monel 400 boiler tubes.

In preparation for the chemical cleaning, water lancing was performed to break up and remove the majority of the deposits on the tubesheet and to open the tube/support structure gap between the boiler tubes and the lattice support structures to allow access of chemical solvents. Chemical cleaning was required to reach all regions of the boilers, clean all boiler tube surfaces, and remove deposits from the boilers. A post-cleaning water flush of the tubesheet was performed to remove insoluble particles of silica, chromites, Trevorite, etc. which settled during the cleaning operation.

Prime contractor for the project was Babcock & Wilcox International (BWI) of Cambridge, Ontario. BWI provided system operators and personnel for handling waste transfer operations. B&W Nuclear Technologies (BWNT) of Lynchburg, Virginia was subcontracted to supply all chemical cleaning equipment, application expertise and technical support. Babcock & Wilcox Alliance Research Center (ARC) of Alliance, Ohio supplied corrosion monitoring and chemistry personnel support. Niagara Technical Consultants (NTC) of Niagara Falls, New York and St. Catharines, Ontario supplied process engineering and operations engineering support. Ontario Hydro (OH) staff completed the team responsible for the cleaning.

2. CHEMICAL PROCESS DEVELOPMENT

In 1978 a major research program was initiated in the USA to develop a non-proprietary process to chemically remove magnetite and copper-based corrosion product deposits from the secondary side of PWR steam generators. The research program was administered by the Electric Power Research Institute (EPRI) and the PWR Steam Generator Owners Group (SGOG). Project participants were Combustion Engineering, Babcock & Wilcox, the Tetrolite Division of Petrolite Corporation, UNC Nuclear Industries and Westinghouse.

The objective of the research program was to define solvents and application techniques required to successfully remove tubesheet sludge deposits, tube deposits and tube support plate crevice deposits without corroding the steam generator materials of construction beyond acceptable levels. After evaluation of many solvents and processes, a procedure consisting of alternate applications of copper and magnetite dissolution solvents was developed^{1,2}. Copper and magnetite are the major components of most secondary side boiler deposits and PND-1 is no exception.^{1a} This procedure has become known in the industry as the EPRI/SGOG process, or simply the SGOG process. It is the process that was applied by BWNT to the PND-1 boilers. It is very similar to the chemical cleaning process previously applied to PND-5 in 1992, PND-6 in 1993, BNGS-4 in 1993 and BNGS-3 in 1994.³ The major difference between the PND-1 cleaning and previous cleanings at Ontario Hydro plants was the addition of a crevice cleaning step. The reasons for including this step are discussed in the next section.

3. CLEANING SOLVENT FORMULATION AND APPLICATION SEQUENCE.

All qualification testing program was performed specifically for PND-1.⁴ Based on this program, the application sequence given in Table 1 was developed.

The major innovation for the PND-1 cleaning compared to other cleanings at Ontario Hydro plants, was the addition of a crevice cleaning step to assist in removing deposits from the narrow openings between the boiler tubes and the lattice support structures. These openings between the boiler tubes and the lattice support structures. These openings were known to be locked in the PND-1 boilers, and in many cases were fully blocked. Some tubes are showing restrictions at the tube support area. As

explained above, water lancing had removed some of the deposits in the tube support area. As explained above, water lancing had removed some of the deposits in the tube support structure but physical constraints as a result of boiler design precluded mechanical cleaning of all the crevice areas. Previous experience at Pickering and Bruce indicated that the magnetite step, while very effective in cleaning tube surfaces, was ineffective in removing thick, tightly packed crevice deposits. It was hoped that by applying a more aggressive solvent, i.e. a crevice cleanings step, that the crevices would be opened. A secondary benefit of adding the crevice step was to improve removal of nickel ferrite. It has limited solubility in the SGOG magnetite step but is more soluble in the crevice solvent because of the lower pH and higher temperature.

The qualification program for the crevice solvent was focused on ensuring acceptable corrosion for the crevice step. No attempt was made to demonstrate crevice cleaning effectiveness due to the inability to accurately mock-up realistic crevices containing deposits. During the program it was found that unacceptable corrosion of Monel 400, the PND-1 boiler tube material, occurred at a temperature of 250°F, the standard EPRI/SGOG crevice solvent temperature. Thus the temperature was limited to 225°F for this application, a temperature that additional testing had shown to be satisfactory.

Copper removal steps were applied first to dissolve all available copper. If copper is not removed prior to a magnetite dissolution step, it will first go into solution then subsequently plate out on all boiler surfaces thus interfering with the efficiency of the magnetite removal step and causing higher corrosion. A magnetite dissolution step was then applied to dissolve the majority of the deposit. Following this, a crevice cleaning step was applied to remove the more recalcitrant deposits located in the crevice regions of the lattice support structures as explained above. Another copper step was then applied to remove any plated copper and the small amount of copper that was deeply buried within the magnetite layer that could not be removed during the first two copper removal steps. Finally, the BWP proprietary passivation step was applied to lay down a thin layer of magnetite on all carbon steel and low alloy surfaces to minimize flash rusting during subsequent maintenance activities.

Table 2 summarizes the composition of the three solvents employed during the PND-1 cleaning.

[a] Average composition of PND-1 deposits: Fe = 37%, Cu = 24%, O = 20%, Ni = 12%, Si = 4%, Zn = 4%.

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4. CHEMICAL CLEANING EQUIPMENT

The equipment used to support the cleaning is located outside the reactor building in a covered bermed area approximately 150 ft x 75 ft. Major components of the equipment are:

- process tanks ranging in size from 34,000 gal to 42,000 gallons for mixing chemical solvents and rinse solutions;
- a 2,500 gallons hydrogen peroxide "day tank" which is located outside the main berm;
- 1,000 kW and 600 kW electric heaters for heating the solvents and rinses either in the process tanks or during recirculation in the boilers;
- recirculation pumps ranging from 500 to 1,000 gpm for recirculating solvents within the process tanks, transferring solvents and rinses to and from the boilers, and for recirculation within the boilers;
- a chemical addition system capable of adding bulk chemicals to the process tanks from drums, totes and tankers;
- interim waste storage tanks ("Frac" tanks) of 20,000 gallons capacity each which are located in a separate covered berm.

All major components are interconnected by either a double 4-inch line or a single 6-inch line. A combination of schedule 40 carbon steel pipe and reinforced rubber hose are used.

A single 6-inch carbon steel line carries solvent from the main berm to the reactor building (RB). Once inside the RB a header distributes the flow to six boilers. During recirculation flow into each boiler is through lancing nozzles N11 or N13 depending upon the solvent level. Flow exits the boilers through the lower feedwater line and the blowdown lines. These connections are shown in Figure 1. Once a solvent exits the boilers it is directed to a header from where a single 6-inch carbon steel line returns it from the RB to the main berm.

5. CORROSION MONITORING

A sophisticated corrosion monitoring system (CMS) was supplied and operated by BWNT as part of their service package. The CMS was used to monitor both free and galvanic corrosion of three materials: AISI-1018, AISI-1018 containing 0.16% Cu, and SMAW (E7018-A1 weld filler metal). These materials had been determined to be representative of the most critical material (i.e., that with the smallest corrosion allowance, lattice support material A-245B) and the most susceptible material (i.e., that which was expected to undergo the most corrosion, weld filler

ASME E-7018 A1) in the PND-1 boilers. Free corrosion was monitored by linear polarization (LP) while galvanic corrosion was monitored by zero resistance ammetry (ZRA). These are standard, field-proven, corrosion monitoring techniques that have been used by BWNT and other chemical cleaning vendors for several years on previous cleanings. Total corrosion was also monitored by weight loss coupons and a lattice bar/baffle plate mockup coupon containing six 2' section of Monel 400 tubing.

Three types of CMS probes were employed during the cleaning:

- (i) a hybrid probe containing ZRA electrodes, LP electrodes, weight loss coupons and a lattice bar mockup coupon;
- (ii) a probe containing only ZRA electrodes;
- (iii) a retractable probe containing only weight loss coupons.

A hybrid probe was installed in each boiler just above the tubesheet in existing sludge lancing nozzles N1 or N4 (see Figure 1). Experience indicated that this was likely to be the region of highest corrosion.

ZRA probes were installed in one boiler in each bank (boiler 10 in the west bank and boiler 7 in the east bank) at various elevations. Again, existing sludge lancing nozzles were employed to gain access to the boiler (see Figure 1). These probes were designed to provide an indication of corrosion as a function of elevation.

Retractable probes were also installed in one boiler in each bank (boiler 6 in the west bank and boiler 3 in the east bank) at two different elevations. These probes were designed to be removed and provide independent confirmation of the electronically obtained CMS LP and ZRA readings without shutting down the cleaning operation.

Corrosion limits were determined for each component in the secondary side of the PND-1 boilers. The most restrictive limits are summarized in Table 3. The material employed in the CMS to represent the PND-1 material is also listed in Table 3. In most cases, it has been determined that the corrosion response of the representative material bounded the actual material, i.e. the corrosion response of the CMS material was equal to or greater than the actual PND-1 material it was representing. The sole exception to this was AISI-1018 containing 0.16% Cu. It showed slightly lower corrosion than A-245B, the support structure material it was representing. To compensate for this, a factor of 1.22 was applied to the AISI-1018 (Cu) CMS readings to obtain an estimate of the corrosion of the support structure material. The 1.22 correction

factor was determined from comparison of the corrosion results of A-245B and the AISI-1018 (Cu) during the qualification program.

The "official" corrosion losses for the cleaning are given in the last column of Table 3. These are the highest values measured by any method in either bank. Thus they are worst case values. For each component and for each material the corrosion loss was much less than the corrosion limit.

6. SUMMARY OF WEST BANK CLEANING

A total of 3,471 kg (7,652 lbs) of deposit was removed through direct dissolution. A breakdown of the amount removed in each process step is given in Table 4. About 29% was copper and about 64% was iron/nickel oxides. All of these values are in good agreement with predicted values. The amount of deposit in the PND-1 boilers was estimated to be 735 kg per boiler.⁵ For a 6 boilers this is equivalent to 4,410 kg. When allowance is made for the 10% insoluble portion this is reduced to 3,969 kg, only 11.4% higher than the amount actually removed and well within the uncertainty of the calculation. The predicted deposit composition, based on 100 g of sludge lacing deposit, was 26% copper and 69% iron/nickel oxides. Again this was in reasonable agreement with the actual composition.

Copper removal steps were performed at essential ambient temperature although the temperature was allowed to rise to 100-115°F towards the end of the step to promote decomposition of residual hydrogen peroxide. Each copper step typically lasted about 10 hours. The maximum copper concentration obtained in the solvent was about 8g/L in the first copper step. The second and third copper steps had much lower concentrations. A graph of the major chemical parameters during Cu W-1 shown in Figure 2. All parameters followed the expected trends.

The iron removal step was performed at ~200°F. It lasted for approximately 80 hours. The maximum iron concentration obtained was about 6g/L. A graph of the major chemical parameters during Fe W-1 is shown in Figure 3. Again all parameters followed the expected trends.

A typical galvanic corrosion response during the magnetite dissolution step is shown in Figure 4. Note the initial peak of 6,000 mils per year (mpy) followed by a rapid drop to the steady state value of 50 mpy. The abrupt drops every 8 hours or so correspond to drain and refill operations which were performed periodically to preclude stagnant areas, or regions of localized solvent depletion within the boilers. Figure 5

shows a typical free corrosion response during the magnetite step.

An interim inspection was performed in boiler 6 after Fe W-1 to determine if a crevice cleaning step was required. The crevices in the tube support structures were still blocked with deposit. In addition, it appeared that some deposit had settled onto the top of the support structures as a result of the previous cleaning steps. Ontario Hydro advised that a crevice cleaning step would definitely be required.

The crevice solvent was injected at 200°F and heating *in situ* to 225°F. Once full operating temperature was reached, periodic venting was initiated to induce boiling to a given depth. The purpose of the boiling is to expel depleted solvent from within the crevices which is replenished by fresh solvent when the boilers are repressurized. Deposit dissolution may be assisted by the mechanical action of boiling as well.

The operation consisted of securing recirculation and reducing pressure to ~1-2 psig by venting N₂ and water vapor. At this pressure the top 1-2 feet of solvent were below the saturation pressure and boiling occurred. Boiling was detected by an abrupt change in the response of the CMS electrodes located near the boiling region and by an increase in level on the boiler sightglasses as bubbles of steam formed. Boiling was allowed to continue for 5 minutes. Pressure and recirculation were then reestablished and the solvent was reheated to 225°F. Typically 4-5°F was lost as a result of boiling.

Two venting operations were performed at level 8 (see Figure 1) over a three hour period. The level was sequentially lowered to levels 7, 6, 5, 4, 3, 2 and 1. It was held at levels 7 and 6 for 2 hours each. Two vent operations were performed at each level. It was held at levels 5 and 4 for 12 hours each with venting being performed every 2 hours.

It was also scheduled to held at level 3 for 12 hours, but required repairs to the piping support structure between the yard and the reactor building extended this step to 17 hours. Venting was not permitted while repairs were underway since it was the vent line supports that were being refurbished. Once repairs were completed, venting operations resumed shortly thereafter on a 1.75 hour cycle to perform the required number of vent cycles (six) without extending the time unduly.

The level was lowered to level 2 and held for 12 hours. a total of 7 vents were performed during this period. It was then lowered to level 1 where it was held for 14 hours. A total of 9 vents were performed on a 1.5 hour frequency. Longer exposure times

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were employed at the lower levels (levels 5, 4, 3, 2 and 1) since the lower support structures were found by inspection during lancing to be more heavily fouled than the upper ones. Also the corrosion limit was higher for the lower lattice supports thus allowing longer exposure times. See Table 3.

Following injection of the crevice solvent, the concentration of dissolved metals started to increase and the free EDTA started to decrease in a manner similar to that of the magnetite dissolution solvent. A graph of the major chemical parameters is shown in Figure 6. The apparent steep rise in dissolved iron concentration between hours 70 and 80 is mainly due to a concentration effect as a result of the ~60 gallons lost during each of the 9 vents. This effect was much less pronounced at higher elevations where the system volume was much larger. All chemical parameters remained within specification throughout the entire crevice cleaning step. No adjustments were necessary.

Maximum corrosion for the west bank cleaning as determined from the CMS and corrosion coupons is given in Table 5. The DMS values were determined by adding the ZRA and LP readings for each material in each step using the electrode which ultimately gave the highest indicated value. Corrosion determined from weight loss of the appropriate ZRA electrode is also listed for comparison. The LP electrodes cannot be used for this comparison since they undergo only free corrosion. The ZRA electrodes undergo both free and galvanic corrosion even though it is only the galvanic portion that is monitored electronically. A more complete theoretical discussion of corrosion monitoring is available elsewhere.⁶

All corrosion losses were well below the previously established limits which are given in Table 3.

A visual inspection of boiler 6 was performed at the first lattice support structure on November 15, 1994, 11 days after the cleaning. This was the last in a series of three inspections at the same location to determine the effectiveness of the cleaning operation. The first inspection was performed before the cleaning started. It showed that the tubes were fouled, the lattice bars had deposits on them, and there was deposit in the crevices. The second inspection, performed after completion of the iron step but before the crevice step, showed that the tube surfaces were clean but the crevices at the tube/ lattice bar intersections remained fouled. This last inspection showed that the crevices were completely clear of deposit and the general condition of the boiler tubing and lattice bars appeared to be in "as new" condition. Based on these positive results,

it was decided to apply the identical series of process steps to the east bank boilers. The only change would be elimination of the interim inspection between the iron and crevice steps since the west bank experience indicated that a crevice step was essential to clean the crevices.

7. SUMMARY OF EAST BANK CLEANING

A total of 3,298 kg (7,271 lbs) of deposit was removed through direct deposit dissolution. A breakdown of the amount removed in each process step is given in Table 6. About 27% was copper and 67% iron/nickel oxides. These numbers are very similar to those from the west bank.

The copper, magnetite and crevice steps were performed in a very similar manner to those in the west bank and will not be discussed here.

Maximum corrosion for the east bank cleaning as determined from the CMS and corrosion coupons is given in Table 7. Results for A-245B, AISI-1018 and AISI-1018 (Cu) are very similar to those in the west bank. The SMAW coupons and electrodes showed far higher corrosion than that indicated electronically by the CMS and far higher than the equivalent values in the west bank. The large difference is attributed to pitting which was evident upon visual examination of the coupons and electrodes. Pits as deep as 51 mils were observed. After considerable investigation the pitting was attributed to loss of inhibitor or inhibitor depletion in the east bank iron step. In the west bank magnetite dissolution solvent excess inhibitor was added to account for potential error in initial solvent formulation. The final concentration was approximately 18 mL/L. In addition, a further 5 mL/L was added as a precautionary measure during one of the drain and refill operations. During the east bank magnetite dissolution step only the amount specified in the qualification program (10 mL/L) was added.

Inspection of the SMAW welds within the east bank boilers showed similar corrosion to that observed on the coupons only on the blowdown header at the tubesheet. This header is no longer used. It was disconnected on both sides when the sludge lancing holes were installed. Thus corrosion of this weld represents no change to boiler integrity. The inspection also showed that the tubes, lattice bars and crevices were completely clear of deposit. In general, the tubes and lattice bars appeared to be in "as new" condition.

8. WASTE HANDLING

All waste chemical cleaning solutions were temporarily stored on the Pickering site in 20,000 gal

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(70,000 L), portable, stainless steel fractionation tanks ("frac tanks"). After confirmation that the waste met all shipping requirements, plans were made to ship the contents to Bruce Nuclear Power Development (BNPD) site for processing in the Spent Solvent Treatment Facility (SSTF) located there.

The waste was shipped to BNPS in 9,000 gal (35,000 L) industrial waste tankers by a commercial hazardous waste hauler. A total of 52 tanker loads were shipped. The first shipment was made on October 22 and the last on December 12, 1994. A total of about 420,000 gal (1,600,000 L) of waste was shipped consisting of approximately 42% copper solvent, 35% iron/crevice solvent and 23% rinse.

9. REFERENCES

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- 3 P.J. Leinonen et al., "Recent Experience in Boiler Chemical Cleaning in Ontario Hydro", Paper 3, presented at Steam Generator and Heat Exchanger Conference, Canadian Nuclear Society, Toronto, Canada, June 1994.
- 4 P.M. Knollmeyer and J.M. Jevic, "PNGS-A Chemical Cleaning Qualification Testing Final Report", BWNT Proprietary Report 51-1234100-00, July 1994.
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- 6 J.M. Jevic, P.M. Knollmeyer and C.M. Daniel, "Corrosion Monitoring During the Chemical Cleaning of Pickering Unit 5", Paper 7, presented at Steam Generator and Heat Exchanger Conference, Canadian Nuclear Society, Toronto, Canada, June 1994.

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Table 1
Application Sequence for Chemical Cleaning of PND-1 Boilers

Step No.	Designation in West Bank	Designation in East Bank	Description
1	R W-1	R E-1	Checkout rinse
2	Cu W-1	Cu E-1	First copper dissolution step
3	Cu W-2	Cu E-2	Second copper dissolution step
4	FVR W-1	FVR E-1	Low volume rinses, full volume rinse and heatup
5	Fe W-1	Fe E-1	Magnetite dissolution step
6	FVR W-2		LVRs, FVR and cooldown of boiler 6 - West bank only
7	Visual Insp.		Visual inspection of boiler 6 - West bank only
8	FVR W-2A		Full volume rinse and heatup - West bank only
9	Cre W-1	Cre E-1	Crevice cleaning step
10	FVR W-3	FVR E-2	Low volume rinse, full volume rinse and cooldown
11	Cu W-3	Cu E-3	Third copper dissolution step
12	BWP W-1	BWP E-1	Passivation step
13	FVR W-4	FVR E-3	Low volume rinse, full volume rinse and cooldown

Table 2
Composition of Solvents Employed During PND-1 Chemical Cleaning

Parameter	Copper Solvent	Magnetite Solvent	Crevice Solvent
EDTA ^[b]	50 g/L	150 g/L	200 g/L
Hydrazine	Not used	10 g/L	Not used
CCI-801 ^[c]	Not used	10 mL/L	20 mL/L
Hydrogen peroxide	30 g/L	Not used	Not used
EDA ^[d]	Added to give pH 10	Not used	Not used
Ammonium hydroxide	10	Added to give pH 7	Added to give pH 6
Application temperature	Not used 25-35°C	93-95°C	104-107°C

[b] Ethylenediaminetetraacetic acid - an organic acid and a chelating agent for iron, copper and other metals

[c] A corrosion inhibitor

[d] Ethylenediamine - an organic base and a chelating agent for copper

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Table 3
Chemical Cleaning Corrosion Summary for PND-1 Boiler Materials

Boiler Component	Boiler Material	Representative CMS Material	Corrosion Limit (mils)	Corrosion Loss (mils)
Lattice supports 6, 7 and 8	A-245B	AISI-1018 with 0.16% Cu	4	1.23
Impingement plate	Corten-A	AISI-1018 with 0.16% Cu	8.5	3.23
Lattice supports 1, 2, 3, 4 and 5	A-245B	AISI-1018 with 0.16% Cu	12	3.23
Shroud support lugs	AISI-1018	AISI-1018	12	3.84
U-bend supports	A-245B	AISI-1018 with 0.16% Cu	12	1.23
Stay tubes	SA-214	AISI-1018	15	3.84
Shielded metal arc weld	ASME E-7018 A1 weld filler	ASME E-7018 A1 weld filler	27.5	19.34*
Shell	AISI-1018	AISI-1018	27.5	3.84

* Localized attack as deep as 51 mils was seen on the east bank SMAW coupons.

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Table 4
Weight of Deposits Removed During Cleaning of PND-1 West Bank Boilers

Step	Deposits Removed (kg)						
	Fe ₃ O ₄	Cu	NiO	ZnO	CaO	Pb	Total
Cu W-1	2	765	6	55	0.7	0.0	829
Cu W-2	6	140	6	10	0.3	0.0	162
Fe W-1	619	1	421	81	6.2	0.4	1,129
Fe W-1A	369	1	195	37	5.2	0.2	607
Cre W-1	395	2	163	27	3.4	0.2	591
Cu W-3	14	103	5	7	0.6	0.0	130
Cu Pass	3	11	9	1	0.0	0.0	24
Total	1,408	1,023	805	218	16	1	3,471

Table 5
Maximum Indicated Corrosion During West Bank Cleaning

Material	Total Indicated Corrosion (mils)	Corrosion from ZRA Electrode Weight Loss (mils)	Corrosion from Coupon Weight Loss (mils)	Lattice Support Mockup Weight Loss (mils)	Lattice Support Mockup Wall Thickness Change (mils)	Lattice Support Mockup Hole Radius Change (mils)
AISI-1018 (Cu) Lattice Supports 6-8 (Note 1)	1.16	1.23	NA	NA	NA	NA
AISI-1018 (Cu) Lattice Supports 1-5 (Note 1)	0.83	0.81	1.20	1.94	2.07	2.20
AISI-1018	2.78	2.62	3.28	NA	NA	NA
SMAW	2.62	3.89	5.28	NA	NA	NA
A-245B	NA	NA	1.49	NA	NA	NA

Note 1: All corrosion losses for AISI-1018 (Cu) have been multiplied by 1.22.

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Table 6
Weight of Deposits Removed During Cleaning of PND-1 East Bank Boilers

Step	Deposits Removed (kg)						
	Fe ₃ O ₄	Cu	NiO	ZnO	CaO	Pb	Total
Cu E-1	3	584	6	27	1.5	0.0	622
Cu E-2	2	120	5	11	0.6	0.0	139
Fe E-1	401	1	201	54	4.6	0.0	662
Fe E-1A	474	0	461	56	5.3	0.2	997
Cre E-1	445	3	172	46	6.0	0.3	672
Cu E-3	6	133	17	0	0.6	0.2	157
Cu Pass	4	41	5	0	0.0	0.0	50
Total	1,335	882	867	194	19	1	3,297

Table 7
Maximum Indicated Corrosion During East Bank Cleaning

Material	Total Indicated Corrosion (mils)	Corrosion from ZRA Electrode Weight Loss (mils)	Corrosion from Coupon Weight Loss (mils)	Lattice Support Mockup Weight Loss (mils)	Lattice Support Mockup Wall Thickness Change (mils)	Lattice Support Mockup Hole Radius Change (mils)
AISI-1018 (Cu) Lattice Supports 6-8 (Note 1)	0.95	0.78	NA	NA	NA	NA
AISI-1018 (Cu) Lattice Supports 1-5 (Note 1)	0.74	0.60	1.89	2.16	2.20	3.23
AISI-1018	1.58	1.41	3.84	NA	NA	NA
SMAW	3.86	7.90	19.34	NA	NA	NA
A-245B	NA	NA	1.65	NA	NA	NA

Note 1: All corrosion losses for AISI-1018 (Cu) have been multiplied by 1.22.

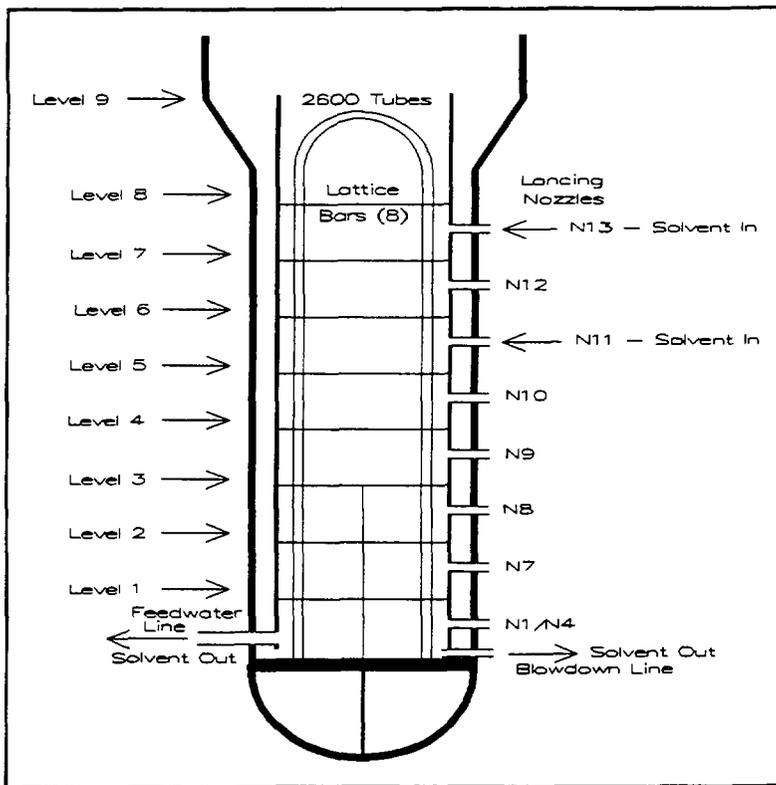


Figure 1
Solvent Connections and Solvent Levels - Pickering 1 Boilers

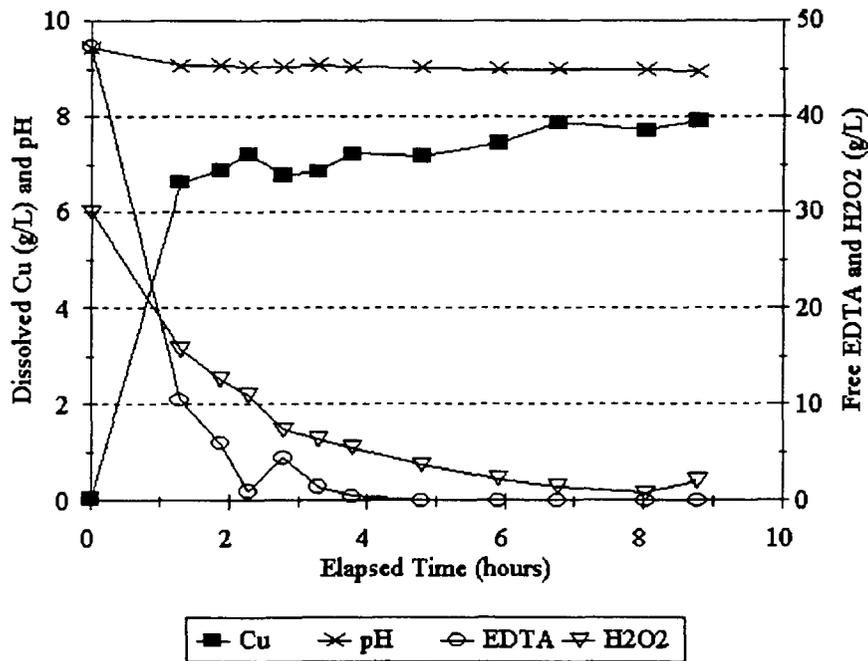


Figure 2
Chemical Parameters During Cu W-1

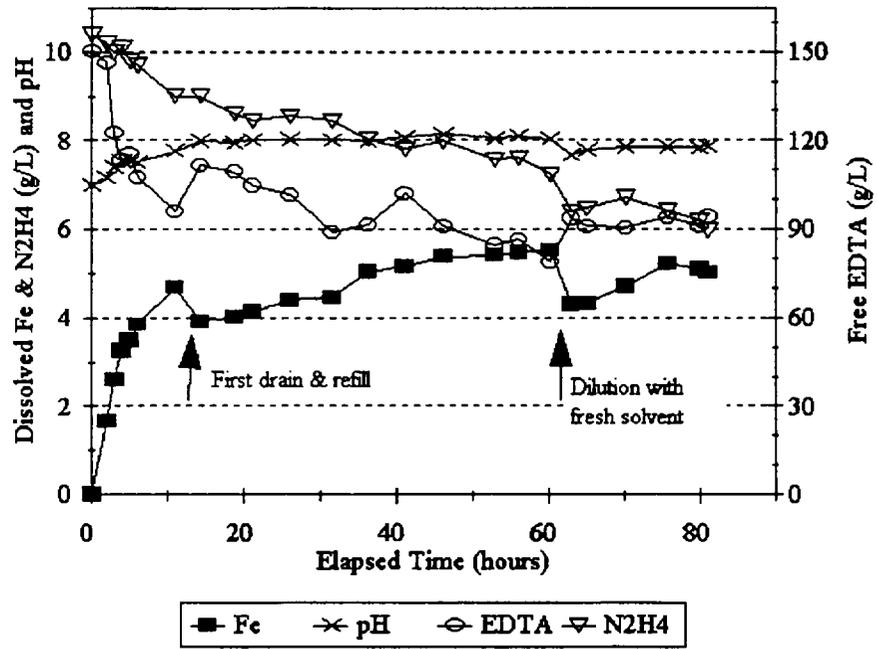


Figure 3
Chemical Parameters During Fe W-1

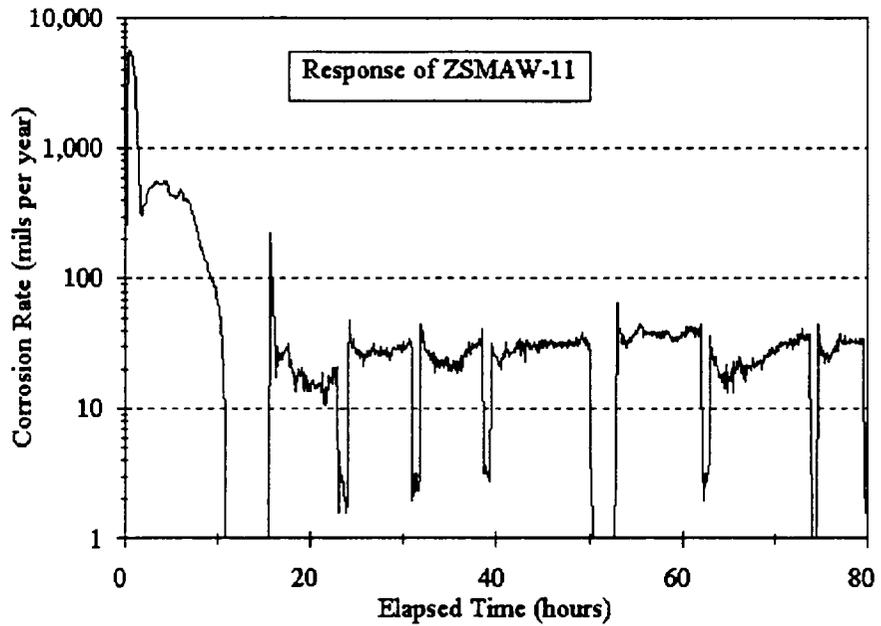


Figure 4
Typical Galvanic Corrosion Response During Fe W-1

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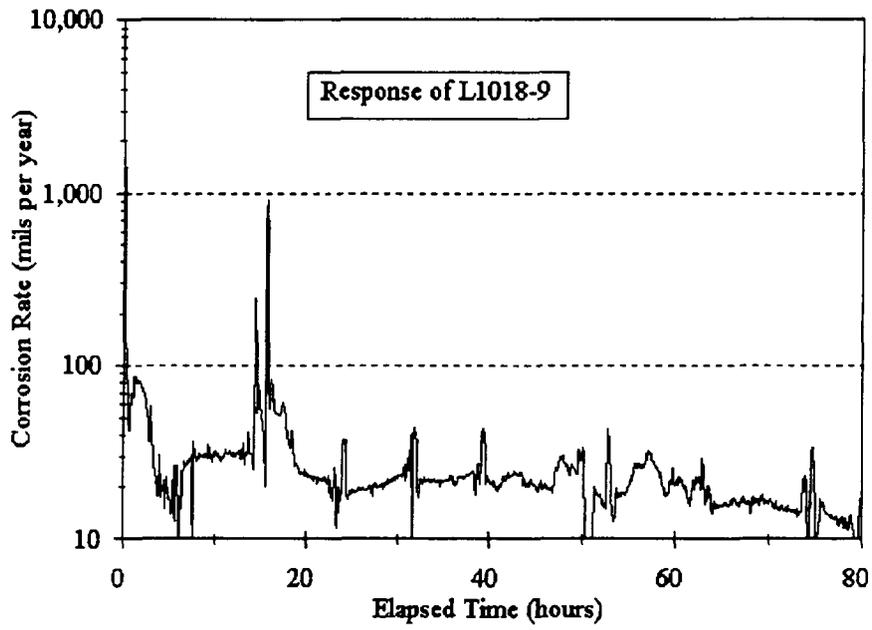


Figure 5
Typical Free Corrosion Response During Fe W-1

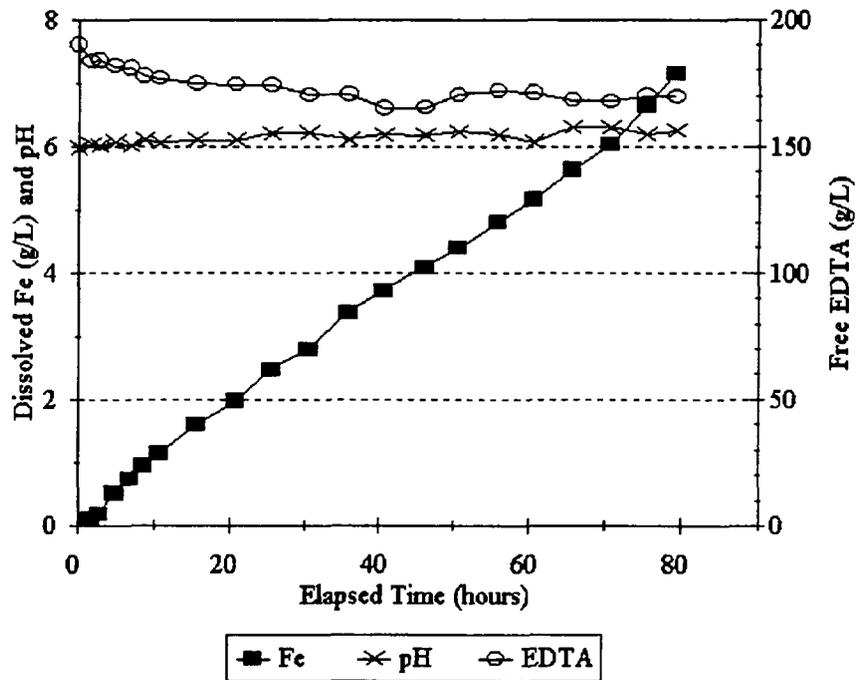


Figure 6
Chemical Parameters During Cre W-1

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