PUBLIC WORKS TECHNICAL BULLETIN 420-49-34
15 June 2001

MAGNETIC WATER TREATMENT

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DEPARTMENT OF THE ARMY
U.S. Army Corps of Engineers
441 G Street, NW
Washington, DC 20314-1000

CEMP-R

Public Works Technical Bulletin 15 June 2001
No. 420-49-34

FACILITIES ENGINEERING
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MAGNETIC WATER TREATMENT

1. Purpose. The purpose of this Public Works Technical Bulletin (PWTB) is to transmit information on a demonstration of magnetic and electronic devices marketed as effective alternatives for scale prevention in water systems.

2. Applicability. This PWTB applies to all U.S. Army Public Works activities involving the use of water systems.

3. References.

a. AR 420-49-02, Facilities Engineering Utility Services, 28 May 1997.

b. TM 5-660, Maintenance and Operation of Water Supply, Treatment, and Distribution Systems, Mar 1997.

4. Discussion.

a. There is a long history of controversy regarding the effectiveness of magnetic water treatment for preventing scale in water systems. Magnetic "treatment" consists of passing potentially scaling water through a magnetic field. Promoters of magnetic devices claim that this simple operation provides a scale-control method, even for water having a high tendency for scaling. It is also often claimed that magnetic exposure can inhibit corrosion.

b. The attached document provides an evaluation of current magnetic water treatment technology. Scientific literature is reviewed and summarized and several devices are tested for scale prevention. In summary the magnetic water treatment devices were not effective for scale control.

c. Although the devices were not effective, it is still very important that Army public works personnel use this information to avoid unnecessary expenditure of manpower and funds to purchase and install these devices.

5. Point of Contact. Questions and/or comments regarding this subject should be directed to the technical POC:

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DEMONSTRATION AND EVALUATION OF MAGNETIC DESCALERS

June 2000

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DEMONSTRATION AND EVALUATION OF MAGNETIC DESCALERS

1 INTRODUCTION

Background

Mineral scale formation in water distribution piping impedes flow, resulting in pressure and volume reduction and increasing operational costs. Chemical cleaning is both costly and time consuming and there are health concerns when chemically cleaning potable water systems. Alternatives to chemicals or ion exchange equipment (cation exchange units operated in the sodium cycle are more commonly referred to as water softeners), that are used to prevent scale formation, have been developed. These alternatives purport to use electric or magnetic fields to change chemical or physical conditions in the water in such a way as to perform one or all of the following functions: prevent mineral scale buildup, remove existing scale, inhibit corrosion, and control algae and bacteria.

Magnetic/electrostatic devices have generated conflicting opinions on their effectiveness. In 1984, USA CERL was commissioned to evaluate magnetic devices. Technical Report M-342, published that year, concluded that the magnetic devices tested were unable to control corrosion and/or mineral scale formation in both heating and cooling applications. Again, in 1996, USA CERL evaluated literature supplied by one magnetic treatment device, and found no compelling technical evidence to support the company=s claims. However, some literature sources have reported some positive effects of magnetic fields in laboratory experiments. In light of this activity, the Department of Energy Federal Energy Management Program has issued a publication that supports the need for unbiased evaluation of current commercial magnetic and electrostatic water treatment devices. A similar study was conducted at Tyndall AFB in Florida, but the results were insufficient to evaluate the performance of such devices.

Objective

The objective of this work is to conduct a field test of magnetic descaler performance. The results will be used to evaluate whether or not the specific devices tested were effective in preventing mineral scale formation in this study.

2 LITERATURE SEARCH

Prior to initiation of the test of the magnetic/electrostatic water treatment devices, a complete literature search was done to identify key test parameters and operational constraints. The results of the literature search[1-96] are listed in Appendix B of this document. The authors

have identified a total of more than 96 references. We have also provided a list (Table 1) of all of the devices for which we have procured product literature over the years. The table also provides a reference to the principle of operation proposed by the manufacturer.

Table 1
Selected Magnetic Water Treatment Devices

Product Name	Principle of Operation	Product Name	Principle of Operation
Natural Energizer	Pyramid Power	Softy	'Electronic Softener'
Nokem	Electromotive Force	SOLA	Catalytic
Paracat Water Stabilizer	Catalytic	Solavite	Catalytic
Petro-Mag	Magnetic	Sonic	Magnetic
Phillips	Electrostatic	Stain-Out	Magnetic
Power Management	Electrostatic	Sullectron	Electronic
Pow-R-Cell	'Flux Force Field'	Superior	Magnetic
Progressive Electronic Water Treater	Electronic	Tarnpure	Silver Ion Release
SALMO Scale Inhibitor	Electronic	TPT Chelator	Softener
Scale Control Systems	Electrostatic	Transfer Rods	Electrostatic Grounding
Scalegon	Electronic	Turbomag	Electromagnetic
Scalemaster	Ultrasonic-Electrostatic	Ultrastat	Electrostatic
Scalewatcher	Electronic	Wateco	Electrostatic
Sentry EMTU	Electromagnetic	Water Energizer	'Resonance Energy Wave'
SFS Scale Free Systems	Electrolytic Grounding	Water Stabilizer	Catalytic
Softron	Magnetic	Worthington	Electrostatic

There are many types of nonchemical water treatment devices which are widely accepted within the engineering community for being predictably effective[90] in a given application and set of operating conditions. These devices include technologies such as filters, separators, deaerators, reverse osmosis, cathodic protection and electro-dialysis among others. These devices all perform in a predictable and reliable fashion under a given set of conditions. The principles on which they operate are well understood and can be easily explained, and their performance under a given set of circumstances can be accurately gauged before they are selected for a specific application. However, the same cannot be said about catalytic, electrostatic, electrolytic, electronic and magnetic water treatment devices. There is a great deal of controversy concerning their effectiveness, and the explanation for how they actually work changes with time and between different manufacturers of the same type of device.

Respected and recognized leaders in both the scientific and consulting engineering community have long expressed a great deal of skepticism regarding the claims of devices such as those listed in Table 1. Herbert H. Uhlig, longtime chairman of the highly respected Corrosion Laboratory in the Department of Metallurgy at the Massachusetts Institute of Technology, was one of the first members of the scientific community to address the issue. He wrote several editorial style papers[1,2] in the 1950's which dismissed these devices for being based on unscientific principles. This trend continues to the present day, and has more recently been echoed by respected consulting engineers[9,10,17] who have encountered field installations of these devices. Authors of books on corrosion engineering[6] and corrosion control[32,61] consistently admonish consumers to regard any of these products with extreme caution.

There have been numerous papers published based on actual field trials and laboratory tests of various devices which purport to operate based on magnetic, electrolytic, electrostatic, catalytic, and other principles which find little or no positive effects for these units under controlled conditions. The first such device to generate widespread discussion was the EVIS unit, which claimed to operate on Acatalytic@ principles. This product was marketed in the 1950's, and generated a great deal of publicity and ultimately the withdrawal of the device from the market. The device advertised that it catalyzed the Acolloidal activity@ of water to prevent scale and corrosion. Some pamphlets distributed by the company even claimed that EVIS-ized water promoted enhanced plant growth. The notoriety of this case generated considerable interest and research[3,5] which largely discredited the performance claims of the manufacturer. Since that time, numerous studies[4,8,9,27] conducted by consulting engineering firms and government research institutions involving field trials of electrostatic and magnetic devices have disputed the manufacturers performance claims. There have also been several laboratory studies[27,31,33] which report little or no positive impacts on the control of scale and corrosion by magnetic devices. Katz has done a number of studies[45,46,60,66] to determine if magnetic fields may effect iron particles in solution that could act as nucleation sites for calcite formation. However, he has found no positive effect of magnet water treatment devices on this process. Coetzze[75] has hypothesized in one study that it was actually the dissolution of zinc from a device that produced the positive effect attributed to the magnetic field. Some states[72] and Canadian provinces have either banned the sale of some devices entirely or issued consumer alerts stating the devices do not work.

However, many people remain convinced that these devices do work. During the last several years, there have been numerous articles relating laboratory and field studies supporting the efficacy of these devices for mineral scale control, and most of these propose some theory which explains the performance of the unit in question. While several field studies[7,11,14,25,29] have been reported in the literature, probably the one most cited is the paper by Grutsch and McClintock[25] of Amoco Oil Company. However, it should be noted that the use of magnetic water treatment devices at Amoco facilities was stopped soon after that paper was presented, and the company has effectively distanced themselves from the results indicated in the paper. There have been several studies[15,26,28,62,78,79] published by university professors or other researchers, which have supported the claims of magnetic or electronic units.

There obviously remains a great deal of disagreement over the effectiveness of magnetic, electrostatic, electrolytic, and electronic water treatment devices. This study cannot hope to resolve that debate, but it can determine the effectiveness of specific devices in controlling mineral scale formation under operating conditions typical of hot water distribution systems in institutional systems.

3 EVALUATION TEST PROCEDURE

Two magnetic (Descal-A-Matic and Aqua Magnetic) and one electronic device (Ener Tec) were each tested against a control at the Rock Island Arsenal Steam Plant using Rock Island Arsenal Water Treatment Plant (WTP) supply. Descal-A-Matic claims to work by Aimparting to the water and salt molecules additional magnetic energy, establishing a single magnetic field direction, upsetting the harmony of crystallization and breaking the intramolecular cohesion.@ Aqua Magnetics does not claim to fully understand the mechanism, but postulates the scale reduction may be brought about by molecules being Apolarized@ in such a way that they do not react in solution. Ener Tec literature states that it is a Linear Kinetic Cell that Acauses the net charge on the charge particle to be increased... increasing the physiosorption, adsorption rate, and strength of bond.@ The magnetically-treated or electronically-treated potable water was heated to approximately 140 degrees Fahrenheit. The heat was supplied by a small steam shell and tube heat exchanger using available base steam supply at the heating plant. Corrosion was measured using test coupons that were placed at the beginning of the loop, before each of the three descaling devices, and after heating to 140 degrees Fahrenheit. Each heat exchanger contained a treated heat exchanger tube and a control, non-treated heat exchanger tube. The test heat exchangers were designed to be easily disassembled for evaluation of scale formation upon completion of the study. The test was conducted for sixty days.

The test apparatus (Figure C1) was constructed on-site at CERL facilities in Champaign, and transported to the Rock Island Arsenal Steam Plant for final installation and balancing prior to the test. For ease of transport and installation, the test apparatus was constructed on a single piece of plywood. Potable water lines were :@ CPVC pipe and fittings, and steam/condensate lines were mild steel. The copper tube used for the heat exchanger tubes was 5/8". The steam lines, valves, the steam trap, and condensate line were 2@, and the steam connections to the heat exchangers were 3/8". Globe valves were installed in the steam line before each heat exchanger were used for modulating steam flow to regulate temperature. There was a temperature gauge in the incoming potable water and on both the test and control lines of each of the three heat exchangers. Each water line was controlled by an individual CPVC globe valve to regulate water flow at 2 GPM as measured by the in-line flowmeters. These flowmeters and globe valves were located downstream from the heat exchangers. A pressure gauge was installed in the steam supply line. The steam pressure varied from a low of 106 psig to a high of 128 psig, but was usually between 118 and 126. The condensate and hot water effluent were routed to waste for the duration of the study. There was a floor drain directly behind the test apparatus that was used for this purpose. Photographs of the actual test apparatus construction can be found in Figures C2-C6.

The Rock Island Arsenal Water Treatment Plant supplies lime softened Mississippi River water for the base supply. While there were small variances in water quality, the overall quality was very consistent for the duration of the test (Table 2) with the exception of temperature. Each individual heat exchanger was controlled to try to maintain the same potable water flow rate (2 gpm) and temperature (140EF) throughout the test procedure. Scale formation during the test did not allow us to maintain the desired temperature. However, the device and control tubes for each individual heat exchanger were maintained at the same flow rate and with the maximum steam flow to attempt to achieve the desired temperature. The operating information was recorded upon a daily log sheet (Table A1, see appendix A) supplied to the water plant operators that monitored the test apparatus and made any necessary adjustments. There was one change in operating procedures during the study. The Rock Island Arsenal Water Treatment Plant only produces and pumps water from 8:00 AM until 4:00 PM daily. The system pressure is supplied by the overhead storage tank during the evening and overnight. Since there is change in pressure at this time, we originally instituted a shutdown of the steam supply to the test apparatus from 4:00 PM until 6:00 PM daily to allow the pressure to stabilize and prevent overheating the loop. We noted that scale flakes could be seen upon start-up, and decided a better course of action would be to simply increase flow for those two hours rather starting and stopping the steam supply. This reduced the thermal shock to the system.

During the course of the study, potable water samples were collected before entering the test apparatus, and after it left each of the three heat exchanger assemblies (both treated and control tubes). Upon completion of the test, visual inspection was made of each heat exchanger and test coupon. Photographs (Figures C7- C12) were taken to detail the results. Mineral scale that formed was removed, weighed and analyzed. Analysis was conducted on a digested sample by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES) to detect metal components, and by X-ray Diffraction to identify the crystalline structure of the deposit. This was of particular interest for analysis of the calcium salts precipitated, since many magnetic device manufacturers claim formation of aragonite instead of calcite as a key to their effectiveness in reducing scale formation on heat exchange surfaces. Aragonite and calcite are different crystalline forms of the same chemical compound, calcium carbonate ($CaCO_3$).

The ICP-AES analysis Aconsists of a flowing stream of gas ionized by an applied radio frequency field typically oscillating at 27.1 MHz. This field is inductively coupled to the ionized gas by a water-cooled coil surrounding a quartz "torch" that supports and confines the plasma. A sample aerosol is generated in an appropriate nebulizer and spray chamber and is carried into the plasma through an injector tube located within the torch. The sample aerosol is injected directly into the ICP, subjecting the constituent atoms to temperatures of about 6000 to 8000 K. Because this results in almost complete dissociation of the molecules, significant reduction in chemical interferences is achieved. The high temperature of the plasma excites atomic emission efficiently. Ionization of a high percentage of atoms produces ionic emission spectra. The ICP provides an optically "thin" source that is not subject to self-absorption except at very high concentrations. Thus linear dynamic ranges of four to six orders of magnitude are observed for many elements."[97]

Table 2
Rock Island Arsenal Cold Distribution

Cold Distribution							
Date	**09/03/99**	**09/09/99**	**09/22/99**	**10/01/99**	**10/08/99**	**10/15/99**	**11/02/99**
M Alkalinity (as $CaCO_3$)	**138**	**134**	**140**	**136**	**144**	**142**	**148**
Hardness (as $CaCO_3$)	**206.7**	**207.8**	**220.1**	**213.6**	**224.2**	**220.9**	**210.0**
Calcium (as Ca)	**54.80**	**55.10**	**56.20**	**53.80**	**57.50**	**56.20**	**50.20**
Magnesium (as Mg)	**16.20**	**16.30**	**18.50**	**18.40**	**18.70**	**18.70**	**17.60**
Sulfate (as SO_4)	**55**	**57**	**52**	**48**	**50**	**55**	**46**
Chloride (as C1)	**25**	**24**	**35**	**31**	**32**	**26**	**25**
Nitrate (as NO_3)	**7.3**	**6.7**	**6.5**	**6.3**	**6.2**	**6.1**	**6.0**
Iron (as Fe)	**0.01**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.03**
Copper (as Cu)	**0.00**	**0.00**	**0.03**	**0.01**	**0.00**	**0.00**	**0.00**
Zinc (as Zn)	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**	**0.00**
Sodium (as Na)	**10.0**	**10.3**	**10.7**	**10.7**	**11.3**	**10.9**	**12.0**
Manganese (Mn)	**0.007**	**0.004**	**0.006**	**0.005**	**0.006**	**0.005**	**0.008**
Total Dissolved Solids	**272**	**276**	**313**	**270**	**265**	**282**	**258**
pH	**7.61**	**7.69**	**7.64**	**7.71**	**7.72**	**7.86**	**7.71**
Temperature (EC)	**27.0**	**27.2**	**22.1**	**20.6**	**17.7**	**17.7**	**15.1**
Silica (as SiO_2)	**9.6**	**9.3**	**9.2**	**7.3**	**7.7**	**7.8**	**7.1**
Ammonia (as NH_4)	**3.9**	**4.0**	**8.1**	**6.8**	**4.6**	**4.0**	**2.3**
Conductivity (ΦS/cm)	**453**	**459**	**505**	**517**	**544**	**476**	**472**

Results are mg/L except for conductivity, pH, and temperature.
No significant amount of phosphate was found in any of the samples.

The actual heat exchanger tubes were made of copper tube (: inch O.D. ∈ I.D.) cut into 30 inch sections. The weight of the tube sections ranged from 380.96 to 382.62 grams. The tube was then placed in the heat exchanger, using compression fittings to provide a seal. After the testing was concluded, the ends of the tube were cut and the tube was removed from the heat exchanger. To prevent the loss of loose scale, the ends of the tube were sealed with duct tape. The immediate following section of the assembly, from the end of the tubes through the flow meter was also collected and sealed. The heat exchanger body was 25" long with 1"extensions on both ends for compression fittings. Each of the heat exchanger tubes was cut into five sections (Figure C12) for evaluation. The first and last sections included a segment of tube that was protruding from the heat exchanger. The end sections of tube were 4-6.5" in length. The middle three sections were all exactly 6" in length. The original intent was to try to determine if the amount of scale was significantly different in the various portions of the heat exchanger tubes. However, the scale that formed was of the Aeggshell@ type that is very brittle, and spalls with stress. This made evaluation of the individual sections impractical. However, segmenting the tubes did make the step of mechanical removal much easier. Scale that came loose from the

tube before it was cut into sections was collected. Each tube section was tapped with a hammer and scraped to remove loose scale, which was collected individually. Loose scale from the section after the heat exchanger was also collected. The restricted opening to the flow meter trapped some of the scale, when it broke off the copper tube. The collected scale was air dried and weighed. Only scale from the middle three sections of tube was used for X-Ray Diffraction analysis, since it was judged deposits in those sections would be the most consistent in thickness and type. Scale from the middle three sections of tube for each heat exchanger was placed in a tungsten carbide container and mixed in a SPEX 8000 powder mill for 20 minutes. The resulting powder was mounted using methanol in a cavity slide. The diffraction pattern was obtained using a Rigaku Rotaflex RU 200B X-ray Diffractometer with a rotating copper anode run at 35kV and 50mA. The resulting diffraction pattern was identified using Jade 3.1 software and the International Center for Diffractometry Data database on CD-ROM.

Not all the scale could be removed mechanically, therefore chemical methods were employed. Hydrochloric (HCl) and nitric (HNO_3) acid were used to remove the remaining scale. A section of tube was placed in a 4000 ml beaker containing about 500 ml deionized water and 20 ml concentrated HNO_3 and 50 ml concentrated HCl. Gas was released as the scale dissolved. Depending on how much scale was present, the reaction lasted from a few seconds to several minutes. When the reaction stopped, the tube was removed, rinsed with deionized water into the beaker and placed on a paper towel. This procedure was employed with the remaining 4 sections of tube from that heat exchanger. An additional aliquot of both acids were added to the beaker. The process was repeated, to ensure that all scale was removed. The contents of the beaker was diluted to 2 liters using a Class A volumetric flask, resulting in a final acid concentration of approximately 5% HCl and 2% HNO_3. This was then diluted 1:10 for ICP analysis. This entire procedure was repeated with the remaining five groups of tube sections. The concentration of calcium and magnesium found by ICP was converted to calcium carbonate. The concentration (in mg/L) was multiplied by two since the final volume of the solution was two liters, and the total weight of scale removed was recorded.

While the primary purpose of this study was to determine the effectiveness of the three devices in controlling calcium hardness scale formation, the decision was to made to monitor the corrosion rate as well to determine if there was a measurable effect by the devices. Since copper tube was used for the heat exchangers, only copper coupons were employed in this study. The copper coupon analysis was processed using ASTM D2688-90, Method B.

The authors provided each of the device manufacturers with a copy of the test plan before the study started, and implemented as many of their suggested changes as possible. The final test plan is found in Appendix D of this report. This study was not designed to test the validity of the theory of operation for any of the devices, merely to test them in as close to a “real world” environment as possible while still providing some control of the operating environment.

4 TEST RESULTS

The corrosion coupon results are detailed in Table A8, and showed no significant impact on the corrosion rate. The control and device coupons all had approximately 0.03 gm of metal loss. Photographs of the coupons after removal from the test apparatus, and after cleaning, are shown in Figures C8 and C9. There is no indication of either an increase or decrease in the corrosion rates of the coupons in the magnetic and electronic devices versus the control loops. The corrosion rate, calculated as mmpy (millimeters penetration per year) for the coupons was 0.32 to 0.43 in the heat exchangers and 0.45 for the cold potable water.

The water samples that were analyzed (Tables A2-A7) showed very little difference in measurable water quality parameters for either the device or the control versus the cold potable water used as a supply. The manufacturers of magnetic devices do not claim any measurable change in water quality as a result of using their device, but these tests were done to confirm the consistency of the water supply and confirm that no change was taking place.

Flakes of scale were visible in the flow meters (Figure C11) during the course of the test. This material was collected and totaled with the other scale in Table A9. Since this is material that was formed in the heat exchangers, we have considered it in our evaluation of the results. The Descal-A-Matic device (1M) had 3.8% less scale than the control (1C), which is well within the expected experimental error for this type of test. The ΔT, or temperature change (Figure C13) through the two tubes was virtually identical for most of the test period, a further indication that the amount of difference in scale accumulation was insignificant relative to the efficiency of the heat exchange taking place. The Aqua Magnetic device (2M) had 3.3% less scale than its control (2C), which was also deemed to be statistically insignificant. The ΔT curve (Figure C14) for Heat Exchanger 2 also indicates the performance for the device and the control were very similar. The Ener Tec device (3M) had 13.9% less scale than its control (3C). Figure C15 shows that the ΔT for both the device and the control were very similar until 10/25/99. This coincides with the shutdown of the loop for the replacement of a leaking section in the CPVC water side loop. Steam and water were shut off and the system was brought back on line after repairs were completed. We suspect that this caused some spalling of the scale to occur and accounts for the difference in ΔT after that point. The temperature exiting the heat exchanger with Ener Tec device was still well below the original operating temperature of 140EF, with the temperature averaging about 115EF.

The resulting XRD patterns were almost identical. Figure C16 shows all six of the patterns on the same page to make the comparison of the individual patterns easier. The fact that they are all basically the same material is obvious from this comparison. This is further reinforced in Figure C17 where all six patterns were overlayed on the same plot. This clearly shows the relative peak height and spacing is nearly identical for all six samples. Individual plots for all six samples are shown in Figures C18-C23. Evaluation of the samples indicated that all six samples were primarily a form of calcite. The XRD scans for the six samples have the reference peaks for this compound added (vertical lines) for easy reference. The peak spacing and intensity indicate an excellent match. Many magnetic device manufacturers assert that their products change the preferential form of calcium carbonate from calcite to aragonite. This was clearly not the case in this study, and to further illustrate this Figure C24 shows one of the samples with the reference peaks for aragonite. The peak spacing is radically different from any

of the samples, and the compound is clearly not aragonite. The particular type of calcite found was a magnesian calcite. Figure C25 contains the ICDD reference data for this compound, PDF#43-0697. The reference sample for PDF#43-0697 had a ratio of 86.1 CaO to 13.6 MgO. This is very similar to the data obtained from the ICP analysis of the material removed from the heat exchanger tubes. This data is presented in Table A10.

5 CONCLUSIONS

The results of this study do not indicate any clear advantage for any of the three devices tested versus a control for the inhibition of mineral scale formation or the corrosion of copper. The test protocol was designed to simulate the method of production of hot water used in many larger institutional type settings that employ a shell and tube heat exchanger for the production of hot water. The findings do not support the claims of the manufacturers regarding the ability of their respective devices prevent mineral scale formation in hot potable water systems. The amount of mineral scale formed for the control versus device heat exchange tubes was relatively constant, and proved to be an effective insulator of heat transfer across the tube surface. The scale formed was found to be a type of calcite (calcium carbonate), and had the same crystalline structure for each heat exchange tube. There was no discernible effect on the crystalline structure of the scale formed by any of the tested devices.

APPENDIX A

TEST RESULTS DATA

Table A1
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
09/01/99 3:00 p.m.	78	0.6	80	124	126	2.0	2.0	122	122	2.0	2.0	125	125	2.0	2.0
09/01/99 6:00 p.m.				Two lines to Heat Ext. broke											
09/02/99 3:45 p.m.	78	0.6	98	137	138	2.0	1.9	143	142	1.8	1.8	150	156	1.8	1.8
09/03/99 4:30 p.m.	78	0.6	112	146	150	1.9	1.8	154	150	1.8	1.9	140	148	2.0	1.9
09/04/99 3:00 a.m.	78	0.6	118	130	128	2.1	1.8	131	131	1.9	2.0	130	133	1.8	2.0
09/04/99 10:30 a.m.	78	0.6	112	120	120	2.0	2.0	125	125	2.0	2.0	124	125	2.0	2.0
09/04/99 4:40 p.m.	79	0.6	119	160	158	1.8	1.2	130	132	1.9	1.9	130	136	1.8	1.8
09/05/99 3:00 a.m.	79	0.6	123	127	126	1.7	2.2	125	126	1.9	1.9	140	120	1.7	2.2
09/05/99 12:00 p.m.	79	0.6	122	120	124	1.8	2.5	122	122	2.0	2.0	135	116	2.0	2.0
09/05/99 7:30 p.m.	79	0.5	124	118	127	2.0	2.0	125	127	1.8	1.8	139	118	2.0	2.5

Note: 09/03/99 to 09/12/99 - Shutdown from approximately 4-6pm due to reduction in water pressure.

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
09/05/99 1:30 a.m.	78	0.6	117	116	124	1.9	1.7	120	122	1.9	1.8	138	122	2.0	1.9
09/06/99 9:30 a.m.	79	0.6	120	120	120	1.9	1.8	120	120	1.9	1.8	135	128	2.0	1.1
09/06/99 7:00 p.m.	78	0.6	122	124	122	1.8	1.8	124	122	1.5	1.5	132	120	2.0	2.0
09/07/99 1:30 a.m.	77	0.6	120	114	116	2.0	2.0	120	120	2.0	2.0	138	124	2.0	2.0
09/07/99 1:00 p.m.	79	0.6	118	126	136	2.0	2.0	122	122	2.0	2.0	130	120	2.0	2.0
09/07/99 8:30 p.m.	78	0.6	118	126	134	2.0	1.5	124	124	1.8	1.8	132	118	2.0	3.0
09/08/99 3:00 a.m.	78	0.6	123	123	122	2.1	2.3	123	120	1.9	2.1	134	120	2.0	2.5
09/08/99 12:00 p.m.	79	0.6	120	120	125	2.2	2.0	120	120	1.8	1.8	135	135	2.0	1.5
09/08/99 7:00 p.m.	78	0.6	118	127	125	2.0	2.0	120	120	1.8	2.0	140	120	1.8	2.0
09/09/99 3:00 a.m.	78	0.6	124	126	125	2.0	1.9	121	119	1.9	2.0	131	122	1.9	2.0

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
09/09/99 10:00 a.m.	78	0.6	120	120	120	2.0	2.0	116	116	2.0	2.0	135	122	2.0	2.0
09/09/99* 11:45 a.m.	78	0.6	119	122	120	2.0	2.0	116	117	2.0	2.0	134	120	2.0	2.7
09/09/99 3:00 p.m.	78	0.6	106	143	134	2.0	2.0	136	143	2.0	2.0	140	148	2.0	2.0
09/09/99 5:30 p.m.	78	0.6	106	134	126	2.8	2.6	144	122	2.0	2.6	126	140	2.5	2.3
09/10/99 3:00 a.m.	78	0.6	108	125	126	2.7	2.6	144	121	1.7	2.4	124	139	2.3	2.1
09/10/99 12:30 p.m.	78	0.5	110	132	130	2.4	2.1	126	138	2.0	2.2	121	133	2.4	2.2
09/10/99 5:30 p.m.	77	0.6	117	132	130	2.3	2.0	138	125	2.1	2.0	124	135	2.1	2.1
09/11/99 3:00 a.m.	77	0.6	116	131	129	2.2	2.0	136	123	2.2	2.1	122	133	2.2	2.1
09/11/99 11:00 a.m.	78	0.5	104	126	122	2.5	2.5	120	131	2.2	2.5	116	130	3.0	2.3
09/11/99 7:00 p.m.	77	0.5	112	127	124	2.1	2.3	122	136	2.0	2.3	120	135	2.8	2.0

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
09/12/99 3:00 a.m.	77	0.6	112	126	124	2.1	2.3	138	130	2.2	1.7	119	134	2.9	2.1
09/12/99 11:00 a.m.	77	0.5	118	128	127	2.0	2.0	122	136	2.0	2.0	121	136	2.0	2.0
09/12/99 7:00 p.m.	77	0.5	118	132	130	2.0	2.0	120	130	2.0	2.0	122	138	2.0	2.0
System down for repairs															
09/20/99 7:00 p.m.	73	0.6	118	116	114	1.5	1.5	120	119	1.4	1.3	123	122	1.2	1.2
09/21/99 3:00 a.m.	72	0.6	120	114	114	2.0	2.0	112	114	2.0	2.0	116	114	2.0	2.0
09/21/99	71	0.5	122	115	116	1.5	1.5	115	114	1.7	1.7	120	122	1.5	1.5
Coupling Broke 6Repairs made, water turned on 09/22/99 1:30 am															
09/22/99* 3:00 a.m.	70	0.6	113	125	125	2.0	2.0	116	136	2.0	2.0	124	128	2.0	2.0
09/22/99 3:45 a.m.	70	0.6	113	126	124	2.0	2.1	112	134	2.3	1.9	124	160	2.0	1.0
09/22/99 7:00 p.m.	72	0.6	113	112	112	2.0	2.0	106	106	2.0	2.0	106	110	2.0	2.0
09/23/99 3:00 a.m.	71	0.6	114	110	112	2.1	2.2	115	114	2.0	2.1	114	115	2.0	2.0

*Water Samples collected

*Water samples collected

Table A1 (continued)
Daily Operation Log Sheet

Note: 09/20/99 -Flow increased to –3 GPM at 4 p.m., then readjust to 2 GPM after water pressure is stable –6 p.m.

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
09/23/99 11:00 p.m.	70	.06	118	110	111	2.2	2.2	111	114	2.1	2.2	111	112	2.0	2.2
09/23/99 5:30 p.m.	70	.06	118	112	113	2.0	2.0	113	116	2.2	1.6	111	114	2.0	1.9
09/27/99 2:15 p.m.	70	.05	119	110	112	2.1	2.0	111	114	2.1	2.0	108	110	2.0	2.0
09/27/99 7:00 p.m.	71	.05	120	115	120	1.8	1.8	116	119	1.8	1.6	117	118	1.5	1.6
09/28/99 2:30 a.m.	70	.05	122	112	112	2.1	2.1	116	114	1.9	1.7	100	108	1.7	2.0
09/28/99 11:00 a.m.	69	.05	120	106	108	2.2	2.2	112	110	2.0	2.5	107	110	2.1	2.0
09/28/99 7:00 p.m.	71	.06	122	109	110	2.0	2.1	114	112	1.8	1.6	112	113	1.8	2.0
09/29/99 3:00 a.m.	70	.06	120	108	109	2.1	2.2	108	110	3.0	2.1	106	108	2.0	2.2
09/29/99 11:00 a.m.	68	.05	120	105	109	2.1	1.9	110	108	2.5	2.1	110	114	1.7	2.0
09/29/99 7:00 p.m.	70	.06	123	108	111	2.0	2.1	110	112	2.2	2.0	112	116	1.8	1.6

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
09/30/99 3:00 a.m.	70	.06	120	106	108	2.0	2.1	110	111	2.0	2.0	108	110	2.0	2.0
09/30/99 11:00 a.m.	68	0.6	126	111	112	1.8	1.8	112	113	1.9	1.8	114	115	1.9	1.9
09/30/99 7:00 p.m.	70	0.6	122	110	113	1.9	1.9	114	116	1.8	1.8	108	114	2.1	1.9
10/01/99 2:00 a.m.	70	0.6	124	110	112	1.9	1.9	115	116	1.7	1.8	108	114	2.0	1.9
10/01/99* 12:45 p.m.	68	0.6	123	102	106	2.0	2.0	106	106	2.0	2.0	106	108	2.0	2.0
10/01/99 1:10 p.m.	67	0.6	118	96	98	3.0	3.0	98	99	3.0	3.0	98	101	3.0	3.0
10/01/99 1:30 p.m.	68	0.6	122	103	106	2.0	2.0	106	107	2.0	2.0	106	106	2.0	2.0
10/01/99 7:00 p.m.	70	0.6	122	108	110	1.9	1.9	114	115	1.7	1.8	108	114	1.9	1.9
10/05/99 11:00 a.m.	66	0.5	127	110	110	2.0	2.1	110	112	3.0	2.1	109	108	1.9	2.1
10/05/99 7:00 p.m.	67	0.6	122	114	112	2.2	2.1	116	118	1.8	1.2	114	114	1.7	1.9

*Water samples collected
Flow increased to –3 GPM at 4 p.m., then readjust to 2 GPM after water pressure is stable –6 p.m.

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/06/99 3:00 a.m.	66	0.6	118	104	118	2.2	2.2	110	104	2.0	2.1	107	109	1.9	2.0
10/06/99 11:00 a.m.	64	0.5	120	98	102	2.2	2.2	104	105	2.0	2.0	104	106	2.0	2.1
10/06/99 7:00 p.m.	66	0.6	122	100	106	2.1	2.0	112	106	2.0	2.0	107	108	2.0	2.0
10/07/99 12:00 p.m.	63	0.6	121	96	103	2.5	2.3	114	102	2.2	2.1	104	102	2.0	2.1
10/07/99 7:00 p.m.	63	0.6	121	104	108	2.0	2.1	116	108	2.2	1.9	110	110	1.9	1.8
10/08/99 3:00 a.m.	63	0.6	124	102	106	2.0	2.0	112	107	1.8	1.9	109	108	1.8	1.7
10/08/99* 12:00 p.m.	62	0.6	122	101	106	2.0	2.0	102	108	2.0	2.0	102	102	2.0	2.0
10/08/99 12:40 p.m.	62	0.6	122	102	108	2.0	2.0	101	107	2.0	2.0	102	102	2.0	2.0
10/08/99 12:50 p.m.	62	0.6	114	94	98	3.0	3.0	92	95	3.0	3.0	94	93	3.0	3.0
10/08/99 1:00 p.m.	62	0.6	121	106	110	2.0	2.0	102	106	2.0	2.0	102	100	2.0	2.0

*Water samples collected

Flow increased to –3 GPM at 4 p.m., then readjust to 2 GPM after water pressure is stable –6 p.m.

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/08/99 7:00 p.m.	63	0.6	122	112	114	1.8	1.9	114	110	1.9	1.8	106	104	1.9	1.9
10/09/99 3:00 a.m.	66	0.6	122	114	114	1.7	1.8	114	108	1.9	1.8	105	104	1.9	1.9
10/09/99 11:00 a.m.	64	0.6	122	108	110	1.8	2.0	100	110	2.0	1.9	100	100	2.0	2.0
10/09/99 7:00 p.m.	63	0.6	224	114	116	1.5	1.9	120	108	1.2	1.8	106	104	1.9	1.9
10/10/99 3:00 a.m.	63	0.6	123	108	112	1.5	1.9	114	102	2.0	1.9	104	102	2.1	2.0
10/10/99 11:00 a.m.	63	0.6	124	106	110	1.5	2.0	110	100	2.0	1.8	100	100	2.0	2.0
10/10/99 7:00 p.m.	63	0.6	126	114	117	1.3	2.0	120	106	1.4	1.6	106	104	2.0	2.0
10/11/99 3:00 a.m.	63	0.6	122	106	120	2.0	1.6	102	100	2.1	2.0	106	104	1.9	1.9
10/11/99 11:00 a.m.	63	0.6	122	100	112	2.2	2.0	112	100	2.5	2.5	100	100	2.0	2.0
10/11/99 7:00 p.m.	64	0.6	124	100	112	2.1	2.0	98	96	1.8	1.6	102	100	2.0	2.0

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag		Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/12/99 3:00 a.m.	64	0.6	121	104	110	2.0	1.9	98	98	1.9	1.8	103	101	2.0	1.9
10/12/99 11:00 a.m.	63	0.6	124	101	112	2.5	2.0	92	90	2.8	3.0	100	100	2.0	2.0
10/12/99 7:00 p.m.	63	0.6	122	108	124	1.8	1.8	94	94	2.5	2.3	108	106	1.8	1.7
10/13/99 3:00 a.m.	65	0.6	122	100	106	2.2	2.2	101	100	1.8	1.9	101	101	2.0	1.9
10/13/99 11:00 a.m.	64	0.6	122	98	103	2.5	2.5	100	104	2.1	2.0	98	98	2.1	2.0
10/13/99 7:00 p.m.	63	0.6	124	96	102	2.3	2.2	108	104	1.9	2.0	103	102	2.0	2.0
10/14/99 3:00 a.m.	64	0.6	124	101	121	2.0	2.1	103	100	2.0	2.0	101	100	2.0	2.0
10/14/99 11:00 a.m.	62	0.6	122	100	114	2.2	1.8	100	97	2.1	2.1	98	97	2.0	2.0
10/14/99 7:00 p.m.	63	0.6	124	104	108	1.9	1.9	108	106	1.9	1.9	102	102	1.9	1.9
10/15/99 3:00 a.m.	64	0.6	124	104	107	1.9	1.8	108	102	1.9	1.9	101	100	2.0	2.0
10/15/99 12:50 p.m.	64	0.6	124	100	108	2.0	2.0	100	102	2.0	2.0	100	98	2.0	2.0

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/15/99* 11:25 a.m.	64	0.6	124	102	108	2.0	2.0	101	104	2.0	2.0	100	98	2.0	2.0
10/15/99 12:20 p.m.	64	0.6	117	94	98	3.0	3.0	92	94	3.0	3.0	92	90	3.0	3.0
10/16/99 3:00 a.m.	66	0.6	126	108	114	2.0	2.0	107	102	1.8	1.9	104	102	1.8	1.8
10/16/99 11:00 a.m.	64	0.6	124	100	106	2.4	2.0	102	100	2.1	2.1	100	100	2.0	2.0
10/16/99 7:00 p.m.	63	0.6	126	100	112	2.0	2.0	108	104	1.9	1.9	104	102	1.8	1.8
10/17/99 3:00 a.m.	66	0.6	128	99	108	2.1	2.0	106	103	1.9	1.9	104	102	1.9	1.8
10/17/99 7:00 a.m.	64	0.6	124	98	104	2.3	2.0	100	102	2.0	2.0	100	100	2.0	2.0
10/17/99 7:00 p.m.	63	0.6	126	100	112	2.0	1.8	108	104	1.9	1.8	103	104	2.0	2.0
10/18/99 3:00 a.m.	62	0.6	123	96	102	2.0	2.0	100	96	2.0	2.0	100	98	1.9	1.9
10/18/99 11:00 a.m.	63	0.6	124	98	102	2.2	2.2	96	98	2.1	2.3	98	98	2.0	2.0

*Water samples collected

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/18/99 7:00 p.m.	64	0.6	126	98	104	2.0	2.0	102	100	2.0	2.1	102	100	1.8	1.9
10/19/99 3:00 a.m.	62	0.6	126	100	108	2.0	2.0	104	102	1.9	1.9	102	102	1.8	1.8
10/19/99 11:00 a.m.	63	0.6	126	98	104	2.0	2.1	98	100	2.1	2.1	98	98	1.9	1.9
10/19/99 7:00 p.m.	64	0.6	126	100	104	2.0	2.0	102	98	1.9	2.0	102	101	1.8	1.8
10/20/99 3:00 a.m.	64	0.6	126	100	110	2.0	2.0	102	100	2.0	2.0	100	98	1.9	1.9
10/20/99 11:00 a.m.	62	0.6	126	98	104	2.1	1.9	96	98	2.3	2.3	96	96	2.0	2.0
10/20/99 7:00 p.m.	64	0.6	126	100	108	2.0	1.8	102	100	2.0	2.1	100	99	2.0	1.9
10/21/99 3:00 a.m.	63	0.6	126	100	108	2.0	1.8	103	100	1.9	1.9	100	99	1.9	1.8
10/21/99 1:00 p.m.	61	0.6	125	97	102	2.0	2.0	96	100	2.0	2.0	96	95	2.0	2.0
10/21/99 5:00 p.m.	62	0.6	124	98	104	2.0	2.0	102	98	1.9	1.9	98	97	1.9	1.8

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/22/99 3:00 a.m.	61	0.6	127	96	101	2.0	2.0	100	96	1.9	2.0	97	96	2.0	1.9
10/22/99 2:00 p.m.	61	0.6	124	96	101	2.0	2.2	94	96	2.4	2.2	96	94	2.0	2.0
10/22/99 7:00 p.m.	61	0.6	128	98	108	1.9	1.8	108	100	1.7	1.9	98	96	2.0	1.9
10/23/99 3:00 a.m.	62	0.6	124	96	104	1.9	1.8	106	98	1.8	1.9	100	98	2.0	1.8
10/23/99 7:00 p.m.	Steam Off/Tube Missing														
10/25/99 11:00 a.m.	60	0.6	118	100	100	2.2	2.5	98	98	2.0	2.2	104	98	2.0	2.1
10/25/99 7:00 p.m.	62	0.6	120	104	106	2.0	2.2	104	102	1.8	2.0	118	104	2.0	2.0
10/26/99 3:00 a.m.	62	0.6	120	108	112	2.0	2.0	102	101	1.9	2.0	117	103	2.0	1.8
10/26/99 11:00 a.m.	58	0.6	120	104	104	2.0	2.2	98	96	2.0	2.2	110	100	2.3	1.9
10/26/99 7:00 p.m.	60	0.6	120	106	110	1.9	2.0	98	96	1.9	2.0	116	102	2.1	1.8

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/27/99 3:15 a.m.	62	0.6	123	110	112	1.9	1.8	100	98	2.0	1.9	118	100	2.1	2.0
10/27/99 11:00 a.m.	59	0.6	120	102	106	2.0	1.9	92	94	2.2	2.0	110	96	2.2	2.1
10/27/99 7:00 p.m.	61	0.6	120	110	114	1.8	1.5	100	98	1.9	2.0	118	100	2.0	2.0
10/28/99 3:00 a.m.	60	0.6	120	100	102	2.0	2.1	94	96	2.0	2.0	114	98	2.1	2.0
10/28/99 10:50 a.m.	56	0.6	120	98	100	2.0	2.0	92	91	2.0	2.1	116	94	2.0	2.0
10/28/99 7:00 p.m.	60	0.6	124	106	110	1.9	1.9	98	98	1.9	1.9	120	98	1.8	1.9
10/29/99 3:00 a.m.	60	0.6	124	106	108	1.9	1.8	98	98	1.9	1.9	120	98	1.8	1.9
10/29/99 11:00 a.m.	58	0.6	122	96	100	2.0	2.0	90	90	2.0	2.0	111	100	2.0	2.0
10/29/99 7:00 p.m.	60	0.6	124	98	102	2.0	2.0	96	96	1.9	1.8	114	102	1.9	2.0
10/30/99 3:00 a.m.	58	0.6	122	98	102	2.0	2.0	92	92	2.0	2.0	118	96	1.9	2.0

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
10/30/99 11:00 a.m.	58	0.6	121	98	100	2.4	2.0	90	90	2.3	2.1	117	94	1.9	2.1
10/30/99 7:00 p.m.	58	0.6	124	102	106	2.0	1.8	92	93	2.0	2.0	122	96	1.8	1.9
10/31/99 3:00 a.m.	60	0.6	124	105	110	2.0	1.8	95	95	1.9	1.9	128	98	2.0	1.9
10/31/99 11:00 a.m.	58	0.6	122	100	104	2.1	2.0	92	90	2.1	2.1	106	98	2.3	1.8
10/31/99 7:00 p.m.	60	0.6	124	118	122	1.6	1.7	104	104	1.8	1.8	122	116	2.0	1.6
11/01/99 3:00 a.m.	58	0.6	120	90	90	2.8	3.0	88	90	2.3	2.3	110	96	2.1	1.9
11/01/99 11:00 a.m.	58	0.6	122	102	104	2.0	2.0	90	92	2.0	2.0	106	94	2.4	2.0
11/01/99 7:00 p.m.	60	0.6	124	113	112	1.6	1.9	96	98	2.0	2.0	116	100	2.1	2.0
11/02/99 3:00 a.m.	62	0.6	124	92	106	3.0	2.0	96	98	1.9	1.9	120	100	1.9	1.7
11/02/99* 9:30 a.m.	58	0.6	122	103	104	2.0	2.0	92	92	2.0	2.0	112	92	2.0	2.0

*Water samples collected

Table A1 (continued)
Daily Operation Log Sheet

Date/Time	Incoming Water Temperature EF	Enertec DC Amps	Supply Steam PSIG	HE #1 Water Temp EF		HE #1 Flow Rate GPM		HE #2 Water Temp EF		HE #2 Flow Rate GPM		HE #3 Water Temp EF		HE #3 Flow Rate GPM	
				Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Mag	Ctrl	Elect	Ctrl	Elect	Ctrl
11/02/99 10:10 a.m.	58	0.6	123	102	104	2.0	2.0	92	91	2.0	2.0	112	92	2.0	2.0
11/02/99 10:25 a.m.	58	0.6	117	90	93	3.0	3.0	85	84	3.0	3.0	98	85	3.0	2.8
11/02/99 10:40 a.m.	58	0.6	124	100	104	2.0	2.0	92	92	2.0	2.0	111	91	2.0	2.0
11/02/99** 11:10 a.m.	57	0.0	0	56	59	3.0	3.0	57	57	3.0	3.0	57	58	3.0	3.0

**11/02/99 Shutdown

Table A2
09/09/99 Water Sample Analyses

09/09/99	Cold Distribution	Heat Exchanger #1		Heat Exchanger #2		Heat Exchanger #3	
		Magnetic	Control	Magnetic	Control	Electronic	Control
M Alkalinity (mg/L as $CaCO_3$)	134	138	134	136	138	138	136
Hardness (mg/L as $CaCO_3$)	207.8	206.7	207.8	208.5	210.0	206.3	211.4
Calcium (mg/L as Ca)	55.10	56.10	55.10	55.20	55.60	55.30	56.00
Magnesium (mg/L as Mg)	16.30	16.60	16.30	16.40	16.50	17.00	16.60
Sulfate (mg/L as SO_4)	57	59	58	58	57	57	59
Chloride (mg/L as C1)	24	24	25	24	23	23	22
Nitrate (mg/L as NO_3)	6.7	6.7	6.7	6.8	6.7	6.6	6.6
Iron (mg/L as Fe)	0.00	0.00	0.01	0.00	0.00	0.01	0.00
Copper (mg/L as Cu)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (mg/L as Zn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium (mg/L as Na)	10.3	10.6	10.4	10.5	10.5	10.6	10.6
Manganese (mg/L Mn)	0.004	0.006	<0.003	0.005	0.005	0.004	<0.003
Total Dissolved Solids (mg/L)	276	274	278	270	273	278	274
pH	7.69	7.66	7.66	7.64	7.76	7.63	7.72
Sample Temperature (EC)	27.2	37.1	36.4	35.6	34.3	37.7	34.1
Silica (mg/L as SiO_2)	9.3	9.4	9.2	9.3	9.3	9.3	9.3
Ammonia (mg/L as NH_4)	4.0	3.7	4.1	3.3	4.1	4.0	3.9
Conductivity (ΦS/cm)	454	457	459	457	458	454	457

Table A3
09/22/99 Water Sample Analyses

09/22/99	Cold Distribution	Heat Exchanger #1		Heat Exchanger #2		Heat Exchanger #3	
		Magnetic	Control	Magnetic	Control	Electronic	Control
M Alkalinity (mg/L as $CaCO_3$)	140	138	138	138	138	138	138
Hardness (mg/L as $CaCO_3$)	220.1	215.4	216.6	211.0	216.6	218.4	217.2
Calcium (mg/L as Ca)	56.20	54.50	54.80	55.50	54.80	55.70	55.40
Magnesium (mg/L as Mg)	18.50	18.40	18.50	18.30	18.50	18.40	18.30
Sulfate (mg/L as SO_4)	52	49	49	53	50	51	52
Chloride (mg/L as C1)	35	35	36	35	36	35	35
Nitrate (mg/L as NO_3)	6.5	6.5	6.5	6.4	6.5	6.4	6.4
Iron (mg/L as Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper (mg/L as Cu)	0.03	0.05	0.00	0.01	0.00	0.00	0.01
Zinc (mg/L as Zn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium (mg/L as Na)	10.7	9.9	9.9	10.6	10.1	10.6	10.7
Manganese (mg/L as Mn)	0.006	0.005	0.005	0.006	0.005	0.005	0.007
Total Dissolved Solids (mg/L)	313	315	325	323	312	313	317
pH	7.64	7.58	7.57	7.70	7.60	7.60	7.63
Sample Temperature (EC)	22.1	53.1	49.4	41.1	54.0	51.3	49.8
Silica (mg/L as SiO_2)	9.2	8.9	9.0	9.1	8.9	9.1	9.1
Ammonia (mg/L as NH_4)	8.1	4.9	7.7	5.0	4.8	4.6	5.7
Conductivity (ΦS/cm)	505	473	472	476	473	477	475

Table A4
10/01/99 Water Sample Analyses

10/01/99	Cold Distribution	Heat Exchanger #1		Heat Exchanger #2		Heat Exchanger #3	
		Magnetic	Control	Magnetic	Control	Electronic	Control
M Alkalinity (mg/L as $CaCO_3$)	136	136	134	140	136	134	136
Hardness (mg/L as $CaCO_3$)	213.6	209.3	212.6	211.0	211.4	214.9	210.5
Calcium (mg/L as Ca)	53.80	52.60	53.40	53.10	53.10	55.00	52.90
Magnesium (mg/L as Mg)	18.40	18.10	18.40	18.20	18.30	18.00	18.20
Sulfate (mg/L as SO_4)	48	47	46	47	48	49	48
Chloride (mg/L as C1)	31	33	33	33	30	30	32
Nitrate (mg/L as NO_3)	6.3	6.5	6.4	6.1	6.3	5.6	6.3
Iron (mg/L as Fe)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Copper (mg/L as Cu)	0.01	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (mg/L as Zn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium (mg/L as Na)	10.7	10.1	10.5	10.1	10.3	10.8	10.1
Manganese (mg/L as Mn)	0.005	0.005	0.006	0.005	0.006	0.004	0.005
Total Dissolved Solids (mg/L)	270	323	266	315	266	246	260
pH	7.71	7.68	7.73	7.79	7.74	7.74	7.74
Sample Temperature (EC)	20.6	38.5	39.5	36.9	41.1	41.4	42.4
Silica (mg/L as SiO_2)	7.3	7.2	7.4	7.3	7.3	7.7	7.3
Ammonia (mg/L as NH_4)	6.8	8.7	5.7	4.1	5.3	4.4	5.3
Conductivity (ΦS/cm)	517	463	461	482	460	462	467

Table A5
10/08/99 Water Sample Analyses

10/08/99	Cold Distribution	Heat Exchanger #1		Heat Exchanger #2		Heat Exchanger #3	
		Magnetic	Control	Magnetic	Control	Electronic	Control
M Alkalinity (mg/L as $CaCO_3$)	144	142	142	142	144	142	144
Hardness (mg/L as $CaCO_3$)	224.2	225.5	220.8	239.2	223.4	236.8	224.1
Calcium (mg/L as Ca)	57.50	57.70	56.50	62.50	57.20	61.70	57.30
Magnesium (mg/L as Mg)	18.70	18.90	18.50	19.30	18.70	19.20	18.80
Sulfate (mg/L as SO_4)	50	50	48	57	50	61	52
Chloride (mg/L as C1)	32	31	29	32	29	32	30
Nitrate (mg/L as NO_3)	6.2	6.1	6.0	6.1	6.0	6.0	6.0
Iron (mg/L as Fe)	0.00	0.02	0.06	0.00	0.00	0.00	0.00
Copper (mg/L as Cu)	0.00	0.00	0.02	0.00	0.00	0.00	0.00
Zinc (mg/L as Zn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium (mg/L as Na)	11.3	11.7	11.1	12.1	11.3	12.7	11.2
Manganese (mg/L as Mn)	0.006	0.006	0.007	0.005	0.005	0.006	0.005
Total Dissolved Solids (mg/L)	265	270	282	268	286	264	282
pH	7.72	7.75	7.75	7.77	7.75	7.76	7.78
Sample Temperature (EC)	17.7	37.9	39.8	36.5	42.2	39.3	38.3
Silica (mg/L as SiO_2)	7.7	7.9	7.7	8.6	7.8	8.6	7.8
Ammonia (mg/L as NH_4)	4.6	5.1	4.6	9.2	4.7	8.3	4.5
Conductivity (ΦS/cm)	544	479	483	482	482	479	486

Table A6
10/15/99 Water Sample Analyses

10/15/99	Cold Distribution	Heat Exchanger #1		Heat Exchanger #2		Heat Exchanger #3	
		Magnetic	Control	Magnetic	Control	Electronic	Control
M Alkalinity (mg/L as $CaCO_3$)	142	142	142	140	144	144	142
Hardness (mg/L as $CaCO_3$)	220.9	215.3	222.3	218.6	222.1	221.8	217.6
Calcium (mg/L as Ca)	56.20	54.80	56.60	55.60	56.50	56.40	55.40
Magnesium (mg/L as Mg)	18.70	18.20	18.80	18.50	18.80	18.80	18.40
Sulfate (mg/L as SO_4)	55	52	54	53	51	53	55
Chloride (mg/L as C1)	26	22	27	25	28	26	28
Nitrate (mg/L as NO_3)	6.1	5.9	6.1	6.0	6.0	6.0	5.9
Iron (mg/L as Fe)	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Copper (mg/L as Cu)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (mg/L as Zn)	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Sodium (mg/L as Na)	10.9	10.6	11.0	10.7	11.2	11.0	11.0
Manganese (mg/L as Mn)	0.005	0.004	0.005	0.005	0.006	0.005	0.006
Total Dissolved Solids (mg/L)	282	280	286	280	276	277	281
pH	7.86	7.65	7.67	7.68	7.65	7.66	7.69
Sample Temperature (EC)	17.7	38.5	38.9	35.5	38.8	37.1	36.0
Silica (mg/L as SiO_2)	7.8	7.7	7.9	7.9	8.0	7.9	7.8
Ammonia (mg/L as NH_4)	4.0	3.9	3.4	3.5	3.7	3.8	3.7
Conductivity (ΦS/cm)	476	475	474	476	475	475	475

Table A7
11/02099 Water Sample Analyses

11/02/99	Cold Distribution	Heat Exchanger #1		Heat Exchanger #2		Heat Exchanger #3	
		Magnetic	Control	Magnetic	Control	Electronic	Control
M Alkalinity (mg/L as $CaCO_3$)	148	148	146	148	146	146	148
Hardness (mg/L as $CaCO_3$)	198.0	201.7	201.9	201.9	201.2	200.7	203.1
Calcium (mg/L as Ca)	50.20	51.00	51.10	51.10	51.00	50.80	51.40
Magnesium (mg/L as Mg)	17.60	18.00	18.00	18.00	17.90	17.90	18.10
Sulfate (mg/L as SO_4)	46	47	46	48	48	47	48
Chloride (mg/L as C1)	25	26	26	25	25	25	26
Nitrate (mg/L as NO_3)	6.0	5.9	5.9	5.9	5.9	5.9	5.9
Iron (mg/L as Fe)	0.03	0.00	0.00	0.00	0.03	0.00	0.00
Copper (mg/L as Cu)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Zinc (mg/L as Zn)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sodium (mg/L as Na)	12.0	11.9	11.7	11.7	11.5	12.1	11.7
Manganese (mg/L as Mn)	0.008	0.008	0.009	0.008	0.008	0.007	0.008
Total Dissolved Solids (mg/L)	258	268	258	260	260	265	271
pH	7.71	7.65	7.62	7.72	7.71	7.65	7.71
Sample Temperature (EC)	15.1	38.7	38.6	31.5	33.2	42.8	33.3
Silica (mg/L as SiO_2)	7.1	7.3	7.2	7.2	7.2	7.3	7.3
Ammonia (mg/L as NH_4)	2.3	2.6	2.4	2.6	2.6	2.5	2.4
Conductivity (ΦS/cm)	472	472	472	472	470	472	476

Table A8
Corrosion Coupon Data

Location	Serial Number	Initial Weight (grams.)	Final Weight (grams.)	Weight Loss (grams)	MMPY	Installed	Removed
Control Cold Dist.	H4550	12.8439	12.8070	0.0369	0.449	09/03/99	11/02/99
1-M Before Heat Exchanger	H4551	12.8598	12.8319	0.0279	0.340	09/03/99	11/02/99
1-M After Heat Exchanger	G1554	13.0806	13.0473	0.0333	0.405	09/03/99	11/02/99
1-C After Heat Exchanger	G1555	13.0586	13.0327	0.0259	0.315	09/03/99	11/02/99
2-M Before Heat Exchanger	G1556	13.2002	13.1691	0.0311	0.379	09/03/99	11/02/99
2-M After Heat Exchanger	G1557	13.1373	13.1070	0.0303	0.369	09/03/99	11/02/99
2-C After Heat Exchanger	G1558	13.0920	13.0648	0.0272	0.331	09/03/99	11/02/99
3-M Before Heat Exchanger	G1559	13.1381	13.1066	0.0315	0.384	09/03/99	11/02/99
3-M After Heat Exchanger	G1560	13.0958	13.0603	0.0355	0.432	09/03/99	11/02/99
3-C After Heat Exchanger	G1561	13.1399	13.1109	0.0290	0.353	09/03/99	11/02/99

Table A9
Total Scale Removed

Location	Loose: Mechanical Removal	Tight: Chemical Removal	Total from Copper Tube	Loose: After Exchanger*	Total from All
1M	1.973	0.942	2.915	2.072	4.987
1C	1.745	1.902	3.647	1.537	5.184
2M	2.254	6.032	8.286	0.098	8.384
2C	4.909	3.720	8.629	0.047	8.676
3M	4.062	1.085	5.147	4.071	9.218
3C	5.156	5.170	10.328	0.381	10.709

***Loose scale, found between the end of the heat exchanger and the flow meter.**

Table A10
Calcium/Magnesium Ratio

Element (as Moles)	1M	1C	2M	2C	3M	3C
Calcium (as CaO)	86	89	91	90	87	90
Magnesium (as MgO)	14	11	9	10	13	10

Note: Other elements were present as minor components.

APPENDIX B

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APPENDIX C

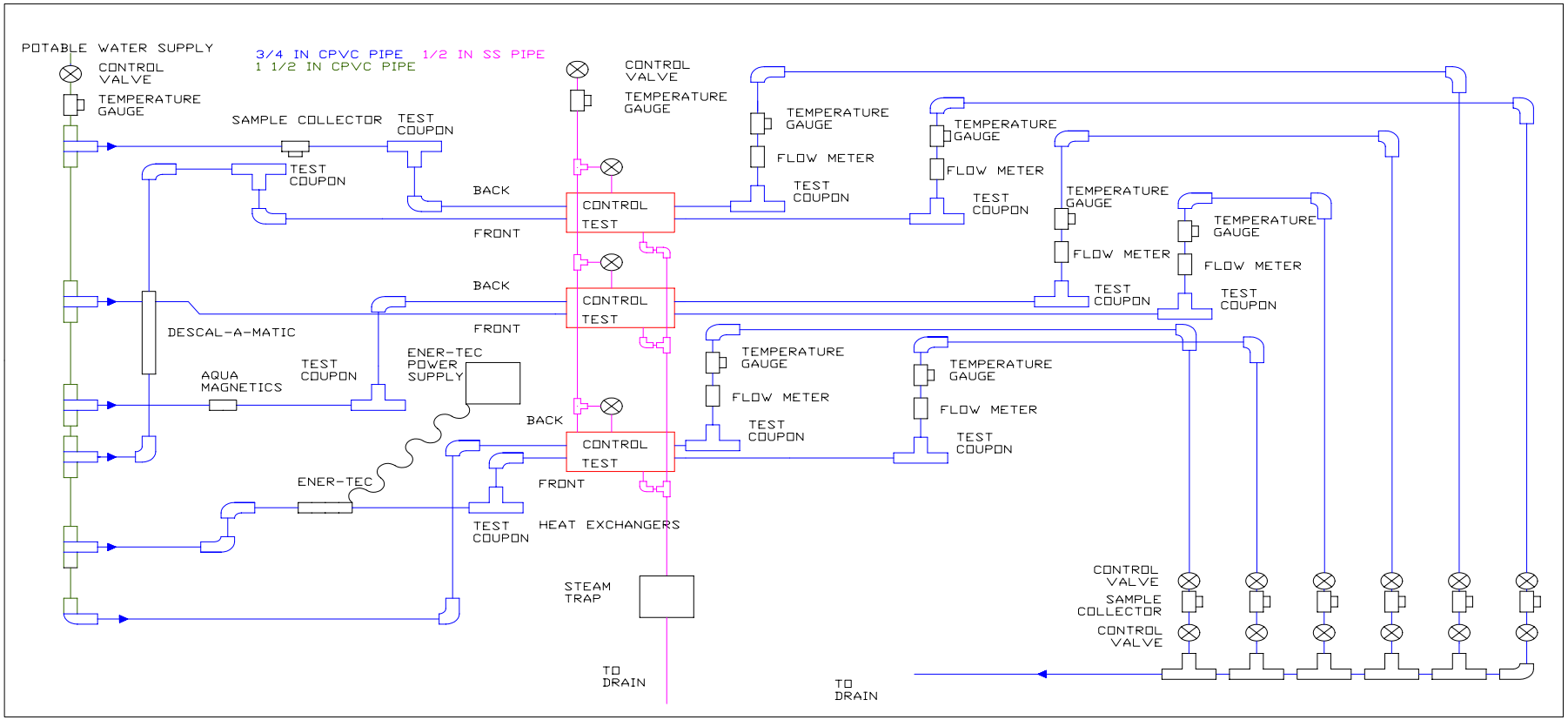

Figure C1: Schematic of Test Apparatus

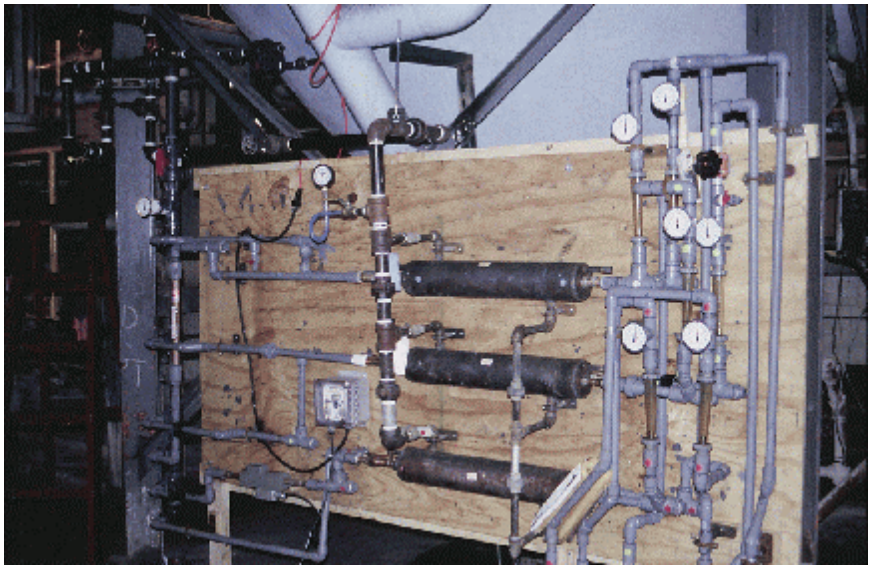

Figure C2
Test Apparatus Before Insulation

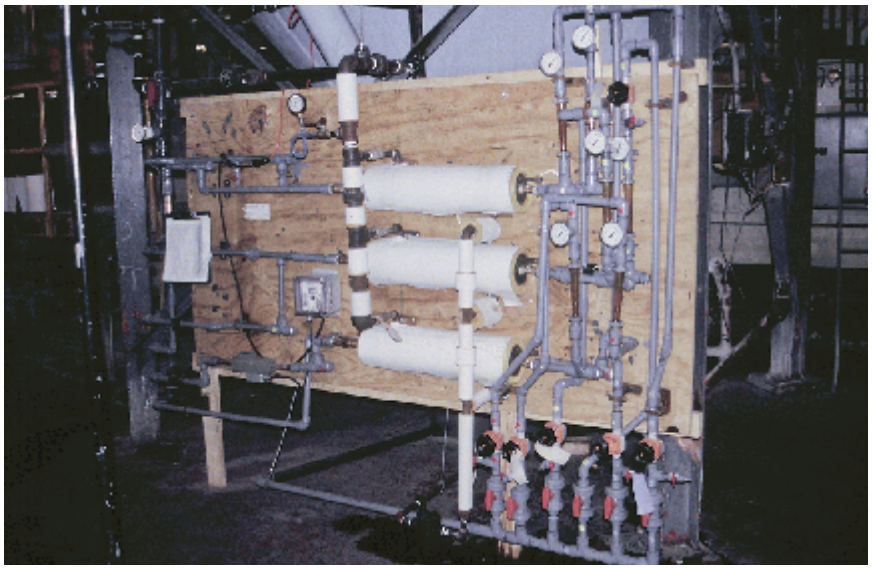

Figure C3
Test Apparatus After Insulation

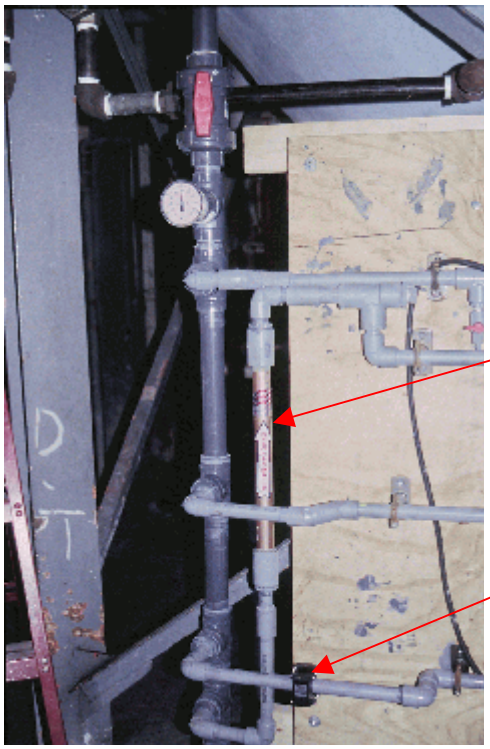

Figure C4
Descal-A-Matic and Aqua Magnetic Devices

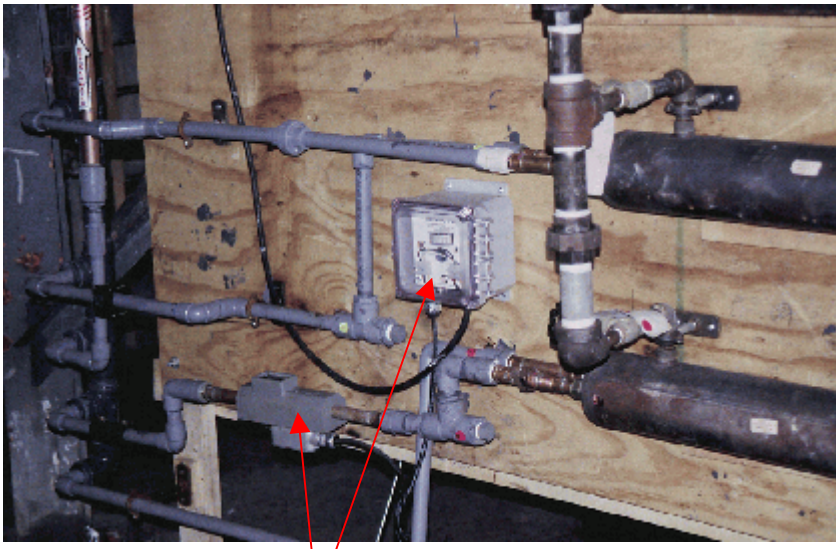

Figure C5
Ener Tec Device

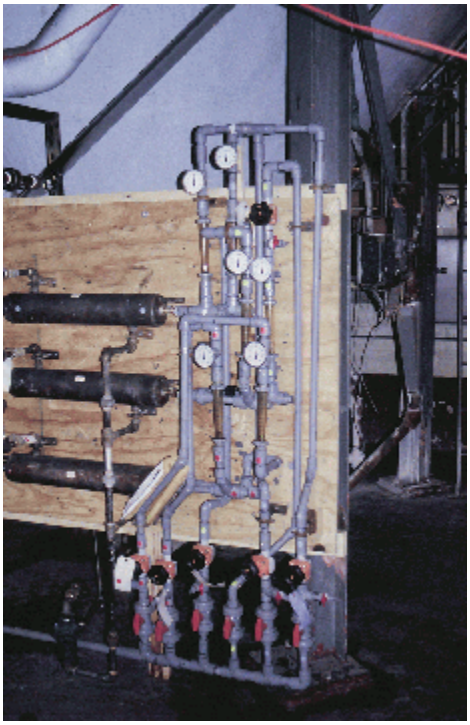

Figure C6
Temperature Gauges, Flow Meters and Control Valves

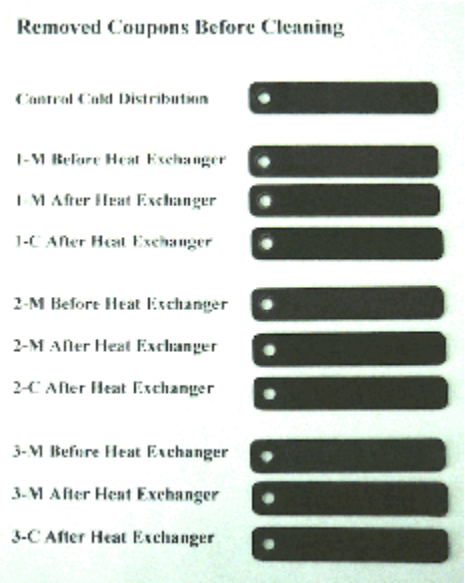

Figure C7
Corrosion Coupons before cleaning

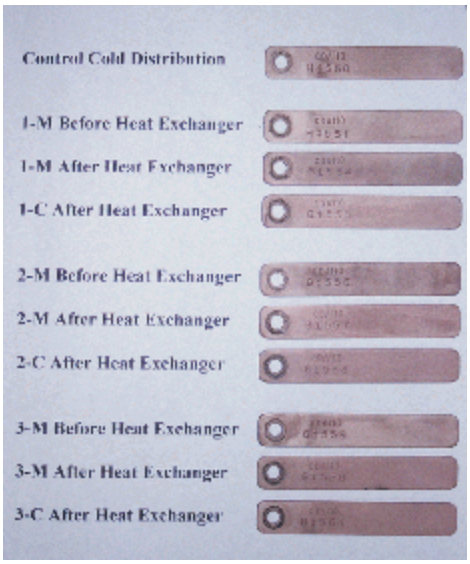

Figure C8
Corrosion Coupons after cleaning

Figure C9
Restricted Opening – Flow Meter

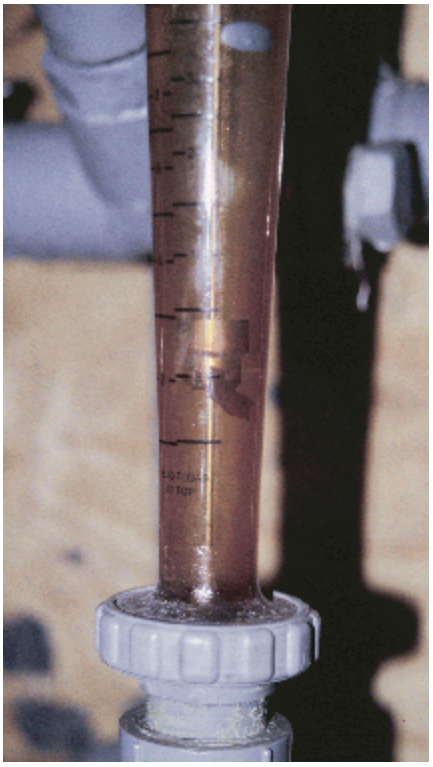

Figure C10
Flowmeter with Scale

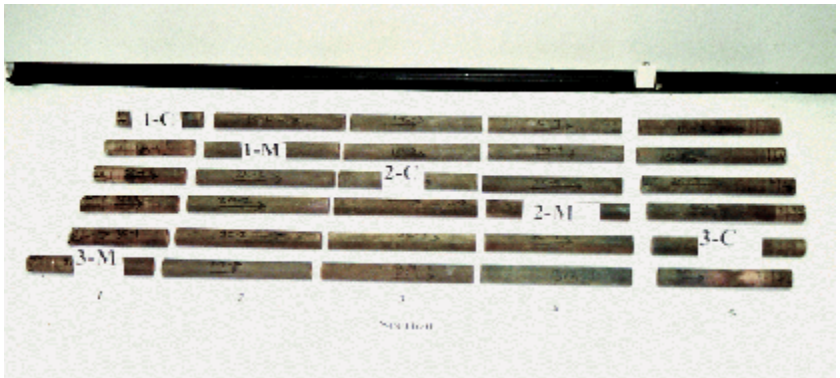

Figure C11
Heat Exchanger Segments

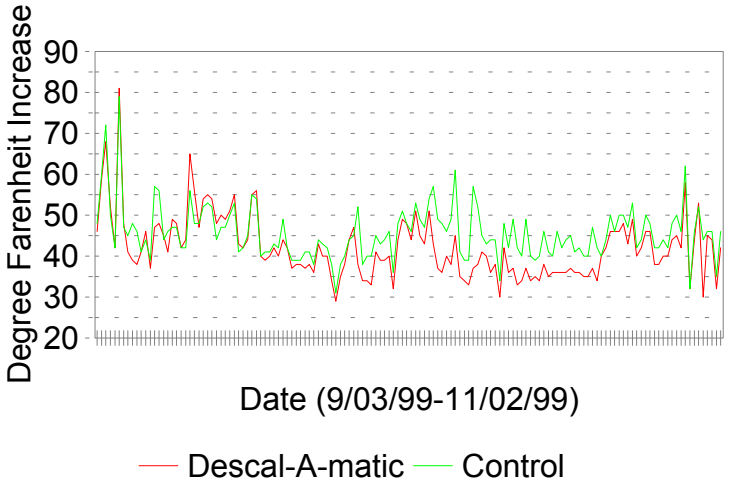

Figure C12
Temperature Change Heat Exchanger #1

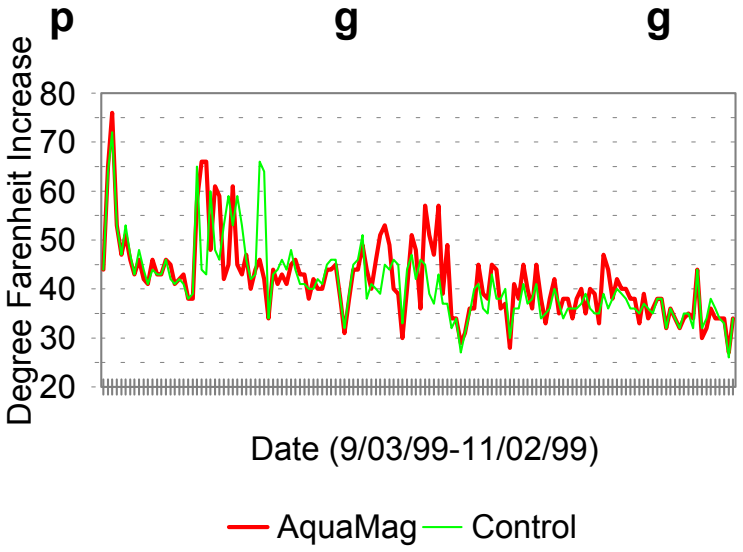

Figure C13
Temperature Change Heat Exchanger #2

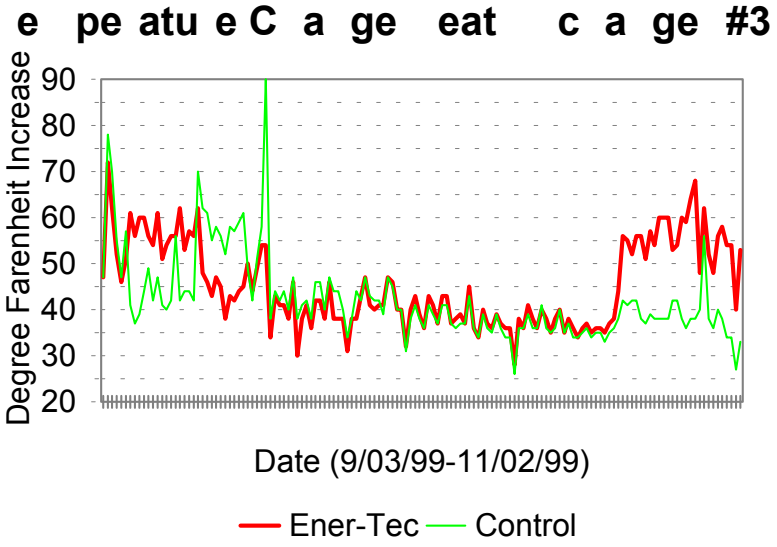

Figure C14
Temperature Change Heat Exchanger #3

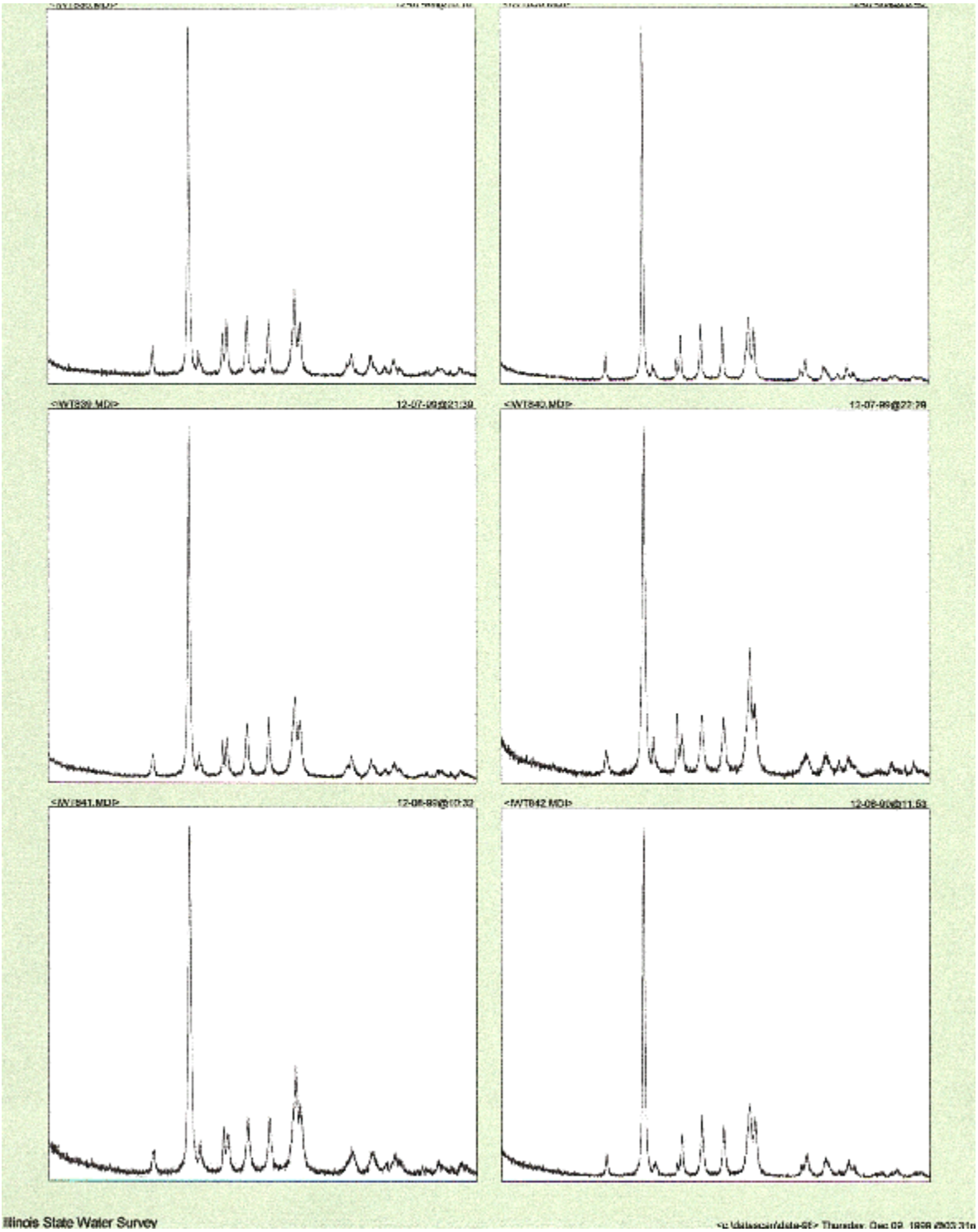

Figure C15
XRD Pattern Comparison

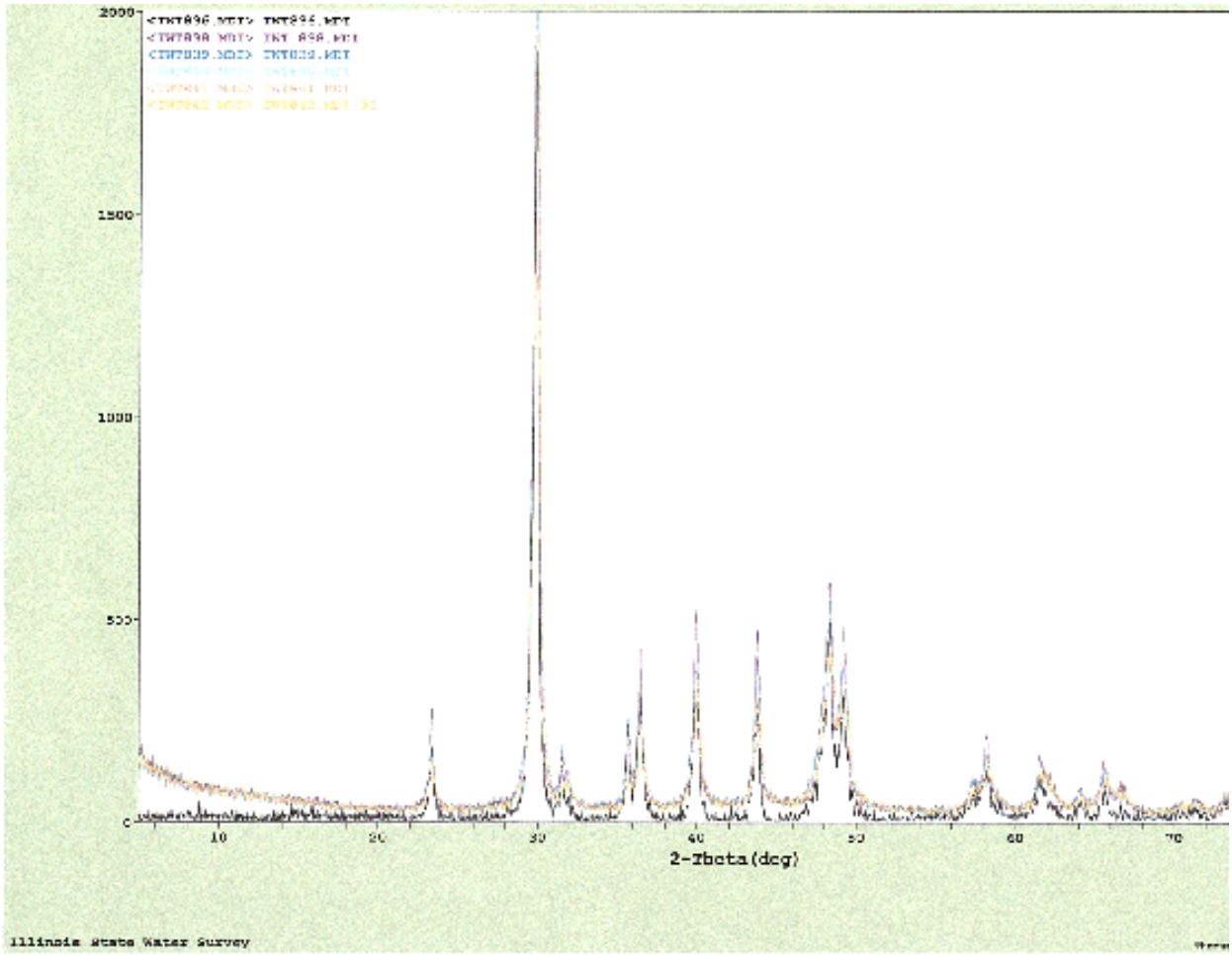

Figure C16
XRD Pattern Overlay

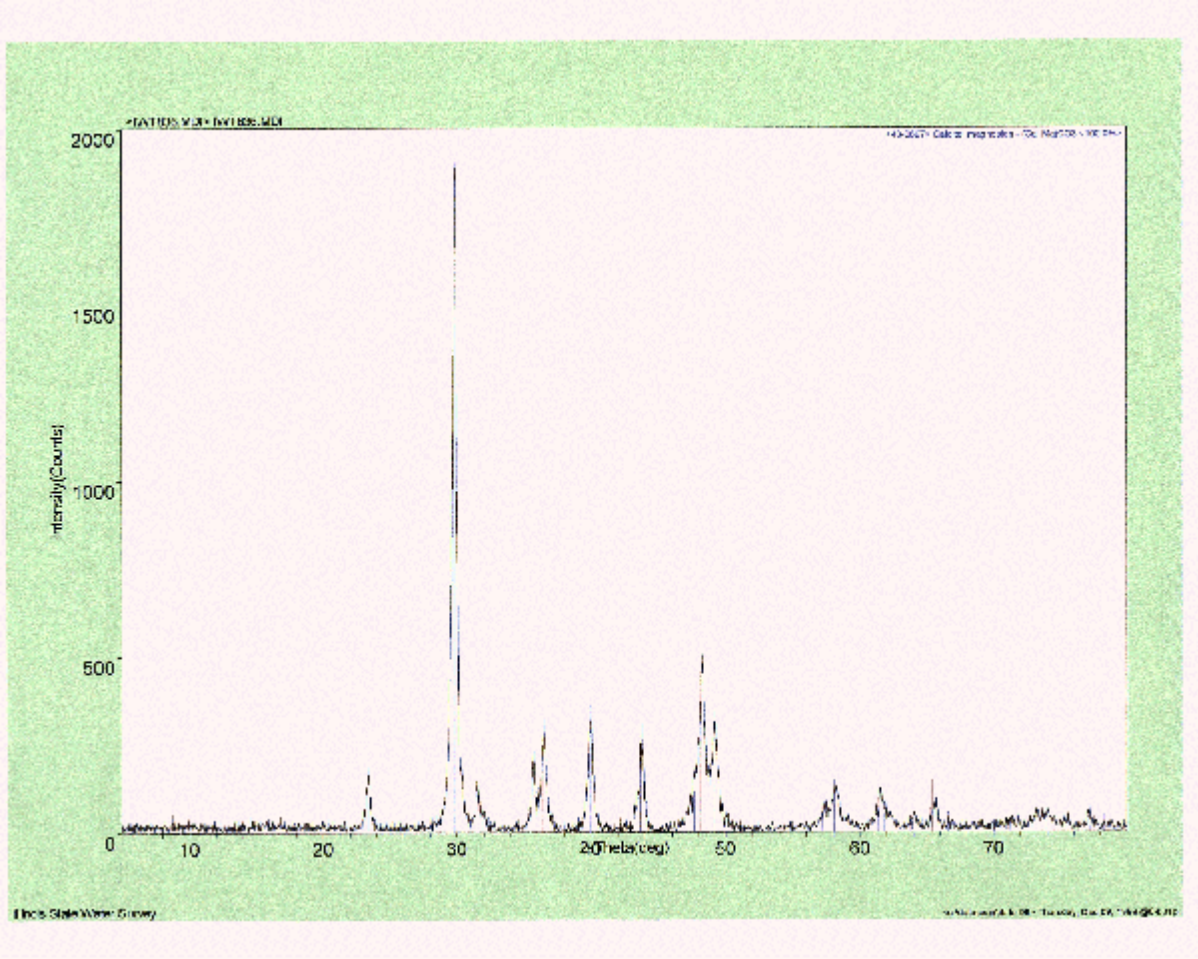

Figure C17
Descal-A-Matic Device XRD Pattern

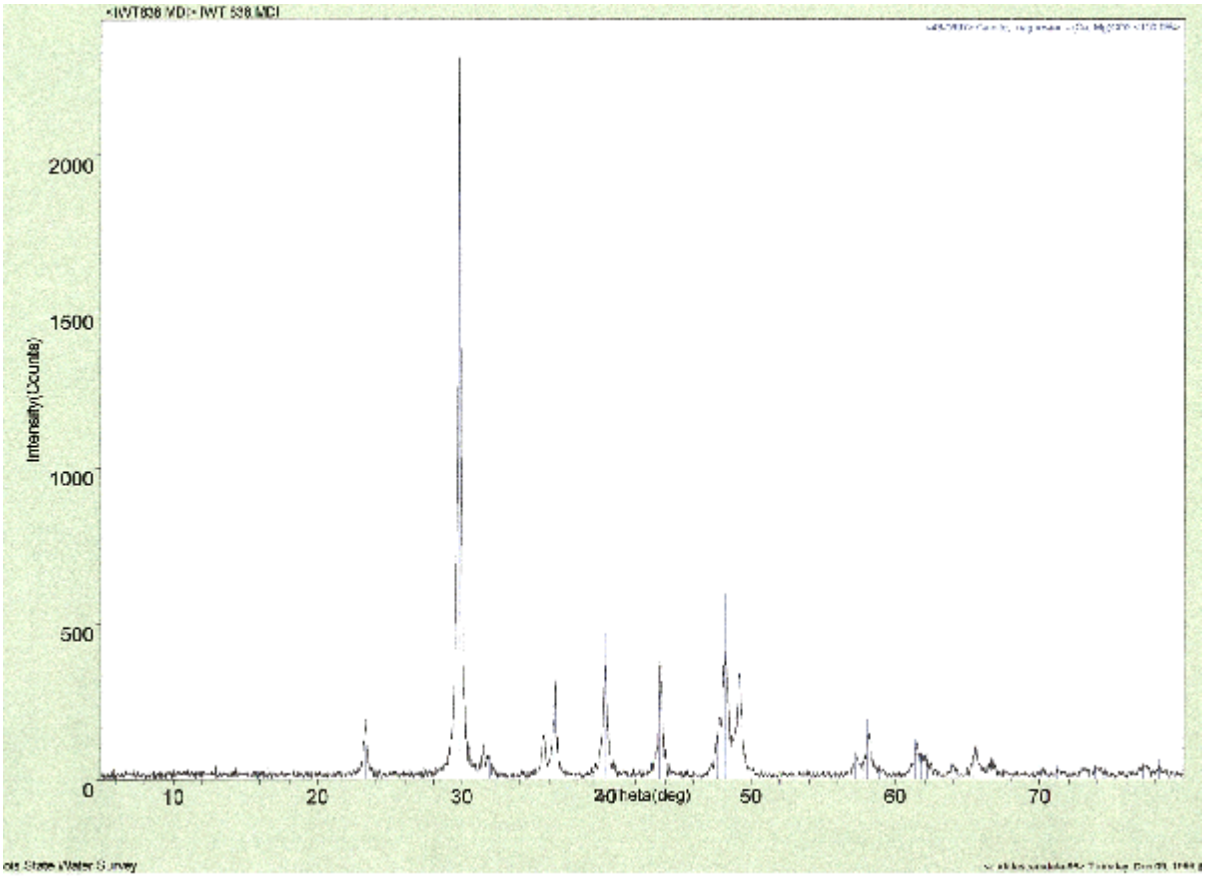

Figure C18
Aqua Magnetic Device XRD Pattern

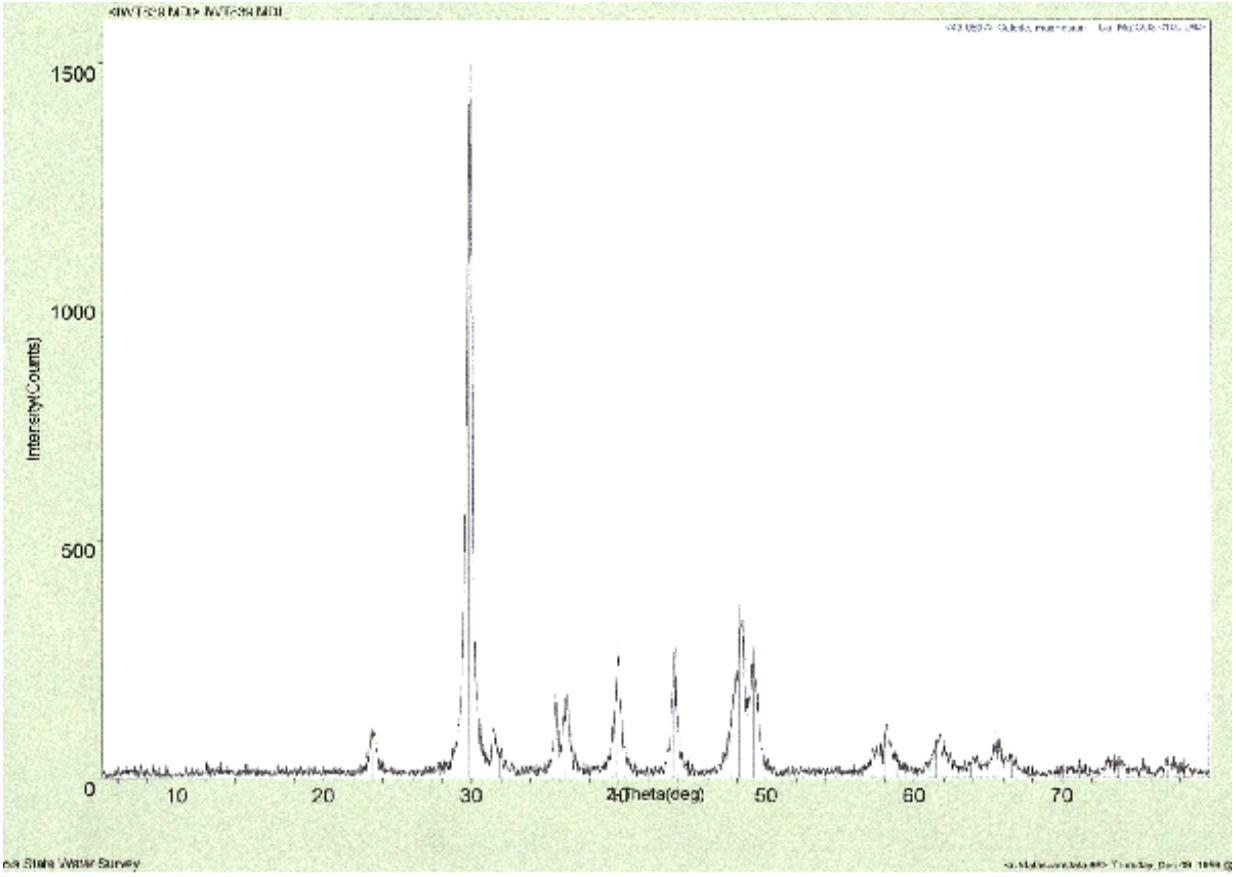

Figure C19
EnerTec Device XRD Pattern

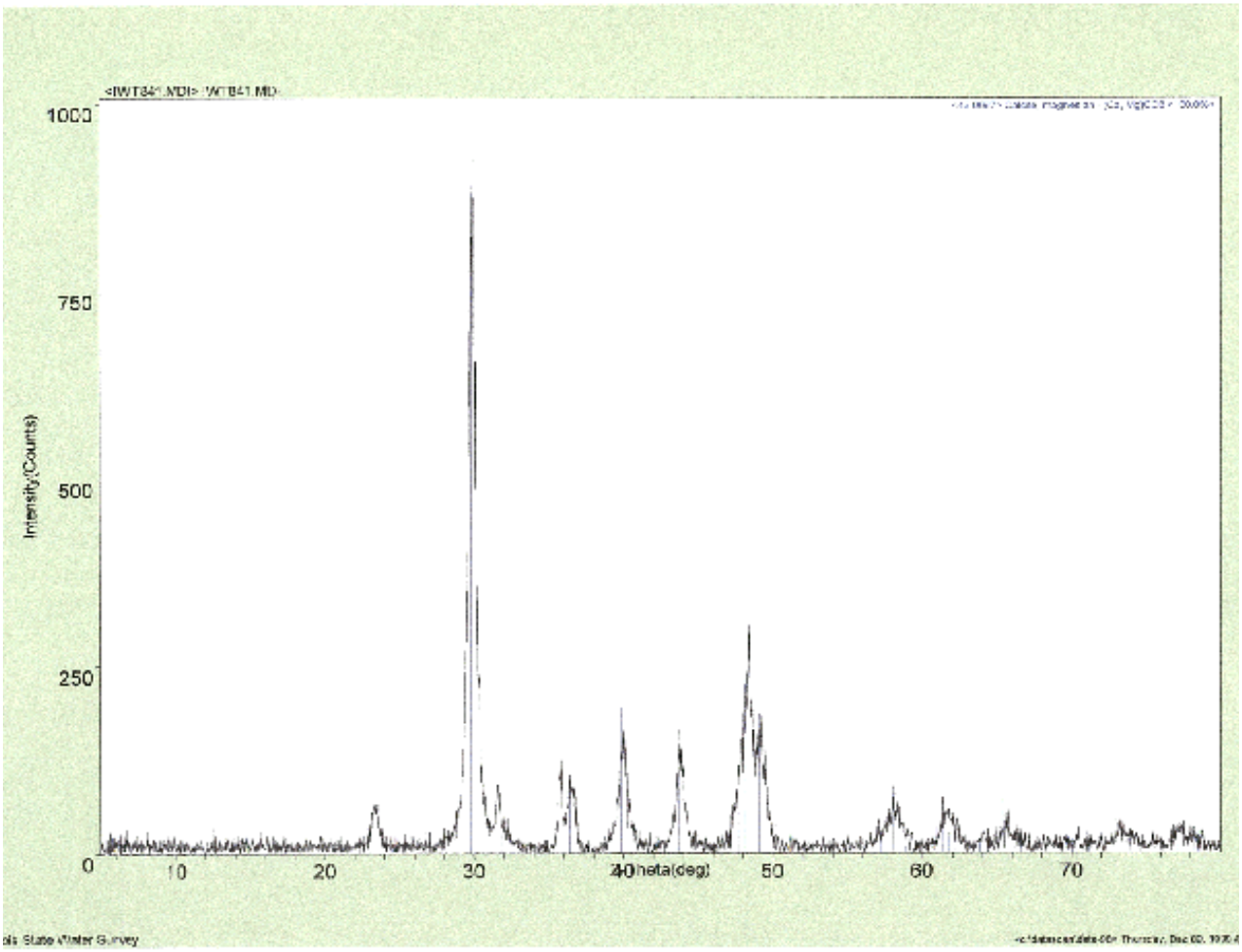

Figure C20
Descal-A-Matic Device Control XRD Pattern

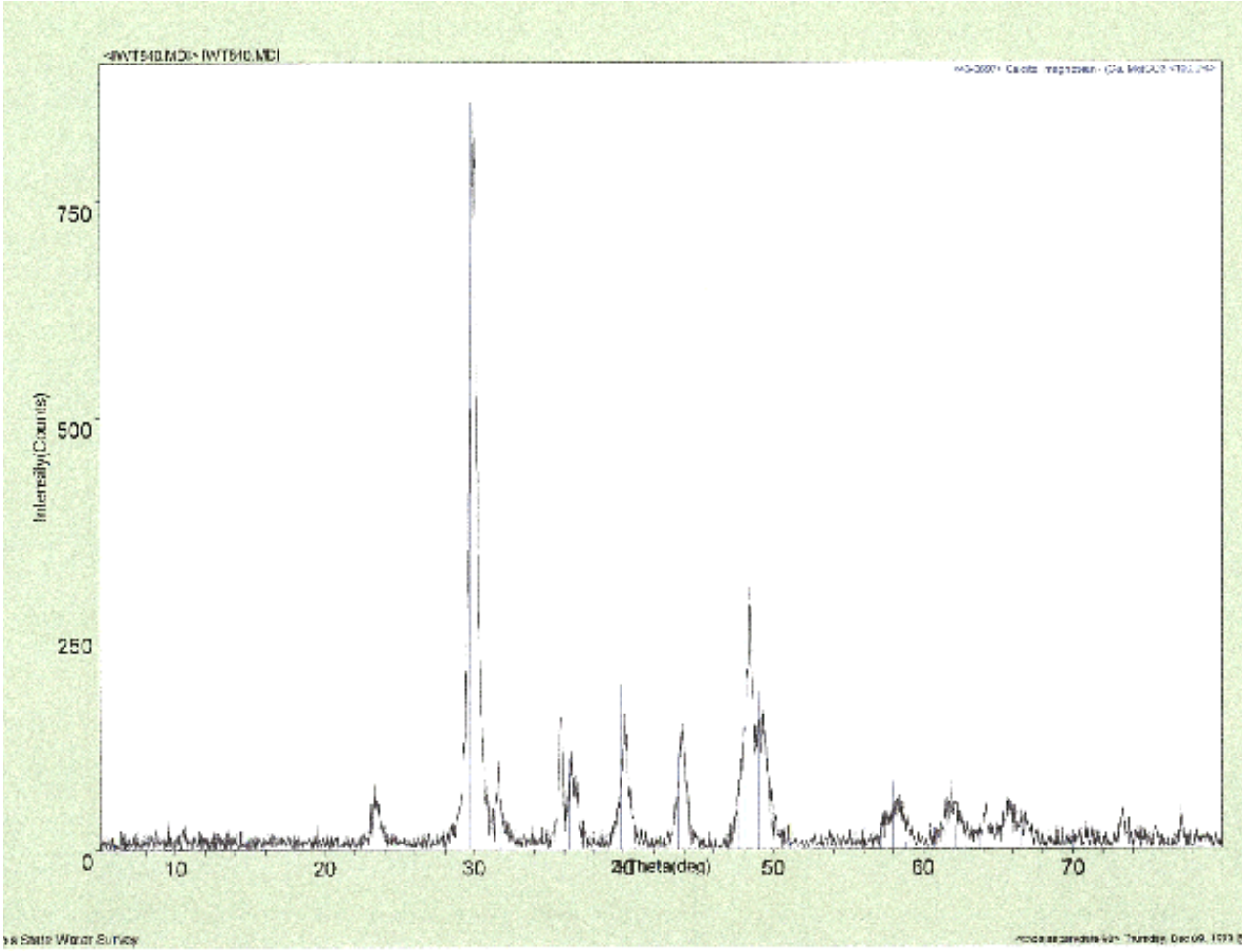

Figure C21
Aqua Magnetic Device Control XRD Pattern

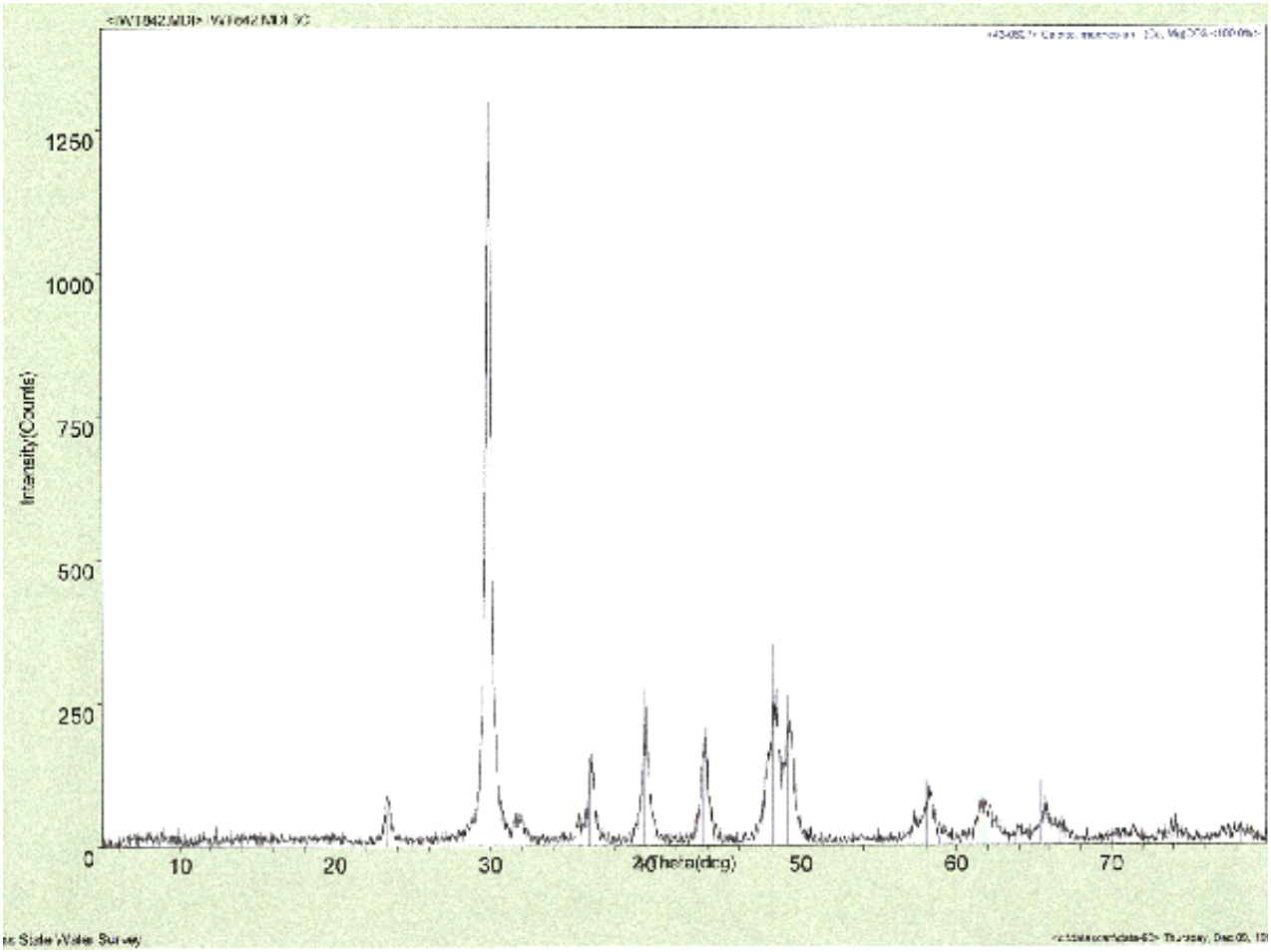

Figure C22
EnerTec Device Control XRD Pattern

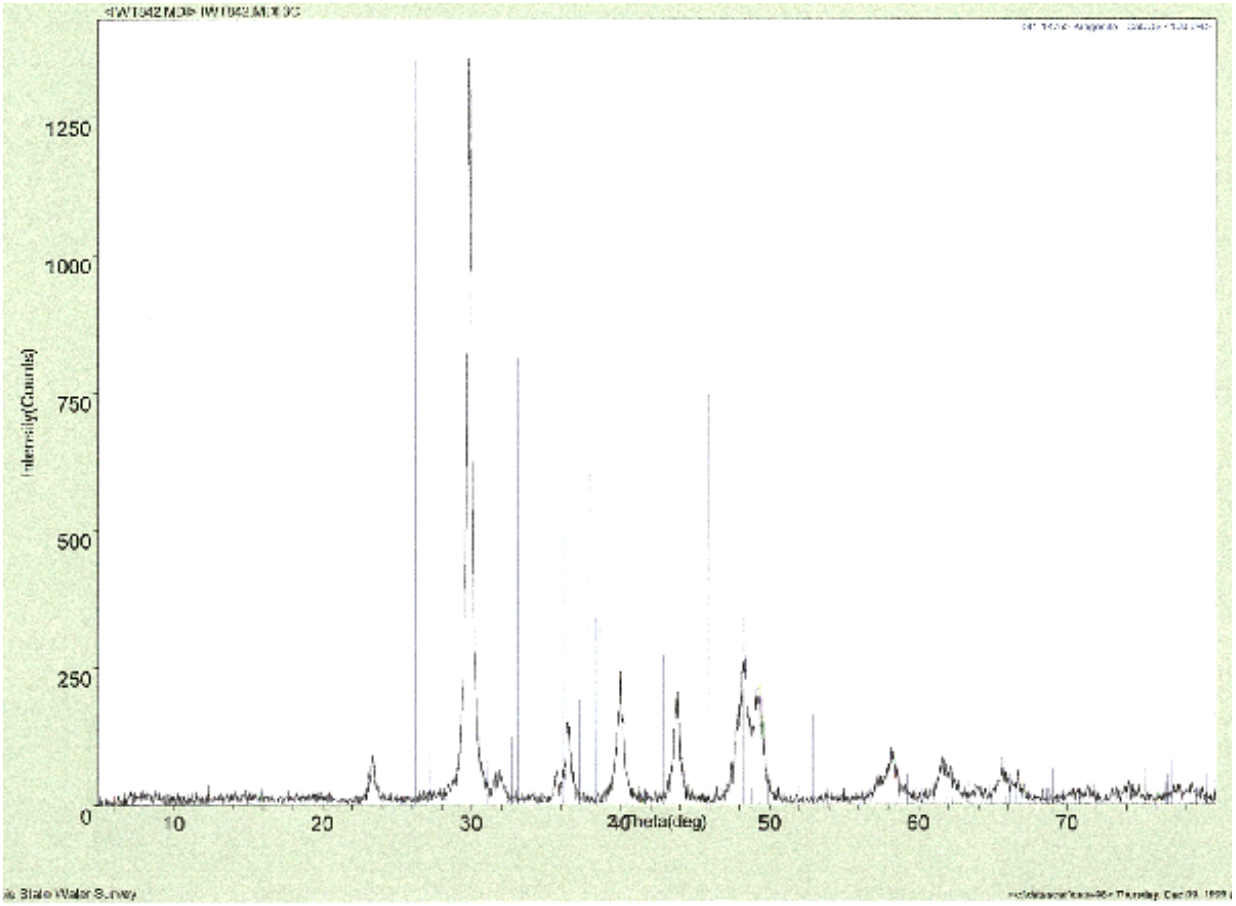

Figure C23
Aragonite Reference Peaks

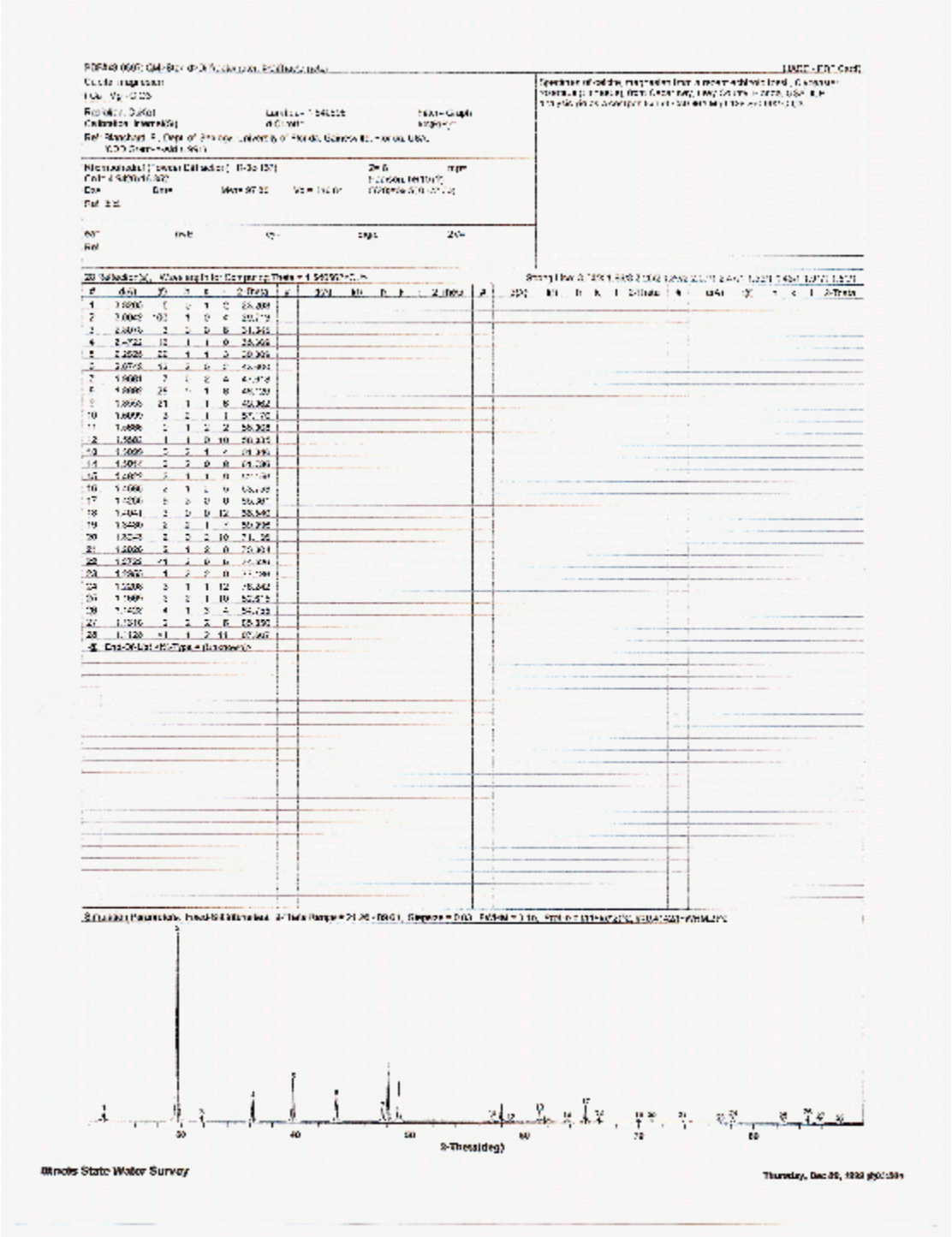

Figure C24
Calcite (magnesian) PDF Card