

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

**MAGNETIC WATER TREATMENT**

Public Works Technical Bulletins are published by the U.S. Army Corps of Engineers, Washington, DC. They are intended to provide information on specific topics in areas of Facilities Engineering and Public Works. They are not intended to establish new DA policy.

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

CEMP-R

Public Works Technical Bulletin  
No. 420-49-34

15 June 2001

FACILITIES ENGINEERING  
UTILITIES

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.

PWTB 420-49-36

15 June 2001

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

U.S. Army Engineer Research and Development Center

Construction Engineering Research Laboratory

ATTN: CEERD-CF-M (Dr. Vincent Hock)

2902 Newmark Drive

Champaign, IL 61822-1072

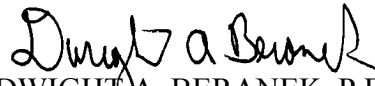
Tel. (217) 373-6753

FAX: (217) 373-7222

e-mail: v-hock@cecer.army.mil

FOR THE COMMANDER:

Encl



DWIGHT A. BERANEK, P.E.

Chief, Engineering and Construction Division

Directorate of Civil Works

# **DEMONSTRATION AND EVALUATION OF MAGNETIC DESCALERS**

**June 2000**

Kent W. Smothers, Charles D. Curtiss,  
Brian T. Gard, Robert H. Strauss, Vincent F. Hock

# 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<sup>1-96</sup> 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**

| <b>Product Name</b>                  | <b>Principle of Operation</b> | <b>Product Name</b> | <b>Principle of Operation</b> |
|--------------------------------------|-------------------------------|---------------------|-------------------------------|
| 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                 | Sullelectron        | 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<sup>90</sup> 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<sup>1,2</sup> 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<sup>9,10,17</sup> who have encountered field installations of these devices. Authors of books on corrosion engineering<sup>6</sup> and corrosion control<sup>32,61</sup> 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<sup>3,5</sup> which largely discredited the performance claims of the manufacturer. Since that time, numerous studies<sup>4,8,9,27</sup> 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<sup>27,31,33</sup> which report little or no positive impacts on the control of scale and corrosion by magnetic devices. Katz has done a number of studies<sup>45,46,60,66</sup> 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<sup>75</sup> 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<sup>72</sup> 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<sup>7,11,14,25,29</sup> have been reported in the literature, probably the one most cited is the paper by Grutsch and McClintock<sup>25</sup> 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<sup>15,26,28,62,78,79</sup> 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 imparting 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 depolarized in such a way that they do not react in solution. Ener Tec literature states that it is a Linear Kinetic Cell that causes 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 ( $\text{CaCO}_3$ ).

The ICP-AES analysis consists 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."<sup>97</sup>

**Table 2**  
**Rock Island Arsenal Cold Distribution**

| <b>Cold Distribution</b>                  |                 |                 |                 |                 |                 |                 |                 |
|---|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| <b>Date</b>                               | <b>09/03/99</b> | <b>09/09/99</b> | <b>09/22/99</b> | <b>10/01/99</b> | <b>10/08/99</b> | <b>10/15/99</b> | <b>11/02/99</b> |
| <b>M Alkalinity (as CaCO<sub>3</sub>)</b> | 138             | 134             | 140             | 136             | 144             | 142             | 148             |
| <b>Hardness (as CaCO<sub>3</sub>)</b>     | 206.7           | 207.8           | 220.1           | 213.6           | 224.2           | 220.9           | 210.0           |
| <b>Calcium (as Ca)</b>                    | 54.80           | 55.10           | 56.20           | 53.80           | 57.50           | 56.20           | 50.20           |
| <b>Magnesium (as Mg)</b>                  | 16.20           | 16.30           | 18.50           | 18.40           | 18.70           | 18.70           | 17.60           |
| <b>Sulfate (as SO<sub>4</sub>)</b>        | 55              | 57              | 52              | 48              | 50              | 55              | 46              |
| <b>Chloride (as Cl)</b>                   | 25              | 24              | 35              | 31              | 32              | 26              | 25              |
| <b>Nitrate (as NO<sub>3</sub>)</b>        | 7.3             | 6.7             | 6.5             | 6.3             | 6.2             | 6.1             | 6.0             |
| <b>Iron (as Fe)</b>                       | 0.01            | 0.00            | 0.00            | 0.00            | 0.00            | 0.00            | 0.03            |
| <b>Copper (as Cu)</b>                     | 0.00            | 0.00            | 0.03            | 0.01            | 0.00            | 0.00            | 0.00            |
| <b>Zinc (as Zn)</b>                       | 0.00            | 0.00            | 0.00            | 0.00            | 0.00            | 0.00            | 0.00            |
| <b>Sodium (as Na)</b>                     | 10.0            | 10.3            | 10.7            | 10.7            | 11.3            | 10.9            | 12.0            |
| <b>Manganese (Mn)</b>                     | 0.007           | 0.004           | 0.006           | 0.005           | 0.006           | 0.005           | 0.008           |
| <b>Total Dissolved Solids</b>             | 272             | 276             | 313             | 270             | 265             | 282             | 258             |
| <b>pH</b>                                 | 7.61            | 7.69            | 7.64            | 7.71            | 7.72            | 7.86            | 7.71            |
| <b>Temperature (EC)</b>                   | 27.0            | 27.2            | 22.1            | 20.6            | 17.7            | 17.7            | 15.1            |
| <b>Silica (as SiO<sub>2</sub>)</b>        | 9.6             | 9.3             | 9.2             | 7.3             | 7.7             | 7.8             | 7.1             |
| <b>Ammonia (as NH<sub>4</sub>)</b>        | 3.9             | 4.0             | 8.1             | 6.8             | 4.6             | 4.0             | 2.3             |
| <b>Conductivity (ΦS/cm)</b>               | 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. e 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 Diffraction Data database on CD-ROM.

Not all the scale could be removed mechanically, therefore chemical methods were employed. Hydrochloric (HCl) and nitric (HNO<sub>3</sub>) 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<sub>3</sub> 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<sub>3</sub>. 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 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  $\Delta T$ , 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  $\Delta T$  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  $\Delta T$  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  $\Delta T$  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 overlaid 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<br>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<br>6:00 p.m.  |                               |                 |                   | Two lines to Heat Ext. broke |      |                     |      |                     |      |                     |      |                     |      |                     |      |
| 09/02/99<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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*<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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*<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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*<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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*<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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*<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>7:00 p.m.  | Steam Off/Tube Missing        |                 |                   |                     |      |                     |      |                     |      |                     |      |                     |      |                     |      |
| 10/25/99<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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<br>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*<br>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<br>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<br>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<br>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**<br>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 <sub>3</sub> ) | 134               | 138               | 134     | 136               | 138     | 138               | 136     |
| Hardness (mg/L as CaCO <sub>3</sub> )     | 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 <sub>4</sub> )        | 57                | 59                | 58      | 58                | 57      | 57                | 59      |
| Chloride (mg/L as Cl)                     | 24                | 24                | 25      | 24                | 23      | 23                | 22      |
| Nitrate (mg/L as NO <sub>3</sub> )        | 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 <sub>2</sub> )        | 9.3               | 9.4               | 9.2     | 9.3               | 9.3     | 9.3               | 9.3     |
| Ammonia (mg/L as NH <sub>4</sub> )        | 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 <sub>3</sub> ) | 140               | 138               | 138     | 138               | 138     | 138               | 138     |
| Hardness (mg/L as CaCO <sub>3</sub> )     | 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 <sub>4</sub> )        | 52                | 49                | 49      | 53                | 50      | 51                | 52      |
| Chloride (mg/L as Cl)                     | 35                | 35                | 36      | 35                | 36      | 35                | 35      |
| Nitrate (mg/L as NO <sub>3</sub> )        | 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 <sub>2</sub> )        | 9.2               | 8.9               | 9.0     | 9.1               | 8.9     | 9.1               | 9.1     |
| Ammonia (mg/L as NH <sub>4</sub> )        | 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 <sub>3</sub> ) | 136               | 136               | 134     | 140               | 136     | 134               | 136     |
| Hardness (mg/L as CaCO <sub>3</sub> )     | 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 <sub>4</sub> )        | 48                | 47                | 46      | 47                | 48      | 49                | 48      |
| Chloride (mg/L as Cl)                     | 31                | 33                | 33      | 33                | 30      | 30                | 32      |
| Nitrate (mg/L as NO <sub>3</sub> )        | 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 <sub>2</sub> )        | 7.3               | 7.2               | 7.4     | 7.3               | 7.3     | 7.7               | 7.3     |
| Ammonia (mg/L as NH <sub>4</sub> )        | 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 <sub>3</sub> ) | 144               | 142               | 142     | 142               | 144     | 142               | 144     |
| Hardness (mg/L as CaCO <sub>3</sub> )     | 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 <sub>4</sub> )        | 50                | 50                | 48      | 57                | 50      | 61                | 52      |
| Chloride (mg/L as Cl)                     | 32                | 31                | 29      | 32                | 29      | 32                | 30      |
| Nitrate (mg/L as NO <sub>3</sub> )        | 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 <sub>2</sub> )        | 7.7               | 7.9               | 7.7     | 8.6               | 7.8     | 8.6               | 7.8     |
| Ammonia (mg/L as NH <sub>4</sub> )        | 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 <sub>3</sub> ) | 142               | 142               | 142     | 140               | 144     | 144               | 142     |
| Hardness (mg/L as CaCO <sub>3</sub> )     | 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 <sub>4</sub> )        | 55                | 52                | 54      | 53                | 51      | 53                | 55      |
| Chloride (mg/L as Cl)                     | 26                | 22                | 27      | 25                | 28      | 26                | 28      |
| Nitrate (mg/L as NO <sub>3</sub> )        | 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 <sub>2</sub> )        | 7.8               | 7.7               | 7.9     | 7.9               | 8.0     | 7.9               | 7.8     |
| Ammonia (mg/L as NH <sub>4</sub> )        | 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 <sub>3</sub> ) | 148               | 148               | 146     | 148               | 146     | 146               | 148     |
| Hardness (mg/L as CaCO <sub>3</sub> )     | 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 <sub>4</sub> )        | 46                | 47                | 46      | 48                | 48      | 47                | 48      |
| Chloride (mg/L as Cl)                     | 25                | 26                | 26      | 25                | 25      | 25                | 26      |
| Nitrate (mg/L as NO <sub>3</sub> )        | 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 <sub>2</sub> )        | 7.1               | 7.3               | 7.2     | 7.2               | 7.2     | 7.3               | 7.3     |
| Ammonia (mg/L as NH <sub>4</sub> )        | 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**

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

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

**Table A10  
Calcium/Magnesium Ratio**

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

Note: Other elements were present as minor components.

## APPENDIX B

### Literature Search Bibliography (1952-1999)

1. **So-called Electrical and Catalytic Treatment of Water for Boilers** Eliassen, Rolf and Uhlig, Herbert H., Journal American Water Works Association, Vol. 44, No. 7, p. 576-582, July 1952.
2. **Corrosion Control by Magic - It's Wonderful** Uhlig, Herbert H. Corrosion, Vol. 8, p.361-363, November 1952.
3. **Report to Water Conditioning Research Council on Water Conditioned by an EVIS Unit** Foster D., Snell Inc., July 1952.
4. **Practical Performance of Water-Conditioning Gadgets** Welder, B.Q. and Partridge, Everett P., Industrial and Engineering Chemistry, Vol. 46, p. 954-960, May 1954.
5. **Experimental Evaluation of 'Water Conditioner' Performance** Eliassen, Rolf and Skrinde, Rolf, Journal American Water Works Association, Vol. 49, No. 9, p.1179-1190, September 1957.
6. **Corrosion Engineering** Fontana, Mars G., and Greene, Norbert, R., McGraw-Hill, Inc., p. 197-198, 1967.
7. **Magnetic Treatment of Water and Aqueous Systems in Flotation and Thickening of Ores and Coals** Klassen, V.I., Proceedings VIII International Mineral Processing Congress, Leningrad, USSR, 1968.
8. **Electrostatic Descaler Testing: An Evaluation** Meckler, Milton, Heating, Piping & Air Conditioning, p. 37-40, August 1974.
9. **The Fatal Lure of Water Treating Gadgets** Dromgoole, J.C. and Forbes, M.C., Proceedings International Water Conference, November 1979.
10. **Water Conditioning Devices - An Update** Wilkes, J. Fred and Baum, Ray, Proceedings International Water Conference, November 1979.
11. **Magnetic Field Conditioning of Industrial Waters** Kvajic, George and Milosevic-Kvajic, Mirjana, Proceedings International Water Conference, November 1979.
12. **The Fatal Lure of Water Treating Gadgets** Dromgoole, J.C. and Forbes, M.C.,



Proceedings National Association of Corrosion Engineers Annual Conference, November 1979.

13. **Nonchemical Water Treating Devices** Wescott, Ralph M., *Materials Performance*, p. 40-42, November 1980.
14. **Efficiency of Some Physical Scale Prevention Methods in Thermal Desalination Plants** Martynova, O.I., *Proc. Int. Symp. Fresh Water Sea*, Vol. 7th, No. 1, p. 399-406, 1980.
15. **A Viable Approach to Water and Wastewater Treatment** Reimers, R.S., deKernion, P.S., Robedeau, F.C., and Leftwich, D.B., *Water Technology*, p. 44-65, May-June 1980.
16. **Prospects of Using Magnetic Wastewater Treatment** Klassen, V.I., State Scientific-Research Institute of Mining and Chemical Raw Materials, *Vodye Resursy* No. 4, p. 146-151, USSR, July-August 1981.
17. **Mechanical Devices for Water Treatment: Just How Effective are They?** Puckorius, P., *Power*, p. 60-62, January 1981.
18. **The Performance of a Magnetic Water Conditioner Under Accelerated Scaling Conditions** Hasson, D., Bramson, D., *Dep. Chem. Eng., Technion-Israel Inst. Technol*, p. 217-273, 1981.
19. **Consulting Services Related to the Theory and Technology of Magnetic Water Treatment** Lane, Russell W., Contract Report for U.S. Army Construction Engineering Research Laboratory, 1981.
20. **Performance Analysis of Permanent Magnet Type Water Treatment Devices** Gruber, C.E., Carda, D.D., *Water Quality Association, Research Reports*, July 1981.
21. **Effect of Magnetic Field on Internal Corrosion of Water Pipelines** Das, C.R., Misra, H.P., *J. Inst. Eng.*, Vol. 63, No. 1, p.30-31, 1982
22. **Reviewing the Usage of Applied-Fields in Industrial Water Treatment-What Works? What Does Not Work?** Reimers, R.S., Anderson, A.C., White, L.E., *Proc. Int. Water Conf., Eng. Soc. West. Pa.* 44<sup>th</sup>, p. 280-291, 1983.
23. **A Review of Scale Formation and Scale Prevention, with Emphasis on Magnetic Water Treatment** Ellingsen, Frank, *Water Supply*, Vol. 1, No.2-3, 1983.
24. **Scale Prevention and Removal by Hydrodynamic Fluid Treatment** Davies, J.H., *Certif Eng.*, Vol. 56, No. 1, p. 4-10, January 1983.
25. **Corrosion and Deposit Control in Alkaline Cooling Water Using Magnetic Water**

- Treatment at Amoco's Largest Refinery** Grutsch, James F. and McClintock, J. Warren, Proceedings National Association of Corrosion Engineers Annual Conference, April 1984.
26. **Magnetic Water Treatment Devices, The Results of a University Study** Busch, Kenneth W., Busch, et. al., Proceedings International Water Conference, October 1984.
  27. **Evaluation of Commercial Magnetic Descalers** Lawrence, Debbie J., U.S. Army Corps of Engineers Construction Engineering Research Laboratory Technical Report M-342, May 1984.
  28. **Laboratory Studies Involving Magnetic Water Treatment Devices** Busch, Kenneth W., Busch, et. al., Proceedings National Association of Corrosion Engineers Annual Conference, March 1984.
  29. **The Control of Scale and Corrosion in Water Systems Using Magnetic Fields** Raisen, Elliott, Proceedings National Association of Corrosion Engineers Annual Conference, April 1984.
  30. **Effectiveness of Magnetic Water Treatment in Suppressing CaCO<sub>3</sub> Scale Deposition** Hanson, D., Bramson, D., Ind. Eng. Chem. Process Des. Dev., Vol. 24, No. 3, p 588-592, 1985.
  31. **Tests of Non-Chemical Scale Control Devices in a Once-Through System** Limpert, G.J.C., and Raber, J.L., Proceedings National Association of Corrosion Engineers Annual Conference, March 1985.
  32. **Water Treatment Specification Manual** Rosa, Frank, McGraw-Hill, Inc., p. 190-191, 1985.
  33. **Quantitative Assessment of the Effectiveness of Permanent Magnetic Water Conditioning Devices** Alleman, James E., Water Quality Association, Research Reports, November 1985.
  34. **Experimental Evidence for Effects of Magnetic Fields on Moving Water** Kronenberg, Klaus, IEEE Transactions on Magnetics, Vol. Mag. 21, No 5., p. 2059-2061, September 1985.
  35. **Experimental Evidence for Effects of Magnetic Fields on Water** Kronenberg, Klaus J., Institute of Electric and Electronic Engineers Transactions on Magnetics, Vol. Mag. No. 5, p. 2059-2061, September 1985.
  36. **Magnetic Treatment Does Work** Carpenter, Roland K., Published by NACE, p.252.1-252.8, March 1985.

37. **Magnetic Treatment of Scale Prevention and Descaling in Water Treatment and Process Systems** Donaldson, J.D., Prod Finish, Vol. 39, No. 9, p. 6-8, 10, September 1986.
38. **Studies of a Water Treatment Device That Uses Magnetic Fields** Busch, Kenneth W., Busch, et. al., National Association of Corrosion Engineers, Vol. 42, No. 4, p. 211-221, April 1986.
39. **Alkalinity - pH Changes with Temperature for Water in Industrial Systems** Emerson, G.D., Ellis Horwood Limited, 1986.
40. **Softening Hard Scale** Chynoweth, Emma, Process Eng, Vol. 68, No. 5, p. 77, 1987.
41. **Scale Prevention in Steel Pretreatment by Magnetic Treatment** Donaldson, John, Grimes, Sue, Steel Times Int., Vol. 11, No. 5, p. 44-45, 1987.
42. **Scale Prevention and Descaling** Donaldson, J.D., Tube International, p. 39-49, March 1988.
43. **Magnetic Field Effect on Crystals** Grimes, Sue M., Tube International, March 1988.
44. **Lifting the Scales From Our Pipes** Donaldson, John, Grimes, Sue, New Sci., Vol. 117, No. 1600, p. 43-46, 1988.
45. **Mechanistic Study of the Effects of Magnetic Fields on Scale Formation** Katz, Joseph L., The John Hopkins University, Progress Report, August 1988.
46. **Magnetic Water Treatment: The Effect of Iron on Calcium Carbonate Nucleation and Growth** Herzog, Ruth E., Shi, Qihong, Patil, Jay N., and Katz, Joseph L., Langmuir, Vol. 5, No. 3, p. 861-867, 1989.
47. **The Effect of Magnetic Fields on Calcium Carbonate Scale Formation** Dalas, Evengelos, Koutsoukos, G.J., Cryst. Growth, Vol. 96, No. 4, p. 802-806. 1989.
48. **Corrosion and Scaling in Water Supply Systems** Legrand, L. and Leroy, P., 1990.
49. **Who Knows the Secret of the Black Magic Tube?** Anon, Finishing, Vol. 14, No. 4, p. 27-28, April 1990.
50. **Magnetic and Electrostatic Methods of Water Treatment** Silman, Harold, Met. Finish, Vol. 88, No. 8, p. 19-20, 1990.
51. **Environmental Engineering 1991** Krenkel, Peter A., Proceedings National Association of Corrosion Engineers Annual Conference, Proceedings of the 1991 Specialty Conference, 1991.

52. **Magnetic Water Treatment** Russian Paper, Fluid-Tech International, 1992.
53. **Soviet Work in the Area of Non-Chemical Fluid Treatment** Russian Paper, Fluid-Tech International, 1992.
54. **Growing Attraction of Magnetic Treatment** Spear, Mike, Process Eng, Vol. 73, No. 5, p. 143 May 1992.
55. **Water Hardness** Russian Paper, Fluid-Tech International, 1992.
56. **Insulating Properties of Scale** Russian Paper, Fluid-Tech International, 1992.
57. **Non-Chemical Scale Control Devices** Limpert, G.J.C., and Raber, J.L., AWT Analyst, p 3- 11, July 1992.
58. **Studies of Some Properties of Magnetically Treated Water** Li, Dexin, et. al., Proc. Int. Symp. Phys. Magn. Mater., 2<sup>nd</sup> Vol 2, p. 809-812, 1992.
59. **Magnetic Treatment of Water - A Theoretical Quantum Model** Srebrenik, S., Magnetic and Electrical Separation, Vol 5, No. 2, p. 71-91, 1993.
60. **Calcite Growth Inhibition by Iron** Katz, J.L., Reick, M.R., Herzog, R.E., Parsiegl, K.I.,Langmuir, Vol. 9, No. 5, p. 1423-1430, 1993.
61. **Control of Scale and Corrosion in Building Water Systems** Lane, Russell W., McGraw-Hill Inc., p. 181-182, 1993.
62. **Effects of a Magnetic Field on the Formation of CaCO<sub>3</sub> Particles** Higashitani, Ko, et. al.,Journal of Colloid and Interface Science, Vol. 156, p. 90-95, 1993.
63. **Effect of Magnetic Field on Evaporator** Cole, Frank, Clarke, Margaret A., Proc. Sugar Process. Res. Conf., p. 64-68, 1993.
64. **Magnetic Water Treatment for Scale Prevention** Lipus, L., Krope, J., Garbai, L., Hung. J. Ind. Chem, Vol. 22, No. 4, p. 239-242, 1994.
65. **Electromagnetic Water Conditioners are Soft Option** H&V Engineer, Vol. 67, No. 724, p. 12-13, 1994.
66. **Calcite Growth and the Inhibiting Effect of Iron (III)** Takasaki, S., Parsiegl, K., Katz, J.L., Journal of Crystal Growth, Vol. 143, p. 261-268, 1994.
67. **Point-of-Use Treatment. Experience with Physical Water Conditioners in the Netherlands** Van Den Hoven, Th. et.al., Kiwa NV, Nieuwegein, 1994.

68. **Water Treatment - The Soft Option** Anon, H&V Engineer, Vol. 67, No. 722, p. 6-8, 1994.
69. **Magnetic Treatment of Water and Scaling** Paiaro, Sastone, Pandolfo, Luciano Ann. Chim, Vol. 84, No. 5-6, p. 271-274, 1994.
70. **Water Quality Association Position Paper on Catalytic, Electromagnetic, and Magnetic Devices Claimed to Treat Drinking Water**, revised July 1994.
71. **Prevention & Control of Water-Caused Problems in Building Potable Water Systems** TPC Publication 7 2nd Edition, NACE International, 1995.
72. **Consumer Alert: Magnetic Water Treatment Devices Do Not Work** Giani, Francine, News Release, Division of Drinking Water, State of Utah, March 15, 1995.
73. **Benefits of Permanent Magnets in Factory Evaporation** Cole, Frank, Clarke, Margaret A., Int. Sugar J., Vol. 98, No. 1166, p. 71-72, 1996.
74. **Magnetic Amelioration of Scale Formation** Baker, John S., and Judd, S.J., Wat. Res., Vol. 30, No. 2, p. 247-260, 1996.
75. **The Role of Zinc in Magnetic and other Physical Water Treatment Methods for the Prevention of Scale** Coetzze, P.P., Yocoby, M., Howell, S., Water SA, Vol. 22, No. 4, p. 319-326, 1996.
76. **Magnets That Don't Do Much to Soften Water** Consumer Reports, p. 8, February 1996.
77. **Magnetically - Enhanced Chemical Disinfection** Ifill, A.S., Baker, J.S., Jud, S.J., Process Safety and Environmental Protection: Transactions of the Institution of Chemical Engineers, Part B Vol. 74, No. 2, May 1996.
78. **Rapid Onset on Calcium Carbonate Crystallization Under the Influence of a Magnetic Field** Wang. Y., Babchin, A.J., Chernyl, L.T., Water Res., Vol. 31, No. 2, p. 346-350, 1997.
79. **Theory of Electronic Anti-Fouling Technology to Control Precipitation Fouling in Heat Exchangers** Cho, Young I., Fan, Chunfu, Choi, Byung-Gap, Int. Comm. Heat Mass Transfer, Vol. 24, No. 6., p. 757-770, 1997.
80. **Using Magnetic Fields to Prevent Scale** Benson, Robert, et. al., Chemtech, Vol. 27, No. 4, p. 34-38, 1997.
81. **Laboratory Studies on Magnetic Water Treatment and their Relationship to a Possible Mechanism for Scale Reduction** Busch, Kenneth W., Busch, Marianna A.,

Desalination, Vol. 109, No. 2, p. 131-148, 1997.

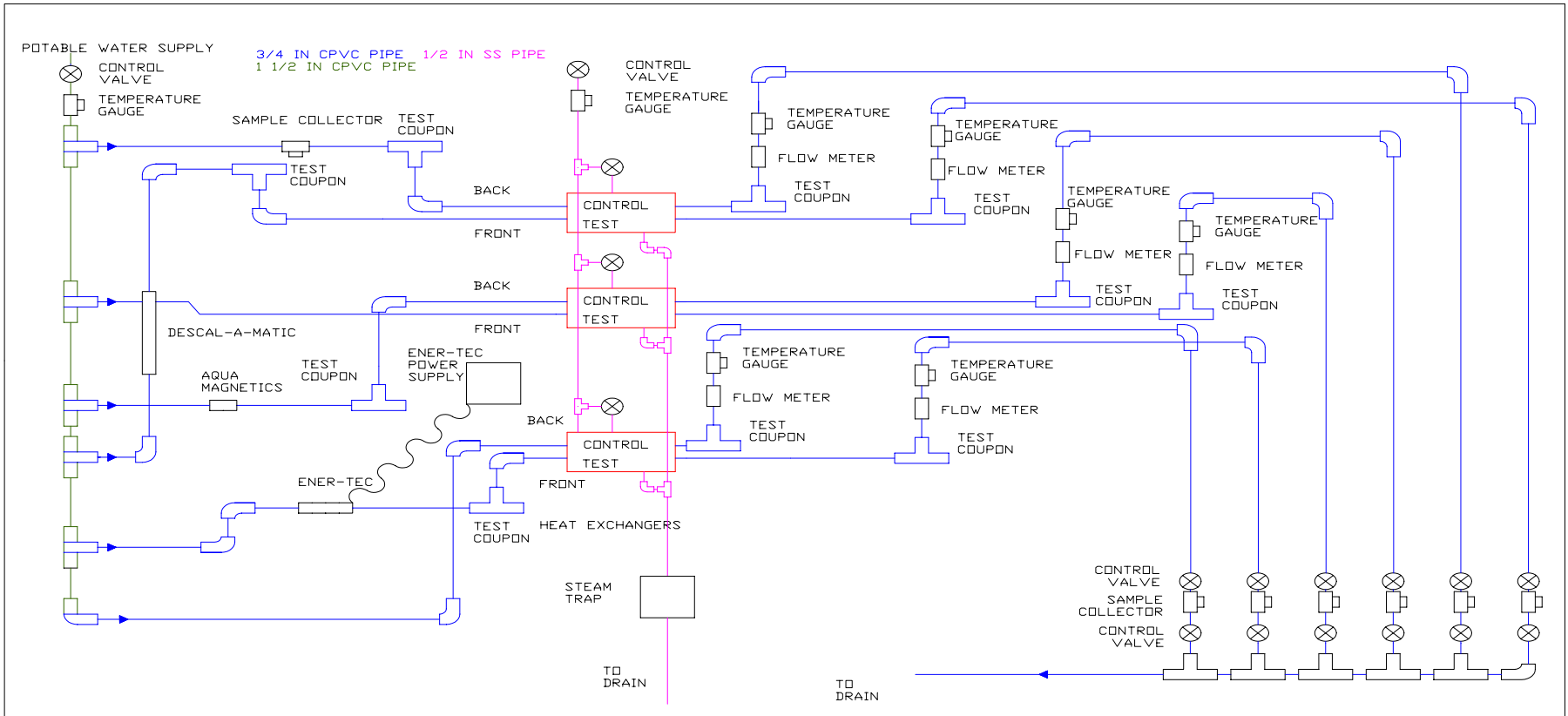
82. **Control Factors in Performance Testing of Nonchemical Water Treatment Devices** NACE Technical Committee National Association of Corrosion Engineers, reaffirmed 1997.
83. **Magnetic Treatment of Calcium Carbonate Scale-Effect of pH Control** Parson, S.A., Bao-Lung, W., Judd, S.J., Stephenson, T., Wat. Res., Vol. 31, No. 2, p. 339-342, 1997.
84. **Basics of Magnetism** Webster, H.A., Correng Publications Service Inc., T-7, p. 1-12, September 1998.
85. **Magnetic Water Treatment for Scale Prevention** Lipus, L., Krope, J., Garbai, L., Hung. J. Ind. Chem, Vol. 26, No. 2, p. 109-112, 1998.
86. **Synergistic Application of Chemical and Electromagnetic Water Treatment in Corrosion and Scale Prevention** Colic, Miroslav, Chien, Allen, Morse, Dwain, Croatian Chemical Society, 1998.
87. **Do Magnetic and Electromagnetic Water Conditioners Work?** Henke, Larry, Water Conditioning & Purification, p. 70-74, July 1998.
88. **Removal of Iron From Sodium Fluorosilicate Scale by Magnetic Treatment** Wang, Chuha, Benson, R., Martin, Dean F., Fla. Sci, Vol. 61, No. 2, p. 88-95, 1998.
89. **Standards for Magnetic Devices Still Seem a Long Way Off** Cummings, Sean, Water Technology, pp 37-42, April 1998.
90. **Predictably Effective Equipment and In Situ Processes Applied to Water Systems** NACE Technical Committee Proceedings National Association of Corrosion Engineers Annual Conference, June 1998.
91. **The Role of Chemical Constituents and Their Effects on Scale Inhibition Following Magnetic Treatment** Reimers, Robert S., Shariat, S.D., Carpenter, Roland K., and Akers, Thomas R..
92. **Magnetic Water Treatment De-Mystified** Kronenberg, Klaus J., Magnets, p. 6.
93. **Non-Chemical Technologies for Scale and Hardness Control** U.S. Department of Energy DOE/EE-0162.
94. **Magnetically Augmented Water Treatment** Parson, S.A., Bao-Lung, W., Judd, S.J., Udol, K., School of Water Sciences, Cranfield University.
95. **Measurements of Magnetic Effects on Electrolyte Solutions by Atomic Force**

Microscope Higashitani, Ko, et. al., Department of Chemical Engineering, Kyoto University.

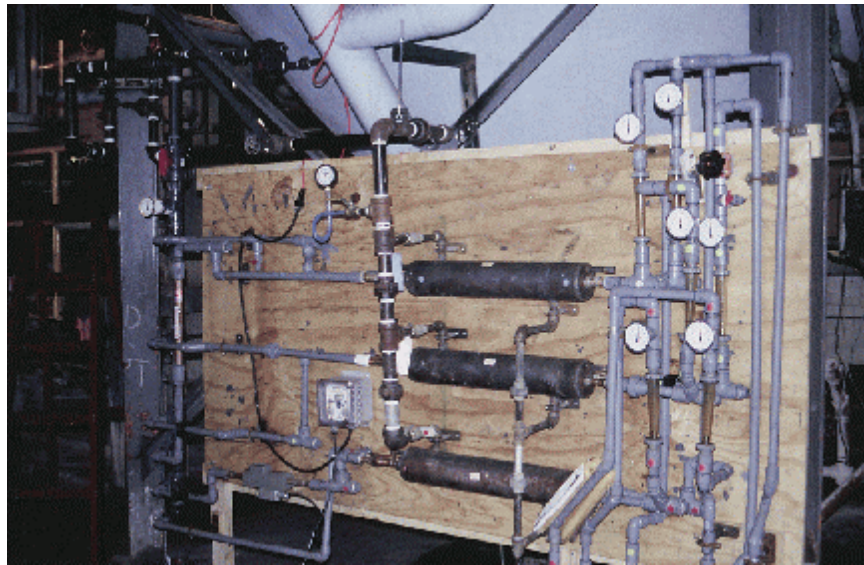
96. **Non-Chemical Water Treatment Technology in Energy Savings Performance Contracting** Soloman B. Williams, Tyndal AFB FL.
97. **Standard Methods.** 17<sup>th</sup> edition, p. 3-54, 1989.

## **APPENDIX C**

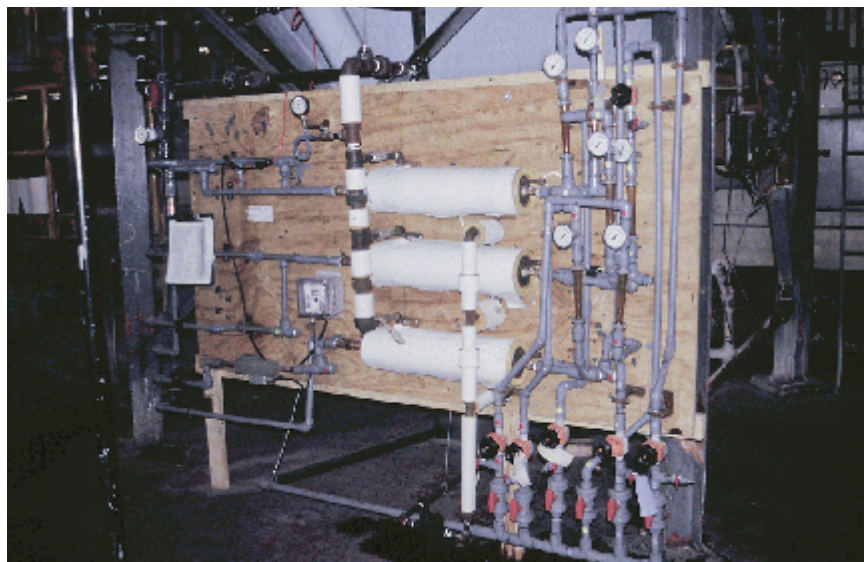




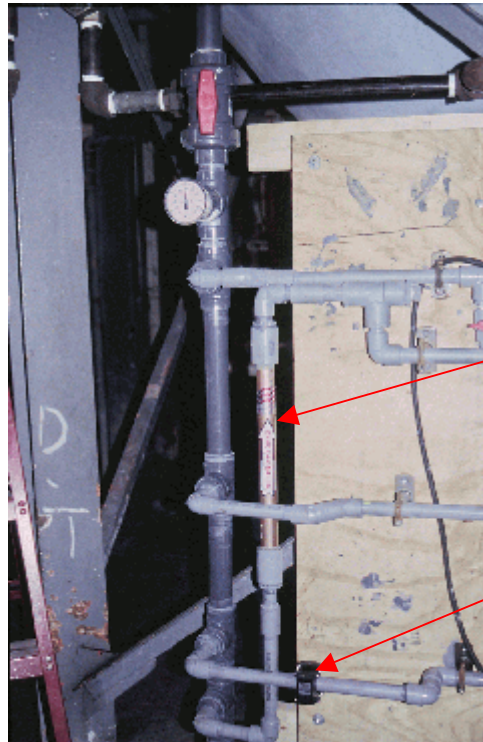
**Figure C1: Schematic of Test Apparatus**



**Figure C2**  
**Test Apparatus Before Insulation**



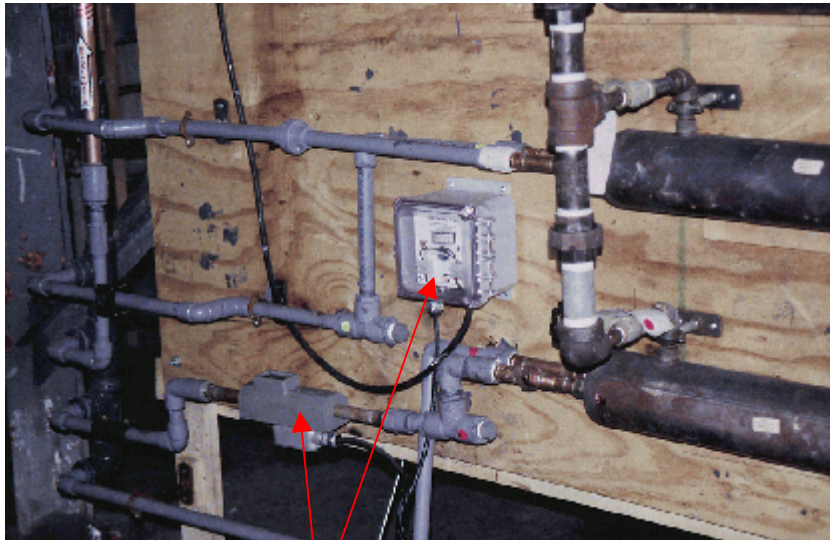
**Figure C3**  
**Test Apparatus After Insulation**



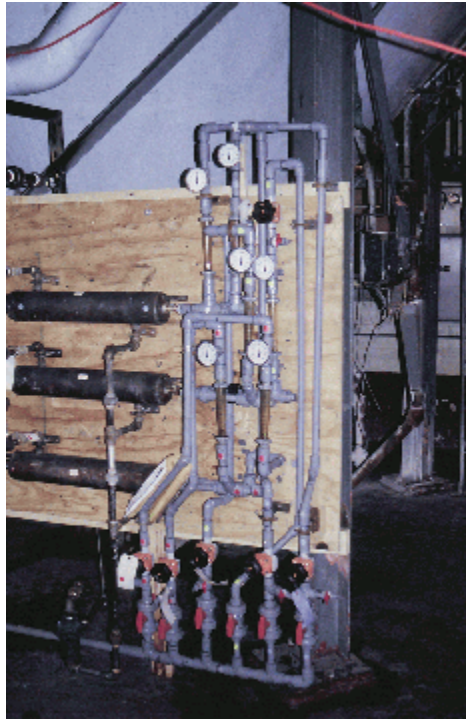
Descal-A-Matic  
Device

Aqua Magnetic  
Device

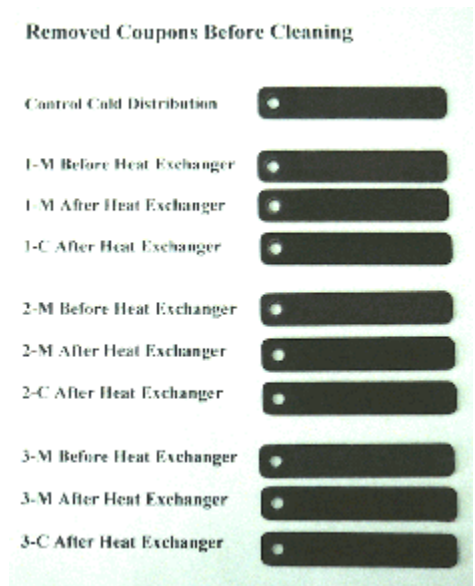
**Figure C4**  
**Descal-A-Matic and Aqua Magnetic Devices**



**Figure C5**  
**Ener Tec Device**



**Figure C6**  
**Temperature Gauges, Flow Meters and Control Valves**



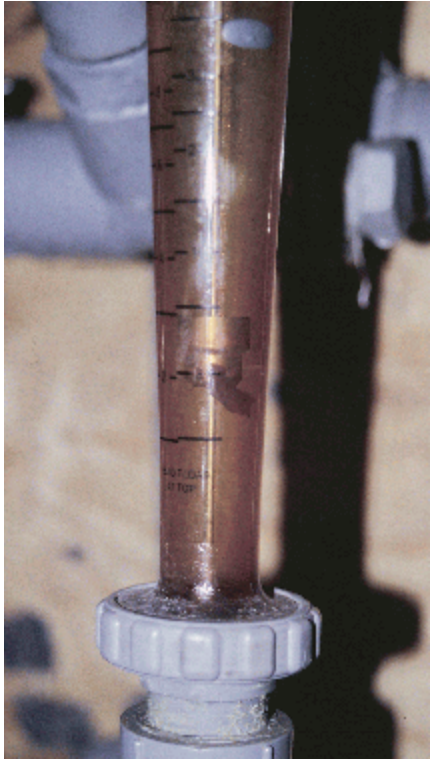
**Figure C7**  
Corrosion Coupons before cleaning



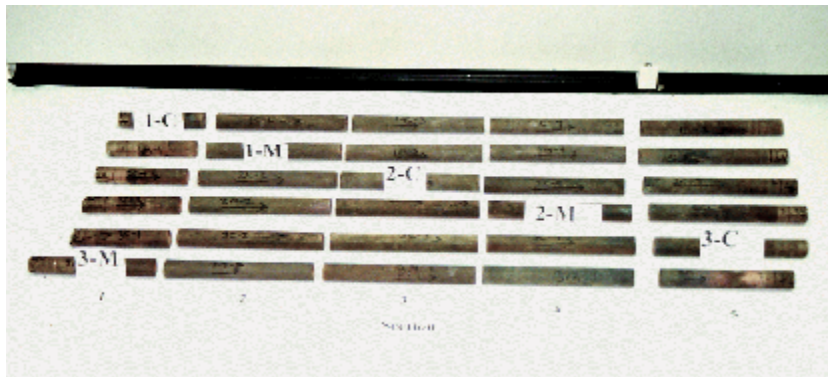
**Figure C8**  
Corrosion Coupons after cleaning



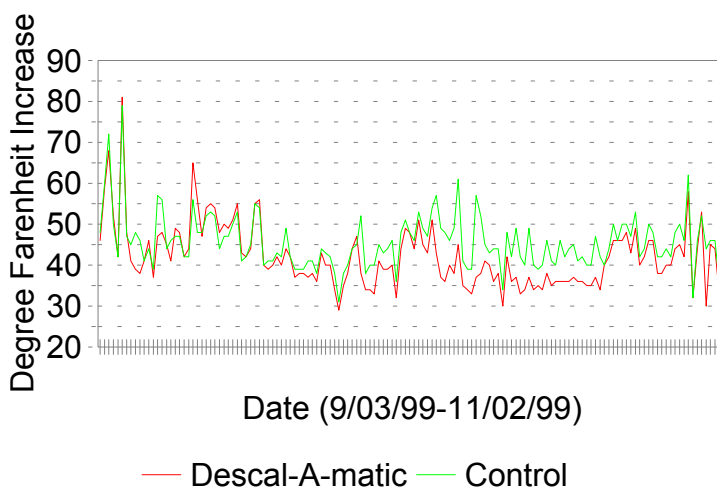
**Figure C9**  
**Restricted Opening – Flow Meter**



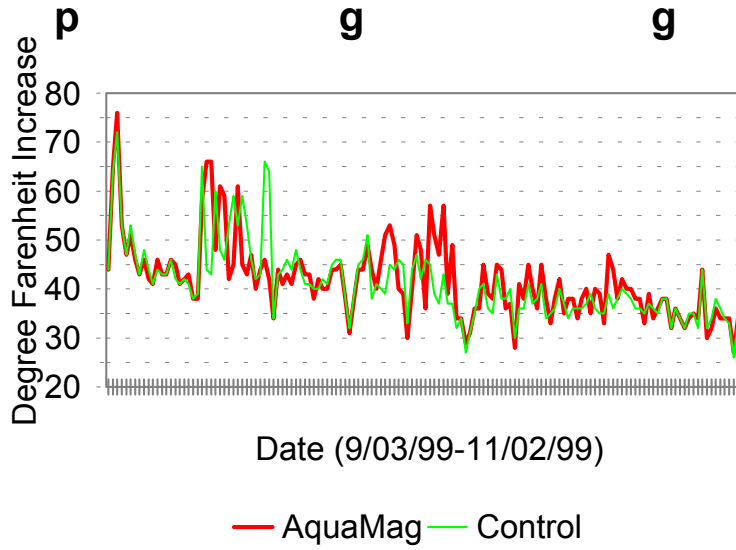
**Figure C10**  
**Flowmeter with Scale**



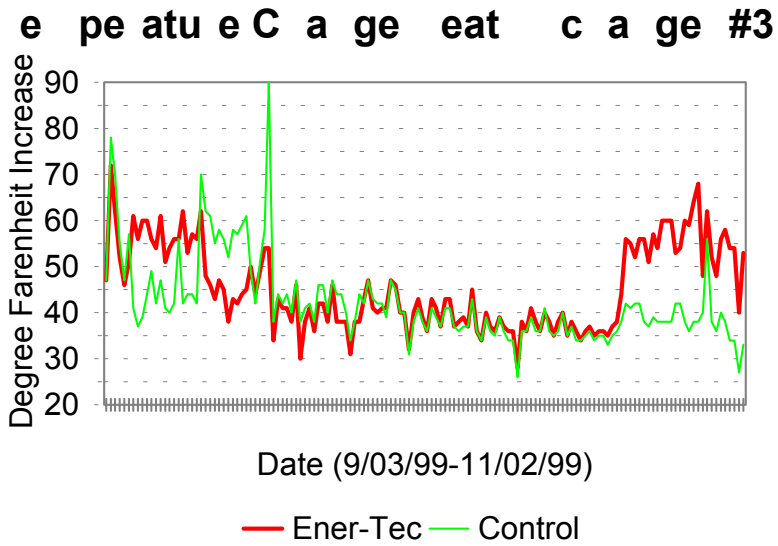
**Figure C11**  
Heat Exchanger Segments



**Figure C12**  
Temperature Change Heat Exchanger #1

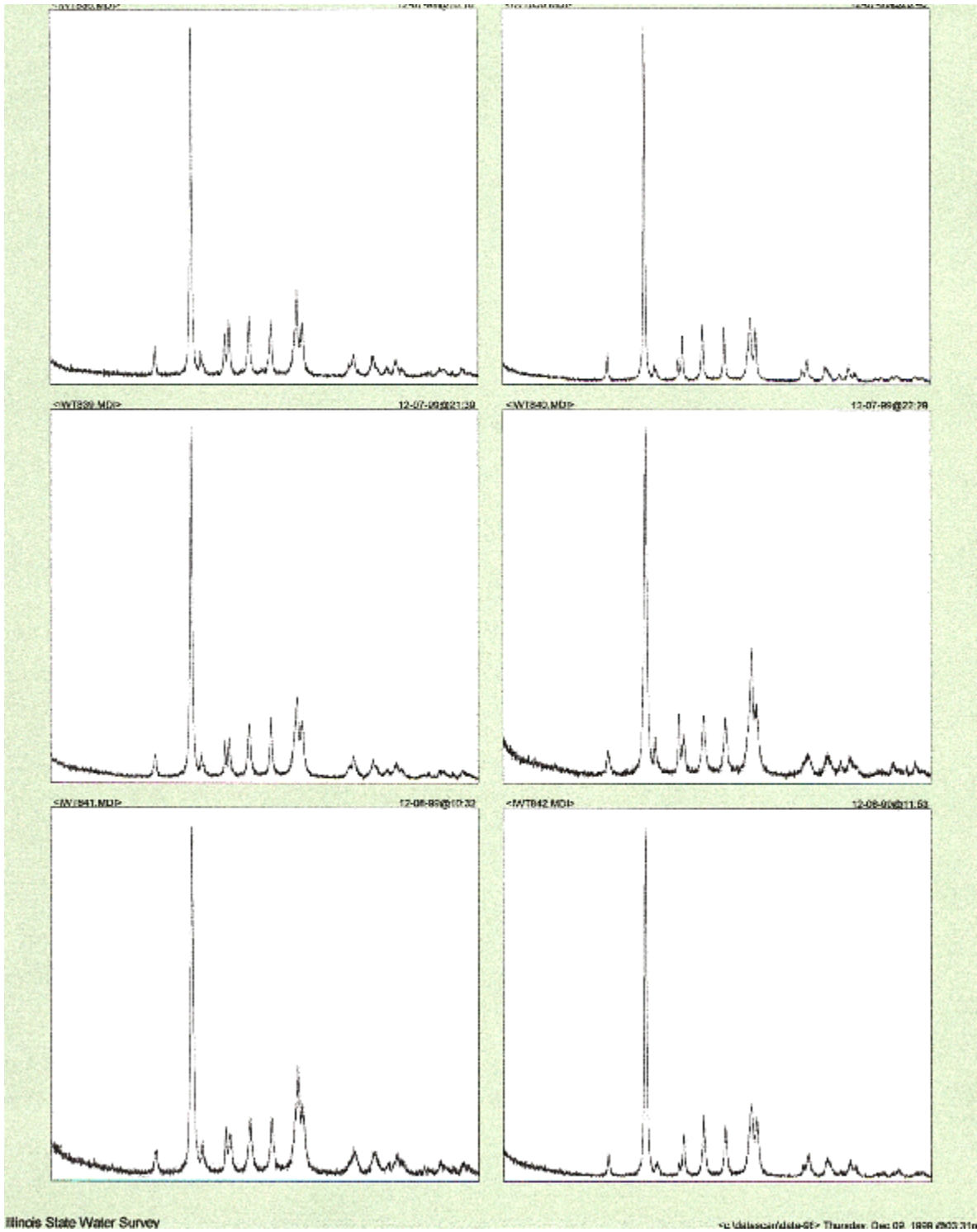


**Figure C13**  
**Temperature Change Heat Exchanger #2**



**Figure C14**  
**Temperature Change Heat Exchanger #3**





**Figure C15**  
**XRD Pattern Comparison**

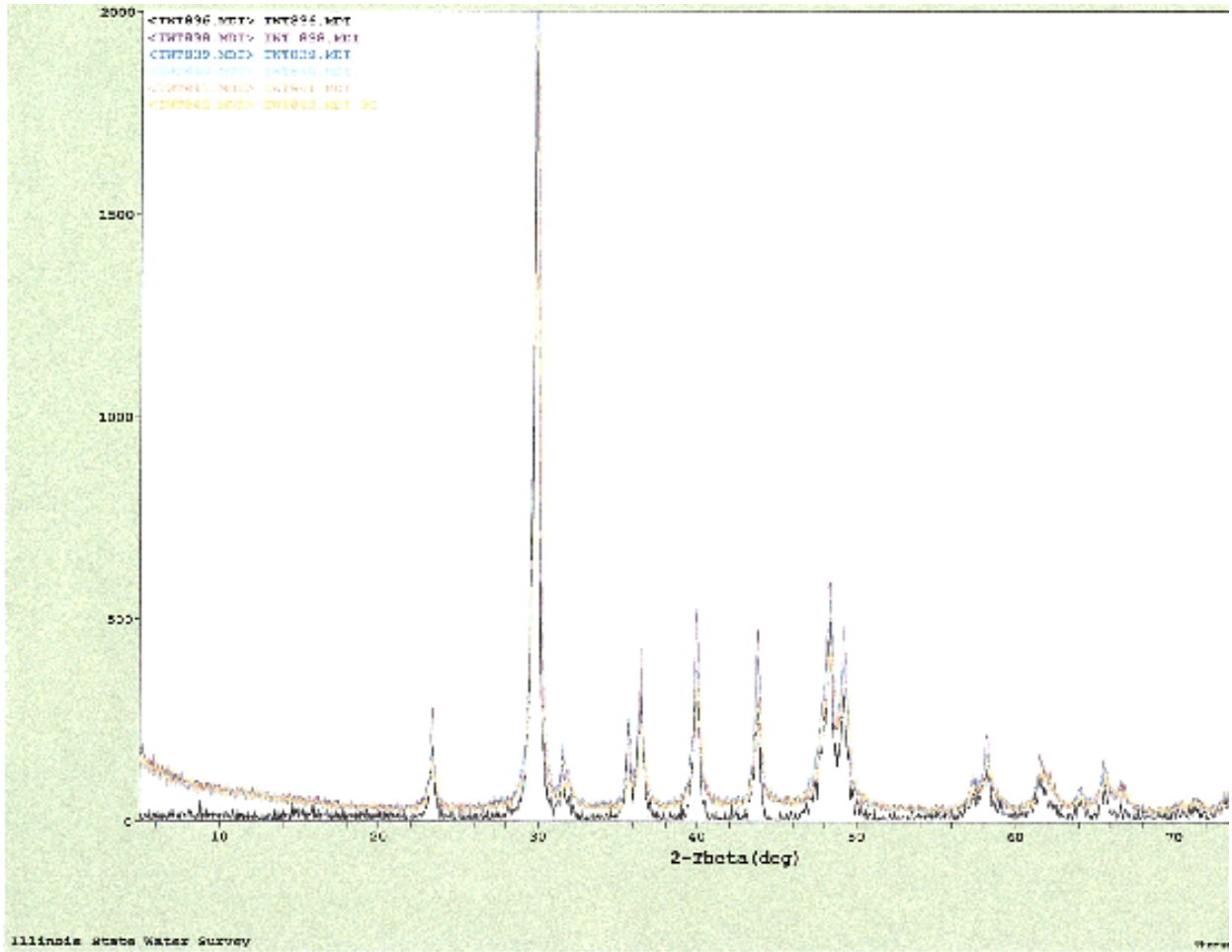
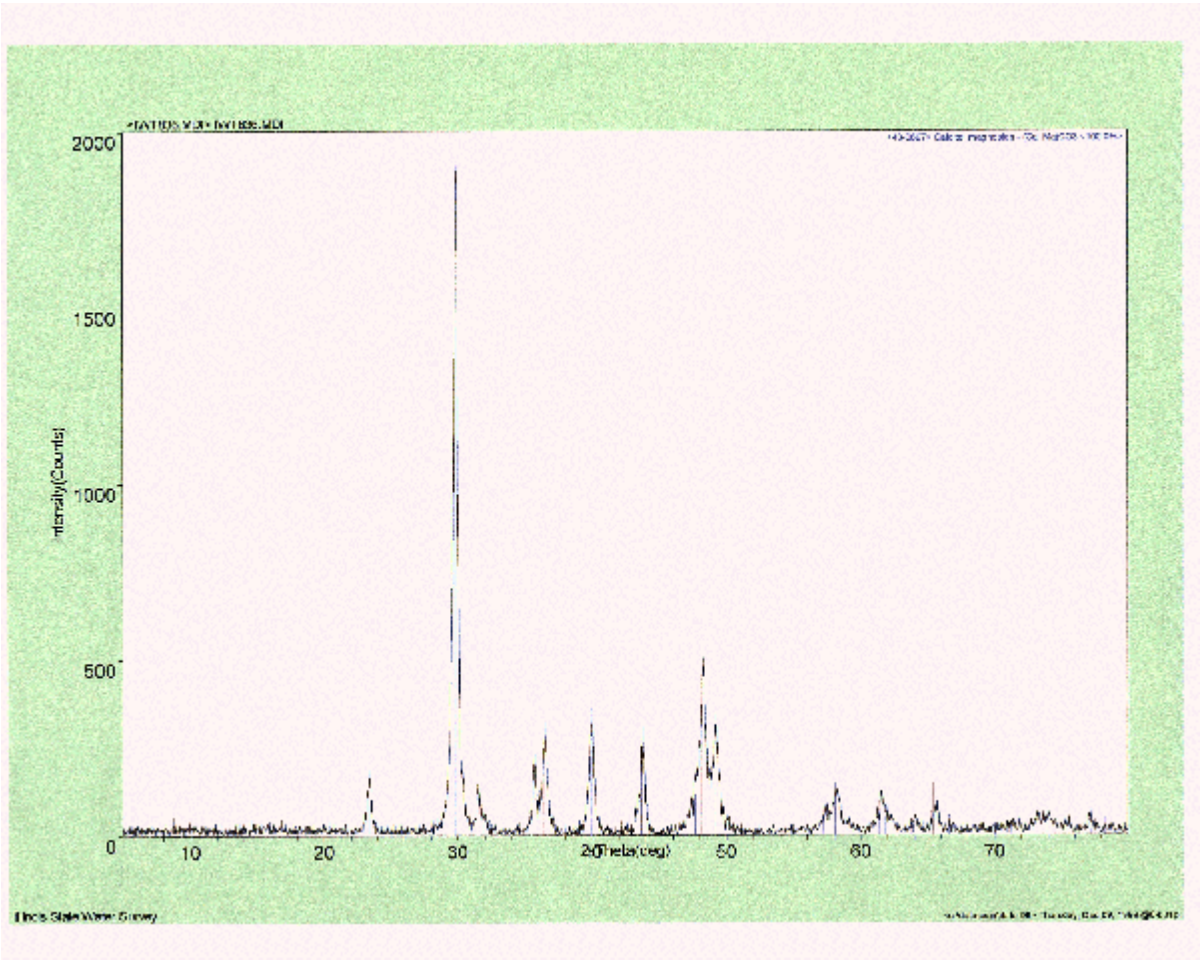
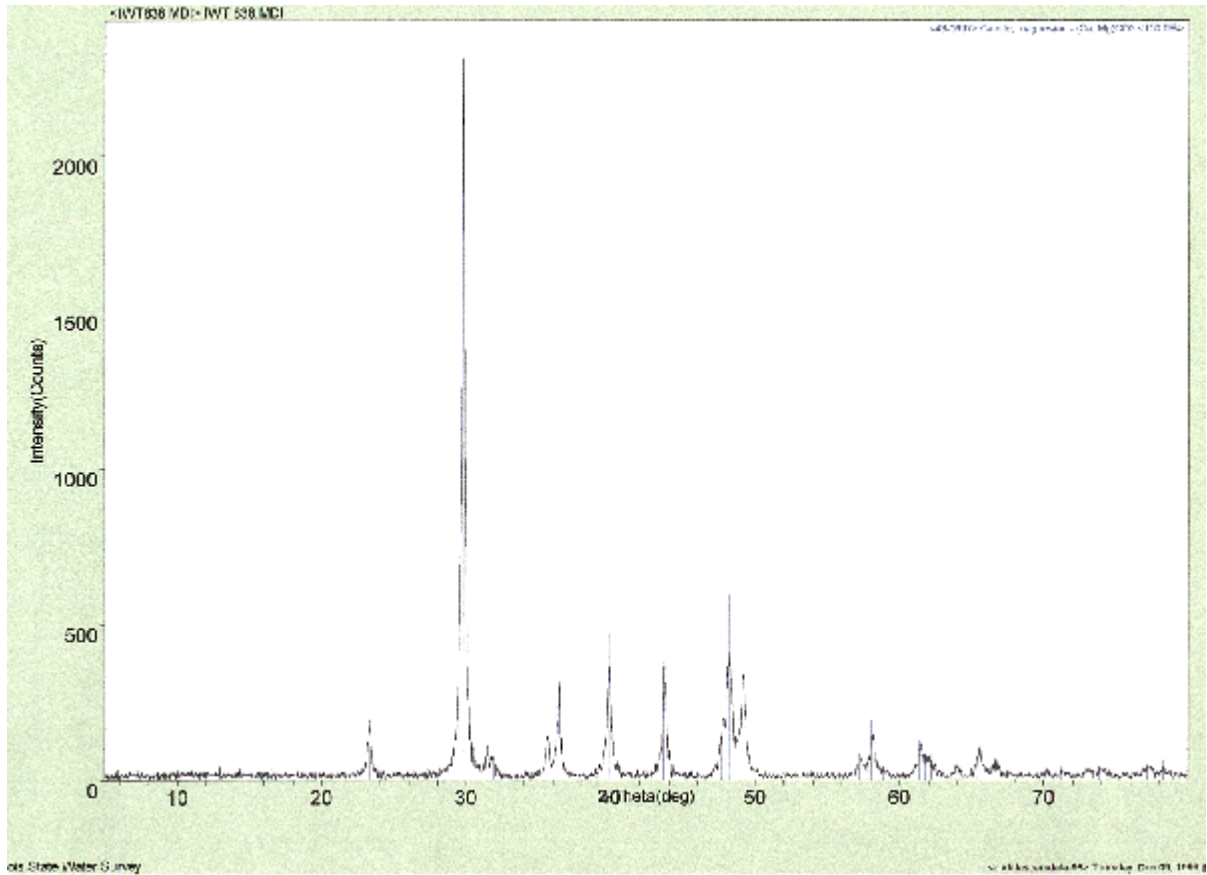


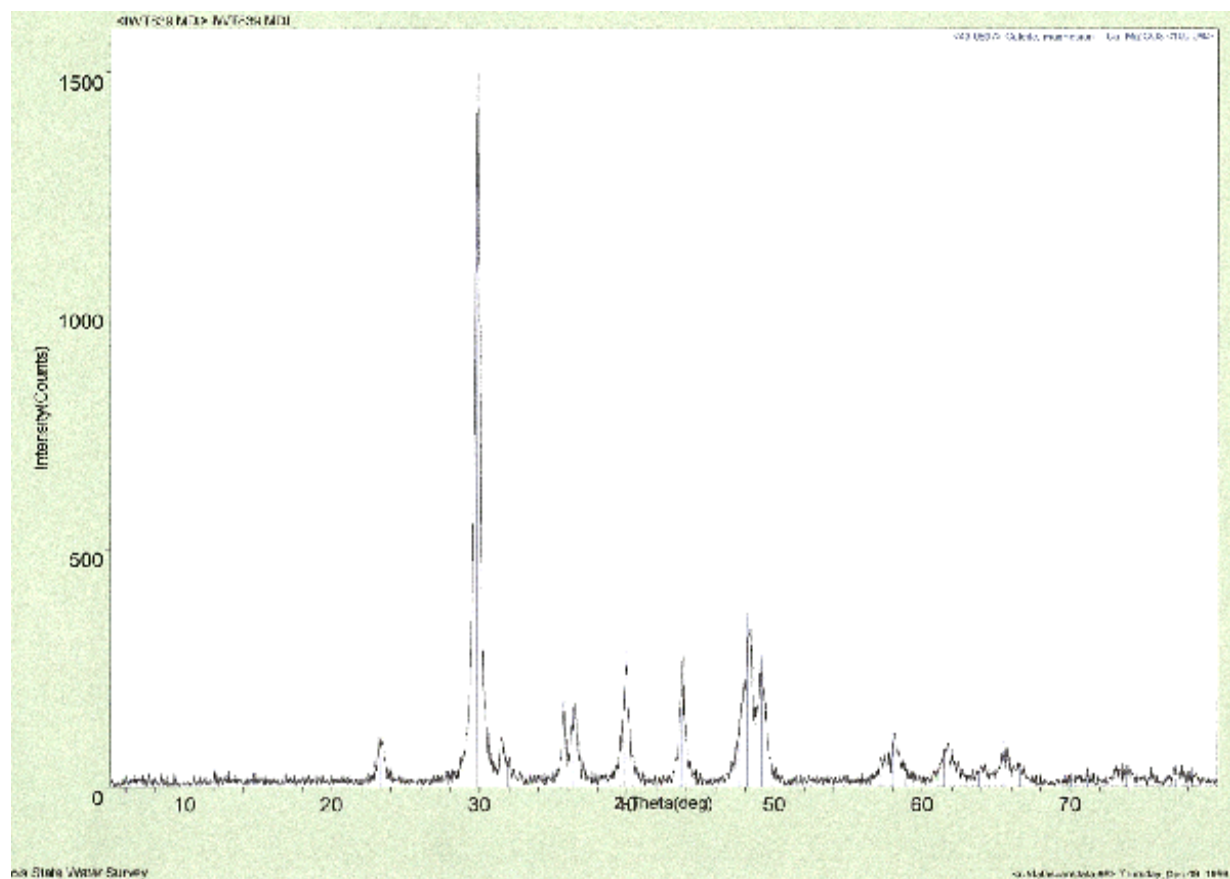
Figure C16  
XRD Pattern Overlay



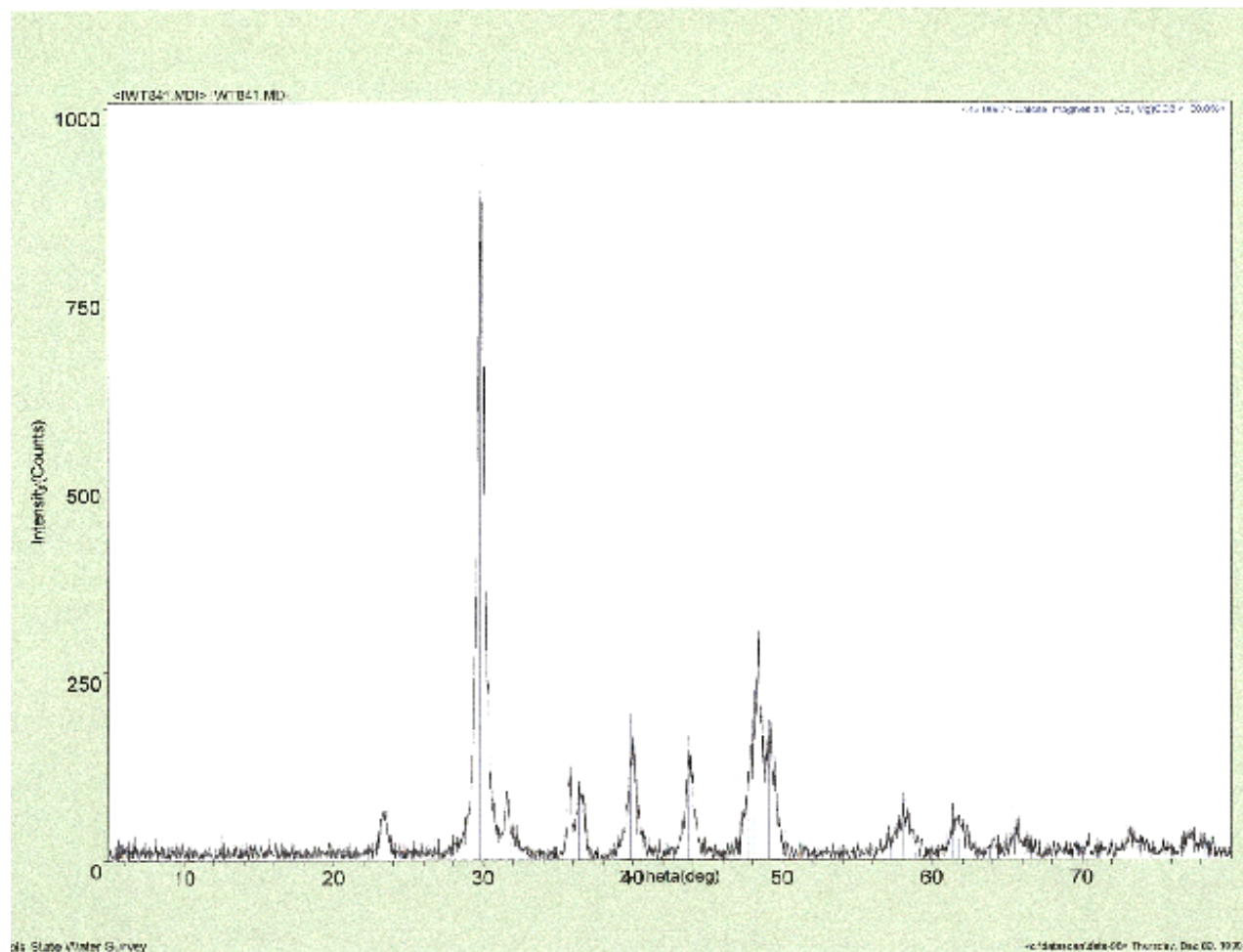
**Figure C17**  
**Descal-A-Matic Device XRD Pattern**



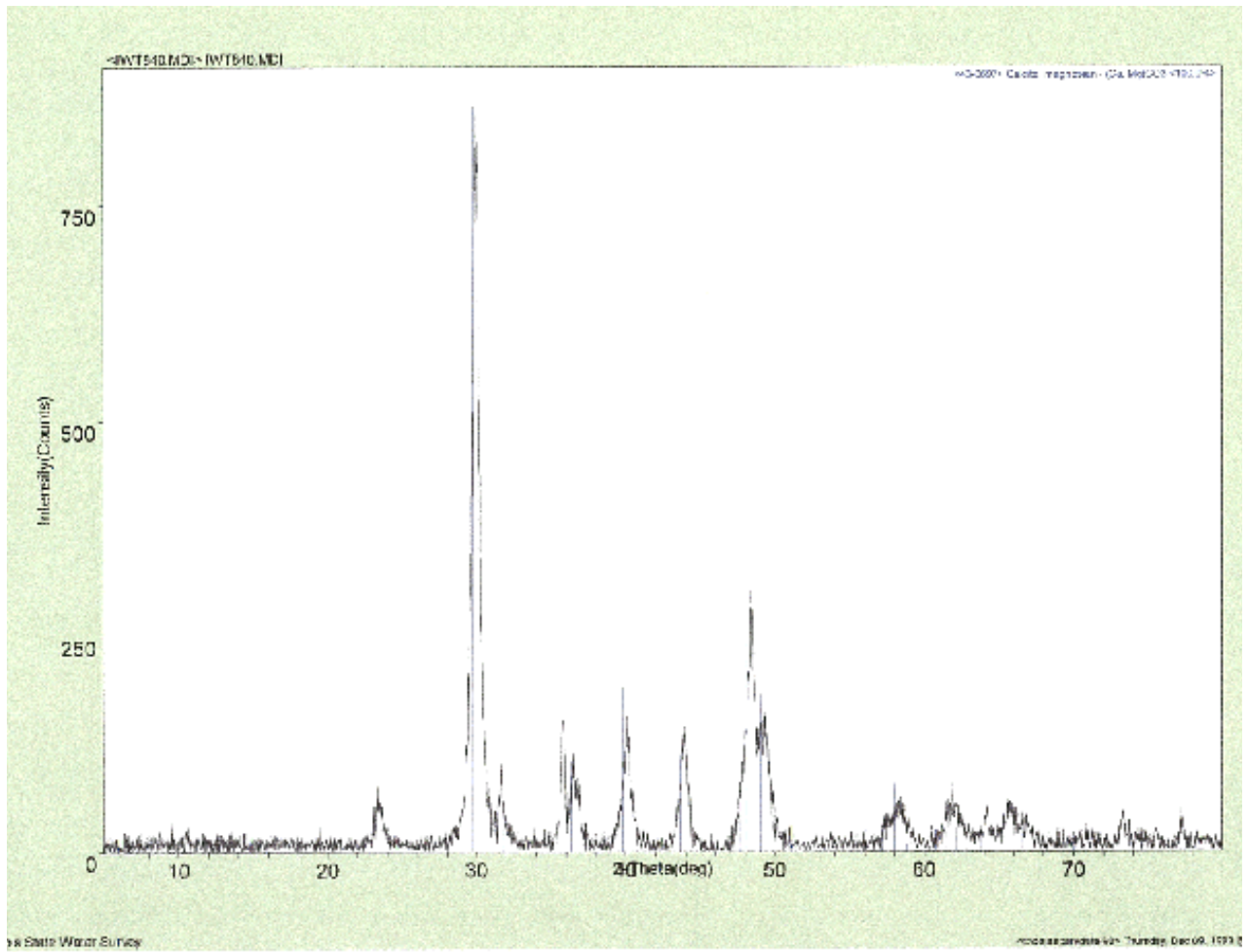
**Figure C18**  
**Aqua Magnetic Device XRD Pattern**



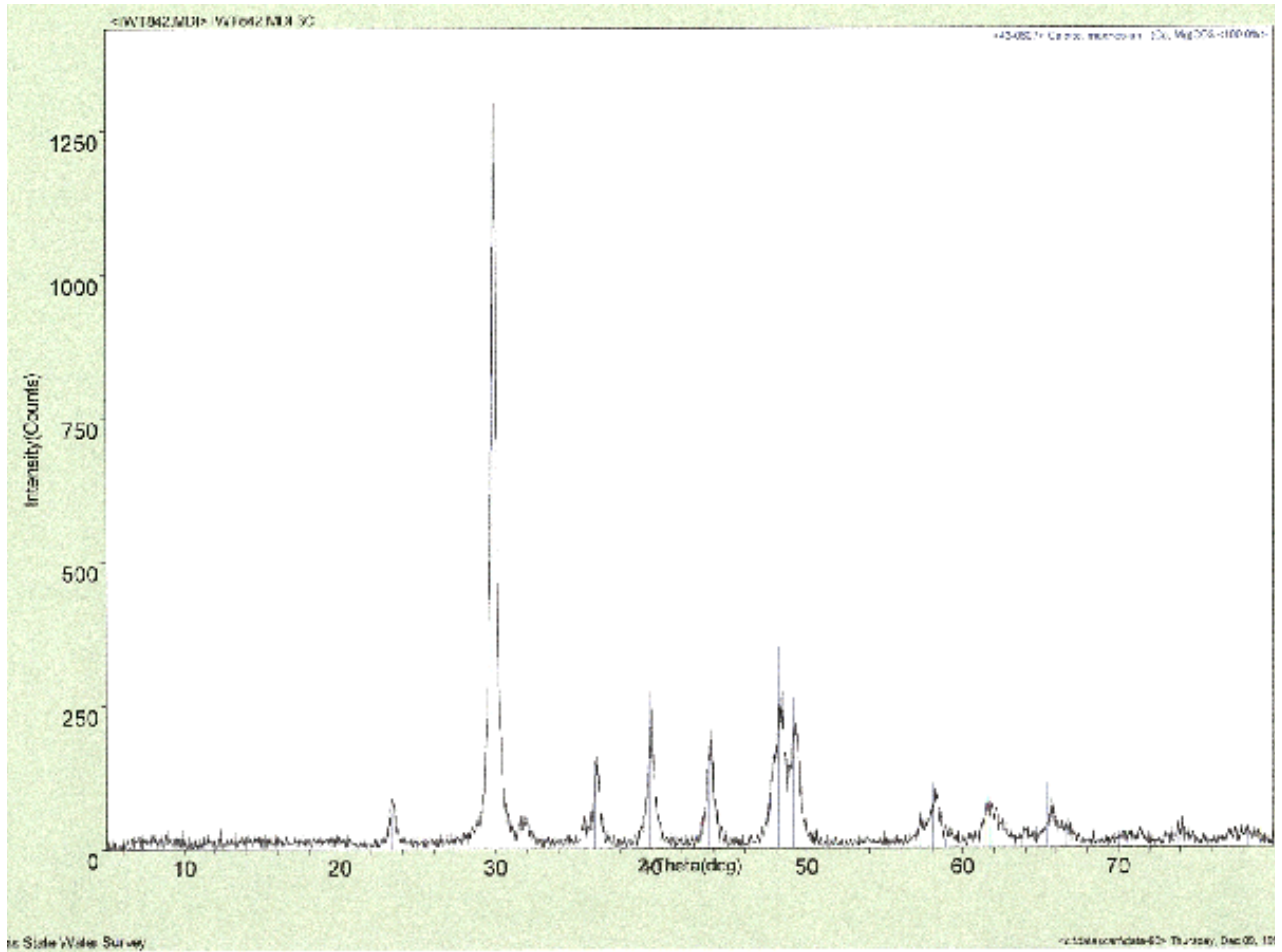
**Figure C19**  
**EnerTec Device XRD Pattern**



**Figure C20**  
**Descal-A-Matic Device Control XRD Pattern**

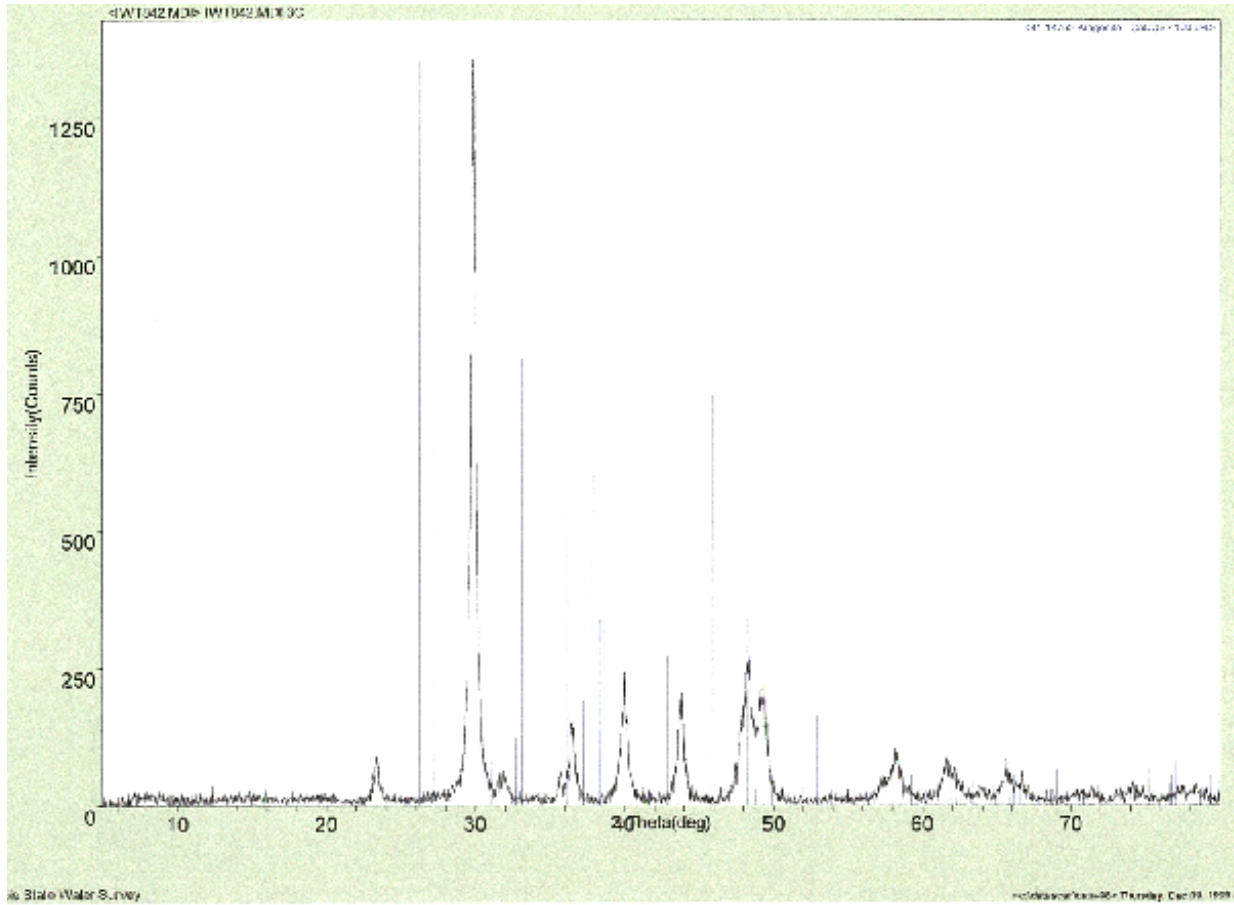


**Figure C21**  
**Aqua Magnetic Device Control XRD Pattern**



**Figure C22**  
**EnerTec Device Control XRD Pattern**





**Figure C23**  
**Aragonite Reference Peaks**

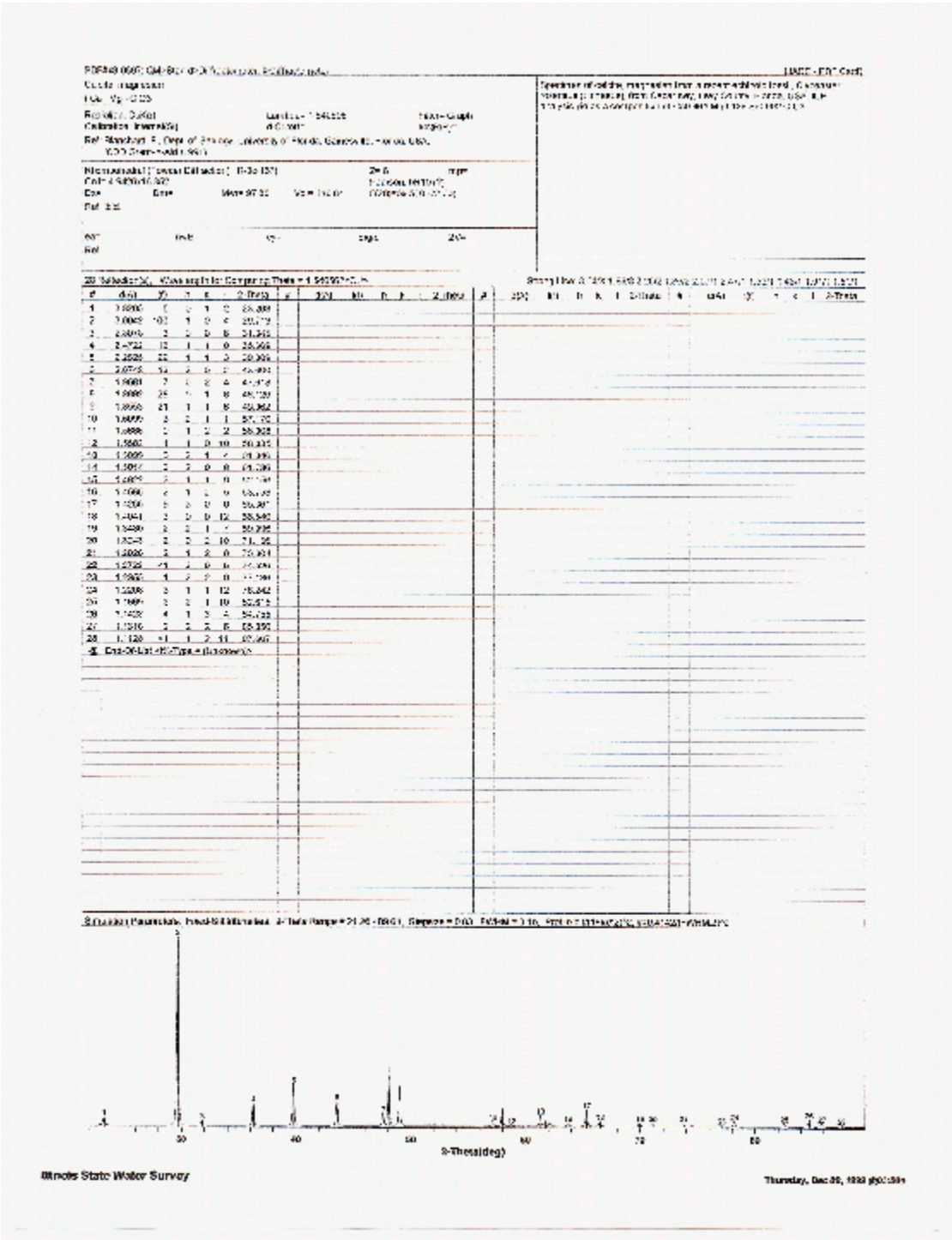


Figure C24  
 Calcite (magnesian) PDF Card