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CHEMICAL TREATMENT SYSTEM EVALUATION FOR THE SALT WATER COOLING SYSTEM AT CALVERT CLIFFS NUCLEAR POWER PLANT (XX-dddd)

XX-dddd
Research Project ----=--

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ABSTRACT

As part of BG&E's Calvert Cliffs Nuclear Power Plant (CCNPP) Life Cycle Management Project, the Salt Water (SW) system (open cycle service water) was identified as a contributor to the unavailability of Safety Related components. The predominant reason for this unavailability, is the maintenance required to restore reductions in the performance of heat exchangers, due to macro and microfouling. Based on the experience of other plants, it was decided to evaluate a chemical treatment program at CCNPP to control microfouling, and to assess the impact on macrofouling and corrosion.

Betz Clamtrol CT-1, a non-oxidizing biocide, was selected because of its effectiveness at controlling biofilm levels at other plants, its acceptability to environmental regulatory agencies, and its surfactant characteristics. This chemical is widely used for the control of zebra mussels and other mollusks in marine and estuarine environments.

The treatment program utilized a movable, skid mounted package to feed CT-1 for one hour a week into the discharge of the SW pumps. In order to determine the effectiveness of the program, only two of four trains were treated. The debris from cleaning of the heat exchanger tubes was collected, dried and weighed for comparison. Additionally, sessile bacteria monitoring/corrosion racks were installed down stream of each heat exchanger.

The treatment program was closely adhered to in Unit 2, only two of 15 treatments were missed. Unit 1 treatments were sporadic due to plant conditions, 9 of 15 treatments were applied at varying intervals. The results of this study indicate that the program was effective in reducing microfouling in the tubes of treated heat exchangers, if the treatment program is adhered to. This report presents further details, results and conclusions from this study.

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Section 1

THE SALT WATER SYSTEM

As part of the Calvert Cliffs Life Cycle Management project, the Salt Water (SW) system (an open cycle service water system) was identified as a major contributor to the unavailability of Safety Related components. The predominant reason for this unavailability is the maintenance required to restore reductions in the performance of the heat exchangers due to macro and microfouling. Modifications to these heat exchangers have been proposed and evaluated, but would require significant capital expenditures and significant plant outage time to implement. Based upon work and operating practices performed at other plants, a relatively low cost, low capital alternative of chemical treatment was evaluated at the Calvert Cliffs Nuclear Power plant to control microfouling, and assess the impact on macrofouling and corrosion.

The purpose of the Salt Water (SW) system at Calvert Cliffs is to transfer heat from the component cooling heat exchangers, the Service Water heat exchangers, and the Emergency Core Cooling System (ECCS) Pump Room air coolers to the Chesapeake Bay, which is the ultimate heat sink for the Plant. The SW system also provides seal cooling water to the Circulating Water Pumps. This system consists of three salt water pumps (one of which is a spare pump) and two trains in each Unit, including the associated valves and piping leading to the various heat exchangers and air coolers served by the system. The heat exchangers are rubber lined carbon steel, while the tube material is 90/10 copper nickel. A combination of macro and microfouling have occurred in these heat exchangers, resulting in frequent inlet channel tubesheet cleanings and four heat exchanger bulletings per train (16 total) per year. These frequent cleanings and maintenance bulletings resulted in large contributions to emergency diesel unavailability and corresponding entries into plant Technical Specification Limiting Condition for Operation. Plant Technical Specifications require Unit shutdown if either train of the SW system is out of service for more than 72 hours.

In assessing the various alternatives, initial efforts focused on installation of a spare heat exchanger to permit periodic maintenance without entering a Tech. Spec. limiting condition. However, an alternative solution would be to minimize the need for cleaning the heat exchangers by minimizing heat exchanger fouling. Various chemical treatment programs were reviewed to accomplish this objective. Previous attempts to minimize fouling using sodium hypochlorite were unsuccessful primarily due to the poor availability of the system at Calvert Cliffs. Other utilities have experienced success
controlling fouling using alternate chemicals such as Clamtrol or hydantoin. Based upon discussions with Betz Laboratories, a method of performing injections using a portable system could be supported with minimal initial capital investment. A test program was developed jointly by Baltimore Gas and Electric and Betz Laboratories with the goal of determining if an alternative chemical treatment program could be developed to preclude microfouling of these critical heat exchangers.

Section 2

TREATMENT PROGRAM DESCRIPTION

Macrofouling and microfouling has been a problem at Calvert Cliffs for a number of years. The macrofouling consists of oysters, crabs, barnacles, hydrozoans (Garvia fracescana) and bryozoans that are either transported to the heat exchangers during operation, or grow in the heat exchangers in the warm, nutrient rich environment. The material transported to the heat exchangers can become lodged at the tube inlets. It is these types of organisms that are removed during the casual cleanings performed as a part of plant operation. While these cleanings are performed on a sometimes frequent basis, they can be performed rather quickly, and do not represent a large contribution to system downtime. Microfouling, on the other hand, is a biofilm, composed of mud, silt, and microorganisms that deposit on the inside diameter surface of the heat exchanger tubing. Such recurrent microfouling has resulted in the quarterly cleanings of the heat exchanger that represent the largest contribution to system unavailability. Microfouling control was the prime objective of the treatment investigation.

The mechanism for microfouling is important to understand as the chemical treatment program and monitoring was influenced by this mechanism. Initially, naturally occurring microorganisms in the bulk Chesapeake Bay water (termed planktonic organisms) attach to the tube ID surface. Once attached (sessile), these organisms begin to colonize the metal surfaces. The sessile microorganisms secrete polymers which firmly adhere to the metal surfaces and prevent the cells from being swept away by the flow of the cooling water. Additionally, these polymers are sticky in nature and therefore aid in the attachment of new microorganisms to the colonized surface as well as other nonliving debris from the bulk water. Cells already on the metal surface continue to grow, replicate, and secrete additional polymeric materials, encouraging further growth of the biofilm. In some instances, the resulting microbial induced deposition has become so severe that complete tubes have been filled with the biofilm material.

Swabs containing biofilm material were obtained from the Calvert Cliffs heat exchangers. Analysis of this material identified only 5-10% of the resulting deposit consisted of actual microorganisms. This is typical of most biofilms as the combination of microbes and polymers can be comprised of 80-90% water by weight. As a result, biofilms have thermal conductivities approaching that of water and reduce heat transfer efficiency similar to what would be seen if an added layer of stagnant water were present. The thermal conductivity of the 90/10 copper/nickel tubing in the Calvert Cliffs heat exchangers is several orders of magnitude greater than the thermal conductivity of water. Therefore, a small increase in the thickness of a biofilm can have can have a very large impact on heat exchanger performance.

In order to remove this material, and restore heat exchanger performance, the heat exchanger must be isolated from the system, drained and the channel cover removed to permit access to the inlet and outlet tubesheets. A cleaning operation is then performed, where the tubes are scraped, one by one, using water

at high pressure to propel spring loaded steel cleaners through the tubes. This type of cleaning is referred to as "bulleting". It is precisely these bulletting operations that have the largest impact on the SW system availability, with as many as 16 total bullettings performed each year. The initial target of the chemical treatment program was the microfouling occurring on the heat exchanger tube surfaces.

In order to address the microfouling, Betz Clamtrol (CT-1) was selected as the chemical of choice. This chemical is a non-oxidizing biocide that has been extensively used in the Great Lakes area for control of zebra mussels, and more recently other mollusks in marine and estuarine environments. Additionally, this particular product has been effective in controlling microfouling at other plants. The major active ingredients in CT-1 are two cationic surfactants, the first being a quaternary ammonium compound, and the second a dodecylguanidine salt. In sufficient concentrations these compounds damage bacterial cell membranes or interfere with the metabolic pathways of the cell. Due to the surfactant properties of CT-1, it can also penetrate the biofilm, removing it from the surface of the system metallurgy. Additionally, removal of the biofilm has an added benefit in that it reduces the potential for Microbiologically Influenced Corrosion (MIC).

The initial target treatment program was to feed product such that a residual of approximately 30 ppm of CT-1 reached the heat exchanger to be treated for a one hour period, once per week. In order to determine the effectiveness of the product in this system, two of the four trains were treated (one per unit), while two trains were left untreated. This set-up permitted a direct comparison of two heat exchangers in each unit so that treatment efficacy could be assessed.

Additionally, so that a more real time data comparison could be performed, the system metallurgy and potential for microfouling was simulated through the installation of corrosion racks on the treated and untreated headers in each unit. These racks were located downstream of the heat exchangers, near the outlet channel. Each corrosion rack consisted of a flow limiting orifice prior to and immediately after the rack to maintain the rack in a flooded condition during the study. Each rack included two corrosion coupons (one with mild steel and the other with 90/10 copper/nickel material (consistent with the heat exchanger tube material). An instantaneous corrosion probe with 90/10 copper nickel tips and two nickel-chromium mesh microbiological (MB) screens were also included so that corrosion rates and MB levels could be determined on a weekly basis during the test program.

Section 3

DATA ANALYSIS AND COLLECTION

The weekly additions of Clamtrol and the associated data collected represented an extensive effort. Each week, the following analyses were conducted to better understand the effect of the treatment and to verify that there were no adverse effects.

Aquatic Toxicity Testing

Aquatic toxicity testing was performed by an independent laboratory to assure that no toxic concentrations were being discharged into the Chesapeake Bay. Such toxicity testing was performed twice, the first during the initial weeks of the program when a 15 ppm concentration for two hours was used. The second test was conducted when the concentration was increased to the target level of 30 ppm, and the injection time was reduced to one hour.

Outfall Concentrations

Outfall concentration tests were performed during every addition to ensure the Clamtrol was consumed in the system and that none could be detected in the discharge to the Bay.

System Demand

Effective concentrations and theoretical uptake of the product in the system were determined. System concentrations were measured at the discharge of the treated heat exchanger and compared to the theoretical concentrations based upon flow indicators.

Instantaneous Corrosion Rates

Instantaneous corrosion rates prior to treatment and during treatment were obtained to determine if any adverse effect on corrosion rates could be seen during application of the product.

Bacterial Activity

As previously cited, screen mesh coupons were included in the corrosion rack to permit monitoring of the sessile aerobic and sulfate reducing microorganisms. Understanding the levels of the sessile bacteria from week to week can provide additional insight relative to the condition of the metal surfaces in the heat exchangers and the degree of microfouling. Simple bulk water counts are not effective in establishing these trends, as the sessile bacteria are responsible for microfouling. The screen coupons were removed on a periodic basis, sonicated to

remove the sessile organisms, and samples inoculated and cultured to determine the bacterial levels. This permitted a direct comparison of the bacterial levels between the treated and untreated heat exchangers.

Suspended Solids

Pre and post treatment suspended solids testing was initially performed on water samples from the corrosion racks to ascertain how much material was being removed from the system surfaces during system treatments. In addition to functioning as a biocide, Betz Clamtrol also exhibits surfactant properties. This permits the product to penetrate the biofilm present on the pipe and tubing surface, and remove the biofilm from these critical surfaces. Due to inaccuracies resulting from small pieces of debris that would slough off the system surfaces both before and during each weekly injection, this method was abandoned. During the later weeks of the test program, comparisons of the amount of suspended solids removed from the screen coupons used for MB monitoring were substituted.

Flows and Pressure Drops

Comparison of flows and pressure drops across the treated and untreated heat exchangers before and after chemical treatment were made to determine if any pressure drop changes could be observed between the heat exchangers.

All of the above tests (except aquatic toxicity testing) were performed on nominal weekly basis. Other tests performed or data collected included comparisons of the amount of material removed during bulletting operations, visual comparisons of the corrosion rack hoses after the tests, and coupon corrosion rates. The test program was initiated in late August, with the first injection performed on August 26, 1992. A weekly injection schedule was planned, with the last injection occurring on December 4, 1992. Final data collection and microbiological assessments were performed on December 17, 1992.

Section 4

RESULTS AND OBSERVATIONS

Based upon the data collected from these efforts and notes and observations during bulletting operations since treatment was initiated, the treatment program accomplished the initial goals outlined, with reductions in microfouling substantiated by the comparatively small amount of material removed during heat exchanger cleanings. Further evidence of program effectiveness was observed in the corrosion rack discharge hoses, particularly for the treated Unit 2 heat exchanger. Some progress was also made on controlling macrofouling. Each of the areas where data was collected are discussed in the following sections for the 17 week period of the test.

One important parameter that underlies the basic results of this test program is difference in frequency of treatment between the heat exchangers in Unit 1 and Unit 2. The number of treatments applied during the course of the study are contained in Figure 4-1. The differences in treatment effectiveness between the heat exchangers is largely attributable to the greater number of applied treatments in the Unit 2 heat exchanger versus the Unit 1 heat exchanger. Following is a discussion of the results obtained.

Microbiological Assessments

Comparisons of the treated and untreated heat exchangers are shown in Figures 4-2 thru 4-5. Both aerobic and anaerobic (sulfate reducing) bacteria are compared. During the course of the study, screen coupons were removed at alternate intervals to ascertain the concentration of sessile organisms in the two systems. The initial weeks of the study focused on the immediate impact of the treatment on MB levels. Therefore, two coupons were removed each week in the treated systems to determine the before and after bacterial levels. These are designated "treated before" and "treated after" in the legend of Figures 4-2 thru 4-5.

As the program progressed the treated after sampling was abandoned in favor of a longer term trending of the coupon sessile bacteria levels. This change occurred near day 60 of the program. As can be seen from these figures, the Clamtrol addition had a major impact on the system bacterial levels for both aerobic and sulfate reducing bacteria, with generally a one to three order magnitude reduction. This is extremely important to note as the typical biofilm is comprised of only 5-10% bacteria. Such a large reduction in bacterial levels should result in a corresponding reduction in biofilm mass. Due to the water content of most biofilms, even a small to moderate decrease in biofilm thickness can result in large improvements in heat transfer efficiency.

Later trending, after day 60, focused on the long term coupon bacterial levels. Hence, treated and untreated coupons were removed and compared on biweekly intervals. For longer term exposure, a perceptible difference in MB levels

did exist, but the spread in the data narrowed from roughly a two order magnitude difference, to somewhat less than one order of magnitude for aerobic bacteria in Unit 2, but still remained two orders of magnitude lower with respect to sulfate reducing bacteria. In the case of Unit 1, the longer term trends are inconsistent, largely due to the inconsistent chemical application schedule.

This longer term trend appears consistent with the observations during cleaning of the heat exchangers in Unit 2. During the quarterly, scheduled cleaning of the treated Unit 2 heat exchanger, the bacterial odor normally encountered during this evolution was totally absent. This reduction in odor is directly attributable to a significant reduction in system bacteria levels, particularly sulfate reducing bacteria. Material scrapings from the bulleting operation were obtained, filtered, dried, and weighed. A total of 1.9 grams per tube of material were removed from the treated heat exchanger, while the untreated heat exchanger in this unit exhibited 10.8 grams per tube of material.

Due to plant operational considerations, the heat exchanger cleanings for Unit 1 were performed too early in the injection schedule to show useful results. After only two chemical treatments had been applied, 8.75 grams of material per tube was removed from the treated heat exchanger, while 8.5 grams of material per tube was removed from the untreated system in this Unit. These results are considered to be inconclusive.

System Corrosion Rates

One of the concerns initially identified in the planning stages for this project was the potential for accelerated corrosion of system components due to the chemical treatment. The purpose of the corrosion monitoring was to establish if such an effect did exist and to quantify the effect. Both instantaneous probes (copper nickel only) and coupons were used in the system corrosion racks to ascertain the differences in corrosion.

Proper interpretation of the instantaneous corrosion probes is required to analyze the resulting data. Two types of measurements were obtained during the program, general corrosion rates, and imbalance readings. As the name implies, general corrosion rates provide an instantaneous measurement of the general corrosion of the material in question (for the Calvert Cliffs Study, 90/10 copper/nickel) and provide a quantitative result. The imbalance readings provide information relative to the pitting potential. If the imbalance reading is higher than the general corrosion reading, then pitting may be the active degradation mechanism. However, if the imbalance reading is less than the general corrosion reading, then pitting is probably not active. Therefore, the imbalance readings are more qualitative in nature.

Results from the instantaneous probes with 90/10 copper nickel metallurgy are displayed in Figures 4-6 thru 4-13. Readings were obtained both before and during the treatment. With the exception of the last few weeks of the Unit 1 test, and week 7 of Unit 1, the imbalance readings were less than the general corrosion readings, indicating that pitting was not active. With respect to general corrosion comparisons of the treated and untreated headers revealed a slightly higher initial rate for the treated systems, averaging approximately 1.0 to 2.0 mils per year higher on the copper/nickel in these systems. This phenomenon was also seen on the coupons removed after the test and shown in Figures 4-14 and 4-15.

Several other factors and data must be considered to properly interpret this result. First, a substantial corrosion data base exists for mild steel and copper bearing materials exposed to Clamtrol, indicating little or no increase in corrosion rates with exposure to even high concentrations of the chemical. Additional evidence supporting this data is seen in the instantaneous corrosion readings taken during the Clamtrol additions. Figures 4-8 and 4-12 show little or no difference in general corrosion rates before or during the chemical additions. Other indicators include the Unit 2 treated system coupon and weekly general corrosion rates. Corrosion rates in this system were lower than in Unit 1, despite the fact that a greater number of treatments were applied in Unit 2. If Clamtrol were having a detrimental effect, a higher relative corrosion rate would be expected in Unit 2, rather than Unit 1.

A disadvantage of simply analyzing corrosion coupons is that they provide a time-averaged corrosion rate. Additional insight is provided from the instantaneous general corrosion readings in Figures 4-6 and 4-10. These figures indicate that the highest absolute corrosion rates and highest rate differences between the treated and untreated systems occurred during the initial weeks of the test. In later weeks, the differences between system corrosion rates became progressively smaller, and were essentially consistent beginning in approximately Week 7 of the program in Unit 2. This data suggests that the largest portion of the corrosion occurred during the initial weeks of the study, and slowly reduced over time. This conclusion is consistent with laboratory and field studies that demonstrate higher initial corrosion rates occur on new, clean metal surfaces until the surface is passivated by a corrosion product film.

From analyzing these factors and the data obtained from this study, the differences in corrosion rates are believed to be related to differences in microfouling and deposition between the treated and untreated systems. The MB data clearly indicate that the surfaces are left in a cleaner condition after treatment, thus promoting more efficient heat transfer. A cleaner surface also permits the base metal to be re-exposed to the naturally aggressive system water, while the untreated, fouled surface is insulated from the environment to a greater degree by the biofilm. The result is that the treated systems would have an initially higher corrosion rate, but would more quickly reach equilibrium than the untreated system. It would be expected that if the coupons were left in service for a longer period of time, there would be essentially no difference between the treated and untreated system corrosion rates.

This explanation is also valid for the differences in mild steel corrosion rates. However, there are several other mitigating factors regarding the SW system that should also be considered for this material. For instance, the carbon steel piping is concrete or rubber lined, insulating the steel from the naturally aggressive system water environment. Therefore, the mild steel corrosion rates observed do not pose a risk to the long terrm operation of the SW system.

Comparisons of Pressure Drop

The pressure drop (delta P) across the treated and untreated salt water system heat exchangers was compared before and after each treatment. All delta Ps were normalized with respect to the 16,83[illegible] GPM minimum Tech Spec flow rate

applicable to each train of this system to permit ready comparison of the data. This data is displayed in Figures 4-16 thru 4-19.

Two factors contributed to changing the pressure differential across the heat exchangers. These factors are addressed in the Introduction of this report. These heat exchangers suffer both macrofouling (clams, oysters, crabs, etc.) and microfouling. Both of these phenomena contribute to higher pressure drops, with periodic casual cleanings performed as needed to address macrofouling, and quarterly bullettings to address microfouling. Casual cleanings particularly can greatly reduce the observed pressure drop for week to week and therefore add complexity to interpretation of the data. Increased heat exchanger performance can be seen after each cleaning bulletting. As a result, it is more difficult to determine the true difference between a treated and untreated heat exchanger from reviewing this data.

However, a generally favorable trend exists in the more consistently treated Unit 2 heat exchanger, with the treated system exhibiting relatively smaller pressure drops than the untreated system. Also, slight delta P improvements were typically seen after treatment, as indicated in Figure 4-17. With respect to Unit 1, however, no similar benefit is seen. This is, believed to be attributable to the inconsistent application of CT-1 on this Unit. Further data correlation is needed in this area if delta P is determined to be an important trending parameter.

Suspended Solids

Comparisons of the suspended solids levels before and during the chemical treatment and between headers were made to quantify the amount of material being removed from the pipe and tubing surfaces during the treatment applications. Due to small pieces of organic matter and organisms that would slough off during or before the treatments, accurate measurements of suspended solids could not be obtained. As a result, this technique could not be relied upon to support this type of data comparison.

However, visual differences in growth occurring on the treated and untreated MB coupons could however be readily observed. The amount of suspended solids present in the sample water containing the coupons could be readily measured and compared between treated and untreated heat exchangers. This alternate method was used as an indication of accumulated biofilm present in the heat exchangers and was initiated approximately mid-way through the 17 week test period. The results from this analytical work are displayed in Figures 4-20 and 4-21.

Where the treatment program was consistently implemented (Unit 2), a dramatic difference in the amount of material removed from the coupon is seen in examining Figure 4-21. Anywhere from one-half to a full order of magnitude difference existed between the treated and untreated systems. This is again consistent with the quantities of material removed during the bulletting operations in the Unit 2 heat exchangers, demonstrating biofilm and hence microfouling control. For Unit 1, no consistent trend again due to the inconsistent application of the treatment.

Product Demand, Toxicity, and Outfall Analysis

Differences between the theoretical and measured concentrations of Clamtrol occur between applications and between headers. Generally, the measured concentration is less than the theoretical, with the difference referred to as demand. Product demand may take two forms, the first is the demand from suspended solids and other organic material. The actives in Clamtrol adsorb to these particles, rendering that portion so adsorbed non-toxic. (In fact, in many areas, this is how the product is detoxified). Additionally, the macro and microorganisms in the system uptake some of the material, lowering the concentrations seen in the system water. The demand of the product has varied from application to application and has ranged from less than 0.5 ppm, to as high as 6.0 ppm. None of these ranges are considered abnormal and fall within the expected range of system demand.

Outfall concentrations were measured on each Unit during each application. None of the applications to date have identified any Clamtrol above the detection limit. Also, both of the two aquatic toxicity tests have been negative.

Visual and Other Observations During Inspections

During the course of the treatment program, the normal heat exchanger cleanings and bullettings were performed. Bulletting operations provided opportunities to inspect the equipment and determine if any differences existed. The first of these occurred in mid September on Unit 1 in the treated heat exchanger after two applications of Clamtrol. No discernable differences were observed in this inspection and other inspections.

The second opportunity for inspection was in the treated Unit 2 heat exchanger. A total of seven applications had been performed in this heat exchanger prior to cleaning. During this inspection, a substantial difference from prior inspections was observed. The most immediate difference was in the lack of odor emanating from the heat exchanger. Typically, a very noticeable, pungent odor is present when opening a heat exchanger due to the large amount of bacteria present. Immediately, it was observed that no such odor was present. Swabs were obtained from inside the tubing in four locations to determine and characterize the bacteria present. These swabs were sent to Betz Laboratories for analysis and no reportable quantities of bacteria were identified. Other swabs obtained from untreated heat exchangers were comprised of 5-10% bacteria.

Another difference from prior cleanings was in the adherence to and length of the macrofouling (primarily hydrozoan and bryozoan) attached to the shell of the heat exchanger. Based upon discussions with plant maintenance personnel who normally conduct these cleanings, these organisms require a substantial amount of effort to remove from the shell and tubesheet. They are normally well secured in these locations, but during this cleaning activity, were much more easily removed. The length of the growth was also estimated to be 1/2 to 2/3 the lengths typically encountered during this time of year. Many could be wiped off by hand or with high

pressure water. Also, the scrapers used in cleaning the tubes could be forced through the tubes with much less effort.

Finally, upon conclusion of the test, the side stream corrosion racks were dismantled. Sections of the discharge hose running to the floor drains were obtained, cut longitudinally, and analyzed. The floor drain sections selected offer the greatest degree of flow and geometric consistency between the hose sections. Relative comparisons between the treated and untreated headers were made and are summarized in the Table 4-1. Photographs were also obtained and are included in Figure 4-22. Dramatic differences exist in the treated and untreated systems, particularly with repect to Unit 2. Some degree of macrofouling control (namely on barnacles) can even be seen in the Unit 1 treated system.

Table 4-1
Comparisons of Discharge Hose Conditions

Area Assessed	#11 Heat Exchanger (Untreated)	#12 Heat Exchanger (Treated)	#21 Heat Exchanger (Untreated)	#22 Heat Exchanger (Treated)
Connection fitting diameter reduction	Reduced approx. 50% due to barnacles, slime, sea grapes, and hydrozoan.	Reduced approx. 30% with similar organisms as in the #11 heat exchanger.	Reduced approx. 25%-30% with similar organisms as in the #11 and #12 heat exchangers.	Barnacles and slime present, but to much lesser degree than in the other heat exchangers. Minor (5%) diameter reduction.
Barnacles in 3 foot section of discharge hose	72 barnacles, mostly medium to large in size.	28 barnacles of medium to small size.	154 barnacles of varying sizes. Many barnacle clusters present.	16 barnacles of small to medium size. Most barnacles were small.
Discharge hose condition and growth.	Continuous slime growth on I.D. surface.	Areas of heavy and light slime growth on I.D. surface.	Intermittent slime and growth on ID hose surface.	Very minor growth on ID surface. Most of hose length remained translucent in color.

PERCENTAGE OF TREATMENT DURING TEST PERIOD
UNIT 1 VS UNIT 2

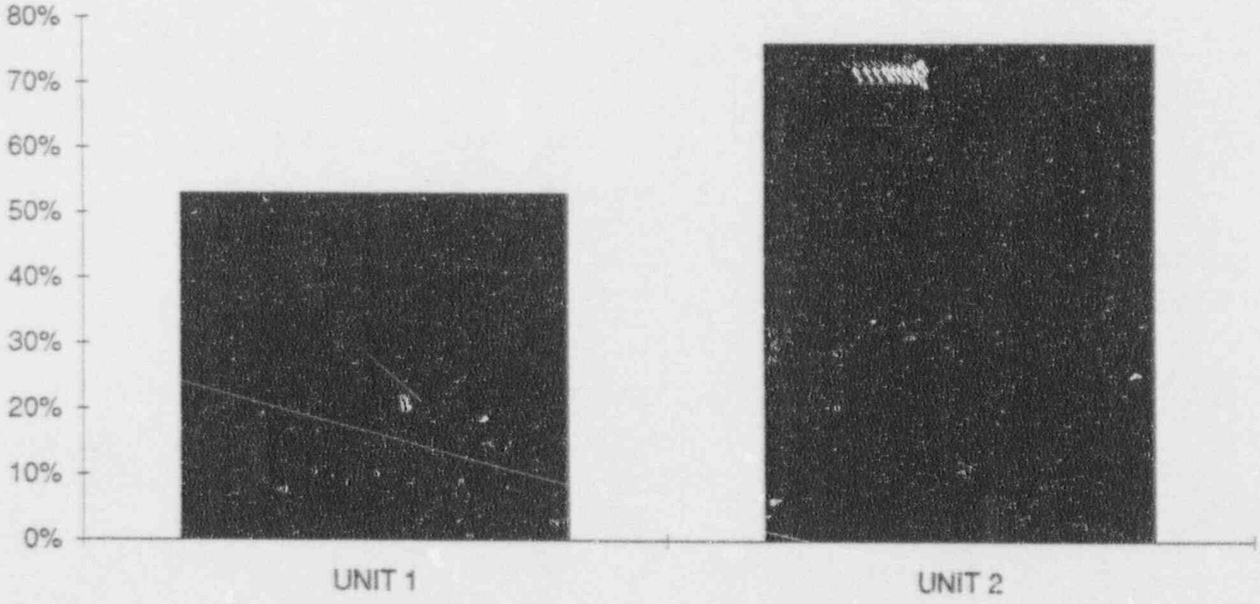


FIGURE 4-1

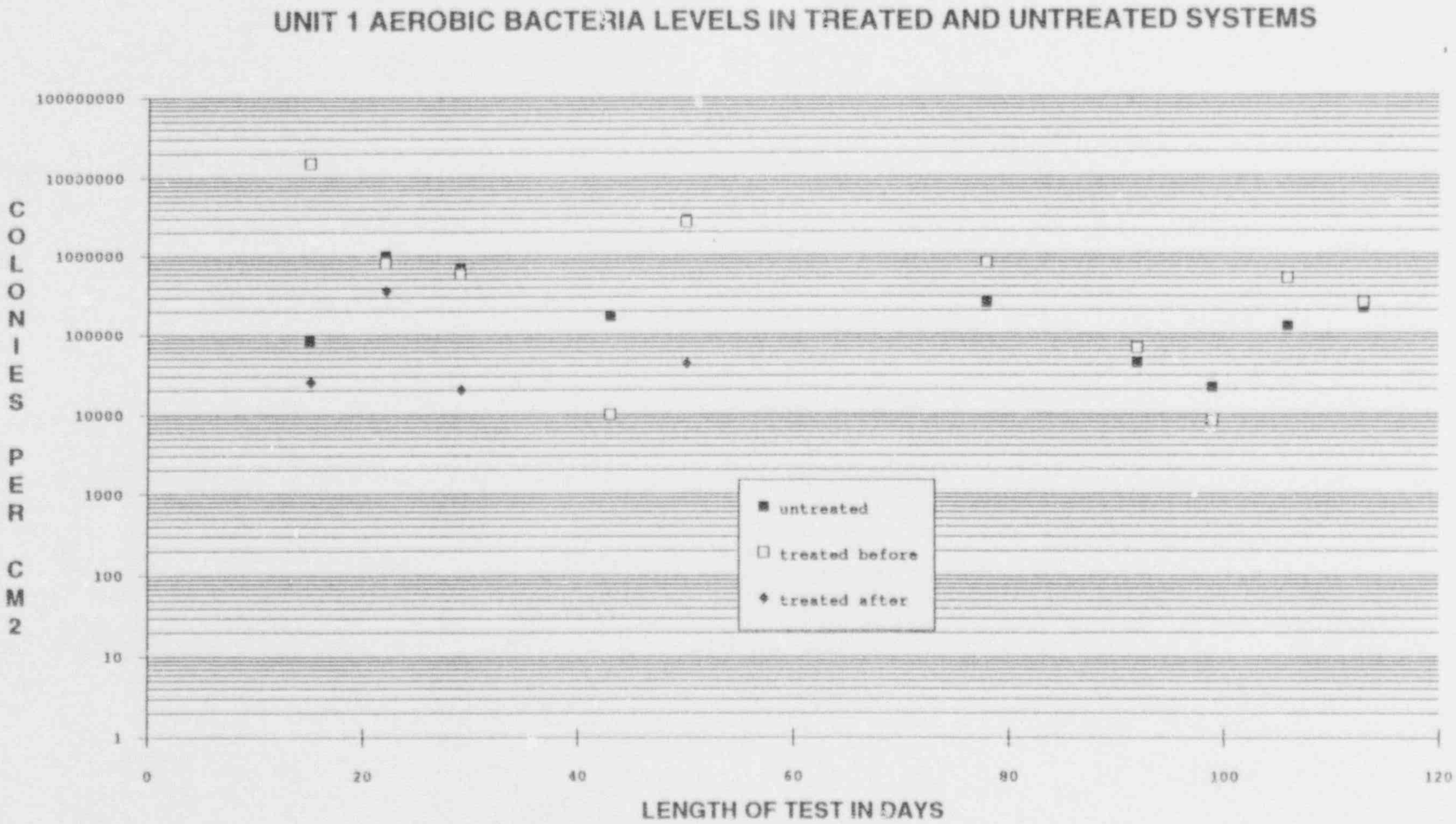

UNIT 1 AEROBIC BACTERIA LEVELS IN TREATED AND UNTREATED SYSTEMS
COLONIES PER CM2
100000000
10000000
1000000
100000
10000
1000
100
10
1
0
20
40
60
80
100
120
LENGTH OF TEST IN DAYS
untreated
treated before
treated after

FIGURE 4-2

UNIT 2 AEROBIC BACTERIA LEVELS IN TREATED AND UNTREATED SYSTEMS

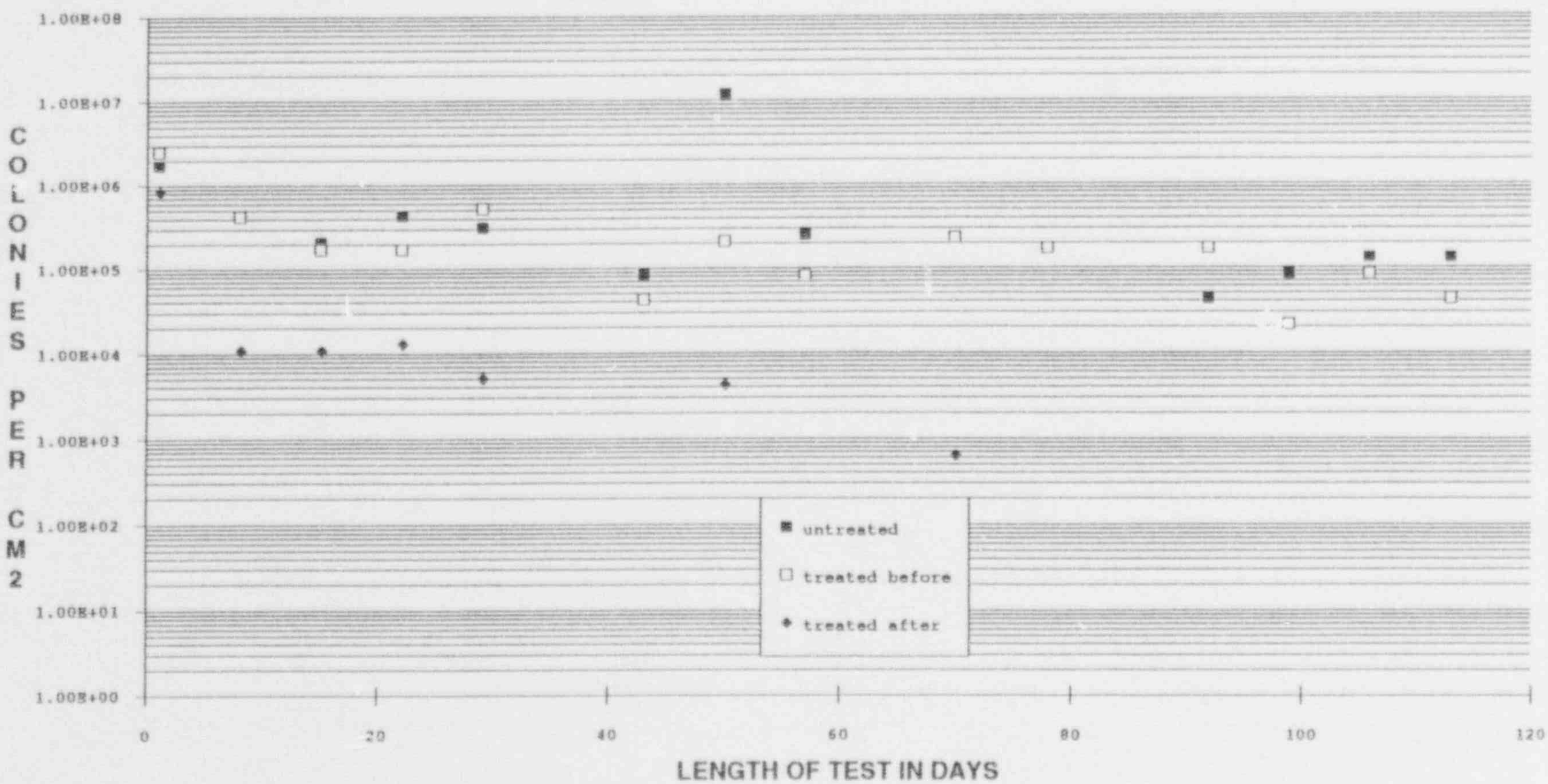


FIGURE 4-3

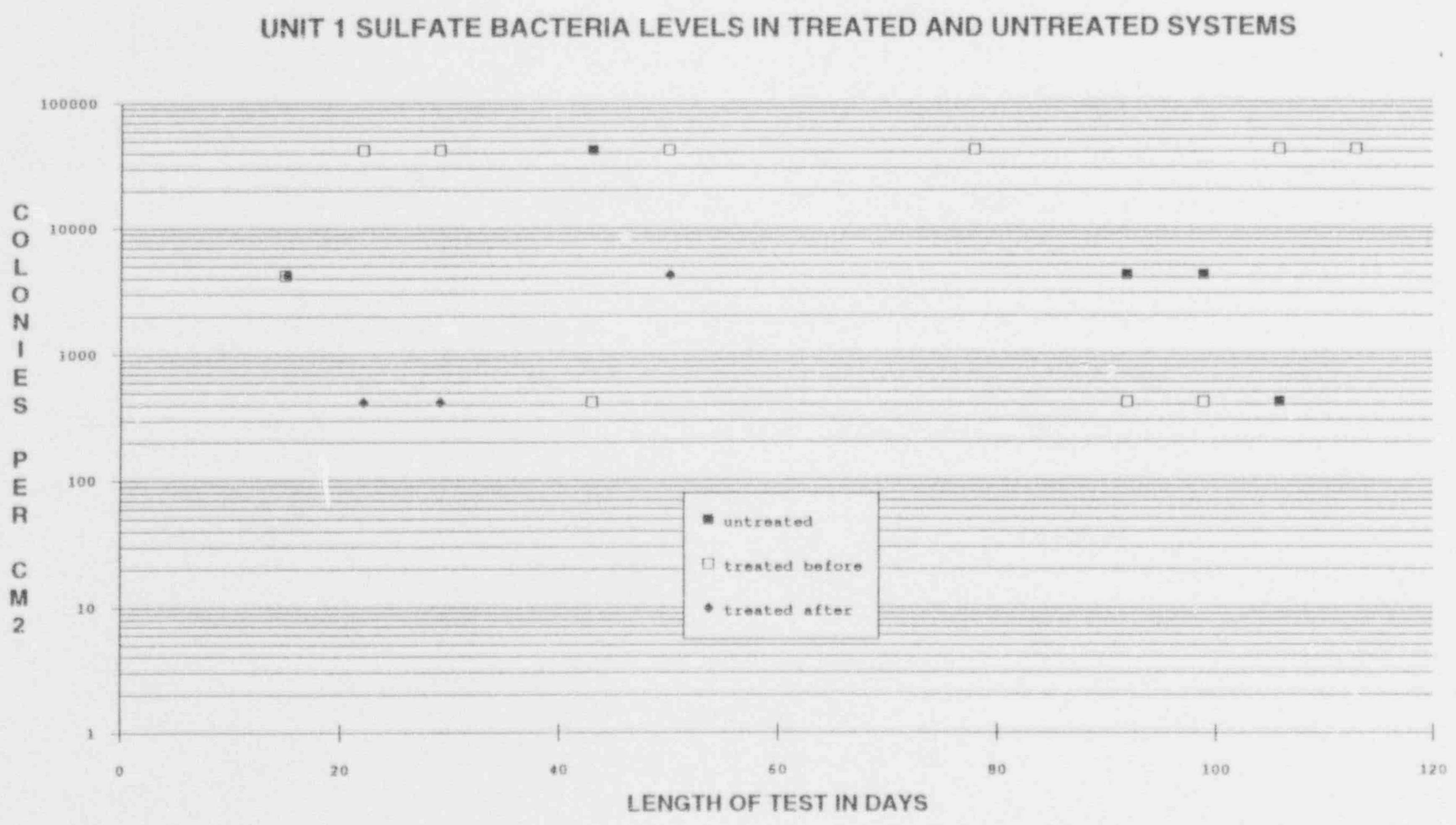

UNIT 1 SULFATE BACTERIA LEVELS IN TREATED AND UNTREATED SYSTEMS
COLONIES PER CM2
100000
10000
1000
100
10
1
0
20
40
60
80
100
120
LENGTH OF TEST IN DAYS
untreated
treated before
treated after

FIGURE 4-4

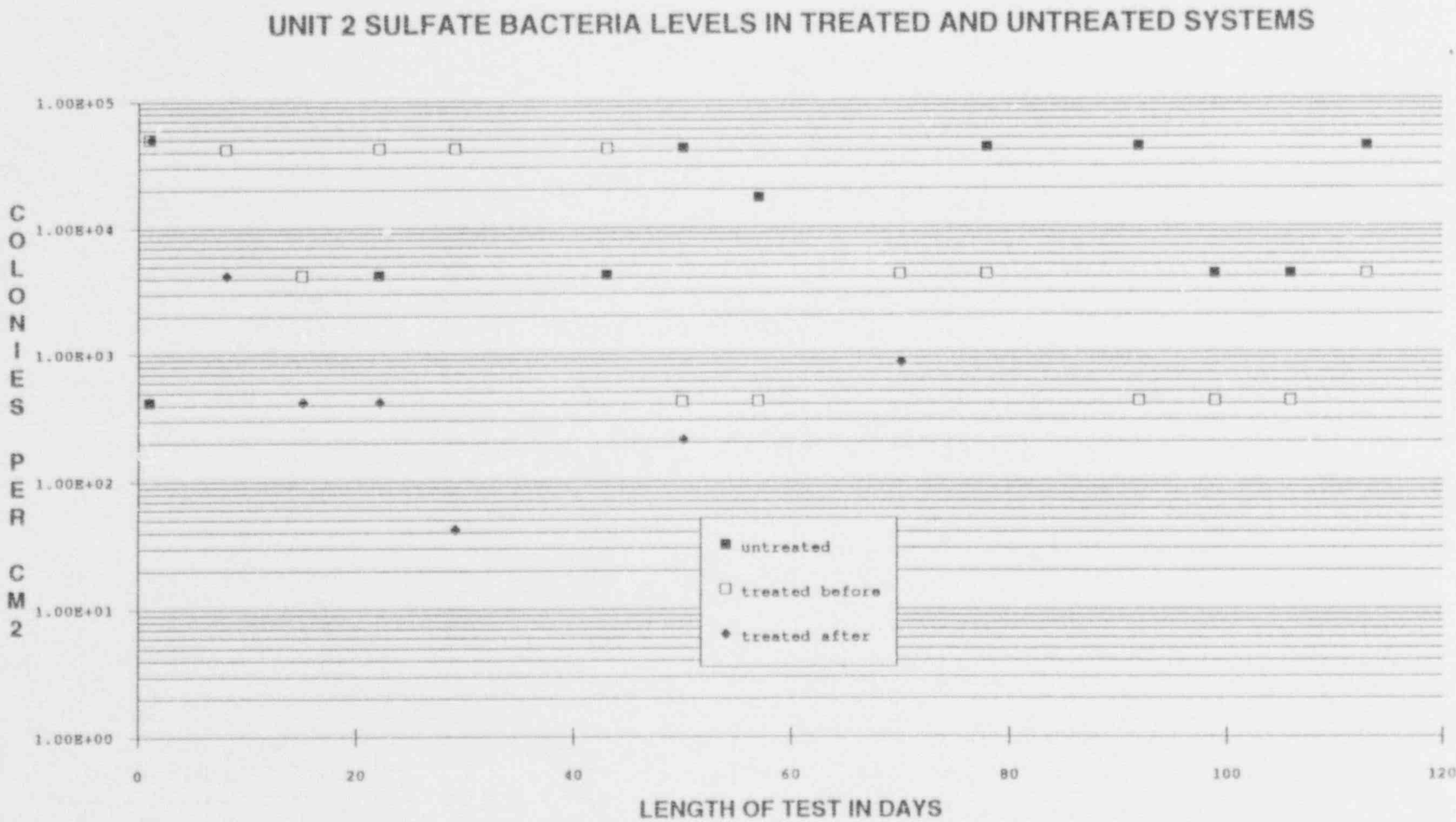

UNIT 2 SULFATE BACTERIA LEVELS IN TREATED AND UNTREATED SYSTEMS
COLONIES PER CM2
1.00E+05
1.00E+04
1.00E+03
1.00E+02
1.00E+01
1.00E+00
0
20
40
60
80
100
120
LENGTH OF TEST IN DAYS
untreated
treated before
treated after

FIGURE 4-5

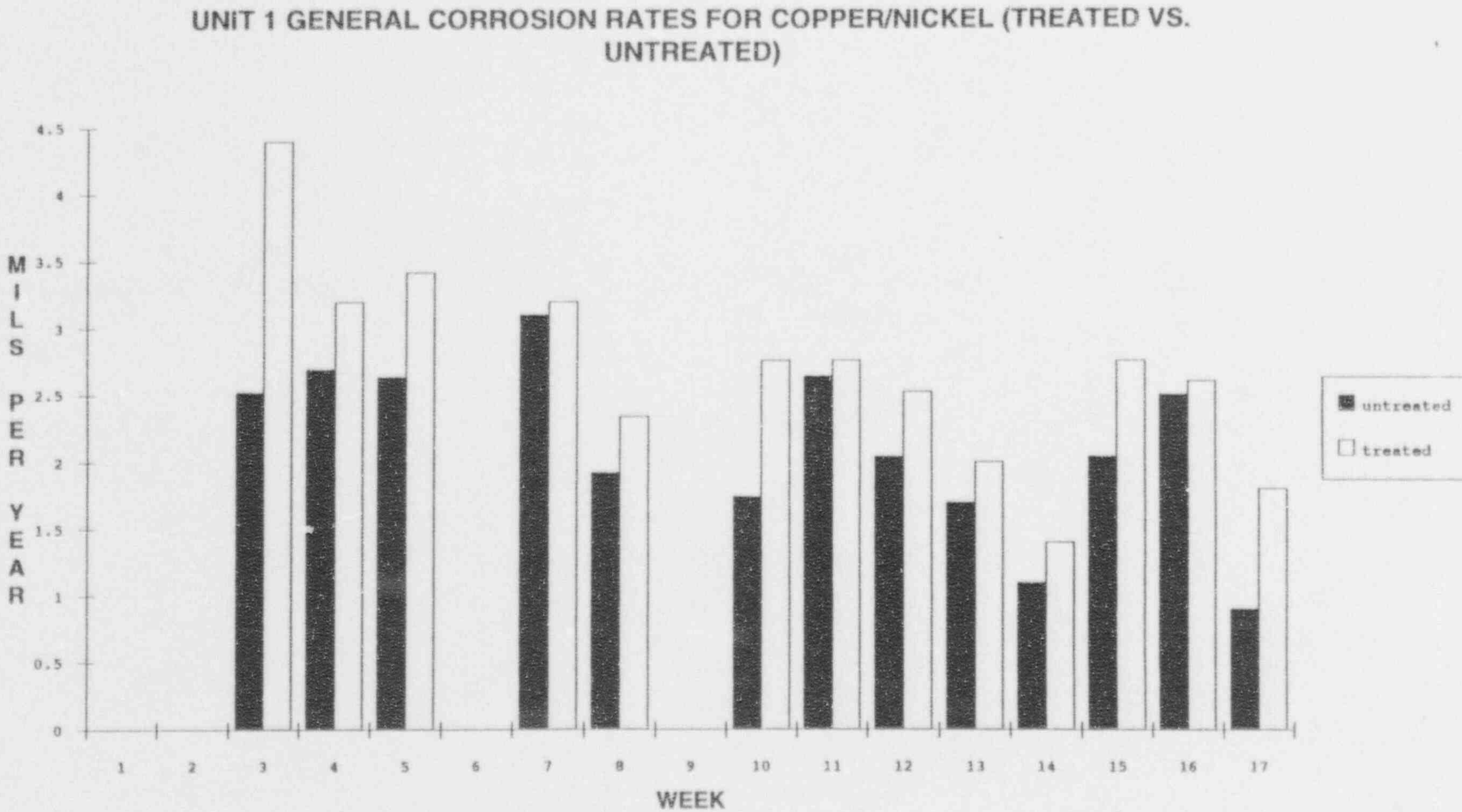

UNIT 1 GENERAL CORROSION RATES FOR COPPER/NICKEL (TREATED VS. UNTREATED)
MILS PER YEAR
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WEEK
untreated
treated

FIGURE 4-6

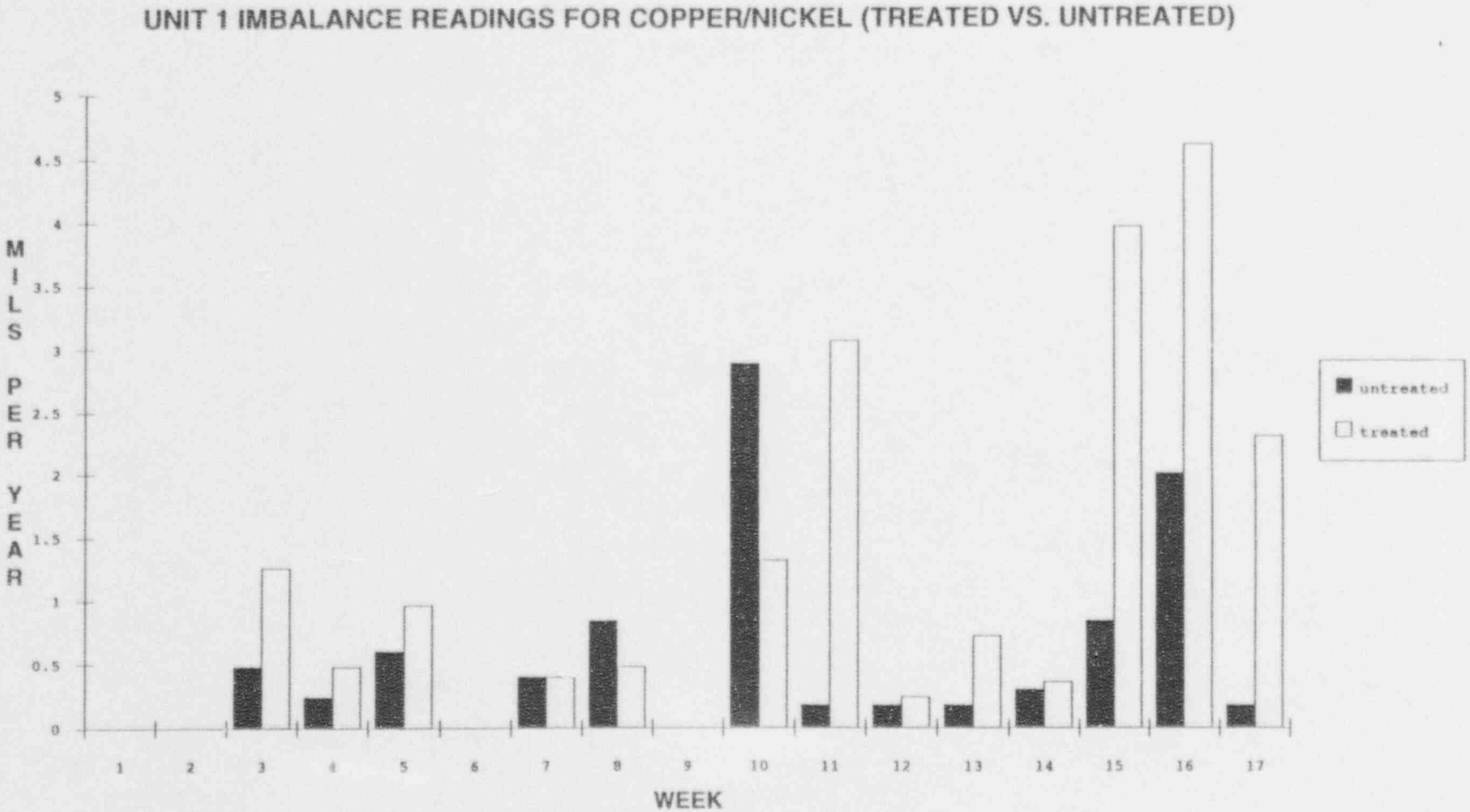

UNIT 1 IMBALANCE READINGS FOR COPPER/NICKEL (TREATED VS. UNTREATED)
MILS PER YEAR
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WEEK
untreated
treated

FIGURE 4-7

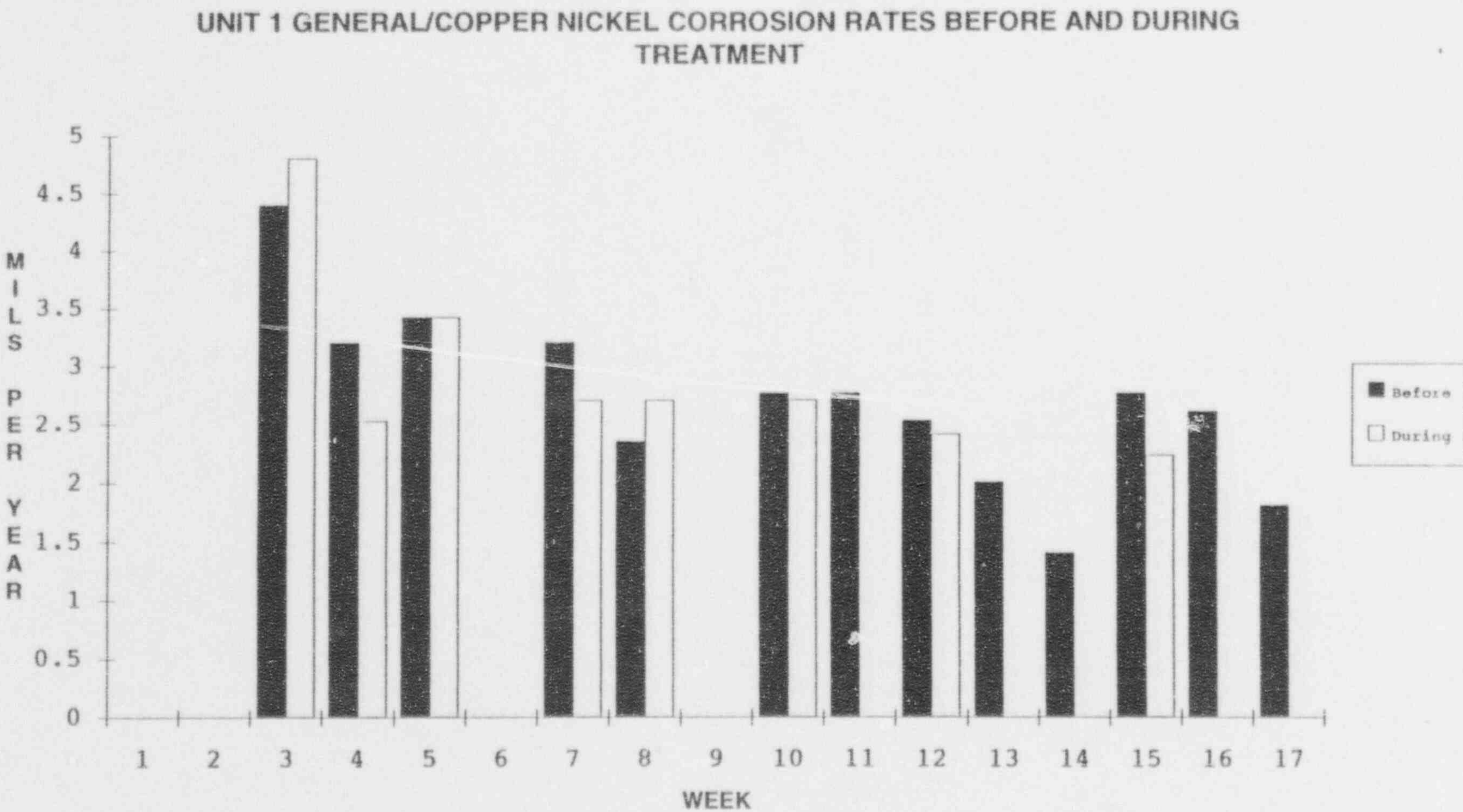

UNIT 1 GENERAL/COPPER NICKEL CORROSION RATES BEFORE AND DURING TREATMENT
MILS PER YEAR
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WEEK
Before
During

FIGURE 4-8

UNIT 1 IMBALANCE READINGS FOR COPPER/NICKEL BEFORE AND DURING TREATMENT

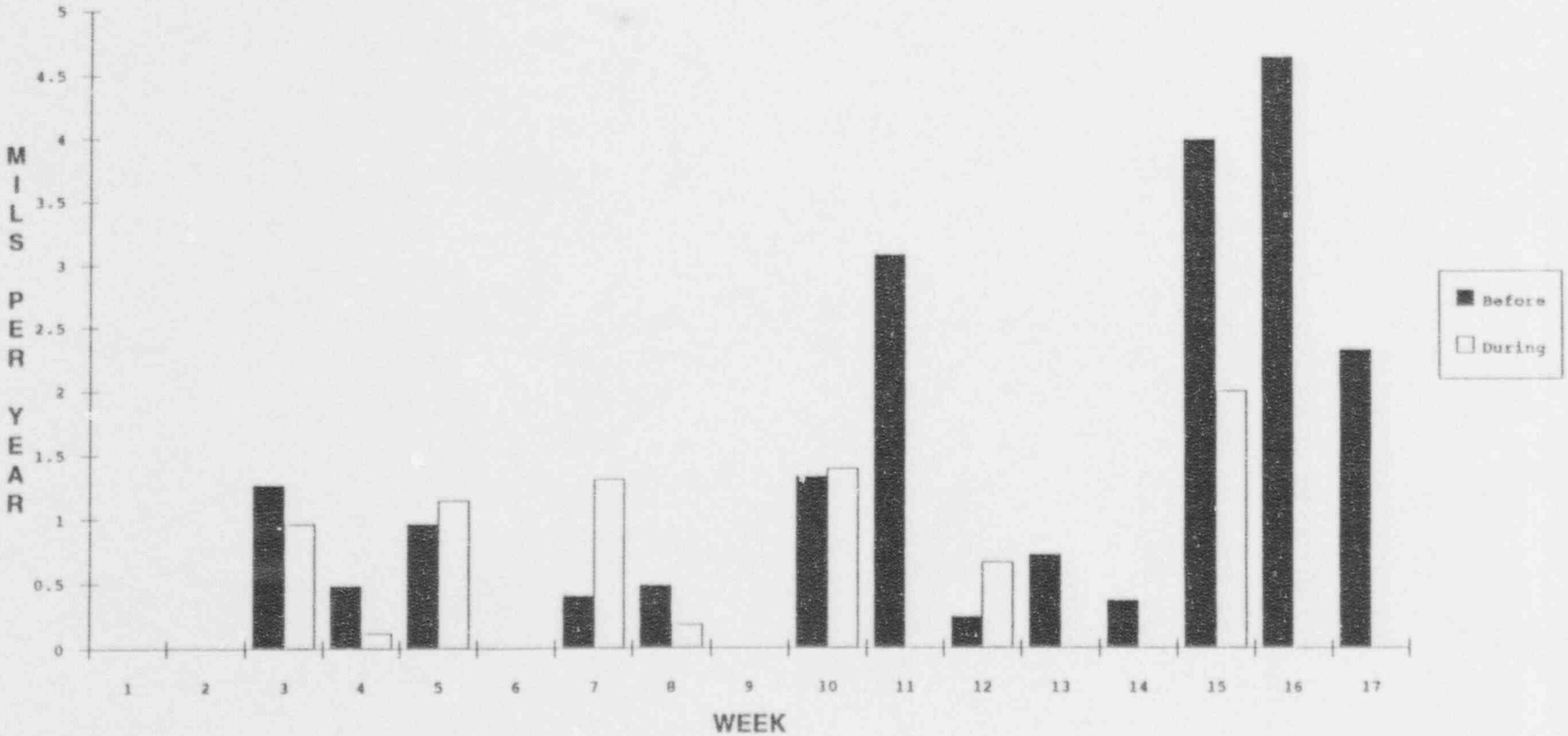


FIGURE 4-9

UNIT 2 GENERAL CORROSION RATE FOR COPPER/NICKEL (TREATED VS. UNTREATED)

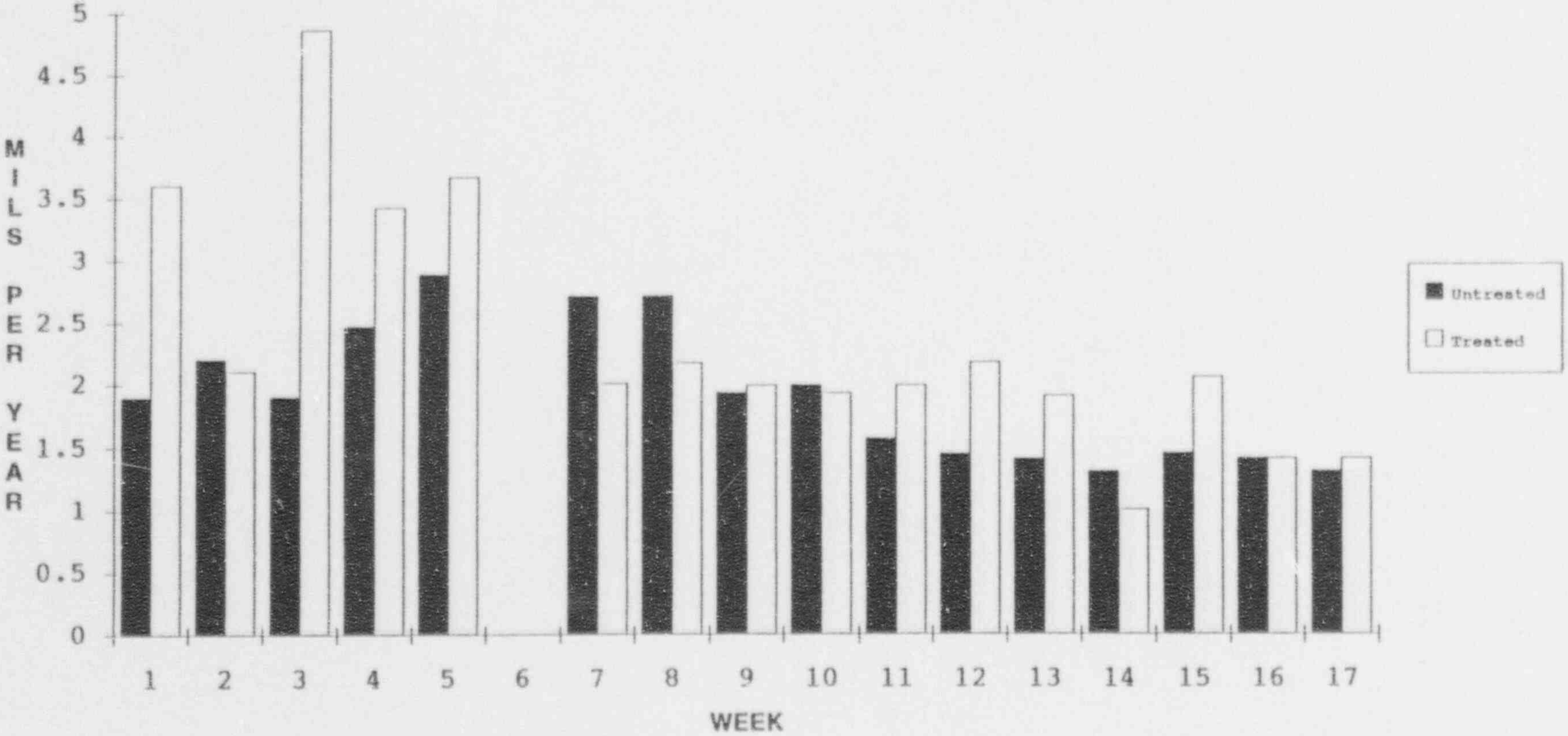


FIGURE 4-10

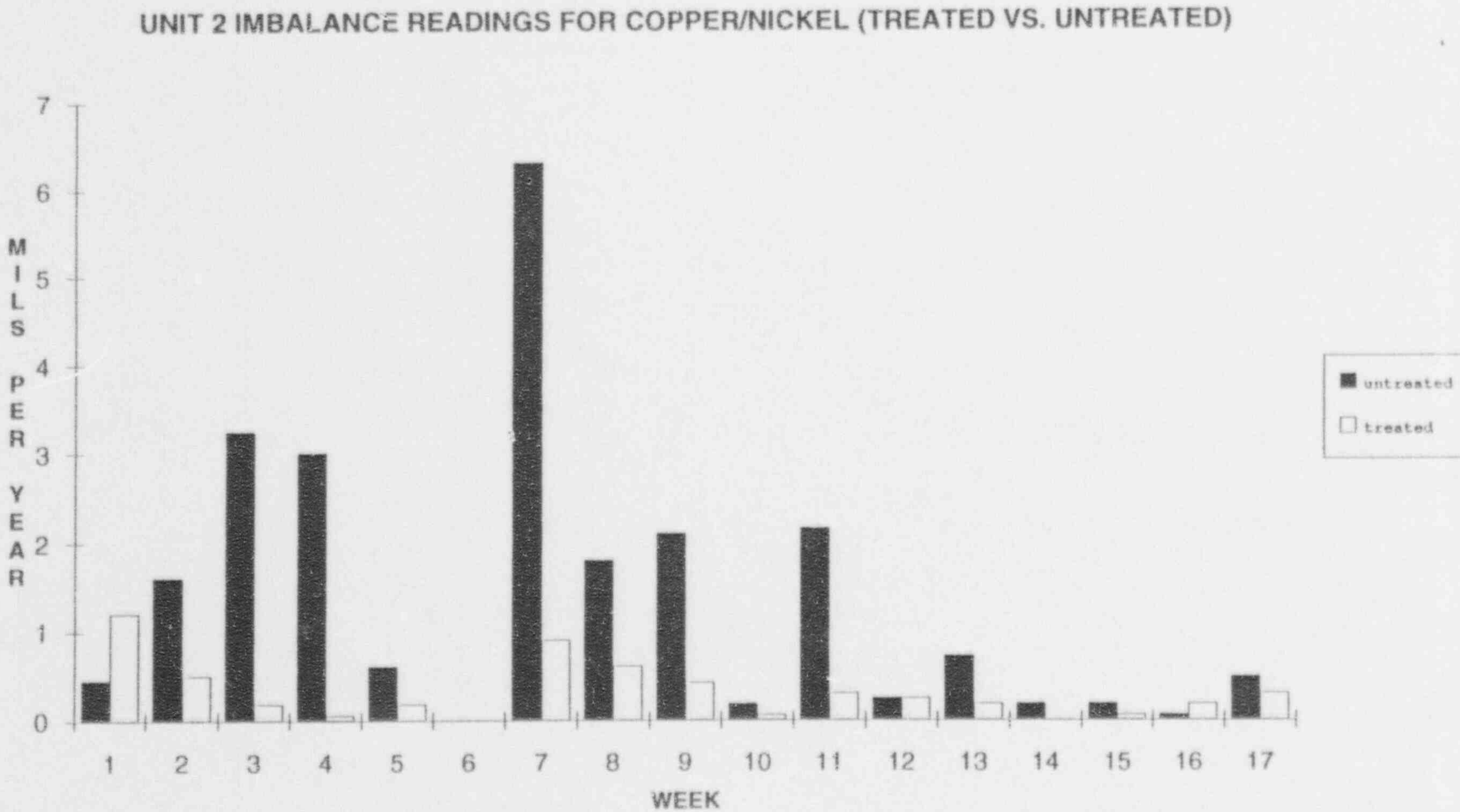

UNIT 2 IMBALANCE READINGS FOR COPPER/NICKEL (TREATED VS. UNTREATED)
MILS PER YEAR
0
1
2
3
4
5
6
7
WEEK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
untreated
treated

FIGURE 4-11

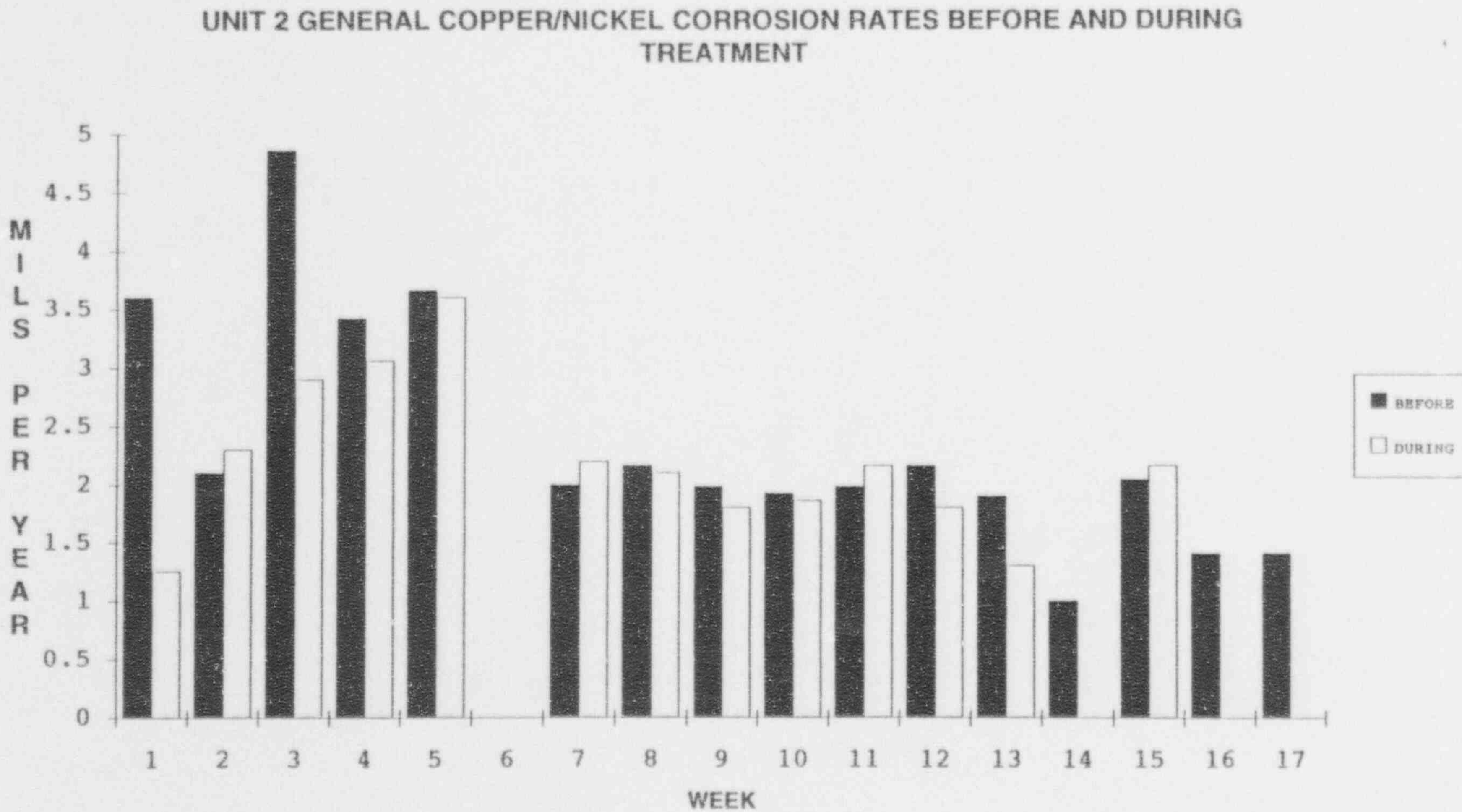
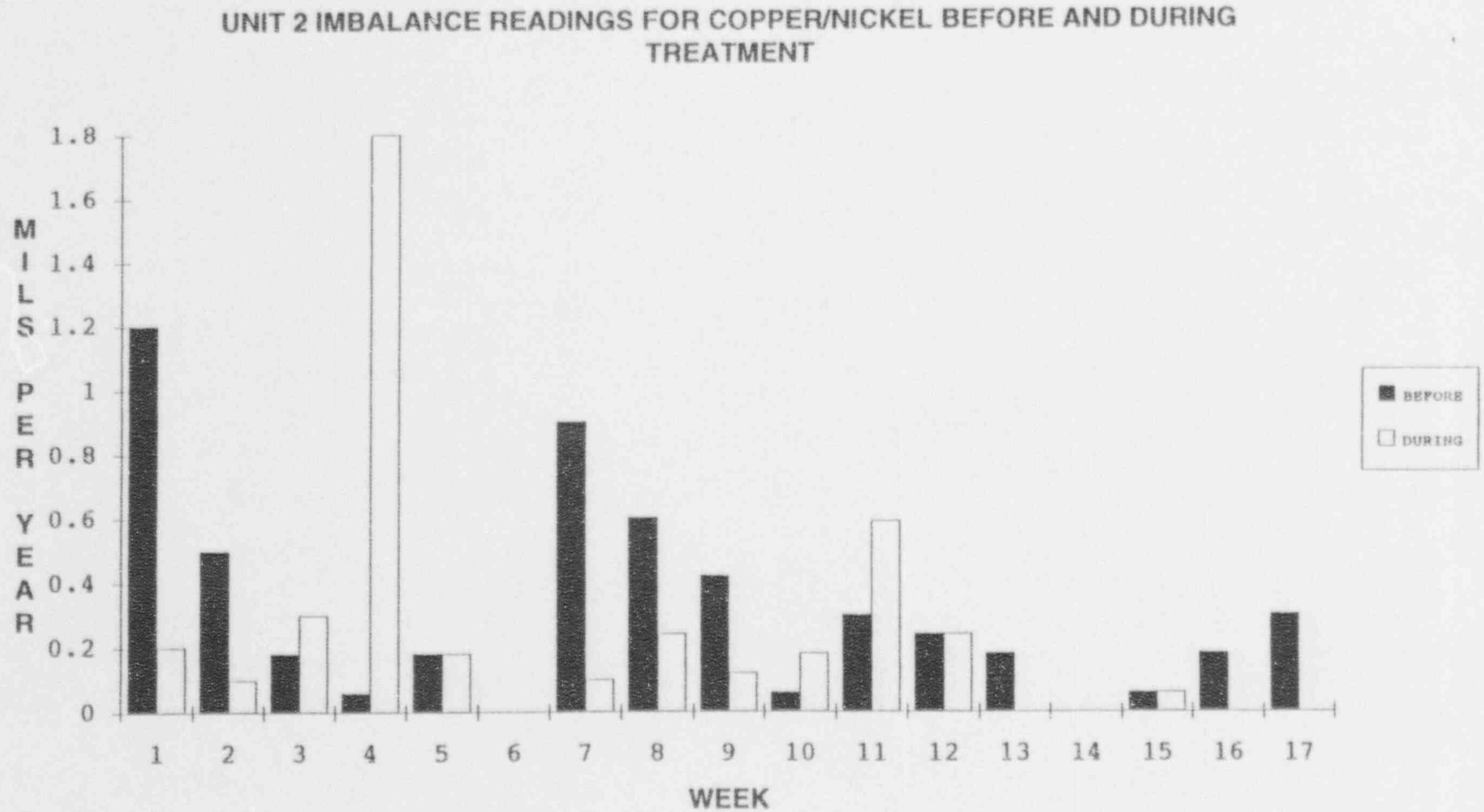

UNIT 2 GENERAL COPPER/NICKEL CORROSION RATES BEFORE AND DURING TREATMENT
MILS PER YEAR
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WEEK
BEFORE
DURING

FIGURE 4-12



UNIT 2 IMBALANCE READINGS FOR COPPER/NICKEL BEFORE AND DURING TREATMENT
MILS PER YEAR
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
WEEK
BEFORE
DURING

FIGURE 4-13

COPPER NICKEL CORROSION RATES FOR UNITS 1 AND 2 (TREATED VS. UNTREATED)

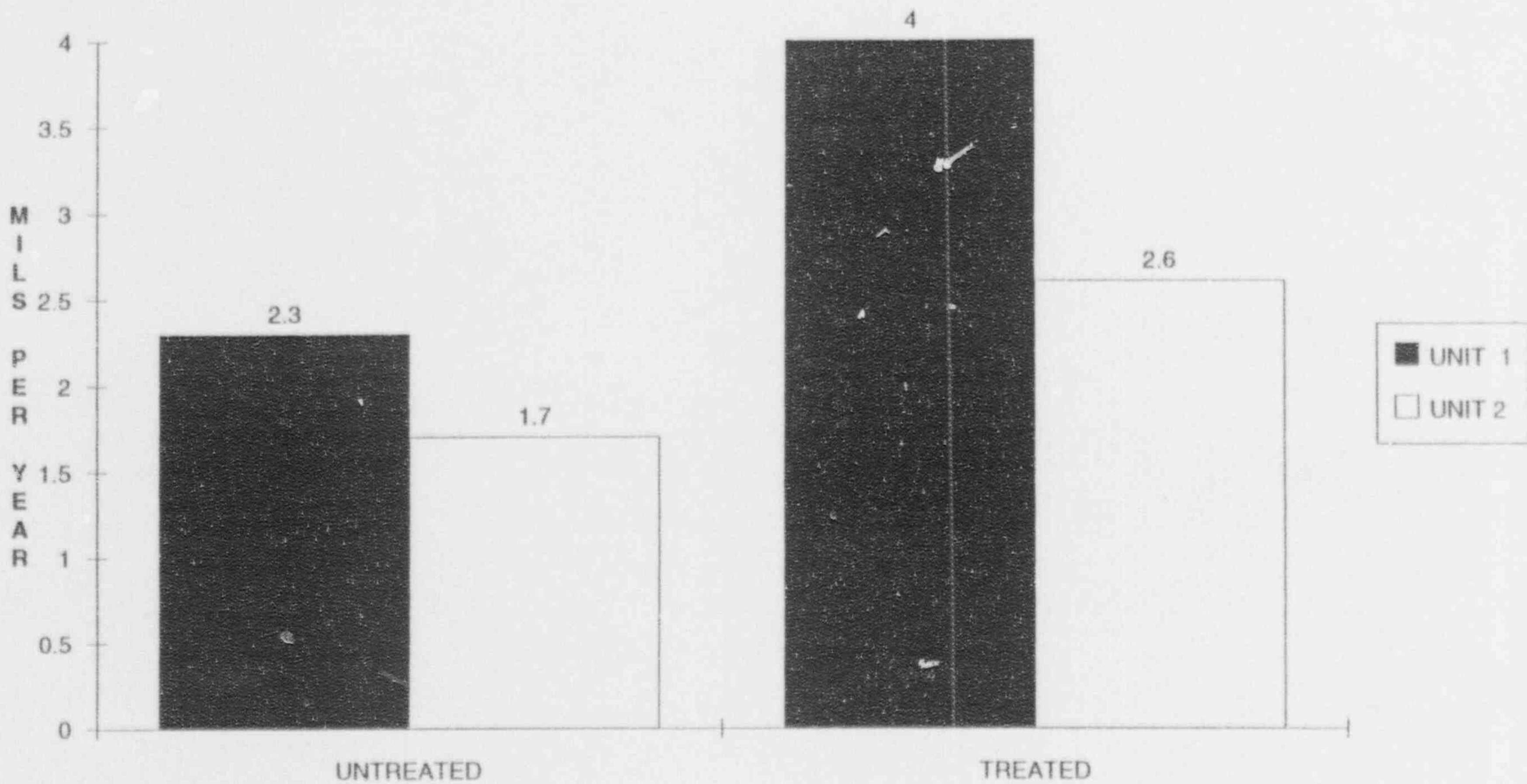


FIGURE 4-14

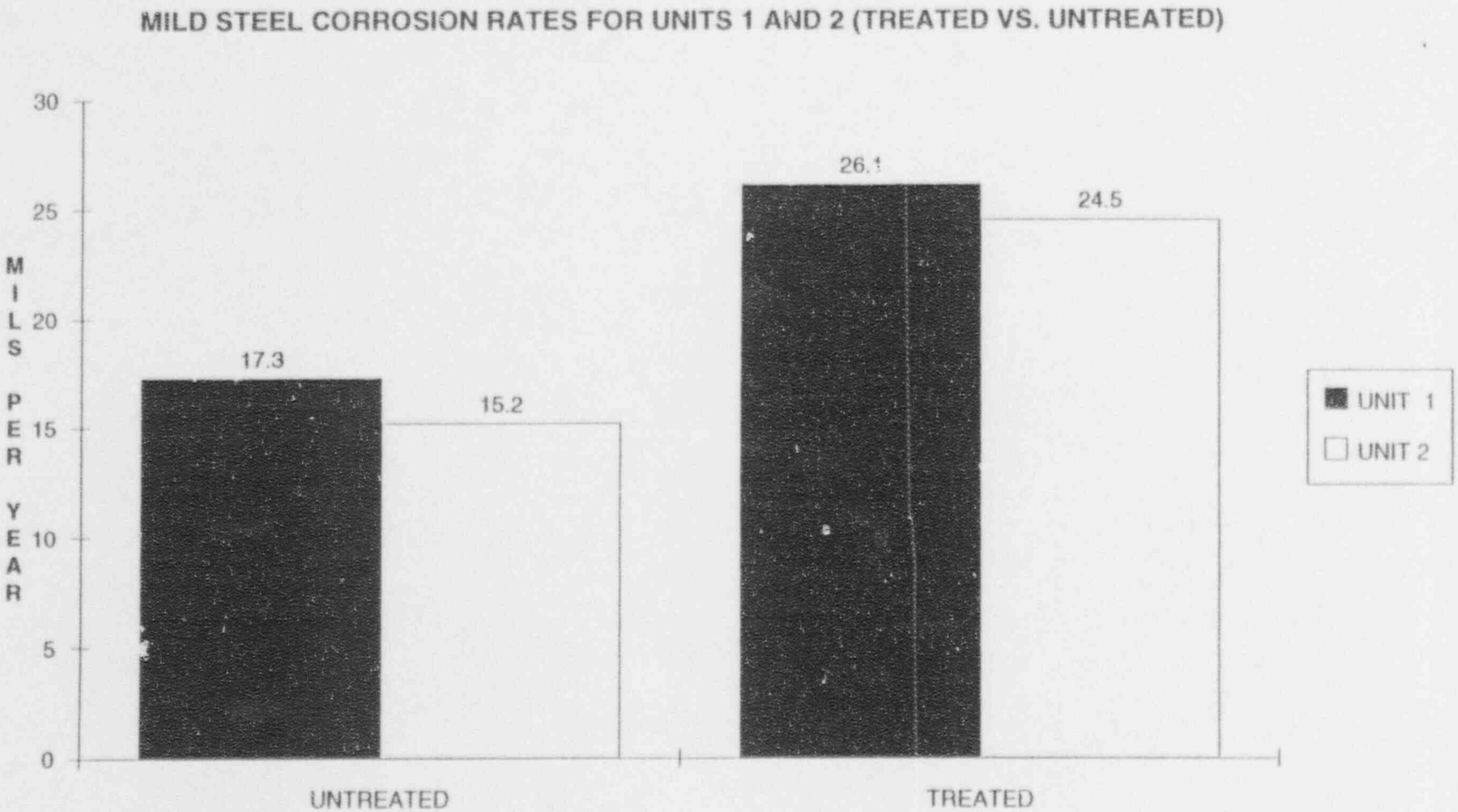

MILD STEEL CORROSION RATES FOR UNITS 1 AND 2 (TREATED VS. UNTREATED)
MILS PER YEAR
30
25
20
15
10
5
0
17.3
15.2
26.1
24.5
UNTREATED
TREATED
UNIT 1
UNIT 2

FIGURE 4-15

UNIT 2 NORMALIZED PRESSURE DIFFERENTIAL (TREATED VS. UNTREATED)

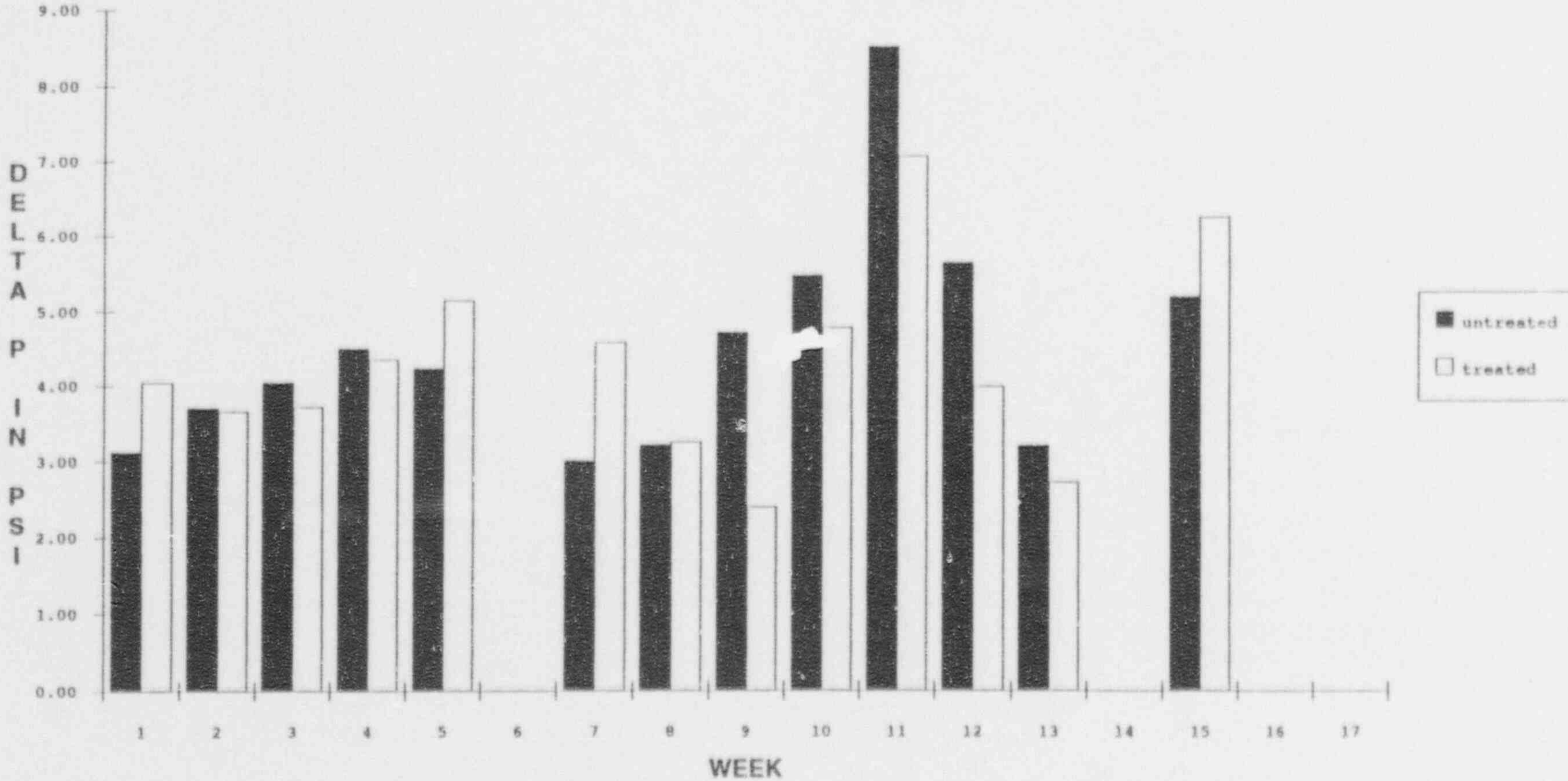


FIGURE 4-16

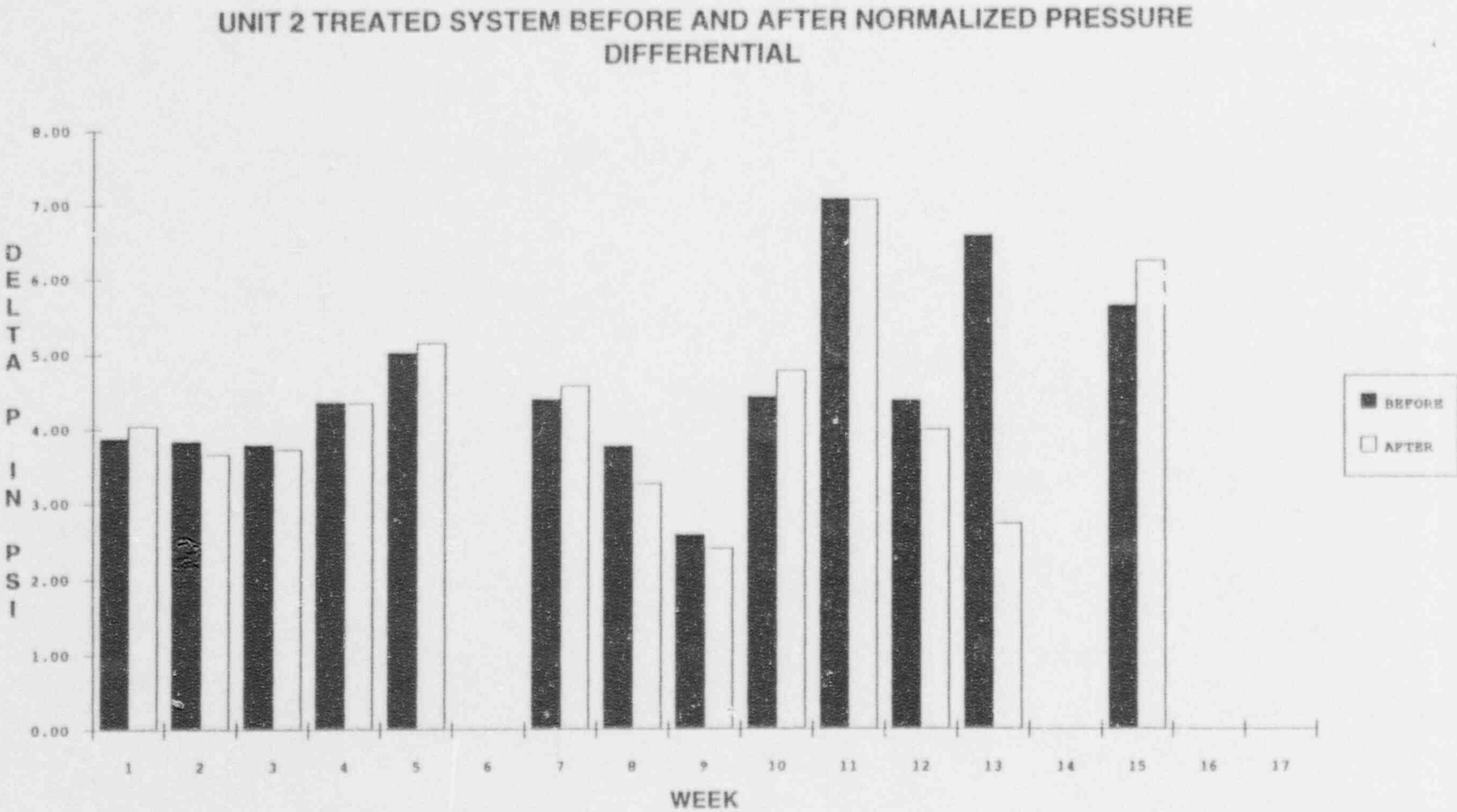

UNIT 2 TREATED SYSTEM BEFORE AND AFTER NORMALIZED PRESSURE DIFFERENTIAL
DELTA P IN PSI
8.00
7.00
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
WEEK
BEFORE
AFTER

FIGURE 4-17

UNIT 1 NORMALIZED PRESSURE DIFFERENTIAL (TREATED VS. UNTREATED)

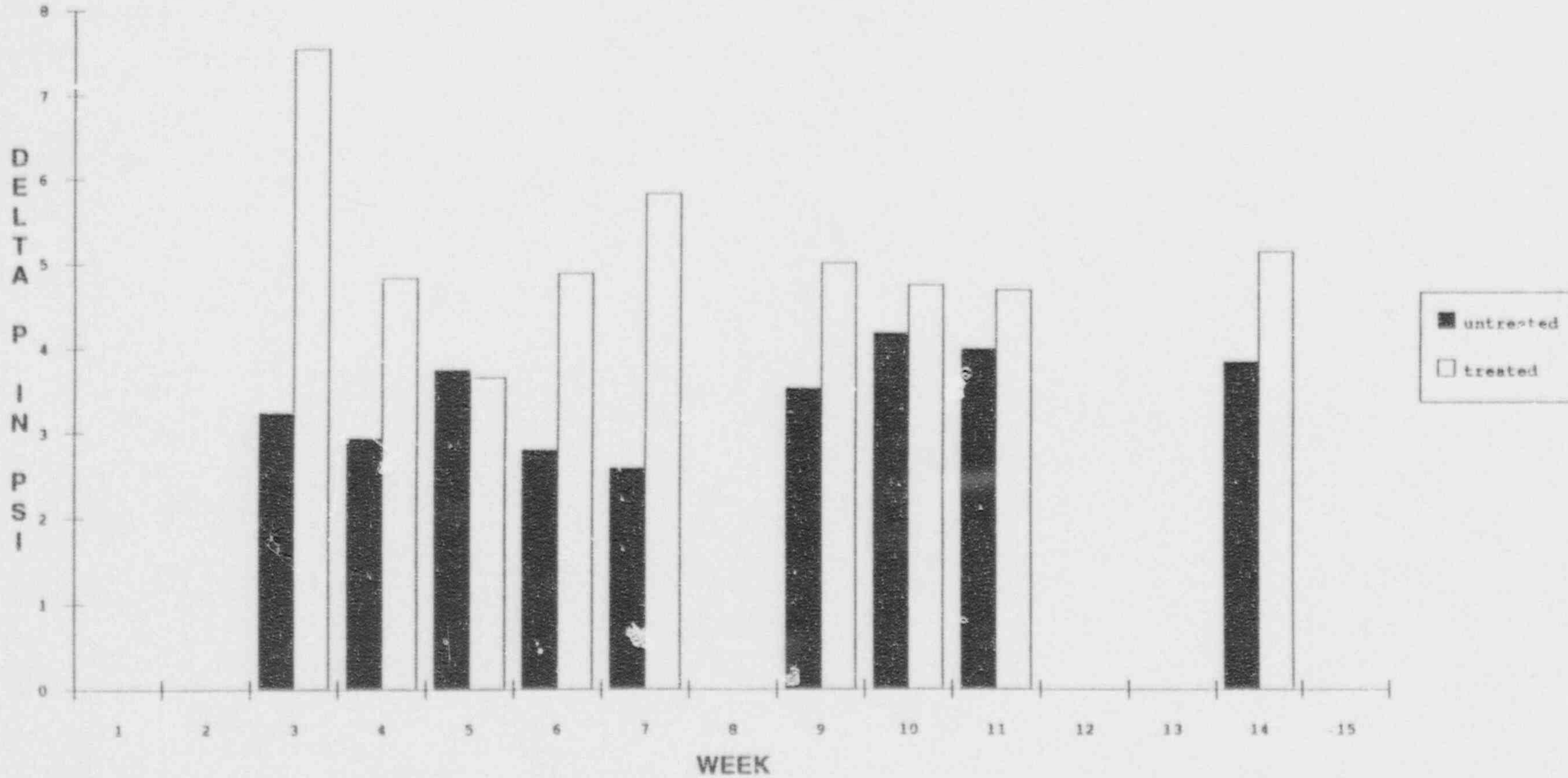


FIGURE 4-18

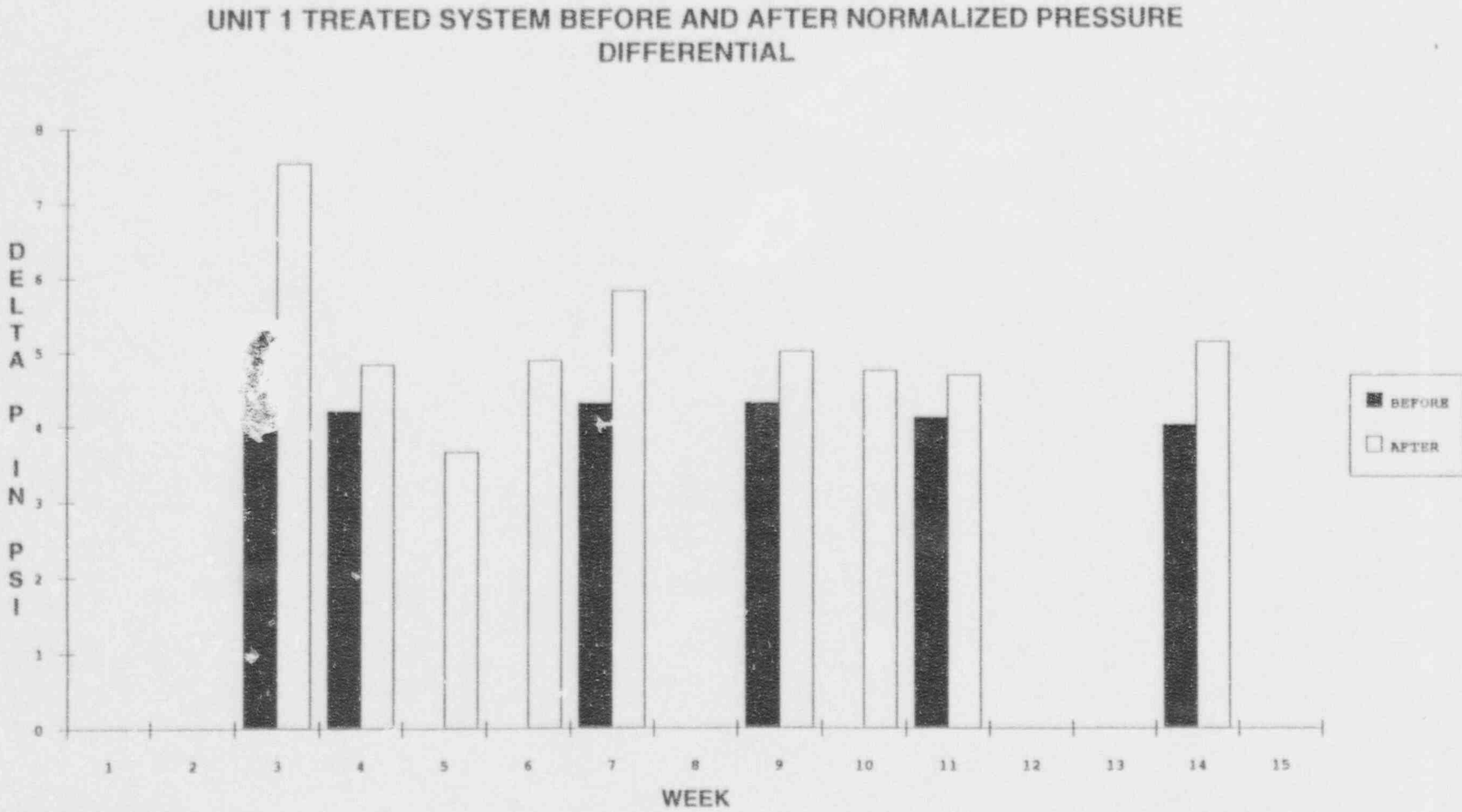

UNIT 1 TREATED SYSTEM BEFORE AND AFTER NORMALIZED PRESSURE DIFFERENTIAL
DELTA P IN PSI
0
1
2
3
4
5
6
7
8
WEEK
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
BEFORE
AFTER

FIGURE 4-19

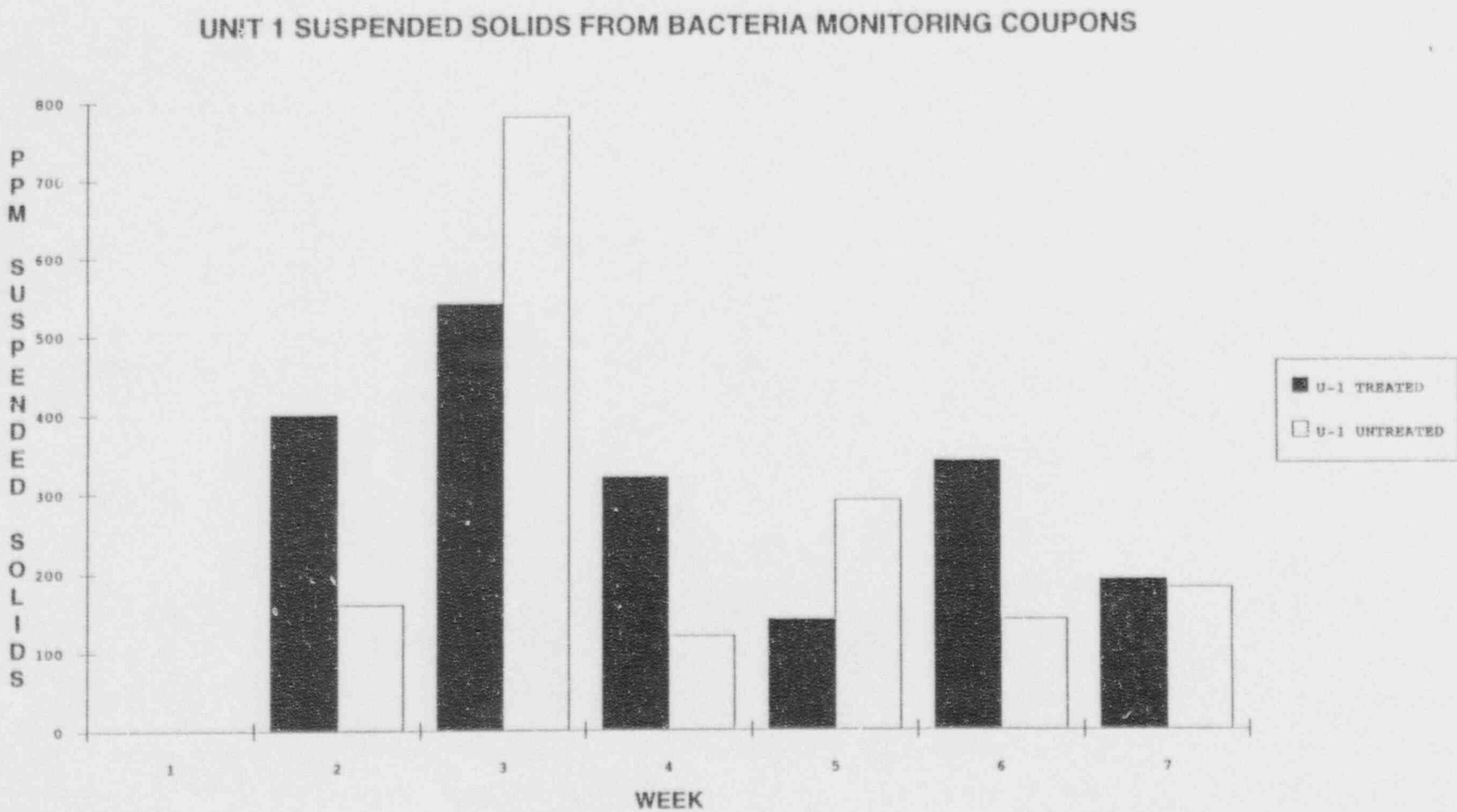

UNIT 1 SUSPENDED SOLIDS FROM BACTERIA MONITORING COUPONS
PPM SUSPENDED SOLIDS
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
WEEK
U-1 TREATED
U-1 UNTREATED

FIGURE 4-20

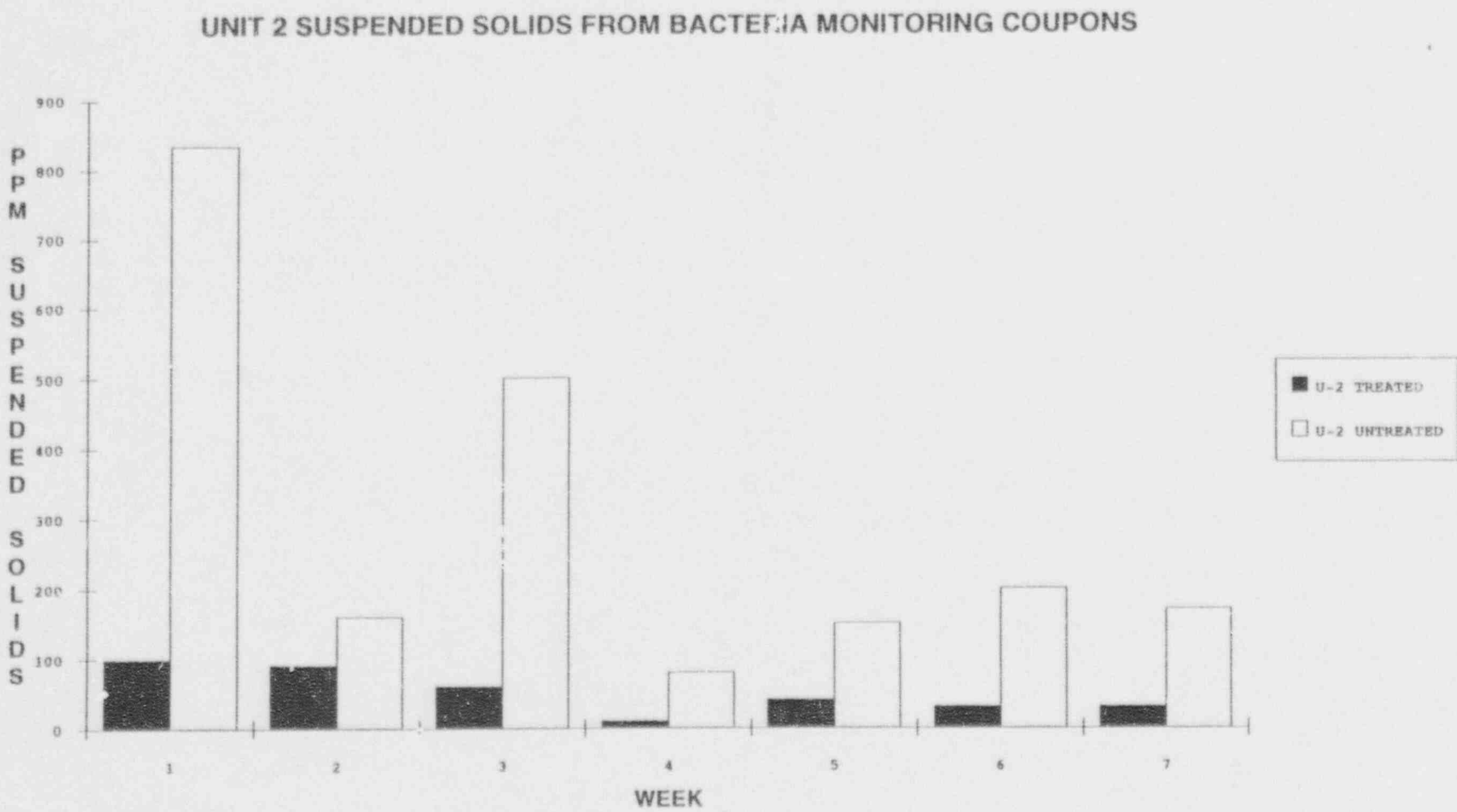

UNIT 2 SUSPENDED SOLIDS FROM BACTERIA MONITORING COUPONS
PPM SUSPENDED SOLIDS
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
7
WEEK
U-2 TREATED
U-2 UNTREATED

FIGURE 4-21

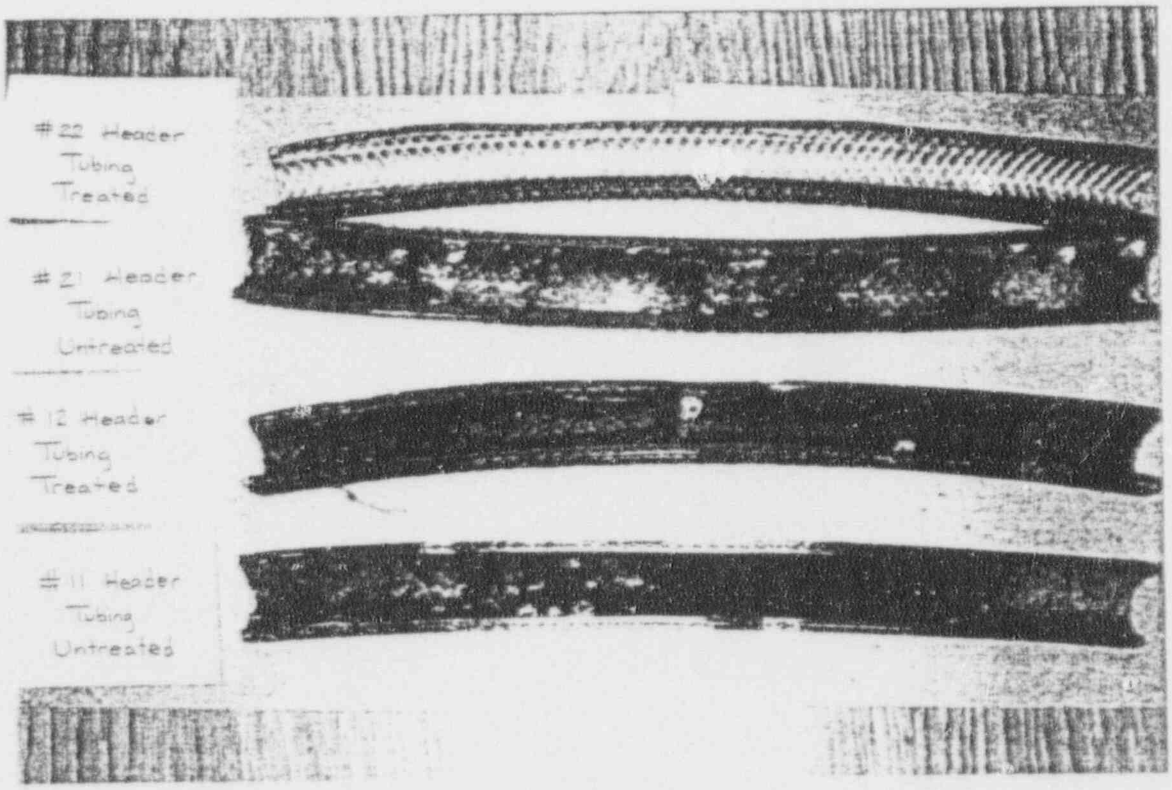


FIGURE 4-22
Photograph of Corrosion Rack Drain Hoses From Treated and Untreated Systems At End of Evaluation

Section 5

CONCLUSIONS AND SUMMARY

The chemical treatment program met the primary objective of substantially reducing microfouling and had an impact on macrofouling, when consistently applied. Indirect evidence of effectiveness included the MB trends and later suspended solids testing form the MB coupons. However, the most convincing evidence supporting treatment effectiveness are the inspection results from the mid-October cleaning program on the Unit 2 treated heat exchanger, especially the microbiological assay performed on the tube surfaces and the amount of material removed from each tube during the cleanings. This data is even more meaningful when considering that this heat exchanger had not been recently cleaned prior to initiation of the Clamtrol injection. These results were later corroborated with the dismantling of the by-pass corrosion racks. Not only had the biofilm and bacterial growth on the discharge hose been reduced, but the recruitment of macrofoulants, such as barnacles had been reduced by up to an order of magnitude when compared to an untreated system. This occurred in an environment very conducive to barnacle recruitment.

A degree of macrofouling control was also established in the treated heat exchangers, particularly the Unit 2 heat exchanger. It is believed that the macrofouling communities require a subsurface layer of microfouling to attach properly to the surfaces and grow. Based upon the ease of removal seen during this last cleaning and the reduced length of the growth, it appears that Clamtrol is having an effect on the microfouled sub-layer, and is therefore inhibiting the growth of the macrofouling organisms.

In order to receive this substantial benefit, the treatment program must be applied on a routine basis. During the course of the 17 week data collection period, the treatment was applied during 76% of the weeks for Unit 2, but only 53% of the weeks for Unit 1. Additionally, on two separate occasions during the target test period, two consecutive weeks of treatment were missed on Unit 1, while no consecutive weeks were missed on Unit 2.

The test program was essentially terminated after December 4, 1992 due to the colder water temperatures. It is believed that these colder water temperatures slow the recruitment rate of both micro and macrofoulants. Another factor considered in the decision to terminate the treatment program is that the heat exchangers have greater margin at the colder water temperatures, reducing the need for a higher cleanliness factor. Reinitiation of the treatment program is anticipated in the early spring when historically the water temperatures again reach 50 degrees.

A corrosion rate increase was seen in the treated systems on both the mild steel and copper/nickel coupons. For mild steel, this increase averaged approximately 10 mils per year, and 1.4 mils per year for copper/nickel. Laboratory and other field data support the fact that Clamtrol is not corrosive to system metallurgy. The observed increase in corrosion rates is believed to be due to the impact of Clamtrol on the new coupon biofilm. By removing the biofilm, the new

Section 6

REFERENCES

1. Betz Laboratories. "Handbook of Industrial Water Conditioning, 9th Edition." Trevose, PA: Betz Laboratories, 1991.

2. EPRI. "Detection and Control of Microbiologically Influenced Corrosion. An Extention of the Sourcebook for Microbiologically Influenced Corrosion in Nuclear Power Plants." Palo Alto: Electric Power Research Institute, 1990.

3. Stone and Webster. "Life Cycle Management Report for the Calvert Cliffs Nuclear Power Plant." Boston: Stone and Webster, 1992.