EVALUATION OF CHLORINE DIOXIDE IN POTABLE WATER SYSTEMS FOR *LEGIONELLA* CONTROL IN A ACUTE CARE HOSPITAL ENVIRONMENT

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ABSTRACT

The Johns Hopkins Hospital in 1999 began to evaluate the safety and efficacy of chlorine dioxide for *Legionella* control in a potable water system in an acute care hospital environment. The evaluation includes chlorine dioxide, its by-products and their impact on *Legionella* and pathogenic bacteria, biofilm, medical and laboratory filtration systems, corrosion rates and the environment.

The application of a delivery system was also evaluated to optimize the efficacy of the disinfectant while maintaining affordable installation, operational and maintenance costs. Installation and operation challenges are discussed and solutions presented. Extensive *Legionella* and pathogenic bacterial culturing and analysis performed during this study are presented. The data clearly shows the effect of chlorine dioxide on *Legionella* and pathogenic bacteria.

Maryland Department of the Environment (MDE) permit requirements and the hospital's approach to compliance and monitoring requirements as mandated by EPA are outlined in the paper. The paper also discusses the application of chlorine dioxide for remediation of potable water systems (cold and hot) contaminated with bacteria. The successful remediation process is described.

INTRODUCTION

In 1999, prior to the June 14, 2000 Report of the Maryland Scientific Working Group to Study Legionella in Water Systems in Healthcare Institutions, Hopkins assembled a *Legionella* task force. The goal of the task force was to develop and implement prevention and control measures to minimize the risk of nosocomial *Legionella* and to control and eliminate *Legionella* in the hospital potable water systems. The *Legionella* task force is comprised of staff from Facilities Engineering, Department of Medicine, Division of Infectious Diseases, Department of Pathology, Microbiology Laboratory, Hospital Epidemiology and Infection Control, Health Safety and Environment, Nursing, Hospital Administration, Public Affairs, Legal and Risk Management. An engineering team was assembled to research, explore and implement methods to control and monitor *Legionella* in the hospital potable water system. The engineering team is comprised of staff from The Johns Hopkins Hospital Facilities Engineering, Water Chemical Service, Inc. and *Legionella* Risk Management.

The focus of this paper is on the work of the engineering team and their results.

METHODS

<u>Disinfection Selection</u>

The hospital researched available methods to disinfect hot and cold potable water systems. A selection criteria was then developed to select a disinfection method. The hospital required that the disinfection method must be Environmental Protection Agency (EPA) approved for potable water disinfection. Additional information necessary to select a disinfection method included: impact on bio-film, residual effect, by-products, environmental and health effects, impact on equipment and piping, impact on dialysis and laboratory equipment impact on organoleptic properties of treated water.

After extensive research of current methods for controlling *Legionella* the hospital selected chlorine dioxide (ClO_2), which is approved by the EPA for use as a potable water disinfectant under CFR Part 141 – National Primary Drinking Water Regulations.[1]

ClO_2 is a gas that can be generated chemically or electrolytically from a sodium chlorite solution. Sodium chlorite is approved by the EPA (EPA registration number 5382-43) as a precursor for generating ClO_2 as a potable water disinfectant. ClO_2 is a powerful oxidant and kills bacteria via oxidative disruption of cellular processes. [2] There are few reports on the use of chlorine dioxide to specifically remove *Legionella* from hospital water supplies despite the fact that it has been used for many years in industrial and municipal water systems.[3,4,5,6] Available limited published data and experience with ClO_2 indicate it is effective.[7,8] Additionally, there is little published data documenting any adverse health effects in humans associated with ClO_2 and its by-products.

After reviewing available data on currently available ClO_2 systems, a new state of the art ClO_2 generation technology system was selected. The system converts 25% sodium chlorite into nearly pure ClO_2 by utilization of an electrochemical cassette oxidation process (Halox Inc, Bridgeport, CT). The ClO_2 equipment and associated delivery system for this study was operated and maintained by the hospital's contracted water treatment company.

Study Site

The hospital receives potable water from the local city municipality operated by the Baltimore City Public Works. BCPW is responsible for compliance with the EPA drinking water regulations. They are required to ensure that the contaminants do not exceed Maximum Contaminant Levels (MCL's) where applicable. In addition to regulated MCL's the EPA has published Maximum Contaminated Level Goals (MCLG's) for *Legionella* as well as other contaminants. Municipalities are not required to meet EPA MCLG's. BCPW currently utilizes chlorine; an EPA approved potable water disinfectant. The water provided meets all federal and state standards for potable water.

A newly constructed building was selected as the study site to evaluate chlorine dioxide. The Weinberg Building of the Johns Hopkins Hospital is a 600,000 sq. foot, 154 bed facility that houses surgical and oncology patients, including bone marrow transplant patients and patients requiring hemodialysis. In addition to general patient care floors and an intensive care unit, the building also houses 16 operating rooms, and surgical pathology, laboratory and sterile processing facilities. When construction plans were made it was decided that a water treatment system would be installed. This decision was based on historic problems with *Legionella* in the hospital water system and of the patient population occupying the building who have a high risk factor for nosocomial *Legionella* infections.

Two, six inch mains serve the building from the BCPW's 40 psig municipality water main. Once in the building the water pressure is increased to 95 psig by two 400 gallon per minute booster pumps. The water main then splits and serves both the potable cold and hot water for the building. There are two semi-instantaneous hot water generators that provide 120 degree F hot water to the building.

The building's cold and hot water piping systems are predominantly constructed of copper pipe with extended branch lines off the water mains. The water distribution mains are looped on each floor and have separate by-pass piping with valves to de-couple each wing of the building for future repairs, maintenance or renovations. Installation of the water system was completed, filled and chlorinated in April 2000; however, it was minimally utilized until the building was occupied in September 2000.

When fully occupied, the building utilizes an average of 140,000 gallons of water per day, equating to 980,000 gallons of water per week. An average flow is 96 gpm with maximum water flow at 170 gpm. Water flow data is obtained utilizing ultrasonic and insertion flow meters.

The hot and cold water piping distribution systems, connected fixtures and equipment were extensively investigated to compare pipe sizing with design verses actual flow rates. This was necessary to identify possible design and operational deficiencies such as "dead –legs", oversize piping, etc. that could impact the effectiveness of the ClO_2 system.

Delivery System

Minimal information was available related to installing and operating the ClO_2 generator on a potable water system. It was therefore necessary for the hospital to test and evaluate several engineering options implemented to maximize the effectiveness of the disinfectant.

The design of the ClO_2 generator system installation was finalized in November 2000. Installation of two generators associated piping, electric and controls were completed early January 2001.

Based on the design of the potable water system capacity and projected water usage, two ClO_2 generators, each capable of generating a 550 mg/l solution, were installed at the point of entry of the potable water distribution system. Installation included booster pumps, inductors, flow meters, corrosion coupon racks, ORP (oxidation and reduction potential) monitor, ClO_2 monitor, pressure gauges, computer monitoring system and associated electrical and piping connections.

The ClO_2 generator system was provided with 3 factory external safety alarms and multiple internal alarms. The three external alarms are chemical, leak, and flow. Additional safety alarms were added;

ClO_2 level and high limit, loss of electrical power to monitors and loss of electrical power to ClO_2 generator system.

Chlorine Dioxide, Chlorite, Chlorate Monitoring
Prior to activation of the system, performance testing and monitoring protocols were established. Testing was essential to measure and compare pre and post startup of the ClO_2 generator system.

ClO_2 and its disinfection by-products were monitored closely during pre-startup and post startup testing. Levels of ClO_2 residuals were obtained and analyzed from both hot and cold-water samples from one site at the main, and on the 1st, 4th and 5th floors, and randomly during *Legionella* sampling. ClO_2 was measured with a wavelength specific spectrophotometer utilizing DPD glycine chemistry. ClO_2 (disinfection by-products, chlorite and chlorate) were evaluated using both ion chromatography (EPA method 300) and amperometric titration methods adapted from the EPA Standard Methods. [9]

When the ClO_2 generator system was activated for continuous operation, levels of ClO_2 were measured continuously with the ClO_2 monitor and daily DPD test to ensure levels did not exceed 0.8 mg/l. ClO_2 and chlorite were also measured throughout the building after continuous activation of the system. EPA standards for chlorate levels in potable water do not currently exist. Chlorate was not measured during continuous operation of the ClO_2 system.

Dialysis and Laboratory Filtration Equipment
No data was available for ClO_2 and its disinfectant byproducts on hemodialysis filtration equipment (carbon and reverse osmosis filtration) and laboratory filtration equipment (carbon and demineralizer filtration).

Extensive testing was conducted to ensure performance of hemodialysis and laboratory equipment prior to continuous operation of the ClO_2 generator system. ClO_2 was introduced at various levels into the hemodialysis and laboratory filtration equipment. Chlorine, ClO_2, chlorate and chlorite levels were measured at each stage of filtration. A water meter was utilized to record total water usage in gallons through the filtration systems. Carbon filters were utilized to remove oxidants and disinfectant by products.

Water for the hemodialysis units is filtered through two external carbon tanks piped in series. The tanks are 10" x 35" with 0.75 cu. ft. of 12x40 mesh Granular Activated Carbon (Norit, acid/washed, low fines granular activated carbon, Norit Americas Inc, Atlanta, GA) #20 flint, underbedding (approx. 4 inches) with 14 inches freeboard. The tanks are design at a flow rate of 3.5 gpm (continuous)/ 5 gpm max., with an operating flow rate of 1 gpm. The water then passes through a portable reverse osmosis unit (Mediport P.B., Better Water, Inc. Smyrna, TN). Water through this unit is pre-filtered through a carbon cartridge. The cartridge is a 0.125 cu. ft. of 20x50 mesh granular activated carbon, acid washed, Minimum iodine #1000. The water is then post filtered by a 10 inch spun wound 5.0 micron sediment filter before passing through the reverse osmosis membrane.

For this application, no historical data was available regarding carbon tank capacities. As a safety precaution, the carbon tanks for portable dialysis equipment were sized to achieve 10 minutes EBCT (empty bed contact time) as required for monochloramines.[10] At the end of testing each day, each carbon tank was backwashed separately to prevent channeling. The tank was backwashed to drain for five-minutes to stir up the carbon. Then the tanks went through a five-minute rinse cycle to slowly reset the carbon, completing the backwashing of the tanks.

Water for the lab filtration equipment passes through one carbon filter (Neu-Ion OA6 carbon tank, Neu-Ion Inc., Baltimore, MD) and two demineralizer filtration tanks for laboratory water pretreatment. The carbon bed is sized for two minute EBCT. The lab filtration system was not modified in any way before, during or after the study. No extra precautions or measures (such as backwashing) were taken prior to, during or after the study.

Corrosion Monitoring
Minimal information was available related to ClO_2 and corrosion particularly in a hospital environment. Corrosion monitoring was performed using standard copper and mild steel coupons placed in bypass racks. Coupons were placed in the potable water supplied to the building from the city, prior to treatment, treated domestic cold water, and treated domestic hot water. The coupons placed upstream of the treatment system served as control. Coupons were also placed in hot and cold domestic water systems of other nearby buildings for baseline monitoring purposes.

***Legionella* and Bacteria Monitoring**
The hospital tested and evaluated the water quality in the building over a 46 month period. Samples of both hot and cold water were taken from an average of 28 sites during multiple stages of the project and numerous distal sites throughout the building on a regular basis. Samples were obtained quarterly except during testing of equipment and water events, when the sampling frequency was increased. Samples were obtained to assess all

patient-care floors in both clinical and non-clinical areas where faucets were used both frequently and infrequently. Samples were also obtained at sites that *Legionella* would most likely colonize, such as areas with “dead legs”, extended branch piping and areas with inadequate hot water return, etc. At each site, faucets were opened and allowed to run for 30 seconds before the sample was collected. Aerators were removed at some of the sites to evaluate the impact of ClO_2 on the devices. Samples were also obtained from the two backflow prevention devices where potable water enters the building, the potable water main after ClO_2 treatment, a dedicated cold-water faucet at the end of the water distribution system, each hot water generator and the hot water return main. For each sample collected, direct and concentrated cultures were performed.

The direct culture consisted of plating 100μl of water directly onto three separate plates of selective media for *Legionella*. The three plates used contained buffered charcoal yeast extract (BCYE) with PAV (polymixin B, anisomycin, and vancomycin), BCYE with DGVP (dye, glycine, vancomycin and polymixin B) and BCYE *Legionella* selective agar (vancomycin, colistin, and anisomycin) (Becton Dickenson, Sparks, MD). The concentrated culture consisted of filtering 50 ml of the original sample through a polycarbonate filter (Whatman, VWR Scientific, West Chester, PA). The filter was then placed into 5ml of the original, unfiltered sample and vortexed. Next, 100μl aliquots were then plated onto each of the three plates. All plates were incubated in CO_2 at 37° C within a moist chamber for 7 days. Colonies suggestive of *Legionella* were sub-cultured on blood agar and BCYE plates. Organisms that grew on BCYE but not on blood agar were identified as *Legionella* species and were then speciated using direct fluorescent antibody reagents (m-TECH, Alpharetta, GA) and the gas liquid chromatography Sherlock™ Microbial Identification System (MIDI Inc., Newark, DE).[11]

Legionella and gram–negative culture data was evaluated. Legionalla data was evaluated at 10 org/ml (typical action level) and total positive Legionalla sites.

Remediation Disinfection Methods

Commonly used methods to remediate potable water systems in healthcare facilities were evaluated. Hyperchlorination and super heating of the potable water system were utilized and their impact on *Legionalla* and bacteria evaluated. No information was available utilizing ClO_2 to remediate potable water systems. Therefore, it was necessary for the hospital to develop a ClO_2 shock remediation treatment method and evaluate its impact on *Legionalla* and bacteria.

Patient Surveillance for *Legionella*

The hospital performs active clinical surveillance for *Legionella* infections. All bronchoalveolar lavage samples taken from in-patients are cultured, and those who have evidence of a lower respiratory tract infection are routinely cultured for *Legionella*. All cultures that grow *Legionella* and all positive urinary antigen tests are reviewed by infection control staff to determine if the case is nosocomial. Patients who have culture confirmed *Legionella* infections up to nine days after admission are considered “possible” nosocomial cases and any patient who has a confirmed infection more than nine days after admission is considered a “definite” nosocomial case. Any case in which the patient’s isolate matches an environmental sample by pulsed field gel electropheresis is considered a definite nosocomial case regardless of the incubation period.

RESULTS

Chlorine Dioxide, and Chlorite Levels

Prior to January 2004, the EPA maximum residual disinfectant level goal (MRDLG) for ClO_2 was 0.8 mg/l, and maximum contaminant level goal (MCLG) for chlorite was 1.0 mg/l.[12]

In January 2004 new EPA guidelines extended ClO_2 and chlorite regulations to small municipalities. Current EPA maximum residual disinfectant level (MRDL) for ClO_2 is 0.8 mg/l, and maximum contaminant level (MCL) for chlorite is 1.0 mg/l.[13]

Between January 2001 and June 2002, ClO_2 and chlorite residuals were monitored throughout the building. The generator system had been set to maintain an average of 0.7 mg/l of ClO_2 and maximum not to exceed of 0.8 mg/l. ClO_2 in the potable water system. This was confirmed as a measured level downstream of the disinfectant induction point. ClO_2 and chlorite residuals did not exceed the EPA maximum residual disinfectant level goal (MRDLG) of 0.8 mg/l and maximum contaminant level goal (MCLG) 1.0 mg/l respectively.

Free chlorine residuals entering the building ranged between 0.71 mg/l and 1.28 mg/l. Total chlorine residuals ranged between 0.93 mg/l and 1.62 mg/l. ClO_2 residuals in the mechanical equipment room downstream of induction ranged between 0.28 mg/l - 0.79 mg/l. ClO_2 and chlorite residuals in cold water averaged at the distal sites between 0.23 mg/l – 0.79 mg/l and 0.22 – 0.68 mg/l respectively. ClO_2 residuals in hot water averaged at the distal sites between 0.1 mg/l – 0.2 mg/l.

In July 2002, the generator system was adjusted to maintain an average ClO_2 residual of 0.5 mg/l in the potable water and maximum ClO_2 not to exceed of 0.8 mg/l. ClO_2 residuals in the mechanical equipment room downstream of induction averaged between 0.28 mg/l - 0.5 mg/l. ClO_2 residuals in cold water averaged at the distal sites between 0.11 mg/l – 0.31 mg/l. ClO_2 in hot water averaged at the distal sites between 0.05 mg/l – 0.2 mg/l.

<u>*Legionella* and Bacteria</u>

Evaluation of *Legionella* and bacteria was divided into three phases:

- Phase I - July 2000 until November 2000, pre and post hyper-chlorination, thermal remediation.

- Phase II - December 2000 until May 2001, ClO_2 system installed, intermittent introduction of elevated residuals of ClO_2 in the potable water system during testing of filtration equipment.

- Phase III - June 2001 until July 2004, continuous introduction of ClO_2 residuals below a 0.8 mg/l in the potable water system.

Legionella cultures in charts 3, 4, 5 and 6 in the appendixes indicate total positive *Legionella* sites and 10 org/ml (typical action level). The data below in Phase I through Phase III references total positive *Legionella* sites in percent.

Phase I data collected between August 31, 2000 and October 18, 2000 indicated no significant reduction in the total gram-negative bacteria sites in both the hot and cold water.[*]

The number of total positive *Legionella* sites decreased.[**] No significant change was noted in positive *Legionella* sites in the cold water. [***] However, a reduction in positive *Legionella* sites in the hot water was observed.[****]

Phase II data collected between January 16, 2001 and February 15, 2001 indicated no detectable gram-negative bacteria in either the cold and hot water systems. The total number of positive *Legionella* sites reduced slightly in the cold and hot water systems.[*****]

Phase III data collected between June 5, 2001 and July 6, 2004 indicated an initial increase followed by

[*] See Chart 1 in Appendixes.
[**] See Chart 3 in Appendixes.
[***] See Chart 5 in Appendixes.
[****] See Chart 6 in Appendixes.
[*****] See Chart 5 & 6 in Appendixes.

a gradual decrease to non-detectable levels of *Legionella* and gram–negative bacteria. These results were obtained even with significant spikes of *Legionella* and gram-negative positive sites occurring around the same period of several disruptions to the buildings potable water service.

The first period of water disruptions occurred between September 2001 and October 2001. Brown water and sediment was introduced into the building potable water system.

During this period, gram-negative sites increased significantly. No change of positive *Legionella* sites was observed.[*] Remediation was not implemented.

The second period of water disruptions occurred between October 2002 and January 2003. Brown water and sediment was introduced into the building including the loss of water pressure in the potable water service. January culture results indicated, an increase in gram-negative bacteria sites.[**] *Legionella* was not detected in the cold water while *Legionella* positive sites increased in the hot water.[***] Again, remediation was not implemented.

The third period of water disruptions occurred between May 5, 2003 and October 9, 2003. Brown water and sediment was introduced into the buildings potable water system. Also, on September 19, 2003 the region experienced heavy rains associated with hurricane “Isabel” which may have impacted water quality in the region.

Water samples obtained on September 24, 2003 and October 6, 2003 indicated a significant increase of gram-negative sites and positive *Legionella* sites in the potable hot water.[****] Most importantly, were the positive cultures of *L. pneumophila*, which up until the September 24, 2003 samples had been *L. anisa*. *Legionella* was not detected in the cold water.[*****]

Water samples obtained on October 10, 2003 after additional disruptions to the potable water service, indicated a further increase of positive *Legionella* sites in the potable hot water system.[******] Positive cultures of *L. pneumophila* were detected in both

[*] See Charts 2 & 4 in Appendixes.
[**] See Chart 2 in Appendixes.
[***] See Charts 5 & 6 in Appendixes.
[****] See Charts 2 & 6 in Appendixes.
[*****] See Chart 5 in Appendixes.
[******] See Chart 6 in Appendixes.

the cold and hot water systems.[*] Gram-negative bacteria in the potable cold and hot water systems also increased.[**]

In response to disruptions, the hospital developed and implemented a flush and ClO_2 shock remediation treatment. Also included was the cleaning of faucet aerators, showerheads and back flow prevention devices. During the cleaning of the back flow prevention devices (which are located in the two six inch potable water mains entering the building) large amounts of sediment was found in the strainers (Figure 1).

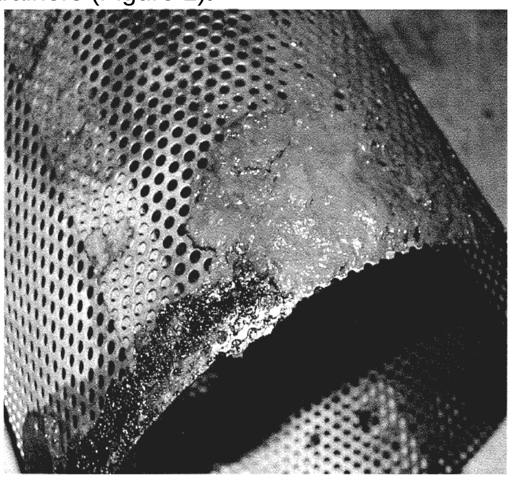

Figure 1 – Strainer

Legionella and bacteria cultures were obtained from both devices. One device had *L. pneumophila* and >1000 org/ml gram-negative bacteria. Test results (post cleaning and disinfection of the devices with chlorine) cultured negative for *Legionella* and gram-negative bacteria.

Water samples obtained post ClO_2 shock and flush remediation treatment on October 28, 2003 indicated significant reduction in the number of positive *Legionella* sites.[***] However, there was an increase in the total gram-negative bacteria sites in the hot water system.[*] All positive *Legionella* sites were *L. anisa* except for one site, which remained positive with <1 org/ml of *L. pneumophila.*

On November 13, 2003 another ClO_2 shock and flush remediation treatment was implemented. Water samples obtained post remediation treatment indicated a slight reduction in gram-negative bacteria sites. *Legionella* positive sites remained the same. However, all positive *Legionella* sites were *L. anisa,* with no detectable *L. pneumophila.*

[*] See Charts 5 & 6 in Appendixes.
[**] See Chart 2 in Appendixes.
[***] See chart 4 in Appendixes.

On November 14, 2003 following the November 13, 2003 remediation daily flushing protocols were developed and implemented for patient rooms.

Since December 2003, *Legionella* and gram-negative bacteria have been non-detectable except on April 1, 2004, which one patient room tested positive with <1 org/ml of *L. pneumophila* and >1000 org/ml gram-negative bacteria.[*] Investigation identified that the site was unoccupied for weeks and the flushing protocols was not implemented. After daily flushing was implemented, *Legionella* and bacteria was not detected.[**]

<u>Remediation Disinfection Method Testing</u>

Hyper-chlorination, super heating and ClO_2 to remediate potable water systems were implemented and evaluated. During hyper-chlorination and super heat treatments, the potable water system could not be used. However, ClO_2 shock remediation enabled the hospital to use the potable water with the only restriction “do not drink”.

Hyper-chlorination of the potable water system was implemented prior to occupancy of the building and this study. The potable water system was treated with chlorine in two stages; the lower floors were chlorinated on March 15, 2000 and the upper floors were chlorinated on April 26, 2000. The potable water system was treated with 200 mg/l of free chlorine for three hours. Water sampling performed on August 31,2000 identified that the potable water system was colonized with gram-negative bacteria and *Legionella*.[***] The test results indicate that hyper-chlorination was not effective in eliminating the bacteria and *Legionella* from the potable water system. Total rebound of bacteria occurred in less than two weeks.[***]

Hyper-chlorination of the potable water system was again implemented prior to occupancy the building. The potable water system was chlorinated on September 2, 2000 with 50 mg/l free chlorine for 24 hours. Water sampling performed on September 6, 2000 identified that the potable water system was still colonized with gram-negative bacteria and *Legionella*.[****] Again, test results indicated that hyper-chlorination reduced, but did not eliminate the gram-negative bacteria and *Legionella* from the potable water system.[****] The system bacteria levels rebounded significantly within days.

[*] See Charts 2 & 4 in Appendixes.
[**] See Chart 4 in Appendixes.
[***] See Chart 1 in Appendixes.
[****] See Charts 1 and 3 in Appendixes.

Super heating of the potable hot water system was implemented prior to building occupancy. On September 9, 2000, the potable hot water system was super heated to approximately 180 degree F and flushed for 10 minutes at each fixture. Showers in patient rooms have anti scald devices, which prevented the shower from being exposed to water temperature above 115 degrees F. Water sampling performed on 9/11/00 indicated that superheating had little to no impact on eliminating gram-negative bacteria and *Legionella* in the hot water system.[*]

ClO_2 shock remediation treatment and flush was developed and implemented by the hospital in October 2003. Elevated levels of ClO_2, averaging >4.0 mg/l were introduced into the building potable water system for six hours. Hot and cold water systems were then flushed at sinks continuously during the six-hour remediation treatment. Sinks with electric valves and showers with mixing valves were flushed periodically during the six-hour remediation. At the end of the remediation, the ClO_2 treatment system was adjusted to normal operation. ClO_2 shock remediation treatment and flush was then followed with daily flushing at patient room sinks and showers. Hot and cold water was flushed for approximately 10 minutes at sinks and showers during the daily cleaning of the patient rooms. Flushing at the fixtures replaces stagnated water in the pipes with treated water to maximize the exposure of ClO_2 to the piping and plumbing fixtures. The ClO_2 shock remediation treatment and flush, along with the daily flushing at patient rooms, has resulted in the elimination of *Legionella* and gram-negative bacteria at all test sites since implemented.[**]

Dialysis and Laboratory Filtration Equipment

The ClO_2 generator system was designed to provide a maximum ClO_2 level of 0.8 mg/l. Before the building was fully occupied, elevated levels as high as 2.0 mg/l of ClO_2 was introduced into the potable water system during water restrictions and non-occupied hours, to test the efficacy of the filtration equipment. When the test ended, the hemodialysis carbon filtration tanks were exposed to 12,310 gallons of elevated levels of ClO_2 treated water, which is equivalent to 67.8 hemodialysis treatments. The carbon filters removed all ClO_2, chlorite and chlorine from the product water to the hemodialysis filtration equipment during the evaluation.

The laboratory carbon filtration tank, at the end of the testing, was exposed to 2,334 gallons of elevated levels of ClO_2 treated water. As with the testing of the hemodialysis unit, the filtration equipment was subjected to levels as high as 2.0 mg/l of ClO_2. The two-minute EBCT carbon filter effectively removed all residuals of ClO_2, chlorite and chlorine during the evaluation.

Corrosion Analysis

Coupons were removed after 54 days, cleaned, dried and weighed. The corrosion rates were calculated based on the weight loss of metal and converted to mils per year (MPY). Corrosion inhibitor chemicals such as phosphate or silicate are not used in the potable water.

The majority of the water supply and re-circulated piping systems are copper with small amounts of brass and steel (<3%). The corrosion rates identified in table 2 indicate the loss of metal to be essentially equal in the treated systems versus the untreated city water supply with the exception of the re-circulated hot water. Analysis of the coupon data, upon first inspection, indicated a corrosion problem for mild steel in the hot water system. Hot water typically has higher corrosion rates than cold water due to increased electron activity however; this could not explain such a large deviation from the cold-water corrosion rates. In reviewing comparison data from other (untreated) all copper hot water systems, we concluded the majority of corrosion was due to galvanic interference created by placing a mild steel coupon in a re-circulated copper piping system, thus producing false elevated corrosion rates.

Analysis of the remaining coupon data indicated the corrosion rates did not differ significantly from the water supply upstream of the chlorine dioxide injection point.

Patient Surveillance for *Legionella*

As of July 2004 no cases of nosocomial *Legionella* infection have been detected in the building.

DISCUSSION

Upon the onset of this study, it was surprising to identify that the potable water distribution system in a new building could be extensively colonized with bacteria and *Legionella*. However, after forty months of extensive testing and evaluation of the point of entry ClO_2 generator system in our building, *Legionella* and bacteria has been eliminated from the buildings potable water system.

It is essential to note that the extended period of time to eliminate *Legionella* and bacteria was related to the impact evaluation of ClO_2. Since minimal information was available related to installing and operating the ClO_2 generator system on a potable water system, it was necessary for the hospital to develop, test and evaluate engineering options as well as monitoring protocols. Additionally, the

[*] See Charts 1 and 3 in Appendixes.

[**] See Charts 2 and 4 in Appendixes.

results were achieved with the ClO_2 generator system operational Monday through Friday 7am – 7pm when water demand was adequate to operate the system.

During the course of the evaluation, shock remediation treatments were not employed until after October 2003, when two flush and ClO_2 shock remediation treatments were implemented.

During the course of the evaluation no extra measures such as daily flushing or cleaning of distal taps were implemented until November 2003. All results prior to November 2003 were based on normal use of distal taps.

Based on testing results, *Legionella* and bacteria would have been eradicated rapidly if ClO_2 shock remediation treatment and flushing daily at distal sites were implemented upon start up. However, the hospital would not have been able to obtain the extensive data on how to maximize the effectiveness of ClO_2 and its impact on *Legionella*.

Identifying Design and Operational Deficiencies

After selecting and installing a ClO_2 generator system, the potable water system was evaluated to identify design and operational deficiencies that could impact the effectiveness of the system. Key deficiencies identified:

- Piping oversized based on potable water usage. Flow rates designed for 300 gpm (600 gpm max.) versus actual measured 96 gpm (170 gpm max.). Over sizing of the pipe resulted in low water velocities and laminar flow conditions. These conditions promote the growth of bacteria and help establish bio-film. Correction of this deficiency was not feasible.

- Booster pumps were oversized based on potable water usage. Booster pumps were designed at 400 gpm each and parallel operation. System over pressurization, pressure surges, water hammer and entrainment of air resulted. Problem was corrected by single pump operation, adjusting control valves and lowering the system operating pressure.

- Hot water generators and piping system were also oversized, based on potable water usage. Pipe oversizing resulted in low water velocities, laminar flow conditions, reduced water circulation, and poor temperature distribution. Piping was modified, and circulator pumps replaced resulting in improved water circulation and temperature.

- Hot and cold water by-pass piping and isolation valves looped on each created "dead-legs". Modification was not feasible, periodic flushing of piping is necessary.

ClO_2 System Modifications

Once the ClO_2 generator system was installed and operational, several engineering options were evaluated to maximize the effectiveness of the disinfectant. Some modifications that proved to be effective were on the feedwater to the ClO_2 generator. A 5.0 micron sediment filter, air separator, feedwater booster pump and pressure regulator were installed to stabilize the operation of the ClO_2 generator system.

ClO_2 System Operation

During pre-startup testing of the ClO_2 generator system, several control problems were identified. The ORP (oxidation and reduction potential) monitor could not control the level of ClO_2 due to fluctuations of chlorine residuals in the potable water supplied by the local city municipality. To correct the problem, ORP control was eliminated and a water flow control system was installed. The water flow control system consist of a flow meter, ClO_2 monitor and computer control system. The flow meter monitors water use and the computer control system collects flow meter data. After every 400 gallons of water flow, ClO_2 is generated based on a preset run time. The ClO_2 is then inducted into the potable water system to maintain the correct feed rate. The ClO_2 monitor shuts down the ClO_2 generator so as not to exceed 0.8 mg/l of ClO_2. Once in operation, the control of ClO_2 residual proved to be very effective.

Laboratory and Hemodialysis Filtration Equipment

To our knowledge the study of ClO_2 and its impact on laboratory and hemodialysis filtration equipment was the first of its kind. The study addressed concerns associated with the ability of carbon filters to effectively remove all oxidant residuals.

Chlorine Dioxide, and Chlorite Levels

The overall operation and control of the ClO_2 generator system was found to be safe based on the Code of Federal Regulations for ClO_2 MCL and chlorite MRDL.

Our test data identified that at maximum concentration of ClO_2 in the potable water main, the levels of ClO_2 and chlorite throughout the building were well below the maximum allowable levels. While chlorate is currently not regulated in drinking water, our test data indicated that chlorate levels never exceeded 0.4 mg/l. Shortly after start up of the ClO_2 generator system, ClO_2 and chlorite residuals were elevated at fixtures closest to source of ClO_2 introduction, but still within acceptable limits.

Eventually, ClO_2 residuals in the cold water distribution system reached equilibrium, and minimal difference in the ClO_2 and chlorite residuals were observed between the fixtures closest and farthest away from the source of ClO_2 introduction. The same was observed with the hot water distribution system. However, ClO_2 residuals were much lower than the cold water system. Investigation identified that oversizing of the hot water system reduced the amount of ClO_2 treated make-up water to the hot water system. The volume of hot water circulated and reheated verses the amount of make-up water was inadequate to maintain elevated residuals of ClO_2 in the system. ClO_2 residuals in the hot water system were increased by purging approximately 2 gpm of return water from the hot water system allowing additional ClO_2 treated water to enter system. Once implemented, ClO_2 residuals increased to an effective range.

<u>Impact on Legionella and Biofilm</u>

Legionella species are recognized to reside in biofilm inside of pipes and flow restrictive devices (such as faucet aerators, showerheads, valves, etc.).

Our test data indicated that ClO_2 effectively penetrated biofilm in the piping system and flow restrictive devices. However, the effectiveness was diminished at distal taps that were used infrequently due to the loss of ClO_2 residual. Continuous monitoring of a sink in a remote area that was infrequently utilized did not achieve negative *Legionella* and bacteria results until daily flushing was implemented. Since implementing the daily flush, the sink has remained free of *Legionella* and gram-negative bacteria.

In November 2003, the protocol to flush patient room fixtures (sinks and showers) daily during cleaning of the bathrooms was implemented. The daily flushing eliminated *Legionella* and gram-negative bacteria at these sites since implemented.

The evaluation of patient room sink aerators removed versus installed showed no difference in culture results exposed to ClO_2 during normal fixture use, both had detectable *Legionella* and gram-negative bacteria. The use of ClO_2, combined with daily flushing eliminated the *Legionella* and gram-negative bacteria at all sites without the removal of aerators.

The impact on biofilm was based on ClO_2 residuals, *Legionella* and bacteria culture results and an actual visual inspection of pipes (Figure 2 and Figure 3).

The biofilm can be clearly seen in Figure 2, which is a section of four-inch diameter copper hot water supply piping that was removed for inspection. Cultures obtained tested positive for gram-negative bacteria and Legionella. Following three weeks of daily exposure to < 0.8 mg/l of ClO_2 and after implementation ClO_2 shock remediation treatment and flush, another section of pipe was removed for inspection approximately three feet away from the first section of pipe (Figure 3). The biofilm was eliminated as shown in Figure 3. Swab cultures obtained from this pipe tested negative for bacteria and *Legionella.*

<u>Remediation Disinfection</u>

The evaluation of commonly used methods to remediate potable water systems such as Hyper-chlorination and super heating proved to be ineffective to reduce and eliminate *Legionella* and gram-negative bacteria. However, the development and implementation of ClO_2 as a shock remediation treatment combined with a flush, proved to be extremely effective against *Legionella* species and gram-negative bacteria. This method was applied on to two older buildings at Hopkins that were heavily colonized with *Legionella* species, *L. pneumophila* and gram-negative bacteria with the same results.

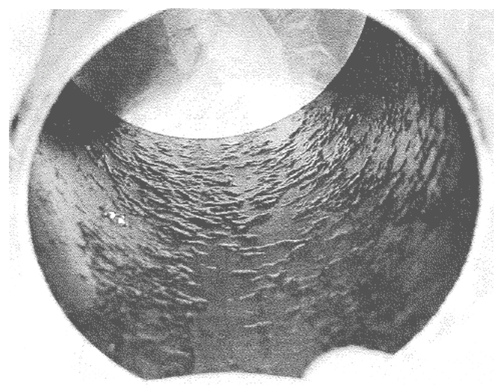

Figure 2 – Pre ClO_2 Treatment

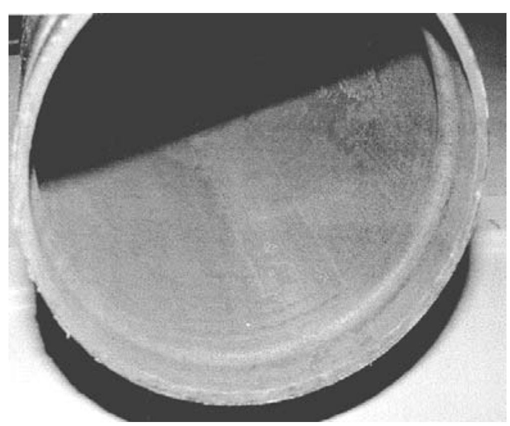

Figure 3 – Post ClO_2 Treatment

Corrosion

Corrosion continues to be a critical concern with any water treatment system, primarily in older buildings. The test data associated with the application of ClO_2 appears to have no deleterious effects on the buildings piping.

The building piping system is primarily copper, and after 40 months of continuous exposure to ClO_2 with no corrosion inhibitor treatment, no significant corrosion was noted. Higher corrosion rates were observed on mild steel coupons installed in the ClO_2 treated hot water system. However, mild steel coupons in a predominately copper re-circulated hot water system cannot be measured reliably due to galvanic interference. Therefore the data obtained for mild steel in the hot water system is inconclusive.

Legionella Monitoring Standards

Legionella monitoring continues to be a subject of discussion. The June 14, 2000 Report of the Maryland Scientific Working Group to Study *Legionella* in Water Systems in Healthcare Institutions recommends:14

- "Water distribution systems within acute care hospitals (i.e., all building plumbing systems that distribute water for human contact) should be routinely cultured, with the time schedule determined by risk assessment for each institution."[14]
- "Hospitals in which this type of assessment is not possible or practical may wish to consider implementation of the Allegheny County guidelines (with a clear recognition of their potentially limited applicability to hospitals in Maryland)."
- "At the same time, there was inadequate data to provide uniform guidelines regarding timing and "action levels" for environmental sampling. It was the opinion of the Scientific Working Group that such decisions are best individualized, depending on hospital-specific risk and performance criteria." [14]

As of July 2004 Centers for Disease Control (CDC) does not recommend regularly scheduled microbiological assay for *Legionella* except in facilities with transplant patients.[15] The CDC Environmental Infection Control Guidelines states, "In-house testing is recommended for facilities with transplant programs as part of a comprehensive treatment/management program."
CDC also recommends that after an outbreak of legionellosis, environmental monitoring is necessary to identify the source and to evaluate efficacy of prevention measures.

The 1997 Allegheny County guidelines state that: "All hospitals should perform an environmental survey yearly. If transplants are performed, then a survey should be performed more often." "If hospital beds are less than 500, a minimum of 10 distal sites should be surveyed. If bed size is greater than 500, 2 distal sites per 100 beds are recommended."[16]

The Johns Hopkins Hospital has implemented an aggressive monitoring and control strategy that exceeds current practice and recommendations in contrast to CDC, Allegheny County, PA, and Report of the Maryland Scientific Working Group. The Facilities Department currently tests a minimum of 28 sites quarterly in the 154 bed Weinberg building. This would be reduced to only 10 test sites minimally on an annual basis, or more often in high-risk patient areas, if Hopkins followed current practice and guidelines.

Based on data obtained from this study, Hopkins developed a testing and monitoring program that has proven to be very effective. Test method and monitoring sites are:

- Potable water supply pre-treatment (where potable water enters the building), 30 second sample
- Potable cold water, post treatment, 30 second sample
- Potable cold water, end of system dedicated cold water faucet such as a hose bib or drinking cooler, 30 second sample
- Potable hot water supply, 30 second sample
- Hot water return, 30 second sample
- Two patient rooms per floor, sink and shower each room, first draw samples (first draw identifies condition of faucet and showerheads since they share both hot and cold water supply)

EPA & MDE Permit Issues and Process

The hospital approached and worked with the Maryland Department of the Environment (MDE) during this study to ensure that the hospital was in full compliance with EPA and MDE regulations.

As a result of adding ClO_2 to the potable water at the point of entry, the hospital became a public water system. However, since the hospital purchases potable water from local city municipality operated by the Baltimore City Public Works, the hospital was considered a non-transient non-community consecutive public water system.

MDE required the following:

- PE stamped construction documents

- Construction permit from the Water Quality Infrastructure Program

- All local and state construction permits

- Certification or application of ClO_2 equipment by (National Sanitation Foundation (NSF)

- The ClO2 system must supervised by an operator certified by the State of Maryland Board of Waterworks and Waste Systems Operators

- Prior to continuous operation of the ClO_2 system, one ClO_2, chlorite and coliform bacteria test by an independent state certified laboratory

- Daily testing of ClO_2 and chlorite at the point of treatment (EPA allows the state flexibility to set monitoring requirements to consecutive water systems)

- Monthly testing of chlorite in the distribution system (three set sample beginning, middle and end of system)

- All test data must be submitted to MDE monthly

SUMMARY

To our knowledge The Johns Hopkins Hospital was the first medical facility in the United States to receive a consecutive public water system permit for the application of a point of entry chlorine dioxide treatment system.

The efficacy of Chlorine dioxide is influence by proper system application, operation, control and monitoring of *Legionella*, pathogenic bacteria and disinfectant residuals. Additionally, identifying and correcting piping deficiencies and understanding water usage is necessary. It is essential that daily flushing protocols and prompt remediation after disruptions to the potable water system be implemented.

Our data confirms that Chlorine dioxide is safe and effective in controlling and eliminating *Legionella,* other pathogenic bacteria and bio-film. Further studies are encouraged.

ACKNOWLEDGMENT

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APPENDIX

CHART 1 - % POSITIVE GRAM NEGATIVE BACTERIA SITES PHASE 1 & 2

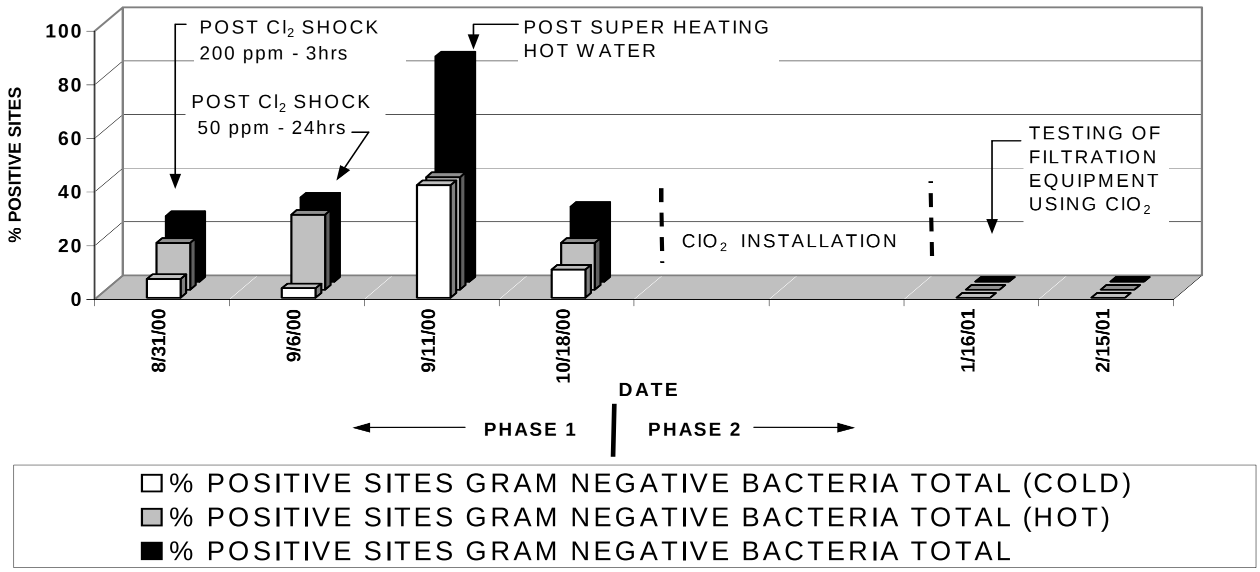
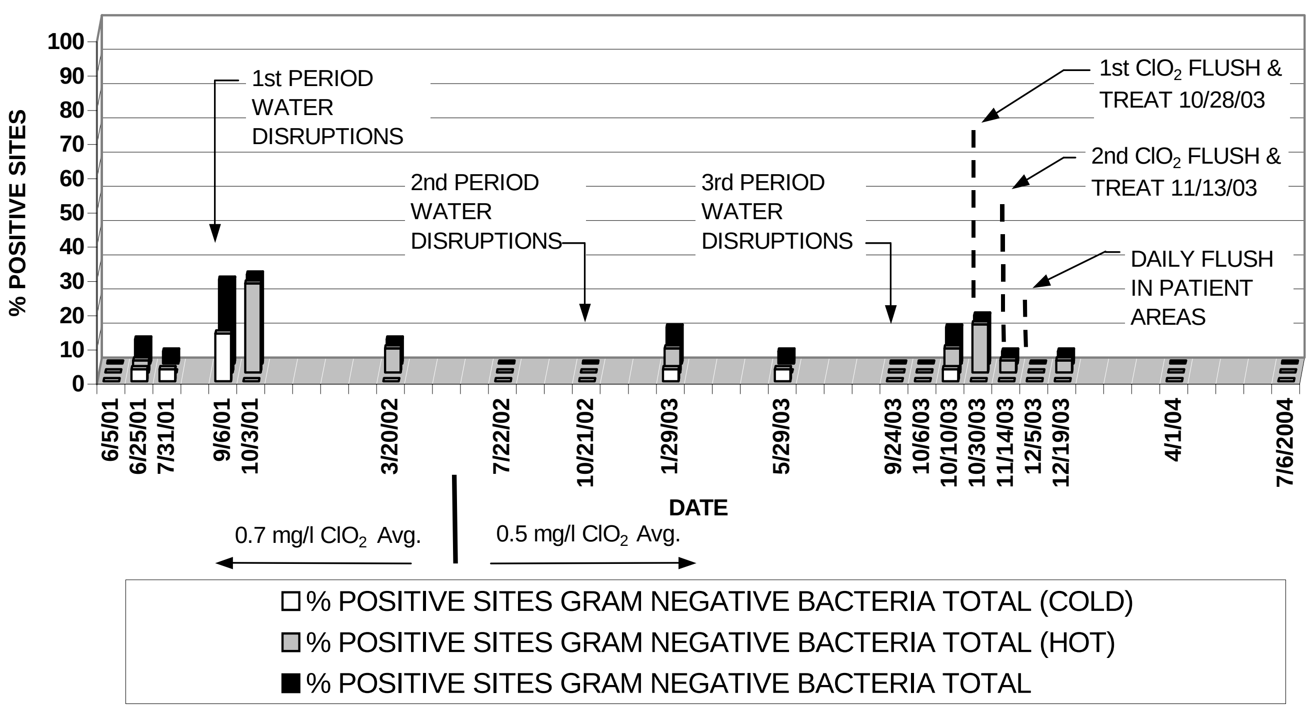


CHART 2 - % POSITIVE GRAM NEGATIVE SITES PHASE 3



APPENDIX

CHART 3 - % POSITIVE LEGIONELLA SITES PHASE 1 & PHASE 2

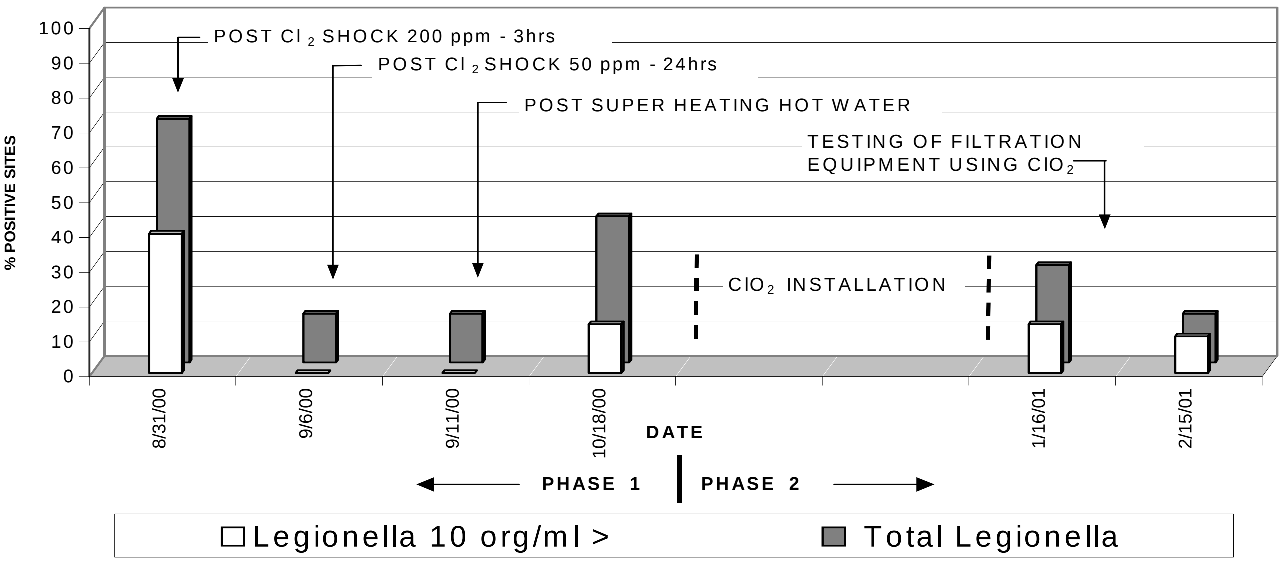
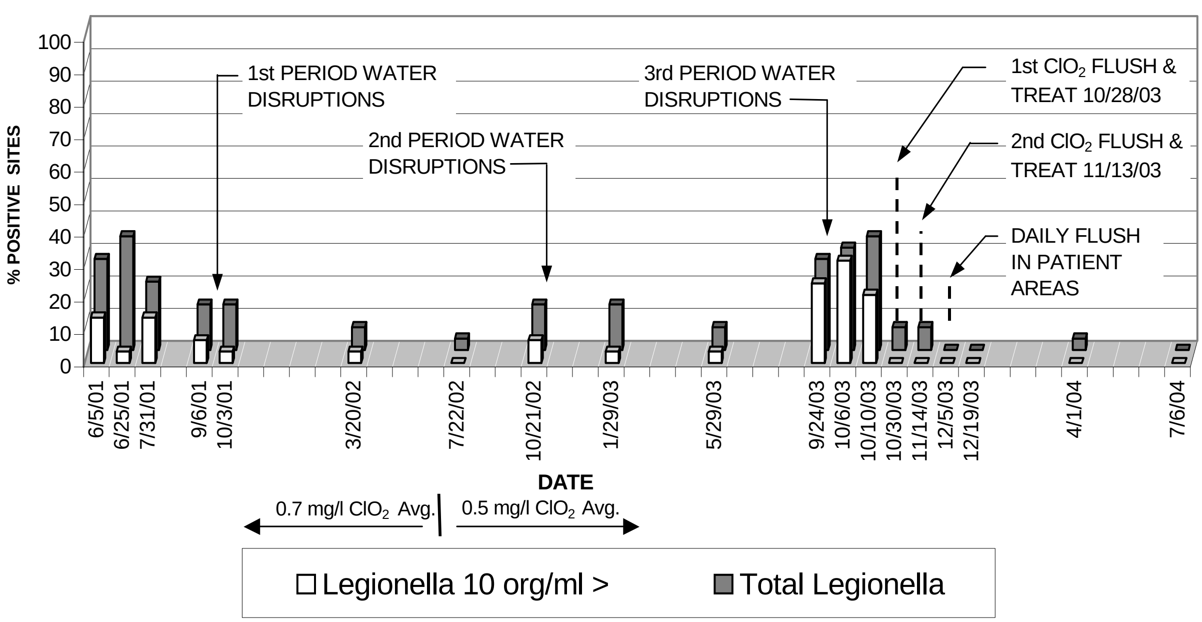


CHART 4 - % POSITIVE LEGIONELLA SITES PHASE 3



APPENDIX

CHART 5 - % POSITIVE LEGIONELLA SITES IN COLD WATER SYSTEM

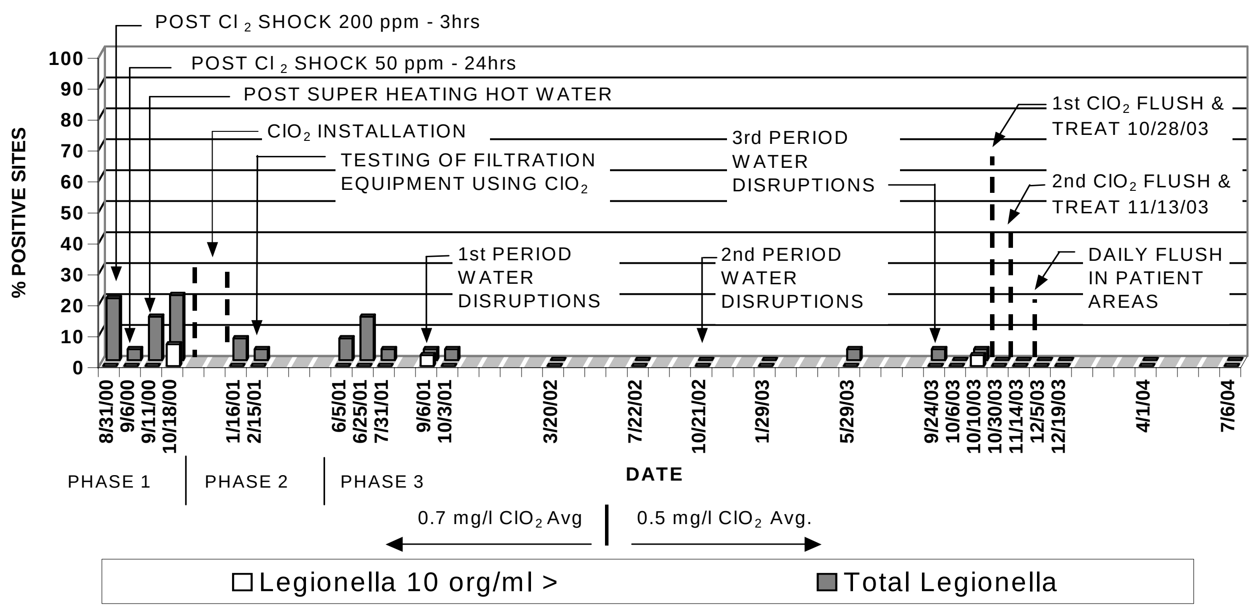
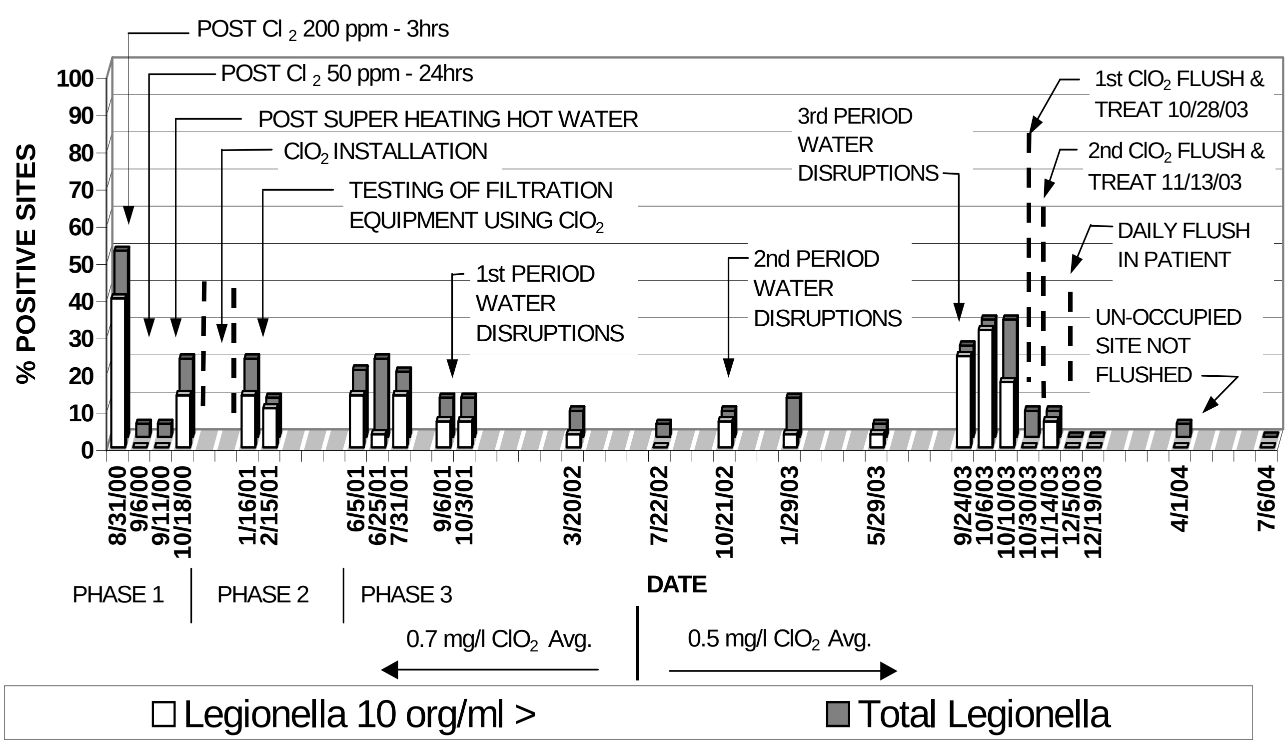


CHART 6 - % LEGIONELLA POSITIVE SITES IN HOT WATER SYSTEM



REFRENCES

[1] Environmental Protection Agency, National primary drinking water regulations. Federal Register 2002;67:14502. Codified at 40 CFR 141.

[2] Chang SL. The safety of water disinfection. Annu Rev Public Health 1982;3:393-418.

[3] Chang SL. The safety of water disinfection. Annu Rev Public Health 1982;3:393-418.

[4] Kallen BA, Robert E. Drinking water chlorination and delivery outcome- a registry based study in Sweden. Reprod Toxicol 2000;14:303.

[5] Wondergem E, van Dijk-Looijaard AM. Chlorine dioxide as a post-disinfectant for Dutch drinking water. Sci Total Environ 1991;102:101-12.

[6] Kanitz S, Franco Y, Patrone V et al. Association between drinking water dis-infection and somatic parameters at birth. Environ Health Perspect 1996;104:516-520.

[7] Hamilton E, Seal DV, Hay J. Comparison of chlorine dioxide and chlorine for control of *Legionella* in a hospital potable water supply. J Hops Infect 1996;32:156-60.

[8] Hood J, Cheape G, Mead A, Curran E. Six years' experience with chlorine dioxide in the control of *Legionella* pneumophila in the potable water supply of Glasgow Royal Infirmary. Abstract presented at 4th decennial conference in nosocomial and healthcare associated infections. Atlanta, GA, March 7, 2000.

[9] Environmental Protection Agency. Standard Methods for the Examination of Water and Wastewater, 20th Edition, Method 4500 ClO2, Washington DC, Environmental Protection Agency.

[10] ANSI / AAMI RD 52:2004 - Dialysate for Hemodialysis AAMI Recommended Practice/ American National Standard

[11] Srinivasan A. MD, Bova G., Ross T., BSN. A 17 Month Evaluation of a Chlorine Dioxide Water Treatment System to control Legionella Species in a Hospital Water Supply. Infection Control and Hosptal Epidemiology August 2003, Vol24 No. 8: 575-579.

[12] Environmental Protection Agency, National primary drinking water regulations. Federal Register 2002;67:14502. Codified at 40 CFR 141.53 and 141.54.

[13] Environmental Protection Agency, National primary drinking water regulations. Federal Register 2002;67:14502. Codified at 40 CFR 141.64 and 141.65.

[14] Maryland Department of Health and Mental Hygiene (MDHMH) 2000. Report of the Maryland Scientific Working Group to Study Legionella in Water Systems in Healthcare Institutions. MDHMH, Baltimore, MD

[15] Centers for Disease Control and Prevention (CDC) Guidelines for Environmental Infection Control in Health-Care Facilities 2003

[16] Allegheny County Health Department, (ACHD) 1997. Approaches to Prevention and Control of Legionella Infection in Allegheny County Health Care Facilities (2nd ed.) ACHD, Pittsburgh, PA.