Thomas M. Laronge, Inc.

RECOMMENDATIONS FOR THE SERVICE WATER SYSTEMS

- ARKANSAS NUCLEAR ONE - UNITS 1 & 2 -

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FOREWORD

THOMAS M. LARONGE, INC. (TML) expresses its thanks to the personnel of ARKANSAS POWER & LIGHT COMPANY (APL) for selecting our corporation. More importantly, we thank the people at Little Rock and at Russellville for their candor and cooperation during the performance of this work. It is this positive support and open communications which make this work possible. Hopefully, past problems will not recur. Hopefully, the water entering the Service Water Systems will not impair the reliable operation of either ANO-1 or ANO-2.

The commentary which we present herein is designed to be succinct. We trust that this direct approach is helpful to APL. We realize that direct comments sometime tend to be more irritating or abrasive than do indirect comments. However, we also firmly believe that this directness is required if APL is to be successful in eliminating their existing waterside corrosion/failure problems with the two (2) Service Water Systems.

Finally, we welcome and request your comments on this work. Comments from experienced people such as yourselves will be incorporated into our working methods. In this way we will persist with our efforts to continually upgrade both our technology base and the quality of our services to industry.

Thomas M. Laronge, Inc.

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RECOMMENDATIONS AND CONCLUSIONS

1. APL should establish a master plan for upgrading the service water systems of ANO Units 1 and 2.

2. The best choice of master plan would appear to be the conversion of both service water systems, and at least, that of Unit 2 to closed loop operation.

3. Given closed loop operation, the precleaned systems should be charged with demineralized water and an appropriate corrosion inhibitor.

4. A corrosion monitoring program should be established for all cooling water systems regardless of whether their operation is open or closed. The significant details appear in the body of this report.

5. If the master plan provides for closed loop service water systems, the needs for a rigorous water chemistry monitoring program as detailed within this report is not as great. If the service water systems are to remain open, it is recommended that the outlined program be conducted for one (1) year with re-evaluation of the need for program extension conducted somewhere between the tenth (10th) and twelveth (12th) month. This will permit extension of the program as required without subjecting it to a loss of continuity.

6. All of the other recommendations, actions, repairs, retrofits, etc. should be compatible with the master plan except for short term necessary measures. We define <u>short term necessary measures</u> to be those items required to extend the safe and uninterrupted operation of ANO Units 1 & 2 for a period of not less than one (1) year nor more than five (5) years.

7. The following are judged to fall within the category of "short term necessary measures" as outlined above:

   a. Retubing and/or replacement of the tubing bundles of exchangers 2E35A & B with E-Brite 26-1 or better alloy making certain that compatible tube sheets and other accessories are employed.

   b. Mechanically clean every possible service water system surface.

   c. Install flushing connections, component isolation connections, pressure indicators, flow indicators, etc. as outlined in this report and/or in our report of December 15, 1980. Obviously, temperature sensing devices would also be helpful.

   d. Install 316L piping in all 2-1/2" or less service.

   e. Re-evaluate your weld needs in conjunction with the installation of 316L to determine weld criticalities with respect to failures. If you desire, employ butt welds in these "critical" unions and socket welds elsewhere. All welds should be carefully stress relieved. We view the use of socket welds, on paper, as being not quite as good as the use of butt welds. However, we view the use of butt welds as being very difficult to justify on a cost effective basis. Were we in the position of having to make the indicated selection, we would be extremely hard pressed to justify the additional time, manpower, cost, etc. associated with butt welds.

   f. Make provisions for intermittently chlorinating the service water influent as described herein. These provisions should include all necessary permits, Technical Specifications, etc. variances, and/or modifications including dechlorination as required.

g. Institute the required changes to enable all off line heat exchangers to be flushed once per shift with at least three (3) exchanger volumes of cooling water at a velocity of between 5 fps and 12 fps.

h. Thoroughly evalulate present inspection procedures, maintenance staff and levels of training in the areas under discussion and upgrade each of these items as required.

i. Make provisions for heating and/or chlorinating the service water systems to kill *Corbicula fluminea* and/or other bivalves.

j. Make extremely careful inspections during your Winter-Spring 1981 refueling outages. Where imminent equipment failure is suggested, repair this as indicated and order upgraded replacement components promptly for installation during subsequent forced outages.

k. Take every possible step to upgrade service water velocities to the range of 5 fps to 8 fps where these are presently lower.

8. The master plan should include following the necessary steps to secure code approval for the use alloys AL 6X and/or AL 29-4C.

9. The master plan should consider all changes such that these have the minimum possible demand for Q approval, etc.

10. If the service water systems are to remain essentially once through,

we prioritize our recommendations for water pretreatment as follows:

a. Granular media filtration.
b. Clarification followed by single stage, 125 micron strainers.
c. Two (2) stage strainers (250 micron followed by 125 micron).

We cannot justify clarification followed by filtration on a cost performance basis. Additionally, we do not believe that simple, two (2) stage straining will meet the needs of the service water systems.

11. We conclude that sufficient land is available for the necessary pretreatment equipment installation.

12. Well water supplies in the vicinity of ANO are believed to be less than adequate for service water system makeup supply.

13. We doubt that the strata associated with Lake Dardanelle would lend itself to the installation of Ranney Wells.

14. The construction of a water pretreatment plant should be considered as a supply of potable water to the City of Russellville, etc.

15. Consideration should be given to lining the existing condenser water boxes and upgrading cathodic protection systems as required.

16. The continuous addtion of catalyzed hydrazine, corrosion inhibitors, dispersants, etc. to the service water influent should be considered as a last resort. Prior to this "last resort" we would first consider the addition of appropriate chemicals on an intermittent basis at elevated residuals.

17. We do not recommend modification of the intake structure to provide for in line settling of suspended solids.

18. We recommend investigation of the efficacy of adding the present dispersant and/or corrosion control proprietary chemicals to the Unit 2 recirculating cooling water system.

19. We do not think that the emergency cooling pond offers a very attractive source for service water systems' cooling water although further evaluation of this possibility is required to draw an accurate conclusion.

20. We conclude that a continuing effort is required with respect to the upgrading of the service water systems.

THE APPARENT BEST APPROACH TO SERVICE WATER SYSTEM PROBLEMS' SOLUTIONS

Essentially all of the available information about the present Service Water Systems, etc. and the fact that Arkansas Nuclear One is a nuclear fueled, steam electric generation station, suggest the need for a well defined, overall approach to problem solutions. A simple, element by element, bandaid approach to problems is strongly advised against.

The nature of the problems experienced by APL are highly site specific. Similarly, the nature of plant operations and management are highly site specific. "Bandaids" tend to be extremely general and not site specific. As such, any use of "bandaids" by APL should be viewed as being, at best, a temporary measure and not a permanent fix. Our experience with problems related to nuclear plants as compared with those associated with fossil fuel plants suggests that the differences between these plants dictates an *a priori* difference in solution approaches to problems. The multitude of specifically nuclear plant related considerations such as: safety, regulatory, cost and manpower are sufficient, to our way of thinking, to make these statements hold true.

Unfortunately, it would appear that the potential for many of these problems has not been properly recognized during the initial phases of plant conception, design and construction. APL is not the only utility that has experienced the types of problems being discussed. These have reportedly occurred to varying degrees at several generating stations. Similar types of problems have occurred in a wide variety of industrial plants. We believe that sufficient technology exists to avoid the occurrence of these problems providing that systems are essentially designed and installed properly.

The purpose of this scenario is not the "reinvention of the wheel". Neither is the purpose to inform APL of what they already know, namely that hindsight is better than foresight. Rather, our purpose is specifically to emphasis the need for detailed planning of overall problem solutions.

The demands of plant operation coupled with relatively short refueling outages and relatively long component delivery lead times implies that APL may face solving their problems over an extended period of time. As such, carefully established priorities within the overall framework that we suggest are believed to be very important to the success or failure which APL will experience at Arkansas Nuclear One.

Unfortunately, there are many aspects of nuclear power plants which are viewed as being entirely different than are their counterparts in fossil fuel power plants or in other industrial systems. Obviously, some of the plant aspects have to be viewed as being different. In our opinion, service water systems are quite similar. The engineering problems associated with the design of the systems in both fossil fuel and in nuclear fuel installations are quite similar. Our experience suggests that one of the most commonly made mistakes in the design of nuclear power plant service water systems is to make these systems open to the environment as opposed to being closed cooling water systems.

The problems associated with the operation of nuclear power plant service water systems appear to be approximately two to four orders of magnitude more complicated, as a minimum, when these systems are open to the environment as opposed to when these systems are closed. Additionally, these are systems which power plant management really does not want to encounter as problems during the normal lifetime of a plant. These are simply "headaches". The associated piping, instruments, heat exchangers, plumbing fixtures, etc. are relatively difficult to physically access and to maintain.

The best service water system at both ANO Unit 1 and Unit 2 would be predicted to be a closed loop system. Therefore, any efforts made by APL in the direction of accomplishing this overall objective would be predicted to have the most benefits. In other words, the use of a closed loop system would seem to be the best solution to the existing problems.

Clams, silt, variable water composition, etc. can all be relatively easily excluded from entering a closed loop service water system. Additionally, problems related to corrosion product accumulation and to biological growths can be relatively easily and cost effectively controlled in closed loop systems. A final consideration related to closed loop system excellence is the fact that a properly designed and executed monitoring program tends to show the onset of problems more rapidly in a closed loop system than in an open loop system. As such, "bandaids" tend to work with closed loop systems where they will not work as effectively with open loop systems.

If balance of plant considerations are judged to make the installation of closed service water cooling systems impossible at either/or ANO Unit 1 or Unit 2, the next best approach is simply to eliminate the bad acters from entering the open systems. Obviously, there is an important consideration for monitoring and control associated with this latter recommendation.

The elimination of potentially harmful contaminants from a once through service water system is a relatively difficult problem. This problem can be altered by using an open recirculating approach providing that the associated cooling tower is properly controlled.

The causes of the problems which APL has experienced are relatively easy to recognize and understand. These are not problems associated with heretofore never experienced technology. From the material failure point of view, excluding the manufacturing and/or installation of any substandard components, the service water system problems are judged by us to be simply a violation of the old adage "cleanliness is next to godliness".

Our experiences with the problems encountered by many operating steam electric generating plants suggest the recurrence of two (2) common problems. These are the absence of sufficient attention to system water chemistry and to system preventative maintenance. We have not been associated with the problems at APL for a sufficiently extended period of time or in sufficient detail to conclude with 100% certainty that these two (2) weaknesses are definitely related to these service water system problems. However, the information which we do have points in this direction.

In concluding this section we suggest that APL make an *a priori* management decision as to how the overall service water systems will be changed in the long run at either or both Unit 1 or Unit 2. We suggest that every possible effort be made to attempt to close the loops associated with each service water system on the waterside. If this cannot be done cost effectively, we would then suggest that water pretreatment systems such as straining, clarification and/or filtration be employed. Finally, the programs associated with system water chemistry and with system preventative maintenance should be reviewed in detail and upgraded as required. In accomplishing these latter two (2) objectives, it might be well to APL's advantage to consider implementing some training programs designed to better inform all personnel of the importance of water chemistry and preventative maintenance to the overall operating success of each power plant.

THE SERVICE WATER SYSTEMS OF ARKANSAS NUCLEAR ONE - UNITS 1 & 2

The Service Water Systems associated with ANO Unit 1 and Unit 2 are quite different. Therefore, it is reasonable to expect that corrosion phenomena, biological growth, etc. will manifest themselves differently in each of these systems. From a component failure point of view resulting from corrosion mechanisms, the generalized time to failures would be predicted to be somewhat longer in Unit 1 than in Unit 2. The operating results to date seem to confirm this retrospective prediction.

At the outset, it is a somewhat difficult engineering problem to design a service water system. These systems are very complex. They are subject to wide ranges in hydraulics, operating temperatures, materials of construction, physical location, etc. In general, the several components of these systems are manufactured by many different suppliers. In operation these systems are typically subjected to many different steady state and nonsteady state operating modes.

There exists some differences in metallurgy of components in Unit 1 and Unit 2. The importance of the metallurgical differences in these systems is only whether the existing metallurgies are capable of providing the necessary service. The failures, primarily in Unit 2 service water system, suggest the existing metallurgies will not provide the required resistances to failures that would otherwise be desirable. In other words, the existing materials coupled with the nature of the operation appear to be susceptible to:

1. Generation of excessive corrosion products.
2. Sulfide cracking of 90-10 copper-nickel.
3. Pitting corrosion of 304 stainless steel.
4. Crevice corrosion of 304 stainless steel.
5. Stress corrosion cracking of 304 stainless steel.
6. Support of biological growth.

In addition to material differences in the service water systems associated with Unit 1 and Unit 2, the basic water chemistry appears to be different. The intake structures of these two (2) units are different. APL has informed us that the difference in intake structures appears to have a significant effect on the levels of accumulating solids in the two (2) service water systems. This levels of solids accumulation appears to be considerably worse in Unit 2 than in Unit 1.

The reported accumulation of siliceous and/or organic debris could also be related to differences in the velocity of cooling waters in these systems. Obviously, the higher the velocity of cooling water, the greater would be the tendency to flush these materials through the systems to the discharge canal.

Research has been done on the relationship between the attachment of certain molluscs to surfaces and the superficial velocities of water associated with these surfaces. As a general summary, *Corbicula fluminea* are reported to not attach to surfaces where the superficial velocity is greater than two (2) meters per second (greater than 6.56 feet per second). Similar results were found for another fresh water bivalve capable of fouling service water systems, *Dreissena Polymorpha*.

The fact that larger accumulations of *Corbicula fluminea* have appeared in Unit 2 than in Unit 1 could be related to these differences in velocity. After all, bulk flows of six (6) to seven (7) feet per second of water are within the range of proper system design. Unfortunately, most cooling water systems employ a bulk flow design which tends to be somewhat less than these numbers. As general guidelines to APL, we would recommend that where changes are made in the cooling water systems, the velocities of this water should fall in the range of five (5) feet per second to eight (8) feet per second.

Another variable which could readily explain the differences in *Corbicula* densities found in Unit 1 and Unit 2 service water systems is associated with the operating temperature ranges of the components of these systems.

It is well known that *Corbicula* growth is functionally dependent upon temperature. The information available to us suggests that the several components of your service water systems operate at different elevated temperature maximums and with different temperature ranges.

The exchanger line up with respect to the direction of cooling water flows in the two (2) systems appears to be significantly different. Additionally, we suspect that the exchanger locations with respect to elevations in these systems is quite different. Obviously, the lengths and sizes of piping involved in these two (2) systems is different. Each of these items could be reasonably expected to amplify system differences associated with corrosion phenomena.

From some of our work with these problems we expect that the heat exchange coefficients vary considerably among the several exchangers involved in these two (2) systems. We also believe that the basic nature of the design of the various heat exchangers has an impact upon the success or failure of the system in use. Our experience with heat exchangers leads us to the simple conclusion that most people experience more problems with U-tube heat exchangers than they do with straight tube heat exchangers. Similarly, shellside exchangers employing cooling water on the shellside tend to cause many more operating problems than do tubeside exchangers. There are probably volumes of information which have been written on this subject as it impacts the operation of chemical and petrochemical plants. This information can be applied to the problems at ANO.

These, other items defined in our report of December 15, 1980, etc. offer ample evidence in support of the observed differences in performance between your two (2) service water systems. Namely, more failures have been experienced in the Unit 2 service water system than in the Unit 1 service water systems.

WATER CHEMISTRY ASSOCIATED WITH THE SERVICE WATER SYSTEMS

The chemistry of the cooling water associated with the service water systems appears to be highly variable. Additionally, the chemistry of the service water systems associated with Unit 1 is predicted to be different than is that associated with Unit 2. These latter differences arise from the differences in the intake structure as explained to us by APL personnel.

If the differences in total solids, suspended solids and/or total disssolved solids differ in the service water influent, the respective cooling waters would be predicted to interact differently with the respective service water system metallurgies. These differences are, in turn, further differentiated by the operating conditions of the respective systems. The net effect is that the corrosivity or the rate of failure in the two (2) systems could be predicted to be different.

Table I and Table II of this report contain information which we prepared for our preliminary report of December 15, 1980. It is important to realize that the ranges of anticipated service water quality shown in Table I were composited by ourselves from several different information sources. In other words, this information is not strictly scientific data. Rather, this is manipulated scientific data.

We learned, subsequent to the preparation of Table I, that APL has information supporting that the range of chemical composition which we have composited may be less than adequate. Specifically, APL has reported a level of chlorides in the raw water of 405 mg/L. Needless to say, this could be directly related to corrosion phenomena.

The service water chemistry suggests that this water should be viewed as being somewhere between fresh water and brackish water as it impacts the corrosivity of both 90-10 copper-nickel and 304 stainless steel. In other words, the available body of scientific information relating to stress corrosion cracking phenomena and to pitting/crevice corrosion phenomena could readily suggest exacerbation and/or occurrence in the presence of the reported service water chemistry.

We elect to look at this situation as being insufficiently defined in terms of scientific parameters to make absolute statements as to whether the service water quality would or would not prove to be corrosive to the aforementioned alloys. There are simply too many variables involved with these phenomena and insufficient definition of the threshold values of each parameter. The significance of these comments is discussed throughout this report as it applies to the APL problems.

In our December 15, 1980 report we suggested the need for developing more information about the chemistry of the raw service water. Subsequent to these statements we learned that APL has experience indicating that the rate of change of chemistry in this water is rather slow. The implication of this latter statement is that the need for detailed raw water analysis may be less frequent than our December 15, 1980 report implied.

The existing analytical chemistry monitoring program provides for analysis of the following parameters:

1. pH.
2. Specific conductance.
3. Total hardness.
4. Calcium.
5. M Alkalinity.
6. Chloride.
7. Silica.
8. Total Phosphate.
9. Sulfate.
10. Iron.

11. Turbidity.
12. Total dissolved solids.
13. Sodium.

Because of the apparent relatively slow change in water chemistry, all of these thirteen (13) parameters are not determined weekly.

We would like to suggest that APL give consideration to analyzying the raw water fairly comoletely once per week. We suggest that this is extremely important if the service water systems of Unit 1 and Unit 2 are to remain essentially once through with respect to cooling water flow. In addition to this program, it might be worth examining the water chemistry twice per day, five (5) days in a row, four (4) to twelve (12) times a year. The information obtained from this latter study would provide a technical basis for assessing the impact of diurnal fluctuations in chemistry. This might be considerable as a result of the biological populations associated with Lake Dardanelle.

In addition to the aforementioned parameters, we would recommend that the following parameters be incluced in the analytical program:

1. Fluoride.
2. Potassium.
3. Dissolved Oxygen.
4. Total Kjeldahl Nitrogen.
5. Nitrate Nitrogen.
6. Total Manganese.
7. Free Carbon Dioxide.
8. P Alkalinity.
9. Temperature.
10. Total Solids.
11. Total Suspended Solids.
12. Bicarbonate.
13. Total Organic Carbon.

Obviously, this looks like a rather large and costly task. We believe that properly planned, this analytical work can be accomplished at a relatively low cost and with a relative low demand on manpower.

Extreme care should be taken in selecting the analytical techniques employed.

Please make certain that the analysis for silica, phosphate, iron, manganese, total hardness and sulfate includes the total quantity of these elements present. In other words, the analyses should report all of the individual species present regardless of their chemical form, their solubility or lack of solubility. Along these lines, it would be well worth taking a few samples of settleable solids and/or suspended solids and subject these to some instrumental analyses. The latter would give APL an idea of what is present in the sediment which could reasonably enter the service water systems.

The analysis for total suspended solids could be alternatively conducted as total filterable solids. This would make the testing much easier. If filterable solids are to be used, we would suggest that APL determine whether there is any differential between filterable solids as analyzed employing 0.45 micron filters and that obtained using 0.2 micron filters. If significant differences exist in the results, we would suggest that 0.2 micron filters be employed in the study. Otherwise, 0.45 micron filters could suit the needs of APL quite adequately.

As appropriate, APL would be advised to conduct most of their analytical testing using the technique of inductively coupled argon plasma spectrometry. The analysis of the sludge and/or sediment from the sample could be conducted using sediment aliquots and energy dispersive x-ray analysis, x-ray powder diffractometry and/or loss on ignition. Obviously, other analytical techniques could be employed as required.

We have tried to suggest techniques which could be used at relatively low cost, with high levels of sensitivity, precision and accuracy, rapid turn around times, etc. We will be pleased to provide other information on this subject as requested by APL.

Where instrumental techniques will not work for individual parameters, wet chemistry must be employed. However, there exists some relatively simple techniques for performing some of the individual analyses. For example, specific ion electrodes can be used with a relatively high degree of accuracy for determining fluoride. The Chemetts test can be used for determining dissolved oxygen. Alternatively, a dissolved oxygen meter could be used for this purpose providing the levels of dissolved oxygen remain greater than 1 ppm as O_2.

We fully realize that we have not included several parameters in our suggested analytical program which could impact power plant operations. However, we have specific purposes in mind for each of the parameters suggested. In establishing this program, we are making the assumption that this information will help APL make the final decision as to whether to close their service water system or to continue to operate this as an open system. Additionally, this information can be used in developing a material balance across the service water system. Obviously, any differences in chemistry between the raw service water influent and the service water discharge reflect interactions between the service water and the components of the service water system.

If APL has information suggesting the presence of relatively high levels and/or the potential for deposition of the following compounds, we would suggest that these be periodically included in the analyses as indicated. These are:

1. Barium.
2. Copper.
3. Strontium.
4. Aluminum.

We are specifically not including any other analysis for sulfur-containing compounds in the requested program. In the first place, the analysis for sulfur forms tends to be difficult, expensive and relatively insensitive. Secondly, the several sulfur forms would not be predicted to be major causes of problems in your service water systems unless they are allowed to accumulate on the surfaces of components. Finally, we suspect that in the APL systems, the influence of sulfur compounds on the corrosion of 90-10 copper-nickel, etc. is related to the biological activity occurring within the service water systems. Our recommendations will include comments designed to control this biological activity.

CORROSION MONITORING

It is our opinion that regardless of what actions are taken by APL with respect to the service water systems and any other cooling water systems, there exists a need for a well defined and continuing corrosion monitoring program. We are assuming that the necessary program is not presently in effect at Arkansas Nuclear One.

The cost of corrosion monitoring is relatively small once the systems required are installed. In fact, the cost of installing the necessary systems are relatively small. The benefits of such a program are relatively great. In the first place, the results of the corrosion monitoring program reflect what is going on within the systems. These results are, individually and collectively, the "picture which is worth a thousand words".

In our December 15, 1980 report, we quoted some corrosion data provided to us by APL. In considering this data, our experience would suggest that it is invalid for one or more reasons. While we don't know the reasons, we would certainly be willing to state that we doubt that you are experiencing 764.3 milligrams per square decimeter per day of corrosion on carbon steel. By the same token, we would suggest that a number such as this supports our belief that there is a need for confirming or refuting the validity of this number and other corrosion information.

The basic program which we recommend to APL would employ the use of standard corrosion coupons placed within properly installed test loops. The necessary information to install these loops is available at no charge from essentially all of the major water treatment chemical vendors. Because of the specificity of this information, we are not including it in this report. However, we know that the vendor which has been supplying chemicals to your plant has this information in printed form. We have copies of this in our office. Similar information is available from the National Association of Corrosion Engineers, the American Society for Testing and Materials, the American Society of Mechanical Engineers, the

We would recommend that the corrosion loops be installed in your raw water system. It may be to your benefit, for the circumvention of Q considerations to install these as a test facility rather than as a parallel structure to your existing service water systems. In other words, small pumps could be installed to supply raw water to the corrosion control loops. If this type of test facility is established, we would suggest that the facility employ multiple corrosion coupon racks. Each rack would reasonably be capable of containing between four (4) and twelve (12) corrosion test coupons.

The program which we envision should employ at least carbon steel and a copper alloy such as Admiralty brass (CDA-443). If additional information is desired, 304 stainless steel, 316 stainless steel, 90-10 copper-nickel coupons, etc. could be employed. We would recommend that these coupons be coupled to their corrosion monitoring system in such a way that an electrical insulator is placed between the actual coupon and any metallic components. Standard coupon holders exist for this purpose. These are typically available at no cost from water treatment chemical vendors.

If copper containing alloy coupons are installed in series with iron containing alloy coupons, the former should be downstream of the latter. It is also a good idea to place the more noble coupons upstream of the least noble coupons.

The corrosion racks should be plumbed such that rotameters or other flow measuring devices are installed in the loop. Additionally, the temperature ranges of the cooling water should be known. Considering the nature of the corrosion problems at Arkansas Nuclear One, the velocity through this loop would be recommended to be somewhere between about 0.5 and 1 foot per second. This low velocity would be predicted to aggravate the corrosion problems. In other words, the corrosion measured on the coupons might reasonably turn out to be worse than that actually experienced in the service water systems, respectively.

It would be much to the benefit of this program to additionally install two (2) to four (4) test heat exchangers in parallel. Corrosion monitoring probes could also be installed at extremely low cost. These probes would allow APL to make either continuous measurements or relatively frequent measurements of instantaneous corrosion rates with great simplicity.

The best recommendations which we could make for installing test heat exchangers would employ operation of these exchangers at 150°F (65.6°C). This temperature should be maintained with an accuracy of ± 5°F (2.8°C) or closer. We would again suggest that these test heat exchangers employ relatively low velocities rather than high velocities. The velocities which we suggest might range from 0.5 feet per second to 2 feet per second. Ideally four (4) heat exchangers would be used in parallel such that two (2) of the exchangers would contain carbon steel tubes and two (2) of the exchangers would contain Admiralty brass (CDA alloy 443) or some other material, perhaps 90-10 copper-nickel (CDA alloy 706).

We envision that the corrosion studies employing coupons and/or test heat exchanger tubes should last thirty (30), sixty (60) and ninety (90) days, respectively. After APL has accumulated a sufficient body of information to define the corrosion phenomena occurring, these exposure times may be refined as indicated by the results. The measurement of instantaneous corrosion rate could be coupled with continuous recording of information. All of the data obtained in this program should be supplemented with visual inspection of the corrosion coupons and/or test heat exchanger tubes. The measurement of instantaneous corrosion rate should be interpreted as a trend rather than as an absolute indicator of corrosion. If the corrosion monitoring program indicates a direct correlation between instantaneous corrosion rates and other monitored corrosion rates, then the former may be used as an absolute indication of corrosion rate. Typically this is not the case in many systems.

Another comment which is very important to the success or failure of this program is our recommendation for using coupons and/or test heat exchanger tubes having appropriately prepared surfaces. Please do not use either coupons or heat exchanger tubes which have exotic surfaces and/or prepassivated surfaces.

A similar program could be established for the cooling water associated with Unit 2 cooling tower basin. As a minimum, multiple corrosion coupons should be installed in this cooling tower basin as soon as is possible.

Where possible, we advocate the installation of spool pieces in pipes suspected of corrosion. These spool pieces can be removed for examination during regular inspections and/or other periods of convenience. Such spool pieces are installed such that a visual inspection of these should prove representative of a visual inspection of the remainder of the system.

It is worth noting that we suspect that ANO is experiencing corrosion in the main condenser cooling water systems associated with both Units 1 and 2. In addition to corrosion of the water boxes, we would suggest that you pay particular attention to any corrosion which is occurring on the air ejector vent pipes. When examining these vent pipes, please note any difference in apparent corrosion rates as you move along these pipes away from their connections to their respective tube sheets. Corrosion of these surfaces are common in systems such as yours from our experience. Additionally, our discussion with APL personnel leads us to believe that a prediction of corrosion in the condenser water boxes at a higher than desirable rate is warranted.

Please let us know if you are in need of any further information and/or assistance with the establishment of a properly designed corrosion monitoring program. We will do our best to assist you in any possible way.

Before leaving this section, we would like to conclude with one further benefit to the recommended program. We believe the results of the corrosion monitoring program which we have suggested will make all parties aware of the need for watching the water chemistry and associated problems at both units of Arkansas Nuclear One. "Seeing is believing!" The program which we have recommended is designed to facilitate this "seeing".

STAFFING, TRAINING AND INSPECTION

In order to solve any of the problems associated with the existing service water systems at Arkansas Nuclear One, APL must obviously have a sufficient number of properly trained individuals. Additionally, appropriate inspection procedures must be utilized. This short discussion highlights some of our observations and thoughts on this subject as it applies to the existing problems.

In our report of December 15, 1980 we discussed our specific observations and recommendations relative to the supplementation of your existing plant chemistry department. We understand that APL independently arrived at similar recommendations and has begun the necessary implementation program. Therefore, the appropriate information will not be repeated herein.

We believe that APL is in the position of just beginning to gather the necessary information relative to the condition and/or performance of their service water systems. The next and subsequent inspections should prove of extreme importance to this information base. Obviously this information base should have major impact upon the recommendations and subsequent actions taken by APL to rectify any problems which are found.

This suggests that the inspection program should best be a highly organized, preplanned venture. In addition to looking at gross component appearance, specific tubes and/or regions of components should be examined. The examination of these areas should be repeated during each inspection. In this way, representative histories will be developed.

Perhaps APL already has established the appropriate, necessary procedures. If so, we have not been made aware of this. We have also not reviewed specific inspection procedures and/or detailed reports.

During inspections, we would recommend photographing significant areas of each system. If you need photograghs rapidly, you may wish to use films such as that supplied by Polaroid or equal. We would recommend that these photographs be supplemented with transparencies made on 35 millimeter or larger format. The appropriate film of choice would be Kodachrome having an ASA exposure index of 25. This material tends to be extremely high in contrast and extremely fine grained.

Reversal type color prints can be made today from Kodachrome transparencies with very little loss in quality. In fact, this can be done directly without going through the internegative process.

Careful attention should be paid to the lighting used to take the photographs. In this way, significant highlight and/or shadow detail will not be masked. Please place a scale such as a ruler in each picture. Additionally, a title card placed in a photograph is often very helpful. This certainly avoids any difficulties encountered in identification subsequent to taking the photograph. Simple and relatively effective titles can be prepared by using a black felt tipped pen and a 3 x 5 plain white index card. Obviously, each of these cards should be dated in addition to being titled.

While the above discussion may sound trivial, we obviously do not think so. A historical record of system components recorded on properly identified photographs can often be used very effectively in analyzing the condition of systems and/or the necessary upgrading of these systems.

We realize that the inspection process is difficult and costly. We further realize that the inspection process associated with a nuclear power generating station is complicated because of security and/or safety precautions. However, it is very important to the proper resolution of your existing service water problems that your next several inspections be carried out with great care and in great detail.

We did not examine the overall staffing of ANO Unit 1, Unit 2 and/or corporate staffing other than as it applies to the chemistry staff specifically. However, in the process of gathering information, meeting with both plant and corporate people, etc. we gained what we elect to call a "gut level feeling". While it is difficult to make major decisions based upon such judgements, we often find these to be very helpful in providing guidance with respect to where one ought to be looking for problems.

We think that it would be well worth APL's efforts to review programs and staffing levels related to inspections and to preventative maintenance. Our experience with industry suggests that properly staffed inspection and preventative maintenance departments have a cost effective benefit whenever the information generated is utilized in a timely fashion. Additionally, this information typically goes a long ways towards avoiding the chaos associated with "emergencies". Additionally, all parties tend to become more aware of the interrelationships among their individual areas of specialization and job demands.

For example, the electrical engineer tends to be more understanding and cognizant of chemistry problems, etc. The mechanical engineer tends to be more comfortable with electrical engineering problems, chemistry problems, biology problems, etc. Middle and upper management tends to be able to better prioritize the decision making process and to better assign both priorities and dollars and cents to these priorities.

Our remaining feeling is that there may exist a need for some positive, generalized training in the areas associated with metallurgy, water chemistry, etc. as it applies practically to the operation of power plants. If this need does exist at APL and if this need is met, we predict that the cost of training will be highly cost effective to APL. The inspector of a system component will be better equipped to report information in a directly usable form to all parties. APL will be much more reliant and comfortable with the information generated than they might otherwise be.

We qualify the above information as being presented strictly with good intentions. There are no intentions on our part in making these statements as negative criticisms. There is the intention of presenting an observation and/or positive criticism. Again, these items are things which we "sensed". We have not been associated with these in sufficient detail to quantify them.

CHEMICAL ADDITIONS

At this time, we do not advocate the addition of water treatment chemicals to the service water systems.

The fact that these systems are both once through cooling water systems and that their flow is variable and that the velocities of the individual components is variable makes the former statement extremely important. In fact, we would advise APL to take every possible step to avoid chemical additions.

There are basically two (2) types of chemicals, not including biological control agents, which could be considered for addition. The first of these would include such compounds as soluble silicates and/or glassy phosphates designed to perform a corrosion inhibiting function. The second class of applicable compounds would be the polymeric dispersants and/or crystal distorting materials. The polymeric materials would be the appropriate molecular weight formulations of neutralized polyacrylic acid and/or polymethacrylic acid. The crystal growth distorters would be materials such as the sodium salts of aminomethylene phosphonic acid or hydroxyethylidene diphosphonic acid.

Chemical addition to a once through system is relatively expensive. Additionally, it is relatively difficult to monitor the effectiveness of this chemical addition. If, as suspected, the velocities within certain key service water system components are low, the use of dispersants may not help the present problems. Finally, one must consider the appropriate impact of chemical additions upon plant operation. Obviously, these must be included in Technical Specifications, N.P.D.E.S. Permits, etc. These complications should be avoided where possible.

Another disadvantage to chemical additions in systems such as those at APL is the fact that dissolved oxygen is believed to be one of the more aggresive materials in cooling water. The control of dissolved oxygen is very difficult and/or very expensive in an open system.

The problems associated with dissolved oxygen can often be controlled by filming the surface of system components. However, proper filming is often dependent upon having a clean system. This is not the case at APL nor would this state be relatively easy to achieve.

As suggested in our report of December 15, 1980 we think it would be worth the effort of APL to investigate whether chemical additions other than chlorination and sulfuric acid are required in the condenser cooling water of Unit 2. We tend to doubt that APL is receiving very much benefit from this chemical addition.

We would recommend that condenser water boxes constructed of carbon steel be lined. We would also recommend that the corrosion monitoring program outlined elsewhere in this report be implemented on the condenser cooling systems associated with Unit 1 and with Unit 2.

We suggest that APL use the analytical chemistry data and the corrosion data gathered from the chemical monitoring program and corrosion monitoring program which we have suggested as a basis for assessing the need for chemical treatment. Many utilities are able to operate their service water systems and/or recirculating cooling water systems and/or once through cooling water systems without chemical additions other than for the purpose of pH control and the control of biological organisms.

Obviously, the control of biological organisms is a very important part of the proper control of service water system chemistry, condenser cooling water chemistry. etc. Arkansas Nuclear One is presently using chlorine for this purpose. Given proper chlorinating procedures, dosages and frequencies, chlorination should be capable of fulfilling the needs of both Units 1 and 2 systems with respect to biological control. Where chlorination requires specific variances from environmental regulations, we suggest that APL attempt to secure these variances. We also suggest that dechlorination practices be followed where these practices can benefit APL.

We have extensive experience in the art of chlorination and the art of dechlorination. Likewise, we possess extensive experience in the science of chlorination and in the science of dechlorination. A combination of this art and science leads us to the conclusion that the best method for dechlorination at the present time tends to be the feed of sodium sulfite (Na_2SO_3) or equivalent. The feed of the sodium sulfite should be adjusted so that it will completely react with the chlorine as quickly as is possible. Excessive feed of sodium sulfite should be avoided. In this way, the residual sulfite will not adversely affect the levels of dissolved oxygen discharged with plant effluent.

The automatic control of dechlorination systems is rudimentary, at best. Obviously, the proper quantity of sulfite must be ratioed to the existing quantity of chlorine. However, the accuracy and/or response time and/or analytical specificity of instrumentation such as that which measures total residual chlorine, oxidation-reduction potential, etc. is not sufficiently good to enable control of dechlorination chemistry in real systems. We suggest that this control can be best effected by employing a timed sequence of sulfite addition prior to the introduction of chlorine into a water system. The sulfite addition can be prolonged after the addition of chlorine has ended. This type of control tends to provide the necessary quality assurance to the dechlorination process.

BIOLOGICAL GROWTH CONTROL

This section will discuss the control of essentially all biological organisms which might reasonably be predicted to cause problems with your service water systems. These organisms include aerobic and anaerobic biota such as bacteria, fungi, molds, slimes and algae. Additionally, this section also discusses the control of bivalves such as *Corbicula fluminea*.

Throughout this report we continually reiterate our belief that the success or failure of your service water systems depends primarily on your ability to operate these systems in a clean fashion. In other words, anything which is capable of accumulating on the surfaces of your heat exchanging equipment can be viewed as a corrodant. The reason for this is simply that the accumulation of dirt on heat exchange surfaces is typically equivalent to the formation of crevices. Pitting corrosion and failure can often be predicted to result in the presence of crevices. We make no attempt to differentiate between pitting corrosion and crevice corrosion. To our way of thinking these are identical as they impact your system.

Your Task 33 "Evaluate the Effects of Continuous Chlorination on Copper-Nickel Tubing and Other Heat Exchanger Material" prepared by Mr. Dan F. Spond recommends that APL not implement a program of continuous chlorination because of the increases in copper monitored during the tests performed in June and August 1980. At this time, we agree with the conclusion drawn, but we are not certain that the reason for not using continuous chlorination is necessarily correct.

It is well known that bivalves such as *Corbicula fluminea* can resist the effects of chlorine under a variety of conditions. The adult organisms can close their shells, rendering the chlorine relatively ineffective. Additionally, chlorination has proven relatively ineffective in the control of these organisms when they are living in sediment. In fact, it is this condition which has been suggested to us as being a problem in Unit 2 service water system.

The first step in controlling the proliferation of biological organisms in your service water systems is to take every possible action to keep the surfaces of these systems free from the accumulation of corrosion products, silts, etc. After this has been achieved, one can consider the proper application of a chemical biocide such as chlorine.

We are not willing to conclude that the increase in copper released during the aforementioned testing necessarily implies a release of base metal from system components. We additionally would want to see other corrosion monitoring studies parallel the Corrater readings. It would also help to understand the relationship between total chlorine fed, total available chlorine monitored, free chlorine monitored and total chlorine residual monitored. We suspect that APL has much of this information, but we are not aware of it. The studies which were conducted in June of 1980 lasted for approximately two (2) hours and thirty-one (31) minutes. Those conducted on August 19, 1980 lasted approximately four (4) hours and thirty (30) minutes. The final studies conducted on August 21, 1980 lasted only one (1) hour. It is reasonable to assume that the conditions within the condenser of Unit 2 and the component cooling water exchangers of Unit 2 which were respectively utilized in the aforementioned studies were not operating in a steady state mode during the chlorination testing. Obviously, this could be a long and detailed discussion. The simple point which we wish to make is that insufficient information exists to draw too many detailed conclusions which we would want to use in making major decisions.

The use of continuous chlorination is frowned on by the U. S. Environmental Protection Agency as is well known to APL. However, given the proper permits, this could be employed. We would suspect that the EPA would require the use of dechlorination if they were to grant any variation permitting continuous chlorination. The use of dechlorination has been discussed elsewhere in this report. If you are in need of other information, we will be happy to supply this. We have been involved in multiple litigations over this subject as it impacted ten (10) different utility plants. Additionally, we have co-authored a technical paper on this subject. It is not an extremely difficult problem, but there are associated costs which should be avoided unless they are absolutely necessary. As with any environmental issue, quality assurance becomes a major item of importance.

Chlorine and/or chlorine derivatives such as hypochlorite salts, bromine chloride, chlorine dioxide, etc. probably offer APL the best choice for a cost effective biocide in a once through system such as the service water system. The choice of compounds for feeding is strictly related to cost, ease of handling, safety considerations and permit considerations. We suspect that the way to apply this type of oxidizing biocide in your service water systems after these have been cleaned would be intermittent application. In combination with this type of application we would recommend the flushing of each exchanger not in use once per shift.

We think that the consideration of making this flushing a once per shift requirement is extremely important to the overall operation of Arkansas Nuclear One. By flushing these exchangers once per shift, the entire operating staff becomes familiar with the operation as part of their routine job responsibilities.

The implied flushing procedure need not last for a long period of time. Given low solids flushing water and relatively good flushing velocities ranging from an absolute minimum of four (4) feet per second to a maximum of fifteen (15) feet per second, three (3) exchanger volumes of flushing water should be sufficient.

The use of intermittent chlorination for a period ranging from approximately thirty (30) minutes to one (1) hour per day should be sufficient to provide the desired control of biological organisms in the service water systems. If the biological organisms are carefully monitored in the system, it may be possible to reduce the frequency of chlorination to somewhere between once per week and twice per week during the winter months and up to a maximum of once per day during the summer months. This type of chlorination procedure is not much different than is that associated with the chlorination of condenser cooling water systems.

The use of chlorine, as we have outlined above, would be predicted to control both aerobic and anaerobic organisms as these would otherwise be expected to have a negative impact upon your service water systems. Once again, mechanical cleanliness of these systems is important. Incidentally, we do not recommend the use of Amertap systems to provide this suggested cleanliness.

Amertap systems are relatively expensive, relatively hard to control, etc. They really are not set up for operation on small component heat exchangers. This is particularly true where the intrinsic characteristics of the cooling water do not tend to be scaling. This appears to be the conditions at ANO 1 under most water conditions which we would expect. If the water became scaling with respect to calcium carbonate, the addition of small amounts of sulfuric acid might be used to overcome this. However, we have not received any information from APL personnel indicating that scaling in the service water systems has been a problem. The calculations which we have presented in Table II indicate that this could be a problem under certain conditions. Once again, there just does not seem to be enough information available to us indicating this. Hopefully, the corrosion monitoring program coupled with the water chemistry analytical program which we have recommended will provide this information base.

The remainder of this section discusses the controls of bivalves in the service water systems of Arkansas Nuclear One. We prefer to view the bivalve problem as not being simply one related to Asiatic Clams

(Corbicula fluminea). The reason for this is simply that historically where one species of bivalves flourish, it is not very long before other species tend to appear. In other words, it is conceivable that other bivalvular organisms will appear in the future.

Most bivalves will not attach to surfaces such as those in the service water systems of ANO 1 and ANO 2 under conditions of high velocities or under conditions of clean surfaces. We strongly believe that low velocities and the presence of sediments are largely responsible for the proliferation of *Corbicula* found in the ANO 2 service water systems.

When these clams are found, the best way to rid them from the system is by mechanically cleaning the system with water jets, steam jets, backflushing, mechanical cleaning, etc. The organisms reportedly will not withstand elevated temperatures for extended periods of time. Therefore, these organisms can be killed by elevating the temperature of the systems to somewhere in the range of 40°C (104°F) to 60°C (140°F). Incidentally, there are specific temperatures which have been measured in the literature which are capable of killing the organisms in a one (1) hour period of time or less. The temperatures which we have referenced essentially skirt the ranges of temperatures necessary to kill these organisms. For example, a 100% kill of *Corbicula* is reported in a thirty (30) minute exposure at 43°C (109.4°F).

It is our opinion that the best solution to the bivalve problem would be to exclude all growth phases from entering the service water system. We make this statement simply because pieces of shells which might lodge in the system could effectively restrict flow. Such pieces of *Corbicula* shell have been found in the service water systems associated with both Units 1 and 2.

Before examining how best to exclude the *Corbicula* from entering the service water system, it should be noted that while we are not recommending continuous chlorination of the raw service water, we are recommending intermittent chlorination. Specifically the recommended approach to intermittent chlorination should provide a total residual chlorine during each chlorination period ranging from 0.2 ppm to 1 ppm depending upon the needs of the APL service water as determined by biological evaluation. One simply cannot predict the exact quantity of residual chlorine required to produce a certain degree of biostasis in the systems.

Chlorine, properly applied, is also effective in controlling bivalves. A combination of elevated temperature and chlorine is particularly effective. Continuous chlorination of *Corbicula* larvae is sufficient to produce essentially a 100% kill according to the literature. Therefore, the treatment which would have the greatest promise for use at ANO 1 would provide for the least possible disruption of normal service water system operation coupled with the maximum possible kill of biota. Additionally, this combination should best be as close as is possible to EPA sanctioned practices.

APL has considered the installation of backflushable service water strainers in a two (2) stage series configuration for the purpose of excluding the entry of *Corbicula* larvae from the service water systems. These strainers, as reported to us by APL personnel, would be capable of excluding objects of 0.01" (250 micron) and 0.005" (125 micron), respectively. It is believed that these strainers will exclude the passage of *Corbicula fluminae* larvae from entering the service system. In any event, these strainers provide a considerably finer straining element than presently exists with the 3/16" perforated stainless steel basket strainers presently installed.

We think there may be another approach to this problem which could offer some very attractive cost performance tradeoffs. We also think that it would be well worth the time and effort of APL personnel to make every possible effort to install all water pretreatment equipment as non-Q alternatives. The existing systems should best then be viewed as the required Q approved systems. We should think that any new components could be installed with the proper bypasses so that they would not have to comply with the restrictive seismic, etc. codes applicable to nuclear power plants.

By pretreating all of the once through water with granular media pressure operated or gravity operated filters, one could exclude not only large objects, but very small objects from entering the service water systems. Much of the debris, which we have suggested is related to the problems in the service water systems, would be excluded by this pretreatment. The effect of filtration is the lowering of the absolute velocity of the suspended solids in the influent water such that these materials remain within the filter media. We view clam larvae as being one form of these suspended solids.

When the differential pressure across the filter media indicates that it is time to backflush these filters, a steam injection step coupled with chlorination could be effectively utilized on the filter media prior to accomplishing the final backflushing rinse. Proper air scouring and air fluidization of the media would insure good contact between biological organisms in the media, steam and/or chlorine. This would be predicted to result in the sterilization of the media coupled with backflushing of the dead organisms and debris.

If APL were still concerned with the introduction of clam larvae to the service water system, a 0.05" (125 micron), single stage, backflushable strainer could be installed on the discharge of the granular media filter. Obviously, the water influent to the strainer would be predicted to have a very high quality of essentially less than 1 ppm of total suspended solids given proper design and operation of granular media filter. This would greatly reduce the backflushing requirements of the strainer as well as reduce the requirement for two (2) stage strainers.

The design of the pretreatment system components including clarifiers and/or granular media filters is discussed in a separate section.

It is conceivable that the emergency cooling pond could be utilized as a supply of service water system influent. However, this is an extremely shallow pond of reportedly four (4) to five (5) foot depth. It additionally reaches relatively high temperatures in the summer months approaching 90°F (32.2°C) to 100°F (37.8°C).

As you are aware, *Corbicula* have been found in the emergency cooling pond. This would appear to be a decided disadvantage to the use of this system for service water system cooling. We would suggest that if the emergency cooling pond could be effectively screened from contact with nature using fences and chemical sterilization, that this could provide a reasonable source of cooling water. One of the considerations which must be given to using the emergency cooling pond as a source of service water cooling is the effect of biological organisms on any sludges generated in the bottom of this pond. Often, manganese tends to concentrate in the bottom of this type of pond as a result of biological metabolism. Additionally, we would suspect that the Q certification requirements for the addition of components to the emergency cooling pond might tend to make this a very cost prohibitive source of cooling water. Whatever APL decides, we would strongly recommend that the quality of water in the emergency cooling pond be viewed as being essentially comparable to that presently being used as a source of service water system makeup. We are told that the water in the emergency cooling pond is somewhat better than that presently being used. However, we suspect that the implied chemistry differences are not sufficient to preclude the promotion of many of the problems which have been associated with the operation of the service water systems.

METALLURGY, WELDING AND COMPONENT FAILURE ANALYSIS

Wherever possible, we recommend that extreme caution be used in the interpretation of the analysis of component failures. Often the most significant information which comes forth from the analysis of failures is the simple fact that "a failure has occurred". Obviously, this information was known to all parties prior to the performance of the analysis.

Additionally, the analysis of failures often requires fairly sizable expenditures of money and time. Often the time required to perform these analyses is longer than would otherwise be desirable.

By far the biggest mistake which can be made is the misinterpretation of failure analysis reports. For example, we strongly believe that many failures of 304 stainless steel subjected to fresh water service that are reported to be the result of chloride-induced stress corrosion cracking are really the result of crevice corrosion.

At the time of preparing this report, we have been made aware of failures related to 90-10 copper-nickel (CDA alloy 706) and 304 stainless steel. We have reviewed failure analysis reports provided by Bechtel Power Corporation and by Southwest Research Institute on the subject of containment cooler corrosion, i.e., sulfide and/or chloride-induced pitting/crevice corrosion failures. The containment service water cooling coils in question were 2VCC 2A, 2B, 2C and/or 2D.

We have not seen any reported failure analysis of 304 stainless steel, carbon steel, etc. We were informed by telephone that 304 stainless steel has failed by persumably stress corrosion cracking. When we questioned whether this was possibly a crevice/pitting type of failure, we were told that this was not the case in at least one (1) examined specimen from the shut down cooling heat exchangers of Unit 2, namely 2E35A, B. We have not seen any photographs and/or inspection reports related to this 304 stainless steel failure.

All of the available information suggests that silt, biological debris and slimes, corrosion products, chlorides and sulfides are capable of concentrating within the service water systems. As we have not seen that information determined for the failure of 304 stainless steel, we do not know whether the failure analysis looked for the presence of manganese. We think that it would be well worthwhile determining the presence of and/or the absence of manganese. Although the literature is not specific on the effect of manganese, it does suggest that manganese can at least be an aggravator of chloride-induced pitting of 304 stainless steel.

Additionally, acids, oxidizing environments and elevated temperatures all tend to aggravate corrosion phenomena associated with austenitic alloys. Our analysis of the service water systems associated with Arkansas Nuclear One Units 1 and 2 suggest that there exist regions within these systems where these three (3) aggravators could exist.

Overall, the metallurgies employed in the service water systems of both Units 1 and 2 are not terrible. What appears to be "terrible" is the combination of the service of these systems with their metallurgies. In our report of December 15, 1980 we referenced the problems associated with low velocity. Subsequent to this, we have reviewed the aforementioned Southwest Research Institute report which we had not seen prior to the preparation of our December 15, 1980 report. The SRI report also suggests that stagnant regions within the service water systems are believed to be major contributors to the observed corrosion phenomena. While the SRI report deals only with the failure of CDA alloy 706, we believe that this can be reasonably extended to the failures of 304 stainless steel via the mechanism of pitting and crevice corrosion.

APL has elected to retube 2E35A & B with the alloy E-Brite 26-1. We see no problem with this decision. We discussed this alloy in our report of December 15, 1980. In our discussion of E-Brite 26-1 and other materials we rated these materials as to their costs. Please be aware that there is one (1) error in this aforementioned information. Alloy AL 6X is more expensive than is alloy AL 29-4C.

In the aforementioned report we also expressed our opinion that 304 stainless steel and 316 stainless steel would not be good choices of materials for use by APL in the service water systems. We included the respective "L" grades in our comments.

In the discussion which follows, we are going to modify these statements slightly to suggest that the use of 316L would be a reasonable choice for system piping 2-1/2" in diameter and smaller. At another point in this report we will recommen that consideration be given to closing the service water systems entirely. The closing of each system will enable the use of a corrosion inhibitor in a very cost effective manner. Under these conditions, the corrosion experienced in the service water systems could be virtually stopped. This presupposes that the systems are filled with water and inhibitor after being totally cleaned and that the chemistry of this system is maintained during operation.

Given that these systems cannot be operated in a closed manner, every possible effort should be made to keep the systems clea and free from the accumulation of debris. In other words, debris should be removed as best as is possible from the raw influent water and should not be allowed to either accumulate within the service water systems as a result of low velocity flow or as a result of corrosion product accumulation. The installation of the more noble material 316L in small diameter piping will greatly help the avoidance of corrosion product accumulation.

It is our feeling that considerably greater potential exists in the Arkansas Nuclear One service water systems for pitting/crevice corrosion than for chloride-induced stress corrosion cracking of austenitic alloys. Furthermore, the existing conditions as they impact system metallurgy and observed system water chemistry appear marginal. While we would not recommend 304 stainless steel or 304L stainless steel for inclusion in the service water systems, the existing body of information might make this material reasonable for consideration if one only looks at the water analysis and at the operating temperatures.

The technical literature definitely contains more information about the resistance of 304 stainless steel to chloride pitting/crevice corrosion than it does for 316 stainless steel. The reason for this is somewhat commercial in nature to our way of thinking. There is more 304 stainless steel in use than there is 316. Therefore, there has been a greater interest and a greater impetus to develop information about this former material.

The reported research which has been done on the austenitic stainless steels tends to suggest that the progress and/or threshold for chloride-induced pitting/crevice corrosion of austenitic materials is dependent upon the *a priori* existence of a crevice. In other words, there must be "dirt" on the surface of the metal in order for chloride cracking to occur in relatively mild environments. Generally, the tighter the crevices the worse is the corrosion potential from a pitting/crevice mechanism. Rust, holes, sharp edges, occluded cavities, etc. all tend to induce chloride pitting/crevice corrosion.

During the performance of this work, we offered APL the opportunity of discussing some of their problems with Mr. George Moller. George is both a personal friend and metallurgical advisor to us. In addition to possessing an excellent academic background in metallurgy, George has a large quantity of practical experience. In fact, George is the co-author of the quantitative information which served as a major part of the basis used by your Mr. Dan F. Spond in the preparation of Task 32A - "ANO Service Water Action Plan".

Mr. Spond discussed some of these items with Mr. Moller and the writer on Tuesday, January 13, 1981.

The data which Mr. Spond quoted was generated from some relatively short term, laboratory, electrochemical testing. As a result of personal communications, we are aware that most of this information has been confirmed in longer term tests. For example, the initial test work which Mr. Spond referenced was performed in tests which lasted about five (5) hours or less. Since this time, approximately ninety (90) day multiple crevice tests have been performed using the Anderson Multiple Crevice Test Device. These multiple crevice tests have evidenced excellent correlation with the original electrochemical data.

Unfortunately, the majority of information available on this subject has been worked out in seawater environment and/or ferric chloride solution. In the latter case, chloride cracking occurred at extremely low levels because of the oxidizing environment. In the former case, the information suggests that the presence of depositing material in seawater creates crevices which aggravate the resulting chloride pitting phenomena. An empirical rule has been worked out for the resistance of austenitic materials in seawater. This has not been worked out at this time for fresh water. The rule to which we refer suggests that the sum of the chromium concentration in the alloy as the weight percentage plus 3.3 times the molybdenum concentration as the weight percent in the alloy should best be greater than 35 in seawater. Hopefully, a similar guideline will be worked out for fresh water systems in the near future.

Obviously, we agree with the comments and the data presented by Mr. Spond. We additionally believe that the most important consideration to the success or failure of the service water systems at ANO as related to chloride pitting/crevice corrosion is the elimination of crevices. The surface of the metal in question simply must be kept clean. This means that biological slimes cannot be allowed to accumulate, mud and silt cannot be allowed to accumulate on the surfaces, etc. Any action which can also reduce the presence of acidic environments, oxidizing environments and/or elevated temperatures at the surfaces of the metal will also help to reduce pitting/crevice corrosion phenomena involving chloride ions.

APL has expressed the desire to change the piping in the service water system which has a diameter of 2-1/2" or less from carbon steel to 316L stainless steel. Basically, we agree with this decision. 316L stainless steel is a readily available material which can be welded with relative ease. Considering the available body of information, it would be essentially next to impossible for us to justify to APL the use of a more exotic material. By exotic material we are referring to an alloy which would contain essentially a higher percentage of molybdenum. The material of choice which might be slightly better than 316L would be 317 and then 904L. Alloy 20 would not be predicted to be any better than would 316L.

Considering the use of 316L piping requires that a decision be made as to whether butt welding or socket welding should be employed. A properly executed butt weld could eliminate crevices within the ANO service water system piping. However, the time involved in making the butt joint was estimated by APL to be approximately six (6) times that required to make a respective socket joint. Considering that several hundred welds are estimated to be required, the use of butt welding versus socket welding would have a major impact on system upgrading costs.

We do not consider ourselves to be experts on welding. We do realize the difficulties associated with butt welding versus socket welding and the obvious increased demands on labor/cost.

We discussed this welding in detail with Mr. Moller. We additionally reviewed literature on this subject with Mr. Moller.

The conclusion which we have reached is, unfortunately, rather indecisive. We would advise APL that the choice of butt welding is a better choice than is the choice of socket welding. However, all of the information which we could obtain did not lead us to the conclusion that socket welding would necessarily result in failures. In fact, Mr. Moller felt that socket welding should be adequate.

If the existing service water system is planned to operate with the existing water for extended periods of time, we would prefer to see APL butt weld every possible joint. However, we would also state that the risk of using socket welds rather than butt welds would appear to be extremely low.

We realize the lack of decisiveness of this recommendation. We also realize the lack of definitive information on this subject. Therefore, we would suggest the possibility of a compromise solution to APL. It might be worth analyzing the required welds in detail with respect to their location in the service water system and the implication of any leak which might result at the weld in the event of failure. Where critical leakages could occur, APL would be advised to use butt welds. Where leaks could be reasonably detected and/or not critical to system operation, APL could reasonably use socket welds.

Obviously, every weld should be stress relieved. Obviously, the choice of the "L" grade of 316 should improve the weld structure by avoiding the tendency towards sensitization and subsequent intergranular cracking.

Wherever welds occur, care should be taken to avoid any restrictions in pipe diameter which could lead to the accumulation of sludge, silt, corrosion products, etc. *in situ*.

Any other comments which we have made relative to metallurgical considerations, welding considerations and/or component failure analyses were previously reported on December 15 and will not be reported again.

One comment which we feel has immediate bearing on our recommendations is the fact that we would sanction the use of 316L piping while we would not sanction the use of 316L tubing in the shut down cooling heat exchangers of Unit 2 (2E35A & B). The reason for this is that we understand that during the initial operation of these heat exchangers, the temperature at the surface of the metal can extend considerably above 150°F (65.6°C). For this reason, alone, we feel that APL would benefit by using E-Brite 26-1 as opposed to 316L tubing.

In the course of examining every possible consideration for system upgrading, APL has considered the use of essentially laying up out of service exchangers with catalyzed hydrazine. Unless the service water system is operated in a closed loop mode, we would like to see this catalyzed hydrazine not used. As your Mr. Alan Smith has pointed out in Task 24B "Evaluate Effectiveness of Hydrazine Addition", hydrazine is presently listed as a hazardous substance because of reported carcinogenicity. Obviously, one should avoid using this if at all possible. Additionally, we are not certain that the information which Mr. Smith references relative to the ability of catalyzed hydrazine to react with oxygen at ambient temperatures is broadly extrapolable to all systems. Rather, we tend to think that even catalyzed hydrazine will not perform the necessary oxygen uptake chemistry at ambient temperatures under all conditions. At least, this must be evaluated *in situ*.

A further consideration with respect to the layup of systems involves the potential for precipitating chemicals from the lay up water as a result of the elevation of the bulk water pH. Obviously, the service water systems at ANO do not use high purity water. Therefore, care must be taken in raising the pH of this water to avoid precipitation of solids on the surfaces of the heat exchangers. If solids deposit, the potential for crevice corrosion and underdeposit corrosion could be greatly accelerated. Under these conditions, the benefit of hydrazine would be expected to be somewhat negative rather than positive.

MECHANICAL TREATMENTS, COMPONENT FLUSHINGS AND ASSOCIATED CONNECTIONS

Along the lines of maintaining service water systems clean, component flushing and/or backflushing has been evaluated by APL. As we interpret the results of these efforts, we view these as being only partially successful. This partial success is not meant to imply any direct reflection upon the personnel of APL. Rather, we believe that the design of the service water systems is such that flushing is extremely difficult.

We do not recommend the installation of proprietary cleaning systems. The available systems are judged by us to be excessively difficult to maintain. This is particularly true when one considers the problems associated with possibly experiencing brushes and/or balls, etc. stuck in critical heat exchanger tubes. Additionally, little can be done with shellside exchangers as has been pointed out throughout this report.

We do recommend the installation of every possible valve and associated flushing connection in convenient locations. We also recommend that heat exchangers subject to extensive lay up periods be flushed once per shift with a minimum of three (3) volumes of clean water at a velocity ranging from 5 fps to 12 fps.

Appropriate temperature, pressure and/or flow monitoring indicators and/or recorders should best be installed at all possible critical locations in the service water systems.

During the upcoming inspections, we recommend that exchangers be mechanically cleaned and put back on line in a clean fashion. We do not believe that the condition of your system will warrant chemical cleaning. Additionally, there would be sizeable difficulties in chemically cleaning your system because of the differences in existing metallurgy and the lack of flushing connections.

Perhaps, by valving exchangers at the supply and discharge header tops, such chemical cleaning and related flushing operations can be performed easily on an as needed basis in the future.

Where possible, inspection ports and/or manways should be installed on the shellside of exchangers to facilitate the inspection process. Obviously, these ports can also be used to facilitate future cleaning. Along the same lines, provisions should be made for venting the top of exchanger shells in event that APL elects to practice air bumping to effectively increase superficial water velocity.

A final item which should be considered is the installation of recycle pumps around heat exchangers. These pumps could readily take suction from the discharge of the cooling water at exchanger outlets and recirculate flow to the exchanger inlets. This would have the effect of increasing the water velocity within the respective exchangers.

HEAT EXCHANGERS

In reviewing the service water systems associated with ANO Unit 1 and Unit 2 we have presented several comments relative to the construction of the associated heat exchangers. Obviously, the question as to whether or not to replace critical components and/or parts of critical components is the major portion of this work.

Should you require addressing the problem of whether or not an entire heat exchanger requires replacement, we would suggest that you review the design of the existing heat exchanger in detail prior to purchasing a duplicate unit. Wherever possible, shellside exchangers subject to low velocity conditions should be avoided. If you must use shellside exchangers, we would suggest you consider the installation of vent connections at the top of the shell as well as strategically located inspection ports and/or manways. Additionally, the direction of installation in the plant should be carefully planned so as to facilitate maintenance. All too often we encounter multiple heat exchanger systems installed in a head to tail array which prevents the removal of tube bundles.

The vent connections which we have recommended are designed to facilitate the use of air bumping when exchanger shellside velocities are less than optimum. Such connections can also be very helpful during chemical cleaning operations, etc. While we sincerely hope that APL does not have to face the problem of installing totally new heat exchangers, we do advise that a very careful design review be performed before installing a new unit.

Wherever possible, heat exchangers tend to perform better when the cooling water is on the tubeside rather than when the cooling water is on the shellside. Additionally, horizontal straight tube exchangers tend to outperform horizontal U-tube exchangers. Additionally, we believe that most people experience much less problems with horizontal tube bundles than they do with vertical tube bundles.

If you face the problems associated with periodic retubing of certain bundles and/or the need for totally cleaning a bundle, it might be a prudent practice to inventory a spare bundle. The ability to be able to completely remove a tube bundle, inspect this, clean this, replace this, etc. makes these functions considerably easier and more effective.

When considering the retubing of heat exchangers, please make certain that the shells, tube sheets, tubes, tube support plates, flanges, etc. are compatible from a metallurigal point of view. Additionally, stressed areas such as welds, tubing bends, etc. should be stress relieved.

As a general recommendation, the following five (5) metallurgies should be eliminated from further consideration for use in your existing service water systems:

1. Galvanized Steel.
2. Admiralty Brass.
3. Aluminum.
4. Copper.
5. 304 Stainless Steel.

The last material, 304 stainless steel, does have some reasonable applications under certain conditions of improved water quality. However, this material is judged by us to be so questionable that it is not worth the risk of considering.

Isolation valving at inlet and outlet headers should be installed wherever possible. Flushing connections within these isolation valves are extremely helpful to component backflushing, cleaning, hydrostatic testing, etc.

When purchasing new components, flushing connections should be added wherever possible. These connection should provide for the control of velocity and for chemical cleaning and rinsing operations, etc.

In summarizing this section, please note that all of our recommendations are designed to facilitate long term structural integrity of heat exchangers, relative ease of maintenance, relative ease of inspection, optimum design velocities and cleanliness of critical surfaces.

WATER PRETREATMENT

Assuming that APL cannot close the service water cooling loops and/or critical portions of these loops, some form of water pretreatment appears to be warranted. Additionally, we suggest that it might be helpful to APL to consider the installation of a water pretreatment plant capable of supplying the municipal water requirements for the City of Russellville, Arkansas, etc. Such an installation might accomplish the needs of Arkansas Nuclear One as well as those of the surrounding community. Obviously, the operation of this plant might help APL achieve a more favorable economic payout on their investment for water treatment equipment.

As mentioned elsewhere in this report, APL has considered the installation of two (2) stage, automatic backwashing, mechanical strainers. These would be predicted to remove a great deal of debris. However, we would predict that these strainers would tend to plug quite readily, necessitating large quantities of backwash water. Additionally, these strainers would not be predicted to remove much of the finely divided material which might otherwise be removable by clarification and/or filtration providing that proper coagulation and flocculation of solids is practiced.

We view the installation of strainers as being only a partial help to the service water systems' problems of Arkansas Nuclear One. We also view this partial solution as being directed at the exclusion of *Corbicula fluminea* from the service water systems. In fact, we think this latter problem could be relatively minor. It is our recommendation that APL give serious consideration to the installation of solids contact clarifiers and/or granular media filters. As mentioned elsewhere, it would be much to APL's advantage to be able to install these clarifiers without meeting any of the critical code requirements associated with nuclear power plants. In other words, the installation of appropriate Q bypasses should be considered such that the existing water flow pathway could be utilized under emergency conditions, in a shut down mode, in a LOCA, etc.

In reviewing Figure No. 3.3-1 of Amendment 5 of what we believe is your Environmental Report, we are assuming that the maximum flows of Unit 1 service water system plus Unit 2 service water system is 29,300 gallons per minute. For purpose of providing the necessary design basis, we will assume that this flow is 30,000 gallons per minute. To further allow for any discrepancies and/or to provide additional pretreated water, we will direct our attention to the design of a system capable of handling 40,000 gallons per minute.

A typical clarifier system which would be predicted to fulfill the needs of Arkansas Nuclear One is that associated with the River Bend Station - Unit 1 of the Gulf States Utilities Company. This clarifier system consists of a splitter box which feeds two (2) solids contact clarifiers, each having an effective diameter of 175 feet. The system includes the necessary chemical addition hardware, underflow solids pumps, etc.

Each of the aforementioned clarifiers has an effective centerwell diameter of 60 feet. Therefore, the net calculation of effective clarification surface area would be 21,226 square feet per unit. Using both units in service at 30,000 gpm influent flow would result in a surface rise rate of approximately 0.71 gpm/ft^2. At 40,000 gpm, this rise rate would be approximately 0.94 gpm/ft^2. This is equivalent to an overflow rate of 1,018 gpd/ft^2 or 1,357 gpd/ft^2, respectively.

The aforementioned rise rate should be adequate to handle your clarification needs. Rise rates of greated than 1.0 gpm/ft^2 or 1,440 gpd/ft^2 would be predicted to lead to carryover of suspended solids and other associated problems with the ANO surface water supply.

To our way of thinking it would be essential to the successful installation of solids contact clarifiers that the underflow solids be permitted to be discharged directly to a receiving body such as Lake Dardanelle and/or be allowed to be discharged to a nonhazardous waste sludge pond.

The applicable chemical feed to these clarifiers would be predicted to involve somewhere between 10 ppm and 25 ppm of filter alum ($Al_2(SO_4)_3 \cdot 18H_2O$) calculated on the basis of the aluminum sulfate content and somewhere between 0.05 ppm and 0.5 ppm of a relative high molecular weight anionic polyacrylamide-acrylic acid copolymer. Alternatively, the feed of from 1 ppm to 4 ppm of a single cationic polyelectrolyte might prove sufficiently effective. We would anticipate that the latter treatment might not remove the organics and/or color associated with the raw water as effectively as would the former treatment. A third treatment which could prove effective would be the use of between 5 ppm and 15 ppm of an iron (III) salt such as ferric chloride ($FeCl_3$) or ferric sulfate ($Fe_2(SO_4)_3$). The feed of the ferric chloride or ferric sulfate should be topped off with a coagulant aid such as that associated with the feed of alum.

Coagulation and flocculation studies coupled with sedimentation studies on the raw water prior to purchasing the referenced clarification equipment can be easily conducted.

The use of clarifiers provides for extended retention of water such that these clarifiers can also serve as effective chlorine contact tanks during the periods of chlorination. To be specific, the clarifiers appropriate for your needs would contain between two (2) and four (4) hours of water at a flow rate of 40,000 gpm.

The clarification equipment which we have described is extremely versatile. Additionally, this equipment would be predicted to be capable of being purchased with a reasonably tight guarantee on the overflow suspended solids concentration. We suspect that this guarantee would be negotiable in the range of 1 ppm to 5 ppm of total suspended solids.

The versatility of the system rests in the fact that the units have the internal capabilities to recycle sludge within the reaction zone of the clarifier. The cost for the clarification equipment which we have outlined including all subsystems, but not including concrete pads and steel tankage erection, would be approximately $2,000,000. If APL elected to purchase this equipment, we would recommend that extreme care be used in selecting the equipment vendor. There are relatively large differences in the performance of clarifiers even though the actual units may appear to be relatively similar in drawings, etc.

We believe that the clarifiers would be capable of certainly excluding adult clams from entering into the service water systems. We do not know whether these clarifiers would be totally effective in removing clam larvae. To preclude the latter, APL could install 125 micron, self backwashing strainers on the clarified water. The advantage of installing these strainers in this position is relatively great. The rate of pressure drop increment with time would be predicted to be dramatically lower than it would be with these strainers installed on the raw water inlet.

The alternative to clarification, as we view the needs of APL, would be the installation of granular media filters. Conventional, downflow, dualmedia filters operated by gravity tend to lose effectiveness in water containing greater than about 50 ppm of total suspended solids. The chief reason for this loss of effectiveness is simply that the filters require backflushing with a greater than desirable frequency. We believe that the service water influent to ANO 1 contains less than 50 ppm of total suspended solids most of the time. However, we have assumed that higher levels of suspended solids could be encountered as shown in Table I.

To provide for sufficient filterability in the presence of higher levels of suspended solids, we would recommend the use of a specialty filtration media such as that supplied with the Varivoid Filter manufactured by the Graver Water Division of Ecodyne Corporation. We do not think that it would be worth the additional expense to use a proprietary, upflow filtration system.

If conventional dualmedia were used consisting of approximatley 1 foot of 0.45 mm effective size sand capped with approximately 2 feet of 0.9 mm to 1.1 mm effective size anthracite coal, we would design the system to handle a hydraulic loading of approximately 3 gpm/ft^2 in the service cycle. Air scouring provisions should be installed to provide approximately 4 scfm/ft^2 of filter area. The necessary backwashing cycle would require about 12 gpm/ft^2 for a period of 10 minutes. The total quantity of backwash would be predicted to range between about 1% and about 6% of total influent flow.

As suggested elsewhere within this report, the backwashing cycle could include a period of time in which chlorine and/or steam are utilized to kill any bivalves which tend to grow in the filter media. Each backflushing cycle should be established based upon a preset differential pressure across the filter bed which would be overridden by a timer in the event that extremely good water is influent to the filters for an extended period of time.

Specific information on Varivoid Filter media should best be obtained from the aforementioned supplier. Additionally, the use of pressure filtration and/or excelerated filtration rates could be designed into a suitable system for use at Arkansas Nuclear One.

The system which we visualize would consist of a minimum of six (6) filters. Conceivably, Arkansas Nuclear One could get by with five (5) filters. However, there are definite advantages to using smaller diameter filters. These can be readily shop fabricated to save money, etc.

The filtration process is often enhanced by the addition of chemicals. However, the chemical requirements for filtration are typically somewhat less than are those for clarification. It is additionally important to minimize the use of chemicals in filtration as these contribute to the increment in differential pressure across the filter media. For example, 5 ppm of alum might serve as a primary coagulant ahead of a filter. This might be effectively followed with approximately 0.1 ppm of a floc strengthening polyelectrolyte.

We would not recommend the use of self contained backwash storage filters at Arkansas Nuclear One. Ratner, we would recommend that the filter backwash be stored in a filtrate tank and pumped to each filter as required. This filter backwash tank should be covered to prevent the proliferation of photosynthetic organisms and debris.

The appropriate filtration system would be estimated to cost between about $2,000,000 and $3,000,000 not including concrete pads, erection and installation. If shop fabricated units complete with face piping are purchased, the installation costs will be minimized.

Before purchasing either clarification and/or filtration systems, it would be well worthwhile to compare the cost of the equipment which we have suggested with similar equipment constructed of concrete such that multiple vessels employ common wall construction. This latter configuration is typically used in municipal water treatment plants. Proprietary clarifier mechanisms and/or proprietary filter underdrains can be purchased for installation in such tanks.

We would be willing to predict that the filtration system outlined above should be capable of removing clam larvae from the influent raw water. However, if APL desired, they could consider the installation of the aforementioned 125 micron, single stage strainers on the filtrate.

The ultimate water pretreatment system, which we believe to be somewhat of an overkill, would include clarification followed by filtration. In this type of system we would not recommend the use of additional strainers.

There are many considerations in comparing the clarification process to the filtration process. Both processes are subject to fluctuations due to changes in hydraulic loading, water chemistry, water temperature, etc. The proper installation of a downflow filtration system could eliminate the adverse effects of most of these variables providing that hydraulic surges be somewhat controllable. Obviously, we favor the installation of single stage filtration systems. We will be pleased to provide you with any other information on these systems and/or provide references to end users who have had success with this type of pretreatment.

Our inspection visit to Arkansas Nuclear One indicated that APL should have sufficient land available for the construction of a water pretreatment system. This was one of the items which we stated we would review as a portion of our scope of services.

A final comment which we feel might offer several advantages to Arkansas Nuclear One relates to having a supply of high quality filtrate at the nuclear plant site. This could readily be utilized as a makeup water source to the primary makeup water demineralizers, etc. The use of this type of water would be predicted to provide the plant with considerably better demineralizer performance than has been experienced in the past. Further details of this discussion are outside of our present scope of work.

TABLE I

RANGE OF ANTICIPATED SERVICE WATER QUALITY[1]

Parameter	Low	High	Average[2]
pH, pH Units	6.5	9.5	8.2
Total Hardness, mg/L as $CaCO_3$	50	225	
Calcium, mg/L as Ca	10	90	44
Magnesium, mg/L as Mg	1	25	
Sodium, mg/L as Na	30	165	
Potassium, mg/L as K	0	10	
Total Iron, mg/L as Fe	0.1	1	
Total Maganese, mg/L as Mn	0	1	
M Alkalinity, mg/L as $CaCO_3$	40	120	80
P Alkalinity, mg/L as $CaCO_3$	0	0	0
Chloride, mg/L as Cl	40	200	
Sulfate, mg/L as SO_4	20	100	
Nitrate, mg/L as NO_3	0	10	
Fluoride, mg/L as F	0	1.5	
Silica, mg/L as SiO_2	0.2	10	
Total Dissolved Solids, mg/L	150	800	350
Suspended Solids, mg/L	10	100	50
Total Solids, mg/L	160	900	400
Equivalent Specific Conductance, μmhos/cm at 25°C (77°F)	250	1,200	
Turbidity, NTU	10	80	
Temperature, °F	33	130	100[3]

NOTES FOR TABLE I:

1. The values which appear in this table have been strictly synthesized for the purpose of generating a reasonable working base.

2. The term <u>average</u> actually has little to no meaning. This is presented here for purposes of calculating a Langelier Saturation Index and a Ryznar Stability Index.

3. This average temperature value assumes that the water is sampled at the discharge of the service water system.

TABLE II

RANGE OF ANTICIPATED SERVICE WATER TENDENCIES TO SCALE WITH CALCIUM CARBONATE OR TO BE CORROSIVE TO MILD STEEL[1,2]

	Langelier Saturation Index	Ryznar Stability Index
Highest apparent scaling tendency water composition[3,5]	2.6	4.3
Lowest apparent scaling tendency water composition[4,5]	-3.0	12.5
Average water composition	0.5	7.3

NOTES FOR TABLE II:

1. All calculations are based upon data taken from Table I.
2. All calculations are approximate.
3. Calculations based upon the assumption that the worst scaling water occurs when pH, alkalinity, temperature and calcium are at the maximums while total solids are at the minimum.
4. Calculations based upon the assumption that the most corrosive water occurs when pH, alkalinity, temperature and calcium are at the minimums while total solids are at the maximum.
5. The assumptions in Notes 3. and 4. above are strictly those implicit in the calculation of the Langelier Saturation Index as a result of the inverse solubility of calcium carbonate with temperature. We are specifically not stating that corrosion rates are inversely related to temperature.