CONF-830649--3

ENGINEERING FACTORS INFLUENCING CORBICULA FOULING IN NUCLEAR-SERVICE WATER SYSTEMS

C. H. Henager
K. I. Johnson
T. L. Page

CONF-830649--3

DE83 015991

June 1983

Presented at the Second International Corbicula Symposium
Hot Springs, Arkansas
June 21-24, 1983

Supported by
the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830

Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

Corbicula fouling is a continuing problem in nuclear-service water systems. More knowledge of biological and engineering factors is needed to develop effective detection and control methods. A data base on *Corbicula* fouling was compiled from nuclear and non-nuclear power stations and industries using raw water. This data base was used in an analysis to identify systems and components which are conducive to fouling by *Corbicula*. Bounds on several engineering parameters such as velocity and temperature which support *Corbicula* growth are given. Service water systems found in BWR and PWR reactors are listed and those that show fouling are identified. Systems with fouling include residual-heat-removal heat exchangers, containment space coolers and high-pressure emergency injection-pump bearing-and-seal coolers. Possible safety implications of *Corbicula* fouling are discussed for specific service water systems. Several effective control methods in current use include backflushing with heated water, centrifugal strainers, and continuous chlorination during spawning seasons.

INTRODUCTION

Fouling of service water systems due to the presence of the asiatic clam, Corbicula, is a continuing problem in the nuclear and non-nuclear power industries alike. Corbicula fouling in nuclear service water systems is especially critical because many service water cooling loops are required for safe shutdown of the reactor. This paper presents engineering factors which have commonly occurred in many instances where Corbicula have been found in nuclear service water system piping. Many of these factors were identified from first-hand accounts given by utility personnel of fouling incidents which involved Corbicula. Utilities and specific nuclear plants which have provided information are not identified by name unless specifically requested by the utility. This is to honor the requests of many utilities that they remain anonymous. The second major source was the utility responses to IE Bulletin 81-03 entitled "Flow Blockage of Cooling Water to Safety System Components by Corbicula sp. (Asiatic Clam) and Mytilus sp. (mussel)". This Bulletin was issued by the Office of Inspection and Enforcement of the U.S. Nuclear Regulatory Commission to all operating plants as well as plants currently under construction. The third major source of information was the published literature on Corbicula.

This study was done at the Pacific Northwest Laboratory, operated by Battelle Memorial Institute for the U.S. Department of Energy. Funding for this project was provided by the U.S. Nuclear Regulatory Commission, Siting and Environmental Branch.

NUCLEAR SERVICE WATER SYSTEMS

Nuclear service water systems are designed to provide cooling water to reactor and auxiliary system components during both normal and accident conditions. The water source is raw water taken directly from a river, lake, or ocean (Haried, 1982). The circulating water system, which cools the main turbine condensers, is considered to be a separate system from the service water systems.

There are two general categories of service water systems which are common to both boiling water reactors (BWRs) and pressurized water reactors (PWRs). They are the essential and nonessential service water systems. The differences are in the type of cooling loads which each system handles.

Generally speaking, the essential service water system cools components within the reactor building which are required for safe shutdown. The essential service water system may also be referred to as the Emergency Equipment Cooling Water (EECW) system, the Service Water (SW) system, or the Essential Raw Cooling Water (ERCW) system. Cooling loops which are served by the essential service water system are classified as safety related.

The nonessential service water system, in general, cools components within the auxiliary building which are not required for safe shutdown of the reactor. This system may also be referred to as the Raw Cooling Water (RCW) system. Cooling loops which are served by the nonessential service water system are classified as nonsafety related.

Another safety related system which often draws its water from the service water system or the service water intake bay is the fire protection system. Since Corbicula fouling may also occur in the fire protection system, it will be considered here along with the service water systems.

The initial water treatment which occurs in the service water intake structure is similar for both BWRs and PWRs. Large chunks of floating debris such as driftwood and ice are removed by the trash racks at the opening of the service water intake structure. After entering the intake structure, the water passes through self-cleaning travelling screens which remove essentially all debris which is greater than one-half inch in diameter. After passing through the service water pumps, the water passes through basket strainers which remove particles greater than one-eighth inch in diameter. Therefore, Corbicula larger than one inch in diameter (Goss and Cain, 1976) which have been found inside service water heat exchangers have come in as larvae and have found suitable conditions for growth inside service water system piping. Thus an effective means of controlling Corbicula inside of service water systems must also address control of Corbicula larvae in the service water.

ENGINEERING FACTORS INFLUENCING CORBICULA FOULING

The engineering factors discussed here seem to have occurred commonly in many instances where Corbicula have been found in service water system piping. Although listed separately, these factors are often found working together to emulate environmental conditions which are known to support Corbicula growth in their natural environment. The general factors which will be described below are:

1. Low Velocity Flow
2. Warm Water Conditions
3. Silting and Corrosion Products
4. System Redundancy and Intermittent Use
5. Valve Leaks and Valving Errors
6. Chlorination Effectiveness and System Reliability
7. Small Diameter Components

Low Velocity Flow

Low velocity flow appears to be a major factor which supports the settlement and growth of Corbicula larvae in service water systems. It is speculated that velocities on the order of one to two feet per second are sufficiently low to allow Corbicula larvae to settle. In the design of municipal water systems, fluid velocities are typically kept above three feet-per-second to prevent silting. Also, Corbicula in the larvae stage have the ability to attach to piping by secreting a byssus thread (Sinclair, 1963). Thus, once the larvae settle and attach, minor increases in velocity will not detach them.

Low velocity flow also provides an ideal environment for the settlement of silt and other suspended particles. One plant reported that during peak run-off periods, levels of suspended solids have reached as high as 10,000 ppm in their service water. Silt deposits provide a natural environment in which Corbicula may grow. The silt layer can also act to protect the young Corbicula larvae from chlorine levels which would be toxic if in direct contact with the larvae.

Unlike stagnant water conditions, low velocity flow provide a continuous supply of fresh food and oxygen to clams in the piping system. Thus low velocity flow not only allow clams to settle and attach to service water system internals, it also provides food and oxygen needed for their growth.

Low velocity flow conditions typically occur at or near geometric discontinuities in the service water system where eddies and backwater conditions exist. Areas which are included in this category are service water inlet structures (see Figure 1), inlets to heat exchanger water boxes, and sudden changes in pipe diameter. Low velocity may also occur in lines with leaking or partially open valves.

Warm Water Conditions

Water temperature is a major factor which determines whether service water cooling loops will support Corbicula growth. Although tolerance limits are somewhat dependent on Corbicula acclimation temperature, the upper and lower limits appear to be near 31 and 2°C, respectively (Mattice and Dye, 1976). Optimum temperatures for Corbicula growth are in the mid 20°C range (Mattice, 1979). Water temperatures within service water systems are in most cases above 2°C with one utility reporting that the water to their turbine bearing lube oil coolers is approximately 16°C. Also, the retention period of water held in redundant heat exchangers or systems which see intermittent use is generally long enough for the service water to reach room temperature (approximately 20°C).

Seasonal temperature extremes affect the population dynamics of Corbicula in the service water source. Low water temperatures have been known to cause severe winter kills in Corbicula populations (Bickel, 1966). It is understandable that the greatest population increases and most severe fouling problems have occurred in the southern United States where winter temperatures of the water source typically remain above 2°C. Also, thermal effluents from power plants can effectively raise minimum seasonal temperatures to where Corbicula in the effluent plume will survive even though populations outside the plume do not.

Silting and Corrosion Products

Other types of fouling such as silt and corrosion products (primarily iron-oxide) are often found in conjunction with clams and clam shells in carbon steel piping. Two utilities in particular have noted this correlation and have replaced portions of their carbon steel service water and fire protection system piping with stainless steel piping.

As stated previously, low velocity flow conditions which allow settlement of Corbicula also allow settlement of other heavier suspended particles such as silt. Silt and mud deposits provide a natural substrate for Corbicula growth. Another important interaction of silt and Corbicula growth in service water systems is that a silt layer can act as a buffer between clam larvae and chlorinated service water. Just as bacteria have a biological oxygen demand, silt exhibits a chemical demand for free chlorine. Therefore, the free stream residual chlorine level may be several times the level which clams buried in a layer of silt may see. Because of this, residual chlorine levels which are known to kill clam larvae when in direct contact may prove ineffective in controlling clam larvae which are protected by a layer of silt.

Corrosion products are often found in conjunction with deposits of silt and Corbicula. Although the interaction between these three factors is not completely understood, there are definite correlations between the presence of silt and corrosion products as well as the correlations between silt and Corbicula deposits which have been previously discussed.

There are two mechanisms which are postulated to be the cause of corrosion of carbon steel in the presence of silt deposits. A well known cause of electrochemical corrosion in carbon steel piping is that a nonuniform distribution of dissolved oxygen renders the area exposed to low oxygen concentration anodic with respect to the area in contact with the higher oxygen concentration (Bacon, 1978). Thus, areas where silt has deposited may become oxygen deficient zones where electrochemical corrosion can occur. One utility in particular has noted that pitting and corrosion in their fire protection system is more prevalent on the bottom inside surface of piping where silt and organic matter has deposited. In this incidence, a chemical analysis of the corrosion product revealed the presence of sulfides (the second mechanism) which are also known to cause accelerated pitting corrosion in carbon steel piping. It was speculated that the sulfides were a result of decomposition of organic matter in the fire protection system.

Further effects of corrosion are a reduction in flow area and an increase in surface roughness, both of which restrict the flow-carrying capacity of piping. Increased surface roughness in particular may provide a more suitable surface for attachment by Corbicula larvae and provide a boundary layer which promotes the settlement of silt. Thus silting, corrosion products, and Corbicula all contribute to degraded flow conditions in the service water system.

System Redundancy and Intermittent Use

Redundant systems and systems which see intermittent use often exhibit low flow and/or stagnant conditions. Several utilities have indicated that fouling typically occurs in systems which see low flow, intermittent flow, or stagnant conditions for extended periods of time.

Redundant cooling loops are provided in the essential service water system and in some nonessential service water cooling loops to ensure continuous cooling in the event that one of the redundant coolers fails. Typical cooling loops with redundant heat exchangers are the Containment Cooling Units, Component Cooling Units, and turbine bearing lube oil coolers. Systems which see intermittent use include those which provide cooling or service water on demand only. Included in this category are containment cooling units, residual heat removal heat exchangers (or letdown coolers), and the fire protection system. Containment cooling units, for example, are only in service when the temperature inside the reactor containment vessel exceeds approximately 120°F.

Both redundant and intermittent use systems are maintained full of service water and in a standby condition. Plant technical specifications call for periodic flow testing to ensure the operability of these systems. Several utilities have increased the frequency of their flow tests after finding _Corbicula_ in systems. Although more frequent flow testing may work to flush the system of silt and small clams, it is also possible that this action could provide a more habitable environment for _Corbicula_ which are trapped in protected areas of the system. The theory behind this is that increased flow testing provides a fresh supply of food and water to the clams more frequently.

An effective means of controlling _Corbicula_ in redundant and intermittent use systems is to schedule flow tests coincident with service water chlorination periods. Thus, when flow testing is completed, the systems are returned to standby condition filled with chlorinated service water. Because service water flow bypasses systems which are in standby mode, failure to chlorinate during flow testing means that the systems which would benefit most from chlorination may never see chlorinated service water. Since finding _Corbicula_ in their redundant and intermittent use systems, several plants have implemented such schedules and have noted its success.

Valve Leaks and Valving Errors

Valve leaks are another cause of low velocity continuous flow conditions. And although from an engineering standpoint these leaks may be minor, they may also be great enough to provide clams with a continuous supply of fresh food and oxygen. _Corbicula_ cannot tolerate reduced oxygen levels (McMahon, 1979). As oxygen levels fall below saturation, oxygen uptake by _Corbicula_ rapidly decreases to approximately ten percent of that at saturation. Other factors such as the oxygen demand of bacteria and formation of corrosion products also act to reduce dissolved oxygen levels in service water. Leaking valves appear to be a primary cause of _Corbicula_ growth in redundant and intermittent use systems which are typically assumed to be ~~totally~~ stagnant.

There are two basic types of valve leaks; actual valve malfunctions, and minor leaks within the design specifications of the valve. Valve malfunctions may be corrected with increased maintenance, but design allowable leaks are a fact of life. Unlike valves in the primary reactor piping (piping which carries reactor coolant water) which are designed to provide zero flow conditions, valves in the service water system when closed may normally allow leaks of up to several gallons per minute depending on the size and use of the valve.

A factor which is related to valve leaks is valving errors. At one plant in particular the combination of an open inlet valve and a closed but leaking outlet valve allowed Corbicula and silt to deposit in the inlet waterbox of a redundant turbine bearing lube oil heat exchanger. The open inlet valve allowed silt and clams to enter the heat exchanger and settle in the waterbox. The leaking outlet valve provided a continuous flow (approximately 1 gpm) of fresh water to the clams and allowed further deposition of clams and silt. The inlet water temperature in this heat exchanger was approximately 60°F. The combination of a continuous low velocity flow of warm service water and the accumulation of silt provided ideal conditions for Corbicula growth. The heat exchanger was in this configuration for approximately nine months during which time clams and silt accumulated to a depth of three to four inches. This fouling incident was discovered during a scheduled visual inspection of the turbine bearing lube oil heat exchanger. During this inspection the online turbine bearing lube oil heat exchanger was found to be completely free of Corbicula and silt deposits. Plant personnel speculated that the weekly chlorination (thirty minutes at 1 ppm residual chlorine) was ineffective in controlling the clams which entered in the larval stage because of the protective layer of silt. The Corbicula were able to burrow into the silt to escape the chlorine.

Chlorination Effectiveness and System Reliability

Chlorination effectiveness and the reliability of chlorination systems are important factors in controling Corbicula larvae. Chlorination has been shown to be one of the most effective means of controlling Corbicula larvae (Isom, 1976). However, if chlorination is not properly scheduled or if residual chlorine levels are not high enough to kill clam larvae, Corbicula may not be kept to a nuisance level. Also, mechanically unreliable chlorination systems can effectively halt all chlorination while the system is down for repair. During this period Corbicula larvae can enter the service water system, settle in protected areas and burrow into silt deposits.

As mentioned previously, chlorination is most effective when scheduled to coincide with clam spawning seasons and flow testing or flushing. Continuous chlorination at 0.5 to 1.0 ppm residual chlorine for one or two three week periods during the spawning season is required to control clam larvae (Isom, 1976). Although dictated somewhat by environmental conditions (primarily water temperature), Corbicula spawning periods are greatest in the summer (July) and late fall (November) (Sinclair, 1963).

TVA has implemented a chlorination program which calls for continuous chlorination of essential service water systems whenever they are in service during clam spawning season. TVA studies have shown that the service water must be chlorinated to a total residual chlorine level of 0.6 to 0.8 ppm to adequately control clam larvae. The program also calls for the nonessential service water systems to be chlorinated to the same levels for two three-week periods corresponding to the beginning and end of clam spawning season. During these chlorination periods a small continuous flow of chlorinated service water is established through all main fire system headers which are normally exposed to raw service water. This ensures that when chlorination has been completed, the fire protection system will remain in standby condition, filled with chlorinated service water.

Correct measurement of residual chlorine levels is also a factor which impacts the effectiveness of a chlorination system. As mentioned previously, silt and other suspended particles in service water have a chemical demand for chlorine. This factor makes residual chlorine levels both time and space dependent. Residual chlorine levels which are measured near the point of injection will be unrealistically high in comparison to levels measured at service water components farther down stream. For this reason residual chlorine levels should be measured downstream from all components where chlorination is required.

Unreliable chlorination systems can also be a major factor in allowing larval Corbicula to become established in service water system piping. Although plant technical specifications call for chlorination at specified times during plant operation, the chlorination system is not mechanically "required" for safe operation. First-hand accounts given by utility personnel indicate that often times chlorination systems do not demand the same level of maintenance attention as do other systems which are more critical to plant operation. Thus plants have remained in operation for periods of several weeks while the chlorination system was out of service. One severe fouling incident related to chlorination system reliability, although not involving Corbicula, occurred in a salt water cooled plant. The Residual Heat Removal (RHR) heat exchangers became fouled by oysters and the severe degree of fouling was directly attributed to the chlorination system being out of service for an extended period of time.

One utility has noted a correlation between the amount of maintenance required by their diaphram type chlorination pumps and whether hypochlorite solution is injected upstream or downstream from the main service water pumps. They have noted that chlorination systems which inject hypochlorite solution downstream from the service water pumps have a higher incidence of pump diaphram failure than similar pumps in systems where hypochlorite solution is injected directly into the service water intake structure. This difference has been attributed to the fact that injection downstream of the service water pumps requires pumping against a back pressure of approximately 50 psig. This pressure, while not unusual for raw water systems, is great enough to shorten the operating life of diaphram type injection pumps.

Small Diameter Components

Corbicula fouling most often manifests itself in small diameter components in the service water and fire protection systems. One utility indicated that fouling due to Corbicula, silt, and corrosion products is most prevalent in pipes of four-inch (100-mm) and smaller diameter, with chronic fouling occurring in pipes two-inches (50-mm) and smaller diameter. An example is fouling of the three-inch supply lines to the reactor building cooling units. This utility has replaced much of its small diameter carbon steel piping with stainless steel piping. They have also replaced service water system piping less than one-inch (25-mm) in diameter with one-inch stainless steel piping.

Several utilities have indicated that heat exchangers with tube diameters of 1/2-inch (13-mm) and less foul more readily than heat exchangers with larger diameter tubes. Pump motor room coolers have frequently fouled with buildups of silt, corrosion, and Corbicula. These coolers also have supply piping which is typically less than four-inches (100-mm) in diameter.

There is some question, however, as to whether Corbicula actually settled and grown in these small diameter components or whether these are simply the locations where adult clams and clam shells have accumulated after being carried into the system. There is some evidence that as the numbers of clams in low velocity areas increases, some of the clams are forced in high flow areas and are carried through the system until they lodge in some constricted area (Mattice, 1983). Typical areas where clams are found are on heat exchanger tube sheets and behind inlet valves to intermittent use systems which are in standby mode.

NUCLEAR SAFETY IMPLICATIONS OF CORBICULA FOULING

Corbicula fouling of the essential and nonessential service water systems both directly and indirectly affects the overall safe operation of nuclear power plants. Essential service water system fouling directly impacts reactor safety because when essential cooling is interrupted during reactor shutdown, an alternate emergency cooling path must be established. Similarly, fouling of certain nonessential service water cooling loops indirectly impact reactor safety because an unscheduled reactor shutdown requires cooling from safety related essential service water cooling loops.

An example of essential service water heat exchangers which have been fouled by Corbicula and which directly impact reactor safety are the Reactor Containment Fan Coolers (sometimes called Containment Cooling Units or Reactor Building Cooling Units) which are common to all PWRs. The Reactor Containment Fan Coolers are designed to remove heat from the containment building during both normal and accident conditions. In Westinghouse PWRs there are a total of five units which operate in parallel (Masche, 1971). During normal operation a maximum of four units are required to remove the design heat load. Therefore, during normal operation one or two cooling units are in standby mode. Other PWR designs typically have four to five units with one or two of them on standby during normal operation.

During normal operation, if flow blockages due to Corbicula in the Reactor Containment Fan Coolers were severe enough that containment cooling requirements could not be met, reactor power would have to be reduced to bring the containment temperature down. During accident conditions severe fouling of the coolers would require that alternate containment cooling be established. If the internal containment temperature and pressure were to rise above allowable levels, core spray would be initiated. Although fouling of Reactor Containment Fan Coolers has not been as severe as would be required to cause core spray to initiate, it has been severe enough to require the shutdown of a nuclear plant to clean the coolers and restore them to their design capacity.

An example of nonessential service water heat exchangers which have fouled with Corbicula and have the potential to indirectly affecting reactor safety are the turbine bearing lube oil coolers. As previously described, a redundant turbine bearing lube oil cooler has fouled with Corbicula due to an open inlet valve and a closed but leaking outlet valve.

As the name implies, turbine bearing lube oil coolers provide cooling to the turbine bearing lubricating oil. Turbine bearing lube oil typically looses its lubricating ability at temperatures above 300°F. Therefore, the turbine bearing lube oil temperature is monitored and if flow blockage of the turbine bearing lube oil coolers were to cause it to exceed the allowable temperature (somewhat below the 300°F maximum), a turbine trip would be initiated. A turbine trip then initiates a reactor scram.

Upon initiation of a scram, initial reactor cooling in a PWR is achieved by dissipating heat through the steam generators and discharging steam to the condensers by means of the turbine steam bypass system. The residual heat removal system (RHR) begins removing heat from the reactor when the reactor water temperature and pressure have dropped to approximately 350°F and 400 psig, respectively. The RHR heat exchangers are cooled by the component cooling loop which is in turn cooled by the component cooling water heat exchangers. The component cooling water heat exchangers are cooled by service water and are part of the essential service water system. Therefore, although the turbine bearing lube oil coolers are not safety related, their fouling could cause a reactor shutdown which relies on safety related service water systems for cooling.

ENGINEERING RECOMMENDATIONS TO MINIMIZE CORBICULA FOULING

Although it is unreasonable to expect the total elimination of Corbicula as a fouling potential in nuclear service water systems, many actions can be taken to reduce their impact to a nuisance level. Some ~~means~~ method such as low level continuous chlorination during Corbicula spawning seasons should be used to control clam larvae. Adult Corbicula are best controlled by physically removing them by cleaning the intake structure and service water system internals.

Conditions should be avoided which lead~~ing~~ to the factors promoting Corbicula settlement and fouling which have been described above ~~should be avoided~~. In the case of redundant and intermittent use systems which must remain in standby condition during operation, chlorination should be scheduled during flow tests and visual inspections of the system internals should be performed during outages. Areas such as intake structures, heat exchanger waterboxes and other low velocity flow areas should be visually inspected for accumulations of Corbicula. During extended outages, service water cooling loops which are not required for residual reactor heat removal ~~and~~ or other essential cooling should ~~such~~ be dewatered. The service water and fire protection systems should be checked for buildups of silt and corrosion products, especially in small diameter piping. Valves which leak excessively or do not operate correctly should be maintained to avoid low velocity flow conditions due to improper valve performance. Also the chlorination system should be maintained with the same level of care as the essential service water system because it's correct operation indirectly impacts the safety related cooling functions of the essential service water system.

Finally, to have a truly effective preventive maintenance program utility personnel must be aware that Corbicula are present in the service water source and that they pose a potential threat to reactor safety and efficient plant operation as a whole. Being aware of the potential for Corbicula fouling is the first step in understanding the importance of implementing these recommendations.

LITERATURE CITED

Bacon, H.E., 1978. Corrosion. In, Mark's Standard Handbook for Mechanical Engineers, pp. 6-106 to 6-117. 8th ed. McGraw Hill, New York.

Bickel, D., 1966. Ecology of Corbicula Manilensis Phillippi in the Ohio River at Louisville, Kentucky. Sterkiana. No. 23, September 1966. pp. 19-24.

Goss, L.B. and C. Cain, 1976. Condenser and Raw Water System Fouling by Corbicula. pp. 11-22. In, L.D. Jensen (ed.), Biofouling Control Procedures. Marcel Dekker, Inc., New York.

Haried, J.A., 1982. Evaluation of Events Involving Service-Water Systems in Nuclear Power Plants, NUREG/CR-2797. U.S. Nuclear Regulatory Commission, Washington, D.C. 62 pp.

Isom, B.G., 1976. Biofouling - State-of-the-Art in Controlling Asiatic Clams (Corbicula Manilensis Philippi) and Other Nuisance Organisms at Power Plants. Unpublished manuscript. North American Benthological Society, 24th Annual Meeting, March 24-26, La Crosse, Wisconsin. 13 pp.

Masche, G., 1971. Systems Summary of a Westinghouse Pressurized Water Reactor Nuclear Power Plant. Westinghouse Nuclear Energy Systems, Pittsburgh, Pennsylvania. 238 pp.

Mattice, J.S., 1979. Interactions of Corbicula sp. with Power Plants. pp. 119-138. In, J.C. Britton, J.S. Mattice, C.E. Murphy, and L.W. Newland, (eds.), Proc., First International Corbicula Symposium. Texan Christian University Research Foundation, Fort Worth, Texas.

Mattice, J.S., and L.L. Dye, 1976. Thermal Tolerance of the Adult Asiatic Clam. pp. 130-135. In, G.W. Esch and R.W. McFarlane (eds.), Thermal Ecology II. CONF-750425. National Technical Information Service, Springfield, Virginia.

Mattice, J.S., 1983. Freshwater Macrofouling and Control with Emphasis on Corbicula. Unpublished manuscript. Paper presented at the Symposium on Condenser Macrofouling Control Technologies - The State-of-the-Art, June 1-3, 1983. Hyannis, Massachusetts. 30 pp.

McMahon, R.F., 1979. Tolerance of Aerial Exposure in the Asiatic Freshwater Clam, Corbicula fluminea (Miller). pp. 227-241. In, J.C. Britton, J.S. Mattice, C.E. Murphy and L.W. Newland, (eds.). TCU Research Foundation, Fort Worth, Texas.

Sinclair, R.M., 1963. Clam Pests in Tennessee Water Supplies. Paper presented at the Kentucky-Tennessee Section Meeting of the Tennessee Stream Pollution Control Board, Nashville, Tennessee. 8 pp.

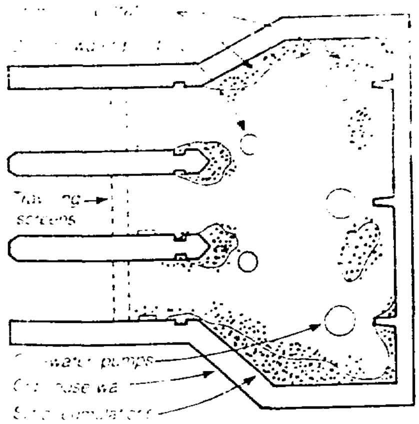

FIGURE 1. Silt and Clam Distribution in Cribhouse