United States
Environmental Protection
Agency

Industrial Environmental Research
Laboratory
Research Triangle Park NC 27711

EPA-600/7-80-026
January 1980

EPA

Assessment of Corrosion Products from Once-through Cooling Systems with Mechanical Antifouling Devices

Interagency Energy/Environment R&D Program Report

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the INTERAGENCY ENERGY-ENVIRONMENT RESEARCH AND DEVELOPMENT series. Reports in this series result from the effort funded under the 17-agency Federal Energy/Environment Research and Development Program. These studies relate to EPA's mission to protect the public health and welfare from adverse effects of pollutants associated with energy systems. The goal of the Program is to assure the rapid development of domestic energy supplies in an environmentally-compatible manner by providing the necessary environmental data and control technology. Investigations include analyses of the transport of energy-related pollutants and their health and ecological effects; assessments of, and development of, control technologies for energy systems; and integrated assessments of a wide range of energy-related environmental issues.

EPA REVIEW NOTICE

EPA-600/7-80-026
January 1980

Assessment of Corrosion Products from Once-through Cooling Systems with Mechanical Antifouling Devices

by

Charles M. Spooner

GCA/Technology Division
Burlington Road
Bedford, Massachusetts 01730

Contract No. 68-02-2607
Task No. 28
Program Element No. INE827

EPA Project Officer: Theodore G. Brna

Industrial Environmental Research Laboratory
Office of Environmental Engineering and Technology
Research Triangle Park, NC 27711

Prepared for

U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Research and Development
Washington, DC 20460

DISCLAIMER

This Final Report was furnished to the Environmental Protection Agency by GCA Corporation, GCA/Technology Division, Burlington Road, Bedford, Massachusetts, 01730, in fulfillment of Contract No. 68-02-2607, Work Assignment No. 28. The opinions, findings, and conclusions expressed are those of the author and not necessarily those of the Environmental Protection Agency. Mention of company or product names is not to be considered as an endorsement by the Environmental Protection Agency.

ABSTRACT

About 67 percent of currently operating steam electric power plants in the United States use once-through cooling systems. Corrosion and biofouling severely reduce the thermal efficiency of heat exchange in the condenser tubes so that various cleaning mechanisms are in use. Once-through systems are cleaned chemically or by manual or on-line mechanical methods.

The U.S. Environmental Protection Agency is concerned that the use of on-line mechanical cleaning methods may lead to increased levels of metals in the effluent due to abrasion of the condenser tubes. This project estimates the significance of this effect based on comments from utilities experienced with the Amertap system and from the manufacturer.

The industry generally does not keep a close account of the causes and magnitude of condenser tube corrosion; however, based on observations offered by the utilities, the Amertap and other systems do not appear to contribute to loss of metal through abrasion in any measurable way. No sufficiently accurate data are available demonstrating that elevated metal levels exist in cooling water effluent over those in the intake water. Recommendations to evaluate this problem more fully are made.

This report was submitted in fulfillment of Contract No. 68-02-2607 by GCA/Technology Division under the sponsorship of the U.S. Environmental Protection Agency. This final report covers the period January 15, 1979 to December 21, 1979, and work was completed on December 31, 1979.

CONTENTS

Abstract. iii
Figures v
Tables. v
List of Conversions from English to SI Units. vi
Acknowledgment. vii

1. Introduction. 1
Chemical Cleaning. 1
Manual Cleaning. 3
On-line Mechanical Cleaning. 4
Purpose and Arrangement of Report. 7
2. Conclusions and Recommendations 12
3. Condenser Tube Construction and Its Fouling 14
Condenser Tube Materials 14
Condenser Tube Fouling 17
4. Economics of Continual Mechanical Cleaning. 18

References 25
Appendices

A. Amertap - Condenser Tube Cleaning Systems in the United States 26
B. Utility Responses to Information Request. 34

FIGURES

Number		Page
1	Distribution of chemicals added to once-through cooling water systems in Maryland	2
2	Increase in generating costs as tube cleanliness decreases	3
3	Schematic arrangement of Amertap tube cleaning system	5
4	Schematic of M.A.N. system reverse flow piping	6

TABLES

Number		Page
1	Power Plants Which Have Replaced Condenser Tubes After Installing Amertap Systems	9
2	Distribution of Replaced Condenser Tubes by Cooling Water Source and Condenser Tube Material (Number of Installations).	9
3	Questionnaire Recipients	10
4	Distribution of Condenser Tube Construction Materials Among Electric Utilities Using the Amertap System	14
5	Distribution of Alloys, Once-Through Systems, Amertap-Equipped	15
6	Condenser Tube Materials for all Electric Utility Units Using the Amertap System	16
7	Typical Amertap System Costs (in 1979 Dollars)	23
8	Effect of Amertap System on Electricity Costs	24
B-1	Utility Responses to Information Request on Amertap Performance	36
B-2	Water Quality Data for Utility Number 4	39
B-3	Water Quality Data for Utility Number 5	40

LIST OF CONVERSIONS FROM ENGLISH TO SI UNITS

TO CONVERT	INTO	MULTIPLY BY
gallons/day	cubic meters/day	0.003785
tons (short)	tonnes (metric)	0.9078
gallons/minute	liters/second	0.06308
feet/second	meters/second	0.3048

ACKNOWLEDGEMENT

The author acknowledges the significant contributions of Mr. David W. Bearg and Mr. Robert J. Bouchard of GCA/Technology Division for their contributions. Thanks are due Mr. Paul W. LaShoto (GCA/Technology Division) for the economic analysis of Section 4.

The advice of Dr. Theodore G. Brna, EPA Project Officer, Emissions/Effluent Technology Branch, is sincerely appreciated.

SECTION 1

INTRODUCTION

In the United States about 67 percent of currently operating steam electric power plants use once-through cooling systems. Flows through these systems dominate the discharge from each facility and, furthermore, these once-through systems used by the electric utility industry lead to discharges of greater volume than seen in nearly any other industry. Flow rates range typically from 500,000 to 700,000 gallons per day per megawatt (electric)[1] or gal/day-MW(e).*

The U.S. Environmental Protection Agency is concerned that the use of mechanical cleaning systems to remove corrosion scale and/or algal growth will introduce significant quantities of metals into the effluent from electric generating plants using once-through cooling systems. The objective of this project is to estimate the magnitude of metal discharge from the abrasion of condenser tubes based on weight loss over the service life of the tubes.

Uninhibited biological growth inside condenser tubes leads to serious heat exchange impairment, excessive tube blockage and accelerated metal corrosion. These problems result in substantial reduction in power output, the derating of the plant, and ultimately, the need for makeup electric power.

There are three fundamental approaches to the control of condenser tube fouling:

- Chemical cleaning
- Manual cleaning
- On-line mechanical cleaning

All three of these techniques apply to once-through cooling systems; however, they are used also in closed systems. Condenser tube fouling in closed cooling systems is generally controlled by continuous use of a biocide. Manual and mechanical cleaning would be applied during system shutdown for maintenance.

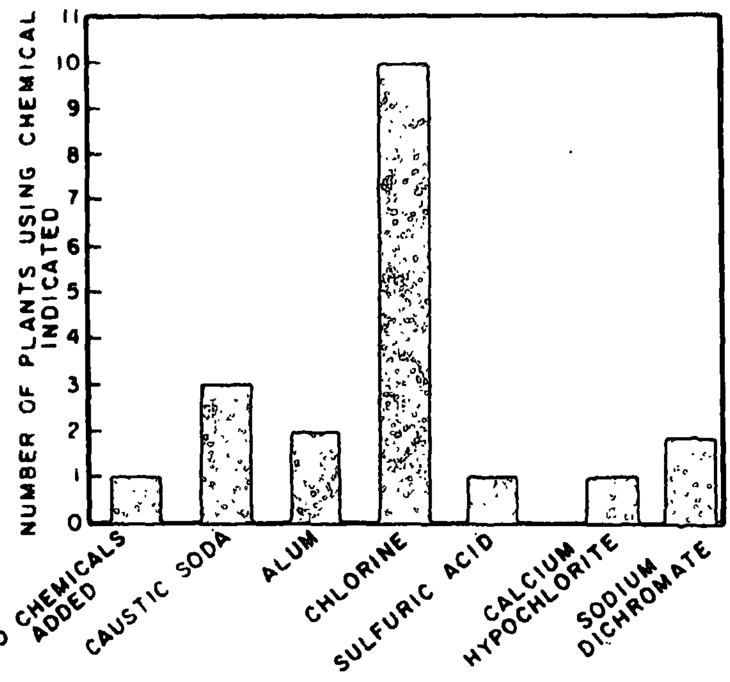
CHEMICAL CLEANING

On-line chemical cleaning involves the use of biocides and corrosion inhibitors to maintain clean surfaces. While chlorine is the most commonly used,

---

*English rather than metric units are used in this report since this is the practice within the industry. A list of English to SI conversion factors is given on page vi of this report.

other chemicals used include caustic soda, alum, sodium dichromate, sulfuric acid, calcium hypochlorite, phosphate, and lime. Figure 1 shows the distribution of chemicals added to once-through cooling water systems as reported in a study of Maryland power plants.[2]



Source: Reference 3, page 38.

Figure 1. Distribution of chemicals added to once-through cooling water systems in Maryland.

Chlorination for biocidal control is both a highly effective and less expensive control method than more complex chemical formulations. Chlorine usage nationwide for the steam electric utility industry is estimated at an average of 0.1 ton/year-MW.[3]

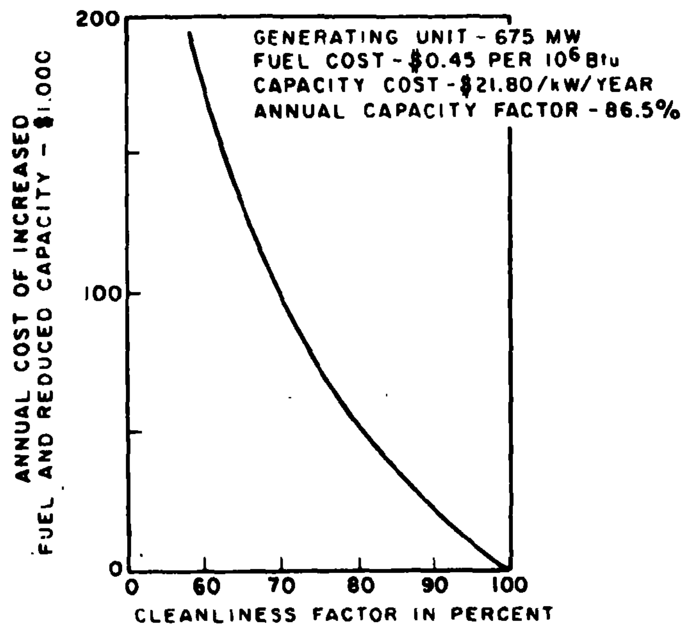
The use of chemicals, and particularly chlorine, is a matter of concern because either the chemicals themselves or their products of reaction are highly toxic to the aquatic ecosystem. Chlorine is added to the system at or near the inlet of the condenser in sufficient quantity to produce a free available chlorine level of 0.1 to 0.6 mg/l in the discharge. The amount and frequency of chlorine addition is a function of biological growth in the tubes and of the chemical chlorine demand by ammonia and other chemical species in the water. The efficacy is reduced when the chlorine is in a combined state, such as occurs when chlorine and ammonia react to form chloramines. On the other hand, discharge of residual free chlorine is discouraged because of the potential production of highly toxic chlorinated hydrocarbons in the receiving waters.

MANUAL CLEANING

Manual cleaning, performed while the condenser is off-line, uses high pressure water or air combined with various types of plugs, scrapers or brushes. Off-line chemical cleaning and descaling are also considered manual approaches.

The main drawback in any manual cleaning system is the requirement that the unit be shut down during the cleaning process. Utilities, therefore, have divided their condensers into smaller subunits, allowing only a portion of the condenser tube system to be removed from service during reduced load periods, eliminating the need for a complete shutdown.

The manual cleaning process itself tends to be inefficient since the average cleanliness factor* between cleanings is relatively low compared with the other two methods and because the procedure is highly labor intensive. As tube cleanliness decreases, condenser backpressure increases, causing the turbine heat rate to increase and generating capability to decrease. Figure 2 shows this relationship for a 675 MW power plant. Additional detail on the relationship between condenser cleanliness factors and operating costs is provided in Section 4.



Source: Reference 2, page 277.

Figure 2. Increase in generating costs as tube cleanliness decreases.

*The cleanliness factor is widely used in the electric utility industry where large heat exchangers are used to express the relative (percentage) loss in heat transfer rate relative to the clean heat transfer rate (100 percent).

In the interests of economy, electric utilities have attempted to reduce the number of maintenance workers at power plants; however, as the number of workers has declined, hourly wages have risen to offset any savings. The number of tubes in the average condenser has also increased. It has been estimated that in 1963 the average utility condenser contained 10,000 tubes and that in 1973 the average condenser contained approximately 40,000 tubes. As larger plants come into service, the number of tubes will continue to rise.

The work required to clean the tubes manually is difficult, hot, dirty and wet. Also, because it must be done during periods of reduced demand, manual cleaning is generally done at night or on weekends. Furthermore, at nuclear units, workers may be exposed to some slight amount of radioactivity. Consequently, manual cleaning is not viewed as being particularly desirable by workers or by management.

ON-LINE MECHANICAL CLEANING

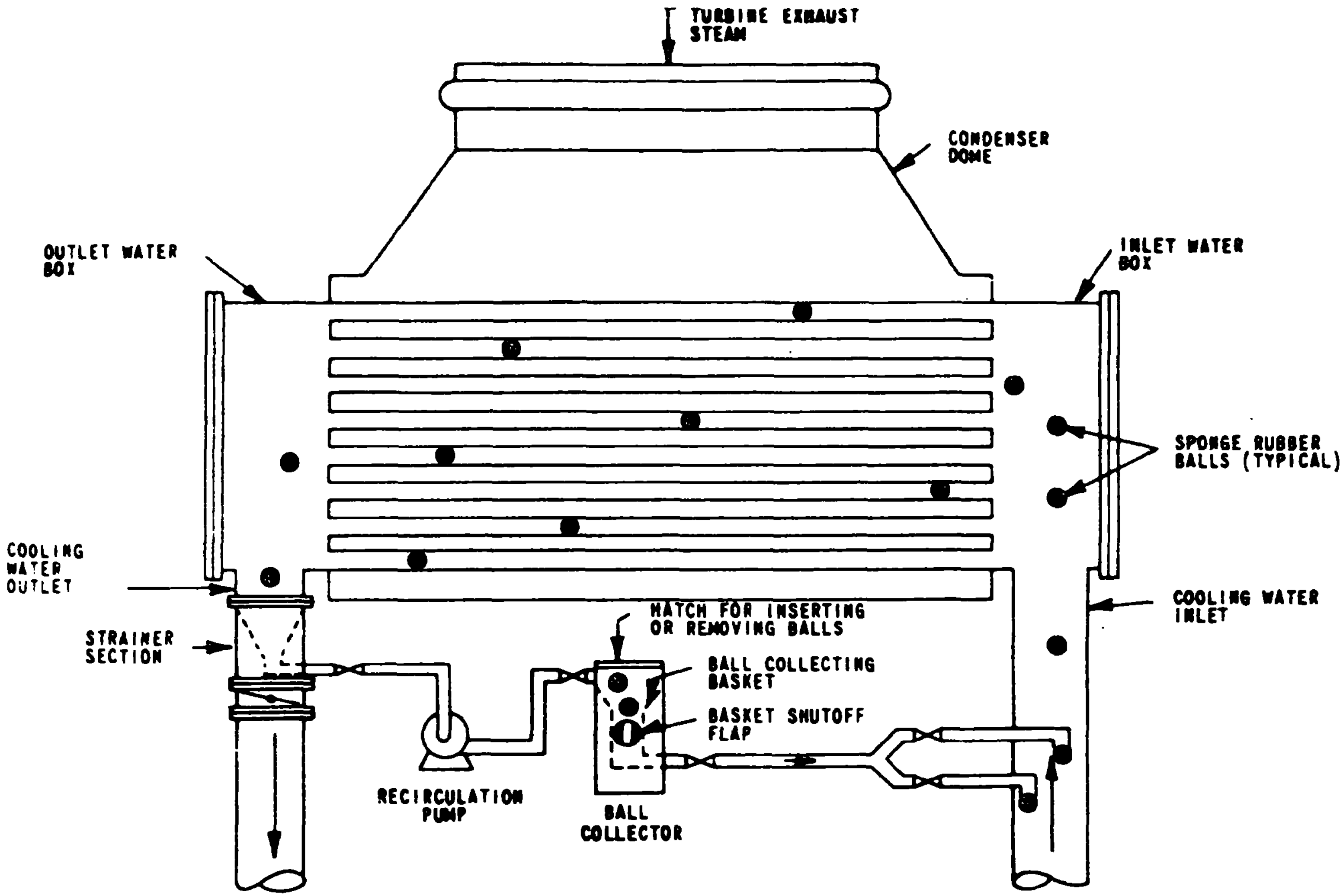
Equipment for automatic on-line mechanical cleaning of condenser tubes is manufactured primarily by two companies. One, the Amertap Corporation of Mineola, New York, uses a system for recirculating sponge balls through the condenser tubes (Figure 3). The other, the M.A.N. Corporation of West Germany, utilizes a brush and cage system (Figure 4). Each system maintains on-line condenser tube cleanliness during normal operation of the plant by mechanical abrasion rather than through a chemical effect. Of the two, Amertap has been the more popular in the United States. About 200 Amertap on-line cleaning systems are either in use or on order for utilities in this country.

Amertap Sponge Ball System

The basic principle of the Amertap system is to circulate slightly oversized sponge rubber balls with the cooling water through the condenser system. The balls are forced through the tubes by the pressure differential created across a ball upon entering a tube. After traveling through the length of the tubes, the balls are collected in a basket at the discharge end. From the collection basket the balls are continually pumped to the inlet for recirculation. An schematic diagram of the Amertap system is shown in Figure 3 (see also Appendix A).

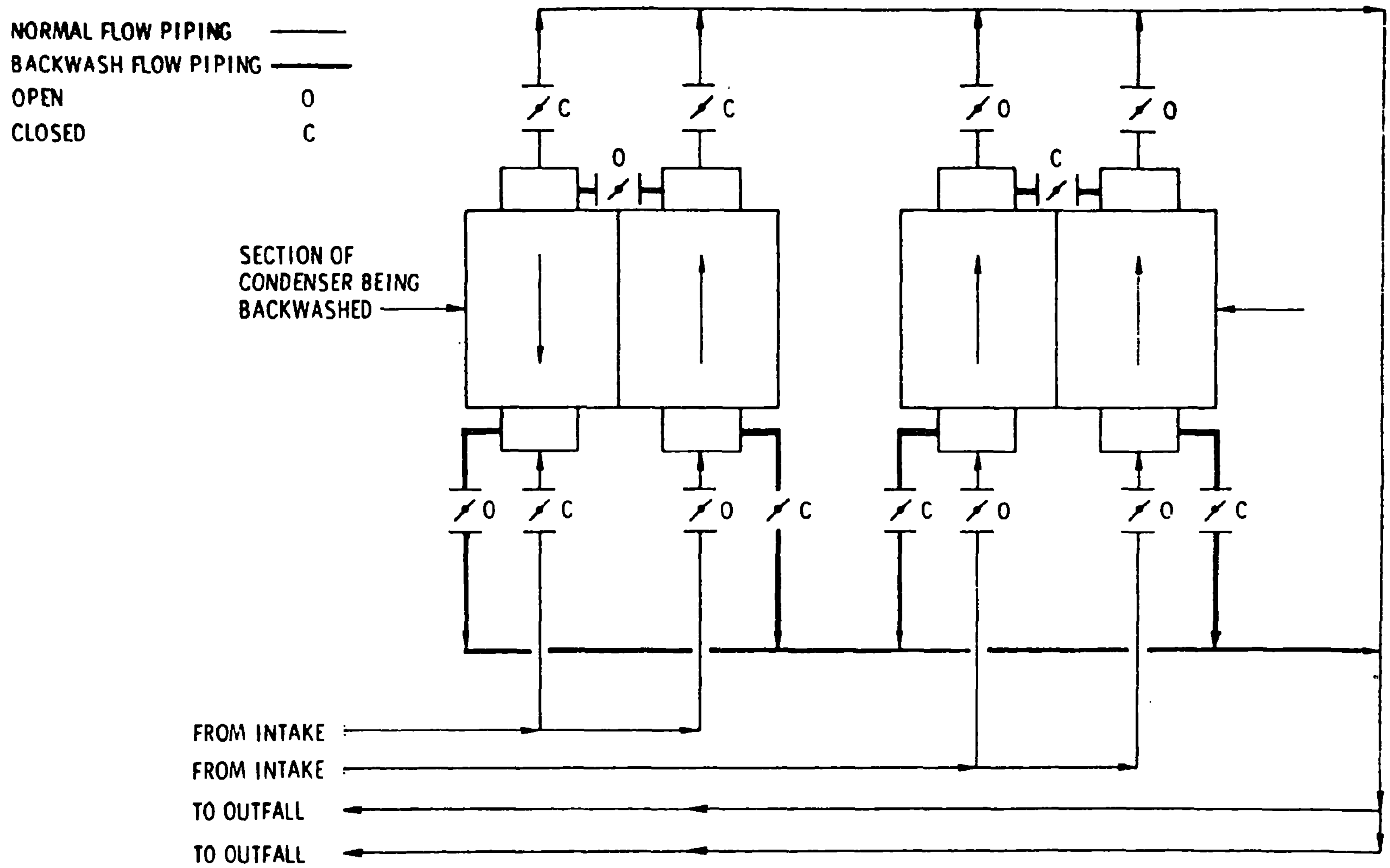
The Amertap sponge balls are nearly the same density as the water and, after being injected into the cooling water system, distribute themselves randomly throughout the waterboxes. The number of balls in the system is approximately 10 percent of the number of tubes in the condenser, and the system is designed so that each ball has a normal circulation time of 20 to 30 seconds. Consequently, each tube is polished approximately every 5 minutes.

The constant rubbing action of the balls cleans the inner walls by wiping away deposits, scale and biological fouling. Any tube that becomes partially blocked at the entrance or within its length, however, will not be unblocked by the balls. Their effectiveness lies in removing soft chemical precipitates, scale or slimes before they become fixed in place. Since the balls are porous, a certain amount of water flows through the balls and loosens any accumulated deposits on the ball surface.



Source: Reference 3, page 32.

Figure 3. Schematic arrangement of Amertap tube cleaning system.



Source: Reference 3, page 34.

Figure 4. Schematic of M.A.N. system reverse flow piping.

Two types of sponge balls are used in the Amertap system: regular sponge balls and abrasive-coated sponge balls. The regular balls are used to maintain tube cleanliness and are used during normal operation. The abrasive-coated balls are to be used only when old deposits need to be removed by scouring, primarily following plant shutdowns.

The M.A.N. Brush and Cage System

The M.A.N. system uses an individual titanium wire brush about 50 mm long for each condenser tube. The outlet end of each condenser tube is fitted with a small plastic cage where the brush remains between cleaning cycles. When the cooling water flow is reversed, all brushes in the condenser are forced through the tubes to plastic cages at what was formerly the inlet end of the tube. Returning the cooling water flow to its normal direction forces the brushes back to their resting position at the outlet end of the condenser tubes. As with the Amertap system, the rubbing action cleans inner tube walls by wiping away deposits. A schematic diagram of the reverse flow piping arrangement of the M.A.N. system is shown in Figure 4.

The plastic cage length is about 75 mm. To attach the plastic cage to the tube ends, the tube ends have to extend 10 mm beyond the tube sheet. Therefore, inlet tube ends have to be straight instead of flared as is the usual practice to avoid inlet end erosion.

To use the system successfully, there must be a capability to reverse the cooling water flow direction with whatever frequency of reversal is desired. In practice, valves are timed to cycle through a flow reversal and return at an assigned frequency. Twice daily is normal. This requirement for the provision of a routine flow reversal is the major reason for the lack of interest in the M.A.N. system.

Various metals are expected to be contained in the cooling water discharge, the species and concentration depending upon inlet water quality, the composition of the condenser tube alloy and its rate of corrosion or erosion. Highly polished, clean condenser tube surfaces are less susceptible to corrosion and erosion than those that are fouled. However, there remains some question whether the maintenance of a highly cleaned surface leads to elevated metal levels in the cooling water due to abrasion.

PURPOSE AND ARRANGEMENT OF REPORT

This report reviews what little data are available on the abrasion potential of the Amertap system and its potential effect on water quality. Numerous telephone interviews and a letter-questionnaire sent to selected equipment suppliers and electric utilities using the Amertap system form the basis of our conclusions since this system is the most widely used in this country. Of 10 questionnaires sent, 6 responses were received from the above sources. Initially, it was hoped that the utilities would have records detailing installed and end-of-service weights for condenser tubes. Apparently this information is of little use considering the effort required to obtain it. Even in terms of scrap value, the utility is apparently credited for the initially installed weight of the condenser tube assembly rather than its weight at the time of removal and replacement. Lacking precise measurements of inlet and outlet trace element chemistry, the probable discharge levels and rates of wear on condenser tubes either with or without the Amertap system cannot be estimated with any certainty.

In an attempt to determine the extent of any corrosion problem posed by use of mechanical cleaning systems, a survey was proposed. Power plants that used mechanical cleaning systems and had, for one reason or another, been forced to replace their condenser tubes would first be identified, then contacted. These candidate plants were pared down to a reasonable number for a quick survey to gather information on unit operating histories. Perhaps the data on which most emphasis was placed were the weights of condenser tubing at purchase and at removal, the difference in weights indicating the amount of corrosion.

Unfortunately, the survey had a number of problems conceptually. Determining the amount of corrosion that had occurred in the mechanically-cleaned system was, in and of itself, irrelevant without comparison to some control condenser subject to identical water quality and flow rates. Certainly some corrosion would occur in the control; the incremental increase in corrosion due to the use of an Amertap system as well as the percentage of increase in corrosion are of interest, not the absolute amount.

In any case, those power plants that had replaced condenser tubes since putting an Amertap system into operation were identified. A total of 85 plants with 198 separate Amertap systems were contacted; the condenser tubes at 10 of the Amertap installations had been replaced. These plants are listed in Table 1.

Clearly, data gathered at some of these plants were not particularly useful. For Pennsylvania Electric's Seward Plant, Consolidated Edison's Arthur Kill No. 2, and both Monongahela Power plants, the Amertap system was in use for only a portion of the time the condenser tubes had been used. It would be impossible to allocate the corrosion into two categories, that which occurred before Amertap and that which took place after Amertap; yet, this would be particularly useful.

Table 2 provides a description of the condenser tubes replaced, characterized by water source and by tube material. This distribution can be compared with Table 4 which describes the distribution of all operating Amertap systems by the same parameters. Some interesting comparisons are possible.

For example, although only 11 percent of all Amertap systems are used to clean copper-nickel condenser tubes, 55 percent of the condenser tubes replaced after installation of an Amertap system were copper-nickel alloy which may indicate that on-line mechanical cleaning is inappropriate. Similarly, although over 50 percent of the Amertap installations clean stainless steel tubes, no stainless tubes have been replaced after installation of an Amertap system.

TABLE 1. POWER PLANTS WHICH HAVE REPLACED CONDENSER TUBES AFTER INSTALLING AMERTAP SYSTEMS

Company	Plant	Condenser tube	Years of use*
Pennsylvania Electric	Seward		
	No. 5	Admiralty	13½/4½
Consolidated Edison	Arthur Kill		
	No. 2	Aluminum-bronze	8/4
	No. 3	Aluminum-brass	4
Los Angeles Department of Water and Power	Haynes Station		
	No. 1	70/30 Copper-nickel	1
Monongahela Power	Albright		
	No. 3	Admiralty	15/4
	Rivesville		
	No. 5	Admiralty	21/10
Potomac Electric	Morgantown		
	No. 1	70/30 Copper-nickel	5
	No. 2	70/30 Copper-nickel	4
Narragansett Electric	Manchester St.	Copper-nickel	-
	South St.	Copper-nickel	-

*Where two figures are given, the first refers to the age of the tubes, the second to the age of the Amertap system, both at the time of tube replacement.

TABLE 2. DISTRIBUTION OF REPLACED CONDENSER TUBES BY COOLING WATER SOURCE AND CONDENSER TUBE MATERIAL (NUMBER OF INSTALLATIONS)

Alloy	Once-through cooling				Recirculation cooling		Total by condenser tube material
	Ocean	Estuary	River	Lake	Cooling pond	Cooling tower	
Stainless Steel	-	-	-	-	-	-	-
Admiralty Brass	-	-	3	-	-	-	3
Copper-Nickel (70/30 & 90/10)	1	3	2	-	-	-	6
Aluminum Brass	-	2	-	-	-	-	2
Titanium	-	-	-	-	-	-	-
Arsenical Copper	-	-	-	-	-	-	-
Arsenical Aluminum	-	-	-	-	-	-	-
Total by cooling water source	1	5	5	-	-	-	11

However, the sample set considered is extremely small. Based on less than a dozen locations that have replaced condenser tubes after operating with the Amertap system, these observations must be considered statistically insignificant. Other factors, not evident in this cursory review, undoubtedly contribute to the rate of corrosion. Water quality, operating procedures, and chlorination practices are examples of parameters that can affect corrosion to some extent. These factors must be considered before making any judgment as to the role of the Amertap system in condenser tube corrosion.

TABLE 3. QUESTIONNAIRE RECIPIENTS

Recipient	Response received
Consolidated Edison	Yes
Duke Power Company	No
Long Island Lighting Company	Yes
Los Angeles Department of Water and Power	No
Mississippi Power Company	No
Monongahela Power Company	Yes
Narragansett Electric Company	No
Pennsylvania Electric Company	Yes
Potomac Electric Power	Yes
Tennessee Valley Authority	Yes

To develop the data necessary to assess the effects of Amertap operation on corrosion, a questionnaire was proposed and mailed to 10 companies, listed in Table 3.

The questionnaire consisted of a request for the following information for each unit equipped with an Amertap system:

1. The date the turbine went commercial, average load factor, and MW rating
2. The date the Amertap system was operational
3. The condenser tube material
4. The quantity of cooling water in gal/min, and the linear velocity of water through the tubes (ft/sec)
5. The range of surface temperatures of the tubes
6. The frequency of Amertap usage for both sponge rubber and abrasive balls

7. The type and frequency of other condenser tube cleaning programs used before or after the mechanical cleaning system installation

8. A description of chlorination practices including duration, dosage, and frequency as well as annual chlorine usage for the year prior to and the year immediately after the installation of the Amertap system

9. Any analytical data on metals emitted from the cooling water system

10. Any available data on increased plant efficiency related to operation of Amertap system

11. Any available water quality data of the intake water

12. The cost of the Amertap system (capital, operating, and maintenance).

Response to the questionnaire was, at best, mixed: six companies responded in some form, although the quality and completeness of the responses varied widely. Companies that did not respond to the data request within a reasonable length of time were given up to three follow-up phone calls to request cooperation. In some cases the phone calls were effective in stimulating a reply; in four cases, each of which received the maximum three follow-up calls over a 2-month period, no reply was ever received. Information obtained from the utilities is presented, in summary form, in Appendix B.

In no case were original tube weights and tube weights on removal available. An informal telephone survey of New England utilities revealed that although the sale of scrap metals including corroded condenser tubes is common practice, the process is not as formalized as had been hoped. Scrap metal accumulated during normal plant operations is sold for salvage, but no attempt is made to differentiate condenser tubing from other metals as, for example, old chain link fence. When the pile of scrap gets large enough, scrap metal buyers will be invited to bid. As a rule the utility will not weigh the scrap before sale, and utility representatives felt that although the buyer may weigh his purchase, no attempt is made to categorize the scrap by original use.

Some scrap is sold on the basis of original or estimated weight. These methods do not expressly consider any effects of corrosion that may have occurred during use.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

A carefully designed study to investigate metal levels in once-through cooling water discharge has not been undertaken to our knowledge. Based on our review of the scanty literature available and from the more revealing information provided by the electric utility industry (1) it appears that corrosion due to abrasion is not a significant problem; moreover (2) there are indications that the use of an abrasion system for condenser tube cleaning ultimately leads to lower releases of metals to the discharge in that the highly corrosive conditions developing locally with extensive biofouling are eliminated. This observation is supported in the responses to the questionnaire and letter surveys regarding the exact nature of condenser tube failure. Local corrosion or pitting occurs at foci of structural weakness, such as at welded seams or as a result of the localized corrosion cells. The more or less uniform removal of the metal that would be expected if abrasive sponge balls do indeed remove metal is not reported.

The operation of electric generating units presents a unique difficulty in assessing by analytical chemistry the possible significance of metals discharged. The extremely large volumes of water discharged and the very low concentrations of metal contaminants make it difficult to distinguish pollution from background. The use of published average metal concentrations for seawater is not appropriate for power plants drawing water from estuarine and surface waters. The true value can be estimated only through repeated sampling of the water at the intake and discharge.

Analytical techniques, such as neutron activation analysis and atomic absorption spectroscopy coupled with extractive chemistry, are sufficiently well developed and sensitive enough to detect the metals of interest in the waste stream. The problem, however, is one of interpreting the analysis with respect to metals due to natural levels in the water feed and that added from mechanical abrasion. The natural variability in composition of the intake water is of the same magnitude as the variation anticipated from abrasion. In addition, there are other sources of metal discharges from the condenser tubes due to local corrosion effects which are more a function of chemistry of metal-water interactions than to effects of mechanical abrasion. Finally, a basic difficulty in planning a sampling program rests with the necessarily short sampling times which are inadequate for the characterization of the low concentrations of metals released over a period of tens of years.

Evaluation of the degree of metal removal by the processes discussed above might also be accomplished through controlled experiments at the bench, or preferably, at the pilot scale.

SECTION 3

CONDENSER TUBE CONSTRUCTION AND ITS FOULING

CONDENSER TUBE MATERIALS

As stated previously, about 67 percent of the currently operating steam electric plants in this country have once-through cooling systems. The large surface area required for efficient heat transfer in the condenser is provided by arrays of tubes, numbering from 5,000 to 50,000 per installation, 7/8 to 1 inch O.D. and from 20 to 60 feet in length. The tubes may be contained in one or as many as six shells, depending on their size and number.

The selection of condenser tube material for a given installation will depend on the anticipated corrosion potential of the cooling water source and other conditions of service. Tube materials may be stainless steel (e.g., 304 or 316), brass alloys (e.g., admiralty brass and aluminum brass), aluminum bronze, arsenical copper, or 90/10 or 70/30 copper-nickel.

The distribution of condenser tube materials for the 152 Amertap installations currently reported to be in service is shown in Table 4.

TABLE 4. DISTRIBUTION OF CONDENSER TUBE CONSTRUCTION MATERIALS AMONG ELECTRIC UTILITIES USING THE AMERTAP SYSTEM

Alloy	Number	Percent of total
Stainless Steel	78	51
Admiralty Brass	33	22
Copper-Nickel (70/30 & 90/10)	17.5*	11
Aluminum Brass	11	7
Titanium	7.5*	5
Arsenical Copper	4	3
Arsenical Aluminum	1	1
Total	152	100

*One condenser with two different shells.

Restricting the population of Amertap installations to include only the 85 once-through cooling situations, the distribution becomes (Table 5):

TABLE 5. DISTRIBUTION OF ALLOYS, ONCE-THROUGH SYSTEMS, AMERTAP-EQUIPPED

Alloy	Number	Percent of use
Stainless Steels	36	42
Admiralty Brass	14	16
Copper-Nickel (70/30 & 90/10)	12.5*	15
Aluminum Brass	11	13
Titanium	7.5*	9
Arsenical Copper	3	4
Arsenical Aluminum	1	1
Total	85	100

*One condenser with two different shells.

The selection of condenser tube material by source of water supply is given in Table 6. Clustering in this table indicates differences in tube material selections for saltwater and freshwater supplies.

Stainless Steel

The alloys of stainless steel in use as condenser tubes are Types 304 and 316. The nominal composition of these two alloys is as follows:

- AISI Type 304: 19 percent Chromium, 10 percent Nickel, and 71 percent Iron
- AISI Type 316: 17 percent Chromium, 12 percent Nickel, 2-1/2 percent Molybdenum, and 68-1/2 percent Iron.

These alloys exhibit high resistance to corrosion. The stainless steels owe their unusual corrosion resistance to a condition know as "passivity," believed by most investigators to result from the presence of thin films of oxide on the surface of the metal. Passivity exerts a greater influence on the resistance of stainless steel to corrosion than on resistance of most other commonly used metals and alloys. This "passive film," stabilized by chromium, is considered to be continuous, nonporous, insoluble, and self-healing. If broken, the film will repair itself when reexposed to a suitable oxiding agent. Stainless steels are best employed under fully aerated (oxidizing) conditions so as to favor the passive state. In addition, the

TABLE 6. CONDENSER TUBE MATERIALS FOR ALL ELECTRIC UTILITY UNITS USING THE AMERTAP SYSTEM

	Ocean	Estuary	River	Lake	Manmade lake or cooling pond	Cooling tower	Total by condenser tube material
Stainless Steel	-	1	33	2	8	34	78
Admiralty Brass	-	-	12	2	4	15	33
Copper Nickel (70/30 & 90/10)	3.5	7*	2	-	1	4	17.5
Aluminum Brass	7	4	-	-	-	-	11
Titanium	0.5	7	-	-	-	-	7.5
Arsenical Copper	-	-	3			1	4
Arsenical Aluminum	-	1	-	-	-	-	1
Total - by cooling water source	11	20	50	4	13	54	152
	85				67		

*Includes one unit on ship channel.

Source: Amertap Corporation (Appendix A).

alloy surface should always be kept clean and free of surface contamination. Otherwise differential aeration or concentration cells are set up which cause pitting and localized rusting.

All types of stainless steel are likely to pit or groove in seawater. The stainless alloys as a group are far more susceptible to localized attack than the copper-base and nickel-base alloys. This effect is noticeable in the very limited use of stainless steel condenser tubes in ocean and estuarine applications. The one estuarine installation listed in Table 6 uses Type 316 stainless steel. The presence of molybdenum in this alloy greatly improves its resistance to pitting in seawater. In fact, this Amertap installation has been in service with the same condenser tubes for approximately 11 years.

In all of the Amertap installations with stainless steel condenser tubes reviewed in this study, there have been no tube replacements or any other indication that the use of a mechanical cleaning system on stainless steel condenser tubes increases the potential for metal removal from the tubes. On the contrary, since stainless steel is highly susceptible to attack under anoxic conditions where oxygen cannot reach the surface of the metal, the use of an Amertap cleaning system should reduce the potential for corrosion with the attendant release of corrosion products. Recommendations to insure satisfactory service life stress the surface condition required of the steel. Smooth surfaces, which are free from defects, all traces of scale, and other foreign material reduce the probability of corrosion. Generally, a highly polished surface has greater resistance to corrosion.

Brasses and Bronzes

Brasses are all basically binary alloys of copper and zinc; however, ternary, quaternary and higher systems containing lead and other elements have been developed for specific purposes. Admiralty brass, for example, has excellent corrosion-resistant properties and is widely used for condenser tubing where fresh, brackish, or acid mine waters serve as water sources.[5]

CONDENSER TUBE FOULING

The probability and nature of condenser tube fouling is, in part, a function of quality of the feed cooling water. High total suspended solids (TSS) will lead to pitting and erosion of individual tubes. This action is seldom uniform along the length of a tube but concentrates at points of higher velocity due to constrictions or irregularities. This type of failure is seen at the point of welding of the tube to the tube sheet.

The general nature of chemical attack by dissolved species in sea and brackish water has been described elsewhere.[6] Estimation of concentrations of chemical species from published values is not sufficiently accurate for the purposes here, however. The concentrations, and particularly concentration ratios, of major chemical species in seawater are remarkably constant. Dilution effects because of mixing with freshwater in estuaries and along the coast generally require, at least, that a salinity measurement be made to reference the value obtained with Standard Sea Water. A single source of analytical data[7] gave a value of 20 ppb for copper with the datum taken from literature values.

SECTION 4

ECONOMICS OF CONTINUAL MECHANICAL CLEANING

Condenser tubes and other pieces of heat exchange equipment operate more efficiently and more economically when kept clean. Biofouling, scale-formation, and corrosion are impediments to heat transfer; consequently, an improperly maintained condenser tube will be unable to effect the transfer of as much heat as a clean tube. To effect the same heat transfer in an unclean tube, the temperature difference between the fluid in the tube and that outside the tube must increase. As tube cleanliness decreases, condenser pressure increases causing the turbine heat rate to increase and generating capability to decrease. Correcting these process inefficiencies can have considerable associated benefits.

However, the benefits arising from enhanced operating efficiency are not attained without cost since all methods of condenser cleaning have some associated expense. For each, there is a cleanliness factor at which the costs of cleaning are offset by the benefits of enhanced heat transfer. The cleanliness factor serves as an adjustment to the overall heat transfer coefficient in thermodynamic computations, correcting for impediments to heat transfer under actual conditions.

If cleaning operations are costly, the cleanliness factor will be allowed to deteriorate significantly before cleaning. Conversely, if the operation is relatively inexpensive, tube cleanliness will be permitted to decline only slightly before cleaning begins. Conceptually, once installed, the Amertap system is so inexpensive to operate that it is allowed to clean continually to prevent even the slightest degradation.

One evaluation technique for reviewing the performance benefits of an Amertap system is to compare the capital, operating and maintenance costs with the savings attributable to the increased cleanliness factor of the condenser tubes.

The projected economics for this type of analysis were performed by Southern Services, Incorporated for Alabama Power's new 818 MW Miller steam electric generating station, Unit 1.[8]

Capital costs for the Amertap system were annualized using a 15 percent capitalization factor, consistent with the assumption of a 30-year plant life and Alabama Power's costs of capital at the time of the computation. Operating costs were estimated based on an average plant load factor of 58 percent.

No maintenance labor costs were attributed to the Amertap system since no additional workers would be required if an Amertap were installed instead of a conventional cleaning apparatus.

Annual costs were estimated as follows:

1.	Installed cost	$150,000
2.	Cost of additional power to compensate for increased pressure drop by strainers required to keep debris out of the condenser	44,000
3.	Cost of additional power to pump recirculating balls	18,000
4.	Cost of replacement balls	63,000
	Total annual cost	$275,000

The benefits attributable to the operation of the Amertap system are derived from the assumption that the tube cleanliness factor will be maintained at 92.5 percent relative to the industry standard of 85 percent. This 7.5 percent increase in cleanliness can be considered conservative since 85 percent cleanliness cannot be relied upon in uncleaned tubes.

The analysis performed by Southern Services applied this improved cleanliness to determine the extent to which heat transfer characteristics were improved and to estimate the reduction in turbine back pressure. This resulted in a projected annual heat rate savings of $369,060 and a capacity savings of $62,000, equivalent to an annual capacity saving of $9,300, so that the projected total annual savings is $378,360. Subtracting the projected costs from the estimated benefits yielded an annual net savings of $103,360. Any increases in the real dollar cost of fuel will translate directly to increased savings.

This incremental analysis considers the worst case. The increase in cleanliness is due to the use of the Amertap system. Consequently, any heat rate savings should be credited to the mechanical cleaning system. However, costs atributable to the Amertap system in this analysis should include only incremental costs to be incurred over and above the costs of conventional cleaning since those dollars would have to be expended merely to maintain an 85 percent cleanliness factor. Thus, a more detailed analysis of all cost elements would be expected to show a lower Amertap cost and a higher net saving. Most industry analyses of changes to operating systems are performed in this manner. Sunk costs or costs of existing procedures are neglected and only those costs or benefits occurring at the margin are considered.

Florida Power and Light Company[9] estimates that it is saving approximately $2 million annually at Turkey Point nuclear plant Unit 3 with an Amertap system. Unlike earlier studies which tended to be somewhat cavalier and hazy about results, rising fuel costs have caused greater emphasis to be placed on fuel saving based on a careful recordkeeping in recent years. As a result, much of the data reported by Florida Power and Light are hard data, rather than estimates or approximations.

The performance of Unit 3 was monitored closely in 1977 and 1978. Actual turbine backpressures were recorded for comparison with the backpressures which would be expected for given inlet temperatures and pressures with a clean condenser. A loss of efficiency due to dirty condenser tubes shows up when the actual backpressure is higher than expected. During 1977, the condensers' loss in efficiency and consequent increase in heat rate caused average losses in unit output equivalent to $2.4 million. Similar calculations for 1978 with a continuous cleaning system installed showed a loss in MWh cost of only $455,000. Thus, the Amertap system saved approximately $2 million dollars, less the capital and operating costs of the system itself.

Unit 4 at Turkey Point is essentially identical to Unit 3 and operates subject to the same conditions. In March 1978 both units' condensers were cleaned; Unit 3 was equipped with an Amertap system and Unit 4 was not. Data gathered from March through July showed annualized savings in Unit 3 of $2,061,000 attributable to increased condenser efficiency. Again, the capital and operating costs of the system must be subtracted from the savings to obtain the net benefit attributable to the use of the Amertap system.

An additional analysis of Amertap condenser cleaning systems was performed by Duke Power Company and was published in June 1978.[10] This analysis considered fuel savings and increased station capacity due to improved heat rejection capability of the surface condensers, greater heat rejection being reflected in lower turbine backpressure.

Duke Power's first automatic cleaning system was installed in the Marshall Unit No. 1 condenser late in 1966. The 350 MW coal-fired unit had been operating for about a year before the system was added. Within 3 weeks, the absolute backpressure dropped by 0.2 in. Hg, improving the unit heat rate by approximately 0.24 percent. Early in 1967, Marshall personnel circulated abrasive-coated rubber balls through the condenser to remove the more stubborn deposits that had accumulated on tube walls prior to installation of the cleaning system. Circulation of the abrasive balls for 18 days improved condenser performance still further, lowering backpressure to 0.6 in. Hg absolute. System performance convinced Duke Power to retrofit a similar cleaning system on the 350 MW Marshall Unit No. 2's condenser in July 1968, and also to equip the 671 MW Marshall Unit Nos. 3 and 4's condensers with them. The total fuel savings attributed to operation of the Marshall cleaning systems through 1975 is more than $700,000 based on an estimate of a 0.15 percent heat rate improvement and actual fuel costs for the period.

In addition to saving fuel, improved turbine performance means increased station capacity. From 1970, the first year all four units were equipped with automatic condenser cleaning systems, through 1975, Marshall station's generating capability increased an average of 3 MW on a base plant capacity of 2042 MW.

Duke Power performed a more complete economic analysis for the cleaning systems at Allen station, which has newer equipment than Marshall. Allen 3, 4 and 5, each rated at 275 MW, have net unit heat rates of 9613 Btu/kWh at a backpressure of 1.5 in. Hg absolute. Unit 5 was equipped with an automatic cleaning system in July 1974 and Unit 3 in March 1975; Unit 4 has no such system. A comparison of condenser heat transfer rates during the period July 1973 to September 1976 indicated that after manual cleaning performance of all units improved somewhat, but that the decrease in heat rate was short lived. In comparison, units with continuous cleaning systems maintained low heat rates throughout the evaluation period. Duke Power engineers estimated a 0.67 percent improvement in Unit 5's heat rate and a 0.32 percent increase in Unit 3's performance. More practically, this meant a reduction in fuel cost for Unit 5 of $234,300 for the period and for Unit 3 a reduction of $67,000. Since no changes were made in Unit 4's operations, it had no improvements in heat rate, no increase in costs and no net savings.

The calculation of the payback period for a mechanical cleaning system used by Duke Power is as follows:

The first step in calculating the payback period for a mechanical cleaning system is to determine the fuel cost saving attributed to the use of that cleaning system. These are the data required for computations (numbers in parentheses are 1976 data for Duke Power's Allen Unit 5):

- Heat rate (9613 Btu/kWh)
- Electricity produced by the unit (1,618,677 MWh)
- Power generation cost ($0.01079/kWh)
- Improvement in heat rate contributed by continuous condenser cleaning (0.67 percent)

The total energy input to Allen Unit 5 in 1976, with the condenser cleaning system in service, was 15.560990 × 10^{12} Btu. The heat input that would have been required if a condenser cleaning system had not been used is:

$$9613 \text{ Btu/kWh} \div (1 - 0.0067) = 9677.8 \text{ Btu/kWh};$$

$$(15.560990 \times 10^{12} \text{ Btu}) \times (9677.8 \text{ Btu/kWh} \div 9613 \text{ Btu/kWh}) = 15.665885 \times 10^{12} \text{ Btu}$$

Thus, the fuel-cost saving in 1976 amounted to:

$$(15.665885 \times 10^{12}) - (15.560990 \times 10^{12}) = 0.104895 \times 10^{12} \text{ Btu};$$

$$(104{,}895 \times 10^{6} \text{ Btu}) \times \left[(\$0.01079/\text{kWh}) \times 1/0.009613 \times 10^{6} \text{ Btu/kWh})\right] = \$117{,}738$$

A saving also resulted from the elimination of manual cleaning, estimated to cost \$4908 per year.

From these savings, one can subtract the additional operating costs incurred by using the continuous cleaning system, as well as the installed cost of the system. At Allen Unit 5, the circulating pumps had to overcome an additional 0.5 ft of head because of the strainer installed in the circulating water system to catch the cleaning balls after passing through the condenser. This resulted in a pump loss of 16.94 kW. The two pumps used to recirculate the cleaning balls from the strainer on the condenser discharge, back to the suction side of the exchanger required another 7.43 kW. Additional pumping costs attributed to condenser cleaning were:

$$(16.94 \text{ kW} + 7.43 \text{ kW}) \times 7200 \text{ hr/yr}^{*} \times \$0.01079/\text{kWh} = \$1893/\text{yr}$$

The annual cost of replacement cleaning balls, based on 1976 data, was \$3532 per year.

Therefore, in 1976 the total saving attributed to use of the condenser cleaning system without considering capital and installation costs was:

Fuel	- \$117,738
Manual cleaning	- 4,908
Pump penalty	- (1,893)
Replacement cleaning balls	- (3,532)
Saving	- \$117,221

The saving for the period beginning July 1974, when the system was installed, through 1976 was:

Fuel	- \$234,300
Manual cleaning	- 12,270
Cost of Amertap cleaning system and debris filter	- (112,817)
Cost of installation	- (100,000)
Pump penalty	- (4,733)
Replacement cleaning balls	- (8,830)
Saving	- \$ 20,190

*Those unfamiliar with electric power plant operation may assume that this figure means the plant operated at an 82 percent capacity factor (7200/8760 = 82 percent). In actuality the plant was available 82 percent of the time, but operated at reduced load some of that time with a resultant capacity factor of 67 percent.

Thus the equipment paid for itself in less than 2-1/2 years and is now returning a significant saving. Note, too, that since today's fuel costs are above 1976 levels the net annual saving exceeds the $117,221 figure calculated.

Another saving that should be considered, though difficult to estimate, is the elimination of outage time to manually clean condenser tubes. Normally, 2 days would be required for this task at Allen and Marshall. Even if cleaning during peak generating periods is avoided, the unit load loss - 13.2 million kWh - and startup costs can run as high as $9800.

It is difficult to determine how much of this should be allocated to manual cleaning of condenser tubes, since other necessary maintenance activities are usually performed simultaneously. However, without the requirement for condenser tube cleaning it would be possible to schedule these shutdowns less frequently.

One more economic advantage of continuous cleaning is the extension of operating life for many types of surface condensers. Operating data indicate that tubes last longer because scale, organic fouling and silting - all of which can contribute to erosion and corrosion - are eliminated. In addition, the need for more radical cleaning methods - acids, for example - which also may limit tube life, are not necessary.

Prior to installation of the continuous cleaning systems at Marshall and Allen, biological fouling in the form of algal slime was particularly heavy at certain times of the year. The only way to combat it was to inject substantial quantities of chlorine into the water. Continuous cleaning has eliminated the need for this.

Amertap system costs can also be considered in the context of how much installation and operation will add to consumer charges. Table 7 gives costs for new and retrofit systems at a small and a large power plant.

TABLE 7. TYPICAL AMERTAP SYSTEM COSTS (IN 1979 DOLLARS)

Plant size	Installation	Capital cost ($/kW)	Operating cost (mills/kWh)	Total cost* (mills/kWh)
100 MW	New	1.60	0.029	0.082
	Retrofit	1.98	0.029	0.095
1000 MW	New	0.77	0.013	0.038
	Retrofit	0.95	0.013	0.044

*
$$\text{Total cost} = \frac{\text{capital cost} \times \text{capital recovery factor}}{\text{annual operating hours}} + \text{operating cost}$$

A capital recovery factor of 15.94 percent was used, consistent with a 15.85 percent cost of capital and a 35-year unit life. A capacity factor of 55 percent was also assumed.

SOURCE: Reference 1, p. IV-21 and IV-23.

Costs reported in Table 7 do not consider any savings which would occur from reduced chlorine consumption or from omitting manual tube cleaning. Chlorination and cleaning practices vary widely from plant to plant, depending predominantly upon water quality.

The effects of Amertap installation and operation on the cost of electricity produced at eight typical generating stations are shown in Table 8. In no case are costs increased by more than 0.5 percent, but even these small increases present a conservative worst case. In addition to savings from reduced chlorine consumption and termination of manual tube cleaning, the Amertap system is expected to maintain condenser tube cleanliness at a consistently high level, contributing to minimizing turbine heat rates and maximizing generating capability.

TABLE 8. EFFECT OF AMERTAP SYSTEM ON ELECTRICITY COSTS

Plant size	Fuel type	Installation	Baseline cost of electricity (mills/kWh)	Amertap system cost (mills/kWh)	Increase due to Amertap system (percent)
100 MW	Coal	New	31.8	0.08	0.3
		Retrofit	22.0	0.10	0.5
	Oil	Retrofit	39.6	0.08	0.2
1000 MW	Coal	New	30.4	0.04	0.1
		Retrofit	20.6	0.04	0.2
	Oil	Retrofit	35.8	0.04	0.1
	Nuclear	New	28.0	0.04	0.1
		Retrofit	19.4	0.04	0.2

SOURCE: Reference 1, p. IV-13, IV-14 and Table 1.

Any utility's decision to install or not install a mechanical cleaning system is predicated upon more than technical feasibility and operating economics. That decision takes place within a regulatory climate created by the various regulatory authorities which differ from state to state. All utilities have an allowed rate of return set by a regulatory agency; that allowed rate of return may be insufficient, excessive or equitable. Should the allowed rate of return be insufficient, companies will avoid investing in capital such as mechanical cleaning systems, choosing instead to incur higher operating costs, in this case for chlorine or manual cleaning, because these costs can be passed through to the consumer directly. Conversely, if an excessive rate of return is permitted, the firm will maximize its capital investment. With an equitable rate of return, regulatory distortions are removed, and decisions can be made on purely technical and economic grounds.

REFERENCES

1. Temple, Barker and Sloane. Economic Analysis for the Revision of Steam-Electric Utility Industry Effluent Limitation Guidelines, (Draft) EPA. April 1979.

2. Development Document for Effluent Limitation Guidelines and New Source Performance Standards for the Steam Electric Power Generating Point Source Category, U.S. Environmental Protection Agency, EPA-440-1-74-029a. October 1974, p. 287.

3. Yu, H.H.S., G.A. Richardson, and W.H. Hedley. Alternatives to Chlorination for Control of Condenser Tube Biofouling. U.S. Environmental Protection Agency, EPA-600/7-77-030, March 1977, p. 38.

4. Weg Scheider, J. J. Cleaning Heat Exchange Tubing in Industry With the Automatic On-Load Tube Brushing System. Cleaning Stainless Steel ASTM STP 538, American Society for Testing and Materials, 1973. p. 211.

5. Uhlige, H. H. The Corrosion Handbook. John Wiley & Sons, Inc. New York, 1948.

6. Uhlige, H. H. Corrosion and Corrosion Control. John Wiley & Sons, Inc. New York, 1963.

7. Long Island Lighting Company. Internal Report, September 1970.

8. Southern Services, Incorporated. Internal Report by D. Stinson, 1974.

9. O'Neil, G. W., Jr., C. J. Baker, and P. J. Harding. On-Line Tube Cleaner Saves $2 million/yr. Electrical World, V. 192, No. 1, July 1, 1979.

10. Holland, T. E., and P. J. Harding. Help Maintain High Efficiency by Cleaning Steam Condensers Continuously, On-Line. Power. V. 122, No. 6, June 1978.

APPENDIX A

AMERTAP

CONDENSER TUBE CLEANING SYSTEMS IN THE UNITED STATES

Source: Amertap Corporation. Amertap Reference List.
Woodbury, New York.
Reproduced with permission of Amertap Corporation.

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL	CONSULTANT	ORDER YEAR
Alabama Power Company	Barry	Mobile River	5	712	Admiralty	Southern Services, Inc.	69
	Gaston	Cooling Tower	5	900	304 SS	Southern Services, Inc.	71
		Makeup:	5–Heat Exch		304 SS		72
		Coosa River					
	Farley (Nuclear)	Cooling Tower	1	860	Titanium	Southern Services, Inc.	75
		Makeup:	2	860	Titanium	Bechtel Corp.	75
		Chattahoochie River					
	Gorgas	Warrior River	10	712	304 SS	Southern Serivces, Inc.	69
	Miller	Cooling Tower	1	660	Admiralty	Southern Services, Inc.	75
		Makeup:	2	660	Admiralty		75
		Black Warrior	3	660	Admiralty		75
		River	4	660	Admiralty		75
Allegheny Power System	Fort Martin	Cooling Tower	1	500	304 SS	Burns & Roe, Inc.	65
		Makeup:	1–Heat Exch		304 SS		65
		Monongahela	2	500	304 SS		65
		River	2–Heat Exch		304 SS		65
	Harrison	Cooling Tower	1	650	304 SS	Gibbs & Hill, Inc.	70
		Makeup:	1–Heat Exch		304 SS		70
		River Water	2	650	304 SS		70
			2–Heat Exch		304 SS		70
			3	650	304 SS		70
			3–Heat Exch		304 SS		70
	Hatfield's Ferry	Monongahela River	1	540	304 SS	United Engineers & Constructors, Inc.	67
			2	540	304 SS		67
		Cooling Tower Makeup: River Water	3	540	304 SS		68
	Pleasants	Cooling Tower	1	600	304 SS	United Engineers & Constructors, Inc.	74
		Makeup:	2	600	304 SS		74
		Ohio River					
Allied Chemical Corp.	Hopewell, Va.	Cooling Tower	Refri. Cond.		304 SS	Self	77
Arkansas Power & Light Company	Arkansas Nuclear One	Cooling Tower Makeup: Dardanelle Reservoir	2	950	90/10 CuNi	Bechtel Corp.	73
	White Bluffs	Cooling Tower	1	700	90/10 CuNi	C.T. Main	74
		Makeup:	2	700	90/10 CuNi		
		Arkansas River		700	90/10 CuNi		
				700	90/10 CuNi		
	Independence	Cooling Tower	1			C.T. Main	74
		Makeup:	2				
		White River					
Baltimore Gas & Electric Co.	Calvert Cliffs (Nuclear)	Chesapeake Bay	1	800	CuNi	Bechtel Corp.	69
			2	800	CuNi		69
Brownsville Public Utility Board	SiRay	Cooling Pond	5	22	Admiralty	Self	75
		Makeup:	6	26	Admiralty		75
		Rio Grande					
Calgary Power Corp.	Sundance	Cooling Pond	2	300	304 SS	Montreal Engineering	77
Carolina Power & Light Co.	L.V. Sutton	Freshwater Lake	2	110	90/10 CuNi	Self	74
Central Maine Power Comm.	Maine Yankee Atomic	Seawater	1	800	AL. Brass	Self	76

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL		CONSULTANT	ORDER YEAR
Central Plants, Inc.	Bunker Hill	Cooling Tower Makeup: City Water	Freon Condenser		Copper		Self	73
	Century City	Cooling Tower Makeup: City Water	Freon Condenser		Copper		Self	70
			Turbine Steam Cond.		Copper			70
			Turbine Steam Cond.		Copper			70
			Freon Condenser		Copper			73
Central Power & Light Company	Davis	Corpus Christi Bay	1	355	Alu-Brass		Sargent & Lundy Engineers	71
			1—Heat Exch		Alu-Brass			71
			2	355	Titanium			73
			2—Heat Exch		Titanium			73
	Joslin	Gulf of Mexico	1	240	Alu-Brass		Sargent & Lundy Engineers	69
			1—Heat Exch		Alu-Brass			69
	Nueces Bay	Nueces Bay	6—Heat Exch		316	SS	Sargent & Lundy Engineers	67
			7	320	Alu-Brass			70
			7—Heat Exch		Alu-Brass			70
Cleveland Electric Illuminating Co.	Perry (Nuclear)	Lake Erie	1—Main	1200	304	SS	Gilbert Assoc. Inc.	74
			2—Main	1200	304	SS		74
			1—Aux		304	SS		74
			2—Aux		304	SS		74
Colorado Springs City of	R.D. Nixon	Cooling Tower	1	200	316	SS	Lutz, Daily & Brain	75
Commonwealth Edison Company	Braidwood (Nuclear)	Cooling Lake Makeup: Kankakee River	1	1120	304	SS	Sargent & Lundy Engineers	74
			2	1120	304	SS		
	Byron (Nuclear)	Cooling Tower Makeup: Rock River	1	1120	304	SS	Sargent & Lundy Engineers	74
			2	1120	304	SS		
	Collins	Man-made Lake Makeup: Illinois River	1	500	304	SS	Sargent & Lundy Engineers	74
			2	500	304	SS		74
			3	500	304	SS		74
			4	500	304	SS		74
			5	500	304	SS		74
	LaSalle (Nuclear)	Man-made Lake	1	1100	304	SS	Sargent & Lundy Engineers	73
			2	1100	304	SS		73
	Zion (Nuclear)	Lake Michigan	1	1100	304	SS	Sargent & Lundy Engineers	69
			2	1100	304	SS		69
Conemaugh Project	Conemaugh	Cooling Tower Makeup: Conemaugh River	1	900	304	SS	Gilbert Associates, Inc.	68
			1—Heat Exch		304	SS		68
			2	900	304	SS		68
			2—Heat Exch		304	SS		68
Consolidated Edison Co., N.Y.	Arthur Kill	Newark Bay	2	335	Alu-Brass		Self	66
			3	500	Titanium			67
Consumer's Power Company	Campbell	Lake Michigan	3	800	304	SS	Gilbert Commwlth.	76
Dairyland Power Cooperative	Genoa No. 3	Mississippi River	1	300	304	SS	Burns & Roe, Inc.	66
			1—Heat Exch		304	SS		66

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL		CONSULTANT	ORDER YEAR
Dayton Power & Light Company	Killen	Cooling Tower Makeup: Ohio River	1	600	90/10 CuNi		Ebasco Services, Inc.	76
			2	600	90/10 CuNi		Ebasco Services, Inc.	76
	Stuart	Ohio River	1	600	Ars. Cu		Ebasco Services, Inc.	66
			2	600	Ars. Cu.			66
			3	600	Ars. Cu.			68
		Cooling Tower Makeup: Ohio River	4	600	Ars. Cu.			71
Delmarva Power & Light Company	Edge Moor	Delaware River	4	162	Ars. Admir		United Engineers & Constructors	64
			5	410	Admiralty		Bechtel Corp.	71
			3	75	Admiralty		Self	78
Duke Power Company	Allen	Catawba River	3	300	Admiralty		Self	73
			5	275	Admiralty			72
	Belews Creek	Belews Creek Lake	1	1100	304	SS	Self	70
			2	1100	304	SS		70
	Catawba	Cooling Tower Makeup: Catawba River	1	1150	304	SS	Self	74
			1–Aux.		304	SS		
			2	1150	304	SS		
			2–Aux.		304	SS		
	Cherokee	Tower	1	1300	304	SS	Self	78
			2	1300	304	SS	Self	
			3	1300	304	SS	Self	
	Marshall	Lake Norman	1	350	Admiralty		Self	66
			2	350	Admiralty			67
			3	671	304	SS		67
			4	671	304	SS		67
	McGuire (Nuclear)	Lake Norman	1	1150	304	SS	Self	71
			1–BFP Cond.		304	SS		73
			2	1150	304	SS		71
			2–BFP Cond.		304	SS		73
	Oconee (Nuclear)	Lake Keowee	1	900	304	SS	Self	68
			2	900	304	SS		68
	Perkins	Fresh Water	1	1300	304	SS	Self	78
			2	1300	304	SS	Self	
			3	1300	304	SS	Self	
Duquesne Light Co.	Beaver Valley	Cooling Tower Makeup: Ohio River	2	880	304	SS	Stone & Webster Boston	78
E.I. duPont de Nemours & Co.	Beaumont Works	Cooling Tower Makeup: Freshwater	Process Steam Cond		90/10 CuNi		Self	70
			Process Heat Exch		304	SS		72
			Process Heat Exch		90/10 CuNi		Self	73
			3500 Ton Refrigeration Condenser		90/10 CuNi		Self	74
East Kentucky Rural Cooperative	Spurlock	Cooling Tower Makeup: Ohio River	2	500	304	SS	Stanley	76
Florida Power & Light Co.	Turkey Point (Nuclear)	Biscayne Bay Cooling Canal	3	740	Alu-Brass		Bechtel Corp.	75
			4	740	Alu-Brass			75
General Foods Corporation	Hoboken Plant	Cooling Tower	Process Heat Exch		Copper		Lewis Refrigeration	71
			Process Heat Exch		Copper		Self	75
	Houston Plant	Cooling Tower	Process Heat Exch		Copper		Lewis Refrigeration	69
			Process Heat Exch		Copper		Self	75

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL		CONSULTANT	ORDER YEAR
Georgia Power Co.	Central Georgia	Cooling Tower Makeup: River Water	1 2	900 900	304 304	SS SS	Southern Services, Inc.	74 74
	Hatch (Nuclear)	Cooling Tower Makeup: Altamah River	1	800	Admiralty		Southern Services, Inc.	70
	Plant Scherer	Ocmulgee River Rum Creek	1-4	818	90/10 CuN		Self	77
	Wansley	Cooling Tower Makeup: River Water	1 2	900 900	304 304	SS SS	Southern Services, Inc.	73 73
	Yates	Cooling Tower Makeup: Chatahoochee River	6 7	350 350	Admiralty Admiralty		Jackson & Moreland	71 71
Hoerner Waldorf Co.	St. Paul	Wells	1	5	304	SS	Self	77
Homer City Project	Homer City	Cooling Tower Makeup: Yellow Creek	1 2	663 663	304 304	SS SS	Gilbert Associates, Inc.	67 67
Hoosier Energy	Merom	Lake	1 2	490 490	90/10 90/10		United Engineers & Constructors, Inc.	77
Houston Lighting & Power Co.	Deepwater	Houston Ship Channel	7	190	CuNi		Self	66
Iowa Southern Utilities	Ottumwa	Cooling Tower Makeup: Des Moines River	1 1– Aux.	675	90/10 CuNi		Black & Veatch	77
Jersey Central Power & Light Co.	Three-Mile Island (Nuclear)	Cooling Tower Makeup: Susquehanna River	2	800	304	SS	Burns & Roe, Inc.	69
Kansas Power & Light Company	Jeffrey Energy Center	Cooling Tower Makeup: Wells	1 2	680 680	304	SS	Black & Veatch	76
Keystone Project	Keystone	Cooling Tower Makeup: Plum-Creek	1 2	900 900	304 304	SS SS	Gilbert Associates, Inc.	65 65
Long Island Lighting Company	Barrett	Broad Channel	1 2	175 175	Alu-Brass Alu-Brass		Self	64 64
	Glenwood	Long Island Sound	4 5	100 100	Alu-Brass Alu-Brass		Self	57 60
Los Angeles Dept. of Water & Power	Haynes	Seal Beach Bay	1 2 3 4	230 230 230 230	70/30 CuNi Alu-Brass 70/30 CuNi 70/30 CuNi		Self	60 60 75 75
Metropolitan Edison Company	Three-Mile Island (Nuclear)	Cooling Tower Makeup: Susquehanna River	1	840	304	SS	Gilbert Associates, Inc.	68
Mississippi Power Company	Plant Daniel	Lake	1 2	500 500	Admiralty Admiralty		Southern Services, Inc.	73 73
	Jack Watson	Cooling Tower Makeup: Biloxi River	5	553	90/10 CuNi		Southern Services, Inc.	76

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL	CONSULTANT	ORDER YEAR
Monongahela Power Co.	Albright	Cheat River	3	125	304 SS	Self	65
	Rivesville	Monongahela River	5 6	51 95	304 SS 304 SS	Self	65 63
	Willow Island	Ohio River	2	165	Admiralty	Self	67
Narragansett Electric Company	Manchester St.	Narragansett Bay	9 10 11	40 40 40	90/10 CuNi 90/10 CuNi 90/10 CuNi	Self	64 64 64
	South Street	Providence River	1 7	47 47	304 SS CuNi	Self	62 62
New Brunswick Electric Power Commission	Coleson Cove	Bay of Fundy	1 2 3	300 300 300	Yarcalbro Alu-Brass	Self	73
Newfoundland & Labrador Hydro	Holyrood	Conception Bay	3	150	Alu-Brass	Montreal Engineering	77
Northeast Utilities	Millstone (Nuclear)	Long Island Sound	3	1200	70/30 CuNi	Stone & Webster, Inc.	74
Northern Petrochemical Company	Morris Ethylene Plant	Cooling Tower Makeup: Wells	1 – Heat Exch 2 – Heat Exch		Inh. Admir. Inh. Admir.	Self	75 75
Northern States Power Company	King	St. Croix River	1	610	304 SS	Pioneer Service & Engineering	65
	Prairie Island (Nuclear)	Mississippi River	1 2	560 560	304 SS 304 SS	Pioneer Service & Engineering	68 68
	Sherburne	Cooling Tower Makeup: Mississippi River	1 1 – Heat Exch 2 2 – Heat Exch	680 680 	304 SS 304 SS 304 SS 304 SS	Black & Veatch	72 72 72 72
Ohio Edison Company	Niles	Mahoning River	1 2	125 125	Ars. Admir. Ars. Admir.	Self	64 64
	Sammis	Ohio River	5 6 7	350 600 625	Ars. Admir. Ars. Admir. Admir.	Commonwealth Associates, Inc.	66 66 69
Ontario Hydro	Bruce (Nuclear)	Lake Huron	5 6 7 8	800 800 800 800	304 SS 304 SS 304 SS 304 SS	Self Self Self Self	77 77 77 77
	Nanticoke	Lake Erie	2	500	Admir.	Self	70
	Thunder Bay	Mission River	2 3	150 150	304 SS 304 SS	London/Monenco London/Monenco	77 77
Pennsylvania Electric Company	Seward	Conemaugh River	5	150	304 SS	Self	64
	Shawville	W. Branch Susquehanna River	1 2 3 4	125 125 165 165	304 SS 304 SS 304 SS 	Self	62 62 62 61
Pennsylvania Electric and N.Y. State Elec. & Gas	Homer City	Cooling Tower Makeup: Blacklick Creek	3 – Main 3 – Aux	600 600	304 SS 304 SS	Ebasco Services, Inc.	74 74

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL	CONSULTANT	ORDER YEAR
Pennsylvania Power & Light Co.	Montour	Cooling Tower	1	814	304 SS	Ebasco Services, Inc.	69
		Makeup:	2	814	304 SS		70
		N. Branch					
		Susquehanna River					
	Susquehanna (Nuclear)	Cooling Tower	1	1120	304 SS	Bechtel Corp.	73
		Makeup:	2	1120	304 SS		73
		Susquehanna River					
Phillips Petroleum	Borger, TX Refinery	Tower, Well Water Makeup	1	12	Admiralty	Self	77
Potomac Electric Power Company	Chalk Point	Patuxent River	1	330	70/30 CuNi	Self	73
			2	330	70/30 CuNi		73
		Cooling Tower	3	600	70/30 CuNi	United Engineers & Constructors	72
		Makeup:	4	600	70/30 CuNi		72
		Patuxent River					
	Morgantown	Potomac River	1	625	70/30 CuNi	Bechtel Corp.	69
			2	625	70/30 CuNi		69
Public Service of Oklahoma	Comanche	Cooling Lake	1	120	Admiralty	Burns & Roe, Inc.	72
		Makeup:					
		Treated Sewage					
		Water					
Salt River Project	Navajo	Lake Powell	1	750	Ars. Cu.	Bechtel Corp.	76
South Carolina Electric & Gas Co.	Summer (Nuclear)	Lake	1	900	304 SS	Gilbert Assoc., Inc.	73
			1—Aux.		304 SS		73
	Wateree	Wateree River	1	375	304 SS	Gilbert Assoc., Inc.	67
			2	375	304 SS		68
	Williams	Cooper River	1	600	304 SS	Gilbert Assoc., Inc.	70
			1—Heat Exch		304 SS		70
Southern Calif. Edison Co.	Coolwater	Cooling Tower	3	236	90/10 CuNi	R.M. Parsons	74
		Makeup: Wells	4	236	90/10 CuNi		
	Mohave	Cooling Tower	1	775	Admiralty	Bechtel Corp.	74
		Makeup:	2	775			
		Colorado River					
	San Onofre (Nuclear)	Pacific	1	450	CuNi/Titanium	Self	75
		Ocean	2	1140	Titanium	Bechtel Corp.	73
			3	1140	Titanium		73
Southwestern Public Service Co.	Harrington	Cooling Tower	1	343	316 SS	Self	73
		Makeup:	1—Heat Exch		Admiralty		74
		Treated Sewage	2	318	316 SS		75
		Water	2—Heat Exch		316 SS		75
		Tower/Treated	3	350	316 SS	Self	77
		Sewage Makeup					
	Jones	Cooling Tower	1	250	316 SS	Self	68
		Makeup:	1—Heat Exch		Admiralty		69
		Treated Sewage	2	250	316 SS		71
		Water	2—Heat Exch		Admiralty		71
	Nichols	Cooling Tower	1	100	Admiralty	Self	71
		Makeup:	2	100	Admiralty		71
		Treated Sewage	3	250	316 SS		66
		Water	3—Heat Exch		Admiralty		74

COMPANY	STATION	C.W. SOURCE	TURBINE NO.	TURBINE MW	TUBE MATERIAL	CONSULTANT	ORDER YEAR
Tennessee Valley Authority	Bellefonte	Tower	1	1213	90/10 CuNi	Self	76
		M/U Tenn. River	2	1213			
	Brown's Ferry (Nuclear)	Cooling Tower	1	1100	Admiralty	Self	68
		Makeup: ,	2	1100	Admiralty		68
		Wheeler Reservoir	3	1100	Admiralty		68
	Hartsville	Cooling Tower M/U Cumberland	1,2,3,4	1300	90/10 CuNi	Self	77
	Phipps Bend	Tower, M/U Holston River	1,2	1300	90/10 CuNi	Self	
	Sequoyah (Nuclear)	Chickamauga Reservoir	1	1171	90/10 CuNi	Self	70
			2	1171	90/10 CuNi		70
	Watts Bar (Nuclear)	Tennessee River	1	1218	Admiralty	Self	74
			2	1218	Admiralty		74
	Widow's Creek	Guntersville Lake	8	500	Admiralty	Self	66/69
Texaco, Inc.	Port Arthur Refinery	Cooling Tower	3	14	Ars. Admir	Self	68
		Makeup: Neches River	Process Steam Cond		Red Brass		70
			Process Heat Exch		Admiralty		70
			Process Heat Exch		Red Brass		72
			Process Steam Cond		Admiralty		73
			Process Heat Exch		Admiralty	Stone & Webster	76
	Tulsa Refinery	Cooling Tower	Process Heat Exch		Carbon Steel	Self	73
Union Carbide Corp. (Linde Div.)	Duquesne	Monongahela River	1	17	Admiralty	Self	64
			Oxygen Cooler		Admiralty	Self	67
United Illuminating Company	English	Mill River	2	15	316 SS	Self	63
			3	15	316 SS		64
			4	15	316 SS		57
			5	15	316 SS		64
			7	40	316 SS		63
			8	40	316 SS		63
U.S. Steel Co.	Southworks Chicago	Lake Michigan	Air Compressor		304 SS	Union Carbide	66
			Oxygen Compressor		304 SS		66
			Turbo-Blower		304 SS	Ingersoll Rand	71
Virginia Electric Power Co.	Mount Storm	Cooling Pond	1	565	304 SS	Stone & Webster	65
			2	565	304 SS	Engineering Corp.	65
			3	565	304 SS		69
	North Anna (Nuclear)	North Anna River	1	892	304 SS	Stone & Webster	70
			2	892	304 SS	Engineering Corp.	70
			3	950	304 SS		72
			4	950	304 SS		72
	Surry (Nuclear)	James River	1	815	90/10 CuNi	Stone & Webster	67
			2	815	90/10 CuNi	Engineering Corp.	67
West Penn Power Company	Mitchell	Monongahela River	3	250	304 SS	Self	64
Youngstown Sheet & Tube Company	Campbell	Mahoning River	1	18.5	Admiralty	Self	68
			Turbo Blower		Admiralty		72

APPENDIX B

UTILITY RESPONSES TO INFORMATION REQUEST

1. Sample Information Request

2. Responses

1. SAMPLE INFORMATION REQUEST

The following is a sample information request sent to various power companies with experience in the operation of Amertap systems. Of particular interest are those stations which have replaced the condenser tubes since the mechanical cleaning system was put into effect.

1. The age of the condenser tubing at the time of installation of the mechanical system and at the time of replacement of the tubing.

2. The weight of the tubing at the time of purchase and at the time of replacement.

For all of the units with Amertap systems, we request the following information:

1. The date the turbine went commercial, average load factor, and MW rating.

2. The date the Amertap system was operational.

3. The condenser tube material.

4. The quantity of cooling water in gallons per minute, and the linear velocity of water through the tubes (ft/sec.).

5. The range of surface temperatures of the tubes.

6. The frequency of Amertap usage for both sponge rubber and abrasive balls.

7. The type and frequency of other condenser tube cleaning programs used before or after the mechanical cleaning system installation.

8. A description of chlorination practices including duration, dosage, and frequency as well as annual chlorine usage for the year prior to and the year immediately after the installation of the Amertap system.

9. Any analytical data on metals emitted from the cooling water system.

10. Any available data on increased plant efficiency related to operation of Amertap system.

11. Any available water quality data of the intake water.

12. The cost of the Amertap system (capital, operating, and maintenance).

TABLE B-1. UTILITY RESPONSES TO INFORMATION REQUEST ON AMERTAP PERFORMANCE

Utility respond-ing	Unit No.	Commence-ment of commercial operation	Avg. load factor (%)	MW rating	Amertap operational	Condenser age at installation/ replacement	Tube material	Water temp. range	Frequency of usage	Type of balls	Other methods	Chlorination practices	Capital outlay ($)	Flow velocity or rate	Water source
1	1	1959	-	360	1967	8 yr 4 mo, 10 yrs	Al-Bronze Ti	-	8 hr-daily continuous	Sponge rubber	HCl (yearly)	100 gal for 20 min (<2 mg/liter chlorine)	-	5.7 ft/sec	Ocean
	2	1969	-	515	1969	New/3 yr	Ti	-	8 hr/day 1 wk/3 mo	Abrasive	Mechanical rubber balls		68,000	5.9 ft/sec	
2	1	1957	83.9	137	1965	8 yr/13 yr	304SS	-	daily-several hrs	Sponge & abrasive	Steel balls (yearly)	1 hr/day	65,916	6.97 ft/sec 99,600 gpm	River
	2	1954	85.9	121	1964	-	Phelps Dodge Superlay (units 2, 3, 4 & 5)	-	June-Sept (continuous)	20% - abrasive 80% - sponge	N/A	N/A		6.99 ft/sec 68,000 gpm	
	3	1954	87.2	128	-	-		-							
	4	1959	87.4	178	-	-		-					199,453	6.57 ft/sec 87,000 gpm	
	5	1960	88.5	178	1965	-		-					82,174		
3	1	-	-	100	1960	-	Al-Brass	-	-	-	-	-			Ocean
4	1	1964	-	-	1975	New/2 yr	Cu-Ni	32°F	-	Sponge balls	-	-	499,900	7 ft/sec	River
	2	1965	-	-	1975	New/3 yr	70-30	-		Sponge balls	-	-	499,900	7 ft/sec	
	3	1975	-	-	1975		70-30	100°F	-	Sponge balls	-	-	318,000	7 ft/sec	
	4	1970	82.9	-	1970	10 yr	70-30	32°F	-	Sponge balls	-	2000 lbs/ day/unit (0.2 mg/liter)	316,000	7 ft/sec	
	5	1971	84.3	-	1971		70-30	90°F	-	Sponge balls	-		316,000	7 ft/sec	
5	1	1975	66.51 5 yr/avg.	550	1970	New	Admi-ralty Cu-Ni 90-10	60°F @ 0.5" Hg	Continuous Amertap	Abrasive balls	Nylon brushes before Amertap installed every 6 wk before & every 2 yrs after Amertap installation (all units)		65,188	7 ft/sec 250,000 gpm	River
	2	1974	78.07 2 yr/avg.	1,098	1974	New	Admi-ralty Cu-Ni 90-10	185°F @ 17" Hg	Continuous Amertap	Abrasive balls			65,188	7 ft/sec 250,000 gpm	
	3	1975	84.97 2 yr/avg.	1,098	1975	New	Admi-Cu-Ni 90-10	60°F @ 0.5" Hg	Continuous Amertap	Abrasive balls			762,378	7 ft/sec 200,000 gpm	
	4	1977	83.78 1 yr/avg.	1,098	1977	New	Admi-ralty Cu-Ni 90-10	135°F @ 5" Hg	Continuous Amertap	Abrasive balls			762,378	7 ft/sec 200,000 gpm	

2. RESPONSES

A summary of operating characteristics and details of condenser tube cleaning practices is given in Table B-1. Additional data for several plants are given below.

UTILITY NUMBER 1

Suspended Solids, ppm	14
pH	7.0
TDS, ppm	18,000
Conductivity, mmhos	24,000
Sodium, ppm Na	6,600
Calcium, ppm Ca	340
Magnesium, ppm Mg	720
Sulfate, ppm SO_4	1,200
Chloride, ppm NaCl	15,100
Silica (reactive), ppm	1.55
Alkalinity, ppm	None
Chemical Oxygen Demand, ppm	2.5

Prior to the installation of the Amertap system, Unit 2 was chemically cleaned with foaming HCℓ acid on an annual basis.

Rubber balls were inserted manually and circulated by air and water jetting.

Each section is chlorinated separately with approximately 100 gallons per dose for 20 minutes duration for each section, adjusted to maintain a plant effluent level of less than 0.2 ppm free chlorine.

UTILITY NUMBER 2

	Date	Average pH	Average acidity	Average Fe	Average suspended solids
Unit No. 1	2-79	5.13	2.0	7.88	34.67
	8-79	4.46	4.5	6.38	12.2
	6-77	4.18	4.3	9.15	6.8
	1-77	4.7	1.3	14.5	8.8
Unit Nos. 2, 3, 4, 5 (same units as table above)	8-72	4.2	-	1.36	454

Chlorination was stopped when the Amertap system was put into operation.

The frequency of usage for sponge and abrasive balls depends on river water quality. Generally, the Unit 1 system operates for a few hours daily using 50 percent sponge rubber and 50 percent abrasive balls. The use of Amertap balls ranges from $1500 to $1600/month at a cost of $22.50/100 abrasive balls and $17.10 for sponge rubber.

Unit No. 2 is operated during June, July, August, and September. During this time the systems are operated 100 percent of the time. Abrasive balls are used 20 percent of the time; sponge rubber balls are used 80 percent of the time.

WATER QUALITY DATA FOR UTILITY NUMBER 3

The following is a summary of analytical data for copper discharged from the cooling water system of a single power station. The tests were run over a 7 day period in 1964. Samples were collected every 48 hours at two different localities.

Abrasive balls were in continuous use over this period. After the first 16 hours, high copper values were recorded. The levels decreased gradually and were negligible by the end of the test.

	Copper (ppb)			
Analysis No.	1	2	3	4
No. 1 inlet	23	20	14	15
No. 1 outlet	47	29	17	12
No. 2 inlet	17	19	21	11
No. 2 outlet	19	17	16	15

UTILITY NUMBER 4

Units 1 and 2 were originally installed with Amertap Systems. The systems performed well, cleaning the condenser tubes in-service. In 1973, condenser tube leaks developed due to thinning and pitting of the walls. The injection of sawdust into the circulating system kept the units in-service but reduced the Amertap operation.

While operation of the Unit No. 5 system is reported to be satisfactory, systems in Units 3 and 4 have never given satisfactory service and are used infrequently.

UTILITY NUMBER 5

The Amertap system is used continuously during normal operation. The abrasive balls are used during startup following a long outage where the circulating pumps have been off and the condenser dewatered. During normal operation, if rubber ball consumption becomes excessive, abrasive balls are used until the rate of use returns to normal.

Unit No. 1 required brushing with nylon brushes approximately every 6 weeks before Amertap installation. With Amertap, brushing is reduced to twice yearly. Units 2, 3, and 4 were installed with Amertap systems. No other cleaning system has been used except during an outage when water at high pressure is passed through the tubes to remove debris.

TABLE B-2. WATER QUALITY DATA FOR UTILITY NUMBER 4

Parameter	Minimum	Average	Maximum	3/28/79 (data for single day)	Units
pH	6.9	-	8.0	7.2	Standard units
Calcium Hardness as $CaCO_3$	60	299	600	120	mg/l
Magnesium Hardness	50	1,317	1,850	380	mg/l
Total Hardness	110	1,485	2,600	500	mg/l
Total Suspended Solids	0.3	32	133	58	mg/l
Total Dissolved Solids	320	8,592	12,986	2,399	mg/l
Total Solids	453	8,647	13,009	2,457	mg/l
Total Alkalinity	44	65	76	48	mg/l
Conductivity	622	13,479	18,600	3,600	μmhos/cm
Sulfates	39	1,467	2,487	2,157	mg/l
SO_2	0.63	1.60	5.20	2.60	mg/l
Other Phosphate	0.2	0.6	3.3	0.5	mg/l
Total Phosphate	0.3	0.9	4.6	0.8	mg/l
Dissolved Oxygen	7.7	9.6	13.2	10.4	mg/l
Zinc	0.044	0.068	0.136	-	mg/l
Iron	0.27	0.89	3.70	1.67	mg/l
Copper	0.012	0.020	0.026	0.012	mg/l
Manganese	0.07	0.092	0.114	-	mg/l
Sodium	592	949	1,134	1,084	mg/l
Chromium		< 0.01	-	< 0.01	mg/l
Nickel	0.01	0.02	0.05	0.01	mg/l

TABLE B-3. WATER QUALITY DATA FOR UTILITY NUMBER 5

Raw Water Intake Analyses

Average for Weekly Samples

Date	pH	Alkalinity Phen. $CaCO_3$	Alkalinity Total $CaCO_3$ mg/l	Total Hard. $CaCO_3$ mg/l	Cond. µmhos/cm	Solids Dissolved mg/l	Solids Suspended mg/l
1974							
1/9-12/30							
Minimum	7.5	-	38	53	125	14	2
Average	7.8	0	63	70	148	93	6
Maximum	8.3	-	80	83	170	162	36

Date	pH	Alkalinity Phen. $CaCO_3$ mg/l	Alkalinity Total $CaCO_3$ mg/l	Solids Dissolved mg/l	Solids Suspended mg/l
1975					
1/6-12/30					
Minimum	7.4	0	37	10	2
Average	-	0	57	89	11
Maximum	8.0	0	67	272	58
Date					
1976					
1/6-6/30					
Minimum	7.5	0	50	36	1
Average	7.7	0	58	82	6
Maximum	8.2	0	65	126	16

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/7-80-026	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE Assessment of Corrosion Products from Once-through Cooling Systems with Mechanical Antifouling Devices		5. REPORT DATE January 1980
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Charles M. Spooner		8. PERFORMING ORGANIZATION REPORT NO. GCA-TR-79-46-G
9. PERFORMING ORGANIZATION NAME AND ADDRESS GCA/Technology Division, Burlington Road, Bedford, Massachusetts 01730		10. PROGRAM ELEMENT NO. INE827
		11. CONTRACT/GRANT NO. 68-02-2607, Task 28
12. SPONSORING AGENCY NAME AND ADDRESS EPA, Office of Research and Development, Industrial Environmental Research Laboratory, Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED Task Final; 1-4/79
		14. SPONSORING AGENCY CODE EPA/600/13

15. SUPPLEMENTARY NOTES IERL-RTP project officer is Theodore G. Brna, Mail Drop 61, 919/541-2683.

16. ABSTRACT The report gives results of an assessment of corrosion products from steam-electric power plant once-through cooling systems equipped with mechanical antifouling devices. (About 67% of the currently operating plants in the U.S. use once-through cooling systems. Various cleaning mechanisms, used to minimize the reduction of the thermal efficiency of heat exchange in the condenser tubes--caused by corrosion and biofouling--include chemical and off- and on-line mechanical methods.) On-line mechanical cleaning may lead to increased levels of metals in the effluent due to abrasion of the condenser tubes. Since some abraded metals at sufficiently high concentrations harm aquatic organisms and lead to other environmental damage, metal concentrations in cooling water discharges which stem from on-line mechanical condenser tube cleaning systems need to be determined. This report addresses the significance of this effect, based mainly on comments from utilities experienced with the Amertap system and from the manufacturer. The industry generally does not keep a close account of the causes and magnitude of condenser tube corrosion; however, based on observations offered by the utilities, the Amertap and other systems do not appear to contribute to loss of metal through abrasion in any measurable way. Further evaluation is recommended.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Assessments	Pollution Control	13B	14B
Steam Electric Power Generation	Condenser Tubes	Stationary Sources		
	Cooling Water	Biofouling	10A	
Cooling Systems		Mechanical Antifouling Devices	13A	
Corrosion Products			11M	
Biodeterioration			06A	

18. DISTRIBUTION STATEMENT Release to Public	19. SECURITY CLASS (This Report) Unclassified	21. NO. OF PAGES 48
	20. SECURITY CLASS (This page) Unclassified	22. PRICE

EPA Form 2220-1 (9-73)