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SHIPBOARD SEWAGE TREATMENT SYSTEM FOR GREAT LAKES VESSELS

by

Craig S. Alig
Alexander E. Lardis

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SHIP MATERIALS ENGINEERING DEPARTMENT
RESEARCH AND DEVELOPMENT REPORT

SHIPBOARD SEWAGE TREATMENT SYSTEM FOR GREAT LAKES VESSELS

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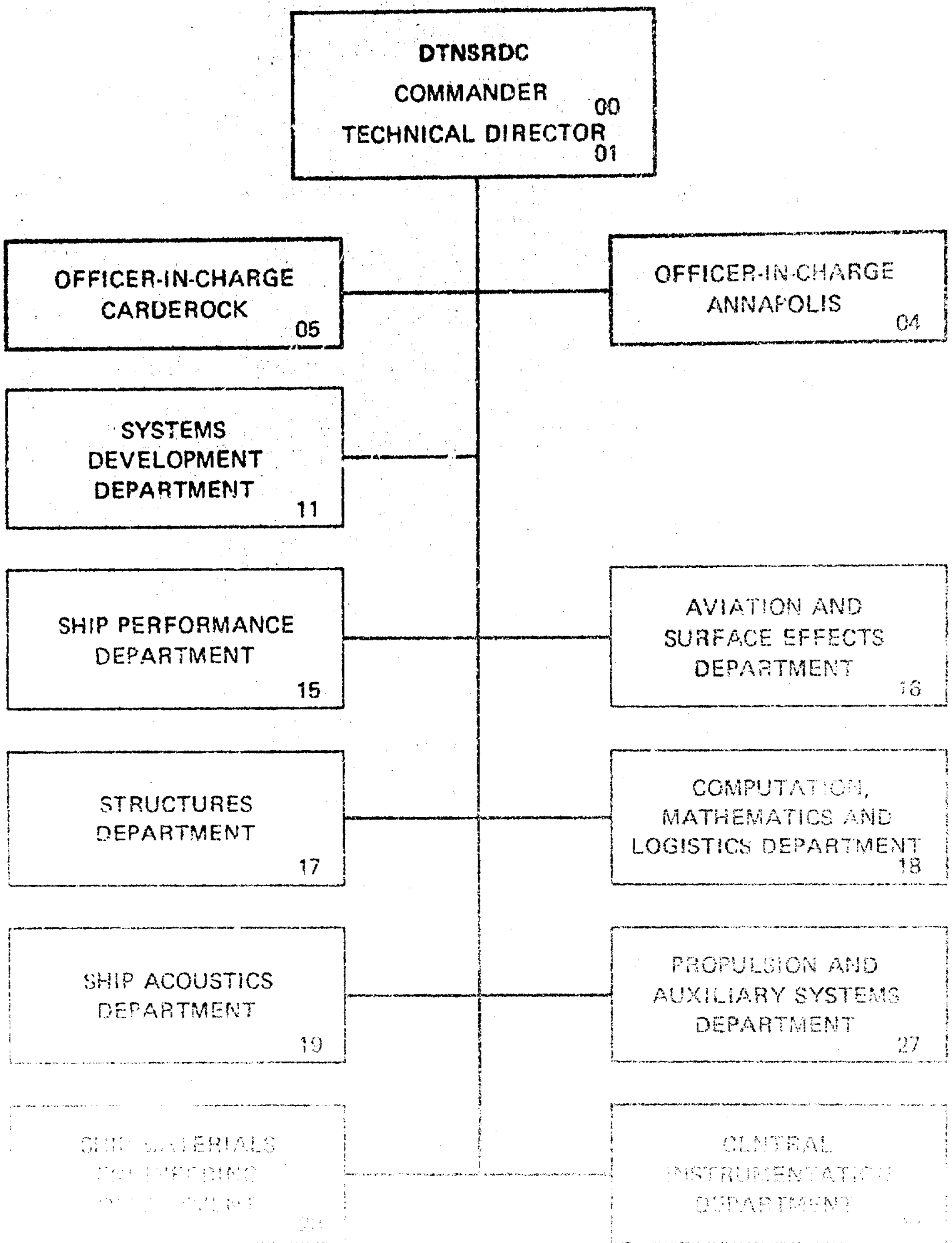

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Two sewage treatment systems aboard Great Lakes iron ore carriers were evaluated: A Chlorinator-Macerator System aboard SS EDWARD B. GREENE, and a BIOGEST "125" System aboard SS WALTER A. STERLING. The systems had been installed in 1962 and 1960, respectively. The lack of trained shipboard operating personnel caused termination of the BIOGEST evaluation. The

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Chlorinator-Macerator evaluation revealed a need for a system with improved operational characteristics.

The Chlorinator-Macerator System was modified to utilize ozonation followed by small additions of sodium hypochlorite solution to complete disinfection and provide a slight chlorine residual. It was designed to (1) minimize manpower operating requirements; (2) simplify maintenance, troubleshooting, and repair; (3) require little logistical support; and (4) interface with existing shipboard piping and electrical systems while complying with the U.S. Environmental Protection Agency's Type-II marine sanitation device Effluent Quality Standards. The new prototype Blackwater Treatment System was evaluated in 1975 and 1976. The system produced effluent within U.S. Environmental Protection Agency Standards for a Type-II marine sanitation device. Design drawings for a prototype treatment system for further development are included.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

Page

LIST OF ABBREVIATIONS

A	Ampere
ac	Alternating current
BOD_5	Five-day biochemical oxygen demand
^oC	Degree Celsius
CCIC	Cleveland-Cliffs Iron Company
cfh	Cubic foot per hour
CL	Chlorine
COD	Chemical oxygen demand
col	Colony
DO	Dissolved oxygen
EPA	Environmental Protection Agency
^oF	Degree Fahrenheit
FC	Fecal coliform bacteria
g	Gram
gpd	Gallon per day
gph	Gallon per hour
gpm	Gallon per minute
H_2O	Water
H_2O_2	Hydrogen peroxide
HO	Hydroxyl radical
HO_2	Hydroperoxyl radical
Hz	Hertz
KI	Potassium iodide
kPag	Kilopascal gauge

ℓ	Liter
m	Meter
MARAD	Maritime Administration
MF	Membrane filter technique of coliform bacteria enumeration
mg	Milligram
ml	Milliliter
MPN	Most probable number of bacteria as determined by the multiple tube fermentation method
MSD	Marine sanitation device
O^-	Oxide radical
O_2	Oxygen
O_3	Ozone
O_3^-	Ozonide radical
OH^-	Hydroxide ion
OSHA	Occupational Safety and Health Administration
ppm	Part per million
psig	Pound per square inch gauge
PVC	Polyvinyl chloride
RC	Residual chlorine
s	Second
SD	Standard deviation
SS	Settleable solids
stdft^3	Standard cubic foot
STS	Sewage treatment system
TOC	Total organic carbon
TSS	Total suspended solids

USCG	United States Coast Guard
V	Volt
vol.	Volume
W_L	Waterline

ABSTRACT

Two sewage treatment systems aboard Great Lakes iron ore carriers were evaluated: A Chlorinator-Macerator System aboard SS EDWARD B. GREENE, and a BIOGEST "25" System aboard SS WALTER A. STERLING. The systems had been installed in 1962 and 1960, respectively. The lack of trained shipboard operating personnel caused termination of the BIOGEST evaluation. The Chlorinator-Macerator evaluation revealed a need for a system with improved operational characteristics.

The Chlorinator-Macerator System was modified to utilize ozonation followed by small additions of sodium hypochlorite solution to complete disinfection and provide a slight chlorine residual. It was designed to (1) minimize manpower operating requirements; (2) simplify maintenance, troubleshooting, and repair; (3) require little logistical support; and (4) interface with existing shipboard piping and electrical systems while complying with the U.S. Environmental Protection Agency's Type-II marine sanitation device Effluent Quality Standards. The new prototype Blackwater Treatment System was evaluated in 1975 and 1976. The system produced effluent within U.S. Environmental Protection Agency Standards for a Type-II marine sanitation device. Design drawings for a prototype treatment system for further development are included.

ADMINISTRATIVE INFORMATION

This work was authorized by the U.S. Department of Commerce, Maritime Administration, Project 12-420-54-421, and was accomplished under Work Unit 2863-538.

BACKGROUND

In March 1973, the Assistant Secretary for Maritime Affairs, Department of Commerce, and the Manager of the Marine Department, Cleveland-Cliffs Iron Company (CCIC), expressed interest in a cooperative undertaking to assist merchant vessels in complying with EPA* effluent quality

*Definitions of abbreviations used are given on page vii.

standards for shipboard sewage treatment systems. The objective of the study was to reduce the capital costs, maintenance costs, and operating time required for crews to keep the shipboard systems then installed in operation. ›veland-Cliffs proposed that a testing program be implemented to determine the operating effectiveness of sewage treatment systems currently in use aboard Great Lakes iron ore carriers operated by CCIC.

On 27 April 1973, a meeting was held at the Maritime Administration, Division of Great Lakes Shipping, U.S. Department of Commerce. The meeting was attended by representatives of the Maritime Administration, the David W. Taylor Naval Ship Research and Development Center, the U.S. Coast Guard, the Environmental Protection Agency, the Cleveland-Cliffs Iron Company, and the Lake Carriers' Association. At that meeting it was decided that the Center was to evaluate the Chlorinator-Macerator* system aboard SS EDWARD B. GREENE and the BIOGEST "25"* system aboard SS WALTER A. STERLING.

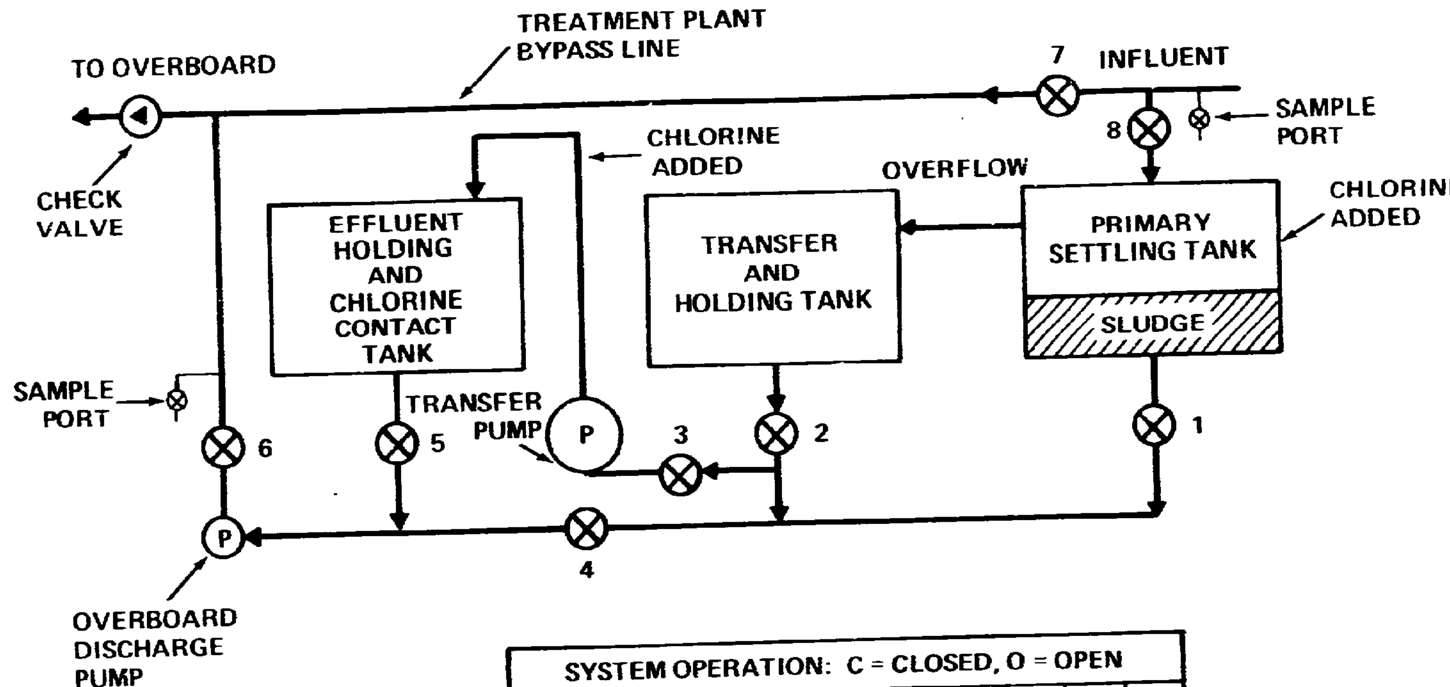
INITIAL SHIPBOARD EVALUATIONS

CHLORINATOR-MACERATOR SYSTEM DESCRIPTION

The first system evaluated was the Chlorinator-Macerator. A schematic of the system is shown in Figure 1. It is designed to treat blackwater (sanitary waste from commodes and urinals only) from the aft portion of the ship by (1) removing and retaining settleable solids for discharge when under way in open waters and (2) disinfecting the aqueous phase of the waste before discharge.

The system is composed of three connected tanks of approximately 300 gal (1.13 m^3) each. Blackwater enters the treatment plant through the primary settling tank; the settleable solids accumulate on the bottom of the tank as sludge. The aqueous phase of the wastewater, which overflows into the transfer tank, is composed of commode and urinal flushing water, urine, and suspended solids which were not removed in the primary settling

*American Shipbuilding Company, Lorain, OH.



SYSTEM OPERATION: C = CLOSED, O = OPEN								
VALVE #	1	2	3	4	5	6	7	8
NORMAL OPN.	C	O	O	C	O	O	C	O
SLUDGE DISCG.	O	C	C	O	C	O	C	O
PLANT BYPASS	–	–	–	–	–	C	O	C

Figure 1 - Chlorinator-Macerator Sewage Treatment System Aboard SS EDWARD B. GREENE

tank. When the transfer tank fills approximately three-quarters full, a liquid level sensor activates the overboard pump which empties the effluent holding and chlorine contact tank. A low-level sensor in the effluent tank activates a sodium hypochlorite pump. Wastewater in the transfer tank then is pumped to the holding tank. A sensor in the effluent holding tank deactivates the sodium hypochlorite pump and the transfer pump when the tank is full. The cycle is repeated each time the transfer tanks fills with wastewater. The sodium hypochlorite is stored as a 12- to 15-percent solution in a 2-gal reservoir. It is injected into the effluent holding tank to destroy the bacteria in the effluent. It is also injected into the primary settling tank as a conditioning agent to control bulking and improve sludge settling.

Sludge accumulated in the bottom of the settling tank must be removed periodically. This is accomplished, as shown in Figure 1, by discharge overboard. System operating instructions specify sludge discharge only in open waters away from shore.

Evaluation

The first Chlorinator-Macerator evaluation was conducted under way aboard GREENE during the period 22-28 September 1973. The objectives of that first evaluation were to become familiar with system operating requirements and to perform a preliminary evaluation of effluent quality.

Effluent quality was determined by analyses of wastewater samples in the DTNSRDC mobile laboratory "Honey," located for this project at the Erie Dock Company, Cleveland, OH. All analyses were conducted in accordance with procedures contained in Standard Methods.[1*] Wastewater samples were collected just prior to entering port, packaged with ice, and transferred to a representative of Cleveland-Cliffs Iron Company. The samples were then flown by scheduled airline to Cleveland where they were picked up and transported to the laboratory for analyses. The test plan called for a maximum of 24 hr between sample collection aboard ship and sample analysis in the laboratory.

*A complete listing of references is given on page 97.

Results

During the evaluation period, it was discovered that the overboard discharge check valve leaked, allowing lake water into the effluent holding tank. This occurred only when the ship was downbound with a load of ore; when upbound empty, the overboard scupper was above the waterline. Therefore, effluent samples were only collected during upbound trips. Influent and transfer tank samples were not affected by the faulty check valve.

Another problem was encountered in transporting samples from the ship at various Great Lakes ports to the mobile laboratory in Cleveland within 24 hr after collection. Samples were sent from Detroit, MI, Saute St. Marie, MI, Marquette, MI, and Duluth, MN. With only one exception, shipping times from those ports exceeded 24 hr. The majority of samples that were analyzed within 24 hr of collection were those hand carried to "Honey" by Center personnel when the ship arrived within reasonable driving distance of Cleveland.

The Chlorinator-Macerator System treated from 5 to 200 gal (19 to 757 ℓ) of influent per hour with a mean flow of approximately 64 gal (242 ℓ) per hour per day. Fecal coliform reduction was from 10^6 organisms per 100 ml in the influent to 10^3 organisms per 100 ml in the clarified effluent. Effluent total suspended solids and BOD were estimated at less than 100 and 50 mg/l, respectively. Based upon the limited number of samples analyzed, there was little reduction in dissolved solids. This is consistent with the degree of treatment expected from a primary treatment system. However, if the periodic overboard discharge of sludge from the bottom of the settling tank is taken into account, the net treatment obtained from the system is near zero. The suspended solids removed from the liquid phase of the waste are concentrated in the sludge, and there is no reduction in sludge bacterial population. The sludge generation rate was estimated as 25 gal (95 ℓ) per week.

To improve effluent disinfection to below 10^3 organisms per 100 ml, the following improvements to the chlorinator portion of the system were recommended:

1. Move the chlorine injection point from its location in the waste transfer pipe to the top of the effluent holding tank, adjacent to the waste transfer pipe inlet. This eliminates the problem of pressure

in the transfer pipe preventing proper chlorine injection and still provides adequate mixing of the chlorine solution in the effluent.

2. Install an adjustable timer in the injection pump control circuit to control pump operating time. The timer should be actuated at the start of the transfer cycle and should be adjustable within a range of approximately 30 to 300 s in intervals of as little as 5 s. This allows control of the quantity of chlorine injected during each pump-out cycle.

3. Install a valve in the injection line at each injection point. This will allow control of the proportions of chlorine injected into the settling tank and the effluent holding tank.

To improve net solids removal obtained from the system, development of an alternative to overboard discharge of sludge into receiving waters was recommended. The initial survey report suggested three sludge disposal options:

1. Retain the sludge on-board within the settling tank for periodic discharge to shore collection facilities. This would involve no major modifications to the system except for a ship-to-shore hose connection. The sludge could be collected ashore in a tank and hauled to a disposal site or pumped to a sewer.

2. Install a separate sludge thickening or drying system to concentrate the sludge and increase the interval between disposal periods.

3. Install an incinerator to reduce the sludge to a sterile ash. The ash then could be removed along with other solid waste.

A decision on the most feasible method of sludge disposal was left to Cleveland-Cliffs because it was not considered an objective of this program. CCIC eliminated discharge to shore collection facilities from consideration due to the unavailability of the facilities and the associated problems of the ship's crew connecting and disconnecting hoses. Shipboard sludge concentration or incineration systems also were discounted because of the complexity of the systems and the cost of installing and maintaining the additional equipment. They chose to incinerate the sludge in the ship's boiler.

It was further recommended that after the chlorinator portion of the system had been upgraded, the system be reevaluated to assess effluent quality improvements.

BIOGEST "25" SYSTEM DESCRIPTION

The second system evaluated was the BIOGEST "25" System. A schematic of the system is shown in Figure 2. It was designed to treat all blackwater and greywater from the aft portion of the ship. The chlorine contact tank was not included in the design of the original system. It will be discussed in context with the upgraded BIOGEST System. Table 1 lists the sources of wastewater.

The BIOGEST System contains approximately 2000 gal (7.6 m^3) of wastewater when operating and treats from 1500 to 5000 gpd (5.7 to 18.9 m^3 per day). Influent enters the aeration tank through a comminutor which reduces the size of the incoming solid waste particles. This speeds the digestive process which occurs in the aeration tank. Aerobic bacteria in the aeration tank digest the organic portion of the wastewater. Clumps of bacteria (activated sludge) flow along with the aqueous phase of the waste into the settling tank. The sludge settles to the bottom of the settling tank where it is picked up by airlift and returned to the aeration tank. The clarified liquid flows into the effluent holding tank. Liquid level probes in the effluent holding tank control the discharge of effluent when the tank is filled.

Evaluation

The first BIOGEST evaluation was conducted under way aboard STERLING during the period 29 September through 8 October 1973. The objectives of the evaluation were to become familiarized with system operating requirements and to evaluate effluent quality. As in the initial Chlorinator-Macerator evaluation, samples were collected aboard ship and sent to the mobile laboratory in Cleveland for analysis.

Results

During the second day of the evaluation it was discovered that the aeration tank drain valve had been open and the aeration tank was empty. Ship's personnel were unaware of the problem. Most of the activated sludge in this tank was being discharged overboard each time the liquid

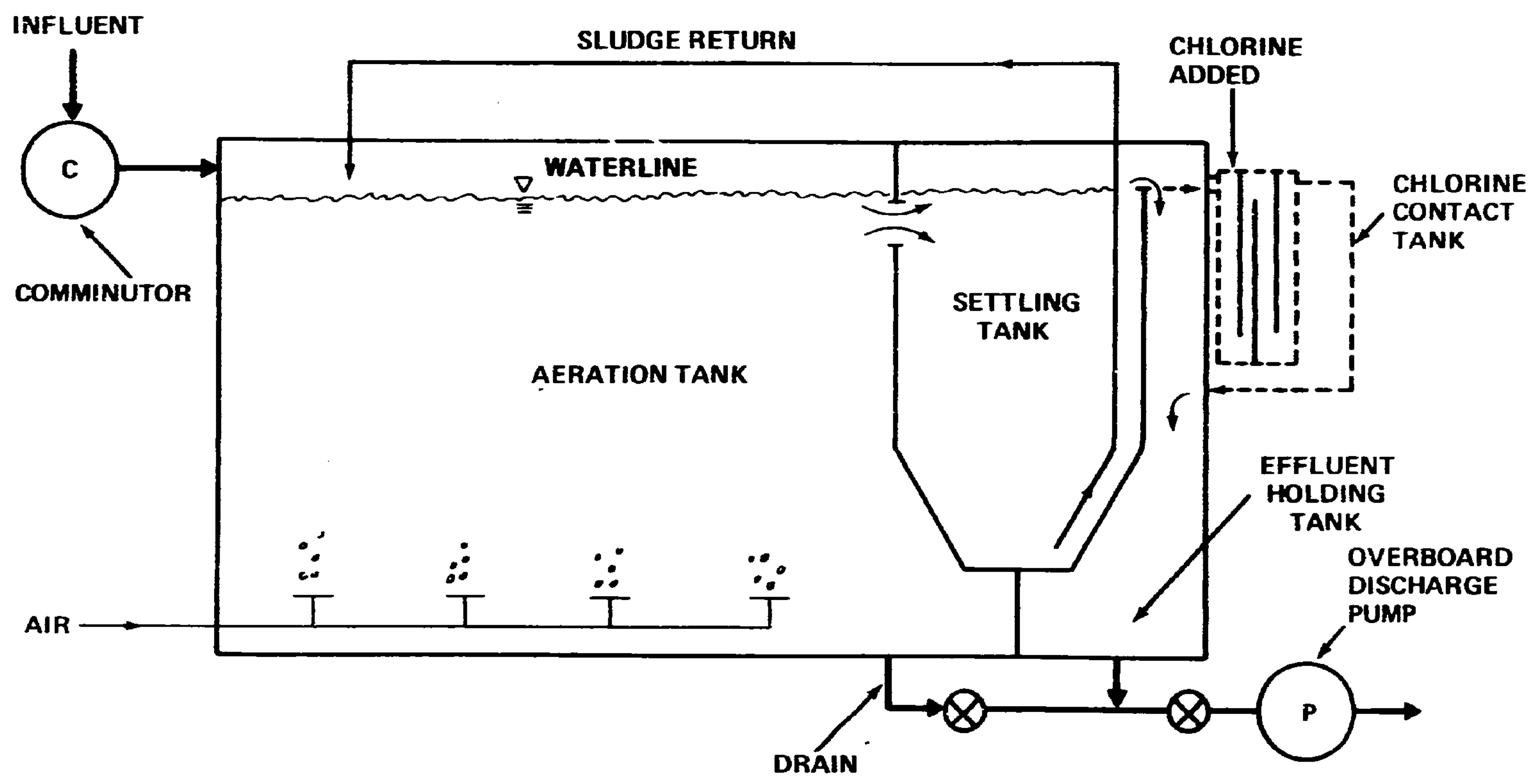


Figure 2 – BIOGEST "25" Marine Sewage Treatment System Aboard SS WALTER A. STERLING

TABLE 1 - SOURCES OF BLACKWATER AND GREYWATER DISCHARGING TO THE AFT BIOGEST TREATMENT PLANT ABOARD SS WALTER A. STERLING

Source	Quantity (Fixtures)
Staterooms	
Shower	18
Wash Basin	18
Commode	18
Passenger Lavatory	
Wash Basin	1
Commode	1
Galley	
Garbage Disposal	1
Dishwasher	2
Sink	3
Ice Cube Maker Drain	1
Refrigerator Drain	4
Wash Basin	1
Commode	1
Locker Room	
Wash Basin	3
Urinal	1
Commode	1
Water-Cooled Air Conditioner	2
Washing Machines	2
Wash Tub	2

level probes in the effluent holding tank activated the overboard discharge pump. The drain valve was closed, and the tank was allowed to fill.

Operation of the treatment plant was monitored for several days after the plant filled. Wastewater samples were collected from the influent and effluent lines, the aeration tank, and the sludge return. As with the Chlorinator-Macerator evaluation aboard GREENE, problems occurred getting samples from STERLING to the mobile laboratory in Cleveland in a timely fashion. Aeration tank dissolved oxygen and settleable solids measurements indicated that the plant did not start up and reach stable operating conditions during the 8 days of the evaluation.

The major deficiency noted in the BIOGEST System aboard STERLING was the absence of effluent disinfection. Therefore, it was recommended that a chlorination system be installed. The recommended system would consist of a chlorine contact tank, a chemical metering pump for injecting sodium hypochlorite disinfectant solution, a control system, and a reservoir for storing the solution. A suggested design for the chlorination system was developed.

It was recommended that, after the above chlorination system had been installed, the BIOGEST System be reevaluated to assess system performance and effluent quality.

EVALUATIONS OF UPGRADED SYSTEMS

CHLORINATOR-MACERATOR EVALUATION

The modifications to the Chlorinator-Macerator that were recommended following the initial evaluation were made aboard GREENE by CCIC during winter 1973-1974. Along with modifications to the Chlorinator-Macerator, CCIC chose to install the waste incineration system shown schematically in Figure 3. The system was manufactured by Babcock & Wilcox Company.* Sludge accumulated in the bottom of the settling tank was transferred to GREENE's boiler by a macerator pump at a rate of approximately 3 gpm (11 ℓ/min). The sludge was mixed with steam and atomized into the boiler through an injection nozzle. The nozzle assembly was inserted into the boiler during the sludge incineration period only. Sludge and steam flow rates were controlled manually with valves on the nozzle. At the end of the burn period, the macerator pump was turned off and a valve adjacent to the pump was closed. The sludge transfer pipe was then purged with steam to force sludge remaining in the transfer pipe into the boiler. The sludge incineration procedure required 30 min of operator time each week, including start-up and shut-down times.

*Babcock & Wilcox, Power Generation Division, Barberton, OH.

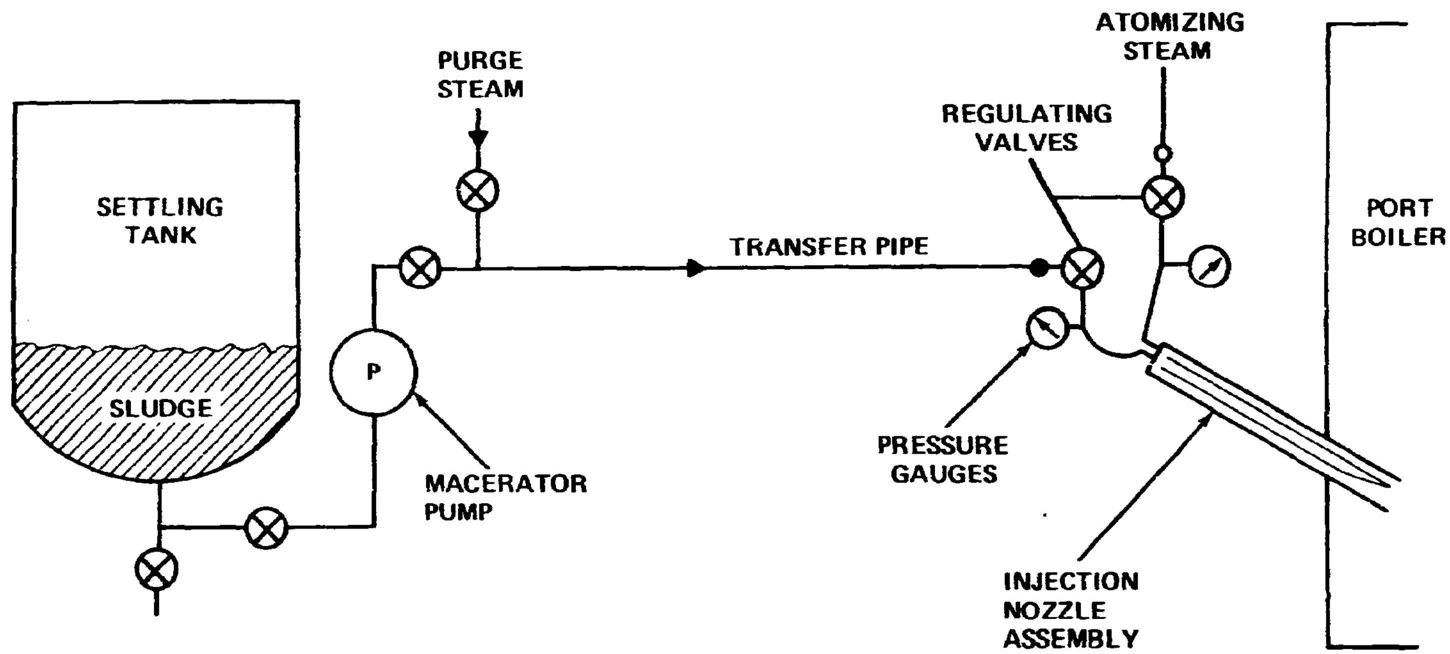


Figure 3 - Babcock & Wilcox Sludge Incineration System
Installed Aboard SS EDWARD B. GREENE

The evaluation began on 25 September 1974. An analytical laboratory was set up aboard GREENE in the engineer's office. This allowed analysis to begin within 2 hr after sample collection. Three influent and three effluent samples were collected each day from the sample ports shown in Figure 1. The samples were analyzed for residual chlorine, total suspended solids, 5-day biochemical oxygen demand, chemical oxygen demand, and fecal coliform bacteria. The chlorination system was set to inject approximately 360 ml of 12-percent sodium hypochlorite solution into the effluent holding tank each time wastewater was pumped from the transfer tank.

An influent flow profile was determined by taking hourly depth soundings of the wastewater in the transfer tank and using the depth to compute wastewater volume. By the fifth day of the evaluation, a daily flow profile had not yet developed as expected. Sampling was suspended on 30 September, and all three tanks were opened for inspection. A 30-in. (0.76 m) long crack was found in the seam where the wall between the transfer tank and the effluent holding tank was welded to the sidewall. This crack allowed wastewater to leak between the two tanks.

The influent was diverted directly overboard through the treatment plant bypass line, and the transfer and settling tanks were cleaned and dried. The crack was sealed with epoxy on 1 October, and normal operation was resumed on 2 October. Transfer tank soundings were resumed on 6 October and continued through 9 October.

Results

Figure 4 is a graph of the average flow profile determined from hourly tank soundings taken over a 4-day period. The average daily flow rate of blackwater through the plant was 1600 gpd (6.1 m^3/day). This was an average of 90 gal (0.34 m^3) per capita per day for the 18 crewmen living aft. The effluent tank discharged five times each day, thereby requiring the injection of about 0.5 gal (1.8 ℓ) of disinfectant per day.

The results of wastewater sample analyses are summarized in Table 2. Influent samples were collected during the period 25-30 September. Effluent samples were collected 2-9 October after the crack between the effluent and transfer tanks was repaired. One sample of sludge was collected from

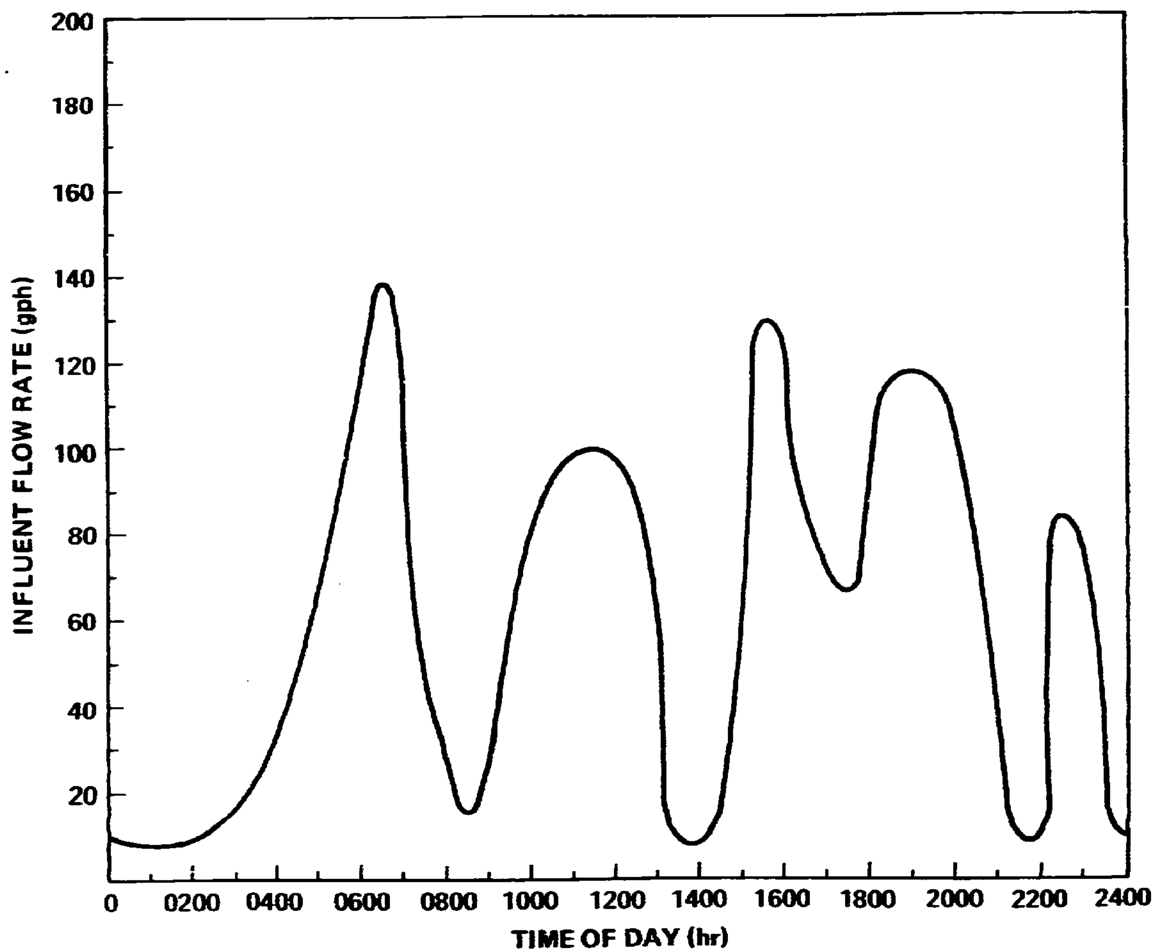


Figure 4 - Daily Influent Flow Profile to the Chlorinator-Macerator Sewage Treatment System

TABLE 2 – SUMMARY OF ANALYTICAL RESULTS OF SAMPLES COLLECTED FROM THE UPGRADED CHLORINATOR-MACERATOR SYSTEM ABOARD SS EDWARD B. GREENE

Parameter	Influent			Effluent					Initial Sludge Pumped to Boiler	Sludge Pumped to Boiler after 10 min
	No. of Samples	Mean	Standard Deviation	No. of Samples	Mean	Standard Deviation	EFA Standard No. of Samples Within	EFA Standard No. of Samples Over		
Temperature (^{o}C)				14	19	2.4	NA	NA		
TSS (mg/l)	15	243	181	15	63	22	15	0	1.8×10^4	68
BOD_5 (mg/l)	13	206	160	5	56	13	NA	NA	5.8×10^3	118
COD (mg/l)	15	534	297	15	237	36	NA	NA	1.7×10^4	372
Residual Chlorine (mg/l)				14	14.8	17	NA	NA		
Fecal Coliform (col/100 ml)	6	5.6×10^5	4.7×10^5	13			11	2		
SS (ml/l) after 30-min settling									950	<5

the sludge transfer pipe during an incineration period on 27 September. Approximately 45 gal (0.17 m^3) of waste was incinerated during 15 min.

Discussion

The high per capita flow rate was attributed to uncalibrated flushometers on the commodes and the lack of urinals which meant that a very large volume of flushwater was used after each urination. A significant reduction, estimated to be at least 50 percent in the volume of blackwater requiring treatment, would result from improved flushometer maintenance and the installation of urinals in heads near work areas. An attendant reduction in disinfectant chemical requirement would also result.

The primary settling tank removed 74 percent of the total suspended solids. All effluent samples were below the Type-II MSD standard of 150 mg/l established by the EPA. This high reduction of solids was attributed to the relatively large particles entering the tank. Feces and toilet tissue traveled only short distances via 4- and 6-in. diameter collection lines leading to the treatment plant. Therefore, very little particle size reduction occurred within the waste collection system, and the large solids settled readily in the settling tank. Furthermore, the solids removal was a true reduction in net solids discharged since the sludge was incinerated in the ship's boiler and not discharged overboard.

Residual chlorine in the plant's effluent ranged from less than 1 to 91 ppm even though the same quantity of disinfectant was added to the effluent tank following each pump-out. Analyses of the 12-percent stock sodium hypochlorite solution purchased by the ship in 1-gal containers showed that the concentration varied from less than 1-percent chlorine to 12-percent chlorine. Thus, no effective control of disinfection could be easily maintained unless every gallon of disinfectant was tested and the injection dosage adjusted accordingly.

In spite of the problem with control of disinfectant dosage, a reasonably good reduction in fecal coliform bacteria concentrations was obtained. Only two of the effluent samples exceeded the Type-II MSD standard of 200 col/100 ml. This reduction was attributed to the relatively large volume of disinfectant solution added to the effluent holding tank following each pump-out. With better control of the concentration of chlorine in the disinfectant, further bacteria reduction and decreased effluent residual chlorine should be attained.

Although evaluation of the upgraded Chlorinator-Macerator demonstrated improved performance compared to the original system, additional improvements in the ship's sewage treatment capability would be required to consistently attain Type-II MSD performance standards while the treatment system operates automatically.

BIOGEST "25" SYSTEM

The modifications to the BIOGEST System that were recommended following the initial evaluation were made aboard STERLING by CCIC during winter 1973-1974. A 20-gal (76-ℓ) chlorine contact tank was fabricated and mounted on the effluent tank end of the system as shown by the dash line in Figure 2. The tank was designed to assure that the disinfectant mixed with the effluent before entering the effluent holding tank.

Inspection of the BIOGEST System on 10 October 1974 revealed the plant was in generally poor condition. The chlorine system was not being operated due to an inadequate supply of sodium hypochlorite, the chlorine contact tank was filled with septic sludge, and the effluent holding tank had a sludge layer several inches thick on the bottom.

A meeting was held on-board with the ship's Chief Engineer and First Assistant to identify the problems associated with operating the BIOGEST System. The Chief Engineer explained that no one on-board had ever been trained to operate the biological system and other, much more serious shipboard equipment maintenance problems caused the BIOGEST to be neglected. It was decided at that time to suspend evaluation of the BIOGEST System pending a decision by CCIC on what manpower resources would be allocated to operate and maintain the system.

OZONATION SYSTEM - DEVELOPMENT

BACKGROUND

A meeting was held at DTNSRDC on 9 April 1974 to discuss continuation of the project in light of the evaluation results to date. Attendees included representatives from the Maritime Administration, CCIC, USCG, and the Center. The following major considerations were identified by Mr. John Horton of CCIC as being the most important for a shipboard wastewater treatment system:

1. Manpower. A shipboard STS should operate automatically with as little routine operator attention as possible. This is necessary due to the increasingly smaller crew sizes on commercial vessels. Other more vital systems demand an increasingly larger portion of a crewman's time.

2. Simplicity. A shipboard STS should be easily understood by ship personnel; it should be easy to maintain, troubleshoot, and repair. No specialized operator training should be required.

3. Logistical Support. A shipboard STS should be as self-supporting as possible to minimize procurement, transportation, storage, and handling of consumable materials. These materials include chemical disinfectants, biological additives, and replacement parts.

4. Compliance with Existing Regulations. A shipboard STS must comply with regulations promulgated by governments within the ship's normal operating area. In the case of the Great Lakes, this includes United States, Canadian, and state waters, as well as local jurisdictions.

5. Physical Characteristics. A shipboard STS should be as compact as possible without sacrificing the component accessibility required for equipment maintenance. The system should, if possible, occupy the same space currently utilized by existing holding tanks or treatment systems, and interface with already installed piping and electrical systems.

6. Cost. A shipboard STS should be economical to purchase, install, and operate; however, none of the previously mentioned considerations should be seriously neglected to achieve minor cost reductions.

Although the second evaluation of the Chlorinator-Macerator aboard GREENE demonstrated that adequate disinfection with this system was feasible, it also showed there were inherent reliability problems and requirements for significant operator attention. Most of the reliability and operator problems were due to the need for frequent sodium hypochlorite addition and the uncertain strength of the stock disinfectant solution. An alternative disinfection process was needed to reduce these problems without seriously increasing the complexity, size, and cost of the system. Another major consideration for future system development was the level of residual chlorine in the effluent discharged overboard. Due to the different governmental jurisdictions exercising control over various portions of the Great Lakes, attendees at the meeting felt that tighter controls on the discharge of effluent containing high concentrations of disinfectants for at least portions of the lakes were inevitable.

Mr. T. Scarano, USCG representative at the meeting, described the favorable experience that Coast Guard was having in the development of a shipboard wastewater treatment system using ozonation of mixed blackwater and greywater streams. Mr. C.R. Dedrickson, MARAD, suggested that preliminary work begin to investigate the possibility of using ozone to treat effluent from the Chlorinator-Macerator System aboard GREENE.

Before discussing the development and ensuing evaluation of the ozonation system, some important properties of ozone, its methods of generation, and its uses will be examined briefly.

OZONE PROPERTIES

Ozone (O_3) is an unstable gas with a characteristic, pungent odor. It is an allotropic (same composition, different properties) form of oxygen and is a powerful oxidizing agent. Its oxidizing power is exceeded only by fluorine.[2,3] It is formed naturally by photochemical reaction of sunlight and atmospheric oxygen in the Earth's stratosphere; at ground level it exists only at very low concentrations and is usually associated with smog and air pollution.[3] Ozone is one and one-half times as dense as oxygen and can be detected by smell at concentrations as low as 0.02 ppm by volume in air. It also has a tendency to decompose slowly in air back to oxygen.

Ozone follows Henry's law;[4] its solubility in water is proportional to its partial pressure over the solution. While it is about ten times more soluble in water than oxygen, once dissolved in water, O_3 is extremely unstable with an effective half-life of approximately 20 min. An increase in temperature and/or the presence of neutral salts and hydroxyl ions will greatly accelerate the rate of decomposition.[5,6] Because of its unstable character, O_3 must be produced at the location it is to be used.

Ozone can be produced by electrical discharge, by ultraviolet exposure of oxygen, and by electroysis of perchloric acid. The only practical and economical method available today for large-scale O_3 production is by the electrical, or corona, discharge principle.[7] In this method of O_3 synethesis, a source gas (dry air or oxygen) is passed into a gastight chamber of an O_3 generator, through a narrow gap separating a series of electrode pairs. When ac power is applied, stray electrons within the high energy field become excited and accelerate between the electrodes. As their velocity increases, the electrons collide with O_2 molecules in the feed gas, causing these molecules to split in two and then recombine with other O_2 molecules to form O_3.[3] Concentrations of O_3 in the order of 2 to 4 percent by weight may be obtained with an O_2 feed.[8] A dry air feed may produce 1 to 2 percent by weight, depending upon the sophistication of the generator.

WASTEWATER OZONATION

Ozone has been used in Europe for the treatment of water for over 75 years. Reviews of its early history and various specific applications have been reported by McCarthy and Smith, Diaper, Venosa, and others.[3-5,9] Today there are over 100 operating water treatment plants worldwide incorporating ozone.[10] The principal use of O_3 has been for the disinfection of potable water supplies. Its use as a disinfectant for municipal and industrial wastewater effluents has been limited because, until recently, there has been no requirement for the disinfection of wastewaters.

In the United States the principal use of O_3 has traditionally been in the chemical industry as an oxidizing agent.[11] More recently, it has been used to control airborne odors from wastewater treatment plants, manufacturing facilities, hospitals, and kitchens.[12,13] Ozone has not been widely accepted in the United States for potable water disinfection, primarily due to the availability of other less expensive chemicals. Additionally, the difficulty in obtaining and maintaining a residual in distribution systems has been cited as a disadvantage of O_3 as a disinfectant. This latter difficulty, however, does not stem from any inherent inability of O_3 to impart a residual, but rather from the fact that the O_3 demand of the water has not been completely met.[14]

Chlorination has long been the method of choice for disinfection of water supplies in the United States. Besides being a less expensive and a more readily available disinfectant, it maintains a residual in the distribution systems for added protection.

Recent studies, however, have shown that some chlorine residuals are toxic to aquatic life,[15-17] and the chlorination of water containing organic compounds can lead to the formation of halogenated compounds, some of which are known or suspected mutagens and carcinogens.[18-20] Today there is a list of over 400 organic compounds found in drinking water supplies that are either recognized or suspect potential carcinogens.[21] Only a relatively few of these have received comprehensive evaluation. In light of these current developments, the entire practice of water disinfection is being reevaluated, and other methods of disinfection and treatment are being investigated.

Ozone has been cited as an alternative method for the disinfection of water and wastewater, and a number of pilot treatment plants in the United States have been operated to demonstrate the feasibility and the advantages of O_3 over other disinfectants.[22] Advantages of using O_3 include its strong oxidizing capabilities, rapid reaction rates, efficient germicidal properties, and the formation of generally nontoxic products. Additionally, O_3 is capable of imparting a dissolved oxygen residual to water and removing color, taste, and odor as well as reducing BOD, COD, and TSS. The greatest advantage of O_3 over halogen disinfectants is its reaction with carbon to carbon double bonds (ozonolysis). Ozonolysis consists of breaking the molecule at the double bond, whereas halogenation consists of incorporating the halogen (i.e., chlorine) into the organic molecule, at the same site.

The germicidal effect of O_3 is not well understood, and a number of theories have been postulated. The most prevalent is that the O_3 attacks the lipid double bonds of the bacterial cell wall or membrane, causing cell lysis. Evidence of bacterial cell lysis after exposure to O_3 has been reported by Pavoni et al.[23] They monitored the COD of ozonated and nonozonated bacterial cultures and found that the COD increased and correlated well with increased bacterial kill. The exact mechanism of O_3

disinfection is probably intimately related to the dissociation of O_3 in water. Apparently, the free radicals formed by this dissociation are the principal reacting species.

The mechanisms and kinetics of the dissociation of O_3 in water, however, are also uncertain. A number of theories have been reviewed recently by Peleg[6] who suggests the following stages for O_3 decomposition in aqueous solutions:

$$O_3 + H_2O \rightarrow O_2 + 2OH \quad (1)$$

$$O_3 + OH \rightarrow O_2 + HO_2 \quad (2)$$

$$O_3 + HO_2 \rightarrow 2O_2 + OH \quad (3)$$

$$OH + OH \rightarrow H_2O_2 \quad (4)$$

$$OH + HO_2 \rightarrow H_2O + O_2 \quad (5)$$

$$OH + OH^- \rightarrow O^- + H_2O \quad (6)$$

$$O^- + O_2 \rightarrow O_3^- \quad (7)$$

$$HO_2 + HO_2 \rightarrow H_2O_2 + O_2 \quad (8)$$

Thus, the possible species that can be found in an aqueous O_3 solution are O_3, OH, HO_2, O^-, O_3^-, and probably free O_2 (since some O_3 will have decomposed in the air before reacting with water).

Substances which have high oxidation potential may also possess high germicidal activity.[6] Ozone has one of the highest oxidation potentials known, 1.24 V. However, the oxidation potential of the hydroxyl radical (OH) has been reported as 2.8 V, which suggests that the OH radical in water may be the species responsible for the strong germicidal activity and not the free O_3 itself. The amount, concentration, and dose of O_3 required for bacterial kill has been looked at by many investigators. Venosa[5] reviewed the literature and concluded that there was controversy, contradiction, and nonfactual subjective judgment concerning the use of O_3 for disinfection of water and wastewater. He cited the need for objective, controlled, and reproducible data on O_3 disinfection technology. Until these data are available, the use of ozone for treatment and/or disinfection of a specific wastewater must be by the method of trial and error.

LABORATORY EVALUATION

A contact system was fabricated to determine the feasibility of treating blackwater aboard ship with ozone. Little or no technical information on the design of low wastewater flow ozone contactors was available other than the effort by Grumman Aerospace* for the USCG under Contract DOT-CG-20733A. Grumman investigated multiple compartment contactors, static mixers, turbine mixers, and packed columns. They measured inlet and outlet dissolved oxygen concentrations to determine the effectiveness of the oxygen/water mixing and/or detention time. They concluded: (1) observations of gas bubbles introduced by porous plugs, sonic nozzles, and static mixers indicated all were equally effective; (2) bubble detention time was increased both by using packing and by increasing liquid column height; and (3) packed columns and turbine reactors performed as well as or better than multiple compartment ractors. The design of a Coast Guard/Grumman contactor was used to fabricate the stainless column as shown in Figure 5.

The column was 68 in. (1.7 m) tall and 10 in. (0.25 m) in diameter. The center segment of the column contained 2.6 ft^3 (0.07 m^3) of Pall ring packing. The Pall rings increased bubble detention time and prevented the bubbles from channeling up the column wall. The operating liquid level inside the column was maintained at approximately 58 in. (1.5 m) to retain 20 gal (76 ℓ) of wastewater during treatment. Primary effluent from a

*Grumman Aerospace Corporation, Bethpage, Long Island, NY.

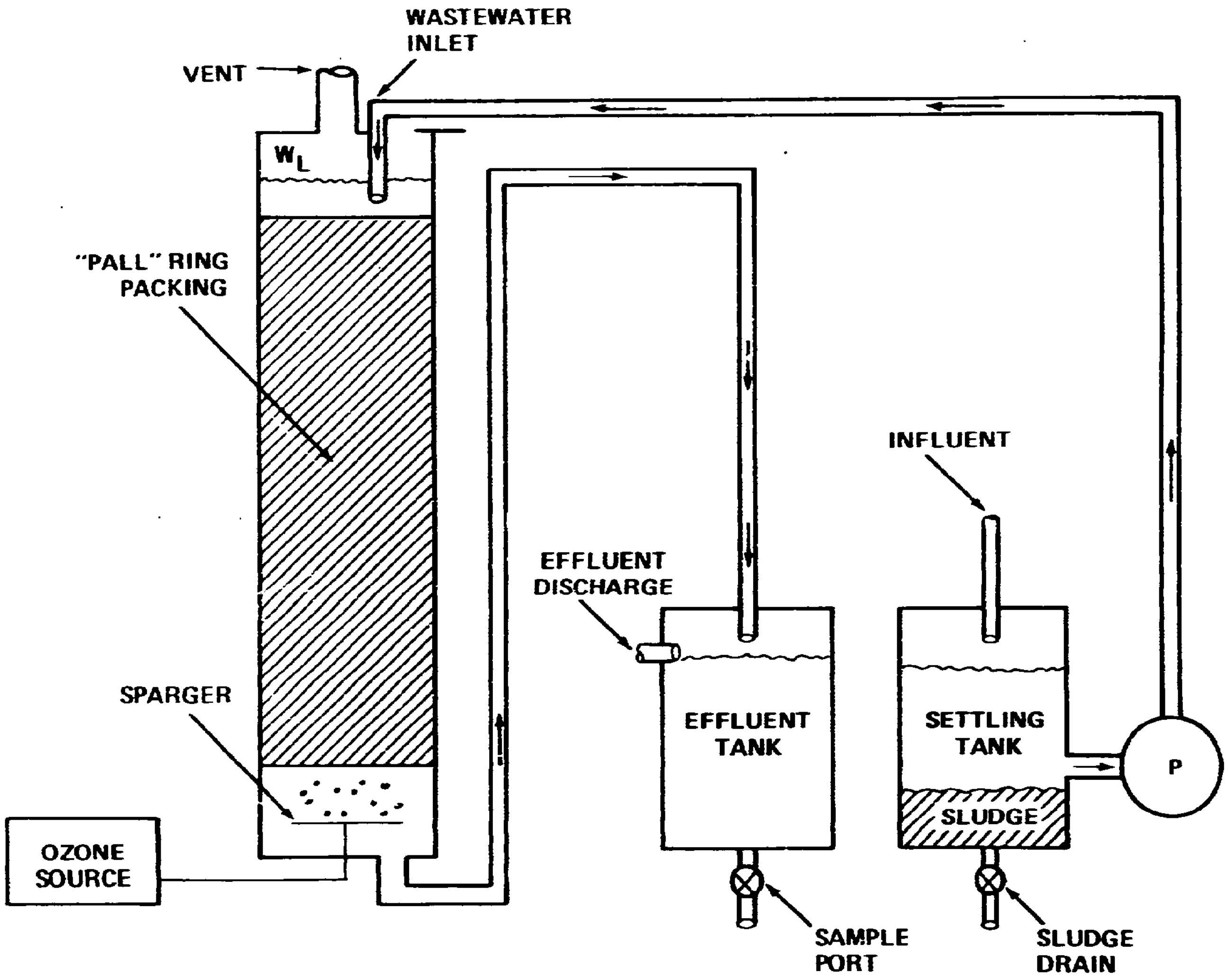


Figure 5 - Ozone Contact Column Laboratory Test Installation

settling tank was pumped into the top of the column at 1 gpm (3.78 l/min) by a positive displacement pump. Ozonated air was bubbled into the bottom of the column through sintered stainless steel spargers.

The ozone was supplied by a W.R. Grace, 1 lb/day (19 g/hr), Model LG-2-L2 corona generator.* It required a standard, grounded 120-V, 10-A, 60-Hz electrical source for power. Compressed air at 75 psig (517 kPag) for the generation of ozone was supplied by the laboratory compressed air supply. The air was filtered and dried by a heatless (pressure swing cycle) drier to a dew point of $-40^{\circ}F$ ($-40^{\circ}C$). The generator was operated at airflows from 10 to 100 $stdft^3$ (0.28 to 2.8 m^3) per hour and at inlet air pressures from 50 to 100 psig (340 to 690 kPag). Electrical power supplied to the corona cell was adjusted manually with a variable resistor. In general, for a given wattage at a low airflow, concentration was high and the yield low; at a high airflow, concentration was low and the yield high.

LABORATORY TEST 1

The reactor was operated from 21 May 1975 through 2 June 1975. The blackwater measured suspended solids concentration of the primary effluent from the Chlorinator-Macerator aboard GREENE was simulated by passing blackwater through a 30-gal (114-ℓ) settling tank and then into the ozone contact column. Settleable solids removed in the settling tank were discharged intermittently to a sanitary sewer. The operating conditions and a summary of test results are contained in Table 3.

Reduction in fecal coliform bacteria was poor. The reduction in total suspended solids (66 percent) appeared to be significant; however, when the column was opened for inspection, the Pall rings were found covered with a slime layer. Although the solids were not quantified, it appears that a portion of the solids reduction in the wastewater was due to entrapment. The packing would have eventually become clogged with organic material if operation of the column continued.

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*W.R. Grace and Company, Baltimore, MD.

TABLE 3 - SUMMARY OF ANALYSES OF INFLUENT AND OZONATED EFFLUENT FROM PACKED STAINLESS STEEL COLUMN

Ozone Dose	44 mg/l*
Sewage Liquid Flow Rate	1 gpm (3.8 l/min)
Influent TSS	412 mg/l
Effluent TSS	140 mg/l
Influent Fecal Coliform	9.2×10^6 col/100 ml
Effluent Fecal Coliform	2.3×10^6 col/100 ml

*mg ozone per liter of wastewater.

It was apparent that a new ozone reactor was needed that would be capable of treating wastewater containing relatively high concentrations of suspended solids without causing a buildup of sludge inside the reactor.

McNabney and Wynne[24] found that the ozone transfer rate of a continuous, counter current, contacting system was not very high. However, the ozonation efficiency for oxidizing organics was high when COD and TOC were high. In batch reactor tests they found that high shear roughly doubles the rate of COD and TOC reduction. Liquid-film transfer controls mass transfer of relatively insoluble gases such as oxygen or ozone. They stated: "When any liquid-gas surface is formed, molecules of both the liquid and the gas orient themselves at the interface. It has been reported that a thin film of water molecules surrounding the gas bubbles at the interface seem to cling to the bubbles and be carried along through the liquid by gas bubbles in their upward journey. This means that the major barrier to mass transfer is imposed by the presence of a stagnant liquid film through which mass transfer must occur. Thus, by increasing the agitation of the liquid phase so as to continually renew contact surface exposed to the gas phase, resistance to mass transfer would be reduced. High agitation in combination with high shearing action would achieve these requirements."[24] Diaper states that, to secure the maximum oxidizing effect with the minimum dose, ozonized air should be divided into the largest possible number of the smallest possible bubbles as it mixes with the water, while maintaining relative motion between the bubbles and water.[25]

OZONE REACTOR DEVELOPMENT

An ozone reactor was designed for treating wastewater containing suspended solids. A schematic of this reactor is shown in Figure 6. The reactor was constructed of two concentric Plexiglas cylinders. Ozonated air injected into a sintered stainless steel sparger located inside the bottom of the inner cylinder causes a rapid upward circulation of wastewater (50 to 75 gpm (190 to 284 l/min)) in the inner cylinder measured as the bubbles rise. Wastewater flows downward between the cylinders. There is a high scouring velocity across the bottom of the reactor because the bottom of the inner cylinder is raised slightly off the lower flange. This high velocity keeps solids from settling and accumulating beneath the sparger. A propeller rotating in the top third of the inner cylinder shears the rising bubbles to increase bubble contact surface area. All entering wastewater must pass through the high shear zone caused by the propeller. The internal flow pattern, propeller, and smooth sides of the columns assure a totally mixed reactor, with the greatest volume of wastewater flowing through the inner column many times before being displaced by incoming wastewater. The device was granted United States Patent 4,072,613 on 7 February 1978.

LABORATORY TEST 2

In July 1975, the Plexiglas reactor (R2) was connected in series with the stainless steel column (R1) as shown in Figure 7. The Pall ring packing in R1 had been removed. The direction of flow through this column was reversed in an attempt to remove solids if they settled beneath the spargers.

Evans[26] reported that most work on ozone disinfection has been done in pure water and single culture systems, and there appears to be a "threshold dose" which must be exceeded, prior to which there is slight bacterial kill and subsequent to which there is rapid kill. Threshold

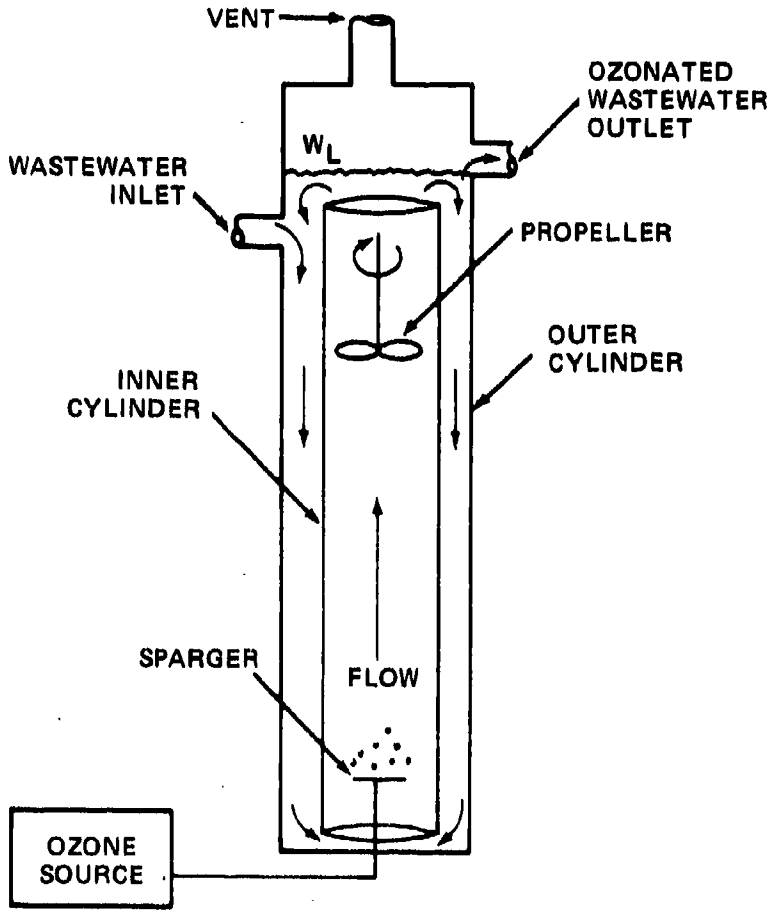


Figure 6 - Concentric Cylinder, Stirred, Wastewater Ozone Reactor

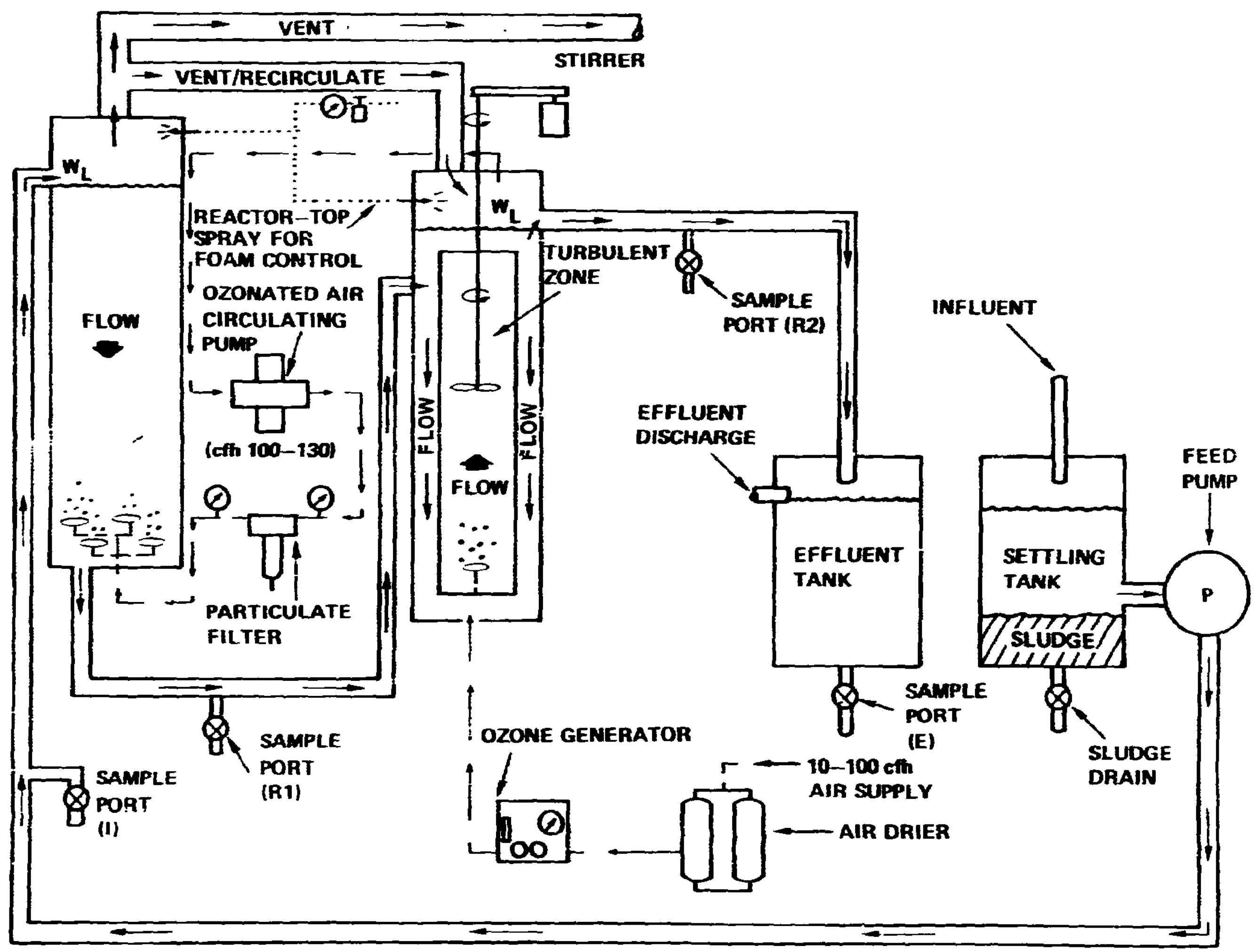


Figure 7 - Ozonation System Laboratory Test Installation

dose is a function of an "ozone demand" of the water which is an inverse function of the degree of treatment prior to ozone application. It is believed that satisfying the ozone demand and disinfection occur simultaneously. Therefore, a greater degree of pretreatment reduces the ozone demand by removal of the more easily oxidizable substances and wastewater solids which "shield" organisms from the disinfectant.[26]

Ozonated air from a 1-lb/day ozone generator was supplied to R2 in order to take advantage of the ozone demand theory described by Evans. The ozone in the bubbles passing through that unit had not reacted completely; therefore, the air space above the water column contained residual ozone. To utilize that ozone, a small diaphragm pump was used to pump the gas from the top of R2 to R1. The lower concentration of ozone in R1 was used to satisfy partially the ozone demand of the wastewater entering the system. The higher concentration of ozone coming from the generator was available in R2 to increase the likelihood of ozone contacting the bacteria.

The ozonated air from R2 was filtered to remove particles that could eventually clog the spargers in R1. The pressure differential across the filter was measured to determine when to replace the filter cartridge.

Table 4 shows the results of two laboratory test runs using different strength influent wastewaters. The data show excellent reductions of fecal coliform bacteria using BOD and TSS concentrations similar to those measured in the primary effluent aboard EDWARD B. GREENE during the 1973 and 1974 Chlorinator-Macerator System evaluations. These findings were the bases of the decision to install the system aboard GREENE and conduct a shipboard evaluation.

OZONATION SYSTEM - INITIAL SHIPBOARD EVALUATION

SYSTEM DESCRIPTION

Automatic controls were installed to operate the ozonation system independently of the Chlorinator-Macerator System. Thus, the ship's sanitary plumbing drains did not have to be secured during ozonation system installation, and the ozonation system could be modified or repaired easily without inconveniencing ship's personnel. The ozonation system was

TABLE 4 - SUMMARY OF ANALYSES OF OZONATED WASTEWATER USING STAINLESS STEEL REACTOR (R1) IN SERIES WITH CONCENTRIC CYLINDER PLEXIGLAS REACTOR (R2), MEAN VALUES

	Influent Wastewater	Effluent From RI	Effluent From R2
Ozone Dose at 36 mg/l with 1 gpm (3.8 l/min) Sewage Flow Rate			
TSS (mg/l)	71	51	41
BOD_5 (mg/l)	101	63	50
Fecal Coliform (col/100 ml)	1.4×10^7	9.7×10^6	57
Ozone Dose at 40 mg/l with 1 gpm (3.8 l/min) Sewage Flow Rate			
TSS (mg/l)	131	96	89
BOD_5 (mg/l)	235	171	126
Fecal Coliform (col/100 ml)	2.5×10^7	6.4×10^6	480

installed aboard GREENE by Cleveland-Cliffs Iron Company on 5 and 6 September 1975. Figure 8 is a schematic of the installation in its initial shipboard configuration. Raw, unmacerated sewage from water closets (there are no urinals on-board) in the aft portion of the ship drains by gravity into an influent tank. Settleable solids in the influent settle to the bottom of the tank where they accumulate as sludge. Baffles in the tank trap floating solids until they decompose and settle with the sludge. The sludge layer that accumulates in the bottom of the settling tank is decomposed anaerobically. Once each week, the sludge is pumped from the bottom of the tank to the ship's port boiler for incineration, as described earlier.

Influent sewage displaces an equal amount of clarified wastewater from the surface of the influent tank, over a weir, and into the primary

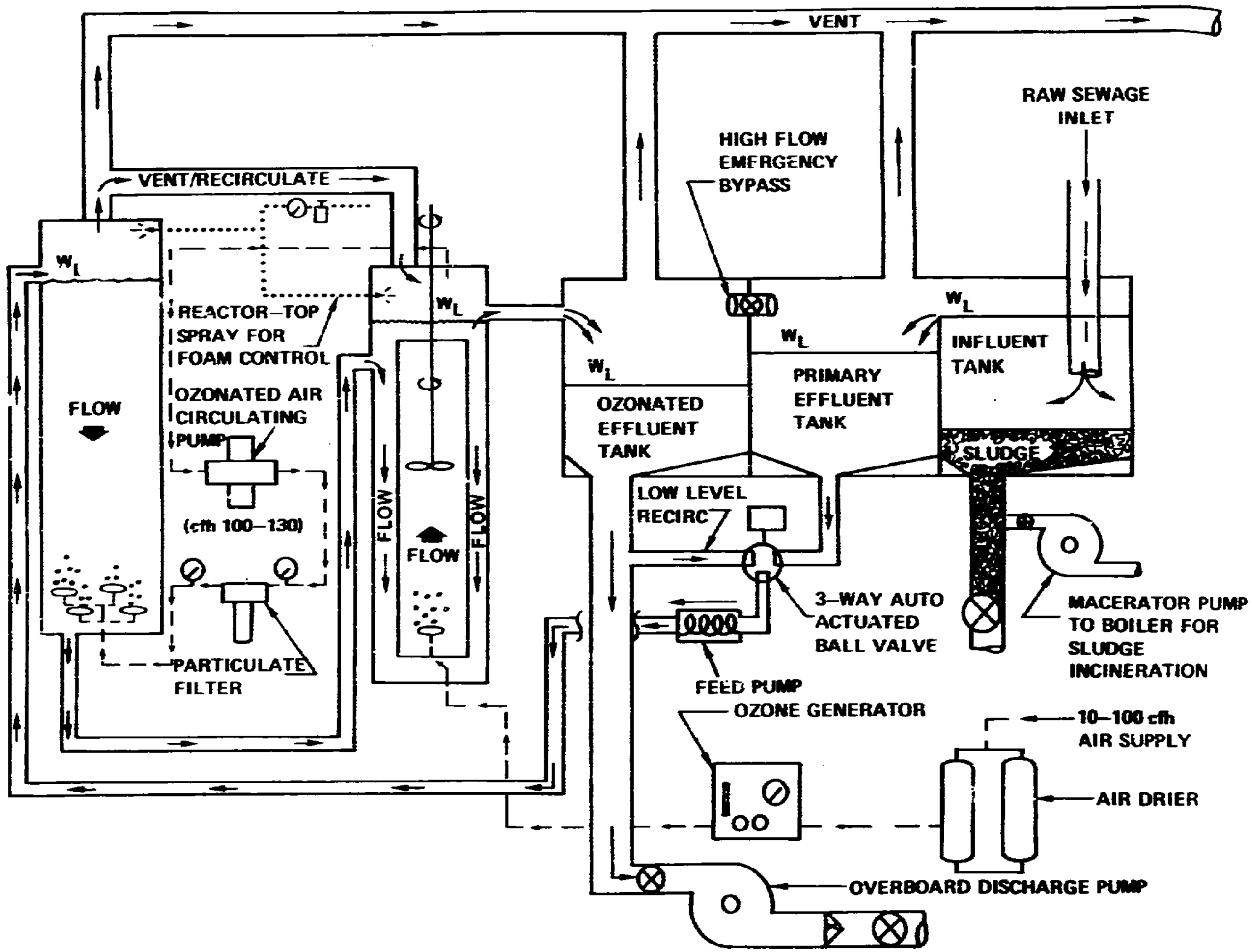


Figure 8 - Initial Shipboard Ozonation System Installation

effluent tank. The nominal detention time in the influent tank is 6 to 8 hr based on a 300-gal (1.14-m^3) tank and a measured daily influent flow of 900 to 1200 gal (3.4 to 4.5 m^3). The primary effluent tank functions as a surge tank. It holds primary effluent (generated during periods of peak flow) for treatment during periods of low flow. A positive displacement, progressing cavity sewage feed pump continuously withdraws wastewater from the primary effluent tank and pumps it into the first-stage ozone reactor. The feed pump flow rate is adjusted as needed by changing the pump-to-motor pulley ratio.

Clarified effluent from the primary effluent tank enters the first-stage stainless steel reactor (R1) and leaves from the top of the second-stage Plexiglas reactor (R2). Ozonated air enters the reactor system through the R2 air sparger and leaves from R1, passing to the atmosphere via an existing vent line. The ozonation system is the same counter-current flow system previously evaluated at the Center. The ozonated effluent from R2 enters the Chlorinator-Macerator's effluent holding tank and is discharged overboard on demand of tank level control sensors.

When the flow rate into the influent tank is insufficient to supply primary effluent to the continuously operating feed pump and the primary effluent tank is nearly empty, a signal to an automatic actuator diverts the three-way ball valve in the inlet line of the feed pump to the low level recirculate position. The ozonated effluent from the ozonated effluent tank recycles back through the ozone reactors. Recirculation continues until the primary effluent level rises. A signal then is sent to the automatic actuator, which returns the three-way ball valve to its original position, and normal operation resumes (see Figure 8). During periods of low level recirculation, an amber light and an elapsed time meter on the control panel are activated.

During the shipboard evaluation, low level recirculation occurred approximately 5 hr each night when the feed pump rate was 0.86 gpm (3.25 l/min). The primary effluent tank liquid level was low at the beginning of each day and allowed maximum utilization of the tank's capacity for absorbing peak flows. Ozone was generated by the same 1-lb/day corona generator used in the laboratory tests.

Laboratory equipment was shipped from DTNSRDC, and an analytical laboratory was set up in the chief engineer's office adjacent to the engine room. This provided the capability to begin analysis for TSS, FC, COD, BOD, and DO immediately after sample collection. All analyses were performed in accordance with Standard Methods.[1]

SYSTEM SAFETY

The sewage feed pump was operated at approximately 1 gpm (3.8 l/min). If an unusually high flow condition occurs (e.g., a commode flushometer stuck open), the holding capacity of the primary effluent tank can be exceeded, causing sewage to back up in the drain lines and possibly overflow from a commode. A 2-in.-diameter pipe, viz, "the high flow emergency bypass line," was installed between the primary effluent tank and the ozonated effluent tank as a precautionary measure during the evaluation. The bypass allows primary effluent to overflow directly into the ozonated effluent tank. When the source of high flow is located and the fault resolved, the feed pump gradually lowers the sewage to a level below the bypass. A high flow bypass condition is indicated by an amber light and recorded on an elapsed time meter located on the control panel. The function of the light and time meter is to alert an operator that high flow conditions exist. If increased normal loading occurs, as indicated by brief but frequent high flow indications, the feed pumping rate can be increased slightly to accommodate it and prevent high flow bypasses from recurring. During the shipboard evaluation, the level of primary effluent never unintentionally reached the high flow emergency bypass line.

An ambient air ozone monitor was incorporated into the shipboard test installation to detect increases in the background ozone concentration in the vicinity of the sewage treatment system. It measured ozone concentration as parts per million (volume) ozone in four ranges (0-0.5, 0-1.0, 0-5.0, and 0-10.0) by photometric detection of the chemiluminescence resulting from the flameless reaction of ozone and chemically pure grade ethylene. The monitor has a variable set alarm which closes an internal switch when a predetermined ozone concentration is exceeded. An alarm on the treatment system control panel will alert engine room duty personnel long before health hazards can develop. Ozone leaks were located by using a filter paper strip that had been saturated with a dilute solution of potassium iodide and dried. The KI filter paper turns brown when exposed to low concentrations of ozone.

INITIAL PERFORMANCE EVALUATION

On 23 September 1975, the system was put on line for the first time to conduct the initial performance evaluation which continued through 4 October 1975. All alarm and control circuits were tested. The ozone generator was not turned on because air pressure began building up in the holding tanks. The vent line for the sewage treatment system tanks leads approximately 40 ft (12 m) upward from the tanks, where it emerges on the upper weather deck aft of the ship's smokestack. A vented cover is welded onto the top of the vent to prevent the entry of foreign objects and rain. An investigation revealed that the tank vent line was clogged with rust.

The vent line was cleaned and proper Chlorinator-Macerator System operation was confirmed. The Chlorinator-Macerator control system was turned off, and the ozonation of GREENE's sewage started on 25 September 1975. Ozonated effluent began flowing into the ozonated-effluent tank at 2135 hr.

Sampling began on 26 September and continued through 2 October 1975. Thirty effluent samples (E), 21 second-stage reactor effluent samples (R2), 14 primary effluent samples (T), 10 influent samples (I), and 4 influent composite samples (IC) were collected during that period. Influent samples were drawn from the raw sewage inlet line before influent entered the system. Primary effluent samples were collected from the discharge line of the feed pump as the primary effluent was being transferred to the first-stage ozone reactor. Ozonated-effluent samples were collected from the discharge line of the overboard discharge pump during a pump-out. Second-stage reactor effluent was sampled before it could enter the ozonated-effluent tank.

Operation of the ozonated air recirculating pump supplying ozone to Reactor R1 was to be observed during the evaluation to determine filter replacement frequency and pump maintenance requirements. However, on

1 October the stainless steel flapper check valves on the inlet side of the pump failed. No ozonated air was pumped to the first-stage reactor until the pump was repaired on 3 October.

RESULTS

Approximately 1100 gal (4.2 m^3) of sewage per day were processed. Twenty-nine effluent samples were collected. A summary of the laboratory analytical results is given in Table 5. Table 6 gives the percent reduction of TSS, FC, COD, and BOD resulting from the treatment.

TABLE 5 - SUMMARY OF LABORATORY ANALYTICAL RESULTS
MEAN VALUES

Sample	No. of Samples	TSS (mg/l)	FC (col/100 ml)	COD (mg/l)	BOD (mg/l)	DO (mg/l)
IC	4	360	10^{6}*	700	300	5.4*
T	14	77	10^{7}	220	131	2.2
E	29	42	3×10^{3}	170	46	8.2

*From influent samples.

TABLE 6 - POLLUTANT REDUCTIONS
DURING PROCESS, PERCENT

Sample From	Sample To	TSS	FC	COD	BOD
IC	T	78	-	68	56
T	E	45	99.97	23	65
IC	E	88	99.70	76	85

Seven effluent fecal coliform samples (24 percent) were below the target level of 1000 col/100 ml, only three effluent samples (10 percent) met the 1980 standard level of 200 col/100 ml, and all effluent TSS samples (100 percent) met the proposed Type-II MSD standard of 150 mg/l.

During the study, the feed pump speed was varied to determine what pumping rate was necessary to prevent the primary effluent tank from filling to the high flow bypass level during peak influent flow rate periods. This was done to keep the daily low level recirculate time as short as possible without ever reaching a high flow condition. A slower feed rate yielded a longer detention time in the ozone reactors. Feed pump rates of 0.5 gpm (1.9 l/min), 0.75 gpm (2.8 l/min), 0.86 gpm (3.25 l/min), and 1.0 gpm (3.8 l/min) were used. A comparison of high flow and low flow elapsed time meter readings indicated that 0.86 gpm (3.25 l/min) was the slowest acceptable flow rate.

The ambient air ozone monitor performed satisfactorily except for an occasional spurious alarm triggered by vibration of the meter. The OSHA standard for exposure to ozone does not permit exceeding a time weighted average of 0.1 ppm during any 8-hr work shift or a 40-hr week. Ambient air ozone concentration readings were recorded each time an effluent sample was collected. Ozone concentration in the air above the ozone reactors rarely exceeded 0.1 ppm. When higher levels were detected, leaks in the piping system were quickly found using the KI paper method and were easily repaired. No ozone was detected escaping to atmosphere from the vent on the upper aft weather deck during this phase of shipboard testing.

During the shipboard study, 8400 ppm (vol.) ozone was measured in the supply from the generator to the second-stage reactor; 32 ppm of ozone was measured going into the first-stage reactor, and 16 ppm of ozone was being vented from the first-stage reactor into the wastewater holding tank vents. Thus, 99.7 percent of the applied ozone was consumed in the reactors.

The filter in the recirculated ozone line not only separated particulates but also separated water vapor. It was necessary to drain the filter cartridge every 2 or 3 days. Cartridge replacement frequency was estimated to be 2 weeks.

DISCUSSION

The objective of the study was to demonstrate that the system was capable of meeting the 30 January 1975 marine sanitation device standard for effluent quality. This required maintaining an effluent with a fecal coliform bacteria concentration less than 200 col/100 ml for a Type-II MSD.

The first effluent samples were collected on 26 September. The effluent fecal coliform concentrations for that day ranged from 1800 to 7600 col/100 ml. These exceeded the levels measured during the laboratory evaluation. To determine if the effluent was being contaminated in the effluent holding tank, samples were collected before the ozonated secondary effluent flowed into the tank. For 20 reactor effluent samples collected during the period 27 September through 2 October, the mean fecal coliform concentration was 3111 col/100 ml. Although this indicated that some fecal contamination could have been picked up inside the holding tank, the high fecal coliform in the reactor effluent samples clearly showed that ozonation was not producing an acceptable discharge. There was no measurable residual ozone in the effluent.

The system was secured at 1800 on 2 October 1975 for inspection. Based on this inspection and analyses of collected data, it was concluded that the general problem of insufficient fecal coliform reduction was probably due to a combination of the following reasons:

1. High Sewage Flow Rate. A higher than normal flow rate reduced the expected contact time. The degree of disinfection is a function of contact time. Although there was a marked reduction in flow from that measured during the Chlorinator-Macerator evaluation, approximately 1100 gal (4.2 m^3) of influent per day entered the system. Thus, approximately 60 gal (227 ℓ) of blackwater per man per day was generated for the 18 men living and working in the aft portion of the ship. Extensive Navy experience has shown that six flushes per man per day could be expected. Thus, an average of 10 gal (38 ℓ) of water was used per commode flush.

2. Inefficient First-Stage Ozonation. During the inspection it was noted that a layer of sludge and slime had accumulated at the bottom of the first-stage reactor (R1). This was probably caused by a combination of factors. The velocity of wastewater was low, and some suspended solids

that may have been carried through the influent settling tank settled to the bottom of the reactor. There is also a space in Reactor R1 between the bottom of the tank and the four spargers which is a stagnant zone with little or no ozone contact. When the reactor was disassembled for inspection, this zone, including the screen supporting the Pall rings, was covered with slimy bacterial growth. The notable exceptions were four 3-in.-diameter circular areas on the screen surface directly above the spargers. Slime was prevented from accumulating in those areas by the ozonated air bubbles rising from the spargers. The slime in the first-stage reactor increased ozone demand. This left less ozone available for disinfection. If all interior surfaces can be contacted with ozonated air, the tank surfaces would remain clean. This is the principle behind the concentric cylinder design as demonstrated in the second-stage reactor (R2). At the end of the test period, the inner walls were clean. The few visible solids observed entering R2 remained in suspension until they were either oxidized or carried from the reactor into the ozonated-effluent tank.

3. Insufficient Ozone Supply. The data showed that 99.7 percent of the generated ozone was consumed in the reactors. There was no ozone residual in the effluent from the second-stage reactor. A review of the literature on disinfection with ozone indicates that a residual ozone content of 0.1 ppm would be sufficient to maintain disinfected effluent. There was still no effluent ozone residual even when the system was working properly at the beginning of the study period. This indicated that the 1-lb/day (19-g/hr) ozone generator may not have generated enough ozone for the system. This was supported by the low (30 ppm by volume) ozone concentration measured in the reactor vents. The wastewater ozone demand apparently had not been fully satisfied, although the chemical effluent quality as shown previously in Table 5 was reasonably good; the physical quality of the effluent was excellent (low turbidity, no color, no odor).

4. Ozonated Air Pump. Failure of the ozonated air recirculation pump near the end of the test period prevented the pretreatment of the primary effluent necessary to satisfy ozone demand before disinfection in the secondary reactor could occur. Although the pump operated reasonably well after its initial failure and subsequent repair, it continued to run

hot to the touch. It is known that the half-life of ozone is temperature dependent, but the decrease in ozone concentration of the recirculated air as it passed through the pump was not measured. The hot running temperature (estimated at 120° to 150°F (49° to 66°C) of the pump had a possible adverse effect on the quantity of ozone supplied to the first-stage reactor.

RECOMMENDATIONS

Based on this evaluation, it was recommended that the following modifications be made to improve the sewage treatment system's performance and reliability and that the system be reevaluated for a 10-day period during the 1976 Great Lakes shipping season (April through December 1976):

1. Adjust, and maintain in adjustment, the flushometers aboard ship; or replace with new flushometers than can be adjusted. They should flush with the minimum amount of water required for satisfactory operation.

2. Clean the vent lines leading from the tanks. This will improve the flushing characteristics of the crew heads.

3. Replace the stainless steel column R1 with a reactor similar in design to R2.

4. Replace the 1-lb/day (19-g/hr) ozone generator with a 2-lb/day (38-g/hr) generator. This should provide enough ozone to achieve satisfactory treatment and still have some reserve capacity.

5. Replace the ozonated air recirculation pump with a cooler operating, more reliable model.

6. Clean and repaint the inside of the ozonated-effluent tank. This will provide a smooth surface and reduce the tendency of organic deposits to collect on the walls of the tank.

7. Shock mount the ozone generator and ambient air monitor to reduce the effect of vibration and the possibility of damage to equipment caused by ship movement.

8. Add a short time delay circuit to the high ambient air ozone concentration circuit to prevent ship's vibration from triggering an alarm.

OZONATION SYSTEM - FINAL SHIPBOARD EVALUTIONS

The following modifications were made to the prototype ozonation system on-board GREENE. The system configuration is shown in Figure 9.

1. The stainless steel column was replaced by a concentric cylinder reactor fabricated of PVC. The concentric-cylinder design ozone reactor had demonstrated its ability to maintain sewage solids in suspension and prevent settling and sludge accumulation on the reactor bottom beneath the spargers.

2. The 1-lb/day (19-g/hr), air-cooled ozone generator was replaced by a 2-lb/day (38-g/hr), water-cooled model. The new generator was modified to assure electrical connections and fasteners were secure and resistant to vibration. It used dry air supplied by its own compressor in lieu of ship's compressed air.

3. The ozonated air recirculating pump was removed from the system. A metering valve was installed in the ozonated air line leading to R2, and a flowmeter with regulating valve was installed in the ozonated air line leading to R1. By adjusting the valves and subtracting the R1 flowmeter reading from the ozone generator flowmeter reading, the ozone supply to each reactor could be controlled and measured. Removal of the pump simplified the system and eliminated the need to monitor pressure drop across the filter and replace the filter when it clogged. A contributing factor in eliminating the pump was the difficulty in finding a cool running pump that would operate continuously while pumping moist, ozonated air at flow rates up to 200 ft^3/hr (5.6 m^3/hr) and pressures from 10 to 30 psig (69 to 207 kPag).

4. The old shipboard flushometers were replaced with new adjustable flushometers to regulate the quantity of water used for flushing. The new flushometers reduced the overall daily hydraulic load from 1100 gal (4.2 m^3) to 400 gal (1.5 m^3).

5. The feed pump supplying primary effluent to the ozone reactors was set at 0.5 gpm (1.9 l/min). Thus, on a daily basis, the system operated in a low level recirculate mode 10.6 hr/day. This provided longer retention time in the reactors and additional treatment of the wastewater being recirculated.

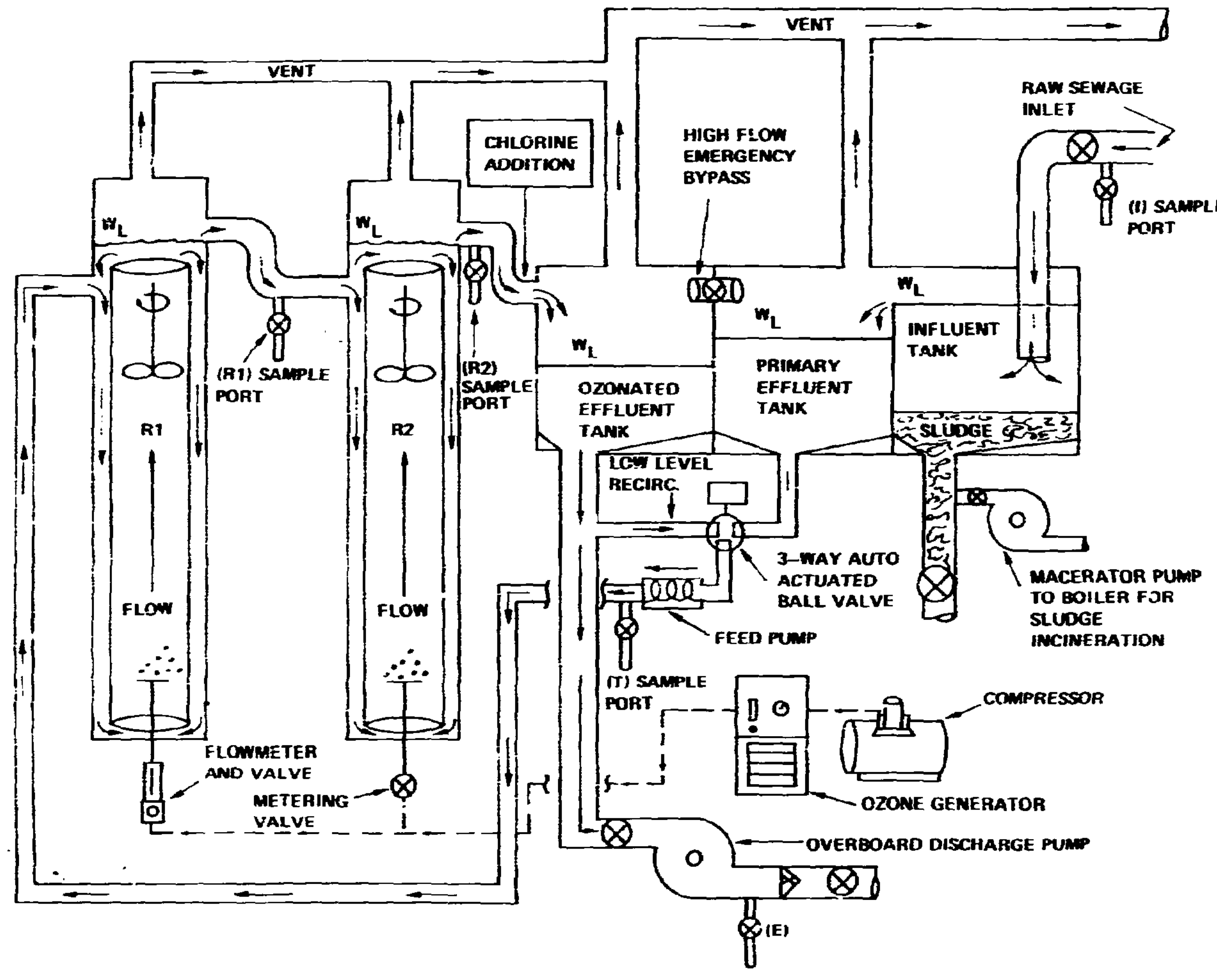


Figure 9 - Final Shipboard Prototype Ozonation System
Aboard SS EDWARD B. GREENE

6. The three Chlorinator-Macerator tanks were sand blasted, and the interiors were painted to provide smooth, clean surfaces.

7. The vent lines from the Chlorinator-Macerator tanks were cleaned and checked for leaks.

JULY 1976 EVALUATION

Evaluation of the upgraded system began on 7 July 1976. The ozone generator was operated at maximum power, and air pressure in the generator was varied from 10 to 17 psig (69 to 117 kPag). Air flow rates were varied from 120 to 190 ft^3/hr (3.4 to 5.3 m^3/hr), with air flow equally distributed between the two ozone reactors. Analyses of various wastewater streams were made on-board GREENE.

On 11 July 1976, a high liquid level alarm signalled that the primary effluent tank was full. An investigation of the problem revealed that the stator in the feed pump was worn and the pump was not pumping effluent to the ozone reactors. The evaluation was suspended until October when another stator was obtained.

Results of 3 days of sampling in July are summarized in Table 7. Data are contained in Appendix A.

TABLE 7 - SUMMARY OF 8-10 JULY 1976 ANALYTICAL RESULTS OF PROTOTYPE OZONATION SYSTEM SHIPBOARD EVALUATION, MEAN VALUES

Parameter	Sample Collection Location				
	I	T	R1	R2	E
FC (col/100 ml)	5.6×10^5	1.4×10^7	5.5×10^5	3.2×10^4	5.5×10^3
TSS (mg/l)	452	58	29	26	16
COD (mg/l)	668	245	175	170	124

Analyses of samples showed good reductions in TSS and COD; however, fecal coliform bacteria concentrations remained higher in the effluent than desired. Additional ozonation did not appear to further reduce fecal coliform concentrations. This was attributed to the remaining ozone demand of the wastewater consuming the ozone before it could contact and destroy all the bacteria. There were no ozone residuals in the effluent.

OCTOBER 1976 EVALUATION

Reevaluation of the prototype system was resumed on 2 October 1976, following repairs of the feed pump. Results of 3 days of sampling are summarized in Table 8. Data are contained in Appendix A.

TABLE 8 - SUMMARY OF 2-4 OCTOBER 1976 ANALYTICAL RESULTS OF PROTOTYPE OZONATION SYSTEM SHIPBOARD EVALUATION, MEAN VALUES

Parameter	Sample Collection Location				
	I	T	R1	R2	E
FC (col/100 ml)	-	24×10^6	4.9×10^5	3.6×10^4	8.3×10^4
TSS (mg/l)	351	234	176	122	201
COD (mg/l)	739	927	586	491	570

As in the July 1976 evaluation, fecal coliform bacteria concentrations in the effluent were high. On 5 October sludge was withdrawn from the bottom of the influent tank and burned in the ship's boiler, and the effluent tank was pumped out and cleaned.

Due to the continuing high residual fecal coliform bacteria in the sewage treatment system's effluent, it was apparent that an additional disinfection step would be required. Further, due to the inherent problem in obtaining a residual ozone level in the effluent holding tank, it was decided to use a very low dose of 5-percent sodium hypochlorite solution (bleach) for this final disinfection step.

A diaphragm-type chemical feed pump and a reservoir were mounted on the ozonated-effluent tank to inject sodium hypochlorite into the line leading from R2 to the effluent holding tank as shown in Figure 9. Five-percent sodium hypochlorite (bleach) was added at a dose rate of 3 ppm. At that dose, stock solution was consumed at a rate of 163 ml/day. That low rate of disinfectant usage was considered acceptable when compared to 1800 ml/day of 12-percent sodium hypochlorite solution used by the Chlorinator-Macerator System.

Sampling resumed on 6 October 1976. Results of that sampling are summarized in Table 9. Data are contained in Appendix A.

TABLE 9 - SUMMARY OF 6-7 OCTOBER 1976 ANALYTICAL RESULTS OF PROTOTYPE OZONATION SYSTEM SHIPBOARD EVALUATION, MEAN VALUES

Parameter	Sample Collection Location				
	I	T	R1	R2	E
FC (col/100 ml)	-	5.6×10^6	2.7×10^5	10	10
TSS (mg/l)	882	72	54	40	35
COD (mg/l)	1476	264	228	217	191
Free Chlorine (ppm)	-	-	-	-	0.87

The prototype ozonation system continued to operate on-board EDWARD B. GREENE from October 1976 through December 1976 with no problems reported by the ship. In December the ozone generator was removed and the ozonation system was secured.

DISCUSSION

The results of the 6-7 October 1976 sampling demonstrated that, with the addition of very small amounts of chlorine to the ozonated effluent, the prototype ozonation system was capable of treating shipboard blackwater to a Type-II MSD Standard. Bacteria destruction was attributed to the complementary effects of ozonation followed by chlorination.

Ozone dissolved in water is extremely unstable and rapidly decomposes with the germidical species reacting quickly with the waste products in the water. For ozone to destroy a bacterial cell, contact with the cell must be made before the ozone or one of its germicidal species reacts with other matter in the waste stream. In primary effluent with high turbidity, TSS, BOD, and COD, such as that found aboard ship, it is difficult to contact all bacterial cells with ozone even at high dose rates and relatively long contact time. Maintaining an ozone residual in such a wastewater appears to be impractical, if not impossible.

Sodium hypochlorite (NaOCl), on the other hand, dissociates to hypochlorous acid (HOCl) and hypochlorite ion (OCl^-). HOCl is the primary germicidal species; it combines with nitrogenous compounds to form chloramines. Chloramines are also effective disinfectants and they have the added advantage of being very long lived in wastewater, thereby adding to chlorine residual.

Thus, in the prototype ozonation system, the ozone greatly reduced the chemical demand of the wastewater for disinfectant while destroying over 99 percent of the fecal coliform bacteria. Thereby, a much lower dose of chlorine was required to complete disinfection than was required for the Chlorinator-Macerator System originally installed aboard GREENE (163 ml of 5-percent HOCl per day versus 1800 ml of 12-percent HOCl per day). Additionally, a very much lower chlorine residual in the effluent holding tank was easily maintained: 1.3-ppm total chlorine with 0.9-ppm free chlorine measured 1 min after sampling. Effluent chlorine residuals in GREENE's original Chlorinator-Macerator were very difficult to maintain and varied widely, ranging to a measured high of 91 ppm with a mean value of 14.8 ppm.

OZONATION SYSTEM - FINAL DESIGN

Based upon the successful operation and evaluation of the prototype treatment system aboard GREENE, the system design was finalized.* A sketch of the system is shown in Figure 10. Appendix B contains copies of the plans and specifications for construction of a complete system. Electrical drawings are not included; equipment installation instructions (effluent discharge pump, feed pump, ozone generator, macerator pump, and liquid level probes) are sufficient to provide information on interconnections. A control panel is provided in the system for locating motor starters, switches, pilot lights, etc, as desired.

In the final design, an inclined screened device removes most solids first. Solids removal by settling had the major disadvantage of maintaining contact between the solid and liquid phases of the waste for too long a period of time. Sludge accumulated in the bottom of the influent tank anaerobically decomposes and thereby greatly increases the quantity of dissolved organic species in the primary effluent.

The solids concentration in the aqueous phase is reduced greatly by intercepting and removing the solids from the flushing water as soon as possible. This will increase the effectiveness of ozonation by greatly reducing the wastewater ozone demand and possibly result in a reduction in the chlorine added, with a consequent reduction of chlorine residual.

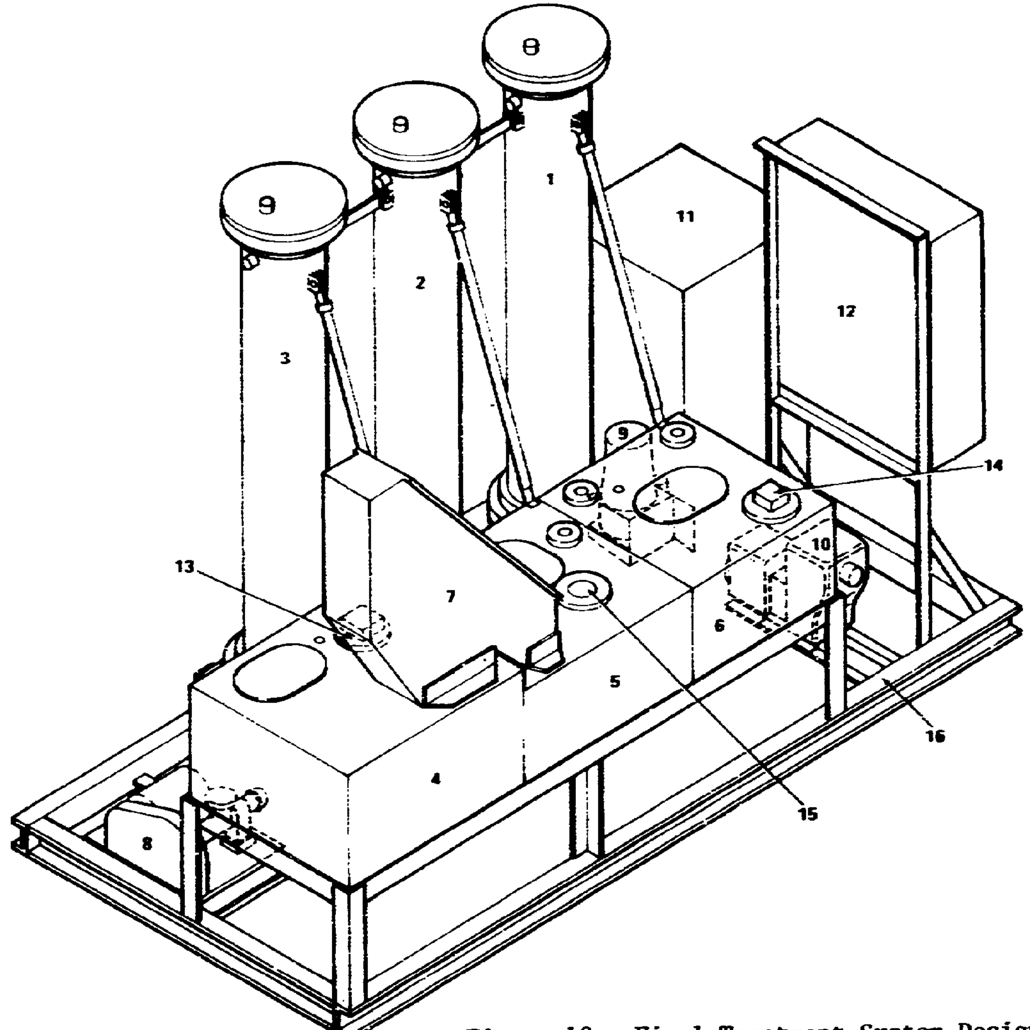
The system layout is designed to accommodate the same space as the Chlorinator-Macerator System aboard GREENE. Components are laid out for ready access for maintenance. The system could be reduced in overall dimensions if desire.

The following is a description of the operation of the system shown in the drawings in Appendix B.

SOLIDS SEPARATION

Ship's sanitary wastewater enters the treatment plant by gravity from the blackwater plumbing drains. The solid and liquid phases are separated

*A U.S. Government patent application for the system has been filed.



1 REACTOR - 1ST STAGE
2 REACTOR - 2ND STAGE
3 REACTOR - 3RD STAGE
4 TANK - PRIMARY EFFLUENT
5 TANK - SLUDGE
6 TANK - HOLDING
7 HYDRASIEVE NO. 552-7
8 FEED PUMP ASSEMBLY
9 MACERATOR PUMP
10 OVERBOARD DISCHARGE PUMP
11 OREC OZONATOR
12 CONTROL PANEL
13 PRIMARY EFFLUENT TANK PROBE
14 HOLDING TANK PROBE
15 SLUDGE HOLDING TANK PROBE
16 BEDPLATE

Figure 10 - Final Treatment System Design

by a Hydrasieve™.* The solids fall into the sludge holding tank. The liquid flows through the screen into the primary effluent tank.

SLUDGE HOLDING TANK

Sludge accumulates in the holding tank until a probe in the tank senses the sludge and actuates a service/pump-out light on the control panel. Service frequency is estimated to be weekly, depending upon waste generated and solid/liquid separation efficiency. A manually started macerator pump withdraws the sludge from the tank. Prior to disposal, the sludge is recirculated several minutes while a fine spray of water enters the tank. This macerates the solids and conditions the sludge for easier tank cleaning and sludge withdrawal. The macerator pump also is used to pump the conditioned sludge to the ship's boiler (or some other location) for disposal. During sludge pump-out, water from the spray nozzle is used to help clean the tank.

PRIMARY EFFLUENT TANK

Liquid from the Hydrasieve accumulates in the primary effluent tank. This tank functions as a surge tank and holds primary effluent (generated during periods of peak flow) for treatment during periods of low flow. A positive displacement progressing cavity feed pump continuously withdraws wastewater from the primary effluent tank and pumps it into the first-stage ozone reactor. Wastewater flows through the three reactors by gravity into the effluent holding tank. When the flow rate into the Hydrasieve is insufficient to supply primary effluent to the feed pump and the level of liquid in the primary effluent tank drops to a low level, a probe in the tank signals an automatic actuator which diverts a three-way ball valve in the inlet line of the feed pump to the low level recirculate position. The effluent from the effluent holding tank then is recycled back through the ozone reactors until the primary effluent level rises. A probe then signals the automatic actuator which returns the three-way ball valve to its original position.

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*C.E. Bauer, Springfield, OH.

EFFLUENT HOLDING TANK

Ozonated and chlorinated wastewater is accumulated in the effluent holding tank. Probes in the tank actuate a circuit which turns on the effluent discharge pump when the tank is full and turns off the pump when the tank is empty.

OZONE REACTORS

The ozone reactors are without stirrers. The stirrers were eliminated to simplify the shipboard system mechanically and to reduce maintenance requirements. In this application any loss of efficiency will be compensated for by an additional (third) ozone reactor to increase contact time. A 2-lb/day (38-g/hr) ozone generator will supply enough ozone for the three reactors. To divide the ozone among the reactors, each is equipped with a regulating flowmeter in the ozone inlet line. The portion of ozone supplied to each reactor should be adjusted so that nearly the same concentration of ozone is measured in the vent above each reactor. This will indicate that the ozone demand of the wastewater being treated in each reactor is satisfied at least to the extent possible by this reactor design and ozone concentration. When adjusting the ozone flow rate, R1 should require more ozone than R2, which should require more than R3.

The adjustment of ozone dose to each reactor should be required only when the system is first put on-line aboard ship, as long as the characteristics of the wastewater entering the reactor do not appreciably change (flow rate, solids concentration, COD, etc). This should not occur under normal conditions and with proper urinal and commode flushometer maintenance.

OZONE GENERATOR

The OREC Model O3DN-1,* 2-lb/day (38-g/hr) ozone generator specified for this system was developed for the U.S. Coast Guard Office of Research and Development (Contract DOT-CG-62, 702-A) specifically for use aboard ships. Specifications are available from OREC.

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*Ozone Research and Equipment Corporation, Phoenix, AZ.

TANK LIQUID LEVEL ALARMS

Each tank is equipped with a high level alarm probe. The primary effluent tank is equipped with a low level alarm in case the motorized ball valve fails in the normal operating position. The feed pump is designed to operate continuously, but it must not run dry; if the low level recirculate fails to operate and the liquid reaches a lower level, a probe signal stops the pump and sounds an audible alarm on the control panel.

REACTOR FOAM CONTROL

The bubbling action in the ozone reactors generates foam in the air space at the top of the reactors. If this foam is allowed to accumulate, it can enter the vents, deposit fine suspended solids stripped from the wastewater, and eventually cause blockages. The foam is broken using fire main water injected as a fine spray across the air space atop of each reactor. Water (1/10 gpm) (0.38 l/min) is sprayed into each reactor at 40 psig (280 kPag).

TANK DRAINS

Each tank and ozone reactor has a drain line. Liquid in the reactors, primary effluent tank, and effluent holding tank can be pumped overboard. The sludge in the sludge tank can be pumped overboard by the macerator pump via the plant bypass line in the event of a failure in the sludge disposal system (not part of this treatment plant). In the event of an overboard discharge pump failure, the reactors and the primary effluent and effluent holding tanks can be drained to the ship's gravity drain system, usually leading to the bilge. Additionally, each tank is equipped with a connection and valve to the fire main for use when cleaning and flushing tanks.

CHLORINATION

The shipboard tests determined that it was necessary to slightly chlorinate the effluent to maintain a residual disinfectant. A chlorination subsystem consisting of a reservoir and adjustable metering pump (not shown in Appendix B) should be included in the system. Sodium hypochlorite solution (laundry bleach) should be injected into the pipe leading from the last ozone reactor to the effluent holding tank. The pump should be adjusted to provide approximately a 3-ppm dose or that dose sufficient to maintain a chlorine residual from 0.5 to 1.0 ppm in the effluent.

CONCLUSIONS

1. Ozone alone did not provide adequate disinfection of the effluent. It was necessary to add small quantities of chlorine to the effluent to maintain a slight residual disinfectant.

2. Ozonation reduced TSS, COD, BOD, and bacteria, eliminated color and odor, and oxygenated the effluent. This conditioning prior to chlorination also acted as a buffer against variations in influent quality. Additionally, ozone treatment helped reduce the variability of the effluent chlorine demand, thus allowing more precise control of chlorine dose rate at low levels and thereby minimizing the concentration of residual chlorine discharged overboard.

3. The treatment system can be operated automatically with weekly replenishment of the chlorine supply (liquid laundry bleach at 5.25-percent sodium hypochlorite) and sludge disposal as required.

RECOMMENDATIONS

The treatment system described in Appendix B is a prototype system design based upon the experience gained during laboratory and shipboard evaluations. As of this report date, which is the termination of the project, the final design system has not been constructed or evaluated. The following are recommended if the system is constructed and installed aboard ship:

1. Determine the effectiveness and capacity of the system based upon the final design.

2. Establish an optimum chlorine dose rate for maintaining a minimum residual in the effluent while retaining satisfactory effluent bacteria kill.

3. Determine the ozone dose rates for each reactor required to treat the wastewater prior to chlorination.

4. Establish an influent quality range such that solids separation, ozonation, and chlorination will consistently produce satisfactory effluent quality.

5. Investigate the system's capability for treating greywater.

ACKNOWLEDGMENTS

This project was a cooperative effort between the Maritime Administration and the Cleveland-Cliffs Iron Company. The Maritime Administration Project Managers were Mr. J. Seelinger and Mr. C.R. Dedrickson (Retired) of the Office of Great Lakes Shipping. The Cleveland-Cliffs Iron Company Project Manager was Mr. J.L. Horton; additional support was provided by Mr. J.C. Culbertson. Their assistance and guidance is greatly appreciated. Assistance also was provided by Mr. Thomas S. Scarano, U.S. Coast Guard, Office of Research and Development, who related the experience of the Coast Guard in shipboard ozonation of sanitary waste and provided guidance for final selection of an ozone generator.

Special recognition goes to Mr. Norman Bragiel, Chief Engineer of SS EDWARD B. GREENE, for his patience and assistance in all aspects of shipboard testing and to the officers and crew of SS EDWARD B. GREENE.

APPENDIX A

TABULATED RESULTS OF SHIPBOARD EVALUATION OF PROTOTYPE SEWAGE TREATMENT SYSTEM ABOARD SS EDWARD B. GREENE

TABLE A.1 - LABORATORY ANALYTICAL RESULTS
JULY 1978 EVALUATION

Date	Time	Influent	Primary Effluent	Effluent From First Contactor	Effluent From Second Contactor	Effluent From Overboard Discharge
Fecal Coliform (col/100 ml)						
7/8/76	0900	5.6×10^5	3.7×10^7	1.4×10^6	6.8×10^3	1.7×10^3
	1500	-	1.9×10^7	9.7×10^4	$>10^5$	$>10^4$
	2200	-	2.8×10^7	$>10^5$	$>10^5$	$>10^4$
7/9/76	1230	-	6×10^6	2×10^6	2.2×10^4	1.2×10^4
	1830	-	6×10^6	6.9×10^5	1.9×10^4	7.6×10^3
7/10/76	0845	-	6.1×10^6	1×10^3	1×10^3	20
	1200	-	3.6×10^6	3×10^3	1.9×10^3	1.4×10^3
	1730	-	3.2×10^6	1.2×10^5	6.7×10^3	550
Mean		5.6×10^5	1.4×10^7	5.5×10^5	3.2×10^4	5.5×10^3
SD		-	1.3×10^7	7.6×10^5	4.25×10^4	4.87×10^3
Total Suspended Solids (mg/l)						
7/8/76	0900		54	21	20	8
	1500	1076	44	-	28	36
	2200		42	38	36	6
7/9/76	1230	216	50	26	28	20
	1830		54	54	36	18
7/10/76	0845		54	12	8	16
	1200	63	52	22	14	20
	1730		110	30	40	6
Mean		452	58	29	26	16
SD		546	22	14	11	10
Chemical Oxygen Demand (mg/l)						
7/8/76	0900		177	117	130	112
	1500	877	207	134	172	125
	2200		255	220	137	65
7/9/78	1230	462	223	133	137	114
	1830		270	243	255	165
7/10/78	0845		231	110	157	102
	1200	666	-	-	90	133
	1730		352	270	278	176
Mean		668	245	175	170	124
SD		208	56	67	65	35

TABLE A.2 - LABORATORY ANALYTICAL RESULTS OCTOBER 1978 EVALUATION

Date	Time	Influent	Primary Effluent	Effluent from			Effluent	
				First Contactor	Second Contactor	Overboard Discharge	Residual Total	Chlorine Free
Fecal Coliform (col/100 ml)								
10/2/76	1200	-	3×10^6	3000	180	2×10^3	-	-
	1600	-	1.9×10^6	2.1×10^4	7.8×10^4	1.8×10^4	-	-
	2000	-	3.4×10^6	3000	400	1.4×10^4	-	-
10/3/76	0800	-	4.2×10^6	1.4×10^6	5.4×10^4	2.3×10^4	-	-
	1200	-	1×10^6	1.3×10^6	7×10^4	9.2×10^4	-	-
	1600	-	2.2×10^6	3.1×10^5	8.4×10^4	3×10^5	-	-
	2000	-	1.4×10^6	3.1×10^5	1.7×10^3	4.5×10^4	-	-
10/4/76	0800	-	2.2×10^6	3.2×10^5	1.4×10^4	1.5×10^5	-	-
	1200	-	2.6×10^6	7.2×10^5	1.8×10^4	9.9×10^4	-	-
*	Mean		2.4×10^6	4.9×10^5	3.6×10^4	8.3×10^4	-	-
	SD		10.0×10^5	5.4×10^5	3.6×10^4	9.5×10^4	-	-
10/6/76	0800	-	5.6×10^6	<100	<10	<10		
	1200	-	6.2×10^6	<100	<10	<10	1.5	0.9
	1600	-	1.1×10^7	1.4×10^6	<10	<10	1.5	1.0
	2000	-	8.1×10^6	7.4×10^4	<10	<10	1.0	0.6
10/7/76	0800	-	1×10^6	1.3×10^5	<10	<10	1.0	1.0
	1200	-	1.6×10^6	<100	<10	<10	1.3	0.8
Mean		-	5.6×10^6	2.7×10^5	<10	<10	1.3	0.9
SD		-	3.8×10^6	5.6×10^5	0	0	0.3	0.2

*Effluent tanks were cleaned and flushed. Five-percent sodium hypochlorite solution was automatically added to effluent from the second ozone contact column at a dose rate of 3 ppm. Total residual chlorine measured in the effluent during 6 and 7 October ranged from 1.0 to 1.5 ppm at the time of effluent discharge.

TABLE A.2 (Continued)

Date	Time	Effluent	Primary Effluent	Effluent from First Contactor	Effluent from Second Contactor	Effluent from Overboard Discharge
Chemical Oxygen Demand (mg/l)						
10/2/76	1200		878	521	597	635
	1600	688	1308	433	344	604
	2000		1030	373	373	398
10/3/76	0800		651	610	521	477
	1200	828	752	664	550	562
	1600		897	610	597	-
	2000		702	610	367	509
10/4/76	0800	702	1251	780	572	771
	1200		872	670	499	600
Mean		739	927	586	491	570
SD		77	230	125	103	113
10/6/76	0800		180	50	126	65
	1200	1476	295	212	169	148
	1600		295	313	288	234
	2000		256	281	277	288
10/7/76	0800	-	-	-	223	220
	1200	-	-	-	-	-
Mean		1476	264	228	217	191
SD			50	106	69	86
Total Suspended Solids (mg/l)						
10/2/76	1200		194	40	74	158
	1600	312	124	94	72	98
	2000		368	50	64	76
10/3/76	0800		112	140	130	98
	1200	428	-	128	116	148
	1600		72	122	176	442
	2000		140	276	106	182
10/4/76	0800	312	616	476	198	374
	1200		248	256	166	232
Mean		351	234	176	122	201
SD		67	180	139	49	128
10/6/76	0800		50	30	12	10
	1200	1200	52	42	32	20
	1600		94	94	70	62
	2000		134	78	58	64
10/7/76	0800	544	40	42	32	22
	1200		60	38	36	30
Mean		882	72	54	40	35
SD		478	36	26	21	23

APPENDIX B

DESIGN DRAWINGS AND MATERIALS LISTS FOR CONSTRUCTION OF A SHIPBOARD SEWAGE TREATMENT SYSTEM FOR GREAT LAKES VESSELS

DTNSRDC Drawing No.	Title
A-28-19031-1	Arrangement of Equipment and Piping Diagrammatic
A-28-19031-2	Details (Tanks, Pads, Base, and Guard Assemblies)
A-28-19031-3	Ozone Reactor Assembly and Details
A-28-19031-4	Foundations
A-28-19031-5	Piping Arrangement (Influent, Vent, and Sludge Disposal)
A-28-19031-6	Piping Arrangement (Fresh Water Fill and Flushing, Ozone Drainage, and Effluent Overboard Discharge)

PC. NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SOURCE

LIST OF MATERIAL - QUANTITIES FOR ONE

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES ..... ±0.01 INCH
3 DECIMAL PLACES .... ±0.005 INCH
WHOLE NUMBERS OR –
FRACTIONS .... ±1/64 INCH
ANGLES .... ±15 MINUTES
ON OTHER SURFACES
SAW CUT .... ±1/16 INCH
MACHINE FLAME CUT.... ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES.

REFERENCES

DATE 8-29-77
DRAWN GUARINO
CHECKED
DESIGNED JG
REVIEWED Ca
APPROVED [signature]
DATE 9-6-77

SEWAGE TREATMENT SYSTEM
ARR'T OF EQUIPMENT
AND
PIPING DIAGRAMATIC

SCALE: $1\frac{1}{2}$" = 1'-0"

DEPARTMENT OF NAVY
DAVID W. TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
CARDEROCK LAB – BETHESDA, MD 20084
ANNAPOLIS LAB – ANNAPOLIS, MD 21402

DTNSRDC NUMBER	REVISION
A-28-19031-1	

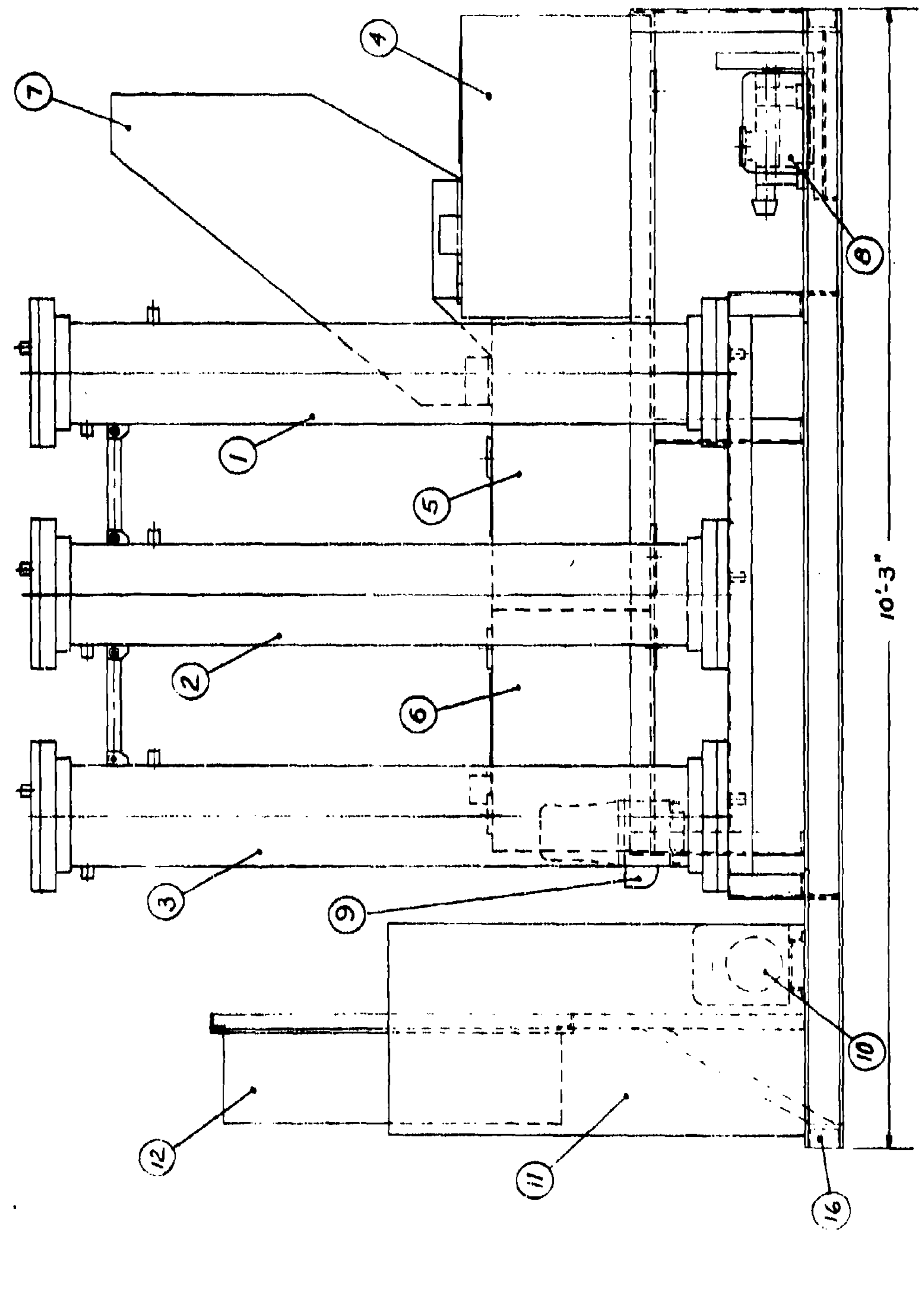
NOTES

1. FRESH WATER FROM FIREMAIN – NOT POTABLE WATER.
2. ALL SPRAY NOZZLES MUST BE INSTALLED TO BE REMOVABLE FOR CLEANING W/O OPENING TANK OR REACTORS.
3. TACK WELD STEEL TANKS TO THEIR ANGLE FRAME FOUNDATION AND TO EACH OTHER WHEN POSITIONED IN PLACE.
4. WITH HYDRASIEVE INSTALLED, SEAL AROUND TANK OPENINGS USING RTV OR EQUIVALENT.

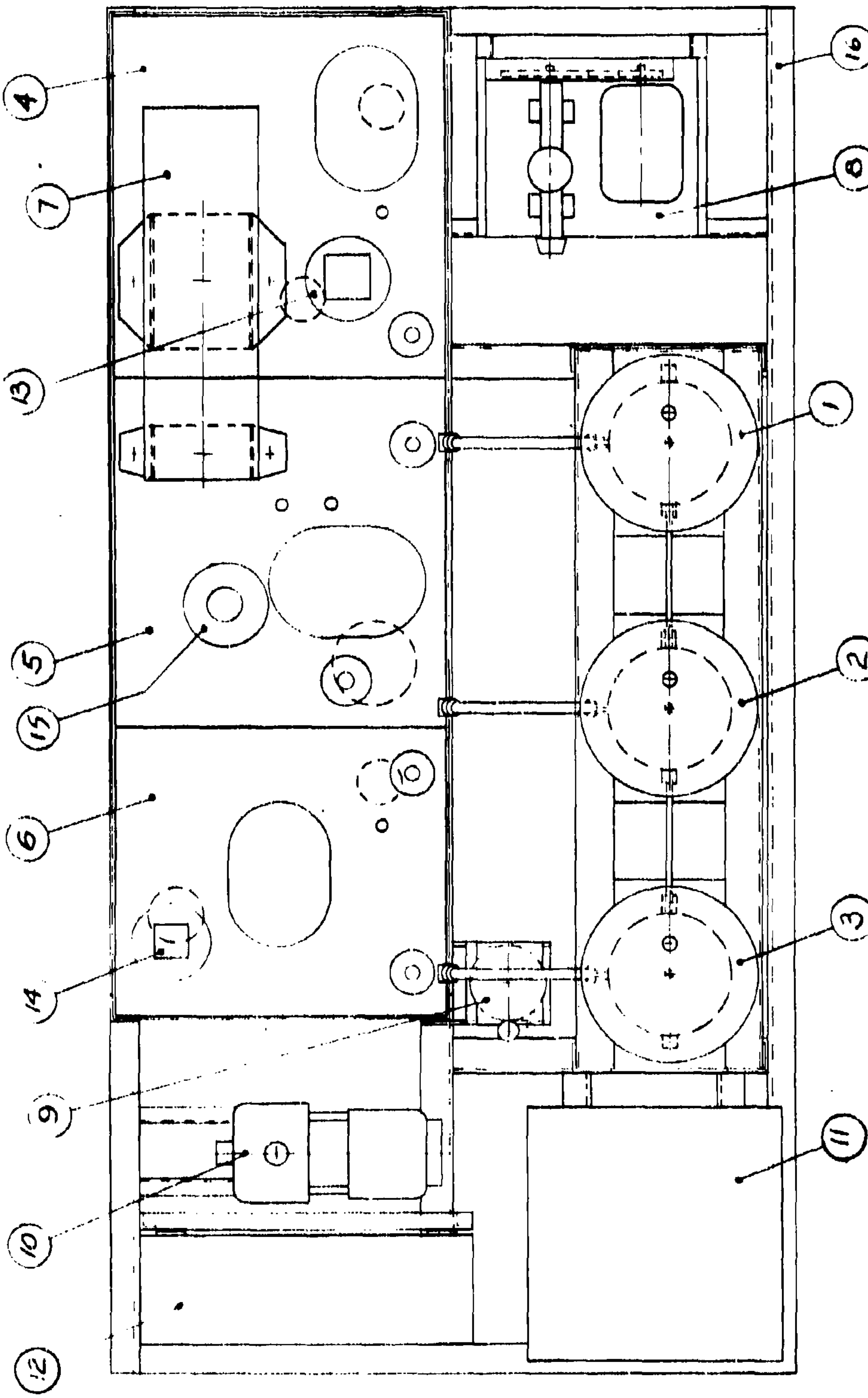
REFERENCES

	1.	SEWAGE TREATMENT SYS - DETAILS:	DTNSRDC A-28-19031-2
	2.	↓ - OZONE REACTOR	↓ -3
	3.	- FOUNDATIONS:	-4
	4.	- PIPING ARRT:	-5
	5.	- ↓ ↓ :	-6
LATER	6.	↓ - ELEC. CONTROL PANEL	↓ -7

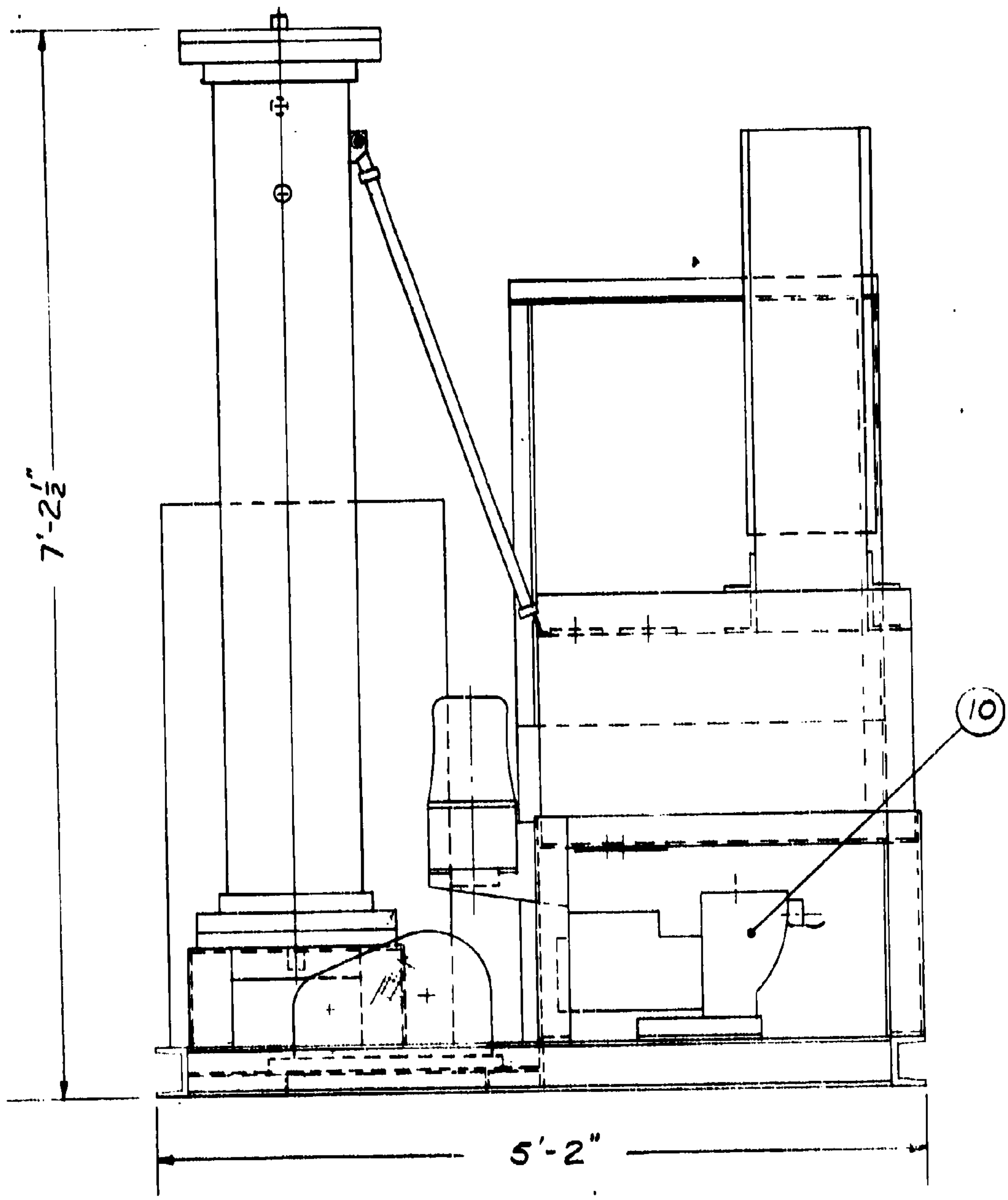
16	BEDPLATE	1	—	REF NO. 3
15	SLUDGE HOLDING TANK PROBE	1	↑	SERIES "R" WITH (2) SWC ELECTRODES DWG B10750I
14	HOLDING TANK PROBE	1		↑ 3F4A
13	PRIMARY EFFLUENT TANK PROBE	1	COMML	WARRICK CONTROL 3F5A
12	CONTROL PANEL	1	—	REF NO 6
11	OREC OZONATOR	1	↑	OZONE RESEARCH & EQUIP CORP MODEL 03DT-1
10	OVERBOARD DISCHARGE PUMP/MOTOR 1½" CENTRIFUGAL	1		PEABODY-BARNES MODEL 1XP5
9	MACERATOR PUMP MODEL SPG-200M-4	1	COMML	HYDR-O-MATIC PUMP CO DWG 5421-6
8	BASE	1	—	REF NO 1
	'V' BELT 5L370	1	↑	
	PUMP PULLEY 8.4 P.D., BK 90	1		
	MOTOR PULLEY 3.2 P.D., BK 34	1		
	MOTOR, 1/3 H.P. 230/460 V 1200 RPM - 3PH - 60Hz	1		TEIC FR 56
	PUMP - PROGRESSING CAVITY 1 GPM @ 450 RPM	1	COMML	ROBBINS & MYERS MOYNO-1L2
	FEED PUMP ASSY	1	—	—
7	HYDRASIEVE NO 552-7	1	COMML	THE BAUER BROS DWG NO D-552359
6	↑ - HOLDING	1		↑ ↑
5	- SLUDGE	1		
4	TANK - PRIMARY EFFLUENT	1		NO. 1
3	↑ - 3RD ↑	1	—	↑
2	- 2ND	1	—	
1	REACTOR - 1ST STAGE	1	—	REF NO. 2



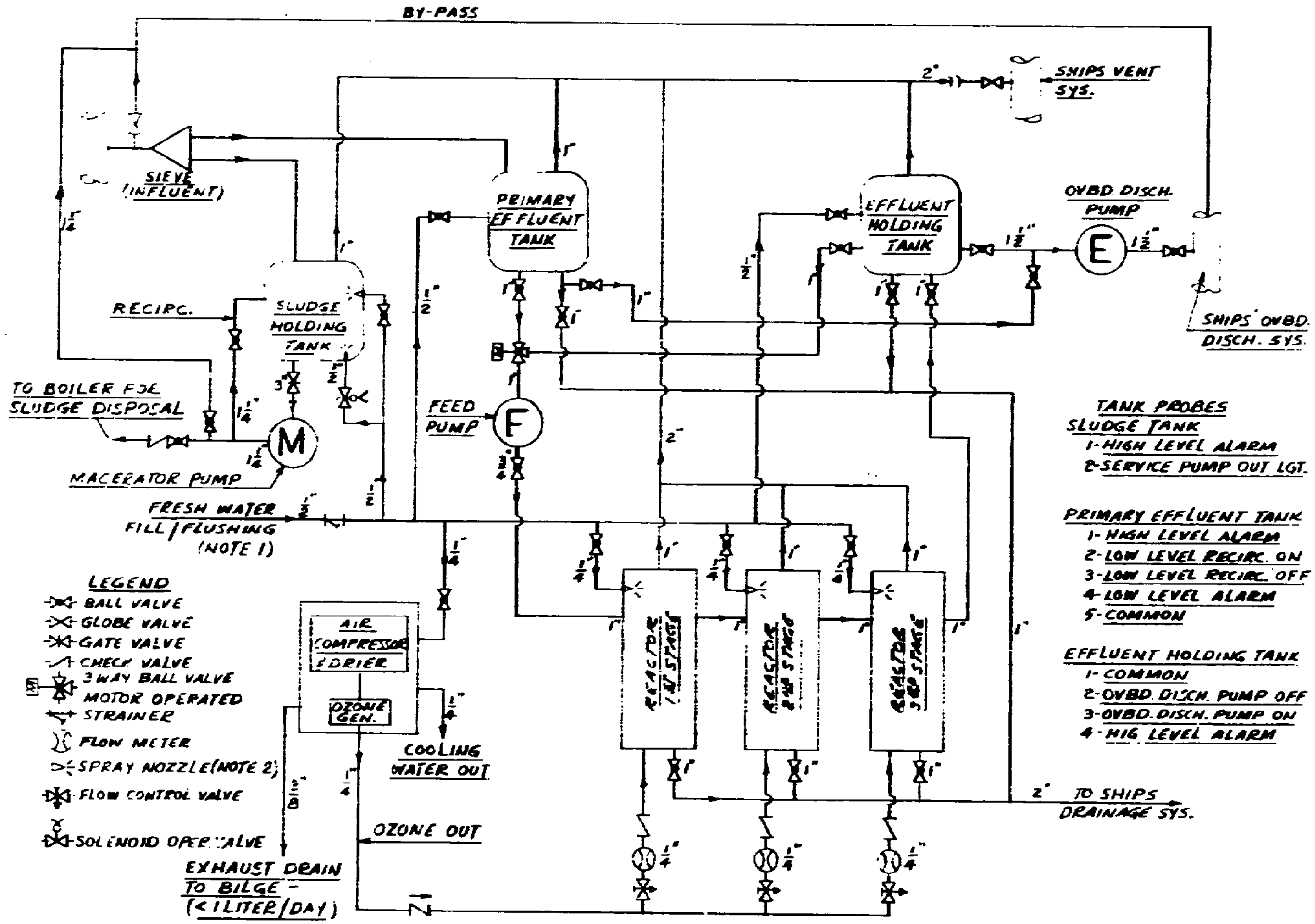
ELEVATION



PLAN



RT. END



PIPING DIAGRAMMATIC

1GPM @ 10 PSI (MAX)

PC. NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SOURCE

LIST OF MATERIAL - QUANTITIES FOR ONE

TOLERANCES UNLESS OTHERWISE SPECIFIED ON MACHINE SURFACES
2 DECIMAL PLACES .... ±0.01 INCH
3 DECIMAL PLACES .... ±0.005 INCH
WHOLE NUMBERS OR –
FRACTIONS .... ±1/64 INCH
ANGLES .... ±15 MINUTES
ON OTHER SURFACES
SAW CUT .... ±1/16 INCH
MACHINE FLAME CUT .... ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES.

REFERENCES

A28-19031-1: SEWAGE TREATMENT SYSTEM - ARRGT. OF EQUIP & PIPING DIAG.

DATE	8-29-77
DRAWN	GUARINO
CHECKED	
DESIGNED	JG
REVIEWED	Ca
APPROVED	[signature]
DATE	9-6-77

SEWAGE TREATMENT SYSTEM

DETAILS

TANKS, PADS, BASE & GUARD

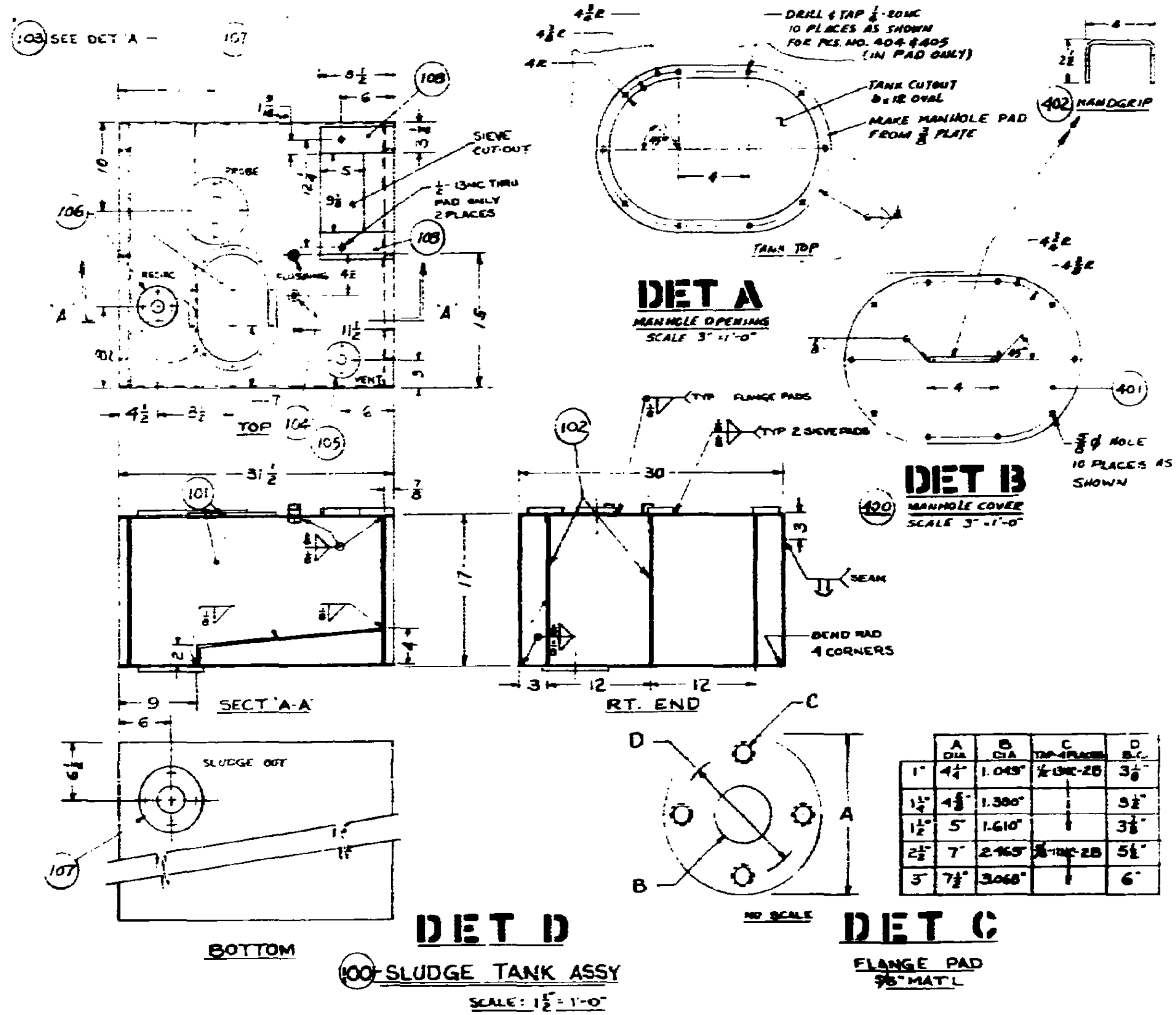
ASSEMBLIES

SCALE: AS NOTED

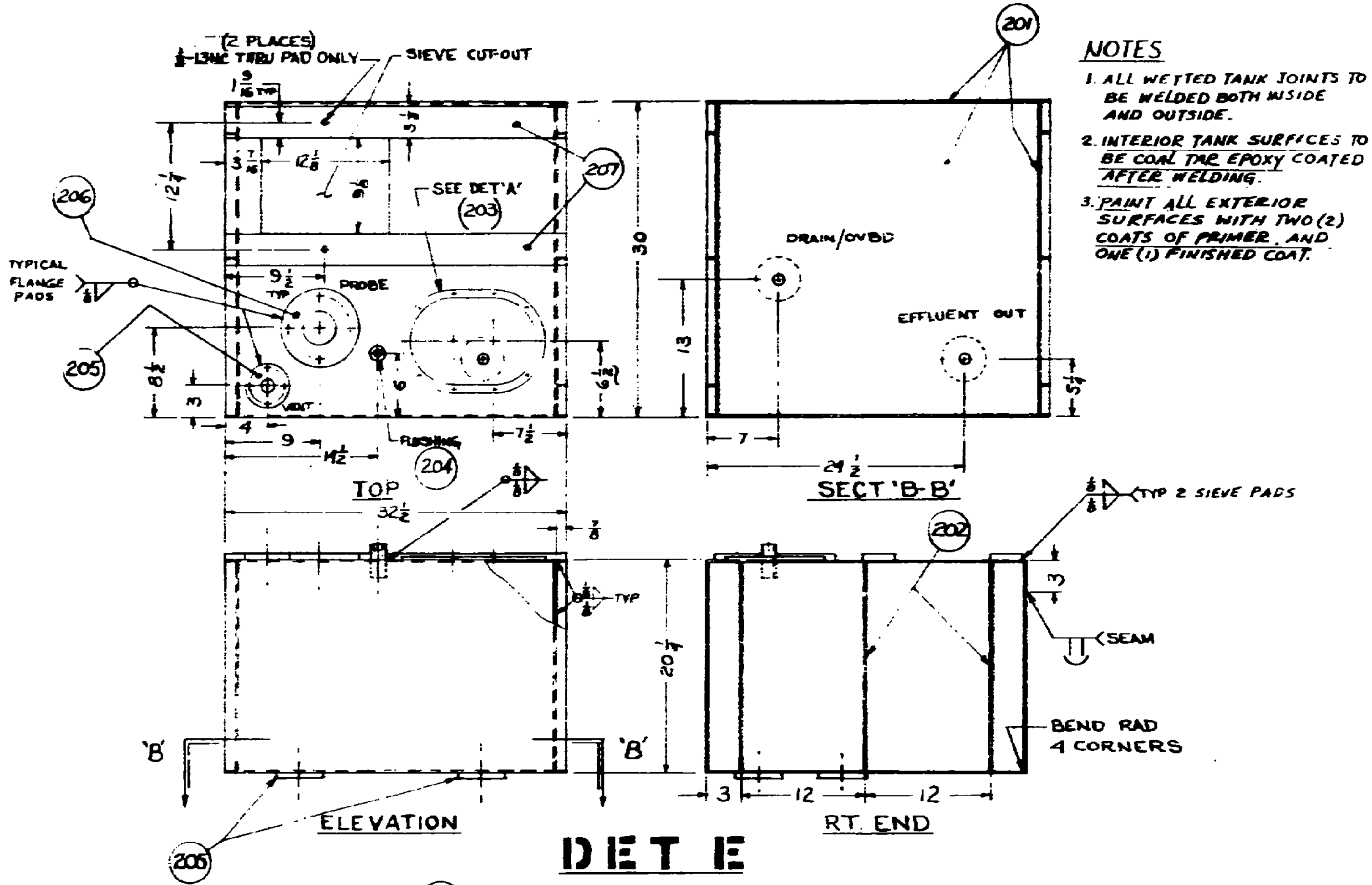
DEPARTMENT OF NAVY
DAVID W. TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
CARDEROCK LAB – BETHESDA, MD. 20084
ANNAPOLIS LAB – ANNAPOLIS, MD. 21402

DTNSRDC NUMBER	REVISION
A-28-19031-2	

603	ANGLE $\frac{1}{8}$ x $\frac{3}{4}$ x $\frac{3}{4}$	2 FT.		
602	EXPANDED METAL MESH	18" x 24"		.048" TH'K
601	#16 GA SHEET HR	36" x 36"	STL	
600	BELT GUARD ASS'Y	1		DETAIL 'H'
507	PLATE - 1$\frac{1}{2}$" HR, 2$\frac{1}{2}$" x 4$\frac{1}{2}$"	2		
506	MACH. SCREW - RDHD #10-24NC	4		$\frac{1}{2}$" IN LONG
505	SPLIT LOCK WASHER $\frac{1}{4}$"	8		
504	CAP SCREW - HEX - $\frac{1}{4}$"-20NC	8		1" IN LONG
503	ANGLE - 1" x 1" x $\frac{1}{8}$"	6 FT.		
502	- $\frac{1}{4}$" HR, 4" x 8"	1		
501	PLATE - $\frac{3}{16}$" HR, 16" x 19"	1	STL	
500	FEED PUMP BASE ASS'Y	1		DETAIL 'G'
405	PLAIN WASHER $\frac{1}{2}$"	30		
404	CAP SCREW - HEX $\frac{1}{2}$"-20NC	30	STL	$\frac{1}{2}$" LONG
403	GASKET - $\frac{1}{16}$" THK	3	SYN. RUBBER	CUT FROM SHEET STK.
402	ROUND ROD	3 FT.		
401	PLATE $\frac{1}{4}$" HR 9$\frac{1}{2}$" x 13$\frac{1}{2}$"	3	STL	
400	MANHOLE COVER ASS'Y	3		DETAIL 'B'
308	$\frac{5}{8}$"-11NC x 1" HEX HD. CAP SCREW & LOCKWASHER	4		FOR PC. 307
307	2$\frac{1}{2}$	1		
306	1$\frac{1}{2}$"	1		
305	FLANGE PAD 1"	3		DETAIL 'C'
304	HALF COUPLING $\frac{1}{2}$" SCREWED	1		
303	MANHOLE PAD	1	STL	DETAIL 'A'
302	FLAT BAR	6	$\frac{3}{16}$" x $\frac{1}{4}$" x 16$\frac{3}{4}$ STRIP STL HR	
301	TANK	1	STL #10 GA, HR	
300	HOLDING TANK ASS'Y	1		DETAIL 'F'
209	$\frac{5}{8}$"-11NC x 1"	4		FOR PC. 206
208	$\frac{1}{2}$"-13NC x 1" HEX HD CAP SCREW & LOCKWASHER	2	STL	FOR PC. 207
207	SIEVE PAD	2	$\frac{3}{8}$" PLATE STL HR	3" x 32$\frac{1}{2}$" LONG
206	3"	1		
205	FLANGE PAD 1"	3		DETAIL 'C'
204	HALF COUPLING $\frac{1}{2}$" SCREWED	1		
203	MANHOLE PAD	1	STL	DETAIL 'A'
202	FLAT BAR	6	$\frac{3}{16}$" x $\frac{1}{4}$" x 20 STRIP STL HR	
201	TANK	1	STL #10 GA, HR	
200	PRIMARY EFFLUENT TANK ASS'Y	1		DETAIL 'E'
110	$\frac{5}{8}$"-11NC x 1"	4		FOR PROBE PC. 107
109	$\frac{1}{2}$"-13NC x 1" HEX. HD CAP SCREW & LOCKWASHER	2	STL	FOR PC. 108
108	SIEVE PAD	2	$\frac{3}{8}$" PLATE STL HR	3" x 8$\frac{1}{2}$" LONG
107	3"	2		
106	1$\frac{1}{2}$"	1		
105	FLANGE PAD 1"	1		DETAIL 'C'
104	HALF COUPLING $\frac{1}{2}$" SCREWED	2		
103	MANHOLE PAD	1	STL	DETAIL 'A'
102	FLAT BAR	6	$\frac{3}{16}$" x $\frac{1}{4}$" x 16$\frac{3}{4}$ STRIP STL HR	
101	TANK	1	STL #10 GA, HR	
100	SLUDGE TANK ASS'Y	1		DETAIL 'D'



	A DIA	B DIA	C TAP-4 PLACES	D B.C.
1"	4¼"	1.049"	½-13NC-2B	3⅛"
1¼"	4⅝"	1.380"	↓	3½"
1½"	5"	1.610"	↓	3⅞"
2½"	7"	2.465"	⅝-11NC-2B	5½"
3"	7½"	3.068"	↓	6"



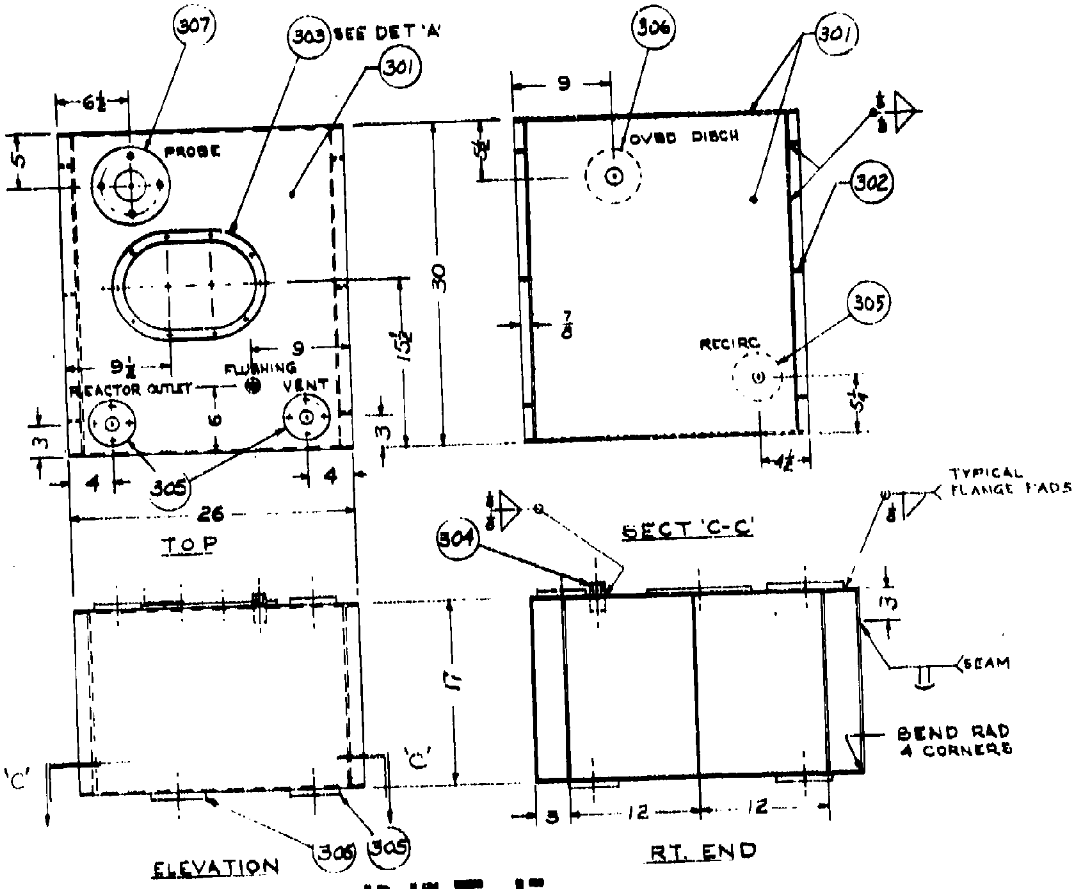
NOTES

1. ALL WETTED TANK JOINTS TO BE WELDED BOTH INSIDE AND OUTSIDE.
2. INTERIOR TANK SURFACES TO BE COAL TAR EPOXY COATED AFTER WELDING.
3. PAINT ALL EXTERIOR SURFACES WITH TWO (2) COATS OF PRIMER, AND ONE (1) FINISHED COAT.

DET E

(200) PRIMARY EFFLUENT TANK ASSY

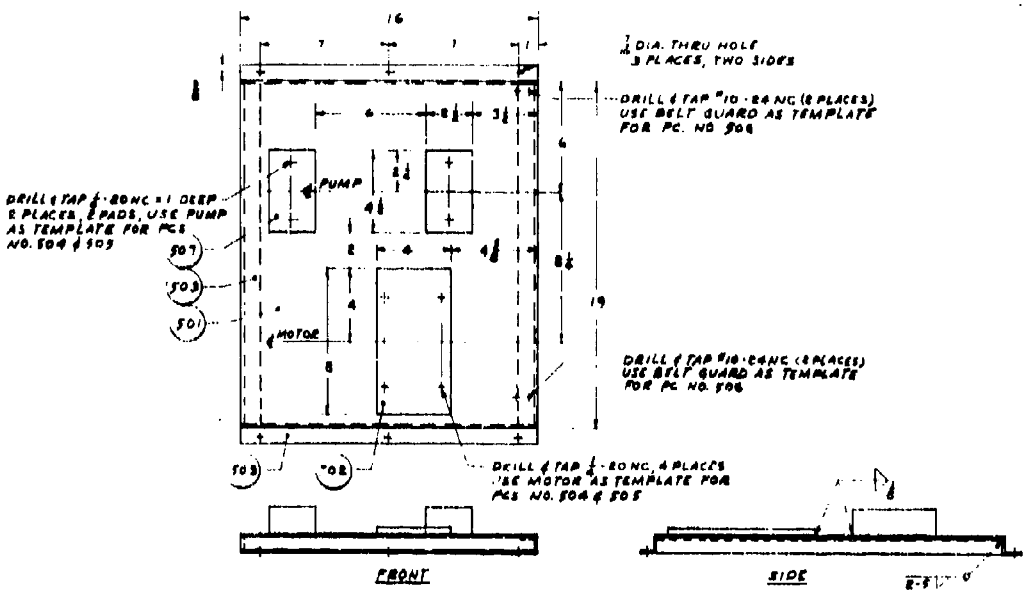
SCALE: 1½" = 1'-0"



DET F

(300) HOLDING TANK ASSY

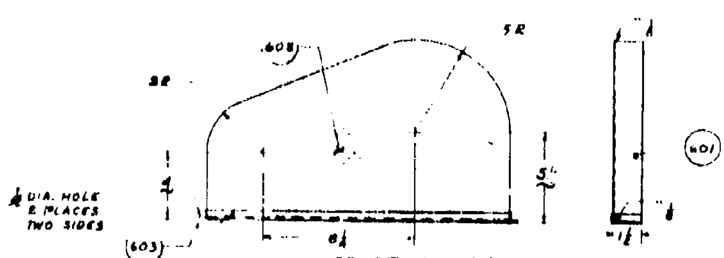
SCALE: 1½"=1'-0"



DET G

(500) FEED PUMP BASE ASS'Y

SCALE: 3" = 1'-0"



DET H

(600) BELT GUARD ASS'Y

SCALE: 3" = 1'-0"

PC. NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SOURCE

LIST OF MATERIAL—QUANTITIES FOR ONE

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES . . . ±0.01 INCH
3 DECIMAL PLACES . . . ±0.005 INCH
WHOLE NUMBERS OR—
FRACTIONS . . . . ±1/64 INCH
ANGLES . . . . . ±15 MINUTES
ON OTHER SURFACES
SAW CUT . . . . ±1/16 INCH
MACHINE FLAME CUT . . . ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES

REFERENCES

A28-19031-1: SEWAGE TREATMENT SYS-ARRGT. OF EQUIP. & PIPING DIAG

DATE: 9-77
DRAWN: [illegible]
CHECKED:
DESIGNED:
REVIEWED: CA
APPROVED: [signature]
DATE: 9-6-77

SEWAGE TREATMENT SYSTEM

OZONE REACTOR

ASSY. & DETAILS

SCALE: AS NOTED

DEPARTMENT OF THE NAVY
DAVID W. TAYLOR
NAVAL SHIP
RESEARCH & DEVELOPMENT
CENTER
CARDEROCK LAB-BETHESDA, MD. 20084
ANNAPOLIS LAB-ANNAPOLIS, MD. 21402

DTNSRDC NUMBER: A28-19031-3
REVISION:

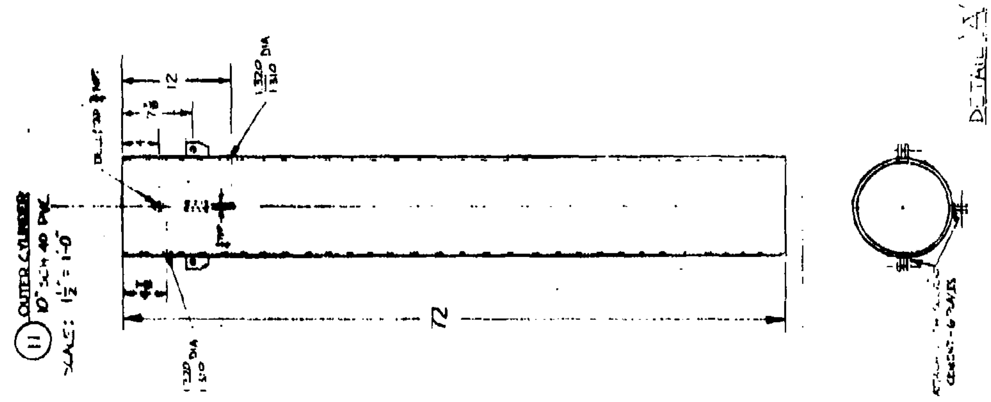
NOTES

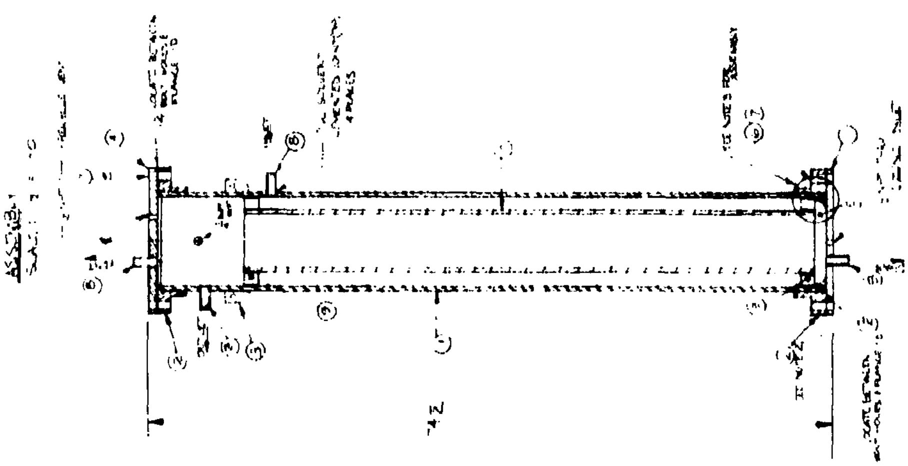
1. ALL CEMENTED JOINTS TO BE JO[illegible] USING PVC CEMENT NO. 711 (PC. 13) & PRIMER NO. 702 (PC. 14)

2. PC 2 TO BE C[illegible] ON[illegible] PC. 11 SO THAT THE INLET-OUTLET CONN'S ARE IN LINE WITH THE BOLT HOLES IN PC. 2.

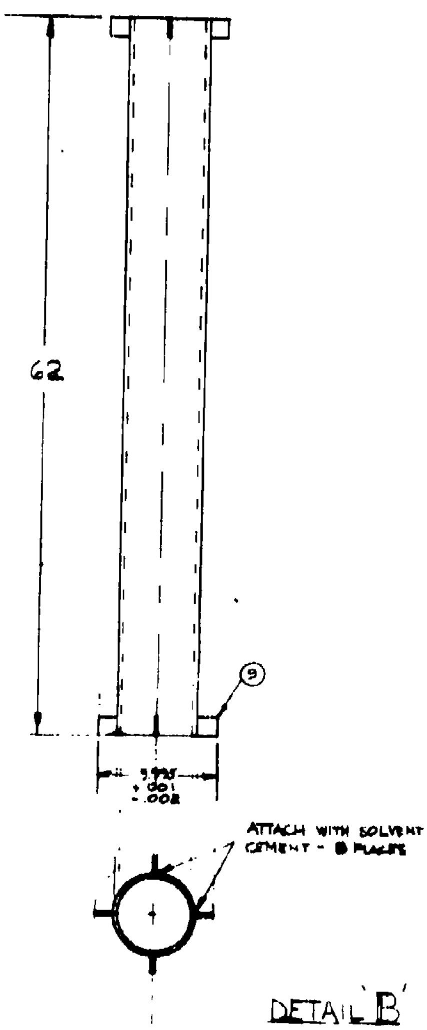
3. INNER CYLINDER (PC 10) RESTS ON TOP OF INSERT (PC 5) INSIDE THE OUTER CYLINDER (PC 11). PCS 10 & 5 ARE SET, NOT GLUED, INTO PC 11.

14	PVC PRIMER - 702 (P70) PURPLE	A.R.	———	PLASTIC PIPING SYSTEMS SOUTH PL[illegible], NJ
13	PVC CEMENT - NO. 711 (GRAY)	A.R.	———	PLASTIC PIPING SYSTEMS SOUTH PLAINFIELD, N.J.
12	GASKET - $\frac{1}{4}$" DIA	A.R.	TEFLON	W L GORE & ASSOC., INC. GORE-TEX JOINT SEALANT
11	PIPE - 10" SCH 40 x 72 LG	1	PVC	SEE DETAIL 'A'
10	PIPE - 6" SCH 40 x 62 LG	1	PVC	SEE DETAIL 'B'
9	TABS - $1\frac{7}{8} \times 1\frac{1}{2} \times \frac{1}{4}$ THK	8	PVC	SEE DETAIL 'H'
8	NIPPLE - 1" SCH 40 PIPE x $2\frac{1}{2}$ LONG; THD 1" NPT ONE END.	4	PVC	
7	STUD - $\frac{7}{8}$ - 9NC x 6" LG	24	CRES	TYPE 303 STAINLESS
6	NUT - $\frac{7}{8}$ - 9NC HEX	48	CRES	TYPE 303 STAINLESS
5	INSERT, 9.995 DIA x $1\frac{1}{4}$ THK	1	PVC	SEE DETAIL 'G'
4	FLANGE, 10" NOM SIZE, BLIND - 150#	1	PVC	SEE DETAIL 'F'
3	PAD EYE	6	PVC	SEE DETAIL 'C'
2	FLANGE, 10" NOM SIZE, SOCKET - 150#	2	PVC	SEE DETAIL 'I'
1	FLANGE, 10" NOM SIZE BLIND - 150#	1	PVC	SEE DETAIL 'E'

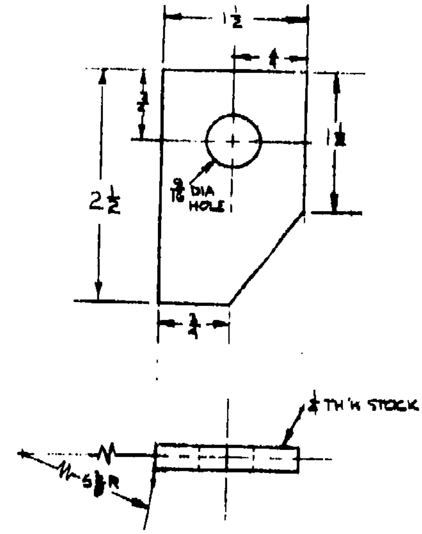

11 OUTER CYLINDER
72
DETAIL 'A'



(10) INNER CYLINDER (SEE NOTE 8)
6" SCH 40 PVC
SCALE: $1\frac{1}{2}$ = 1'-0"

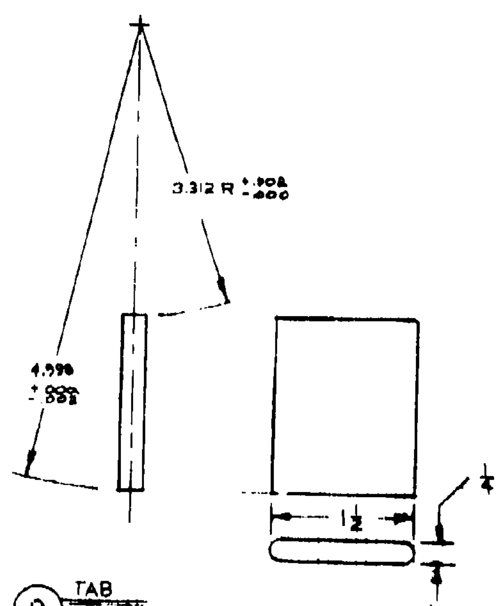


DETAIL 'B'



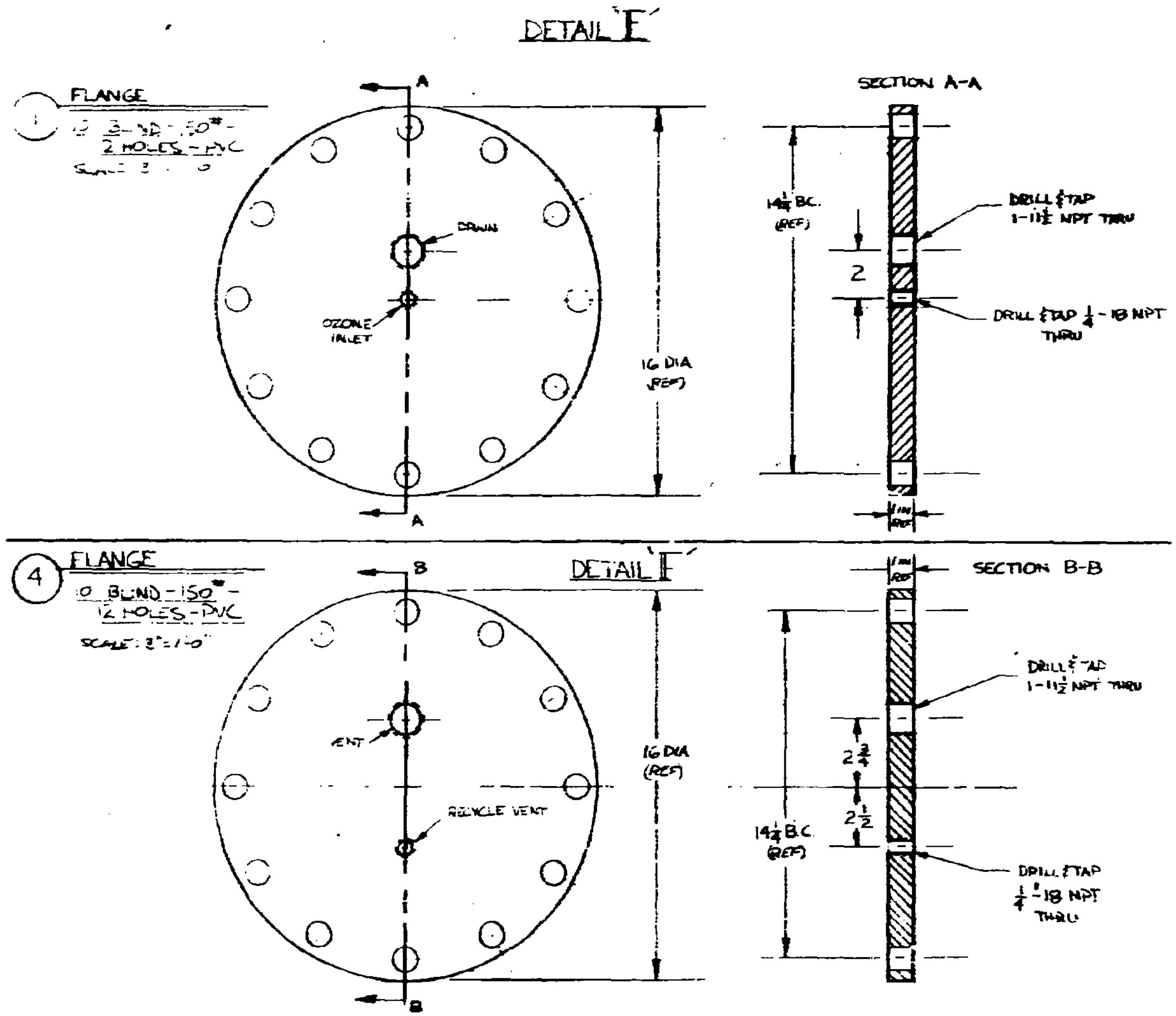
(3) PAD EYE
1/4 TH'K STOCK PVC
SCALE: FULL

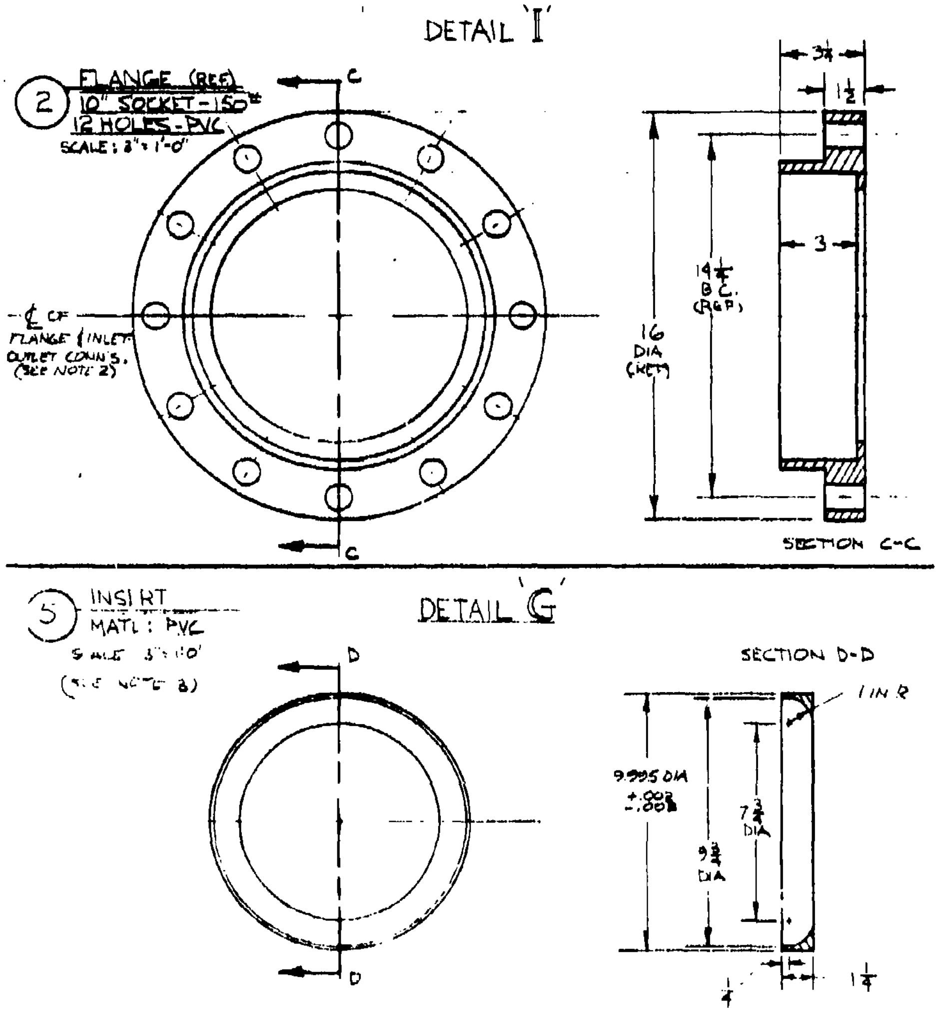
DETAIL 'C'



(9) TAB
1/4 THK STOCK PVC
SCALE: FULL

DETAIL 'H'


DETAIL "F"
FLANGE
12 BLIND-150# - 12 HOLES - PVC
DRAIN
OZONE INLET
16 DIA (REF)
SECTION A-A
14¼ B.C. (REF)
2
DRILL & TAP 1-11½ NPT THRU
DRILL & TAP ¼-18 NPT THRU
4
FLANGE
10 BLIND-150# - 12 HOLES - PVC
SCALE: 3"=1'-0"
DETAIL "F"
VENT
RECYCLE VENT
16 DIA (REF)
SECTION B-B
14¼ B.C. (REF)
2¾
2½
DRILL & TAP 1-11½ NPT THRU
DRILL & TAP ¼-18 NPT THRU
A
B


DETAIL 'I'
2
FLANGE (REF)
10" SOCKET-150#
12 HOLES-PVC
SCALE: 3" = 1'-0"
C
℄ OF FLANGE { INLET OUTLET CONN'S. (SEE NOTE 2)
3¼
1½
3
14¼ B.C. (REF)
16 DIA (REF)
SECTION C-C
5
INSERT
MATL: PVC
DETAIL 'G'
D
SECTION D-D
1 IN R
9.995 DIA
7¾ DIA
9¾ DIA
1¼

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES . . . . . ±0.01 INCH
3 DECIMAL PLACES . . . . ±0.005 INCH
WHOLE NUMBERS OR –
FRACTIONS . . . . ±1/64 INCH
ANGLES. . . . . ±15 MINUTES
ON OTHER SURFACES
SAW CUT . . . . ±1/16 INCH
MACHINE FLAME CUT. . . . ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES.

REFERENCES

A28-19031-1 : SEWAGE TREATMENT SYSTEM - ARRGT. OF EQUIP. & PIPING DIAG.

PC. NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SOURCE

LIST OF MATERIAL - QUANTITIES FOR ONE

DATE 8-29-77
DRAWN GUARINO
CHECKED
DESIGNED JG
REVIEWED CA
APPROVED [signature]
DATE 9-6-77

SEWAGE TREATMENT SYSTEM

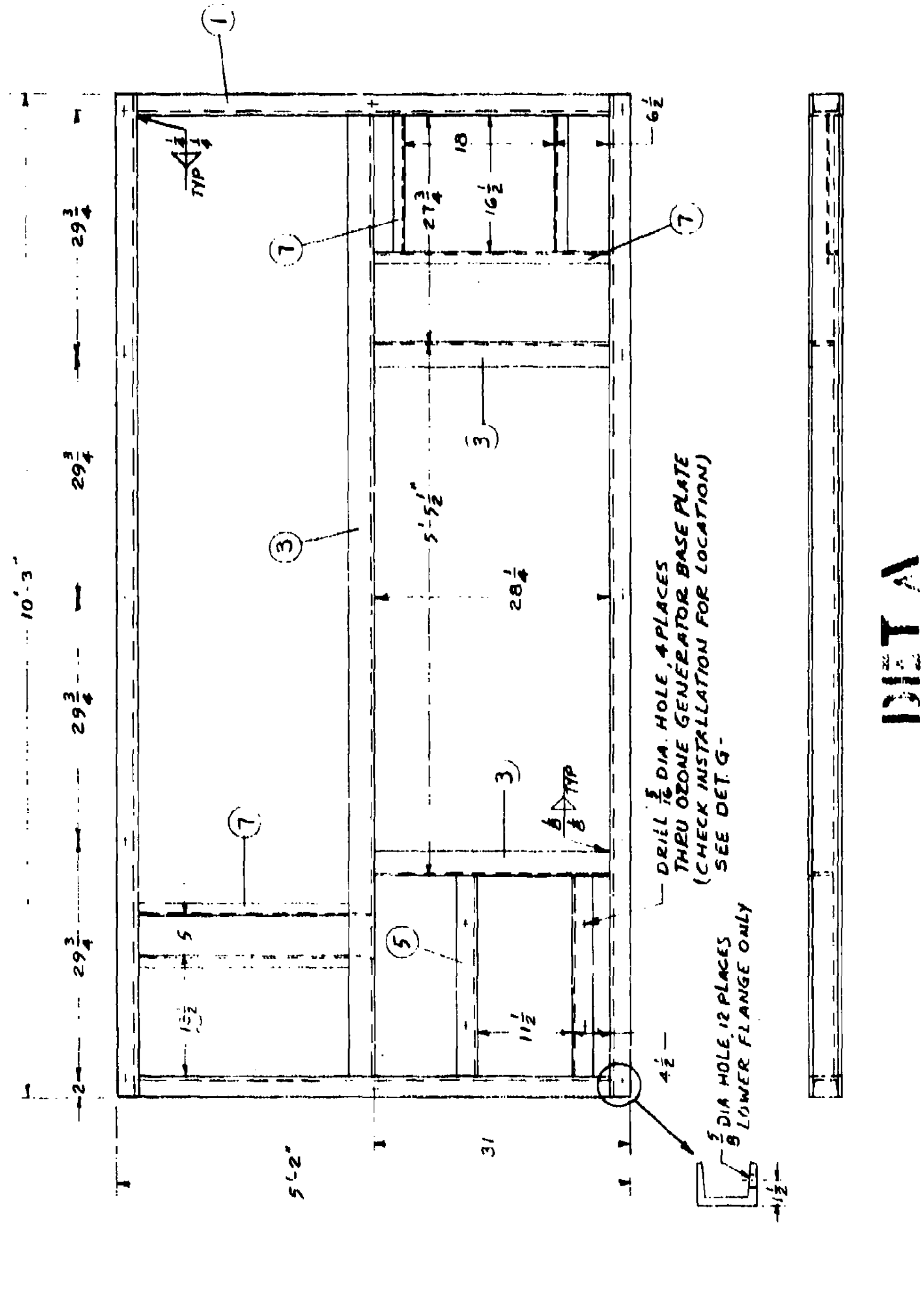
FOUNDATIONS

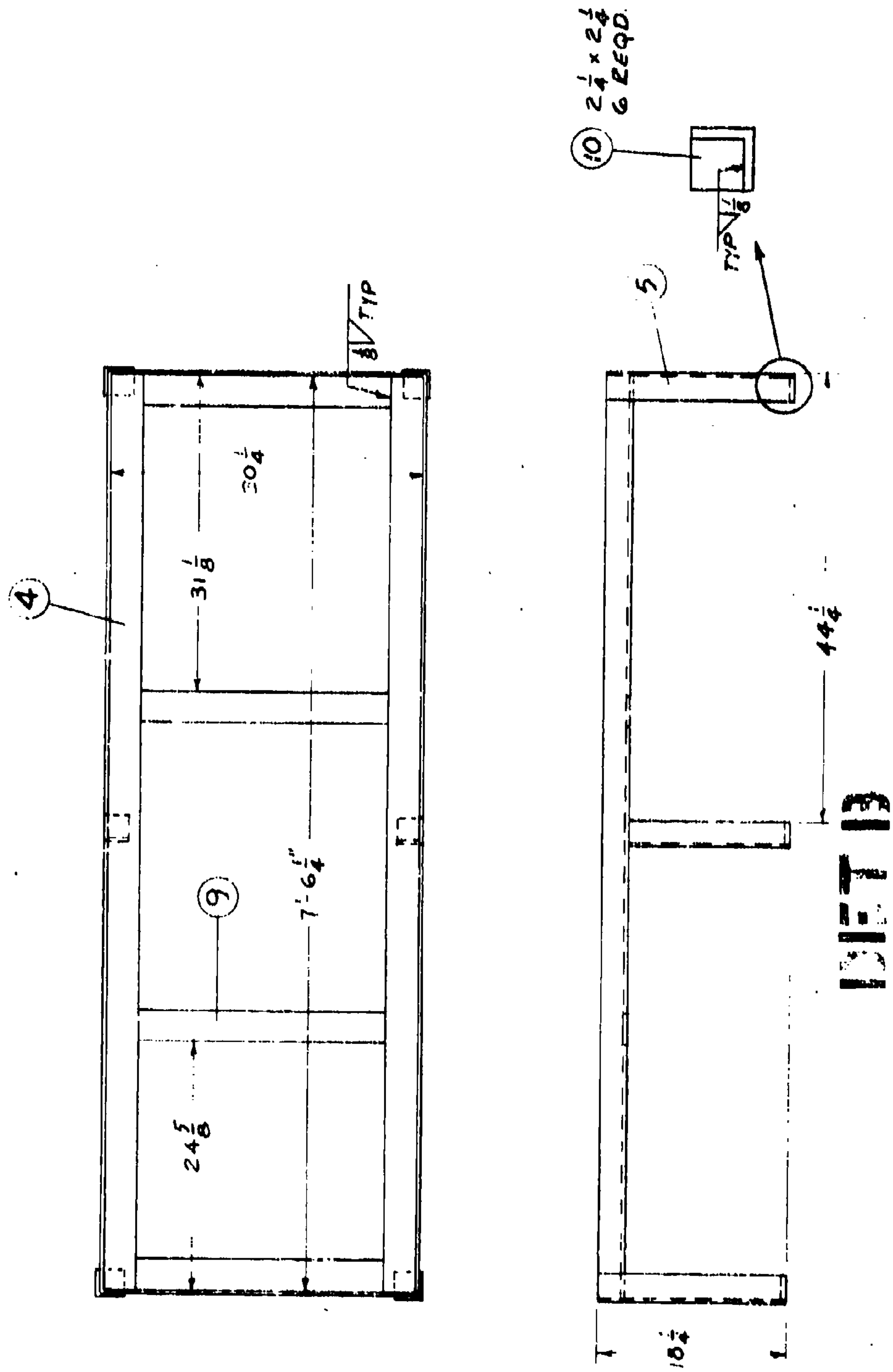
SCALE 1" = 1'-0" & NOTED

DEPARTMENT OF NAVY
DAVID W. TAYLOR
NAVAL SHIP
RESEARCH & DEVELOPMENT
CENTER
CARDEROCK LAB – BETHESDA, MD 20084
ANNAPOLIS LAB – ANNAPOLIS, MD 21402

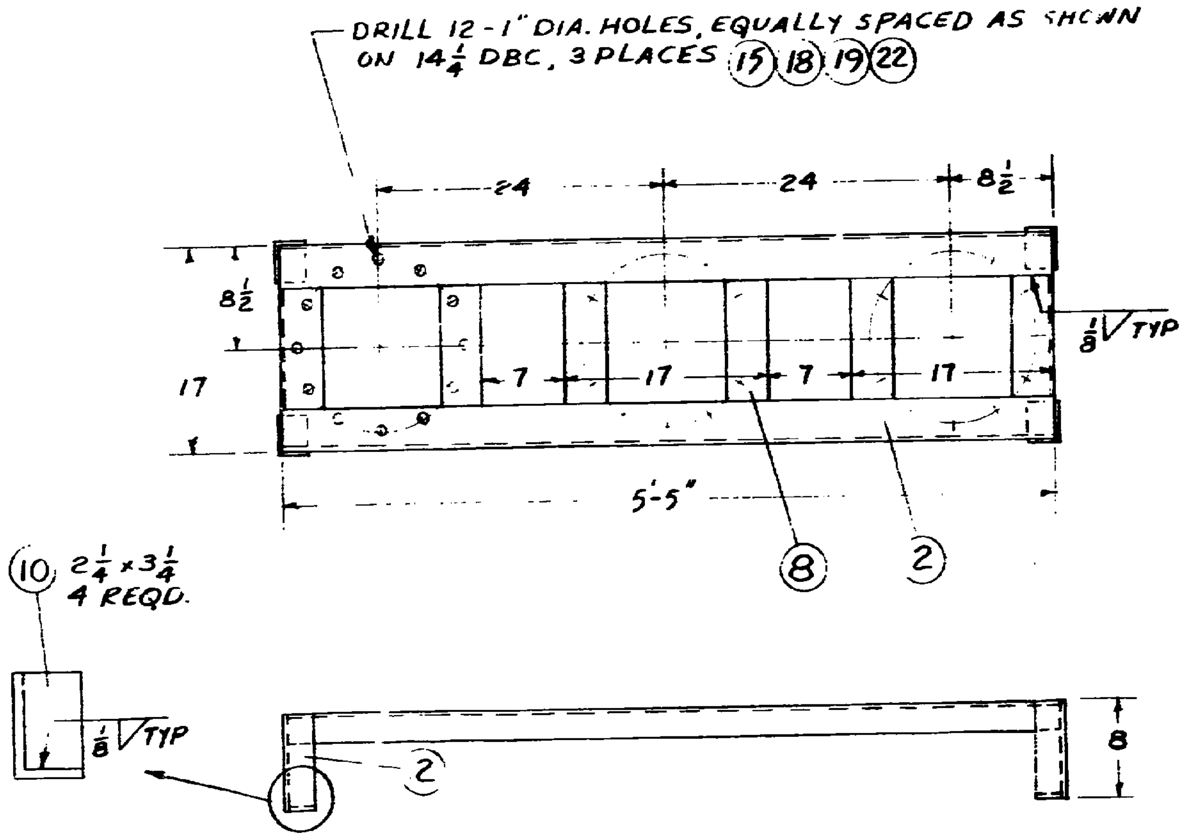
DTNSRDC NUMBER: A28-19031-4
REVISION:

22	$\frac{7}{8}$"-9NC	36		
21	$\frac{1}{2}$"-13NC	7		
20	$\frac{3}{8}$"-16NC HEX. NUT	14		
19	$\frac{7}{8}$" PLAIN WASHER	36		
18	$\frac{7}{8}$"	36		
17	$\frac{1}{2}$"	7		
16	$\frac{3}{8}$" LOCKWASHER	14		
15	$\frac{7}{8}$"-9NC	36		4" LONG
14	$\frac{1}{2}$"-13NC	7		$1\frac{1}{2}$" LONG
13	$\frac{3}{8}$"-16NC HEX. HD. BOLT	14		1" LONG
12	1" NOM. PIPE, SCH. 40	12FT.	STEEL	
11	BRACE FITTING-PIPE	6	MAL. IRON	GRINNELL FIG. 204
10	$\frac{1}{4}$" PLATE	45 REQD		
9	3" x $\frac{1}{4}$"	6FT.		
8	$3\frac{1}{2}$" x $\frac{1}{4}$" STRIP	4FT.		
7	$1\frac{1}{2}$" x $1\frac{1}{2}$" x $\frac{1}{8}$"	12FT.		
6	$1\frac{3}{4}$" x $1\frac{3}{4}$" x $\frac{1}{8}$"	20FT.		
5	$2\frac{1}{2}$" x $2\frac{1}{2}$" x $\frac{1}{4}$"	10FT.		
4	3" x $2\frac{1}{2}$" x $\frac{1}{4}$"	20FT.		
3	3" x 3" x $\frac{1}{4}$"	15FT.		
2	$3\frac{1}{2}$" x $2\frac{1}{2}$" x $\frac{1}{4}$" ANGLE	16FT.		
1	MC 4" x 13.8#/FT. CHANNEL	31FT.	STEEL	

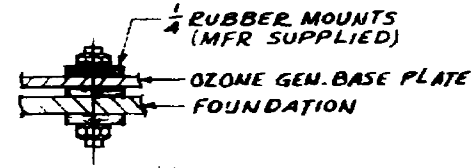

DRILL 5/16 DIA. HOLE, 4 PLACES
THRU OZONE GENERATOR BASE PLATE
(CHECK INSTALLATION FOR LOCATION)
SEE DET. G-
5/8 DIA HOLE, 12 PLACES
LOWER FLANGE ONLY
10'-3"
29 3/4
5'-2"
31
5'-5 1/2"
28 1/4
27 3/4
16 1/2
18
6 1/2
11 1/2
4 1/2
TYP



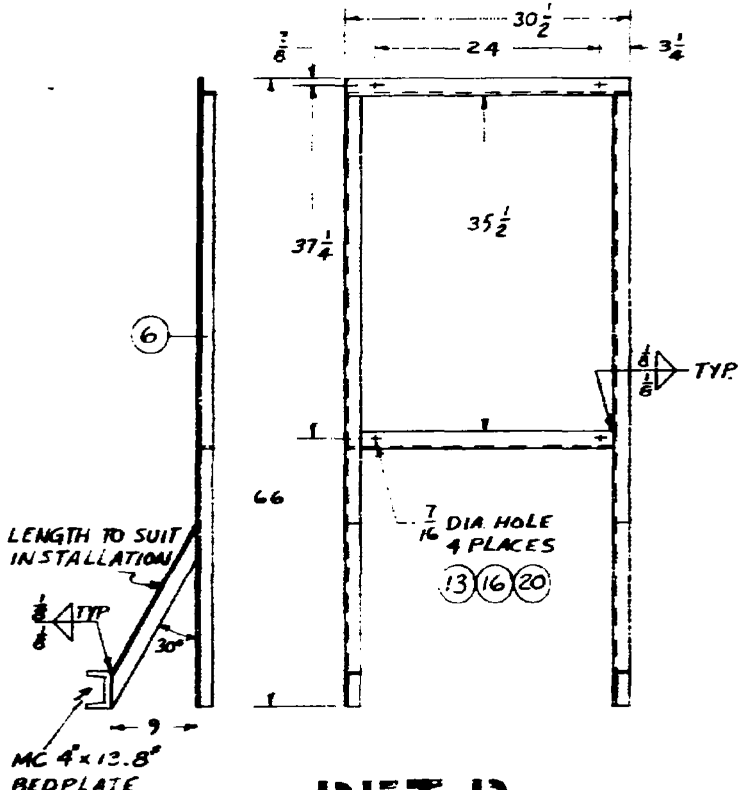
10
2 1/4 x 2 1/4
6 REQD
TYP 1/8
5
1/8 TYP
4
31 1/8
30 1/4
9
7'-6 1/4"
24 5/8
44 1/4
18 1/4


DRILL 12 - 1" DIA. HOLES, EQUALLY SPACED AS SHOWN
ON 14 1/4 DBC, 3 PLACES (15) (18) (19) (22)
24
24
8 1/2
8 1/2
17
7
17
7
17
1/8 TYP
5'-5"
8
2
10
2 1/4 x 3 1/4
4 REQD.
1/8 TYP
2
8

DET C

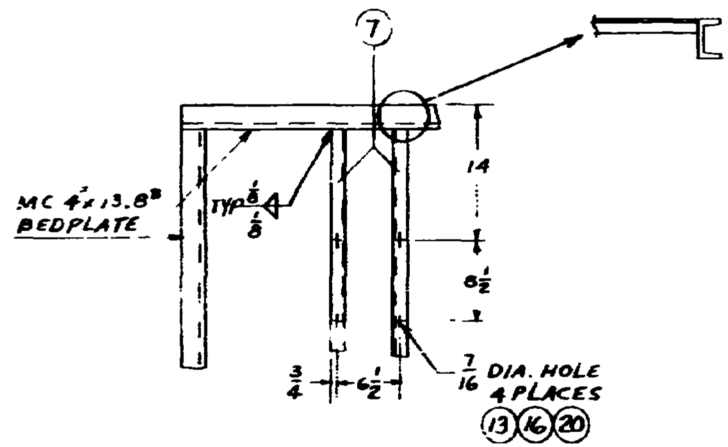


1/4 RUBBER MOUNTS (MFR SUPPLIED)
OZONE GEN. BASE PLATE
FOUNDATION



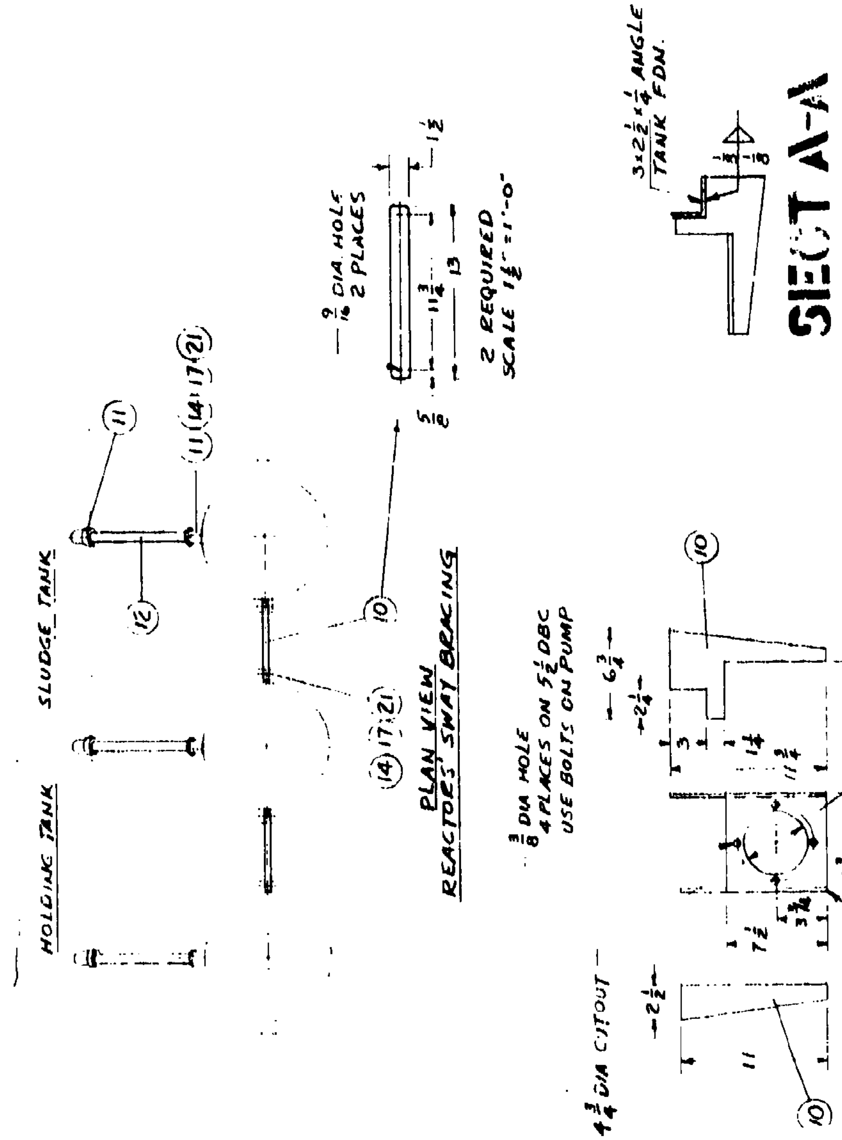
30 1/2
24
3 1/4
7/8
37 1/4
35 1/2
66
6
TYP.
7/16 DIA. HOLE 4 PLACES
13 16 20
LENGTH TO SUIT INSTALLATION
TYP
30°
9
MC 4"x 13.8# BEDPLATE

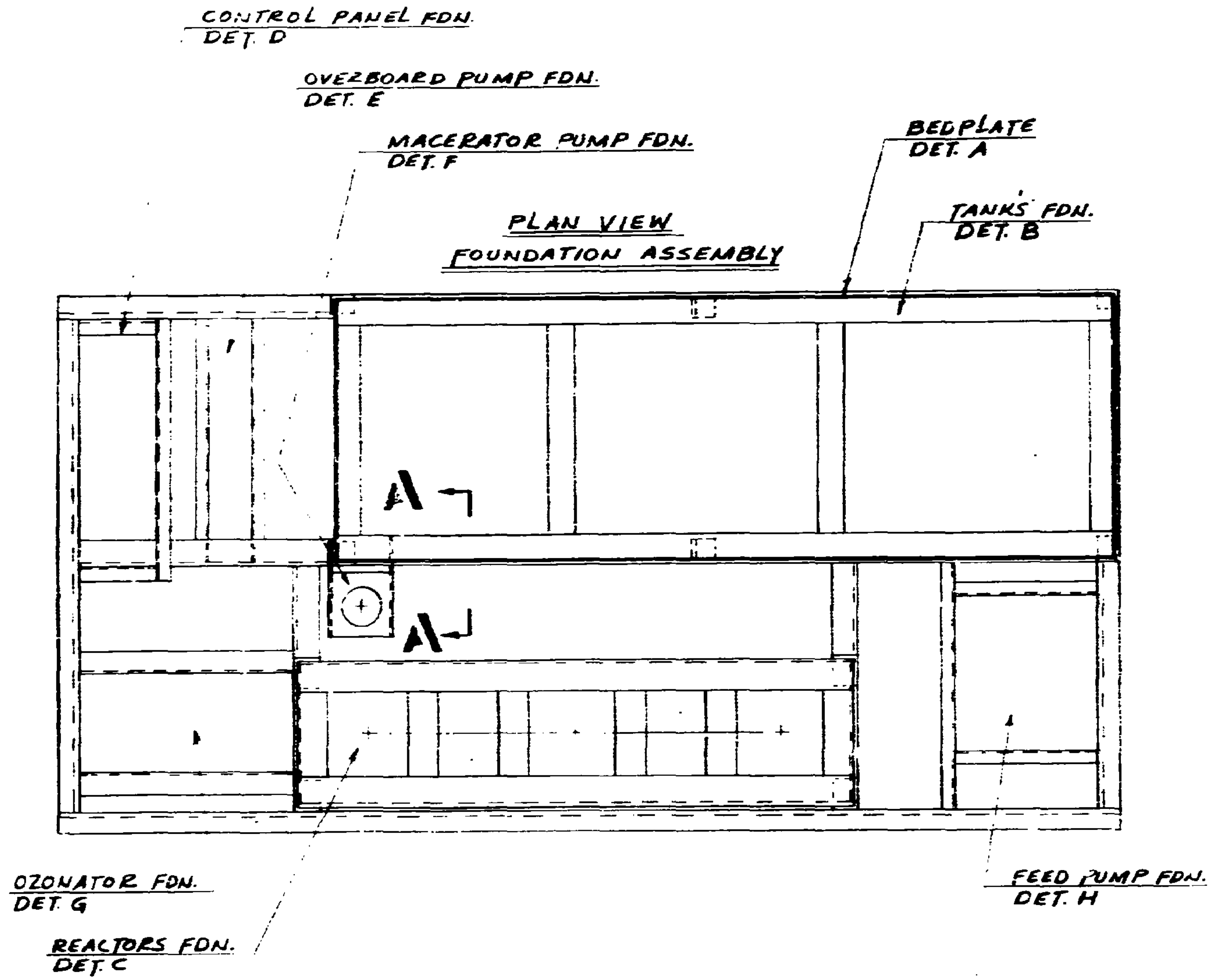
DET D



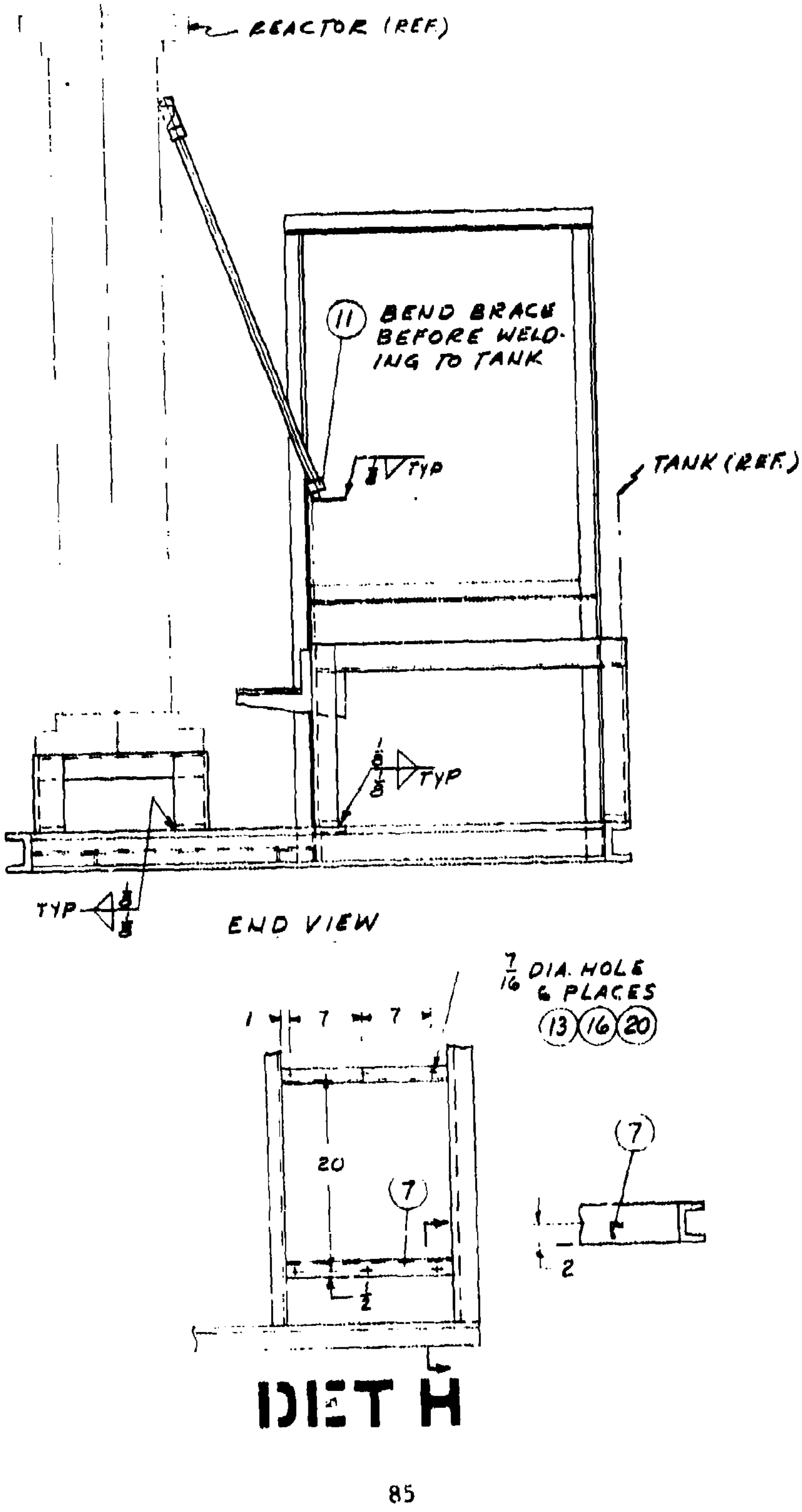
7
MC 4"x 13.8# BEDPLATE
TYP
14
8 1/2
3/4
6 1/2
7/16 DIA. HOLE 4 PLACES
13 16 20

DET E


HOLDING TANK
SLUDGE TANK
PLAN VIEW
REACTORS' SWAY BRACING
9/16 DIA HOLE
2 PLACES
2 REQUIRED
SCALE 1 1/2" = 1'-0"
3/8 DIA HOLE
4 PLACES ON 5 1/2 DBC
USE BOLTS ON PUMP
4 3/4 DIA CUTOUT
TYP
3x2 1/2x1/4 ANGLE
TANK FDN.
SECT A-A



CONTROL PANEL FDN.
DET. D
OVERBOARD PUMP FDN.
DET. E
MACERATOR PUMP FDN.
DET. F
BEDPLATE
DET. A
TANKS' FDN.
DET. B
PLAN VIEW
FOUNDATION ASSEMBLY
A
A
OZONATOR FDN.
DET. G
REACTORS FDN.
DET. C
FEED PUMP FDN.
DET. H


REACTOR (REF.)
11
BEND BRACE BEFORE WELDING TO TANK
TYP
TANK (REF.)
TYP
TYP
END VIEW
7/16 DIA. HOLE 6 PLACES
13
16
20
1
7
7
20
7
7
2

DET H

PC. NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SOURCE
LIST OF MATERIAL - QUANTITIES FOR ONE				

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES . . . . . ±0.01 INCH
3 DECIMAL PLACES . . . . ±0.005 INCH
WHOLE NUMBERS OR –
FRACTIONS . . . . ±1/64 INCH
ANGLES. . . . . ±15 MINUTES
ON OTHER SURFACES
SAW CUT . . . . ±1/16 INCH
MACHINE FLAME CUT. . . . ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES.

REFERENCES

A-28-19031-1: SEWAGE TREATMENT SYS - ARR'T OF EQUIP & PIPING DIAG.

DATE	8-29-77
DRAWN	GUARINO
CHECKED	
DESIGNED	JG
REVIEWED	CA
APPROVED	[signature]
DATE	9-6-77

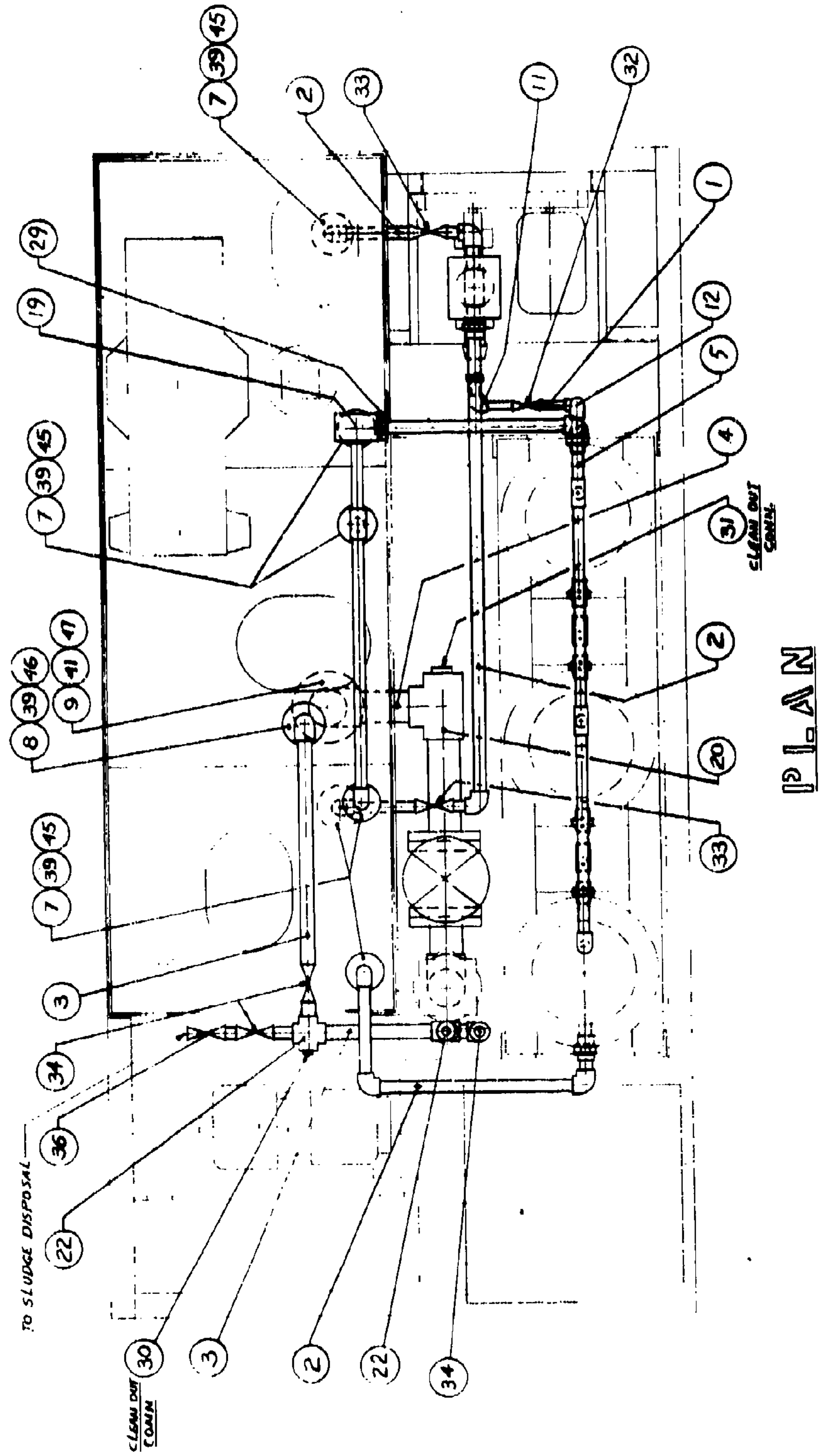
SEWAGE TREATMENT SYSTEM
PIPING ARRANGEMENT
INFLUENT, VENT AND
SLUDGE DISPOSAL

SCALE: $1\frac{1}{2}$" = 1'-0"

DEPARTMENT OF NAVY
DAVID W. TAYLOR NAVAL SHIP RESEARCH & DEVELOPMENT CENTER
CARDEROCK LAB - BETHESDA, MD 20084
ANNAPOLIS LAB - ANNAPOLIS, MD 21402

DTNSRDC NUMBER	REVISION
A-28-19031-5	

48	↑ - ↑	2	↑	↑ : 3" ↑ - ↑ (RF)
47	-	1		: 3" -
46	-	1		: 1¼" -
45	GASKET - FULL FACE	7	BUNA-N	FOR: 1" FLANGE ASA
44	↑ - ↑ - ⅝"-11 NC	6	↑ ↑ ↑	
43	NUT·HEX·½"-13NC	4		
42	↑ - ↑ - ↑ x 3" ↑	6		
41	- - ⅝"-11NC x 1½"	4		
40	- - x 2"	4		
39	BOLT·HEX HD·½"-13NC x 1" LONG	28	STL ASTM A-307 GR B	
38	[illegible]	1	COMML	[illegible] A-75
37	↑ GATE - 3" ↑	1	↑	FLANGED
36	VALVE, CHECK - 1½"	1		SCREWED·HORIZ.SWING
35	VALVE, BALL MIXER DIVERTER 1"	1		[illegible]
34	↑ ↑ - 1½"	3		↑ ↑
33	- 1"	3		
32	VALVE, BALL - ¾"	1	STEEL	·TOP ENTRY
31	↑ ↑ - 3"	1	↑ ↑ ↑	
30	PLUG-SQ.HD. - 1½ NOM	2	STL ASTM A-181 GR 1	SCREWED
29	↑ - 2" MPT x 1" SOCK.	1	PVC ASTM D-1874 - 69	
28	- 2" x 1" ↑	1	↑ ↑ ↑	
27	RED. BUSH. - 1" x ¾" SCREWED	1	STL ASTM A-181 GR 1	
26	↑ - SOCKET - 1" ↑	3	PVC ASTM-1874-69	
25	- ↑ - 1½"	1	↑ ↑ ↑	
24	- - 1"	7		
23	UNION· - ¾"	1		
22	CROSS·SCREWED-1½"	2	STL·ASTM A-181- GR 1	
21	↑ - SOCKET - 1"	2	PVC· ASTM-1874-69	
20	- ↑ - 3"	1	↑ ↑ ↑	
19	- 2"	1		
18	TEE - SCREWED- 1"	2	STL·ASTM A-181· GR 1	
17				
16				
15	↑ ↑ - 1"	2	PVC·ASTM D-1874-69	SOCKET
14	3"	2	↑ ↑ ↑	↑
13	- 1½"	2		
12	- 1"	14		
11	ELBOW-90° - ¾"	2		SCREWED
10	↑ ↑ - 3"	2		↑ - ↑ - RAISED FACE
9	- 3"	1		- - ↑
8	- 1½"	1		- -
7	FLANGE·SL.ON·1"	7	STL· ASTM A-181 GR 1	ASA · 150# - FLAT FACE
6				
5	↑ ↑ - 1"	12 FT	PVC ·ASTM D-1874-69	
4	- 3"	6 FT	↑ - ↑ ↑	↑
3	- 1½"	16 FT	-	
2	- 1"	20 FT	-	
1	PIPE-SCH 40·¾" NOM	10 FT	STL·ASTM A-106 GR B	SEAMLESS


PLAN
TO SLUDGE DISPOSAL
CLEAN OUT CONN.
CLEAN OUT CONN.
1
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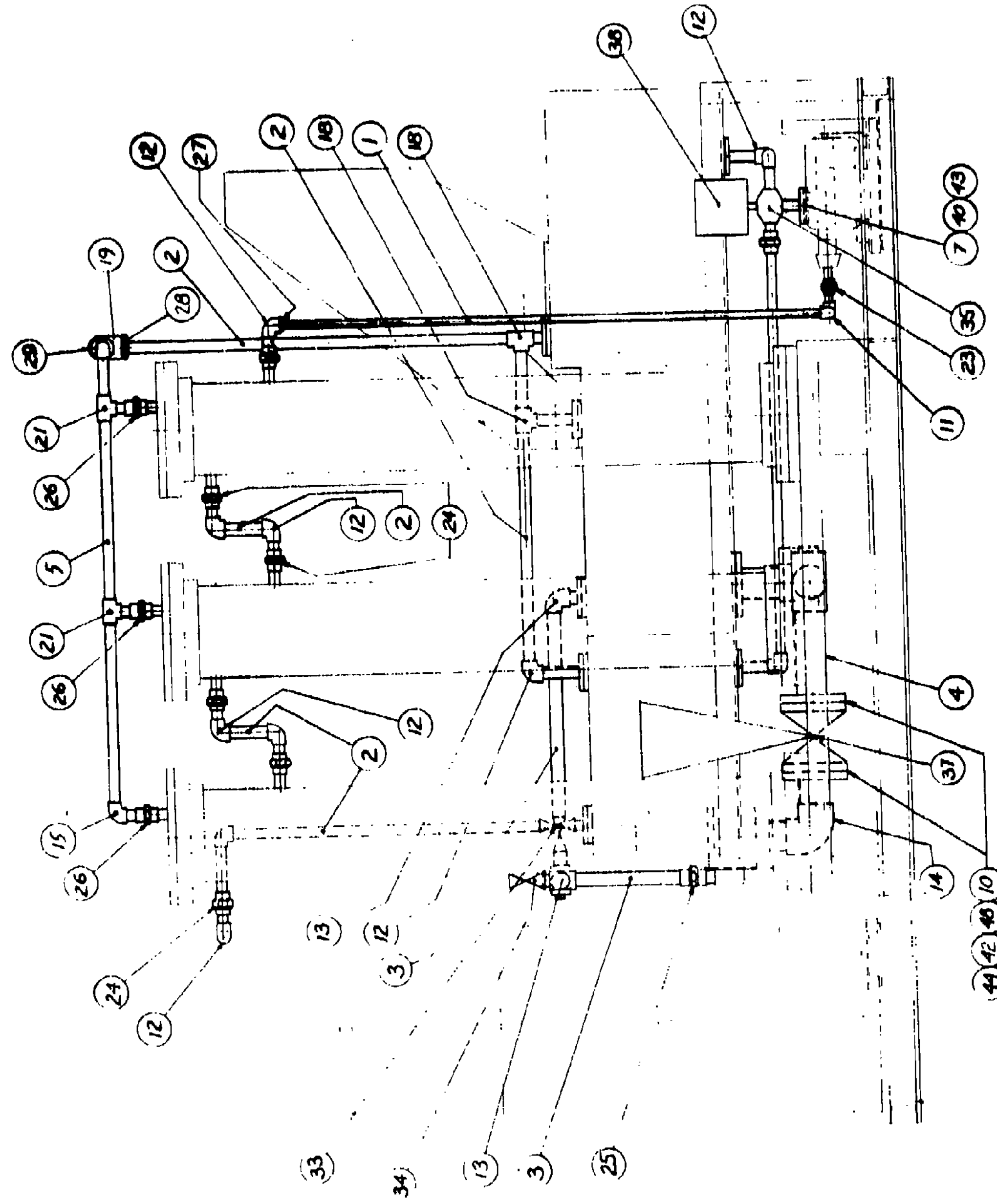

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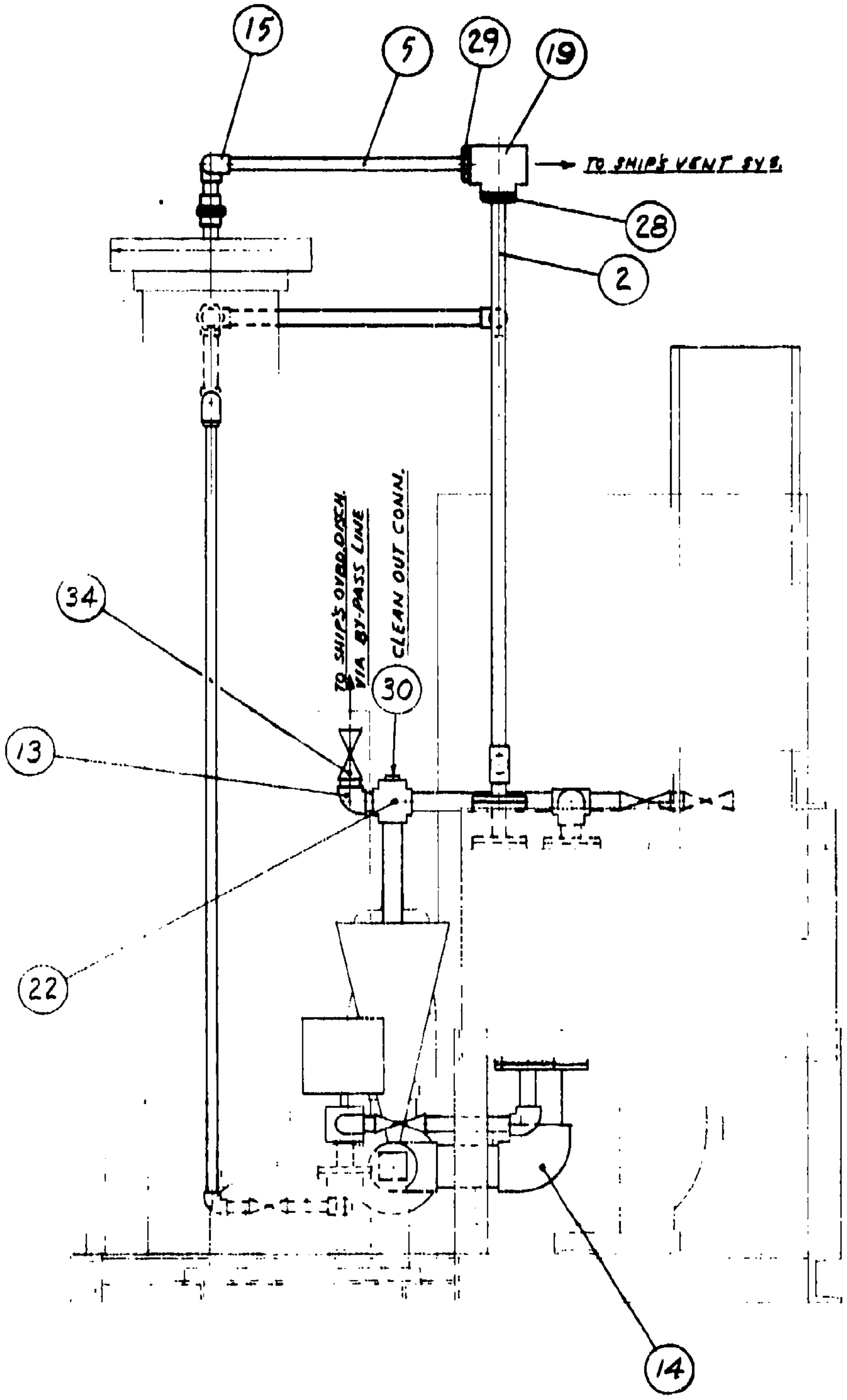
ELEVATION



15
5
29
19
TO SHIP'S VENT SYS.
28
2
TO SHIP'S OVBD. DISCH. VIA BY-PASS LINE
CLEAN OUT CONN.
34
30
13
22
14

RT. END

PC. NO.	NAME OF PIECE	NO. REQ'D.	MATERIAL	SOURCE

LIST OF MATERIAL - QUANTITIES FOR ONE

TOLERANCES UNLESS OTHERWISE SPECIFIED
ON MACHINE SURFACES
2 DECIMAL PLACES ...... ±0.01 INCH
3 DECIMAL PLACES ...... ±0.005 INCH
WHOLE NUMBERS OR — FRACTIONS ...... ±1/64 INCH
ANGLES ...... ±15 MINUTES
ON OTHER SURFACES
SAW CUT ...... ±1/16 INCH
MACHINE FLAME CUT ...... ±1/16 INCH
FINISHES ARE RMS VALUES EXPRESSED IN MICRO-INCHES.

REFERENCES

A-28-19031-1 : SEWAGE TREATMENT SYS.-ARR'T OF EQUIP. & PIPING DIAG.

DATE	8-29-77
DRAWN	GUARINO
CHECKED	
DESIGNED	JG
REVIEWED	CA
APPROVED	[signature]
DATE	9-6-77

SEWAGE TREATMENT SYSTEM

PIPING ARRANGEMENT

F.W. FILL & FLUSHING, OZONE, DRAINAGE AND EFFLUENT OVERBOARD DISCHARGE

SCALE: $1\frac{1}{2}$" = 1'-0"

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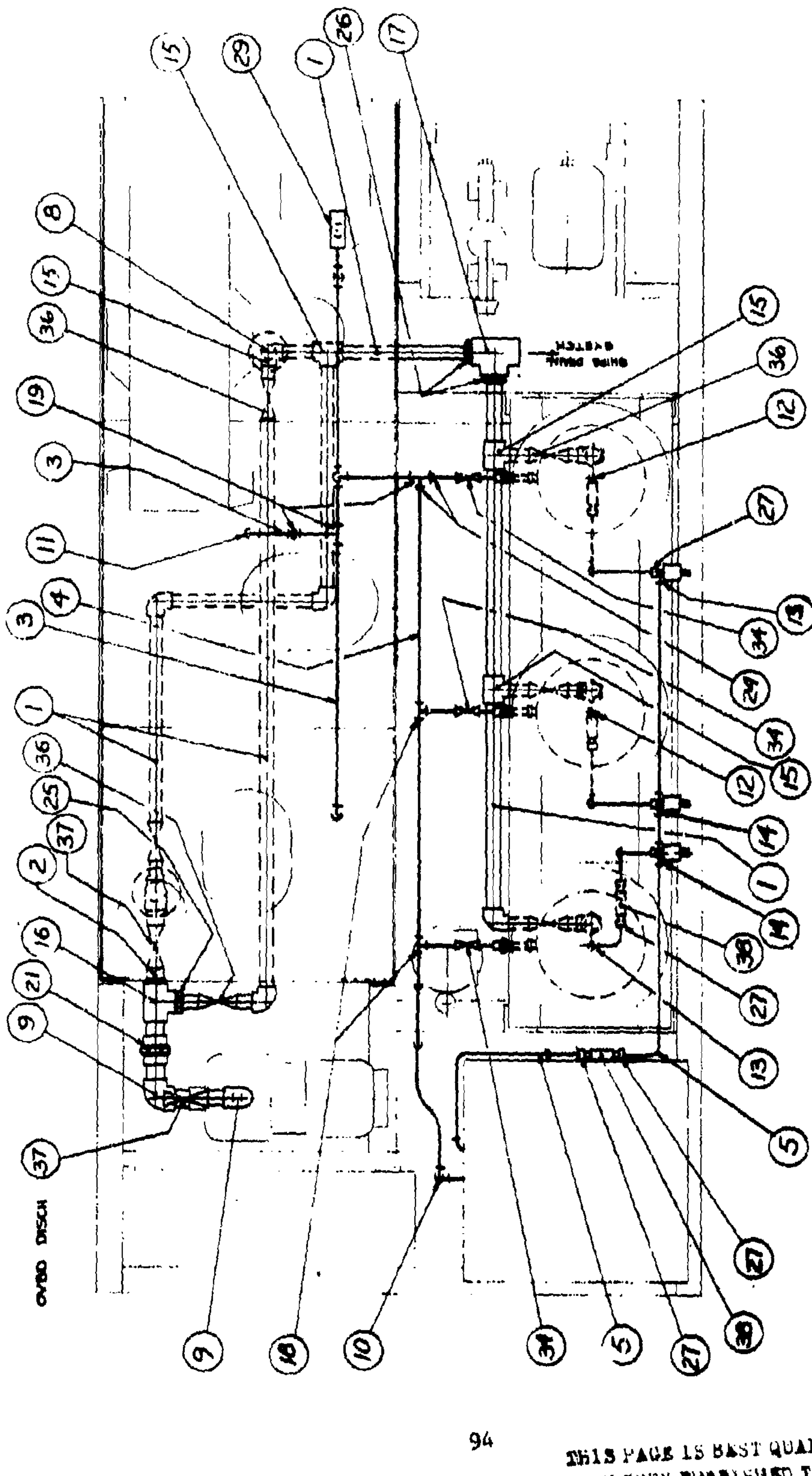
DTNSRDC NUMBER	REVISION
A-28-19031-6	

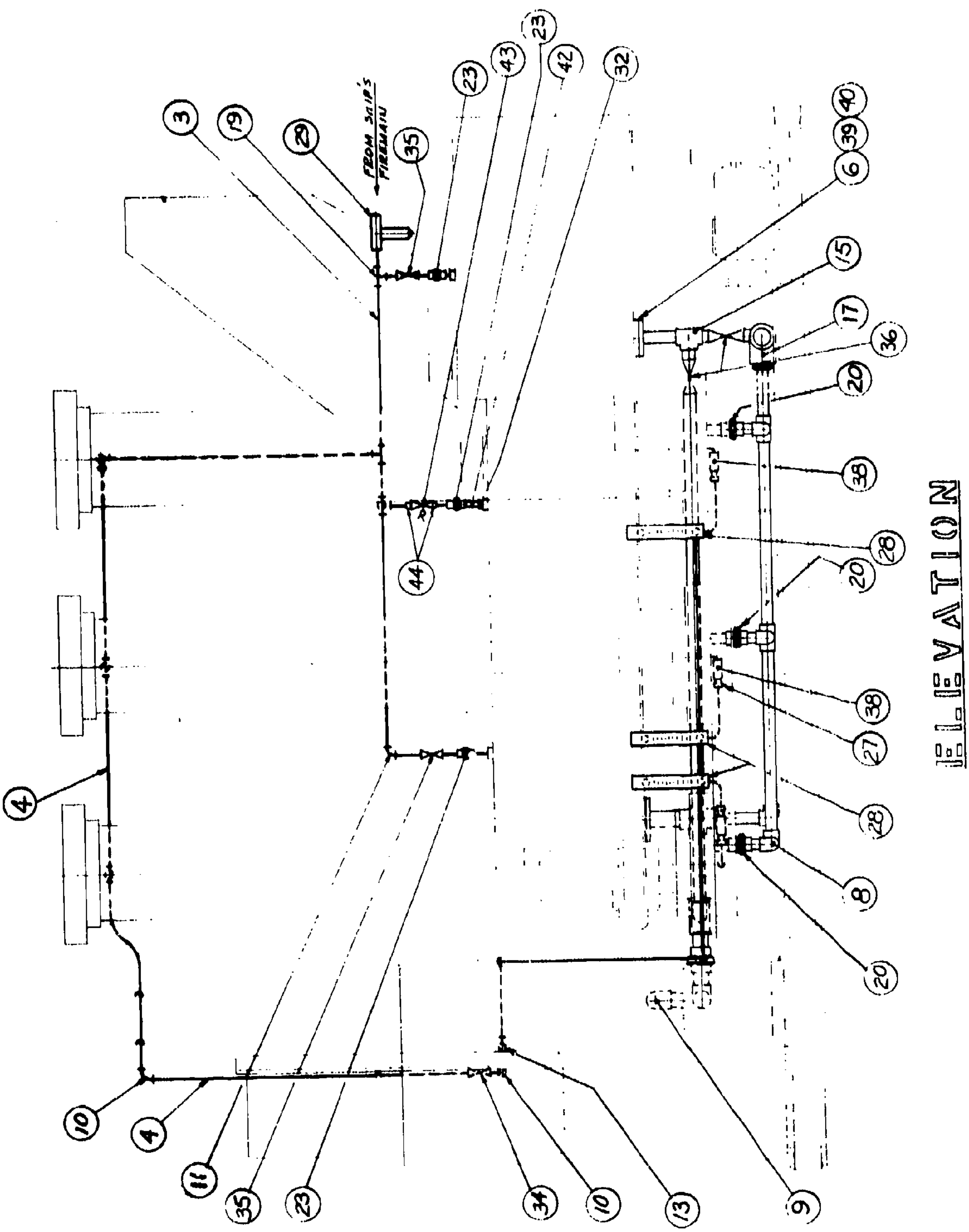
44	MALE CONNECTOR 1/2" OD TUBE × 3/8" MNPT	2	↑	SWAGELOK B-810-1-6
43	3/8" SOLENOID VALVE 2 WAY · NORMALLY CLOSED	1		ASCO CAT. # 8210C93
42	NOZZLE 1/2" UNIJET · FLAT SPRAY TIP	1	BRASS	SPRAYING SYS. 1/2 TT-11002
41	↑ - ↑	1	↑	↑ 1 1/2" ↑ ↑
40	GASKET · FULL FACE	1	BUNA-N	FOR 1" ASA FLANGE
39	BOLT · HEX. HD · 1/2" · 13NC × 1"	8	STEEL	
38	↑ · CHECK · 1/2"(F)NPT	4	S. STL 303	CIRCLE SEAL 262T-1-2PP
37	- ↑ - ↑ · 1 1/2"	2	↑	↑
36	· SCREWED · 1"	7	STEEL	
35	- - ↑ · 1/2"	3	↑	
34	VALVE · BALL · SIL BRAZE · 1/2"	4	BRONZE	TOP ENTRY
33	↑ ↑	3	S. STL	↑
32	ADAPTER · WALL MOUNTING	2	BRASS	SPRAYING SYS. #4068
31	↑ · 1/2" ↑ ↑	3	S STL	SPRAYING SYS. 1/4 TT-11002
30	NOZZLE · 1/4" UNIJET FLAT SPRAY TIP	1	↑	SPRAYING SYS 1/4 TT-11015
29	LINE STRAINER · 1/2"(F)NPT	1	BRASS	SPRAYING SYS 1/2 TW 50 MESH SCREEN.
28	FLOW METER 1/2"(F)NPT	3	POLY CARBONATE PLASTIC	DWYER #RMB-55-SSV 5"(10-100) SCALE W/METER VALVE
27	MALE CONNECTOR	9	S STL 316	1/2"(M) PIPE × 1/2"(OD) TUBE
26	↑ · ↑ · 2" × 1"	2	↑ ↑ ↑	
25	RED. BUSH · SCREWED · 1 1/2" × 1"	2	STL · ASTM · A181 GR I	
24	REDUCER · ↑ · 1/2" × 1/4"	2	↑	
23	↑ - · 1/2" ↑	4		
22	· SIL BRAZE · 1/2"	3	BRONZE	
21	· ↑ · 1 1/2"	1	↑ ↑ ↑	
20	UNION · SCREWED · 1"	3	STL · ASTM A181 GR I	
19	↑ ↑ · 1/2"	5	↑	
18	- SIL · BRAZE · 1/2"	2	BRONZE	
17	- ↑ · 2"	1	↑ ↑ ↑	
16	- · 1 1/2"	2		
15	· SCREWED · 1" NOM	4	STL · ASTM A181 GR I	
14	TEE · 1/2" TUBE × 1/2" TUBE × 1/2" NPT (MALE)	2	↑ ↑	
13	↑ - ↑ · 1/2" MPS × 1/2" TUBE OD	3		
12	- · 1/2" NPT (MALE)	2	S STL 316	
11	- · ↑ · 1/2" ↑	2	↑	
10	· · SIL BRAZE · 1/2"	2	BRONZE	
9	- - ↑ · 1 1/2"	2	↑ · ↑ ↑	
8	ELBOW · 90° SCREWED · 1"	9	-	
7	↑ · ↑ · 1 1/2"	1	·	↑ ↑ · ↑
6	FLANGE · SLIP ON 1" NOM	1	STL · ASTM A181 GR I	150# ASA · FLAT FACE
5	TUBING: 1/2" O.D. × .065" WALL	20 FT	S STL ASTM A269 TYPE 316	
4	↑ - ↑ · 1/2" ↑	20 FT	↑ - ↑ ↑	
3	- STD · 1/2"	20 FT.	CU · ASTM · B42 TYPE DHP	
2	- ↑ · 1 1/2"	6 FT	↑ · ↑ ↑	↑
1	PIPE · SCH 40 · 1" NOM	60 FT	STL · ASTM · A106 GR B	SEAMLESS

NOTES:

1. DRAINAGE PIPING TO BE INSTALLED WITH A 1/8 PER FOOT PITCH TOWARDS THE SHIP'S CONNECTION 2" TEE.
2. PIPING TO BE SUPPORTED AS REQUIRED.



PLAN


ELEVATION
FROM SHIP'S FIREMAIN
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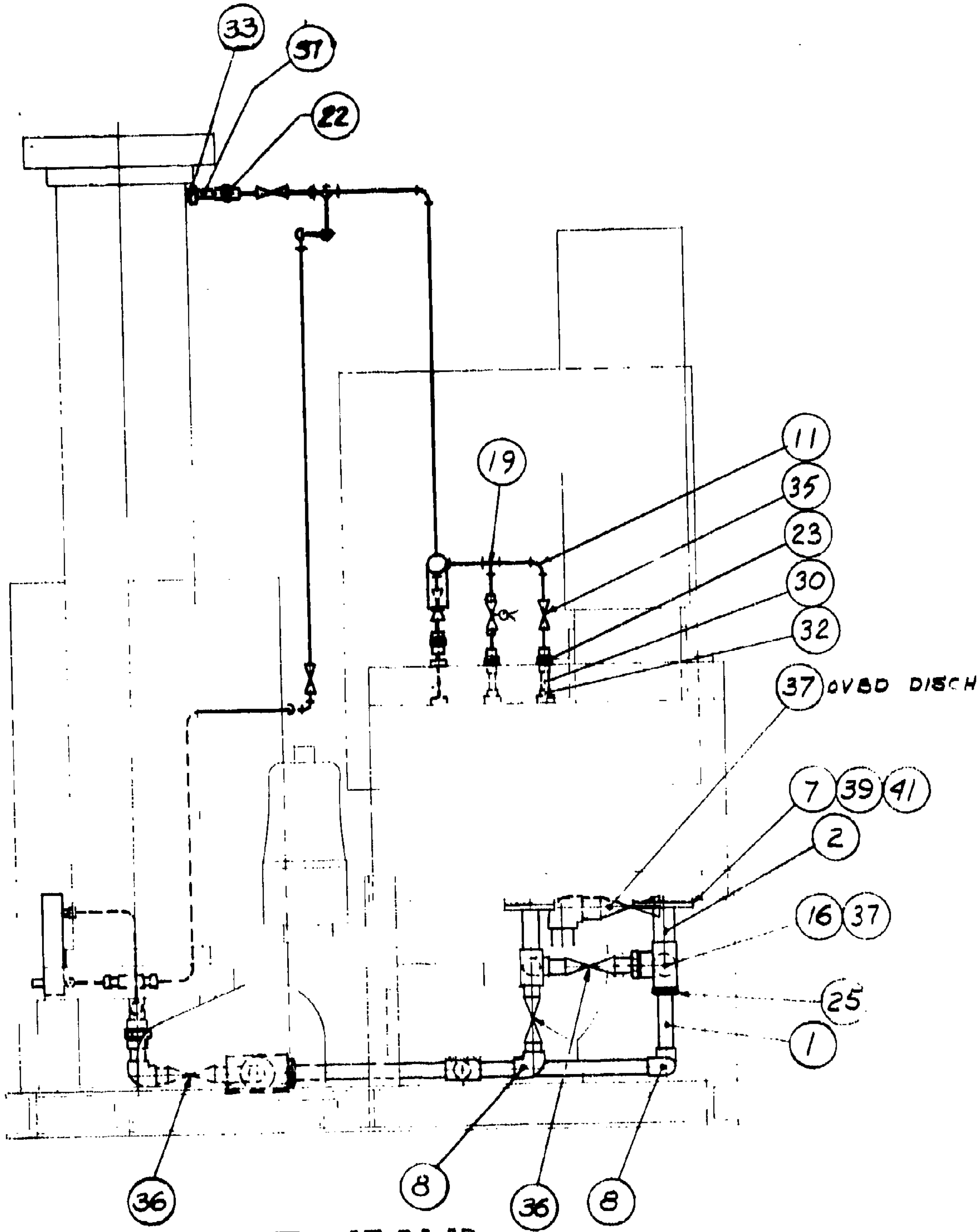

RT. END

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