Report 3948

ADA029530

Laboratory Evaluation of the GATX Evaporative Toilet System

NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20034

LABORATORY EVALUATION OF THE GATX EVAPORATIVE TOILET SYSTEM

by

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APPROVED FOR public release; distribution unlimited 23 APR 1976

MATERIALS DEPARTMENT
ANNAPOLIS

RESEARCH AND DEVELOPMENT REPORT

July 1973

Report 3948

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Naval Ship Research and Development Center
Bethesda, Md. 20034

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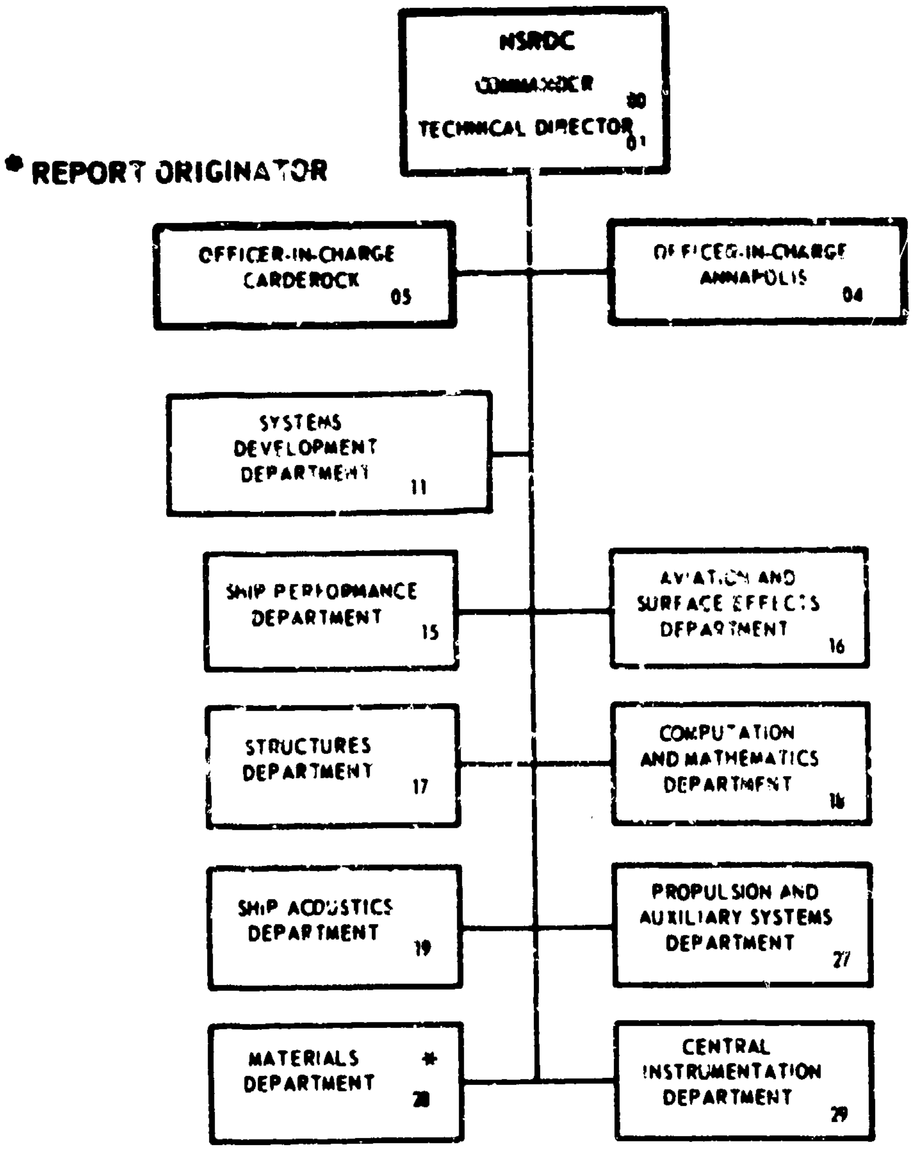

DEPARTMENT OF THE NAVY

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ABSTRACT

The evaporative toilet system manutured by General American Transportation Corporation was accepted for laboratory evaluation aboard mobile noise barge, MONOB YAG 61.

After minor problems during the installation and breaking-in periods, the system operated over 700 hours before a critical failure was recorded on 7 January 1973. The failure was due in part to a plumbing arrangement. Corrective action was taken, and the system operated an additional 1150 hours without failure, to demonstrate successfully the required mean time between failures of 500 hours.

A maintainability demonstration involving 22 maintenance events was unsuccessful due primarily to the design and installation locations of the evaporator/holding tank subsystem. The specified maximum repair time of 5 hours was exceeded by 1 hour, and the specified maximum repair time of 1 hour for components of the transport function was exceeded in two different maintenance events. Installation problems, which could be avoided in future programs, are considered the main cause for the one critical system failure and the maximum repair time of 6 hours.

The odor of the water vapor released from the vent stack is the principal user objection to the system.

Recommendations are made on ways to improve the reliability, maintainability, habitability, and performance of the General American Transportation Corporation system. Most of these are for areas of minor deficiencies related to the fact that the complete system was not fully tailored to the marine environment to which it was subjected during the evaluation.

ADMINISTRATIVE INFORMATION

This work was accomplished under Task Area S4657, program element 63721N, Work Unit 1-2860-124. This report is applicable to milestones 18 and 19, TDP S46-57X (page 1.7) of March 1973.

A test and evaluation plan was developed for NAVSHIPS (SHIPS 03412), reference (a). This laboratory was tasked to provide on-site coordination and to conduct the evaluation, reference (a). Assistance in system operation, data recording, and reporting was given under contract by Bradford Computer and Systems, Incorporated, reference (b).

ADMINISTRATIVE REFERENCES

(a) "NAVSHIPS Test and Evaluation Plan for the GATX Evaporative Type Shipboard Sewage Treatment System," NAVSEC (SEC 6159) (7 Nov 1972)

(b) NAVSHIPS contract ~~N00600-72-D-0613 dated~~ 30 Dec 1971

ACKNOWLEDGMENTS

This work was conducted under the sponsorship of NAVSHIPS. The program manager was Mr. Frank Ventriglio, NAVSHIPS (SHIPS 03412B). Technical management was provided by Mr. Carl Schaller of NAVSEC (SEC 6159B). Excellent cooperation in the performance of the evaluation was provided by Lt. E. R. Hazelwood, OIC of MONOB, and his crew. The Navy appreciates the assistance of the Broward County Air and Water Pollution Board in performing laboratory analyses.

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INTRODUCTION

The evaporative toilet system built by General American Research Division of General American Transportation Corporation (GATX) is one of several candidate shipboard waste treatment systems being evaluated by the Navy. The mobile noise barge (MONOB YAG 61), operated by NSRDC out of Port Everglades, Florida, was selected as the laboratory test site for this evaluation. The installation and evaluation were made at the request of NAVSHIPS (SHIPS 03412B).

The details of the reliability and maintainability test and evaluation plans, reference (a), were prepared by NAVSEC. The details of the GATX system and specific events of installing, breaking-in, and evaluating during the 3 months of system operation were published earlier.[1,2,3]

BACKGROUND

POLLUTION ABATEMENT PROGRAM

The Navy is committed to install waste treatment/management systems on surface craft in the near future with the objective of eliminating the discharge of either treated or untreated sanitary wastes into navigable zone (harbor or coastal) waters. The decision to install collection, holding, and transfer (CHT) systems aboard ships to permit collecting and holding of all non-oily liquid wastes within a 12-mile range of shore and with subsequent discharge to a shore facility, is one approach to the pollution problem. The holding capacity is predicated on weight and space compensation limitations without compromising the combat effectiveness of the ship. However, several types of ships (salvage, amphibious, etc) operate for considerable periods of time within the 3- and 12-mile distances from shore. In addition, ships at anchor would also not have access to pier side sewer connection. There are also advantages of shipboard treatment systems for Navy ships operating in sensitive foreign ports, especially those near recreational or fishing areas. Thus, effort is continuing to develop an effective and reliable marine waste treatment systems with a no-discharge capability.

[1]Superscripts refer to similarly numbered entries in the Technical References at the end of the text.

As part of the effort to develop a suitable marine waste treatment system, this laboratory is evaluating several alternate systems. In February 1972, General American Transportation Corporation proposed to make available to NAVSHIPS, at no cost to the Navy, one evaporative toilet system for laboratory evaluation. The proposal was accepted, a test site was selected, and equipment installation was begun in September 1972.

SYSTEM DESCRIPTION

The GATX evaporative toilet system operates on the principle of volume reduction of sewage by boiling off some of the water content. The evaporator retains the remaining liquid and solid wastes in the form of a sludge which can be pumped to a shore facility or into unrestricted waters. A simplified schematic diagram of the operation is shown in figure 1.

System operation is initiated by flushing the water closet, shown in figure 2, which automatically introduces a controlled volume of flush water and a disinfectant solution to the water closet. The flushing action also activates, through the automatic control circuitry housed in the control panel shown in figure 3, the macerator/transfer (M/T) pump shown in figure 4. The pump grinds the solid wastes and transfers the slurry to the evaporator tank shown in figure 5. Level switches in the tank control the electrical heating systems which boil off water until solids concentration reaches 15%-20%, at which time the residue in the tank is pumped to a shore facility or overboard.

The system installed on MONOB is a version of the GATX system that uses fresh water for flushing, as converted to conform to Navy requirements for salt-water flushing. The system, which is designed to service a full-time crew of 25 men for a period of 30 days, consists of three controlled (limited) volume water closets, a controlled-volume urinal, three M/T pumps, an evaporator tank, controls for automatic operation, a discharge pump, and associated plumbing. An alternate mode of operation, for use in unrestricted waters, consists of bypassing the limited volume flush controls, the M/T pumps, and the evaporator tank. This permits full volume flushing and overboard discharge by gravity flow of the sewage.

EVALUATION SITE

MONOB was selected as the evaluation site for the GATX system for two major reasons. First, the ship is a laboratory vessel under NSRDC administrative control, with an operating cycle of approximately 2 weeks at sea and 1 week in port. This was considered to be very useful for the planned program.

Second, the port authorities for the cruise-ship harbor, Port Everglades, used as an operating base by MONOB, have asked the Navy to help minimize pollution in the harbor. The installation of the GATX system allows no-discharge operation in port and thus serves local antipollution interests while demonstrating the lead the Navy has taken in the abatement of water pollution caused by ships.

INVESTIGATION

TEST AND EVALUATION PLAN

The requirements and procedures for the evaluation of the GATX system were written by NAVSEC (SEC 6159B) in collaboration with NSRDC personnel.

The stated objectives of the tests are to furnish data permitting a quantitative evaluation of performance, reliability, and maintainability of the GATX system during a laboratory evaluation aboard MONOB. Specifically, the GATX system is required to demonstrate that the minimum mean time between failures (MTBF) is 500 hours at the 90% confidence level with salt-water flushing.

Following a successful reliability demonstration, a maintainability demonstration was scheduled with a minimum of 20 maintenance events. The demonstration is considered successful if the data show that 95% of all maintenance actions will take less than 5 hours' repair time, at a 90% confidence level. Additional details of the selection and simulation of maintenance events are included in appendix A, along with the maintainability demonstration results. Simulation is required when the failure record is insufficient for maintainability demonstration purposes.

Concurrent with the reliability evaluation, samples of condensed stack vapor and of the sludge were to be chemically analyzed to quantify sewage treatment characteristics of the systems.

NSRDC has the primary responsibility of conducting and evaluating the tests. Technical assistance from GATX has been available when needed. Daily monitoring of the system and recording of test data have been the responsibility of the engineering staff aboard MONOB. In addition, the MONOB crew performed approximately half of the maintenance events in the maintainability demonstration. A technician from NSRDC/A performed the balance of the events.

SYSTEM INSTALLATION

A local ship repair organization, Marine Acoustical Systems Division of Tracor, Incorporated. (TRACOR/MAS), installed the GATX system aboard MONOB. Installation began 1 October 1972 and was completed sufficiently to allow pretest checkout by the manufacturer on 4 November 1972.

The GATX system constitutes half of the water closets and urinals aboard MONOB. However, when in port, the units not tied into the GATX system are secured. Therefore, in port the ship does not discharge sewage overboard when the GATX system is operating in the normal (processing) mode. The complement of the head facilities on MONOB is:

- Captain's Head - Poop Deck. One above-deck GATX water closet.

- Port Head - Main Deck. One controlled-volume-flush (CVF) urinal, two standard GATX water closets.

- Starboard Head - Main Deck. One urinal, two water closets.

- Aft Head - Main Deck. One water closet.

Figure 6 indicates the installation of the units in areas 1 and 2, the evaporator tank mounted in the aft head on the main deck, and the pump assembly and piping mounted below the main deck in the machinery room and the bunk room. In order to utilize direct gravity feed, the pump assembly is mounted below and within 10 feet of the port head. The pumping distance from there to the evaporator tank is approximately 30 feet. Similarly, there is 30 feet of pumping distance from the above-deck pump in the Captain's head to the connection with the main soil line to the evaporator which is aft of the dual pumps in the machinery room.

As shown in figure 6, an overboard discharge pump is part of the system. The pump and overboard line are in a storage compartment directly below the evaporator tank. An additional line has been run from the sludge pump up through the aft head to a shore disposal connection on the main deck.

The heavily insulated vent pipe from the evaporator tank has been run directly above the tank and approximately 20 feet above the poop deck to enhance the dilution and dispersion of objectionable odors in the water vapor.

RESULTS

PRETEST SHAKEDOWN

The GATX system (excepting the commode in the Captain's head) was operated in a pretest shakedown period from 4 November to 8 December 1972. The purpose of this period of operation was to allow the manufacturer to correct any quality control or synthesis problems which might occur without their counting against the system in the reliability demonstration. The major problems which occurred during this period were:

- The water volume per flush, passed by the solenoid actuated Sloan valve on the urinal, varied from the intended 1 pint to 1 gallon. The problem was found to be a defective leather gasket which was corrected by replacement with a standard rubber gasket.

- A leak developed in a union directly below the evaporator tank, evidently due to faulty installation. The problem was corrected by replacement of plumbing parts.

- The low-level float sensor in the evaporator tank failed due to a crack in the rubber sleeve covering the associated mercury switch. The sleeve was replaced to correct the problem.

RELIABILITY EVALUATION

The GATX system reliability evaluation phase was initiated on 9 December 1972. On 7 January 1973, after 703 hours of operation, a critical failure occurred. Corrective action was taken (clean-out) and the reliability test restarted on 11 January 1973. Completion of 1150 hours of subsequent testing occurred on 2 March 1973. During sea duty, system performance data were collected on each watch by the engineering staff aboard MONOB. The data recording was reduced to approximately once per day while the ship was in port. Details of the instrumentation and test procedures are included in appendix B. Details of all significant events occurring during the 3-month test period have been presented.[1,2,3] These events are summarized briefly as follows:

- During December 1972, two system outages occurred due to causes external to the system; they are not considered in the evaluation criteria.

• On 7 January 1973, a critical failure of the system occurred when both M/T pumps in the machinery room cut off due to solids accumulation at the 90° bends in the soil line. This problem has been discussed in detail.[2] Corrective action included the installation of a hose connection with cutoff valve on the manifold flange near the pumps to permit backflushing, to overboard, of the soil lines. (Replacement with curved elbow connections would also reduce or eliminate solids accumulation.) Other suggested corrective measures are contained in the System Reliability section of this report.

• As a result of the above event and an observed tendency for solids buildup directly below the water closets, the crew initiated additional cleaning and flushing of the water closets in the port head. Cleaning was facilitiated by running a connection from the adjacent fire water main to the vent pipe for the water closets.

• On 8 February 1973, the gasket for the viewing port on the evaporator tank was replaced to prevent odor escaping into the aft head area. The gasket had been improperly seated during inspection of the tank prior to the start of the test; the event was therefore not considered a system failure.

• On 8 February 1973, the sensor floats were found to be inoperative due to a heavy accumulation of sludge over the floats and connecting arms. Since the system had been operated for 2 months without emptying and cleaning the tank (1 month operation is recommended by the manufacturer), the failure of the sensor was considered due to external causes. To prevent this situation recurring, the tank should be cleaned at least once every 6 weeks whether loading justifies it or not.

• On 28 February 1973, the upper level sensor was found to be inoperative due to a permanent set in the rubber sleeve covering the mercury switch. Replacing the sleeve with one of a different durometer rating corrected the problem. The replacement sleeve was supplied by GATX. The event was determined to be a minor failure.

• Accumulation of salt deposits degrading the operation of both the urinal Sloan valve and the evaporator tank rinse nozzle was observed. Periodic inspection and cleaning of these two items are recommended for preventive maintenance (PM).

MAINTAINABILITY EVALUATION

The maintainability evaluation was completed during the month following the successful completion of the reliability demonstration phase. All maintenance events that occurred during the reliability demonstration phase were applied to the maintainability demonstration. Appendix A presents details of the test plan, apportionment of tasks, conduct of the maintainability demonstration, and results.

The corrective maintenance (CM) times observed during the demonstration are summarized in figure 7. As shown in more detail in appendix A, these data are used in the specified relationship to quantify the maximum maintenance time. That is:

$$T = \bar{D}_{CM} + 2.2\ S_{CM}$$

where

T = log of sample maximum corrective downtime. The time is recorded in minutes.

$\bar{D}_{CM}$ = average of the logs of the downtimes.

S_{CM} = sample standard deviation of the logs of the downtimes.

$$T = 1.65785 + 2.2\ (0.41077)$$

$$= 2.56156$$

$$= \log 364 \text{ minutes or 6 hours 4 minutes.}$$

This exceeds the specified maximum maintenance time of 5 hours. Similarly, maintenance events B2 and B3 for the transport function both exceed the specified limit of 1 hour.

As noted in section 5 of appendix A, the troubleshooting section of the Operation and Maintenance Manual needs more information. Many maintenance events used during the demonstration are either not covered in the manual or the information is not complete. Seven areas for improvement noted during conduct of the demonstration are listed in appendix A. The list does not constitute a thorough evaluation but is an indication of how the manual can be improved for maintenance purposes.

PERFORMANCE

Although there are no quantitative requirements for performance in the test plan, qualitative requirements for the collection and analysis of operational performance data are given in section 3 of the plan, reference (a).

Analysis of Vent Stack Condensate

The strongest criticism of the GATX system by the MONOB crew is the odor of the vapors from the evaporator vent stack.

On three separate occasions, NSRDC personnel collected samples of condensed stack gases, or condensate, for chemical analyses. Results and testing details are presented in appendix C. The initial samples, 8 February 1973, were taken from the sampling port directly above the evaporator tank. The high chemical oxygen demand (COD) and chloride content indicate solids carryover in aerosol droplets. The two subsequent sample groups were taken from the top of the vent stack. They are considered more realistic. The results indicate ranges of:

COD	140-310 mg/l*
Coliform Bacteria Count	<10 MPN**/100 ml
Ammonia	370-1630 mg/l
Chloride	1.1-2.1 mg/l

Sludge Analysis

Under normal conditions of operation and loading, the concentration of the sludge in the evaporator tank builds up to 15% to 20% solids, after which the tank must be serviced. On three separate dates, samples were obtained for analyses while the tank was in a condition of high or maximum solids concentration. Results of the analyses are presented with details of sampling and testing techniques in appendix C.

As the most representative results, those for the 26 February 1973 sample are as follows:

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* Abbreviations used in this text are from the GPO Style Manual, 1973, unless otherwise noted.
**MPN = Most probable number.

Total Residue	24.9%
Total Volatile Residue	6.1%
Salinity	10.9%
COD	2.4 pph
Coliform Bacteria	<100 MPN/100 ml
pH	7.1%

The total residue contains sea salt from the flushing water.

Other Data

Approximately 300 log sheets were collected during the conduct of the reliability evaluation. The data they contain can be used to determine loading rates, total operating time for all components, boil-off rates, and total power consumption.

A data sheet showing eight of the more significant data elements appear in appendix C with daily entries at the beginning and at the end of the reliability evaluation.

DISCUSSION

SYSTEM RELIABILITY

The one event recorded as a critical failure of the system (see first entry at top of page 6) was deactivation of the M/T pumps due to solids accumulation in the soil lines below the port head. In the MONOB installation there is one [illegible]° bend in the vertical soil line plus four more 90° bends in a 12-foot (approximately) horizontal run to the M/T pumps. The contractor recommends that the pumps be located as close as possible to the water closets or within a maximum of 8 feet.

There is no room to mount the M/T pump assembly in the bunk room directly below the port head. However, one of the horizontal bends in the soil line could be eliminated by reorienting the axis of the pumps 90° from their current fore-and-aft alignment. The pumps are small enough and close enough to the center line of the ship not to be concerned with shaft alignment.

The corrective action of installing a backflush connection is effective in eliminating any clogging that may occur, but it does not prevent the occurrence. Future installations should be planned to have the M/T pumps closer to the water closets and to have curved 90° elbow bends.

The failure discussed in the foregoing appears to be related to the manner of installing the system, rather than to the system proper. As stated in the section on Reliability Evaluation, 1150 hours of testing were completed after this failure; formal recording of data was then terminated. System operation was continued. At this point, total test time amounted to 1853 hours. Calculation of the MTBF results in a value of 477 hours, at the 90% confidence level, if the critical failure is counted as a system failure. If it is not so counted, the estimated lower limit of the MTBF is 815 hours.[2] If preventive maintenance is done, clogging will not occur. In that sense, the system would be considered as a "changed system." Then the 1150-hour period would be a new test, leading to 500 hours MTBF. Component failures are discussed in the next section. These did not constitute major or critical failures.

COMPONENT RELIABILITY

Two failures of the level-sensor assembly occurred during the total operating time of the system (more than 2200 hours). One failure was due to sludge accumulation, and regular scheduled cleaning (PM) would eliminate this type of sensor problem. The other failure was with the rubber sleeve covering a float switch. Two sleeves have been replaced with ones of a different durometer rating which may correct the problem. Until sufficient additional operational data become available, the float system (rubber sleeve) must be considered the least reliable component in the system.

CORRECTIVE MAINTENANCE

As evidenced from the results of the maintainability demonstration, the inaccessibility of the heaters and thermoswitches caused the maintainability test failure. The evaporator tank, with these components on it, is covered with fiber glass insulation and a metal shroud. The shroud pieces are held together with sheet metal screws in two vertical seams, 180° apart. On MONOB, with the tank strapped into a corner, it is impossible to remove the shrouding without disconnecting the tank and moving it out from the corner. Obviously, this should be avoided on future installations. An alternate approach could be taken in the redesign of the shroud to have a hinge connection in the rear of the tank and two vertical seams on the front half.

On the assumption that the accessibility of the heaters and thermoswitches might not be a problem in future installations, the maximum maintenance time, statistic T, was recomputed excluding times for events C3 and C4 (see appendix A). The results are:

$$T = 1.56733 + 2.2\ (0.30262)$$

$$= 2.23309$$

$$= \text{Log } 171 \text{ minutes or } 2 \text{ hours } 51 \text{ minutes.}$$

This illustrates that if these two "outliers" could be excluded from the distribution shown in figure 7, the GATX system could easily meet the requirements stipulated.

The requirement of 1-hour maximum repair time for components of the transport function was not met due to the time required to replace an M/T pump. Although there is little doubt that with experience the maintenance crew could reduce this time to less than 2 hours, the validity of this requirement is questioned - especially since the pumps operate in active redundancy and having one pump off-line for repair does not cause loss of the transport function.

PREVENTIVE MAINTENANCE

The preventive maintenance requirements for the GATX are nominal. In fact, the absence of extensive preventive maintenance efforts precluded a demonstration similar to that for corrective maintenance.

However, during the reliability demonstration, the following additional cleaning, or preventive maintenance, efforts were found to be necessary to prevent a related subfunction degradation.

Disassemble and Clean Urinal-Flush Sloan Valve

If not cleaned every 3 or 4 weeks, the valving action will degrade to where approximately 1/2 pint of flush water flows rather than the desired 1 pint. The effort to remove the valve and clean out the salt deposits requires approximately 10 minutes.

Intensified Cleaning of Water Closets and Soil Lines

On MONOB the water closets are cleaned daily. With the controlled-volume-flush of the GATX system, it has been found that the slight increase in bowl soiling requires additional daily cleaning. This problem was accentuated on the outboard or No. 2 water closet. A slight deformation of the vitreous china prevented the pad on the flapper valve from seating properly. The result was a leak off of the residual pint of water in the basin and increase of soiling due to the relatively dry bowl.

A modification may improve the problem of soiling while also improving reliability. The two foot pedals used for the separate fill and flush operations would be replaced by one. With the simplified mechanical linkage (more reliable), the operation would be changed to meter in 3 pints of flush water as the flapper valve closes after flushing. The 3 pints would remain in the bowl until the next flush. This would reduce the amount of soiling currently experienced with a 1-pint residual.

The problem of clogging at the 90° bends of the soil lines was mentioned earlier. If the resulting backup was noted in the line below the bowls, the engineering personnel doing the daily cleaning would normally open the overboard valve and flush out the lines with extra water in the head area. The reason for clogging directly below the water closet is related to the installation. The soil lines from the water closets separately feed into a manifold, then overboard through a cutoff valve or inboard to the pump assembly. Between the water closet connections and the pump, there is a separate vent line connection. Thus, the pumps have no suction beyond the vent line. If the option exists in future installations, the vent line should be closer to the water closets to facilitate transport of the wastes. The total cleaning effort should take approximately 35 minutes.

Clean Level Sensors Every 6 Weeks

If not serviced and cleaned in the normal 1-month period, an additional preventive maintenance effort of cleaning off the float assembly every 6 weeks should be included to prevent solids buildup from deactivating the function. This action should take approximately 45 minutes.

Check and Clean Water Fill Nozzle

Each time the evaporator tank is emptied and cleaned, a separate preventive maintenance action is necessary to remove the water fill nozzle and clean out any salt deposits. This would prevent the nozzle from being closed completely. This specific effort should take about 20 minutes.

The additional cleaning effort for the GATX system, particularly relative to clogging in the soil lines, is the second strongest criticism by the MONOB crew of the system; the primary criticism concerns the vent odor.

ELIMINATION OF ODOR IN THE VENTED WATER VAPOR

Since the odor is the strongest criticism of the GATX system, the elimination of the odor is receiving considerable attention. An approach now being finalized is catalytic oxidation of the malodorous components of the water vapor.

Interim Solutions

The catalytic converter seems to be the preferred approach, but the following interim solutions could be tried while waiting for production of a test model to use on MONOB.

- Run evaporator vent stack overboard. If the stack were run 2 feet below water level, the water vapor would condense and drain into the water. Care would have to be taken to install both pressure and vacuum release valves in the line.

- Spray the vapor with water. The vapor would be passed through a water spray which should condense the undesirable malodorous components. The condensate and spray water would drain overboard.

- Inject warm air into the stack. This would result in elevation of the stack plume and in dilution of the odor. The air must be heated to prevent condensation within the stack.

Catalytic Converter

GATX is developing a catalytic converter or oxidizer in which the malodorous components of the vapor react in the presence of a heated catalyst with oxygen (air) at a slightly elevated temperature. An experimental small-scale model has been successfully operated in the GATX laboratory (observed by NSRDC personnel). Efforts are underway to produce a working model for installation and evaluation aboard MONOB. When installed, the catalytic converter will be adjacent to the evaporator tank in the aft head.

Ozone Injection

The use of ozone for oxidizing the odor components of the water vapor is objectionable to some, for reasons of health and safety hazards. If an ozone generator is used, mounted outside on the poop deck, and ozone is injected into the stack at the poop deck level, these hazards appear to be negligible. In the additional 20 feet of the stack from the poop deck to the top, the ozone would probably oxidize the unwanted components so that only a negligible amount would be vented to the atmosphere. If the approaches in the Interim Solutions and Catalytic Converter sections are not successful, additional planning effort will be put into ozonation methods.

CONCLUSIONS

The GATX system has completed 1853 hours of documented operation aboard the ocean-going research vessel MONOB to demonstrate a MTBF of 477 hours at a 90% confidence level. One critical failure occurred after 703 hours of operation.

The maintainability demonstration was unsuccessful on both specifications. While the specified maximum maintenance time is 5 hours, it actually consumed 6 hours and 4 minutes. The excessive time is attributed to inaccessibility of the evaporator tank for maintenance events. The specified maximum repair time of 1 hour for the transport function was exceeded on two maintenance events. The water vapor and the residual sludge are both sterile. Installation problems, that could be avoided in future programs, were the major causes for the one critical system failure and the unsuccessful attempt to demonstrate the specified maximum downtime. If the installation-related failure is not to be held against the GATX system proper, the MTBF is in excess of 800 hours.

The major problem of the GATX system is the objectionable odor issuing from the evaporator tank.

RECOMMENDATIONS

The GATX system should be considered as a feasible system for installation on Navy ships. Conditions are that installation precautions relative to the location of the M/T pumps and the evaporator tank be followed, and an effective odor-reducing component be made an integral part of the system.

Efforts should continue for test and evaluation of an effective odor-reducing component for the GATX system.

The following specific recommendations will improve the performance, reliability, maintainability, and habitability characteristics of the GATX system:

- Clean the two level sensor assemblies in the evaporator tank at least once every 6 weeks of system operation to prevent loss of level-sensing function from solids accumulation.

- Check the rinse nozzle in the evaporator tank each time the tank is serviced to prevent clogging by salt deposits.

- Mount the M/T pumps within the recommended 8 feet (maximum distance) from the water closets.

- Ninety-degree bends in the soil lines between the water closets and the M/T pump should all be curved rather than angular.

- Mount components, such as the evaporator tank, so that they are readily accessible for maintenance.

- If the evaporator tank must be mounted in a corner, use a multisection hinged shroud assembly so maintenance can be performed without having to uncouple and move the tank assembly.

- Disassemble and clean urinal-flush Sloan valve every 3 to 4 weeks to prevent gradual decrease of flush volume due to salt deposits.

- Redesign flushing mechanism to increase residual water in the water closet which would reduce current amount of soiling and resultant cleaning efforts.

- Revise the Operation and Maintenance Manual to include information now missing.

FUTURE WORK

The results presented indicate that with minor changes in design, and in installation procedures, the GATX evaporative toilet system could be satisfactory to the Navy for shipboard applications.

The major immediate effort will be in the area of correcting the odor problem. The installation, test, and evaluation of the catalytic converter takes precedence, but some of the interim solutions discussed in the text may be tried on MONOB as a local effort.

Subject to results of efforts to improve maintainability and to resolve the odor problem, a proposal will be made for installation of a Navy specification unit on a ship that is acceptable to the Operational Test and Evaluation Force, Norfolk, Virginia. Installation would be followed by shakedown operation and an operational test.

TECHNICAL REFERENCES

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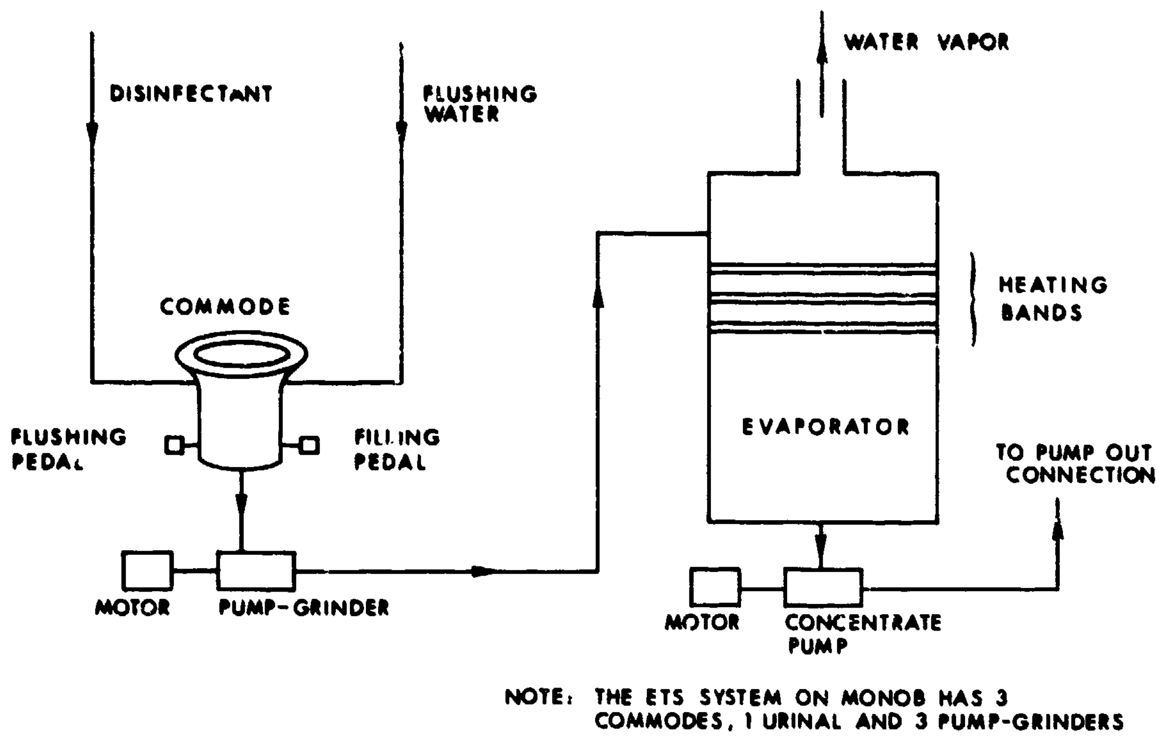


Figure 1
Evaporative Toilet System on
Research Vessel MONOB

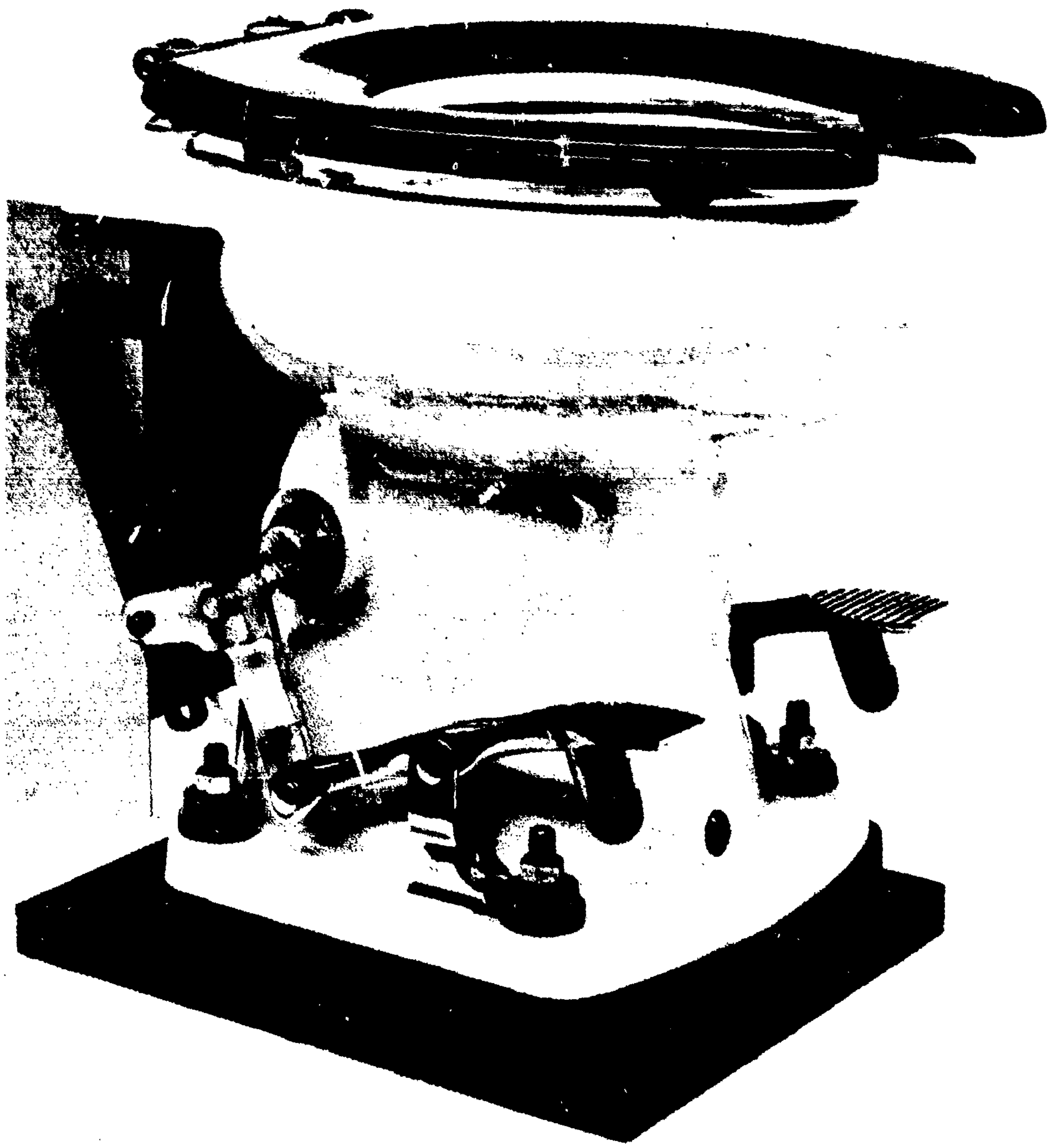


Figure 2
Controlled-Volume-Flush Water Closet

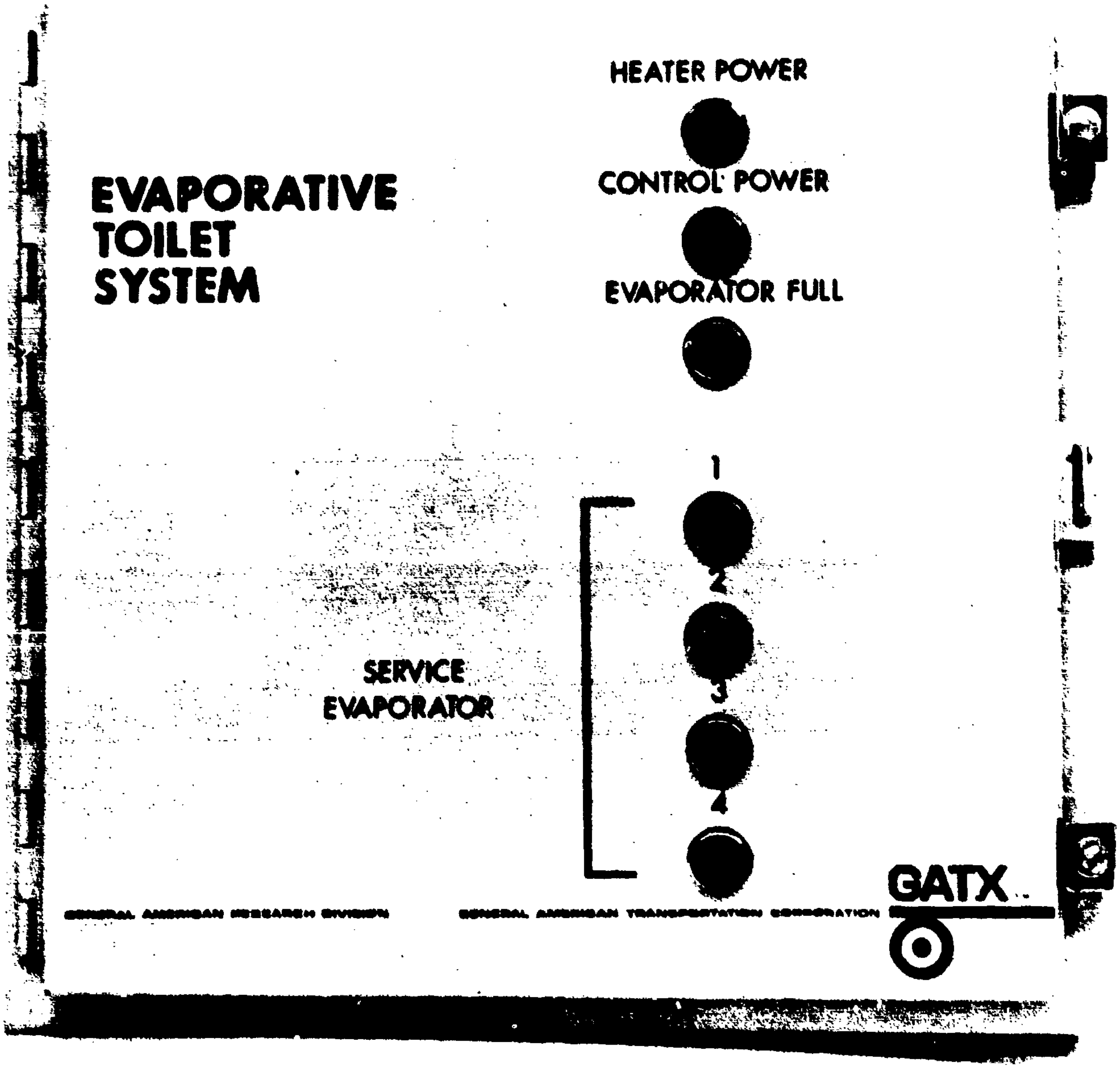


Figure 3
Controls Panel

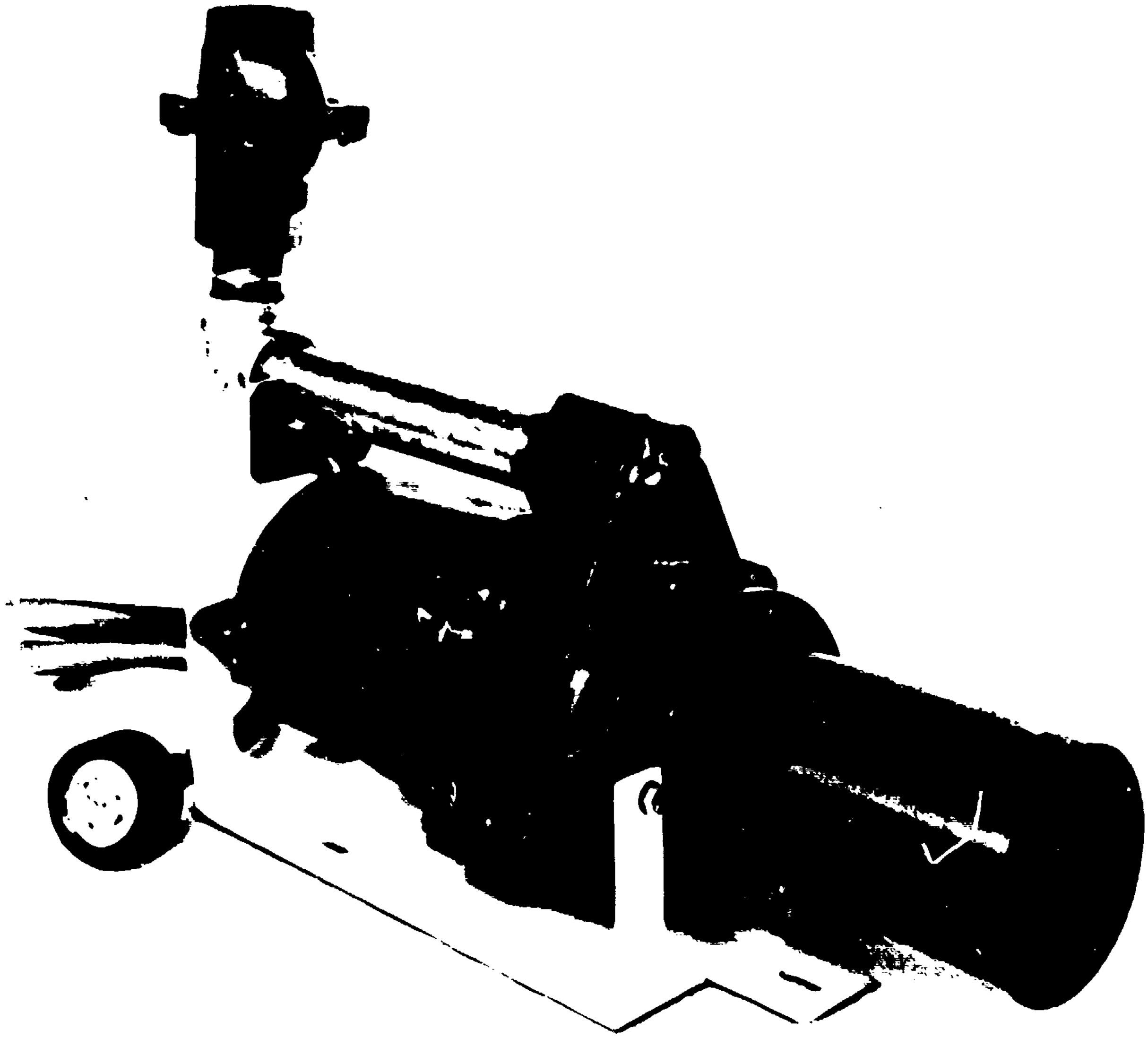
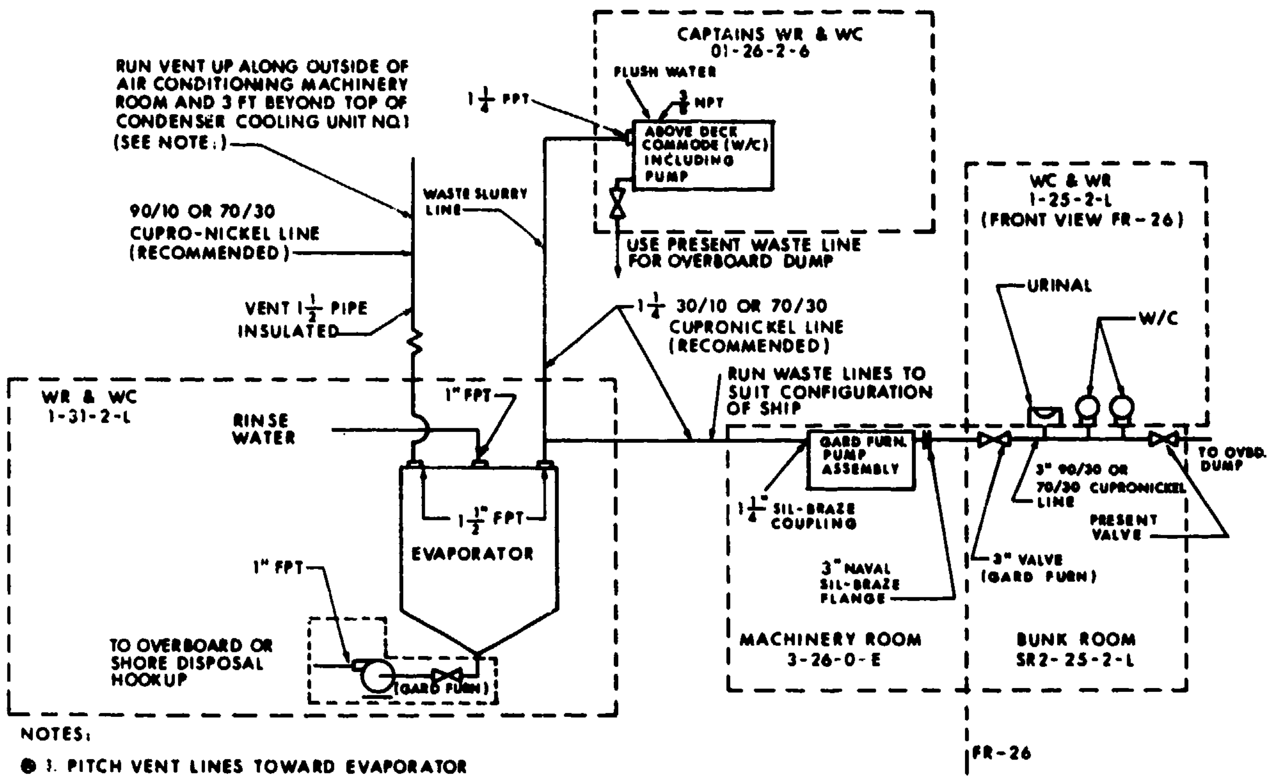


Figure 4
Macerator/Transfer Pump

Figure 5 - Evaporator Tank



NOTES:

1. PITCH VENT LINES TOWARD EVAPORATOR 1/2"/FT MINIMUM TO ELIMINATE CONDENSATE POCKETS

Figure 6
Operational Schematic (MONOB)

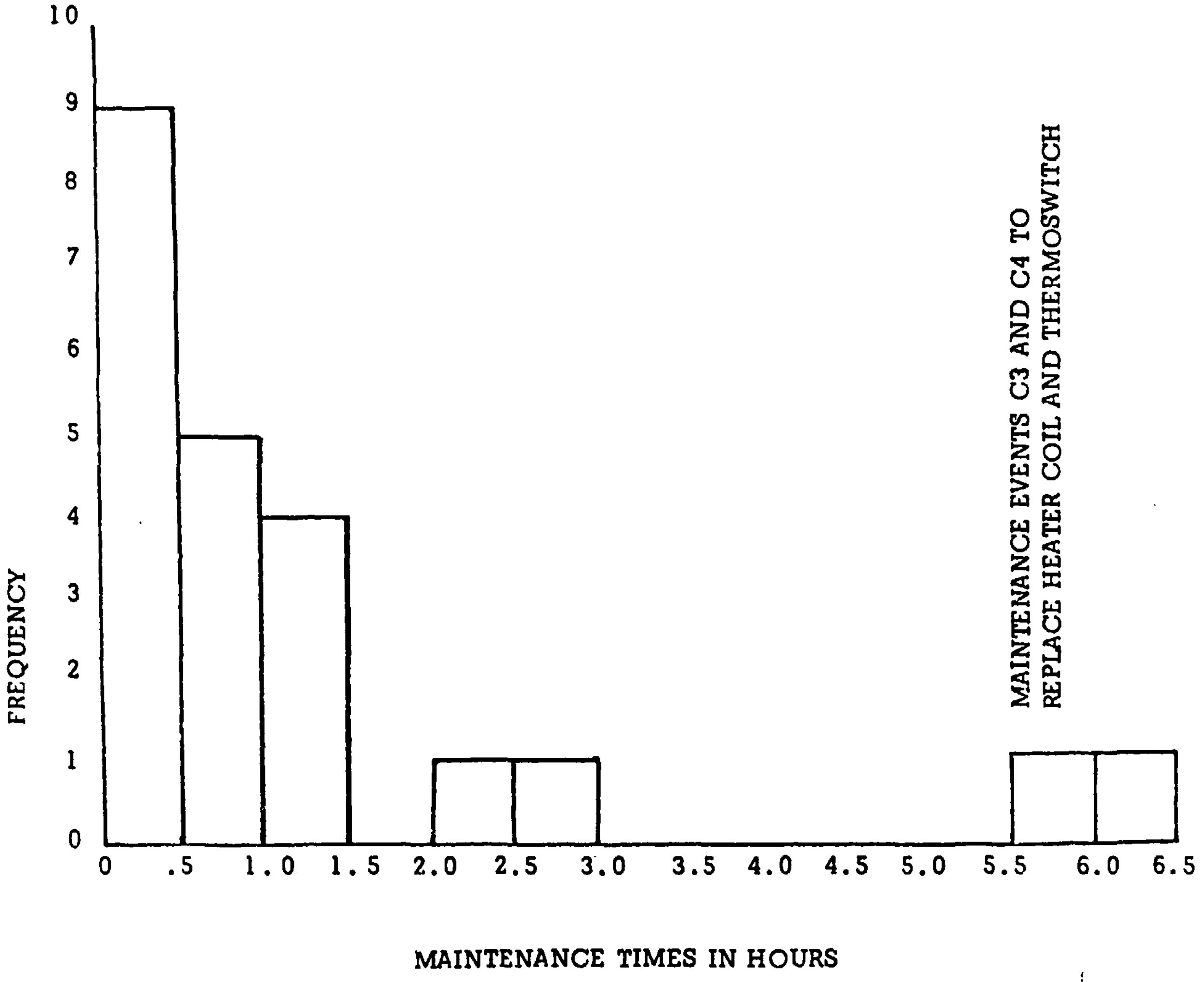


Figure 7
Corrective Maintenance Times Distribution

APPENDIX A

MAINTAINABILITY DEMONSTRATION

Test Objectives and Plan

The maintainability evaluation objectives stated in the "GATX Evaporative Type Sewage Treatment System Shipboard Test and Evaluation Plan"* of 7 November 1972 are that the unit demonstrate a maximum repair time of 5 hours. Also, repairs on components in the transport system shall be completed within 1 hour.

As specified in paragraph 4.3 of the Test Plan, analysis will be performed on 20 corrective maintenance actions. Assuming a log normal distribution of the maintenance times, a decision will be made with the equation:

$$T = \overline{D}_{CM} + 2.2\ S_{CM}$$

where:

T = log of sample maximum corrective downtime

$\overline{D}_{CM}$ = average of the logarithms (logs) of the corrective maintenance downtimes

S_{CM} = sample standard deviation of the logs of the downtimes.

Since the specified maximum downtime is 5 hours, an accept (success) decision can be made if the statistic T is less than the log of five; a reject (failure) decision can be made if the T value is more than the log of five. The accept decision is conditional on the repair times of the transport system being less than 1 hour. This procedure is noted in the Test Plan as a guarantee with 90% confidence that 95% of the repair times are less than 5 hours. Since it was developed for this evaluation, the statistical plan differs in required sample size (20) and value of $\emptyset$ (2.2) from equivalent values for Test Plan (B_2) for $M_{MAX\ ct}$ given in MIL-STD-471.**

*Referred to as the "Test Plan" in subsequent discussions.
**This deviation from MIL-STD-471 was recommended by B. S. Orleans (SHIPS 0311), H. Feingold (NSRDC 186.1), and D. V. Woytowitz (SEC 6141F).

The Test Plan specifies in paragraph 4.4 that sections A10.3.1 and A10.3.2 of MIL-STD-471 be followed in the selection and simulation of maintenance events to be used in the demonstration. Details of event selection are given in the next section.

Task Apportionment

The Test Plan specifies that the procedures for maintenance task selection given in paragraph A10.3 of MIL-STD-471 be followed. In general, the procedures are:

- List all items in the system to be considered. In the GATX system, the components are listed within four functional categories of the system.

- Determine failure rates for each item. This was a problem since there is no readily available compendium of failure rates on waste treatment systems. Data sources and related information are included with table 1-A.

- Determine the percent contribution of each item to the total corrective maintenance tasks.

- Apportion the number of corrective maintenance tasks to be demonstrated in proportion to the item percent contribution to the total maintenance tasks.

The above procedures were followed in generating table 1-A with the exception that the percent contribution is shown at the subfunction level only. The relative contribution of the items was considered in selecting the types of maintenance events for each of the four subfunctions, as shown in table 2-A.

Conduct of Maintainability Evaluation

The selection of the maintenance events shown in table 2-A and their simulation was coordinated with GATX personnel. A GATX engineer was also a member of the on-site evaluation monitoring team with NAVSEC and NSRDC/A representatives.

The Test Plan specified a minimum of 20 events for evaluation. The other two have been included because they tend to increase the statistical confidence of the results, and it was convenient to include them during the evaluation.

TABLE 1-A - CORRECTIVE MAINTENANCE TASK SELECTION

Item and Quantity, η	Failure Rate λ per 10^6 h	Total Failure Rate $\eta\lambda$	Item Percent Contribution	Failure Rate Data Source
Category A				
Flushing and Metering Function	35	35	16.3	
Water Closets[1] (3)	10	30		
CVF Valve	1			GE (Farada)
CVF Cylinder	1			GE (Farada)
CVF Check Valve	1			GE (Farada)
Flapper Valve	1			GE (Farada)
Spring	2			Estimated
Cam	1			Estimated
Linkage	3			Estimated
Urinal Flush	5	5		GE (Farada)
Solenoid Valve	3			GE (Farada)
Switch and Relay	2			
Category B				
Transport Function	79.4	79.4	37.0	
M/T Pumps (2)	31.3	62.6		GATX[2]
Above Deck M/T Pump	12.5	12.5		GATX[2]
Sludge Pump	1.3	1.3		GATX[2]
Valves (4)	0.8	3		GE (Farada)
Category C				
Evaporate and Hold Function[3]	32	32	14.9	GATX
Level Sensors (2)	9	18		GE, DO (Modified)
Thermoswitches (4)	1.7	7		GE (Farada)
Heater (6)	1	6		MIL-HDBK 217
Tank and Gasket	1	1		GE (Farada)
Category D				
Control Function	68.5	68.5	31.8	
Flush Control Relay (2)	2.5	5		GE (Farada)
Heater Thermal Relay (4)	1	4		GE (Farada)
Isolation Transformer	1	1		GE (Farada)
Voltage Control Circuit	3	3		GE (Farada)
Level Sensor Fuse	1	1		GE (Farada)
Circuit Breaker (2)	1	2		GE (Farada)
Pump Control Relay (3)	2.5	7.5		GE (Farada)
Heater Relay (4)	1.5	6		GE (Farada)
Commode Relay (3)	2.5	7.5		GE (Farada)
Pump Lockout Relay	2.5	2.5		GE (Farada)
Heater Relay (4)	1	4		GE (Farada)
Reset Relay	1	1		GE (Farada)
Alarm Relay	1	1		GE (Farada)
Power Reset Alarm	1	1		GE (Farada)
Pump Failure Relay (2)	1	2		GE (Farada)
Pump Switchover Relay (2)	1	2		GE (Farada)
Level Sensor Relay (2)	2.5	5		GE (Farada)
Level Sensor Transformer	1	1		GE (Farada)
Indicator Lights (10)	1	10		MIL-HDBK 217
Control Switches (4)	0.5	2		MIL-HDBK 217
		214.9		

[1]GATX specifications of 10,000 cycles translated to a relatively high failure rate. Water closet failure rates generated from functional component data as shown.

[2]GATX specifications of 20,000 cycles for the pumps were used with the appropriate use factor to obtain system-time-based failure rates.

[3]GATX specifications of 26,000 hours MTBF for the tank assembly were converted to 31,200 system hours between failure or 32 failures per 10^6 hours.

Note: Data sources noted as GATX, GE, and DO refer to reliability data on the item (or similar item) submitted to Ship Systems Command by General American Transportation Corporation, General Electric Company, and General Dynamics Corporation (Dorr-Oliver), respectively.

GE - General Electric; DO - Dorr-Oliver.

TABLE 2-A
MAINTAINABILITY EVALUATION EVENTS

A1	Replace Flapper Pad - Water Closet 2
A2	Replace Urinal Flush Valve Solenoid
A3	Repair Return Spring - Water Closet 1
A4	Repair Inoperative Linkage - Above Deck Water Closet
A5	Replace Leaking Check Valve in CVF Assembly
B1	Repair Open Connection - M/T Pump 1
B2	Replace Defective M/T Pump
B3	Repair Inoperative Flush Switch
B4	Repair Inoperative Pressure Switch
B5	Repair Inoperative Pump Switch - Above Deck Water Closet
B6	Repair Starter Switch - Sludge Pump
C1	Repair Inoperative Level Sensor
C2	Replace Defective Sleeve - Level Sensor
C3	Replace Defective Thermal Switch
C4	Replace Defective Heater Coil
C5	Replace Defective Gasket - Observation Port
D1	Replace Defective Pump Switchover Relay
D2	Replace Open Sensor Fuse
D3	Replace Defective Sensor Time Delay Relay
D4	Correct Low Heater Power (Triac Adjust.)
D5	Replace Defective Pump Cutoff Relay
D6	Correct Open Power - Transformer Lead

By mutual agreement, half of the maintenance events would be performed by maintenance personnel aboard MONOB who have had 6 months' familiarity with the system. A qualified laboratory technician from NSRDC/A, with experience with similar systems, would complete the maintenance events. The crew could not take time to perform all the events due to existing operational requirements. The unavailability of the crew was evident during the evaluation period, with the result that 13 of the 22 events were performed by other than crew members.

With the exception of the four maintenance events that occurred during operation of the GATX, none of the maintenance personnel involved knew of the event until they were asked to troubleshoot the system. The procedure used was as follows:

• Time was recorded when the technician was asked to troubleshoot the system. In each case, he would start at the water closets to check for correct operation.

• He would then check all indicators and switch positions on the control panel in the machinery room.

• He would then check operation of the evaporator tank, sludge pump, and the vapor discharge.

• Time records showed the time for fault diagnosis and the time for repair or replacement in both elapsed time and man-hours. Administrative and logistics times were not included.

• In the few cases where no symptoms could be detected during normal troubleshooting, additional clues were given to the technician at appropriate times.

Simulation was achieved by inserting defective relays, opening leads, and maladjusting mechanical and electrical connections. Specific events are discussed in the data sheets used, see Test Plan.

Two of the maintenance events selected for the Evaporate and Hold Function required special consideration. The two events are: Replace Defective Thermal Switch and Replace Defective Heater Coil. In each case, it would have been necessary to disconnect the evaporator tank in order to move it away from its corner location to be able to complete the maintenance. This action was not feasible aboard MONOB since a new tile floor over the stanchion feet of the tank would have had to be ripped up. By mutual agreement, the tank removal time was estimated to take a minimum of 5 hours. Added to this time was the measured diagnostic times and the replacement times for each item.

Results

An accept (success) decision is possible if none of the maintenance times for the transport subfunction takes more than an hour, and the statistic T is less than the log of 5 (hours) where:

$$T = \overline{D}_{CM} + 2.2\ S_{CM}$$

T = Log of sample maximum corrective downtime

$\overline{D}_{CM}$ = Average of the logs of the corrective maintenance downtimes

S_{CM} = Sample standard deviation of the logs of the downtimes.

Relative to the 1-hour constraint, the replacement of the M/T pump (item B2) required 2 hours and 15 minutes. Using the data given in table 3-A for 22 events:

$$T = 1.65785 + 2.2\ (0.410777)$$

$$= 2.56156$$

Antilog T = 364.39 minutes or over 6 hours.

Recomputing excluding items C3 and C4:

$$T = 1.56733 + 2.2\ (0.30262)$$

$$= 2.23309$$

Antilog T = 171.04 minutes or less than 3 hours.

TABLE 3-A
MAINTAINABILITY EVALUATION RESULTS

Event	Time minutes	Log	Log^2
A1	27	1.43136	2.04879
A2	27	1.43136	2.64879
A3	10	1.00000	1.00000
A4	11	1.04139	1.08449
A5	31	1.49136	2.17941
B1	19	1.27875	1.63520
B2	135	2.13033	4.53831
B3	66	1.81954	3.31073
B4	25	1.39794	1.95423
B5	43	1.63347	2.66820
B6	19	1.27875	1.63520
C1	65	1.81291	3.28664
C2	120	2.67918	4.32299
C3	381	2.58092	6.66115
C4	351	2.54531	6.47860
C5	45	1.65321	2.74336
D1	76	1.88081	3.53745
D2	56	1.74819	3.05617
D3	28	1.44716	2.09427
D4	66	1.81954	3.31073
D5	26	1.41497	2.00214
D6	36	1.55630	2.42207
		36.47275	64.00992

Adequacy of the Operating and Troubleshooting Manual

None of the maintenance personnel involved in the evaluation was given a detailed briefing of how every component of the system operates. All were given time to read the manual and operate the system beforehand. Some comments on the adequacy of the manual follows:

- Controlled-volume-flush (CVF) circuit diagram was missing. During the related maintenance event, this diagram was added to the manual.

- An exploded view of the input connection for the M/T pump would have facilitated removal.

- Details of the mechanical or electrical connections for the above deck water closets were not included.

- Written details for the switchover circuit, including the pressure switch, are not included in the manual.

- The overall circuit diagrams have been reduced too much for easy reading. In some cases, connection numbers, etc, have been eliminated by poor printing.

- Inclusion of voltage values (or current values) at critical points on the diagram would help.

- The troubleshooting procedures are adequate for the events covered, but more failure modes should be covered. Maintenance events in the overboard mode or service mode are not included.

APPENDIX B

RELIABILITY DEMONSTRATION

Test Objectives

The GATX Evaporative Type Sewage Treatment System Shipboard Test and Evaluation Plan (Test Plan), prepared by NAVSEC, specifies the required reliability of the system as 500 hours MTBF under normal operation. The test objective is to furnish data to determine if the system meets this requirement. The GATX system is required to operate with salt-water flush for 1150 hours without failure to demonstrate 500 hours MTBF with a 90% confidence level.

Test Plan

This laboratory has the primary responsibility of conducting and evaluating the tests of the GATX system. The Mobile Noise Barge (MONOB YAG 61) was used as a test bed with assistance from the MONOB engineering staff in monitoring the system and collecting test data.

After the GATX system was installed and instrumented, the manufacturer was allowed to operate the system and perform corrective maintenance for 4 weeks in order to eliminate any synthesis problems.

Once the manufacturer decided the system was ready to test, the formal reliability test period was started. During the reliability test period, a data log (attachment 1-B) was filled out for each watch while MONOB was at sea and approximately once a day when in port. Successful completion of the reliability evaluation occurred only after the system operated for 1150 hours without a major or critical system failure. A critical failure is defined as any malfunction which causes the system to shut down or causes diversion of sewage. A major failure is defined as any malfunction which would, if not corrected, preclude processing of sewage.

Instrumentation

The GATX system is extensively instrumented to obtain data for reliability computations at system and component levels, operating efficiency, and operational or duty factors of principal components.

The instruments added to the GATX are:

- Elapsed Time Indicators (6)
  - Total System
  - Heater Power
  - M/T Pump 1
  - M/T Pump 2
  - M/T Pump 3 (Above Deck)
  - Sludge Pump
- Kilowatt-Hour Wattmeter (1) - Heater Power
- Actuation Counters (4)
  - Urinal Flush
  - M/T Pump 1
  - M/T Pump 2
  - M/T Pump 3 (Above Deck)
- Flowmeters (3)
  - Urinal
  - Water Closets 1 and 2
  - Above Deck Water Closets.

The GATX system has the following operating lights to denote the status of the system:

- Heater Power
- Control Power
- Evaporator Full (Denotes tank full and pump off.)
- Service Evaporator 1

- Service Evaporator 2 (When lit, denotes heater band off. When two are lit, service is imminent.)

- Service Evaporator 3

- Service Evaporator 4

- Junction Box Level (Denotes 80-gallon level and allows heaters to come on.)

- Pump 1 Malfunction (Denotes no pressure buildup.)

- Pump 2 Malfunction (Denotes no pressure buildup.)

The elapsed time indicators (ETI's), flowmeters, and other instrumentation are not considered as parts of the system for the reliability evaluation. In other words, a failure of any of the instruments included for monitoring purposes will not be considered as a failure of the GATX system. In addition, to prevent the operation of any of the M/T pumps during a sonar test, a relay connection was placed in the power input to these pumps. When the sonar test circuit relay was actuated, power was cut off to these pumps. This relay is also not considered part of the GATX system.

Conduct of the Evaluation

During the 4-week period of the pretest shakedown and the reliability evaluation, the MONOB operated the GATX system, performed maintenance, and recorded test data. An Operation and Maintenance Manual for the GATX system was available to the crew plus an additional installation drawing of the system on MONOB. Any problems not covered by the manual were resolved by telephone conversation with NSRDC and GATX engineers. The crew recorded test data each watch at sea on the log form furnished (see attachment 1-B) as per written instructions shown in attachment 2-B. During the test period, it became impractical for the log sheets to be filled out each watch while MONOB was in port, so the instructions were changed to daily recordings while in port.

ATTACHMENT 1-B

FORM 1

LOG

Date________________Time______________Remarks______________________

Engineer Watch____________ ______________________________

______________________ ______________________________
Failure Occurred

Maintenance Performed (If failure-fill out form 4)__________

____

Reason____

* STATUS	HTR. PWR.	CONT. PWR.	EVAP. FULL	No. 1	No. 2	No. 3	No. 4	LEVEL-JCN BOX	AUDIBLE

* Check ( ) If on During Watch

Meter/Counter Readings

1. Captain's Head

   Flush Water Flow Meter Readings __________

   Water Closet Counter Reading __________

   Macerator Pump Elapsed Time #3 __________

2. Crew's Head

   Flush Water Flow Meter Reading

   (a) Water Closets __________

   (b) Urinal __________

   #1 Macerator Pump Elapsed Time __________

ATTACHMENT 1-B

FORM 1

LOG
(Continuation)

	#1 Water Closet Counter Reading	________
	#2 Macerator Pump Elapsed Time	________
	#2 Water Closet Counter Reading	________
	Urinal Counter Reading	________
3.	Overboard Discharge Pump Elapsed Time	________
4.	Evaporator KW-HR Meter Reading	________
5.	Evaporator Elapsed Time Reading (HEATERS)	________
6.	Total System	________
7.	Malfunction	Pump 1________ Pump 2 ________

ATTACHMENT 2-B

TEST PROCEDURES FOR RMA EVALUATION
OF GATX ET WASTE TREATMENT SYSTEM
(The initial three sections present system description, purpose of test, and discussion of the test phases.)

PROCEDURES

Daily (Each Watch) Log

A log sheet (form 1) will be completed by each engineering watch during the breaking-in and reliability test phases for the GATX system.

The lower section of the log sheet contains 13 meter readings to be recorded once each watch. The time these readings are taken (±30 minutes) should be recorded at the top of the form with the date and name of the watch personnel. Any maintenance actions, either corrective or preventive, or changes in operational status of the GATX system will also be recorded in the top section of the form.

The first eight status subheadings shown refer to the status indicator lights on the system. The first seven lights are on the front panel of the control box in the machinery room. The eighth light, denoting liquid level, is located on top of the junction box attached to the evaporator in the aft head. The final subheading of "AUDIBLE" refers to the audible alarm on the system which sounds when more than one of the three heater bands has overheated. This condition indicates the need for evaporator pump out in the near future.

Failure and Maintenance Reports

Whenever any component or system failure occurs, a Maintainability/Human Factors Failure Report should be written, if possible during the same watch in which the event was observed. This is necessary not only for the sake of completness but also because some of the more difficult maintenance efforts may be delayed until MONOB docks. At that time details of the event may have been forgotten.

Preventive Maintenance (PM) and Servicing

The only PM effort required by MONOB personnel during the breaking-in and reliability test phases is a daily check that the system is operating satisfactorily. This would be done in the process of collecting the data required for the log sheet.

As part of the daily check, the liquid level in the dye and disinfectant tanks should be checked so they can be refilled as needed. The other routine servicing would be normal cleaning of the bowls in which a standard household toilet cleaner (nondetergent) should be used without using any more flush water than necessary.

General Instructions

Detailed operating and maintenance instructions for the GATX system are available in the watch office. A current list of spare parts will be maintained and kept with the instructions.

Any system or component failure which cannot be corrected by MONOB personnel while at sea, due to lack of spares or any other reason, should be reported by radio to NSRDC/A (Code 286). This laboratory's personnel will arrange for the necessary spares and maintenance capabilities to correct the failure.

The log sheets and failure reports will be reviewed daily for completeness and accuracy and filed for delivery to NSRDC/A (Code 286).

APPENDIX C

PERFORMANCE DATA

TEST OBJECTIVES

The Test Plan* does not present any quantitative performance requirements or details of evaluation. Section 3 of the Test Plan does specify that analyses be performed on sludge and condensate samples (of the vent stack gases).

The many data elements included in the data log sheet (attachment 1-B of appendix B) lend themselves to computation of loading rates, boil-off rates, component total-operate times, and system efficiency. These computations are not specified or required but can be furnished if desired.

PROCEDURES AND RESULTS

Sludge Analysis

Samples for analysis were taken on three different dates. Results of the analyses are given in table 1-C. Some differences existed in the sampling techniques, so each will be discussed briefly.

On 9 January 1973, the system had been operating on test for a month and solids concentration was approaching cutoff. The sample was taken from the sampling port below the tank and was part of a 1-gallon volume pumped from the bottom of the tank. The analyses were performed by the Broward County Water Pollution Laboratory.

As a result of the observed stratification of the tank contents during preceding sampling efforts, a different sampling technique was used for the 26 February 1973 collection. A 2-inch plastic tube with a plug at the bottom was put into the tank with the plug open. As it touched the bottom, the plug was closed, the result being a core sample. Three samples were obtained and analyzed. The averages for the three samples are given in table 1-C.

Because of the improved sampling technique, the data for the 26 February 1973 samples are considered more realistic.

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*"NAVSHIPS Test and Evaluation Plan for the GATX Evaporative Type Shipboard Sewage Treatment System," NAVSEC (SEC 6159) (7 Nov 1972)

TABLE 1-C
ANALYSIS OF SLUDGE SAMPLES*

	9 January	8 February	26 February**
Total Dry Solids, %	38.6	31.2	24.9
Total Volatile Solids, %	22.2	7.3	6.1
Coliform, MPN/100 ml	0	0	<100
pH, %	6.0	6.9	7.1
Salinity, %	33.0	13.8	10.9
COD, pph	-	5.9	3.3
Biochemical Oxygen Demand (BOD), pph	-	3.7	-
Total Organic Carbon (TOC), %	-	-	2.4

*Analytical procedures used are from Standard Methods for the Examination of Water and Waste Water, 13th edition American Public Health Association, Washington, D.C. 1971
**Average for three samples.
pph - Parts per hundred.

Condensate Analysis

The composition and properties of the vent stack vapors are necessary information to determine the feasibility of some of the recommended corrective actions for correcting the odor problem. To obtain this information, condensate samples were taken on three different dates for analysis.

On 8 February 1973, the samples were taken from a sampling port directly above the evaporator tank. Analyses were performed by both the Broward County Water Pollution Central Laboratory and NSRDC/A. Results from both laboratories, table 2-C, showed higher than expected values of COD, BOD, pH, and solids. Apparently, some of the solids in the tank were carried by an aerosol effect to the adjacent sampling port.

TABLE 2-C
ANALYSIS OF CONDENSATE SAMPLES*

	8 February	8 February	26 February**
TOC, mg/l	-	1300	160
COD, mg/l	4862	2032	310
BOD_5, mg/l	115	390	47
pH, %	9.1	9.4	7.3
Total Solids, mg/l	-	123	<1
Volatile Solids, mg/l	-	83	-
Coliform, MPN/100 ml	0	-	<3

*Analytical procedures used are from Standard Methods for the Examination of Water and Waste Water, 13th edition, American Public Heat Association, Washington, D.C. 1971
**Average for three sample.

The subsequent samples obtained on 26 February 1973 were taken from the top of the vent stack. The results obtained by NSRDC/A, table 2-C, are more consistent with expected values. Similarly, four samples were taken from the top of the vent stack on 20 March 1973, analyzed by NSRDC/A, and results shown in table 3-C. The BOD_5 evaluations for this last group of samples were inconsistent and are included in table 4-C for the sake of completeness. For unknown reasons, the oxygen demand value varies as a function of the dilution. The assumption is that the sample contains a toxic material which kills off the bacteria inversely with the amount of dilution.

As an adjunct to the final group of distillate samples, coliform swab samples were taken from five different locations in the vent stack and the evaporator tank top. Results are shown in table 5-C. Some bacteria were found in the sampling tee, which normally is fairly cool and stagnant.

TABLE 3-C
ANALYSIS OF CONDENSATE SAMPLES TAKEN
20 MARCH 1973

	Sample 1	Sample 2	Sample 3	Sample 4
TOC, mg/l	250	130	80	340
COD, mg/l	250	160	140	-
BOD_5	Questionable Results, See Table 4-C			
pH, %	9.34	9.56	9.84	9.46
Total Solids, mg/l	55	28	36	-
Volatile Solids, mg/l	49	31	38	-
Coliform, MPN/100 ml	<10	<10	<10	<10
NH_3, mg/l	980	480	370	1630
Cl^-, mg/l	2.1	1.1	1.1	-
Inorganic Carbon, mg/l	380	150	60	520

Notes: All samples taken from the top of the vent stack. All analyses performed at NSRDC/A using procedures from <u>Standard Methods for the Examination of Water and Waste Water</u>, 13th edition, American Public Health Association, Washington, D.C. 1971

TABLE 4-C
BOD$_5$ ANALYSIS OF CONDENSATE SAMPLES TAKEN
20 MARCH 1973

Sample No.	Test No.	Dilution	BOD$_5$ mg/l
1	1	1/10	23.5
1	2	1/10	18.5
1	3	1/30	13.5
1	4	1/30	7.5
1	5	1/150	427.5
1	6	1/150	382.5
2	1	1/10	48.5
2	2	1/10	54.5
2	3	1/30	91.5
2	4	1/30	73.5
2	5	1/150	292.5
2	6	1/150	262.5
3	1	1/10	6.5
3	2	1/10	8.5
3	3	1/30	13.5
3	4	1/30	10.5
3	5	1/150	262.5
3	6	1/150	332.5
4	1	1/10	59.5
4	2	1/10	54.5
4	3	1/30	151.5
4	4	1/30	136.5
4	5	1/150	427.5
4	6	1/150	307.5
Blank			6.75
Blank			6.75

Note: Inconsistent results indicate possibility of a toxic agent in the condensate.

TABLE 5-C
COLIFORM SWAB SAMPLE ANALYSIS

Sample No.	Swabbed Area	No. of Coliform Colonies
1	6 inches below top of vent (cool)	0
2	6 inches below top of vent (hot)	0
3	6 inches above bottom of vent	0
4	3 inches above bottom of vent	0
5	Sample port	5
6	Inspection port	0
Notes:	Samples taken 20 March 1973. Swabs were washed with 100 ml sterile buffer (H_2O and phosphate buffer), and this 100 ml was filtered for coliform count determination by NSRDC/A.	

Other Data

The data sheets, attachment 1-B of appendix B, were filled out by the crew during each watch while on sea duty and once per day while in port. For illustration purposes, table 6-C is included with daily readings for some of the most significant parameters taken at the start and finish of the reliability evaluation period.

TABLE 6-C
SAMPLE DATA FROM LOG SHEETS AT THE START AND FINISH OF THE RELIABILITY EVALUATION

Date	#3 Pump Elapsed Time	Water Closet	Urinal Flow Meter	#1 Pump Elapsed Time	#2 Pump Elapsed Time	Evaporator KW-HR Meter	Heater Elapsed Time	Total System Elapsed Time
9 Dec 72	0.9	1325	7738	3.8	1.6	6682		
10 Dec 72	4.7	1330	7748	6.8	2.8	6600	28097	
11 Dec 72	7.3	1347	7769	12.5	6.8	6702	42674	71.2
12 Dec 72	10.2	1352	7789	17.3	8.8	6714	5685.3	94.7
13 Dec 72	14.3	1359	7809	21.3	12.5	6725	71174	118.6
14 Dec 72	18.2	1366	7831	24.0	14.5	6737	8587.2	143.1
15 Dec 72	22.1	1474	7851	27.2	16.8	6748	9986.2	166.4
16 Dec 72	25.4	1382	7866	29.2	20.7	6761	11445.0	190.7
17 Dec 72	27.9	1391	7890	31.9	24.8	6767	12866.4	214.4
18 Dec 72	29.3	1407	7908	35.0	27.8	6774	14314.0	238.4
19 Dec 72	31.3	1415	7933	39.6	30.3	6680	15805.3	263.1
20 Dec 72	33.1	1420	7940	42.5	30.6	6786	16698.9	278.0
7 Feb 73	122.2	1830	8233	219.4	154.9		88083.0	1407.8
8 Feb 73	123.1	1838	8234	223.3	155.9		89245.6	1490.0
9 Feb 73	123.1	1842	8235	224.9	156.9		90152.8	1505.1
12 Feb 73	127.0	1857	8254	233.2	162.2	7163	94653.6	1580.0
13 Feb 73	130.3	1862	8264	236.0	163.7	7170	96072.4	1603.7
14 Feb 73	135.0	1871	8270	239.1	167.1	7270	97520.7	1627.9
15 Feb 73	138.2	1875	8672	241.7	171.3	7188	98705.6	1647.6
16 Feb 73	143.1	1883	8285	245.3	173.9	7207	00405.3	1676.0
17 Feb 73	146.5	1894	8292	249.9	176.6	7217	102069.1	1703.7
18 Feb 73	147.4	1895	8294	252.1	176.6	7210	102785.6	1715.6
19 Feb 73	148.4	1905	8298	255.4	178.0	7228	5026.2	1753.0
20 Feb 73	148.4	1910	8301	258.1	179.6	7221	106004.5	1769.5
23 Feb 73	150.4	1947	8317	271.0	190.5	7245	[illegible]	1852.4
25 Feb 73	150.4	1951	8320	273.8	191.3	7241	13565.3	1895.3
26 Feb 73	151.0	1959	8165	279.0	194.4		14952.8	1918.4
27 Feb 73	151.0	1962	8324	279.8	195.0	7259	15872.9	1934.3
1 Mar 73	151.8	1979	8333	289.2	199.4	7266	17524.2	1951.8
2 Mar 73	153.0	2091	8339	297.7	205.6	7276	19052.5	1957.3

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28-735, July 1973

Security Classification UNCLASSIFIED

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ship Research and Development Center Annapolis, Maryland 21402	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

6 Laboratory Evaluation of the GATX Evaporative Toilet System.

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

9 ~~Contractors Report~~ - Research and Development rept.

5. AUTHOR(S) (First name, middle initial, last name)

10 Willem van Hees [redacted] Louis C. Gills (Bradford Computer & Systems, Inc.)

6. REPORT DATE 11 Jul[redacted]73	7a. TOTAL NO. OF PAGES 52	7b. NO. OF REFS 6

8a. CONTRACT OR GRANT NO. 16 b. PROJECT NO. Task Area S4657 c. Program Element 63721N d. Work Unit 1-2860-124	9a. ORIGINATOR'S REPORT NUMBER(S) 19 3948 18 DTNSRDC 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) 14 MAT-28-735

10. DISTRIBUTION STATEMENT

[redacted]60.

11. SUPPLEMENTARY NOTES 12 50p.	12. SPONSORING MILITARY ACTIVITY NAVSHIPS (SHIPS 03412B)

13. ABSTRACT

The evaporative toilet system manufactured by General American Transportation Corporation was accepted for laboratory evaluation aboard mobile noise barge, MONOB YAG 61. After minor problems during the installation and debugging periods, the system operated over 700 hours before a critical failure was recorded on 7 January 1973. The failure was due in part to a plumbing arrangement. Corrective action was taken, and the system operated an additional 1150 hours without failure, to demonstrate successfully the required mean time between failures of 500 hours. A maintainability demonstration involving 22 maintenance events was unsuccessful due primarily to the design and installation locations of the evaporator/holding tank subsystem. The specified maximum repair time of 5 hours was exceeded by 1 hour, and the specified maximum repair time of 1 hour for components of the transport function was exceeded in two different maintenance events. Installation problems, which could be avoided in future programs, are considered the main cause for the one critical system failure and the maximum repair time of 6 hours. The odor of the water vapor released from the vent stack is the principal user objection to the

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DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

UNCLASSIFIED
Security Classification

408635

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Pollution abatement Water pollution Shipboard treatment Waste treatment Evaporative toilet Waste concentration Waste evaporation Sterile sludge Sanitary system						

ABSTRACT (cont)

system. Recommendations are made on ways to improve the reliability, maintainability, habitability, and performance of the General American Transportation Corporation system. Most of these are for areas of minor deficiencies related to the fact that the complete system was not fully tailored to the marine environment to which it was subjected during the evaluation.

(Authors)