OTEC-1 Test Operations Experience
Final Report

Prepared for the U.S. Department of Energy
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I. INTRODUCTION

A. MISSION

A mission of the Department of Energy (DOE) is to develop inexhaustible and renewable sources of substantial quantities of baseload electricity and to develop renewable sources of energy for products that are energy intensive. Through its Division of Ocean Energy Systems, Office of Solar Power Applications, DOE is developing technology for economically competitive, operationally safe, and environmentally acceptable solar electric systems. The solar technology program of DOE includes ocean thermal energy conversion (OTEC). OTEC uses the difference in temperature in the ocean between the surface and at depth to run a heat cycle that vaporizes and condenses a working fluid such as anhydrous ammonia.

The OTEC-1 test facility was the initial step toward full-scale in-ocean deployment of OTEC equipment and components. The primary objectives of the OTEC-1 project were to:

1) Assess developing heat exchanger technology. Secondary objectives were to provide power system performance data and to evaluate biofouling countermeasures
2) Assess the effect of OTEC-1 on the environment and effect of the environment on the operation of OTEC-1
3) Provide input to the OTEC pilot plant project and OTEC program.

Additional secondary objectives were to provide ocean engineering baseline data on hull, stationkeeping, and cold water pipe (CWP) configuration and to provide information on the effect of the OTEC-1 test facility and power system operation on the ambient ocean environment to assist in the development of environmental guidelines.

A test site located approximately 12 nautical miles off the west coast of the Island of Hawaii was selected for the OTEC-1 project (Figure 1-1).

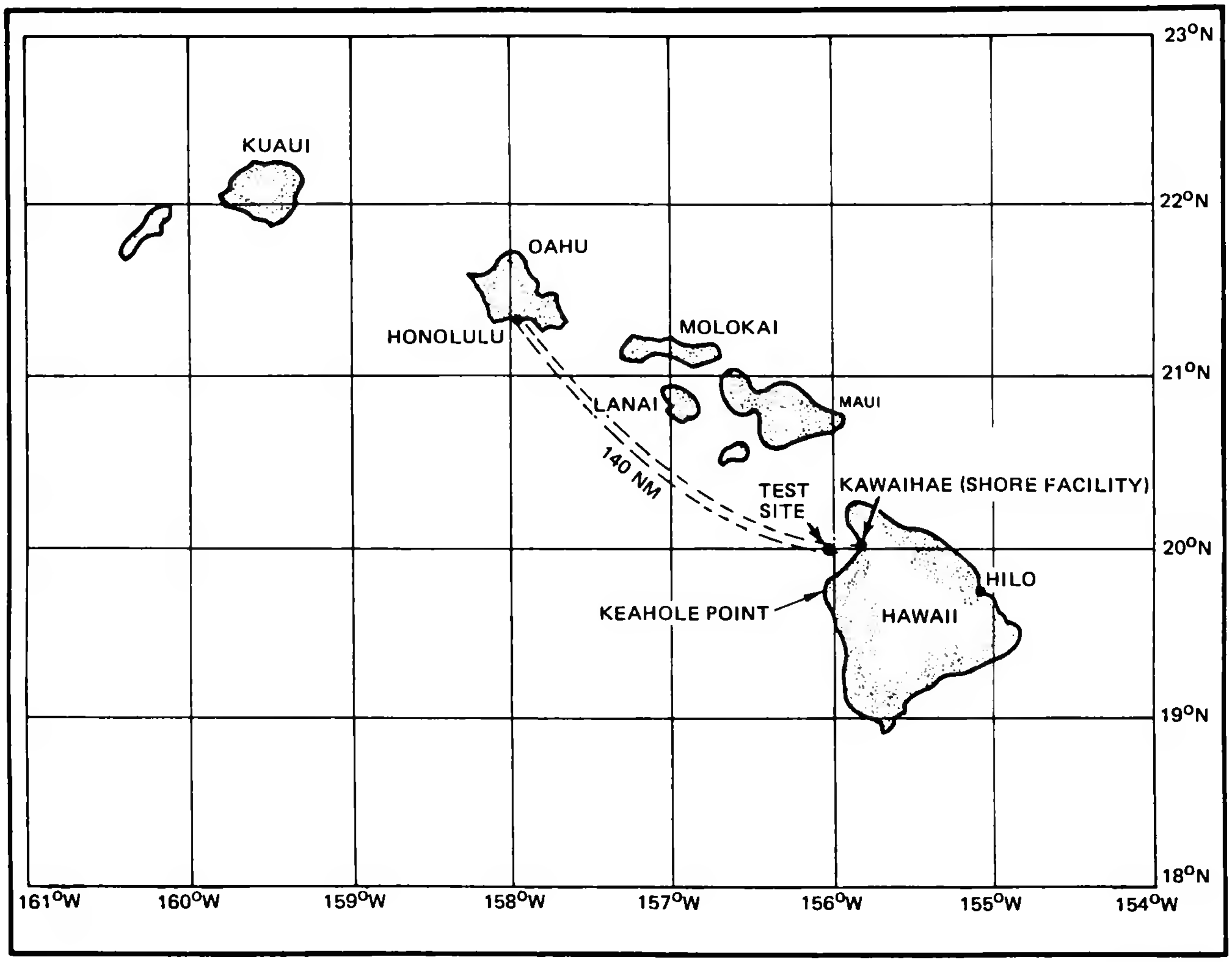

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Figure 1-1. OTEC-1 Test Site

Studies made of several potentially suitable areas resulted in the Hawaii location being selected as most conducive to a testing schedule with maximum delta-temperature periods and minimum weather interruptions.

Since the greatest uncertainty with OTEC was adjudged to be the test heat exchangers, the OTEC-1 platform was designed to provide, at the earliest schedule and minimum cost, a facility for testing heat exchangers. Inherent in this approach was the selection of the minimum necessary, readily available nonprototypic subsystems and components. The absence of a turbine generator, the utilization of inefficient pumps, the application of available CWP technology, the presence of an elaborate data acquisition system, etc., were deliberate steps taken to achieve the near-term limited objectives. OTEC-1 was never intended to satisfy the goals of an OTEC pilot plant.

The OTEC-1 project consisted of three phases: (1) design (Phase I), (2) construction and checkout (Phase II), and (3) operations (Phase III). Through a competitive process, DOE selected a systems integration contractor (SIC), Global Marine Development, Inc. (GMDI), to design and construct the test facility and selected TRW, Inc., as test article contractor (TAC), to design and fabricate the 1-MWe test heat exchanger set.

Through Phase I, GMDI developed specifications, designs, and procurement documents for both the shipboard modifications and the OTEC test apparatus. Long-lead procurements were initiated.

During Phase II, the USNS Chepachet, a mothballed WW II T-2 tanker, was transported from Suisun Bay, California, to the Northwest Marine Iron Works shipyard in Portland, Oregon, for reactivation and conversion. Existing shipboard systems were inspected and upgraded, and the OTEC support systems and test article set were installed. This phase concluded with the transit of the test platform (renamed the Ocean Energy Converter, or OEC) to Hawaii for attachment to the moor, attachment of the CWP, and acceptance tests.

Following acceptance tests, the OEC was turned over to the Energy Technology Engineering Center (ETEC) for Phase III. The ship's systems were operated by Tracor Marine, Inc., a subcontractor to ETEC as facility operations contractor (FOC). During Phase III, Argonne National Laboratory (ANL) was responsible for test planning, power system evaluation, and biofouling/corrosion; Lawrence Berkeley Laboratory (LBL) was responsible for environmental monitoring/evaluation; and the National Oceanic and Atmospheric Administration (NOAA) was responsible for ocean engineering evaluation, including CWP, stationkeeping, and seawater system performance.

During Phase III, the complete integrated system was operated, and information was obtained on the performance of the test article, the performance of the seawater and ammonia systems, the operation of the platform and moor systems, the effects of biofouling countermeasures, and the effects of the OTEC cycle on the environment. After several months spent in completing construction of the test system and checking out and repairing the various sytems, 4 months of test operations were conducted before funding constraints caused the discontinuation of the test program. Plans were made for long-term storage and/or disposition of the test facility. The OEC is currently located at Pearl Harbor, in the U.S. Navy Inactive Reserve Fleet anchorage. The CWP was placed in underwater storage adjacent to the moor, awaiting a decision on final disposition. In October 1982, the CWP was recovered and custody given to the State of Hawaii (see Section VI).

Although the test period lasted only about 4 months, deployment and at-sea operation of a large-scale OTEC plant was demonstrated, and information was obtained towards satisfying each of the objectives of the OTEC-1 project. Thus, OTEC-1 was a key step in furthering DOE's role of helping to overcome technical and institutional (e.g., legal, shipping, environmental) barriers to OTEC commercialization and in encouraging early industry participation.

This document summarizes the OTEC-1 test operations experience, discusses technical lessons learned, and makes recommendations for future OTEC plants.

B. SCOPE

This report summarizes the activities for which ETEC was responsible to DOE as the OEC test operations manager. These activities took place during the period from 15 December 1980 (when the OEC was transferred from GMDI to ETEC via DOE) through 24 June 1981 (when the vessel was secured in the U.S. Navy reserve fleet). Administrative custody of the OEC and its appurtenances was retained by ETEC except for those items that have been officially transferred to others.

Several aspects of the first deployment test program were assigned to other organizations as follows: LBL was responsible for environmental aspects, ANL was responsible for evaluation of the heat exchangers and biofouling/corrosion modules, and NOAA was responsible for ocean engineering aspects. Data and reports were collected and forwarded to those organizations for their analysis and dissemination to the OTEC community. This report makes reference to those reports to avoid repetition.

Should researchers need more detailed information than presented here, ETEC has all of the test operations and vessel log books, raw data recordings (charts and tapes), procedures, manuals, drawings, copies of weekly highlight reports, monthly summary reports, and copies of periodic reports issued by the on-board experimenter's representative. This information can be examined via requests to DOE.

C. MAJOR ACCOMPLISHMENTS

The details presented in this and other reports are synthesized below:

1) Testing of the 1-MWe heat exchangers validated and confirmed the analytical procedures used in designing the ammonia evaporators and condensers. It also demonstrated the operability of engineering-scale equipment; however, the practical

utility of the enhanced surfaces is questionable. The effectiveness of biofouling control measures, as applied, was demonstrated.

2) The interrelationship between the OTEC-1 platform and the ocean produced no adverse environmental impact. It was shown that conservative engineering practices successfully enabled deployment and operation under conditions that exceeded the design envelope.

3) Some special features demonstrated by the OTEC-1 platform included: placement of the largest deep mooring known; design, fabrication, deployment, operation, release, and recovery of the largest CWP known; operation of an OTEC platform in a grazing mode; feasibility and practicality of operation in a single-point mooring array; and demonstration that a mixed effluent discharge at or near the surface may be an option.

4) The operating and maintenance approach for OTEC, as characterized by OTEC-1, demonstrated that a small crew is adequate for normal operations, that defective tubes in a shell and tube heat exchanger can be conventionally repaired on-station, and that the logistics of resupply is practical and reasonable.

5) The extent to which the operational experience gained can be directly transferred to the pilot plant program is of necessity limited by the degree of similarity between design and site-specific features.

6) Goals not achieved were primarily associated with a lack of long-term testing exposure caused by funding limitations. Problems included insufficient information to determine an optimum biofouling control regimen; inability to qualify corrosion specimens due to inadequate exposure durations; insufficient long-term environmental effects of an operating OTEC facility; and no chance to demonstrate that the OEC equipment and procedures were adequate for retrieval of a detached CWP.

7) Some administrative accomplishments of the operational program included: a high visibility showpiece for DOE in the eyes of Congress, utilities, industrialists, academia, and the general public; a demonstration of interfunctional (DOE, ETEC, ANL, LBL, etc.) and interagency (DOE, U.S. Navy, Marad, USCG, NOAA, etc.) cooperation; evidence of compliance with regulatory functions (EPA, USCG, county, state, etc.).

D. EXECUTIVE RECOMMENDATIONS

The following recommendations are offered for organizations contemplating future projects of such complexity and magnitude:

1) Given that separate organizations have specialized expertise, a single on-site manager should have the authority to integrate the needs of the project and assign priorities to the available sources.
2) The concept of a single point of communication for all activities of the test program is good provided that the person has the authority cited above and has no organizational biases.
3) Considering the efforts required to bring such a test program into being, the requirements for advance budgetary planning need to be developed and assured to support the test programs.
4) A major difficulty experienced during the testing operation was the lack of postconstruction testing of the experimental equipment and instrumentation. The schedular objective of placing the test platform onsite made remote site repair both difficult and costly during initial startup. This required the test operators to diagnose problems, correct deficient documentation, perform rework, do redesign and repair, and complete construction. It is recommended that work be performed by those to whom it was contracted and that adequate budget and schedule be provided.

5) Some generalized operational recommendations for future designers include:

   a) Have operating procedures for subsystems and equipment prepared by the designers and have them available for first use during checkouts and final demonstration during acceptance testing.

   b) Have the end user be responsible for design, fabrication, and checkout of the instrumentation and control systems, including all operating, verification, and maintenance procedures.

   c) Provide good accessibility to equipment and instrumentation in the plant design to ensure safe and efficient operation, inspection, maintenance, and repair.

II. SUMMARY DESCRIPTION OF OTEC-1

OTEC-1 consisted of:

1) The U.S. Navy T2-SE-A1 turboelectric drive Chepachet, converted to a test platform
2) A 1-MWe (equivalent) test article set consisting of an evaporator, a condenser, and a phase separator
3) A power system consisting of a closed-loop ammonia system, warm water system, cold water system, and mixed water discharge (MWD) system
4) The CWP assembly
5) Support systems such as the moor, environmental support equipment, chlorination equipment, biofouling and corrosion modules, instrumentation and control (I&C) van equipment
6) The shore support facility.

A pressure-reducing valve located in the ammonia loop was used to simulate a power-generating turbine.

OTEC-1 was instrumented to provide information to the data acquisition and processing system to monitor not only the performance of the heat cycle, but also the performance of the test platform positioning system and the condition of the environment. An environmental laboratory (EL) was installed on board the vessel; it analyzed samples from the test articles and the environment to provide data relative to the effects of the OTEC cycle on the environment and of the heat transfer fluids on the material used in the system. Figure 2-1 depicts the test platform with its major facility characteristics. Table 2-1 lists the key events associated with the program. Table 2-2 lists the key events associated with the OEC.

The power loop was a closed-system Rankine cycle, in which anhydrous ammonia (NH_3) was the working fluid. Warm seawater from the surface supplied the energy source; cold seawater from deep below provided the "sink" to

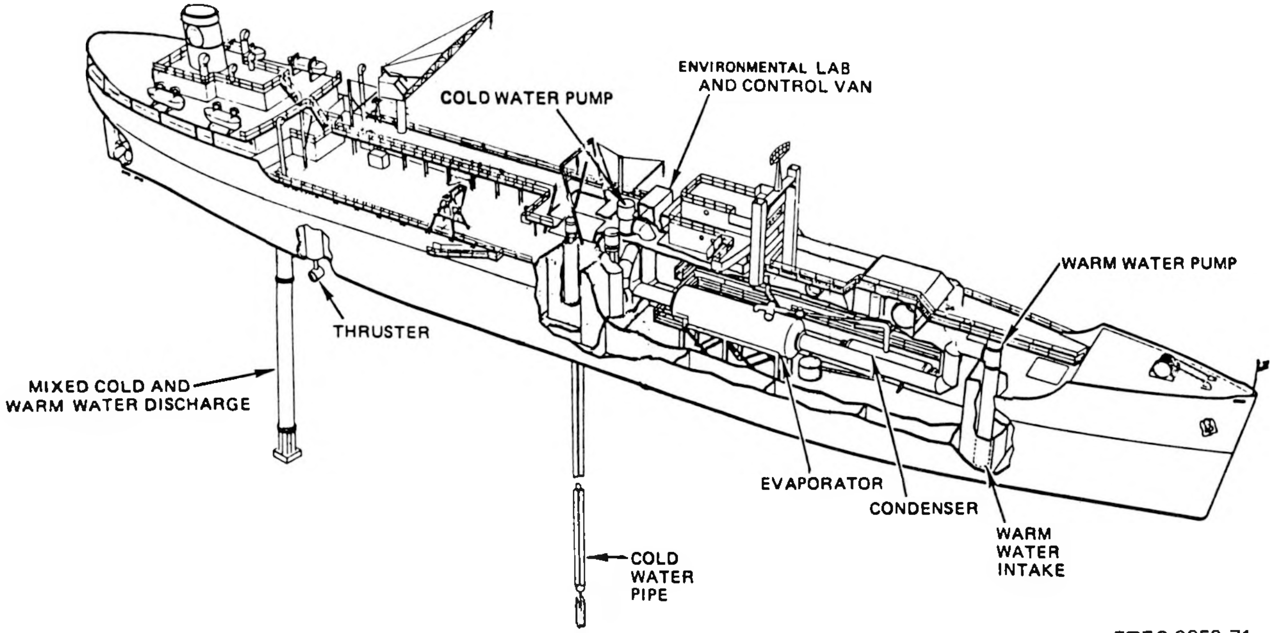


Figure 2-1. OTEC-1 Platform (OEC)

TABLE 2-1

KEY EVENTS FOR OTEC-1 FACILITY

Award of SIC contract	October 1978
Completion of final design	April through May 1979
Completion of construction and sea trials	June 1980
Transit to Hawaii and dedication	22 June through 5 July 1980
Completion of construction of test systems and modification of CWP	5 July through 10 November 1980
Acceptance testing and turnover to operations	10 November through 15 December 1980
Water system operation	December 1980 through April 1981
Ammonia system operation	January 1981 through March 1981
Release CWP and depart test site	13 April 1981
Excessing and disposal of facility	24 April 1981 through 7 December 1982

TABLE 2-2
KEY EVENTS FOR OEC

10 May 1980	Dockside trials at Portland, Oregon
1 Jun	OEC left Portland for sea trials at Port Angeles, Washington
2 Jun	Commenced sea trials
9 Jun	Completed sea trials
10 Jun	OEC left Port Angeles and arrived at Longview, Washington
22 Jun	OEC left Longview and arrived at Astoria, Oregon, for radar repairs
23 Jun	OEC left Astoria for transit to Honolulu Harbor, Hawaii
1 Jul	OEC arrived in Honolulu Harbor, Pier 10, then moved to Pier 9
5 Jul	OEC dedication ceremonies and open house
6 Jul	Open house
8 Jul	OEC left Honolulu for Kawaihae Harbor, Hawaii
9 Jul	OEC arrived in Kawaihae Harbor, held dedication ceremonies and open house
28 Jul	OEC on mooring site
4 Aug	Mooring line released, OEC back to Kawaihae pier
7 Oct	OEC left Kawaihae for Honolulu
8 Oct	OEC arrived in Honolulu Harbor, Pier 41
24 Oct	OEC left Honolulu for Kawaihae Harbor
31 Oct	OEC on mooring site, CWP towed out of Kawaihae Harbor
1 Nov	CWP arrived at site and uprighted
4 Nov	CWP installed on OEC
11 Nov	Warm and mixed water pumps started, also Amertap system
12 Nov	CWP started, also Amertap system
17 Nov	Cable released from bottom of CWP
18 Nov	Chloropac unit started for evaporator
19 Nov	Chloropac unit started for condenser
1 Dec	CWP drop test completed
14 Dec	Tracor Marine takes over as FOC
31 Dec	Initial OTEC-mode checkout operation
7 Jan 1981	First dye test on MWD plume
23 Jan	OTEC-mode tests began
3 Mar	Amertap systems (evaporator and condenser) stopped
4 Mar	OEC slipped moor, on OTEC grazing mode
6 Mar	OEC reattached to moor
18 Mar	OTEC-mode stopped
1 Apr	Noise signature of ship taken by U.S. Navy
11-12 Apr	Second dye test on MWD plume
12 Apr	Seawater pumps (three) shut down
13 Apr	Moor line released, CWP dropped, and OEC left for Kawaihae
14 Apr	OEC arrived at Kawaihae
20 Apr	OEC left for Honolulu Harbor
21 Apr	OEC arrived in Honolulu Harbor, Pier 39
29 May	LNH_3 offloaded
10 Jun	State of Hawaii completed equipment offloading
17 Jun	OEC towed from Honolulu Harbor to U.S. Navy Reserve Fleet, Middle Loch, Pearl Harbor, Hawaii
24 Jun	OEC secured to six anchor buoys
8 Oct 1982	CWP recovered and stored in Kawaihae Harbor
9 Oct	CWP turned over to State of Hawaii
7 Dec	OEC turned over to State of Hawaii

reject waste heat. The ammonia entered the evaporator as a liquid, where it was vaporized at elevated pressure. The ammonia vapor was then conducted to a pressure-reducing valve which simulated, thermodynamically, the energy-extraction turbine. The spent ammonia vapor was then admitted to the condenser, where the low-pressure vapor was returned to a liquid state, transferring waste heat to the cold water. A return pump elevated the pressure and returned the liquid ammonia to the evaporator, completing the cycle.

To convert the USNS Chepachet to an OEC required using several unique systems. The midship configuration consisted of a large section in which was housed the "moonpool," or cold water sump. It was open to the CWP assembly interface and formed a free-surface supply tank from which cold water was drawn by the cold water pump. The CWP assembly connected the moonpool through a gimbal/diaphragm assembly and extended to approximately 2200 ft beneath the surface of the ocean. The CWP was constructed of three 4-ft-diameter polyethylene pipes banded together and connected to the gimbal/diaphragm assembly through a metal transition. The end of the CWP was weighted to minimize the displacement of the pipe by ocean currents.

The gimbal/diaphragm was a ball and socket assembly mounted within a two-axis frame that permitted the CWP to move freely within a cone beneath the OEC. This design prevented warm surface water from mixing with the cold water and enabled the pipe to move with respect to the ship in pitch and roll; heave had to be accommodated by structural integrity.

For those periods when the weather might force the test platform to leave the moor and seek shelter, the CWP could be detached and, stabilized by a buoyant collar on its top, stored on the ocean floor in a vertical position. Then, when the weather permitted, it could be recovered. For ocean currents strong enough to reach the maximum gimbal angle, the OEC could be released from the moor to operate in the "grazing" mode until the currents subsided enough to allow reattaching the OEC to the moor. Movement of the OEC about the moor was controlled by two retractable thrusters.

The MWD pipe exhausted the mixed discharge water (condenser and evaporator discharge water) from a mixing tank to one of several depths below the ocean surface, depending on the test configuration. The MWD was stabilized by a weight attached to the lower end of the MWD pipe in a manner similar to that for the CWP. The MWD hose never was adequate, even after several modifications, and so the MWD was not used during the test period. Ref. 1 is a detailed failure report.

The OEC was attached to the single-point moor and moved within a prescribed watch circle. To keep the CWP from becoming entangled with the anchor system, two 1000-hp thrusters, located aft of the forecastle and forward of the poop deck, provided additional position control. They were capable of being retracted into a "trunk" during transit to and from the moor site.

The OTEC-1 test site was located approximately at 19°56' N, 156°10' W off Keahole Point of the "Big" island of Hawaii. The surface moor was anchored at a depth of approximately 4000 ft. A shore facility at Kawaihae Harbor provided logistical support for the operation. A crew boat provided regular service between the shore facility and OEC, transporting both personnel and equipment.

A. DESIGN CRITERIA FOR OTEC-1

The SIC prepared designs for converting the USNS Chepachet to meet the DOE criteria for the OTEC-1 test platform. These criteria established a capacity of 1 MWe (40 MWt) as the basis for the power system design.

The SIC began design work on 1 October 1978. A preliminary design review was held in December 1978, and a final design review in May 1979. The design bases for the OTEC-1 systems are listed below:

1) Plant design life: 5 yr
2) Operating environment (onsite ocean conditions with the CWP attached): up to and including 16-ft significant waves, 30-knot winds, and 1.2-knot surface currents

3) Survival environment (onsite ocean conditions without the CWP attached): up to and including 41-ft significant waves, 100-knot winds, and 2.0-knot surface currents
4) Stationkeeping: single point moor with thruster assist
5) Vessel conversion: to meet the requirements of the USCG and ABS for classification as a "miscellaneous research" vessel in regard to personnel, hull, and machinery and to qualify for all design, construction, and operation permits required by local, state, and federal jurisdictions
6) Process equipment, process control, and data acquisition subsystems: sufficient for an experimental test operation of a 40-MWt OTEC system
7) Provide a self-sustaining operational test facility to accommodate the test heat exchangers and associated experimental subsystems, necessary auxiliary subsystems, and water discharge subsystem
8) Extraction and conversion to electrical energy were not to be accomplished
9) Site the experiment such that a minimum ΔT of 36°F exists for no fewer than 5 out of any 12 months and a minimum annual ΔT of 29°F would be obtained.

B. OTEC-1 SYSTEM DESIGN DESCRIPTIONS

As described above, OTEC-1 consisted of an oceangoing tanker converted to a test platform having the capability of testing heat exchangers with capacities of up to 1 MWe (40 MWt). This section describes the systems that composed the OTEC-1 test platform.

The USNS Chepachet, renamed the Ocean Energy Converter (OEC), was converted and modified to provide all the elements required for the OTEC mission. She continued her dual ABS classification of Maltese Cross A1E and Maltese Cross AMS. Her service was changed from "oil carrier" to "ocean research," and a certificate of inspection was issued as a "miscellaneous vessel, research platform for OTEC-1 service."

For our purposes here, OTEC-1 consisted of (1) the test platform (the OEC), (2) the CWP assembly, (3) the seawater system, (4) the test article set, (5) the ammonia system, (6) the biofouling and corrosion modules, (7) the chlorination system, (8) the Amertap system, (9) the instrumentation and control system, (10) the environmental monitoring system, and (11) the shore/ship logistic supply system.

A complete listing of the design reports, drawings, operating and maintenance manuals, and acceptance test procedures prepared by GMDI (et al.) is given in Ref. 22 and not continuously referred to herein. An overall summary design report was not issued; this report is not intended to serve that function.

1. Test Platform

The OTEC-1 platform consisted of a former U.S. Navy T-2 tanker modified to support the OTEC-1 power plant, auxiliary systems, and crew under the conditions delineated in the test plan (Ref. 2) and to meet the design criteria listed in Section II.A.

In addition to the reactivated existing ship structures, the OTEC-1 platform consisted of the following special OTEC-1 related structural, containment, and space features:

1) A cold water sump from which water was pumped through intake screens
2) A CWP attachment fixture integral with the cold water sump but sealed to prevent the intrusion of warm water
3) A warm water sump from which water was pumped through screens
4) Fume-tight isolation bulkheads for the ammonia containment spaces
5) Deck-mounted CWP and gimbal-handling equipment
6) A vessel positioning system for controlling the platform on the watch circle

7) Single-point mooring

8) Provisions for accommodating the I&C van and the EL.

The mooring system was a passive clump anchor attached at the bow of the vessel and assisted by two manually controlled, steerable thrusters; to prevent fouling the CWP with the mooring line, these thrusters provided a degree of maneuverability while moored. The platform was able to operate while maintaining a 2.6-mile-diameter "watch circle" under the operational and survival sea conditions listed in Section II.A.

The passive anchoring system consisted of 150 tons of chain as a clump mass anchor, a subsurface syntatic buoy supporting the anchor cable, a surface buoy connected to the subsurface buoy and to a floating mooring line, and interconnecting cables and hawsers.

The existing propulsion and ship service power systems, lighting systems, and communications systems and equipment were reactivated and upgraded to the requirements of the U.S. Coast Guard. The steam turboelectric drive of the T-2 tanker played a large part in its selection for use in the OTEC-1 project. The power plant generated steam from which a turbine generator produced electric power. In the propulsion mode, the power was directed to a traction motor, which drove the main screw. In the OTEC mode, the power was not available to the propulsion system, but was provided to distribution busses from which the water and ammonia pumps, hotel loads, thrusters, and experimental systems were operated. The ship's power plant was nominally rated at approximately 5.4 MWe. The provisions for the self-contained I&C van included electrical power, emergency breathing air, structural support, air conditioning, and weather-protected access.

The provisions for the self-contained EL included electrical power, air conditioning, utility water and drainage, structural support, and weather-protected access.

The CWP/gimbal-handling equipment included main-deck-mounted components as follows: a 150-ton double-drum winch with 2500 ft of 2-1/4-in. wire for

CWP retrieval, an "A" frame support structure over the cold water sump to fair lead the wire rope for CWP and/or gimbal rigging; an over-the-side frame to fair lead the wire rope over-the-side for CWP deployment and retrieval; and miscellaneous sheaves, guides, and small electrical winches to assist operations. The rigging equipment was also designed to elevate the gimbal/diaphragm assembly to the main deck level for maintenance, repair, and for securing when the vessel was in transit.

2. CWP Assembly

The CWP assembly consisted of three major subassemblies: the CWP, the gimbal/diaphragm assembly, and CWP instrumentation. Functionally, the cold water sump was connected to the cold water supply, at about 2200 ft below the surface, by the CWP. As water was pumped out of the sump, the hydrostatic pressure differential would force water up through the CWP to restore the displaced water. The elevation head difference between the surface of the cold water sump and the surface of the sea was 6 to 7 ft at nominal flow conditions, which represents the frictional head loss the water experienced in the transit through the CWP.

The pipe assembly (Figure 2-2) comprised three 48-in.-diameter polyethylene pipe sections with upper and lower steel transition elements. At the upper end, the pipes merged into a single flow and attachment channel. A bottom weight, supported by cables within each pipe, limited pipe motion. Special equipment for deploying and recovering the pipe after release was also provided. The pipe assembly interfaced with the hull at the gimbal/diaphragm assembly, which structurally supported the pipe and isolated the pitch and roll motions. The upper diaphragm element supported the gimbal and mated with the ship's moonpool structure. It provided a sealed interface at the bottom of the moonpool between the cold water in the sump and the adjacent warmer surface water. A coarse "trash" grate screen was used on the bottom to exclude large objects and marine life.

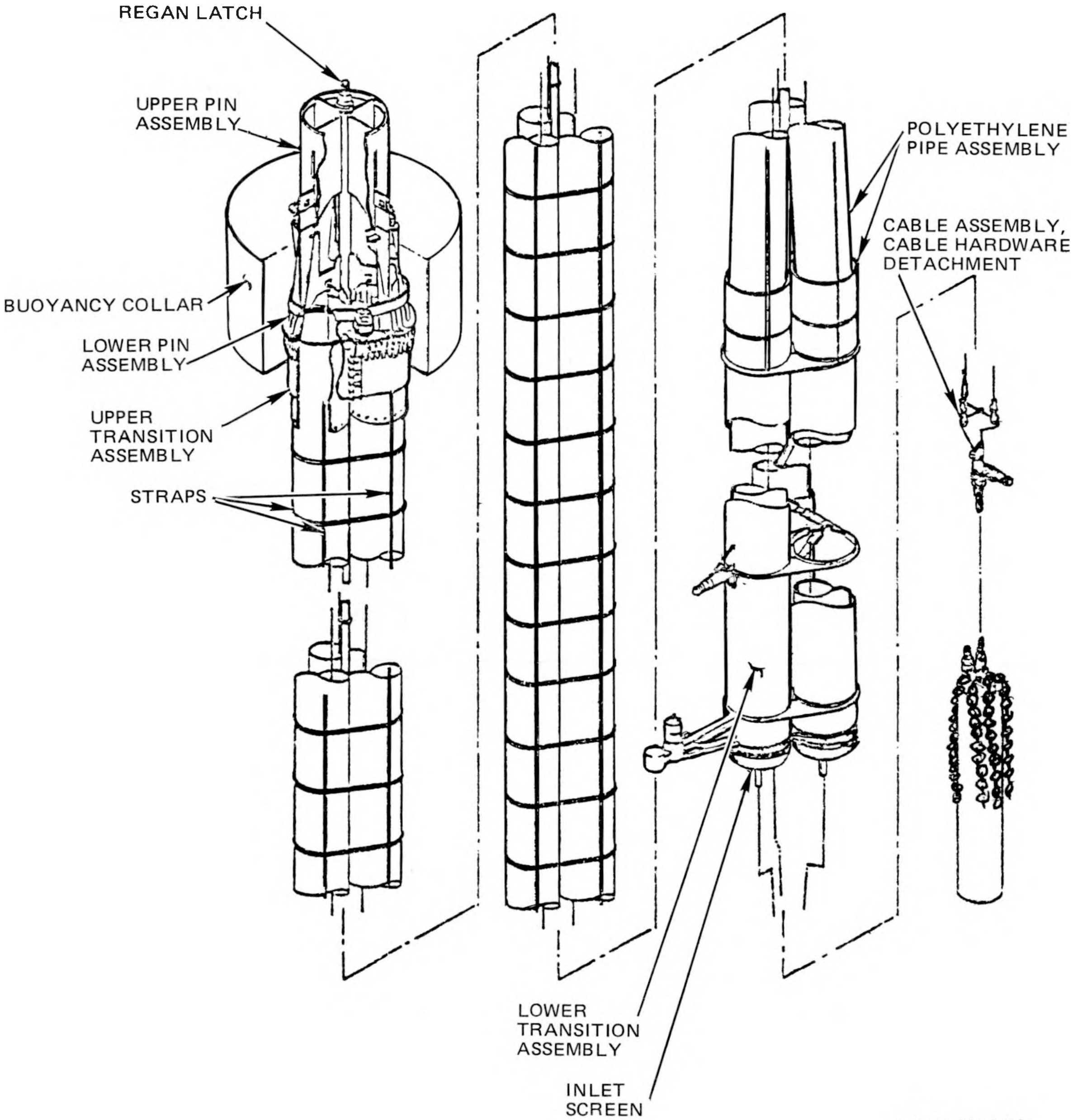


Figure 2-2. CWP Assembly

The gimbal (Figure 2-3) consisted of an outer ring, an inner yoke socket, and four bearings. The socket mated around the top end of the pipe assembly and connected through four attachment dogs, which could be released hydraulically.

The CWP-handling equipment, consisting of a deck-mounted moonpool "A"-frame structure, one overside crane structure, plus a dual 150-ton winch, provided the capability to deploy (upend), recover, keelhaul, and mate the pipe assembly. This equipment could also lift the gimbal/diaphragm assembly up to deck level for maintenance and stowage when the vessel was in transit.

Instrumentation was installed on the gimbal assembly to measure both angular motion (gimbal pitch and roll) and the three-dimensional forces transmitted through the CWP and ship structures. The strains in the CWP were measured via linear variable differential transformers (LVDTs) located on the pipe plastic material. In addition, a 6-in. centerway polyethylene tube was provided for insertion of a retrievable instrumentation package.

During the deployment of the CWP, surface currents damaged some of the conduits carrying signal wire. By the time the instrumentation had been connected and checkouts begun, it was discovered that the diver-accessible instruments had a corrosion-related failure. An incident report was issued.[3] No data were obtained between November 1980 and March 1981. The nonmetallic rework suggested by the failure analysis was implemented during the final month of operation.

To assist in determining the position of the CWP, two acoustic beacons were attached to the lower transition assembly. These were observed on an X-Y cathode-ray tube display. The acoustic beacon system operated satisfactorily.

3. Seawater Systems

The seawater systems described here were part of the OTEC-1 test system and were not functionally related to the seawater circuits used for shipboard

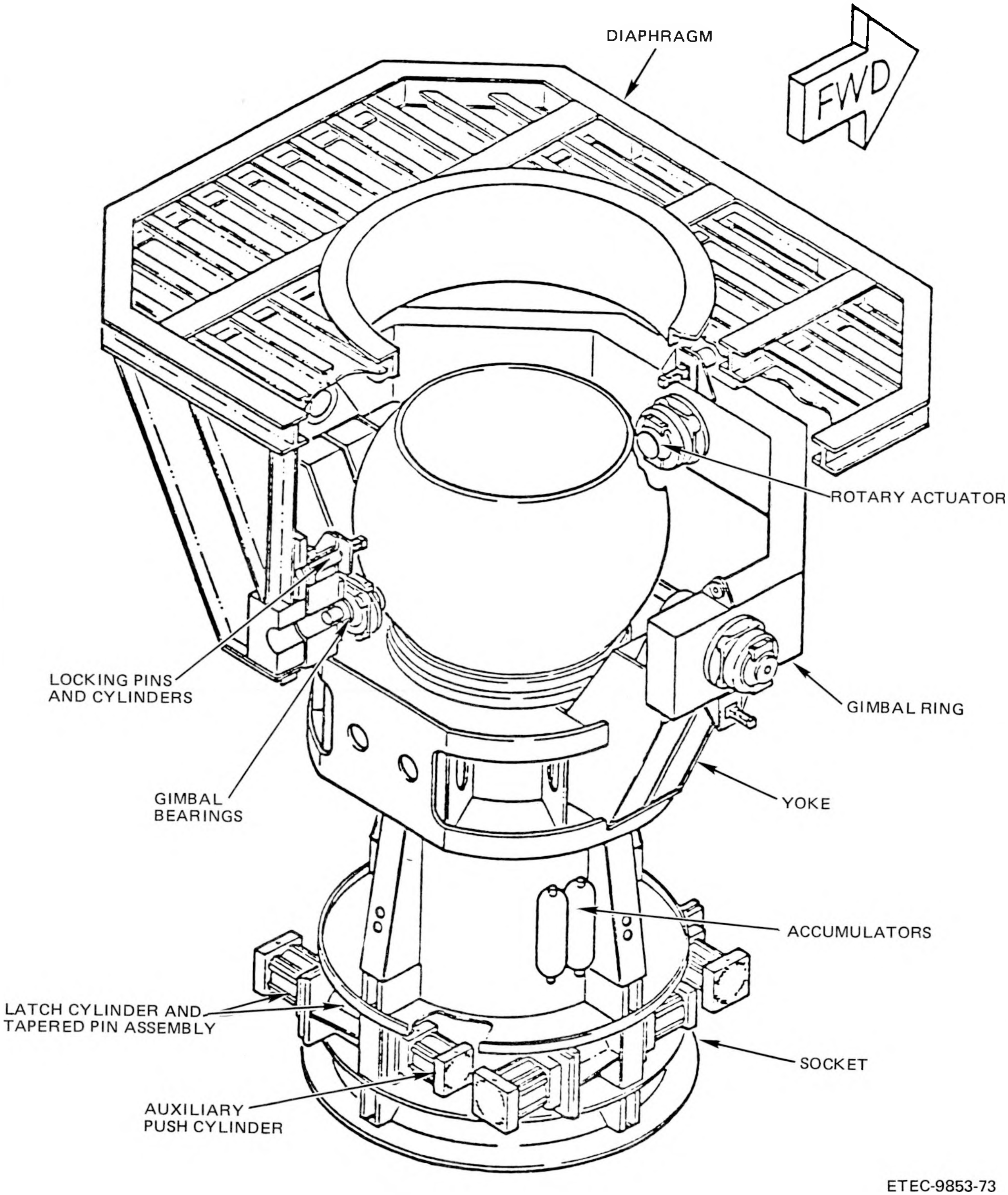


Figure 2-3. CWP Gimbal/Diaphragm Assembly

operation (e.g., ballast, firemain). The OTEC-1 seawater system installed aboard the OEC included the following major subsystems: the warm water system, the cold water system, and the MWD system.

The warm water system (Figure 2-4) drew surface (warm) seawater through a penetration in the bottom shell of the ship's hull. The penetration was fitted with a velocity cap to ensure horizontal incoming flow. The warm water flowed up a standpipe, into the warm water sump. Two sets of dual-screen panels located in the warm water sump were used to filter out objectional items, while allowing on-line cleaning. The seawater was pumped from the warm water sump through the test circuit evaporator, where it transferred its heat to the liquid ammonia, causing the ammonia to vaporize. After flowing through the evaporator, the seawater was discharged into a mixing tank at midship together with the spent cold water. Nominal flow through the warm water system was 82,600 gpm at 80°F; the maximum flow was 115% of nominal. The warm water pump was a single-stage axial-flow unit with a bell inlet, driven by a 600-hp SCR-controlled variable-speed dc motor.

The cold water system (Figure 2-5) drew cold water from the moonpool sump, which was connected to the CWP through a gimbal/diaphragm assembly. Cold water drawn from the 2200-ft level into the sump passed through secondary screens located adjacent to the moonpool and was picked up by the cold water pump. The cold water pump delivered a nominal flow of 68,200 gpm at 15-ft developed head; maximum flow was 115% of nominal. The cold water pump was a single-stage axial-flow unit with a bell inlet, driven by a 500-hp SCR-controlled variable-speed dc motor.

The cold water system pumped the cold "bottom" water through the test circuit condenser, where it condensed the ammonia vapor being passed from the evaporator, phase separator, and throttle valve. Water exiting the condenser flowed to the midship mixing tank before being discharged to the ocean.

The MWD system (Figure 2-6) accumulated and mixed the cold and warm water from the test heat exchangers and pumped it overboard. Normal operation

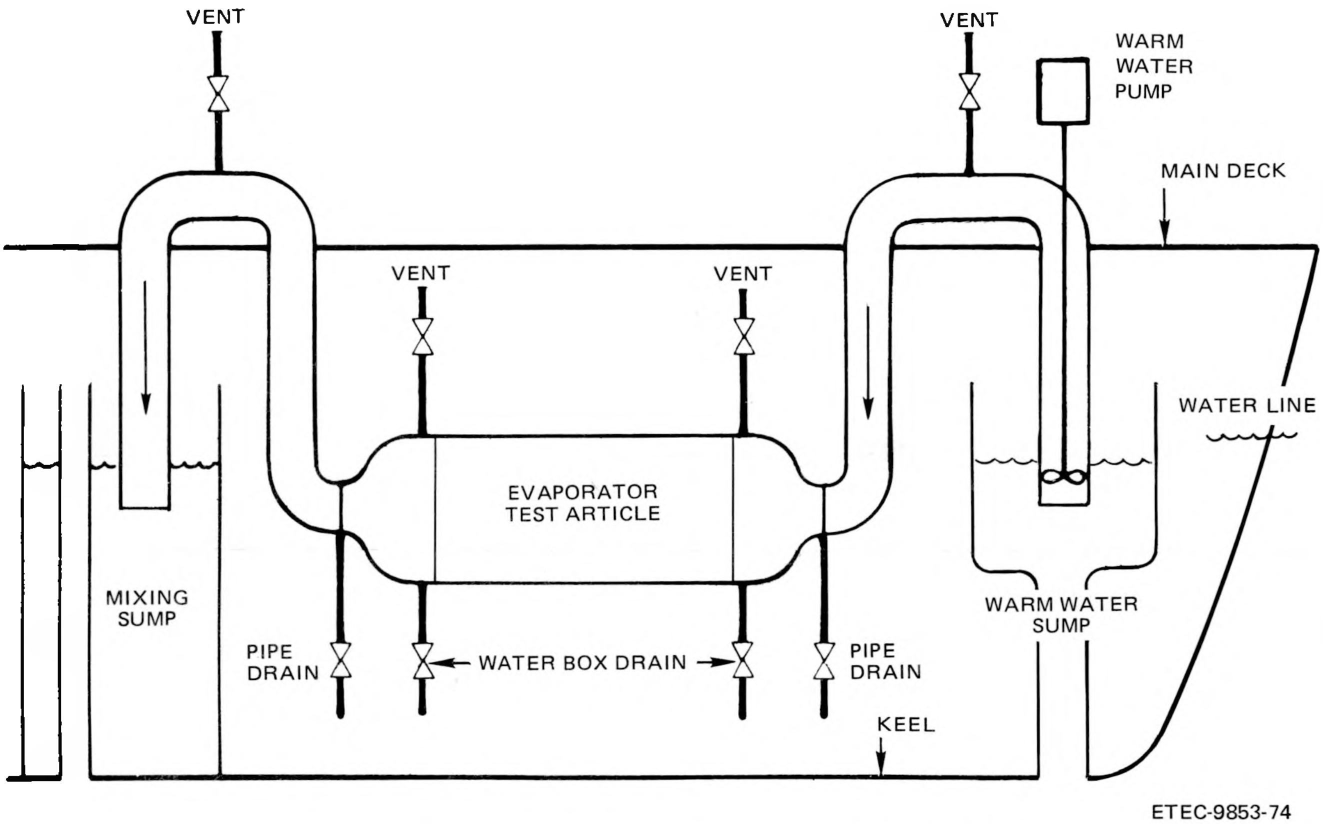


Figure 2-4. Warm Water System Flow Diagram

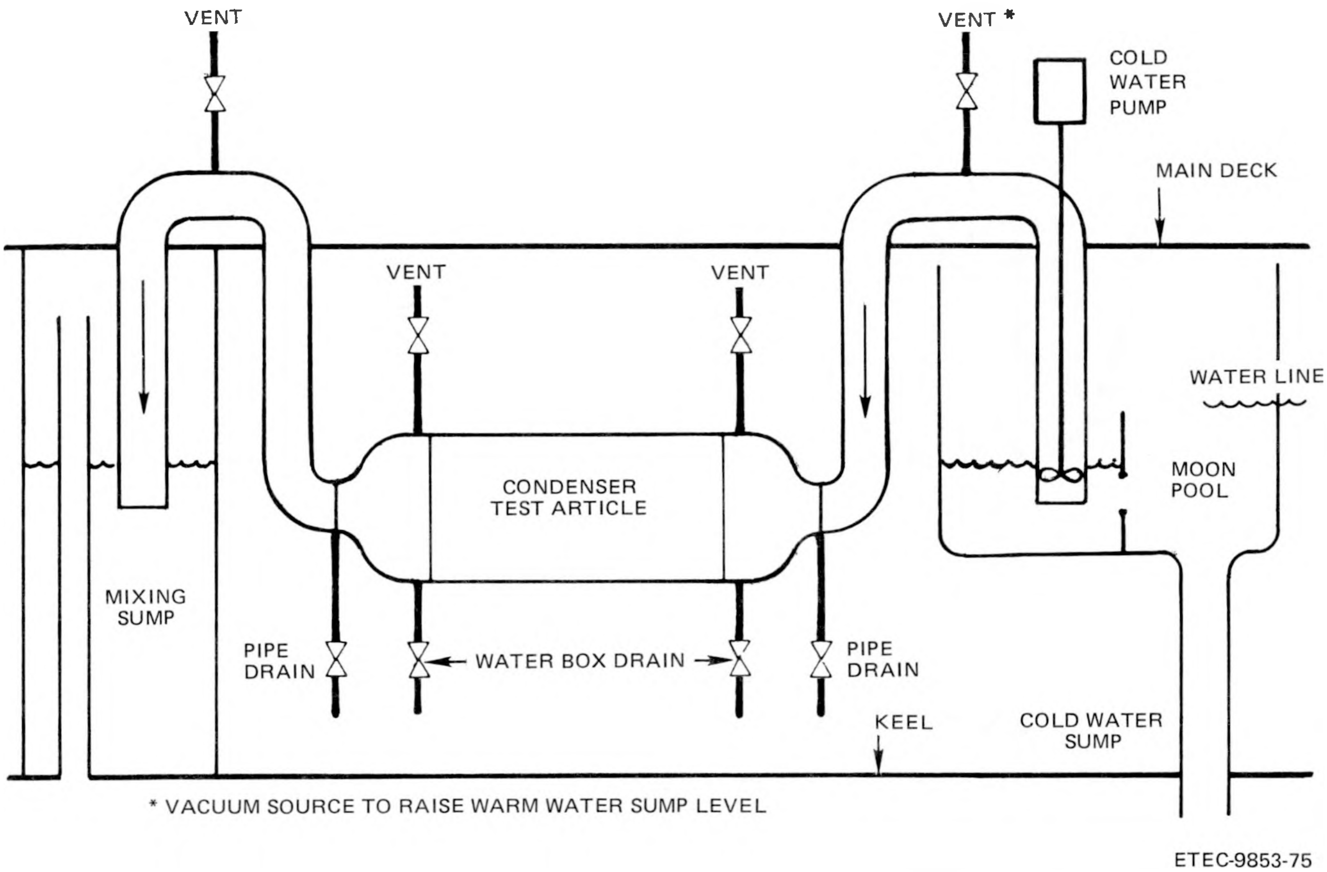


Figure 2-5. Cold Water System Flow Diagram

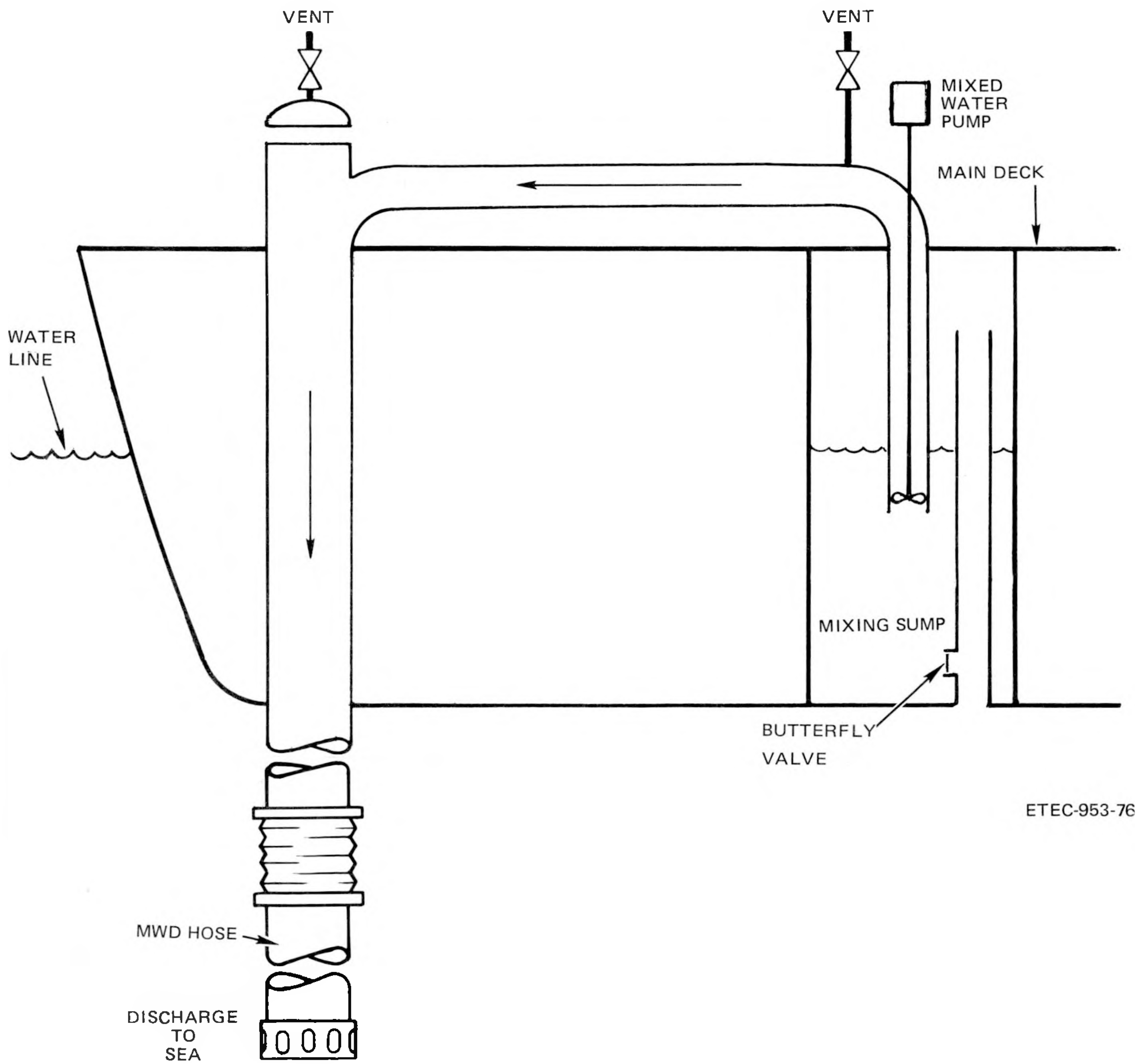


Figure 2-6. Mixed Water Discharge System Flow Diagram

involved using the mixed water pump to pump the mixed discharge effluent through the MWD pipe to a depth below the test platform. But, because the fabric MWD pipe failed repeatedly, the effluent was, during most of the test period, discharged immediately below the hull of the OEC. The mixed water pump was a single-stage axial-flow unit with a bell inlet, driven by a 700-hp variable-speed dc motor.

Located within the mixing sump was a 26-ft-tall open standpipe, which penetrated the bottom shell plating of the hull and was fitted with a branch-connected, deck-operated, normally open butterly valve. Should either the cold or warm water circuit stop pumping, the valve (in the open position) could permit seawater to flow into the sump, enabling the continued operation of the MWD system. Should the mixed water pump fail during normal operation, the combined output of the cold water and warm water pumps had a path to the ocean via the standpipe and thus the heat exchangers could continue to operate.

4. Test Article Set

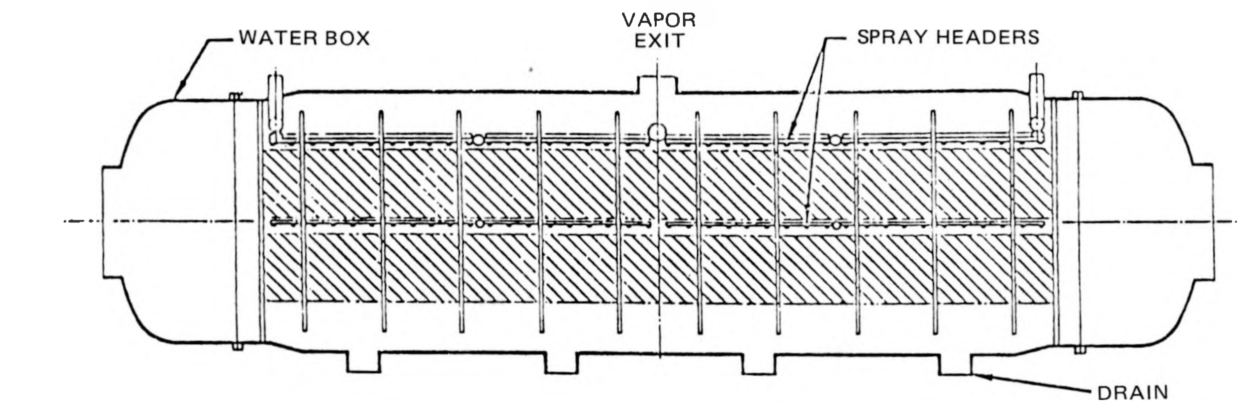
The test article set consisted of the evaporator, evaporator drain tank, condenser, and phase separator.

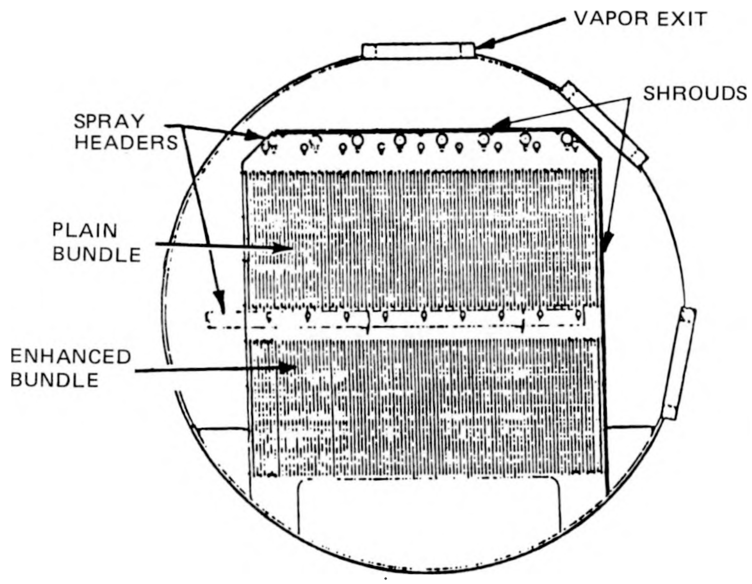
The evaporator was an ASME Section VIII Division 1, TEMA class C horizontal shell and tube unit with the tube bundle split into two sections. The upper section consisted of 3152 smooth-surface titanium tubes, the lower half of 3152 titanium tubes enhanced on the outer (NH_3 side) surface; these were housed in a shell 13 ft in diameter by 54 ft in length. (Refer to Table 2-3 and Figure 2-7.) The unit was designed to evaporate 256,000 lb/h of ammonia at a temperature of 72°F at 133.4 psia. The heating fluid was 80°F seawater pumped once through the tubes at a nominal rate of 82,600 gpm. Ammonia feed to the evaporator was at a temperature of about 48°F and a pressure of about 134.4 psia.

TABLE 2-3

DESIGN CHARACTERISTICS OF THE 1-MWe EVAPORATOR

Operating conditions	
Duty [Btu/h (kcal/h)]	40 MWt [1.3×10^8 (3.3×10^7)]
Seawater flow (gpm)	82,600
Seawater inlet temperature [°F (°C)]	80 (26.7)
Seawater outlet temperature [°F (°C)]	76.6 (24.8)
Ammonia flow [lb/h (kg/h)]	256,000 (116,000)
Ammonia inlet temperature [°F (°C)]	48.0 (8.9)
Ammonia outlet temperature [°F (°C)]	72.0 (22.2)
Ammonia pressure (psia)	133.4
Design conditions	
Type	Tube and shell
Code	ASME Section VIII Division 1
Design pressure (psig)	190
Design temperature [°F (°C)]	100 (37.8)
Seawater pressure drop (psid) maximum	5
Equipment configuration	
Shell length [ft (m)]	54 (16.5)
Shell diameter [ft (m)]	13 (4)
Shell material	Carbon steel
Shell thickness [in. (cm)]	1.25 (3.17)
Tube material	Titanium
Tube diameter [in. (cm)]	1 (2.5)
Tube wall thickness [in. (mm)]	0.028 (0.71)
Tube spacing, -30° triangular pitch (base) [in. (cm)]	2.165 (5.50)
Effective tube length [ft (m)]	37.5 (11.4)
Number of tubes	6,304
Surface required [ft^2 (m^2)]	61,890 (5,750)





EVAPORATOR CHARACTERISTICS	
SHELL OD (ft)	13
SHELL LENGTH (ft)	54
NUMBER OF TUBES	6304
TUBE OD (in.)	1.0
TUBE WALL (in.)	0.028
EFFECTIVE TUBE LENGTH (ft)	37.5
TRANSFER SURFACE (ft^2)	61,890
SEAWATER VELOCITY (fps)	6.0
ΔP IN TUBES (psi)	3.0
OVERALL U ($Btu/h \cdot ft^2 \cdot {}^oF$)	364
LMTD (${}^oF$)	6.16
h, NH_3 SIDE ($Btu/h \cdot ft^2 \cdot {}^oF$)	880
h, H_2O SIDE ($Btu/h \cdot ft^2 \cdot {}^oF$)	1140

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Figure 2-7. Evaporator Configuration and Characteristics

Contained within the evaporator were three circuits of ammonia spray nozzles: two longitudinal tiers over the top half bundle and one tier longitudinally between the upper and lower tube bundles. This arrangement allowed the ammonia to be fed regionally. Unevaporated ammonia was drained through four lines on the bottom of the evaporator to the external sump tank. Ammonia could be supplied at rates up to five times the nominal evaporation rate. This was a reflux ratio of four.

The evaporator contained internal supports and manways on the ammonia side that allowed shrouds to be added during the test program to change the internal configuration. This allowed testing the effects of changing the vapor velocity. These shrouds also were designed to permit operation as a partially or completely flooded tube bundle, and windows were provided for observing the operation of the evaporator.

The evaporator contained a series of instrumented tubes. Six of the 6304 tubes were formed into an external closed-loop system containing deionized water controlled at flow rates and temperatures identical to the seawater conditions being evaluated at the time. These tubes provided a nonbiofouling control group. Twenty-four additional tubes were formed into external open loops, i.e., the warm seawater outlet from those were directed through measuring devices (for measuring flow rate and temperature and for counting balls) and then returned to the warm seawater return line. These provided samples where biofouling countermeasures were experimentally separable and where spatial heat transfer effects could be detected. These experimental features produced essentially no data because of inadequate design and construction.

The evaporator drain tank (T-1) was attached parallel to and below the evaporator by four free-gravity drain nozzles. The tank received unevaporated ammonia from the evaporator and condensate from the condenser and phase separator. The mixed supply of liquid ammonia was pumped from the evaporator drain tank, through the ammonia reflux pumps, and to the evaporator.

The condenser was an ASME Section VIII Division 1, TEMA class C horizontal shell and tube unit containing 5526 plain-surface, single-pass titanium tubes housed in a shell 9.2 ft in diameter by 50 ft in length. (Refer to Table 2-4 and Figure 2-8.) The unit was designed to receive 256,000 lb/h of ammonia (97.5% quality) at 86.4 psia and 48°F. The cooling fluid was 40°F seawater circulated through the tubes at a nominal rate of 68,170 gpm. The ammonia conditions leaving the condenser were about 48°F and about 89.4 psia. The condenser was not designed for vacuum operation. The condensed ammonia flowed to five drain pots; the center pot contained a liquid level controller to control the ammonia flow back to the evaporator.

One safety relief valve (PSV-6) was provided on the shell. The condenser also contained a series of instrumented tubes similar to those in the evaporator.

Noncondensible gases (O_2, N_2, etc.) were vented from the evaporator through four noncondensible vents located at the lower section of the evaporator, utilizing vent baffles installed for the purpose.

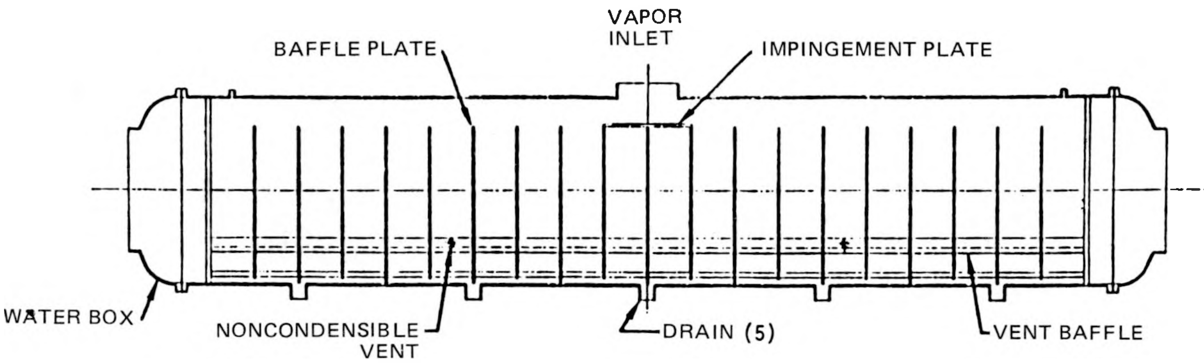
The phase separator located between the evaporator and the condenser was a horizontal, cylindrical device manufactured to Section VIII of the ASME Code and ANSI B31.1. It was designed to accept 266,000 lb/h of 96% or higher quality ammonia and to provide a minimum outlet quality of 99.5%. The moist ammonia first encountered a splash plate and then flowed through a wire mesh section. Condensate from both sections flowed to a single discharge point, from which it flowed via the condensate return system to the evaporator drain tank. A liquid level control system was provided.

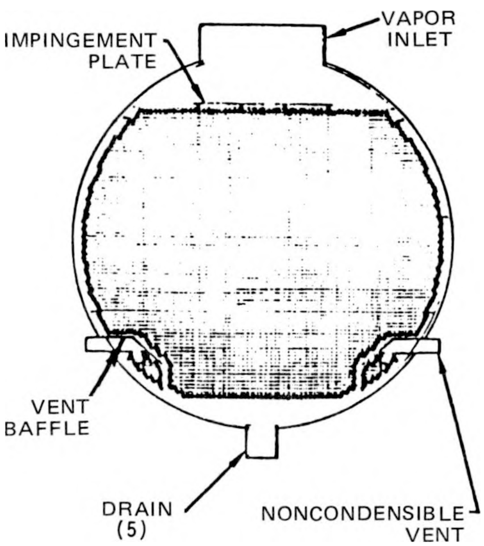
The evaporator and the condenser each contained 30 instrumented tubes: 24 were open loop (used seawater from the respective cold water and warm water systems) and 6 were closed loop (used deionized water). A common heater-chiller unit was utilized to provide water temperature control of the closed-loop systems.

TABLE 2-4

CRITERIA OF THE 1-MWe CONDENSER

Operating conditions	
Duty [Btu/h (kcal/h)]	40 (MWt) [1.3×10^8 (3.3×10^7)]
Seawater flow (gpm)	68,170
Seawater inlet temperature [°F (°C)]	40 (4.4)
Seawater outlet temperature [°F (°C)]	44.2 (6.8)
Ammonia flow [lb/h (kg/h)]	256,000 (116,000)
Ammonia temperature [°F (°C)]	48.0 (8.9)
Ammonia pressure (psia)	86.4
Ammonia inlet quality (%)	97.5
Design conditions	
Type	Tube and shell
Code	ASME Section VIII Division 1
Design pressure (psig)	190
Design temperature [°F (°C)]	100 (37.8)
Seawater pressure drop (psid) maximum	5
Equipment configuration	
Shell length [ft (m)]	50.4 (15.4)
Shell diameter [ft (m)]	9.2 (2.8)
Shell material	Carbon steel
Shell thickness [in. (cm)]	0.875 (2.223)
Tube material	Titanium
Tube diameter [in. (cm)]	1 (2.5)
Tube wall thickness [in. (mm)]	0.028 (0.71)
Tube spacing, 60° triangular pitch (base) [in. (cm)]	1.250 (3.18)
Effective tube length [ft (m)]	42 (12.8)
Number of tubes	5,526
Surface required [ft^2 (m^2)]	59,800 (5,555)





CONDENSER CHARACTERISTICS

SHELL OD (ft)	9.2
SHELL LENGTH (ft)	50.4
NUMBER OF TUBES	5526
TUBE OD (in.)	1.0
TUBE WALL (in.)	0.028
EFFECTIVE TUBE LENGTH (ft)	42
TRANSFER SURFACE (ft^2)	59,800
SEAWATER VELOCITY (fps)	5.6
ΔP IN TUBES (psi)	3.3
OVERALL U (Btu/h · ft^2 · °F	403
LMTD (°F)	5.7
h, NH_3 SIDE (Btu/h ·ft^2 · °F)	1428
h, H_2O SIDE (Btu/h · ft^2 · °F)	963

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Figure 2-8. Condenser Configuration and Characteristics

5. Ammonia Collections, Pumping, Distribution, Testing, and Control

The OTEC-1 ammonia system consisted of two main subsystems: the ammonia power loop and the ammonia support subsystem. The ammonia power loop consisted of the evaporator and condenser (described above); the evaporator drain tank (T-1); the phase separator (T-2) (described above); the filter (F-1); reflux pumps P-1 and P-2; the condensate return pump (P-106); and the necessary valves, instrumentation, and piping to complete the ammonia loop. The ammonia support subsystem consisted of the ammonia storage tanks (T-402 and T-403); the ammonia blowdown tank (T-405); the ammonia transfer pump (P-402); the blowdown tank pump (T-403); and the necessary valves, instrumentation, and piping to complete the loop.

In the ammonia power loop (Figure 2-9), the liquid ammonia was collected by the five gravity sumps integral with the base of the condenser. The five streams were fed to a common manifold, which in turn fed the main condensate return pump (P-106). A vent line was provided at the pump to bleed gaseous ammonia back to the condenser during startup operations. The liquid ammonia was pumped to the evaporator drain tank (T-1) along with the liquid ammonia stream from the phase separator (T-2). From the drain tank, the liquid ammonia passed through a filter (F-1) and then fed any single or combination of reflux pumps (P-1 and P-2), depending on the test conditions. The pump(s) discharged the liquid ammonia to the various spray nozzles in the evaporator as required by the test program. Any unevaporated ammonia drained (by gravity) back to the drain tank.

A 10-in. throttle valve was placed between the evaporator and the condenser to simulate the expected enthalpy change of a power-generating ammonia turbine. The throttle valve sensed and controlled the vapor pressure in the line upstream from the valve. The valve operations boundaries were full open (83.3 psig) and full closed (155.7 psia). In the first case, the flow was zero and the vapor pressure equalled the saturation pressure due to the warm water temperatures.

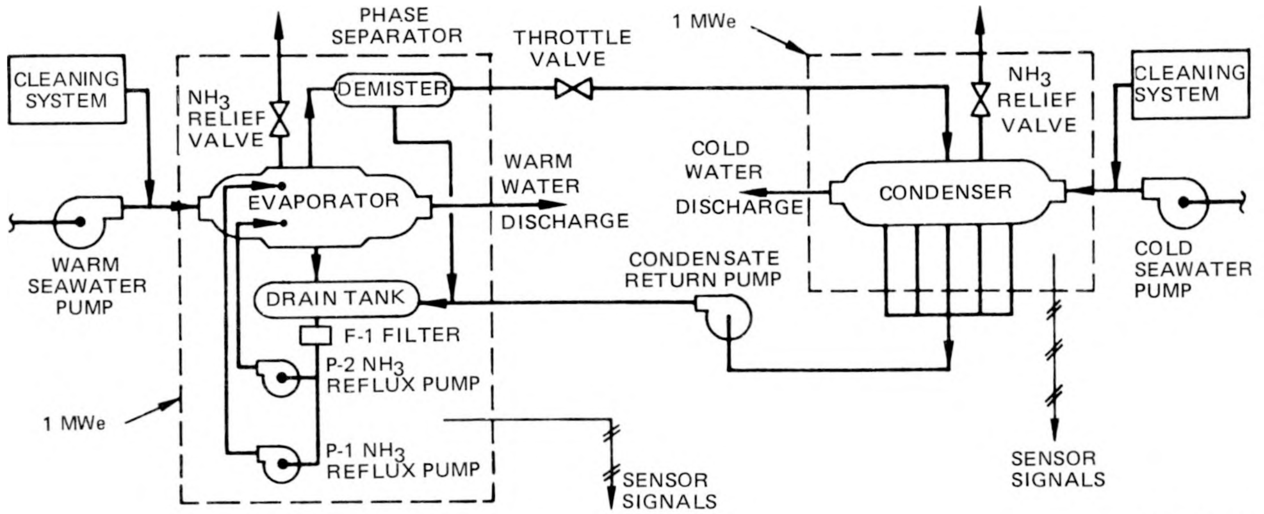

Figure 2-9. 1-MWe Power Loop OTEC-1 Interfaces

Vaporized ammonia left the evaporator and passed through the phase separator (T-2), where the quality of the ammonia was raised from 96% vapor to 99.5% vapor. The gaseous ammonia then passed through the throttle valve (V-111), which was designed to simulate the pressure drop of an OTEC system turbine. After leaving the throttle valve, the gaseous ammonia was conducted to the condenser.

The ammonia power loop had the necessary instrumentation and control system to operate the loop over the required test conditions.

The ammonia support subsystem (Figure 2-10) was designed to receive, store, and deliver ammonia to the ammonia power loop. A storage capacity of 8000 gal was based on one power loop load plus consumption losses due to periodic purgings and ammonia used for quality measurements. Additionally, the ammonia support subsystem was able to store the full ammonia power loop load at any time and specifically during high sea states or other emergencies requiring the emptying of the experimental test loop. The system could receive from or discharge to shore tanks, a support vessel alongside, or small canisters on board.

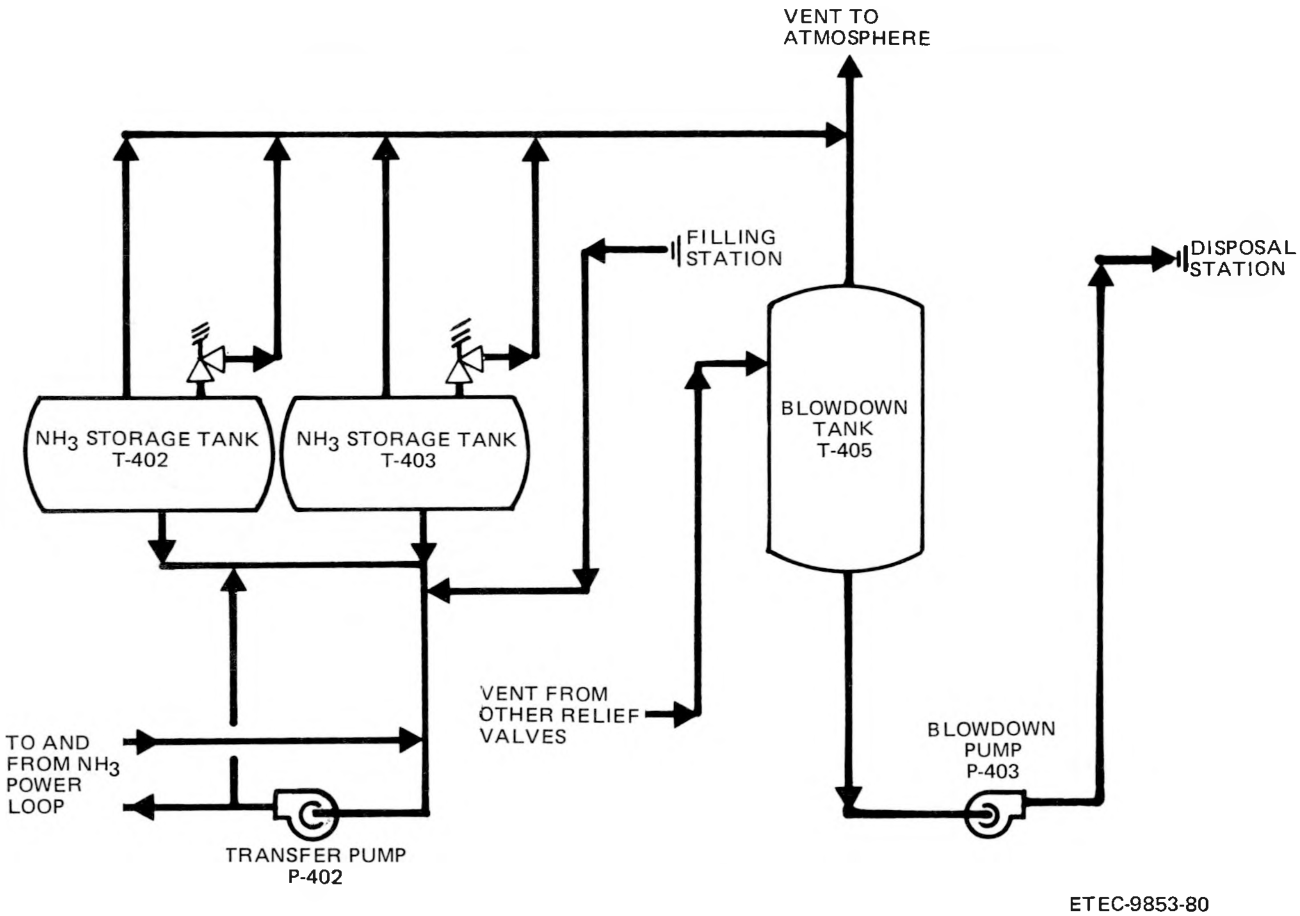

Figure 2-10. Schematic — Ammonia Support Subsystem

The 8000 gal of refrigeration-grade anhydrous ammonia was stored in two identical horizontal 4000-gal storage tanks, T-402 and T-403. Initially, the total inventory of ammonia was loaded into the two tanks. Ammonia was withdrawn from the ammonia storage tanks and transferred to the ammonia power (test) loop by the ammonia transfer pump, P-402.

The ammonia system was able to collect and dispose of all of the waste ammonia while complying with permits concerning discharge to air and ocean or retention for disposal ashore.

Nitrogen purge gas for the ammonia power loop was supplied from a bank of 162 GN_2 cylinders, each with a storage capacity of 300 ft^3 at 2650 psig. The gas was distributed from the GN_2 cylinders at 2650 psig through a pressure-reducing system to the test article distribution manifold in the test compartment at 100 psig. Purge controls were located in the test compartment, and a manifold pressure remote readout was located in the instrumentation and control van. Because of the combustion/explosion hazard during the filling process, the ammonia system was purged of oxygen before ammonia was admitted. And, when clearing the system to allow personnel entry, the ammonia was purged before air was admitted, again to avoid the combustion/explosion risk but also to preclude worker exposure to ammonia vapor.

6. Biofouling and Corrosion Modules

Although instrumentation to measure the overall performance of the heat exchanger had been installed, and selected tubes had been instrumented for flow and temperature measurements, it was thought necessary to obtain high-resolution information about the development of fouling film resistance to heat transfer. Eight standardized biofouling and control test modules (BCMs) were provided by ANL for installation aboard the OEC. The BCMs were connected to the piping for the OTEC-1 seawater system at various points to evaluate the effect of chlorinated versus nonchlorinated water on heat transfer and to provide specimens for evaluating the corrosion and biofouling that result from exposure to seawater from these points in the system. Four modules were connected with the cold water system and were located in the observation compartment. The other four were operated on warm water and were located forward of the test heat exchangers in the test compartment. The "tracking" BCMs were controlled to experience the same operating conditions (velocity) as a typical heat exchanger tube.

The BCMs were sophisticated analytical devices designed to accurately monitor changes in fouling film resistance in a water-filled tube heat exchanger and to eventually provide specimens of tube segments for physical examination of biological and corrosion films. The basic module consisted of a serpentine path of tubes with each path containing a bypass leg. The uppermost pass contained the heat transfer monitor (HTM) and ultrasonic flowmeter elements. The remaining three passes contained corrosion and/or biofouling sample tubes. The HTM measured changes in the overall heat transfer coefficient through the wall of a heat exchanger tube caused by the buildup of a biofouling film on the interior of the tube. Table 2-5 describes the module assignments, and Figure 2-11 depicts a BCM installation with component descriptions.

Data from the operation of the BCMs were recorded on the OTEC-1 data acquisition system, located in the I&C van. Computer programs were incorporated that allowed for examination of signal outputs, operational control of the units, and calculation of results.

The principles of operation, the testing sequences, and the results of the test are described in detail in Refs. 2, 11, and 14.

7. Chlorination System

The chlorination system was one of the two systems used to control biofouling in the OTEC-1 seawater circuits. The chlorine generator was an electrolytic cell that produced sodium hypochlorite ($NaOCl$) and hydrogen gas

TABLE 2-5

BCM ASSIGNMENTS

Module	Water Source	Operating Conditions	Fouling Countermeasure
Evaporator			
1	HX inlet, chlorinated	Tracks HX, nominal flow ±1%	As in HX
2	HX inlet, untreated raw	Continuous (13 gpm, 6 ft/s), no shutdown longer than 2 h	None
3	HX inlet, untreated raw	Continuous (13 gpm, 6 ft/s), no shutdown longer than 2 h	Chlorine plus Amertap or Amertap alone
4	HX inlet, untreated raw	Continuous (13 gpm, 6 ft/s), no shutdown longer than 2 h	Chlorine plus Amertap or chlorine alone
Condenser			
5	HX inlet, untreated raw	Continuous (13 gpm, 6 ft/s), no shutdown longer than 2 h	None
6	HX inlet, untreated raw	Continuous (13 gpm, 6 ft/s), no shutdown longer than 2 h	Chlorine plus Amertap or Amertap alone
7	HX inlet, untreated raw	Continuous (13 gpm, 6 ft/s), no shutdown longer than 2 h	Chlorine plus Amertap or chlorine alone
8	HX inlet, chlorinated	Tracks HX, nominal flow ±1%	As in HX

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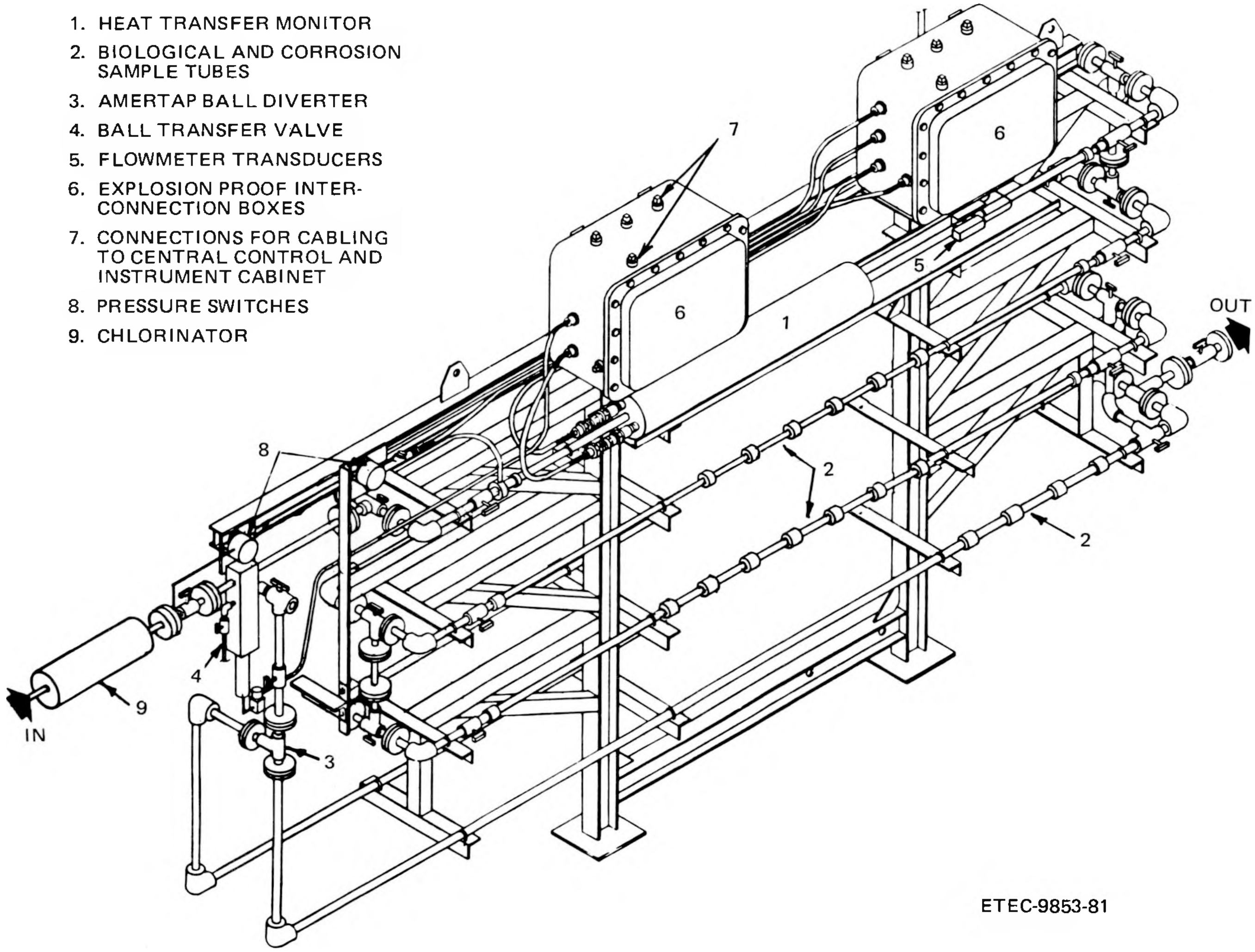


Figure 2-11. Biofouling and Corrosion Module — Typical

(H_2) from warm seawater. The maximum capacity of the generators was 80 lb/h of equivalent chlorine. A control system was used to monitor chlorine concentrations and chlorine flow, backed up by periodic amperometric titrations.

The chlorine generating system (Figure 2-12) was located on the main deck amidship at frames 65-67. The main skid-mounted components included a chlorine generator electrolytic cell assembly, power supply and rectifier, Delta Scientific chlorine analyzer, main conductor busbar, and equipment controls. The seawater supply pump, duplex strainer, and suction block valves were located at the lower level of the forward pump room. Warm seawater from the pump was fed to the two generators via plastic piping.

An automatic control system to adjust the chlorine concentration was provided in the design but failed to function due to the location of the sensors and some installation problems. The regimen of applying a relatively high dosage for a short period was not conducive to automatic control. After generator amperage versus concentration had been calibrated, manual control was used satisfactorily.

8. Amertap System

The Amertap system (Figure 2-13) was a biofouling control system that mechanically cleaned the OTEC-1 heat exchanger tubes. The tubes were cleaned by the abrasive contact of sponge rubber balls passing through the tubes. The balls were injected into the seawater upstream from the heat exchangers and removed downstream. The requirements were:

1) Continuous tube cleaning
2) Independent ball supply and collection for each heat exchanger
3) Collection screens in each water stream while in operation
4) Visual inspection and verification of ball flow
5) Monitoring from I&C van.

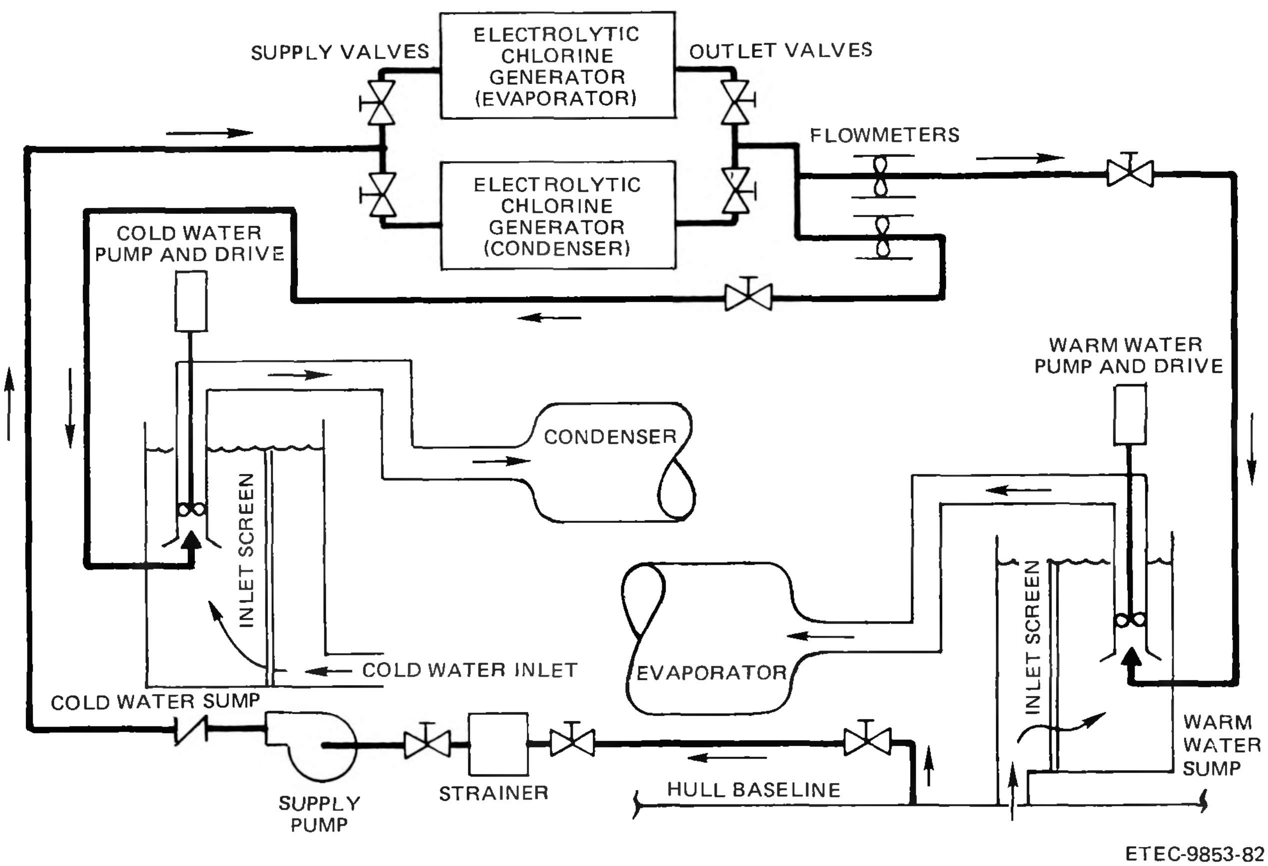


Figure 2-12. Chlorination System Flow Diagram

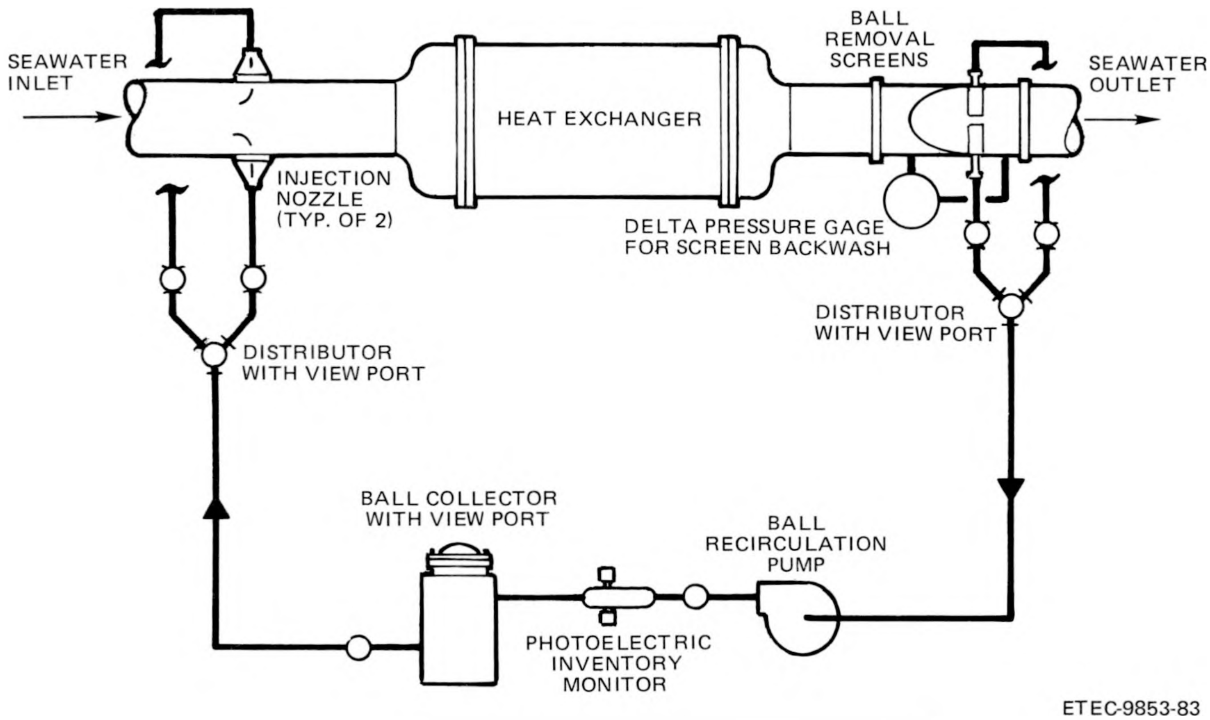


Figure 2-13. Amertap Subsystem (Typical of either Evaporator or Condenser)

The average tube-cleaning frequency was once every 15 min; the ability to adjust the cleaning frequency was set by the total ball inventory in the system. The system had the capability to replace used worn sponge rubber balls and also to substitute abrasive silicon carbide-coated sponge rubber cleaning balls; the latter were available for use with severe fouling or mineral incrustation of the heat exchanger tubes. (They were never used, however.)

The Amertap system (evaporator and condenser) consisted of a ball removal screen section, a pressure differential switch, ball circulation monitors, a ball collector unit, a ball recirculation pump, injection nozzles, and diverters and valves, as depicted in Figure 2-13.

The Amertap strainer section was installed downstream from the heat exchanger to collect the cleaning balls that had passed through the exchangers. The construction and design of the strainer section conformed to

CG-115 standards for mechanical hardware. The screen housing was fabricated of carbon steel (ASME SA283) and neoprene rubber liner up to the flanged ends to ensure material continuity. A manway was provided to allow entry. Screen backwash was a manual operation for both the upper (main collecting) screens and the lower (diversion and removal) screens.

A pressure differential switch was provided (within the pressure gage) to indicate when the accumulation of material on the strainer section was excessive and to initiate remote alarms to signal that operator action was required. Two pressure differential settings for alarm were provided: at 10 in. WG and at 20 in. WG, corresponding to normal and emergency backwash conditions, respectively.

The ball circulation monitors were provided to monitor continuously the inventory of cleaning balls for the Amertap system. The monitors had local reading and remote alarm contacts to signal when the inventory was insufficient to maintain normal cleaning operation. The device was a solid-state photoelectric unit with an in-line sensing section and a wall-mounted transmitter located near the sensing unit.

The ball collector unit was provided to allow the entire charge of cleaning balls to be removed manually from the circulating system and held in a basket. This permitted performing the inspection and replacement of the ball charge necessary for normal maintenance. Drain and vent, as well as isolation valves, were provided to allow access. All of the parts of this unit that are in continuous contact with seawater were made of stainless steel or equivalent noncorrosive materials. The top of the collector had a view port of sufficient size to allow a view of the internal operation.

The ball recirculation pump circulated the cleaning balls from the strainer section to the injector nozzles. The pump was specially designed to not damage the balls as they passed through, and the primary function of the pump was to return the balls from the low-pressure region to a higher pressure region.

The injection nozzles injected the tube-cleaning balls into the main seawater flow stream ahead of the heat exchangers and far enough upstream to ensure that the balls would be properly and uniformly distributed as they entered the water boxes of the heat exchanger. The nozzles were attached to the piping system with 8-in. standard ANSI flanges and were mounted horizontally opposed in the main seawater lines.

The diverters ensured that the distribution of balls to the injection nozzle was proper and that the flow of balls from the strainer screens was indexed. These units were equipped with view ports to allow visual verification of proper ball circulation and as a check of piping blockage or uneven ball distribution. All valves required for the operation of this subsystem were of ball-type construction, for manual operation, of through-bore design, and of WKM Corporation manufacture or approved equivalent. Valves were supplied by vendors as part of the Amertap unit.

9. Protection and Safety Systems

Since the OEC is unique in that large test articles, flowing liquid, and gaseous ammonia, together with their attendant support systems, are aboard, the possibility of ammonia spillage was taken into account in the design. Special alarm and shutdown features were provided consistent with requirements for shipboard ammonia systems. The vessel's existing general alarm system was reactivated and extended to include new habitation and work areas, in keeping with USCG regulations.

The major protection and safety systems used aboard the OEC related to ammonia and its effects and included protected ammonia storage above decks, isolation of the OTEC test compartment with fume-tight closures and a high-volume air purge system, ammonia spill (fume) detectors and sensors, an automatic spill washdown and flushing system, and breathing air systems for emergency use.

Two large ammonia storage tanks, each with a usable capacity of 4000 gal, were located on deck. This external storage system included a canvas cover (to minimize the effect of sunlight on the containers), ammonia toxic sensors, a seawater deluge system, automatic relief valves, and a catch basin to drain any liquid ammonia that might leak from the storage tanks or associated piping.

The OTEC-1 test compartment was constructed to allow entry through three air-lock-type hatches. Air pressure within the test compartment was kept lower than either within the entrance air locks or outside the test compartment. This was done so that any leakage of ammonia gas would not escape the test compartment except through the vent stacks (as planned). A two-stage air exchange/ventilation system was installed in the OTEC test compartment; it was automatically controlled via the ammonia leak detection system. At the normal or low flow rate, the test compartment air was exchanged every 8 min. When the toxic alarm system was activated, the high flow rate would automatically be activated, reducing the time for complete air exchange to 4 min.

A complete ammonia alarm system using sensors to detect the presence of ammonia was provided. Sixteen sensors were installed near potential leak areas to provide an early warning of escaping gas in the OTEC compartment and vent stacks. Alarm bells were also provided in work areas that might be polluted by escaping toxic gases, in the pilot house, and in the OTEC (I&C) van.

Lower explosion limit (LEL) meters were provided within the OTEC compartment to sense the air mixture for the approach to an explosive mixture rate. Readouts and alarms were provided at the pilot house and I&C van.

The OEC was equipped with a firemain system that extended the length of the vessel at the main deck level and had branches to all areas of the vessel and its various compartments, including a deck washdown system. To combat fire in the OTEC compartment, a freshwater deluge system was installed; this system drew water from the No. 3 port and starboard wing tanks. The OTEC compartment deluge was controlled by the deluge switch located in the I&C van.

To prevent cryogenic liquid ammonia from being spilled on vessel structural members or retained in working spaces within the OTEC test compartment, a series of deflectors, catch pans, and ducts was installed to route spillage to a collection, dilution, and disposition system located in the hold. Minor spills could be washed down by properly suited personnel using in-compartment hoses rather than by the total water deluge system.

Other safety devices used within the OTEC compartment included a breathing air system, a communication system, personnel emergency shower and face wash equipment, and safety clothing.

Emergency breathing air was available in several configurations: through a piped supply within the compartment through an umbilical line to a face mask, through a self-contained (30-min duration) backpack, and through a self-contained (5-min duration) hip pack model.

Personnel inside the OTEC test compartment communicated among themselves and with those outside the compartment using either portable walkie-talkies or the installed head set, multijack outlet system.

Standard safety clothing was readily available to personnel as protection against toxic gas and fire. This clothing included rubber gloves, boots and raincoats, face shields, helmets, and canister-type face masks. Face wash fountains and emergency showers were located at appropriate points both inside and outside the OTEC compartment.

10. Instrumentation and Control System

The OTEC-1 power plant was controlled and operated from the I&C van, which was located aft of the ship's bridge above the main deck and adjacent to the environmental van. The I&C van contained control and display equipment, data acquisition and processing equipment, and auxiliary equipment. Conditioned air was supplied for equipment and personnel. To protect the equipment, the I&C van mounting provided for air conditioning, shock, and vibration.

The van was constructed as a separate, self-contained subassembly. The installation was accomplished by mechanical tie-down, power connection at a junction panel, and instrumentation/control devices attached at junction terminal strips.

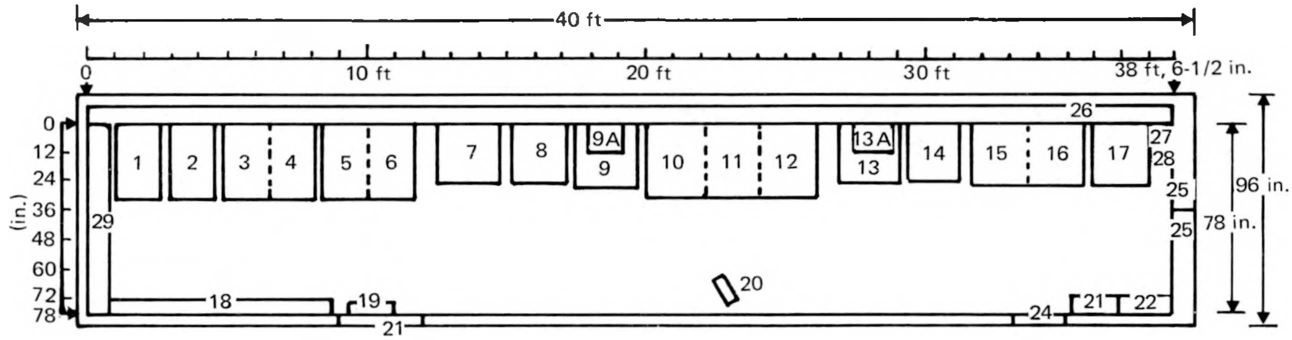
The control and display equipment consisted of the test control station and strip chart recorders. The data processing eqipment included two complete minicomputer systems, signal conditioning equipment, and peripheral devices. The auxiliary equipment consisted of the junction boxes and cabling, which provided the interface between the control, display, and data processing equipment in the van and the external equipment.

The arrangement of the equipment in the I&C van is shown in Figure 2-14. The equipment was installed along one wall of the van against the air conditioning plenum, which ducted cooling air into the individual equipment racks.

OTEC-1 included systems for measuring flow, temperature, pressure, strain, level, vibration, displacement, load, and position. Each system comprised a transducer, a transmitter and interconnecting cabling to the signal junction box, signal conditioning, and data display equipment. The measuring systems had been designed and installed to provide maximum environmental protection. The signal junction box provided terminals for all the interface signals plus 50% spares. It provided for shield terminations and included a ground bus to a single point ground in the vicinity of the junction box.

The cables, routed through cable trays, interconnected the displays, equipment racks, and junction boxes. In the trays, the cables were secured by clamps or other suitable means and were protected from abrasion. Strain relief was provided as required.

The signal conditioner received the data signal from the transducer and, under software control, adjusted signal scaling, multiplexed and converted the signal to digital format, and transmitted the digital data to the computer.



1 & 2 SIGNAL CONDITIONING
3 & 4 PDP 11/34 CENTRAL PROCESSING UNITS (CPUs)
5 & 6 MAGNETIC TAPE RECORDERS
7 DEC WRITER (CPU NO. 2)
8 CRT/KEYBOARD (CPU NO. 2)
9 LINE PRINTER
(7 – 9: SOFTWARE DEVELOPMENT STATION)
9A CCTV MONITOR NO. 1
10 THRU 12 CONTROL CONSOLE
11 CRT/KEYBOARD (CPU NO. 1)
(10 – 12, 11: TEST CONTROL STATION)
13 DEC WRITER (CPU NO. 1)
14 CRT/KEYBOARD (CPU NO. 1)
(13, 14: DATA ACQUISITION STATION)
13A CCTV MONITOR NO. 2

15 & 16 GRAPHIC RECORDERS
17 CCTV
18 SIGNAL J-BOX
19 INSTRUMENT POWER SUPPLY (ABOVE DOOR)
20 CCTV CAMERA
21 UTILITY POWER J-BOX
22 UNINTERRUPTABLE POWER SOURCE (UPS) J-BOX
23 36-in. DOOR – WEATHERTIGHT
24 26-in. DOOR – WATERTIGHT (EMERGENCY)
25 CARGO DOORS (NORMALLY SEALED)
26 AIR SUPPLY PLENUM AND CABLE TRAYS
27 COMMUNICATIONS/VIDEO CABLE ENTRY
28 GENERAL ALARM BELL
29 CABLE TRAYS

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Figure 2-14. I&C Center Arrangement

The scaling adjustment, analog-to-digital conversion, and transmission of data were under the full control of the computer software. The signal conditioner also received digital signals from the computer, converted them to continuous analog signals, and transmitted this analog information to the strip chart recorders. The signal conditioner could input and output digital as well as analog signals. By adding the appropriate cards, the signal conditioning capabilities could be expanded by 50%.

The strip chart recorders received analog data from the signal conditioners and recorded these data for a continuous hard-copy record. Sixteen channels were provided. Strip chart recorder paper was manually controlled at the strip chart racks. The measurements to display on the strip chart recorders were selected by the operator and input to the computer via the CRT terminal(s).

Several OTEC plant functions were remotely controlled by proportional controllers at the test control station. These included the drive speed of the water and ammonia pumps, the positioning of the control valve, and fluid level.

The test control station had a set of switches with associated display lights to control discrete plant operating parameters (e.g., on-off, open-close). In addition, local controls were used where feasible for some plant parameters.

Alarms received from the alarm instrumentation were hard wired to alarm lights at the test operator's station. The alarm lights remained on as long as the alarm conditions existed. The ship's systems were controlled from the bridge.

11. Environmental Monitoring

This task was the second major objective of the OTEC-1 project. The plan for environmental monitoring originally included six phases, corresponding to the six original phases of the OTEC-1 project:

Phase I — Preoperational (before arrival of the OEC)
Phase II — Pretest (OEC in place, before start of testing)
Phase III — Operational (OEC operating) 9-month period
Phase IV — Postoperational (OEC away) 3-month period
Phase V — Operational (OEC operating) 24-month period
Phase VI — Postoperational (repeat of Phase IV)

However, because budget problems led to the shortening of the OTEC-1 test program, only the first four phases were conducted. Two basic monitoring segments were accomplished: those related to shipboard studies and those performed in the operational area, away from the ship. On this task, the overall responsibility for executing, interpreting, and reporting belonged to LBL through its contractor EG&G Environmental Consultants.

The environmental laboratory consisted of a 20 by 10 by 9-ft van, furnished with analytical equipment by ETEC. EG&G's subcontractor, AECOS, eventually operated the van under a direct contract with LBL. In addition to the standard laboratory refrigerator, freezer, and associated storage and working spaces, the van was outfitted with specialized equipment to measure water purity and other environment-related parameters.

The studies conducted aboard OEC were related to the requirements of the National Pollutent Discharge Elimination System (NPDES), Permit HI0110271 (sampling of effluents) and taking of meteorological data. Samples were evaluated aboard the OEC using the environmental laboratory equipment or were sent to a shore-based contractor for evaluation. Effluents monitored included evaporator and condenser water, deck drainage, sanitary wastes, domestic wastes, ballast water, bilge water (OTEC compartment), engine cooling water, seawater from fire pumps, boiler blowdown, distillation plant brine, and refrigerator cooler water.

Meteorological data obtained aboard the OEC were recorded on the computer-based data acquisition system. It recorded data on wind speed, wind direction, and air temperature. Barometric pressure and wet and dry bulb air temperatures were measured on the bridge for inclusion in the environmental log.

Studies conducted in the area around the OEC included plume studies, current profile studies, wave rider studies, and oceanographic cruises. Plume studies were conducted by discharging dye tracers through the MWD. Due to the continued failure of the discharge pipe, initial results were consid- ered inconclusive. Later evidence revealed a rapid drop of the MWD to lower ocean depths, even though the discharge was close to the OEC hull. Cruises were performed on a regular schedule to pull instrument strings located in the vicinity of the OEC and obtain data. Fish samples were obtained in the test area to determine what effect the operation of the test platform had on fish populations.

C. CONSTRUCTION OF OTEC-1 (HIGHLIGHTS)

The SIC began work on reactivating and converting the USNS Chepachet to the OEC during November 1978 by moving the vessel from its moor at Suisun Bay to the Bethleham Steel Shipyard in San Francisco. The vessel remained there temporarily to enable the SIC and DOE consultants to perform a detailed inspection to confirm its suitability for conversion to the OTEC-1 test platform.

Early in February 1979, the vessel was moved to the Northwest Marine Ironworks in Portland, Oregon, where the reactivation/conversion work was performed. During the remainder of the year, the ship's equipment was reactivated, and the test article set and related power system equipment were installed. The vessel was placed in drydock in December 1979, where those tasks related to below-waterline hull penetrations were accomplished (e.g., installation of the gimbal assembly support, hull survey, tailshaft reactivation, installation of the thruster and warm water intake).

During January 1980, the I&C van and the BCM hardware were received at the shipyard and installed. In February 1980, the ship's mooring system was deployed at the test site in Hawaii.

Construction at the shipyard was effectively complete through dockside trials by early June 1980, and preparations were made for the transit to Puget Sound for sea trials. A list of dockside checkouts is contained in Table 2-6. A final construction report was not issued.

An attempt to load ammonia was terminated after excessive joint leakage was observed when only gaseous NH_3 was introduced. The leaks were located using Freon as a detector and sealed using a two-part epoxy as a sealant.

TABLE 2-6
DOCKSIDE TRIALS

Warm water system	Firemain system
Cold water system	Existing ventilation
Mixed discharge pumping system	Galley and pantry equipment
Ammonia power loop	Breathing air
Ammonia storage and transfer system	Laundry equipment
Instrument air system	Ship's thruster assembly
Amertap system	Alarm systems
Nitrogen purge system	Engine order telegraph
Chlorinator system	Anemometer
Water deluge system	Sound-powered phone system
OTEC compartment ventilation and I&C van air conditioning systems	Automatic-dial phone system
	Deepwater discharge
Tanks and compartments	CWP handling
Distilling plant	Pedestal crane
Miscellaneous auxiliary water systems	Instrumentation
CO_2 system	Painting and stencilling

D. SEA TRIALS

The purpose of the sea trials (Table 2-7), beyond meeting Coast Guard requirements for certification, was to operate, to the extent possible, all of the OTEC-1 test equipment to verify the adequacy of construction. The notable failures of this test were the deepwater discharge hose system, the main water flow and level instrumentation, and the chlorination water supply system. Many items could not be tested for lack of construction completion (e.g., BCMs, instrumented tube loops, environmental laboratory, I&C van operational software).

After the dockside trials at the Portland shipyard and before sea trials in Puget Sound, Mount St. Helens erupted, causing the waterway between Portland and Longview, Washington, to fill with silt and debris, temporarily preventing the vessel from moving to Puget Sound for sea trials. After the

TABLE 2-7
SEA TRIALS

Navigation equipment calibration
Ballasting procedure
Vibration and noise measurements
Ahead steering trial
Astern steering trial
Quick reversal — ahead to astern
Quick reversal — astern to ahead
Maneuvering trial
Anchor-handling test
Endurance trials
Distilling plant
Warm water system operational trial
Cold water system operational trial
Amertap and chlorinator system trials
MWD system operational trial

channel had been dredged, the vessel proceeded to Puget Sound for final check-out. After these trials, the vessel was to have returned to Portland for the critical repairs necessary before the transit to Hawaii. But because of the risk of further eruptions and of further delays, the vessel was instead returned to Longview for those repairs.

During transit to Puget Sound, the gimbal/diaphragm assembly was in place in the transit (up) position. During the short period at Longview, a repair crew under the direction of TRW repaired the test evaporator shrouds and frames, which had been damaged during hydro testing at the manufacturer's plant.

The first charge of liquid ammonia was loaded aboard the OEC at Longview, thus verifying the adequacy of the leak detection and repair procedure and enabling vent/purge system and ammonia pumps to be operated and checked. Because the content of water (scavenged from the system) in the ammonia was high, the entire inventory was disposed of and replaced with a fresh, clean, dry charge.

Although much work remained incomplete and unchecked, the OEC was dispatched to Hawaii to meet the dedication ceremony schedule. A sea trials report was not issued.

E. TRANSIT TO HAWAII

With the sea trials complete, the test evaporator repaired, and the ammonia reloaded, the Chepachet now renamed OEC (Ocean Energy Converter) left Longview and headed down the Columbia River for Astoria, Washington. Difficulties encountered with the ship's radar caused a 1-day stopover in Astoria for repairs. Finally, on 23 June 1980, the OEC departed for Hawaii.

During this passage, the ETEC operations crew, on board for the first time, continued work on the fabrication/assembly of the instrumented loops and

BCMs. The instrumentation loops were checked and repaired as necessary, and the turbine flowmeters in the NH_3 system were checked and calibrated. Modifications to the computer software, which resulted from physical changes to the BCMs, continued throughout the transit period. In addition, the combined crew received extensive training in the use of the breathing air systems and the safety systems. Also, shipboard fire and boat drills under the direction of the ship's master were held regularly.

The OEC arrived at Honolulu, Hawaii, on 1 July 1980. Formal dedication ceremonies were held on 5 July, and on 8 July, following an open-house and ship refueling, the OEC departed for Kawaihae Harbor on the Island of Hawaii.

In the period from then through November 1980, the following activities were undertaken to prepare all systems for integrated operation:

1) High currents were measured at the test site. The results led to the decision to delay the project to add instrumentation to the CWP and to install a heavier CWP bottom weight. This made it necessary to replace the CWP-handling deck winch with one having a higher capacity (150 tons versus 75 tons).
2) The MWD pipe was repaired and checked out. Repeated failures were experienced.
3) The construction of the instrumented loops, BCMs, and related software was continued.
4) The second thruster was installed and checked out.
5) The temperature sensors were calibrated using the copper block method.
6) The flowmeters were calibrated.
7) TRW repaired the evaporator tubes.
8) A second beacon was added to the bottom of the CWP.
9) Ammonia resupply components were installed.

The key events following the departure from Honolulu on 8 July 1980 were as follows:

1) Arrived Kawaihae Harbor on 9 July; dedication ceremonies held.
2) EPA permit became effective 18 July. OEC first coupled to moor on 28 July.
3) OEC returned to anchorage outside of Kawaihae Harbor on 4 August as a result of CWP instrumentation installation decision.
4) OEC returned to Kawaihae Harbor dock on 8 August.
5) OEC anchored outside Kawaihae Harbor (a sugar barge was loading) on 23 August.
6) OEC returned to Kawaihae Harbor on 24 August.
7) OEC anchored outside Kawaihae Harbor on 31 August.
8) OEC returned to Kawaihae Harbor dock on 7 September.
9) OEC moved to anchorage outside Kawaihae Harbor on 2 October in preparation for transit to Honolulu for major work.
10) OEC departed anchorage for Honolulu on 7 October.
11) OEC arrived in Honolulu on 8 October for installation of larger deck winch, activation of second thruster, and installation of ammonia resupply components.
12) OEC departed Honolulu on 24 October and arrived at Kawaihae Harbor on the same day. OEC docked in the harbor on the morning of 25 October; left dock and anchored outside harbor due to traffic; returned to dock on 26 October.
13) OEC returned to anchorage outside Kawaihae Harbor on 29 October, in preparation for transit to the moor site.

F. DEPLOYMENT

Placement of the mass anchor and the mooring system had been scheduled for early February 1980. But in unwinding the steel cables that were to be used for the mooring system, several kinks were found; this required substituting new cable on the spool. The procedure prepared by GMDI's subcontractor P.A.R. for placing the moor was reviewed and modified before it was accepted. The mooring system was placed on 20 February 1980, following several tropical storms that had threatened to cause further schedule slippage.

The EPA permit required that the OEC not be attached to the moor before 18 July 1980, the effective date of the permit. Problems with excessive currents then delayed the attachment until 27 July 1980. In response to the decision described below to add instrumentation to the CWP, the OEC left the moor on 4 August 1980 for Kawaihae Harbor and for eventual transit to Honolulu.

The excessively high currrents observed during the initial hookup to the moor were unexpected and led DOE to the decision to delay the project to add instrumentation to the CWP as a precaution against overstressing the CWP assembly and to take other actions to counter the effects of the stronger currents. Reevaluation of the CWP design led to the conclusion that the maximum deflection of the pipe in high surface currents could be reduced by adding weight to the existing weight suspended on the cable. Analysis of the hardware indicted that a significant gain could be made by adding 35,000 lb to the 68,000 lb weight and that only the deck winch would require upgrading. To enhance detection of significant strains being encountered, strain instrumentation was identified and made a prelaunch constraint. These items had far-reaching effects: the OEC was returned to Honolulu for the deck winch changeout; the forward thruster was determined to be needed (given the higher current possible) and completion of the installation was ordered; additional unfinished ammonia resupply equipment was installed; and an all-out effort was made to obtain and install hardware for the CWP strain measurements. On 30 October 1980, the OEC returned to the moor site and was attached to the moor early the next day. Immediately following acknowledgement of the vessel's attachment to the moor, the CWP assembly was dispatched to the moor area.

Launching the CWP from the beach at Kawaihae was a critical operation. The pipe assembly, with the floatation collar nearest the water's edge, was pulled by a large ocean-going tug down the track, while two cranes (a 50 ton and a 140 ton) lifted sections off the track and into the water. A bulldozer at the trailing end provided runaway resistance. As the pipe neared the water, the railroad trucks were pulled out from under the pipe in what proved to be a largely uneventful, well-planned, and well-executed operation. Before the CWP was launched into the water, and again after launching, the special instrumentation was checked and calibrated.

The towing of the CWP to the site was also substantially uneventful, with one exception. A sudden shift in the direction of surface currents caused small waves to break over the submerged pipe. This action damaged some of the special instrumentation conduit and wiring.

The CWP assembly arrived at the OEC on 1 November and was upended. By 4 November 1980, the CWP had been keelhauled and attached to the OEC gimbal assembly. There was a problem in releasing a handling cable attached to the bottom of the CWP, but it was resolved when, during the emplacement of an explosive unit lowered to sever the cable, the explosive unit tripped the cable release mechanism. Damage to the LVDT cable assemblies was visually identified. Later, six refurbished LVDTs were installed at the 50-ft depth; these supplied some data from the segment of the CWP considered to be the most stressed.

G. ACCEPTANCE TESTS

After the CWP had been attached to the OEC at the moor and the MWD pipe had been deployed, DOE accepance testing was initiated. For some of the systems related directly to the OTEC power plant, several problems were encountered that never were completely resolved during the remainder of the test program. These included the following:

1) Continual failure of the MWD pipe
2) Repeated failures of components in the BCMs
3) Contamination of the NH_3 system components, believed caused by corrosive products produced when water was used in the test articles during construction
4) Failure of the water system sonic flowmeters caused by the void fractions existing in the fluid streams
5) Inability to maintain the instrumented tube systems on-line due to leaks, kinked hoses, plugging of hose/tube elements by Amertap balls, and low priority given for repairs.

Table 2-8 lists the test items identified for DOE acceptance tests, including the moor, the vessel, and the operating systems.

At this point in DOE acceptance testing, Tracor Marine was selected (through competitive bidding) as FOC. Under contract to ETEC, the Tracor team came aboard the OEC on 14 December 1980 and assumed control of the vessel from GMDI, the outgoing SIC. DOE officially accepted the OEC from GMDI via the document reproduced in Figure 2-15.

Although contractually specified as deliverables from the SIC, neither a final sea trials report nor an acceptance test report was issued.

The OEC was accepted by DOE, acknowledging that certain discrepancies still existed for which no specific date for correction was known and that these would be corrected by the oncoming Tracor crew and/or the ETEC test crew. These deficiencies are listed in Figure 2-16.

H. TEST PROGRAM

The criteria for the OTEC-1 test program for the first deployment were first described in an ETEC test request[6] released on 17 November 1978. From this document, the test experimenters (ANL), supported by ETEC, prepared the

TABLE 2-8

ACCEPTANCE TEST AGENDA

Task	Requirements and Comments
Recheck ship systems	Check alignments, settings, operations
Attach ship to moor	Monitor tension, monitor watch circle maintenance
Attach CWP to ship	Monitor loads, positions, instrumentation: confirm mateup
Detach CWP: reattach	Verify procedure (controlled or free fall)
Deploy deepwater discharge	Confirm procedure
Deploy screens	Mechanical fitup
Prepare Amertap systems	Charge with balls (main units and BCMs), control positions
Confirm breathing air system	Manifold charged, compressor operation, portable equipment checked
Check Chloropac	Equipment aligned
Check GN_2	System full
Energize control/instrument air	Manifolds charged, valves aligned, system walked
Activate ammonia detection/spill	Deluge system aligned, toxic sensors calibrated, explosion sensors calibrated, ventilation checked (low/high)
Check I&C van	Equipment operational, system initialized
Check instrumentation system	Confirm energized, initial values, in-calibration
Check test-related articles	Heater/chiller filled and ready, valve initial positions, equipment ready
Nitrogen purge ammonia system	2% oxygen in exhaust
Introduce ammonia to purge	No significant leakage, use vapor pressure only
Perform leak check (water)	Cold, warm, mixed: check MWD hose, check instrumentation
Initiate water flow	No water leakage allowed, check CWP instruments
Confirm design performance	Flow range, stability, controller actions
Start up Amertap systems	Confirm circulation, instruments, bypass sytem
Start up chlorination	Confirm operation, instruments, auto control
Pull samples	Perform analysis
Start up heater/chiller	Confirm operation, instruments, and controls
Start up instrumented loops and perform calibration	Confirm operation and instruments
Start up biofouling modules	Confirm operation, instruments, control response
Fill ammonia system	Confirm procedure, review instruments
Initiate circulation of ammonia and confirm design basis	Confirm procedure, review instruments' range, controllability, stability

TRANSFER AND

ACCEPTANCE OF SS OCEAN ENERGY CONVERTER

The undersigned, acting this date as the authorized representative of the U.S. Department of Energy, and certifies that he has been duly authorized to sign this acceptance, does hereby accept possession and assume responsibility for the SS OCEAN ENERGY CONVERTER, in its present condition located at or about 19°56'24.93"N latitude, 156°09'47.84" W longitude, from Global Marine Development Inc., of Irvine, California. On and after December 15, 1980: (1) GMDI is hereby relieved of any and all responsibility for the SS OCEAN ENERGY CONVERTER, its equipment, safety, operation, maintenance and all personnel thereon or in its proximity, and (2) as between GMDI and the Government, the Government accepts for its own account all further responsibility, risk and liability for the said vessel, its personnel safety and operation. The terms and conditions of Contract DE-AC03-78ET20539 shall apply with regard to operation and responsibility for the vessel prior to December 15, 1980.

By this acceptance, the undersigned further certifies that Global Marine Development Inc., has delivered the vessel as provided in its contract number DE-AC03-78ET20539 and the changes thereto in effect on the date of this document, except that said contract shall administratively remain in effect until such time as undefinitized completed work is negotiated and the contract modified to equitably reflect completion, at which time Global Marine Development Inc., will be notified of the closeout of said contract.

Signed for the U.S. Department of Energy, 15 December 1980,

by [signature]

James K. Hartman
Project Manager
U.S. Department of Energy

Condition as stated in Condition Report dated Dec 14, 1980.

Attested to: [signature] (Signature) Dec. 14, 1980 (Date)

JAMES DRANOS
(Name)
111 6TH ST.,

ETEC-9853-85

Figure 2-15. Transfer and Acceptance of S.S. Ocean Energy Converter

S.S. OCEAN ENERGY CONVERTER (OTEC-1)

Condition Report
as of December 14, 1980

1. Sonic Flowmeters not working properly in large water pipes (CW, WW, MW).
2. Large quantities of air are observed in WW Pump discharge.
3. The present Deep Water Discharge hose has not been tested above 50% flow.
4. The After NH_3 Resupply System Station not installed.
5. NH_3 Transfer Pumps P-402 has been removed from circuit for repair and is currently on ship and P-403 has been sent to shop for repair. Roth Pump Company to repair under warranty.
6. NH_3 Condensate Feed Pump P-106 has been assembled with new seals but has not been operated.
7. NH_3 Transfer piping not flushed of debris. P-106 inlet has been cleaned.
8. All odors not eliminated from Sewage Treatment Plant.
9. Amertap System Strainer has large differential pressure reading. Vendor states acceptable.
10. Amertap System - condenser balls wear greater than expected.
11. Level indicator in cold water sump not working.
12. One viewing window in one airlock cracked in one laminate.
13. Chloropac Unit discharge is limited to 160 gpm which is acceptable.
14. Large Water Pumps (CW, WW, MW) operating at less than 100% design flowrate.
15. Three day detailed inventory and material custody transfer was accomplished per DOE direction.

All ship systems and all other OTEC plant systems apparently working well.

GMDI
Capt. James Drahos
SS Ocean Energy Converter

DOE
James K. Hartman
OTEC-1 Project Manager

ETEC-9853-86

Figure 2-16. S.S. Ocean Energy Converter (OTEC-1) Condition Report

Test Plan for the First Deployment,[2] dated March 1980. An ambitious 8-month schedule was established for testing the power system and acquiring environmental data. This program is shown in Figure 2-17 and summarized below:

1) Planned tests related to the power systems including the following:

   <u>4-MWe Configuration</u> (shrouds in place)
      Vapor velocity baseline
      Reflux Ratio: top only, top and mid-plane, mid-plane only

   <u>1-MWe Configuration</u> (shrouds removed)
      Baseline
      Reflux Ratio: top only, top and mid-plane, mid-plane only

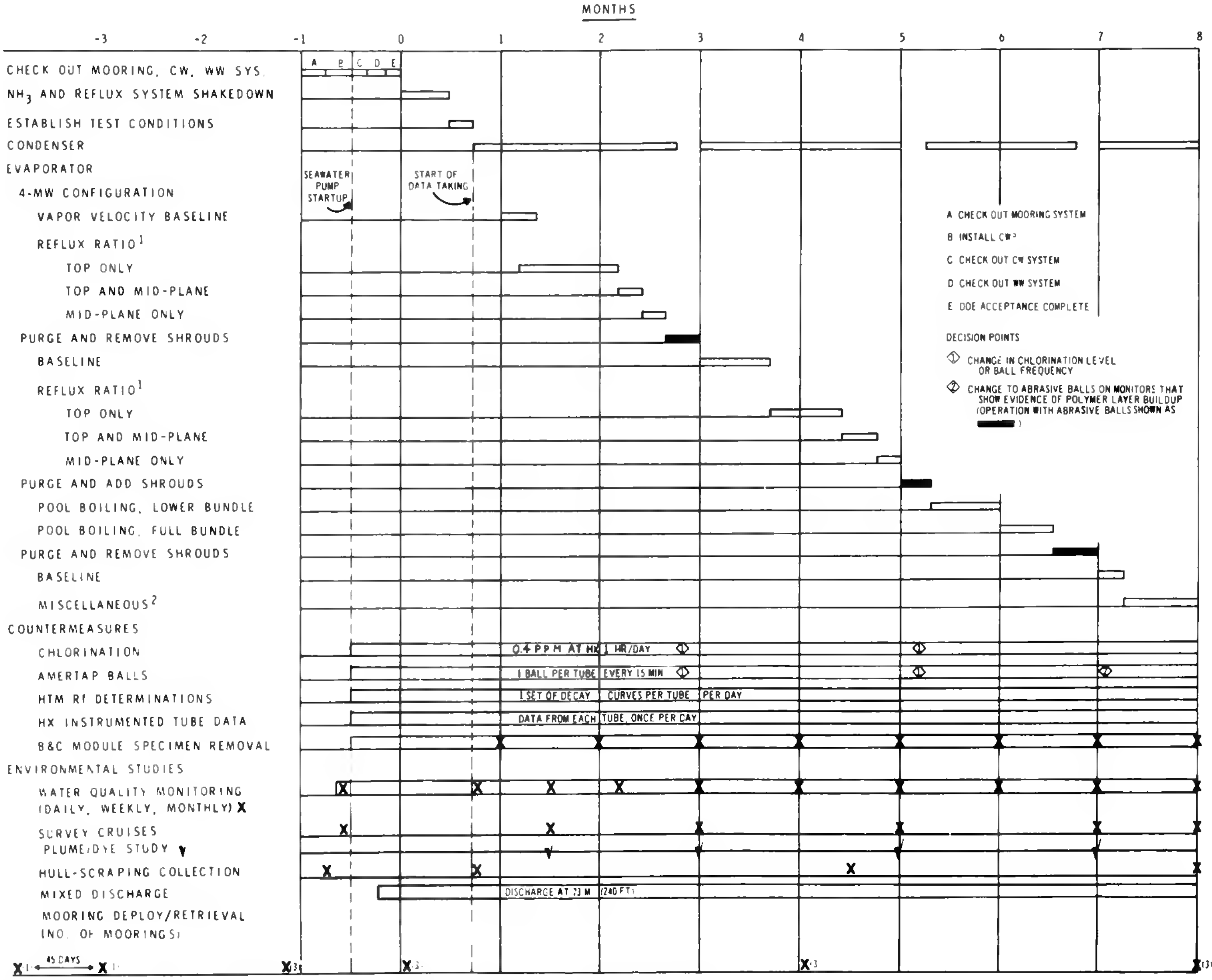
   <u>Pool Boiling, Lower Bundle</u> (shrouds in place)
   <u>Pool Boiling, Full Bundle</u> (shrouds removed)
   <u>1-MWe Configuration</u> (shrouds removed)
      Baseline

2) Countermeasures to be investigated included:

   Chlorination
   Amertap balls
   HTM R_f determinations
   Heat exchanger instrumented tube data
   BCM specimen removal

3) Environmental studies planned included:

   Water quality monitoring
   Survey cruises – plume/dye studies
   Hull scraping collection
   Mixed discharge
   Number of OEC moorings.



1 BASELINE TEST WILL BE REPEATED AT THE END OF EACH TEST SEQUENCE TO ASSESS ANY CHANGES

2 DEACT./REACT., RANGEABILITY, H_2O IN NH_3, ETC.

ETEC-9853-87

Figure 2-17. OTEC-1 Test Schedule

For the actual test program, initial testing of the OTEC power system in the 4-MWe configuration (shrouds in place) revealed that the vapor velocity had little or no effect on the performance of the heat exchangers. This fact combined with budget limitations resulted in all of the heat exchanger tests being performed in the 4-MWe configuration (shrouds in place) and considerably shortened the schedule.

To determine the effectiveness of the biofouling countermeasures being used, eight BCMs were installed. Four were associated with the operation of the warm water system, four with the operation of the cold water system. Two of these modules were used to track the heat exchangers. The intended test matrix for these modules is shown in Table 2-9. However, because of the shortened test schedule, only the parameters under the column "First 4 Months" were actually used.

The test portion of the OTEC-1 program was directed by DOE-HQ, whereas the design, construction, deployment, and checkouts had been directed by DOE-SAN. Overall planning for the test program was performed by the Test Planning Evaluation Working Group (TPEWG), made up of technical members of the OTEC community. Day-to-day test direction was by the Joint Test Group (JTG), consisting of personnel from the various experimenters (ANL, LBL, NOAA) and ETEC. An experimenter's representative from ANL was assigned to the test program. This interrelationship is shown in Figure 2-18.

The organization of the operating crew aboard the OEC is shown in Figure 2-19; the operating crew consisted of the Tracor crew (shipboard systems, CWP, moor), the ETEC test director crew, the experimenter's representative(s), and the LBL subcontractor for the onboard environmental monitoring task (AECOS). This organization applied only to conducting the experiment; the vessel master remained responsible for personnel and platform safety.

Data produced by the experiments aboard the OEC were duplicated onboard, with the duplicated tapes delivered to the ETEC Santa Susana facility data

TABLE 2-9

TEST MATRIX FOR BIOFOULING AND CORROSION MODULES

Unit	Test Periods and Levels			
	First 4 Months	Second 4 Months[a]		
		Level 1 (++)	Level 2 (+)	Level 3 (-)
Evaporator[b]	Chlorination: 0.4 ppm for for 1 h/day Amertap: 1 ball/15 min	Chlorination: 0.1 ppm continuously Amertap: 1 ball/15 min	Chlorination: 1.0 ppm for 24 min/day Amertap: 1 ball/15 min	Chlorination: 0.4 ppm for 1 h/day Amertap: 1 ball/h
BCMs[c]				
#1 (8)	Same as in evaporator (condenser)	Same as in evaporator (condenser)	Same as in evaporator (condenser)	Same as in evaporator (condenser)
#2 (5)	Chlorination: none Amertap: none (If R_f reaches 0.0005 ft^2·h·°F/Btu, clean by manual brushing.)	Chlorination: none Amertap: none (If R_f reaches 0.0005 ft^2·h·°F/Btu, clean by manual brushing.)	Chlorination: none Amertap: none (If R_f reaches 0.0005 ft^2·h·°F/Btu, clean by manual brushing.)	Chlorination: none Amertap: none (If R_f reaches 0.0005 ft^2·h·°F/Btu, clean by manual brushing.)
#3 (6)	Chlorination: 1.0 ppm for 24 min/day Amertap: 1 ball/15 min	Continue as in first 4 months, without initial manual cleaning Continue as in first 4 months, without initial manual cleaning	Continue as in first 4 months, without initial manual cleaning Continue as in first 4 months, without initial manual cleaning	Chlorination: none Amertap: 1 ball/15 min
#4 (7)	Chlorination: 0.1 ppm continuously Amertap: 1 ball/15 min	Continue as in first 4 months, without initial manual cleaning Continue as in first 4 months, without initial manual cleaning	Continue as in first 4 months, without initial manual cleaning Continue as in first 4 months, without initial manual cleaning	Chlorination: 0.4 ppm for 1 h/day Amertap: none

[a] Never implemented

[b] All specifications under "Test Periods and Levels" are the same for the condenser.

[c] Module numbers in parentheses are the corresponding ones for the condenser.

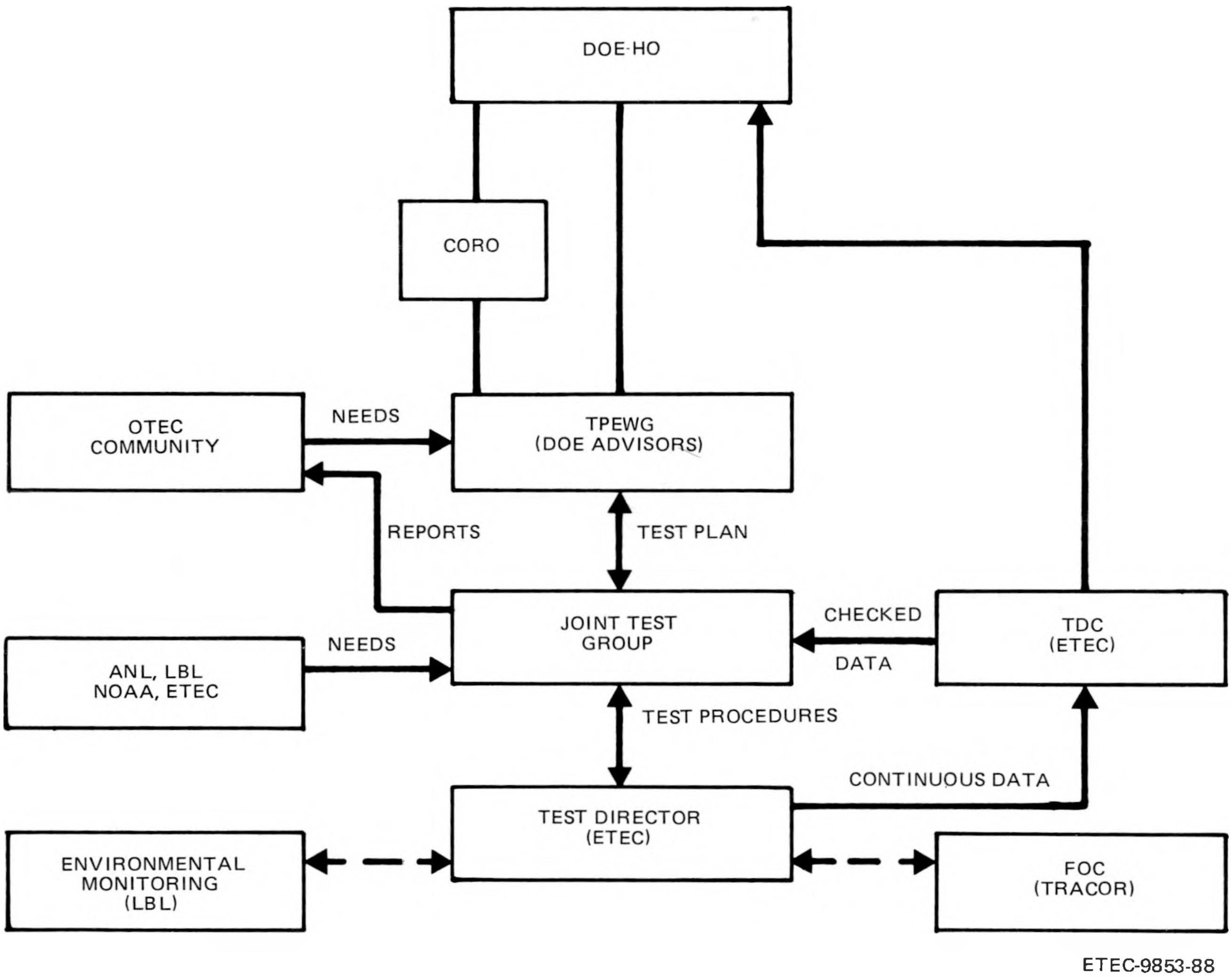


Figure 2-18. Experimental Program Director

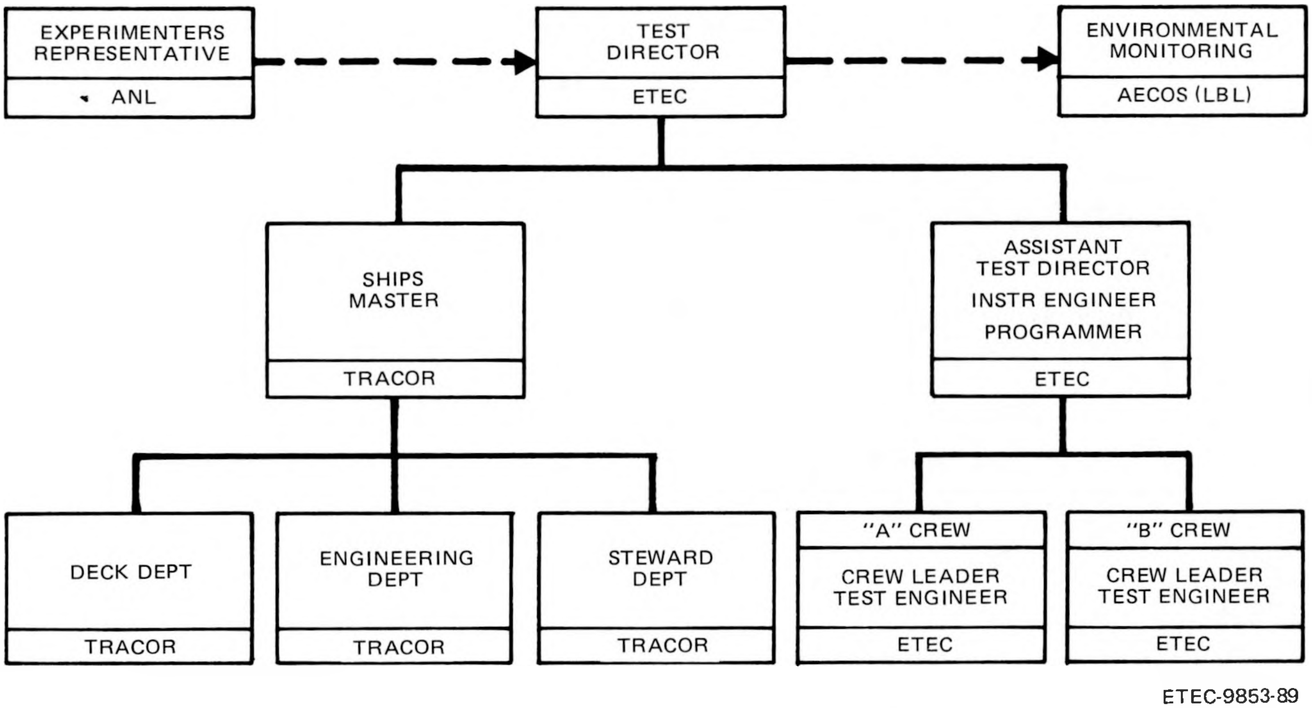


Figure 2-19. Ocean Energy Converter Operating Crew

center, and the original tapes put into permanent storage at the ETEC headquarters office. The ETEC data center scaled the tapes (converted the digital information into engineering units) and provided the JTG with scaled tapes and, in some cases, plots. Concurrent with the distribution of data tapes as described above, specific data were reduced aboard the vessel as required to identify the results needed to plan the tests to follow. The presence of several experimenter's representatives aboard the vessel during the heat exchanger test period enabled the rapid evaluation of test results and the subsequent planning for the next test series. In general, with the exception of the flooded bundle tests, which were eliminated, the test data acquired satisfied the needs of the experimenters. Figure 2-20 shows the OTEC-1 data flow chart.

I. ENVIRONMENTAL MONITORING PROGRAM

Environmental experiments involved monitoring effluents from the OTEC-1 platform (principally the power system discharge) and monitoring and sampling the ocean near the platform. The environmental tests included measuring water streams on board the test platform (as shown in Table 2-10) and measuring the ambient ocean from other vessels and moored instruments. Measurements began before the platform (OEC) was deployed and continued during the test article and power system studies and during periods when the test platform was absent from the site.

LBL, the DOE lead laboratory for this major objective, employed onsite subcontractor support, furnished the necessary reports and data for EPA permit compliance, and reported the data and conclusions from these tasks (as detailed in Refs. 5, 19, 27, and 28).

J. SHORE SUPPORT

An operations support activity was established early in the OTEC-1 program to facilitate the transition from the construction of the OTEC-1 test

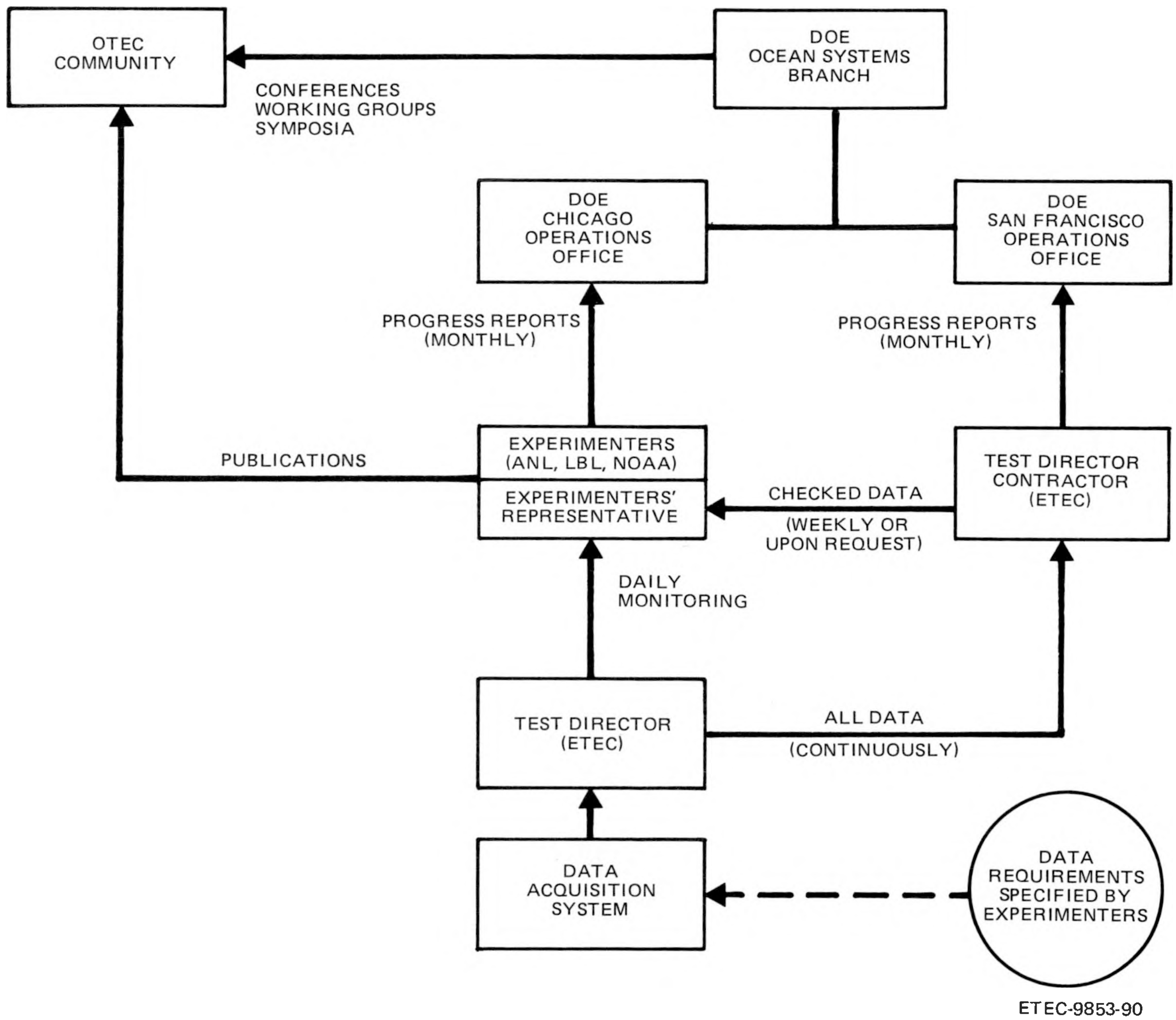


Figure 2-20. OTEC-1 Data Flow Diagram

TABLE 2-10

SAMPLING AND ROUTINE WATER CHARACTERIZATION ON OTEC-1

Parameter	Environmental Studies			BCM Studies	
	Evaporator Raw Water Intake[a]	Condenser Raw Water Intake[b]	Mixed Discharge Effluent[c]	Evaporator/ Condenser Hx Inflow[d]	Evaporator/ Condenser Hx Discharge
Chlorine demand	Daily (weekly)	Daily (weekly)	-	-	-
Total residual oxidant	-	-	Daily[e]	Daily	Daily
Ammonia	Daily	Daily	Daily[e]	-	Daily
Suspended solids	Weekly	Weekly	Weekly[e]	-	-
Nitrate[f]	Weekly	Weekly	Weekly[e]	-	-
Total nitrogen	Weekly	Weekly	Weekly	-	-
Phosphate[f]	Weekly	Weekly	Weekly[e]	-	-
Total phosphorus	Weekly	Weekly	Weekly	-	-
Silicates	Weekly	Weekly	Weekly[e]	-	-
pH	Weekly	Weekly	Weekly	-	-
Salinity	Weekly	Weekly	Weekly	-	-
Alkalinity	Weekly	Weekly	Weekly	-	-
Titanium	-	-	Monthly[e]	-	-
Iron	-	-	Monthly[e]	-	-
Aluminum	-	-	Monthly[e]	-	-
Copper	Monthly	Monthly	Monthly	-	-
Total organic carbon	Monthly	Monthly	Monthly	-	-
EMC biological chemical analysis[g]	Monthly	Monthly	Monthly	-	-

[a]Tap on ANL module 2
[b]Tap on ANL module 6
[c]Tap d.s. of port tank 5
[d]Taps on ANL modules 1 and 8

[e]Required by EPA permit, performed by AECOS, Inc.
[f]EDP permit says nitrate and phosphate

[g]Alternative to listed monthly parameters is the same analyses as done on cruise.

platform to its operational phase. The three major elements of the support organization consisted of the Kawaihae Harbor shore facility (operated by FOC) and the Kailua Kona office and the ETEC west coast facility (both manned by ETEC personnel).

An integrated support operation was a necessity because the OEC needed constant resupply of materials and personnel, quick turnaround was needed on critical procurements, and continuous communication was required with program managers at DOE headquarters and their consultants.

The materials, equipment, and repair services needed at the test site often were unavailable in the Hawaiian Islands. Overcoming this obstacle necessitated close communications between the Kailua Kona office and the support organization on the west coast (ETEC). A routine was established by the FOC (Tracor Marine) for resupplying the OEC with materials and manpower. A supply and personnel vessel was provided by the FOC on the basis of three round trips per week between the Kawaihae Harbor shore facility and the OEC. Unexpected needs (e.g., tours by official visitors, transporting of critical hardware for shore-side repairs) dictated an increase in frequency.

It became apparent that supplies such as ship's fuel, nitrogen gas, and liquid ammonia could not be ordered and delivered in a routine manner. The remoteness of the test site, the limited availability of supplies in quantity, and the infrequency of surface deliveries made it necessary to incorporate into procurement schedules sufficient time to accommodate these factors. As an example, liquid ammonia is available in limited quantities in Honolulu, but is shipped by surface transport from the mainland.

1. Kawaihae Harbor Shore Facility

Before the OEC departed from Portland, the systems integration contractor (GMDI) had established and manned the shore facility at Kawaihae Harbor, Hawaii, as the site for assembling and launching the CWP. The responsibilities of the FOC required a base of operations, which the existing Kawaihae facility satisfied. The tasks and duties of the FOC included the provision for:

1) Transport of personnel and supplies from ship to shore
2) Material control and warehousing
3) Ship-to-shore communications
4) Security and visitor control
5) Control and storage of spares
6) Documentation files
7) Inspection services
8) Accounting services
9) Medical assistance
10) Purchasing services.

The FOC contracted for services, supplies, and equipment leases and manned the shore facility to provide the above services. A VHF communications link was established at the shore facility, allowing communications between the shore, the OEC on the site, and the supply vessel in transit. Special procurements and services beyond the scope of the FOC were implemented by ETEC via the Kailua Kona office, or directly through the west coast ETEC facility.

2. Kailua Kona Office

This office in Kailua Kona, Hawaii, provided a direct link between the OEC at sea, ETEC personnel in transit, and the west coast ETEC facility. UHF radios were installed at the Kailua Kona office, in two automobiles of the ETEC test organization, and aboard the OEC. This provided an integrated communication system between test participants; the shore facility; and (via a telephone patch system) the west coast ETEC facility, DOE-SAN, and DOE headquarters. The value of this radio relay was dramatically demonstrated during the period when the OEC experienced high currents and high gimbal angles, and there was a need to reduce the gimbal angle or to drop the CWP. The FOC senior site manager, the ship's master, the test director, and the assistant test director, in widely separated locations, were able to communicate and arrive at a decision for that circumstance. In addition, several walkie-talkie radios were used (same frequency as the UHF radios) to alert off-duty personnel to the needs aboard the OEC.

3. ETEC West Coast Facility

Program direction from ETEC generally originated from the ETEC facility located in the Santa Susana mountains, north of Los Angeles. Most of the OTEC-1 procurements and service contracts were processed through ETEC, with arrangements made for delivery direct to the Kawaihae Harbor shore facility. Duplicate data tapes mailed from the Kailua Kona office were processed at the ETEC facility, and scaled tapes and plots were sent to the JTG for analysis, test planning, and external dissemination.

Time zone differences between the OTEC-1 project office at DOE-HQ and the Hawaiian facility made the midpoint location of the ETEC west coast facility convenient. Direction received from DOE-HQ at the ETEC west coast facility was expeditiously passed on to the ETEC test group aboard ship for action.

The experience gained during the test operations period at Hawaii led to certain conclusions and recommendations that should apply to any similar operation:

1) Operating in a relatively remote location, such as the moor area off the island of Hawaii, requires a good communication system. The combination of VHF, UHF, and walkie-talkies used for the OTEC-1 operation provided adequate communications for both routine and nonroutine situations. Coupled with the telephone link to ETEC, DOE-SAN, DOE-HQ, and other participating organizations, information and direction were expeditiously transferred.

2) The shore support facility as established by the SIC and operated by the FOC was able to handle all routine resupply requirements, such as food and materials, fueling, and communications.

3) Difficulties were experienced in the resupply of anhydrous ammonia to the OEC. Some ammonia was available in the Honolulu area, but not enough to satisfy requirements. Since no ammonia was produced in Hawaii, any large procurements required a lead time sufficient to allow for the acquisition of shipping containers, such as DOT 51 transport tanks, and the routine shipment of filled tanks via surface conveyance to the remote test site.

4) During construction of the OTEC-1 test platform, DOE-HQ added a requirement for a safety analysis report.[7] Such a requirement would normally have been added early in the design phase. Coming so late in the construction phase necessitated an intensive investigation into safety-oriented planning and reporting by the SIC. Future projects should apply this lesson learned to plan for such a study and report from the earliest phase of the project, requiring of the designers specific safety studies as required by DOE guidance.

5003K/jbv

III. TEST RESULTS SUMMARY

A. GENERAL

In this report, results are summarized for those systems, subsystems, and components that were either purposely tested or required monitoring during OTEC-1 operations. This included seawater and ammonia systems operation, test article (heat exchanger) testing, CWP and gimbal monitoring, chlorination system operation, Amertap system operation, BCM operation, and on-board environmental monitoring.

B. DATA ACQUISITION AND REDUCTION

The I&C van on board the OEC contained the data acquisition system (DAS). The DAS could sample and record all channels of data, apply calibration and correction factors to the data, and provide real-time computation and display (with hard copy) of selected parameters in engineering units. Data could be recorded on tape and disc at selectable rates. The disc had a 24-h capacity, and data could be recalled and displayed from the disc on damand. Data tapes were duplicated on the OEC and then transferred to ETEC in California for final editing and the preparation of selected engineering data plots for preliminary evaluation of data. All of the tapes and selected hardcopy were then sent to ANL, NOAA, etc., for detailed evaluation. Also, there were two eight-channel strip chart recorders available for continuous display of any parameter connected to the DAS, selected by the operator.

During test operations, 13 software programs were used extensively for real-time data reduction, analysis, and display to provide system information to test personnel. These programs, listed in Table 3-1, are discussed in this section.

TABLE 3-1

OTEC-1 REAL-TIME DATA DISPLAYS

1)	Heat exchanger performance calculations (on demand)
2)	Operators data display (10 sets of 40 parameters – on demand)
3)	Any individual parameter (once per second – on demand)
4)	CWP and gimbal data (on demand)
5)	Daily heat exchanger performance summary (every 6 h)
6)	Average on all parameters (for 6-h period – on demand)
7)	Environmental data (every 1 h)
8)	Daily biofouling module data summary (once per day)
9)	Biofouling module data display (once per hour)
10)	Real-time analysis of cooldown data (one cooldown per 2-h period for biofouling modules)
11)	Out-of-limits alarm display (when exceeded)
12)	Recall and display data from disc (24-h capacity – on demand)
13)	Strip chart display program (16 channels – operator choice)

1. Heat Exchanger Performance Calculations

This data-reduction program, based on equations developed in the OTEC-1 test plan,[2] allowed overall evaporator/condenser performance to be evaluated real-time. A typical hard-copy printout is shown in Figure 3-1. This program was available on demand.

2. Operators' Data Display

This program allowed the display of 10 sets or the grouping of 40 parameters in engineering units, selectable by operating personnel and displayed on demand. Figure 3-2 shows a typical example of pressures, temperatures, etc. This display was designed to provide a "snap-shot" of a selected (or operator definable) group of parameters to give the status of a particular component or subsystem. Examples include the level, pressure, and temperature of the ammonia storage tanks.

OTEC-1 ENGINEERING OUTPUT DATA				16-FEB-81	00141159
CONDENSER PARAMETERS		VALUE	EVAPORATOR PARAMETERS		VALUE
TP H2O IN	DEG F	41.6	TP H2O IN	DEG F	77.5
TP H2O OUT	DEG F	44.6	TP H2O OUT	DEG F	75.3
FLOW H2O	GPM	67.	PLAIN	DEG F	76.2
HT FLUX (H2O)	MW	31.	ENHCD	DEG F	74.3
HTC (H2O)	U	391.	FLOW H2O	GPM	98.
TP SAT NH3	DEG F	47.8			
HT FLUX (H2O)		MW	31.		
PR SAT NH3	PSIG	70.7	PLAIN	MW	9.
HT FLUX (NH3)	MW	31.	ENHCD	MW	22.
HTC (NH3)	U	391.	HTC OVERALL (H2O)	U	406.
TP NH3 IN	DEG F	64.3	PLAIN	U	213.
TP NH3 OUT	DEG F	46.1	ENHCD	U	667.
FLOW NH3 DN #1	GPM	97.	TP SAT NH3	DEG F	72.1
FLOW NH3 DN #3	GPM	164.	PR SAT NH3	PSIG	115.1
FLOW NH3 DN #5	GPM	0.	HT FLUX (NH3)	MW	31.
FLOW NH3 RETURN	GPM	595.	HTC OVERALL (NH3)	U	406.
FLOW NH3 RETURN	#/HR	187082.	FLOW NH3 VAPOR	#/HR	197806.
DP COND H2O	PSID	1.6	QUALITY	PCT	99.1
DP EVAP H2O	PSID	2.2	FLOW REFLUX P1	GPM	11.
TP REFLUX	DEG F	57.2	FLOW REFLUX P2U	GPM	8.
REFLUX RATIO	PCT	59.9	FLOW REFLUX P2M	GPM	1001.

Figure 3-1. Typical Hard-Copy Printout for Heat Exchanger Performance

3. <u>Any Individual Parameter</u>

Test personnel could select any single parameter to be read out once per second. The parameter was updated continuously and displayed in engineering terms. Figure 3-3 shows a typical sequence for a condenser inlet waterbox pressure. This display was designed to provide real-time status during calibrations or during transient operations. Access to and changes of parameters were much more efficient than selection and output to the strip charts.

4. <u>CWP and Gimbal Data</u>

This analysis program provided a statistical summary of key parameters, indicating gimbal angles and forces, pipe forces, and LVDT readings. The information was used to judge the pipe/gimbal dynamics at any time. Figure 3-4 shows the CWP gimbal assembly force diagram and summary analysis. Figure 3-5 shows a typical actual printout of data elements. Such a printout

OTEC OPERATIONS OUTPUT PARAMETERS REV-800204
13-FEB-81 11:20:31

SEQ.	TAG NUMBER	VALUE	SEQ.	TAG NUMBER	VALUE
442	P101A	466.03	443	P101V	624.79
444	P103A	379.56	445	P103V	708.33
438	P100A	525.14	439	P100V	537.35
116	LE101	32.44	118	LE104	24.29
74	TE8-1	76.97	73	TE8-2	77.13
75	TE8-3	77.19	332	TE9-2	77.03
330	TE9-4	76.97	328	TE9-6	77.00
326	TE9-8	77.02	345	TE16-1	41.60
344	TE16-2	41.50	343	TE16-3	41.68
342	TE16-4	41.64	85	TE15-2	41.66
87	TE15-4	41.72	89	TE15-6	41.75
91	TE15-8	41.64	105	PE7-1	5.42
106	PE7-2	9.53	107	PE7-3	9.45
108	PE7-4	9.39	109	PE8-1	-0.01
348	PE8-2	6.82	349	PE8-3	6.86
350	PE8-4	7.63	353	PE13-1	1.35
352	PE13-2	5.21	351	PE13-3	5.67
110	PE13-4	5.18	357	PE12-1	-1.23
356	PE12-2	3.51	355	PE12-3	3.51
354	PE12-4	3.54	367	FE103	65.43

OUTPUT COMPLETE

Figure 3-2. Typical Printout of Operator's Data

SEQ # : 110 DATE 13-FEB-81
TAG NO. : PE13-4
DESCRIPTION : COND,INLET WTRBX,OUTBOARD,(PSIG CORRECTE
MUX NO. : 0 MUX ADDRESS : 132176 (OCTAL)
SCALING TYPE : 0 COEFFTS - A : -7.117 B : .12277E-01

SCALED	COUNTS	MV	MA	DATA	TIME
5.210	1004	5020.	9.805	16064	11:19:50
5.259	1008	5040.	9.844	16128	11:19:51
5.578	1034	5170.	10.10	16544	11:19:52
5.922	1062	5310.	10.37	16992	11:19:53
5.922	1062	5310.	10.37	16992	11:19:54
5.762	1049	5245.	10.24	16784	11:19:55
5.345	1015	5075.	9.912	16240	11:19:56
5.062	992	4960.	9.687	15872	11:19:57

Figure 3-3. Selected Individual Parameter — Typical

Tag No.	Mean	RMS	Max.	Min.	
FGPH	10.87	1.98	15.93	4.99	
FGPV	68.35	8.34	92.43	43.13	
FGSH	-24.22	1.66	-19.75	-28.94	
FGSV	110.35	8.75	135.88	86.67	
FGFH	-18.75	4.86	-8.30	-31.68	
FGFV	81.91	8.81	108.47	56.99	
FGAH	19.40	4.86	30.78	8.28	
FGAV	83.02	7.90	106.60	60.84	
GPITCH	6.84	3.88	13.37	0.00	
GROLL	10.04	3.90	18.73	3.96	
GHEAVE (VERTICAL)	165.46	16.65	215.58	118.23	= FGAV + FGFV
GSURGE (FORE/AFT)	-60.86	12.51	-32.54	-93.82	= PH+SH+Pitch angle comp.
GSWAY (ATHWARTSHP)	-33.71	9.64	-11.74	-57.63	= AH+FH+Roll angle comp.
GTILT	12.28	5.10	22.64	4.42	= Pipe cone angle
GAZMTH	58.05	10.31	90.00	40.22	= Pipe bearing
PHEAVE	178.28	16.99	227.75	129.36	= Axial force on pipe
PTORQ	-9.03	1.64	-4.90	-12.98	= Twist force on pipe

CWP GIMBAL ASSEMBLY

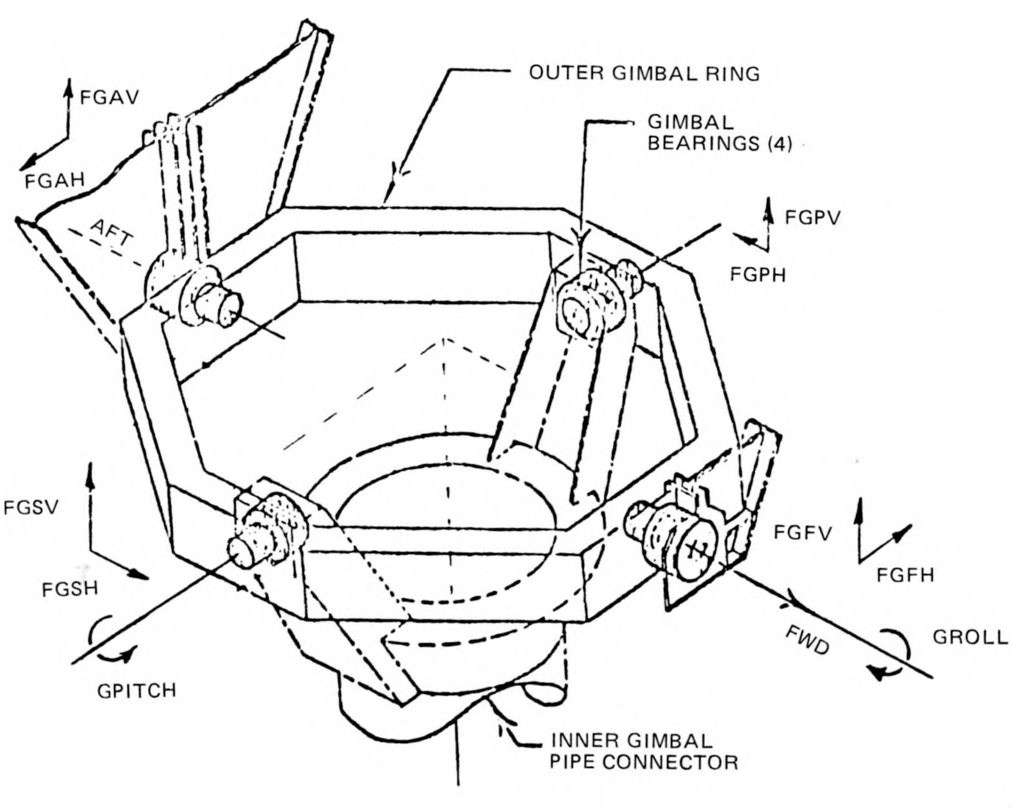


Figure 3-4. CWP Parameter Group
(960 samples at 4 samples/s from 1810:12 to 1814:13, 24 Feb 81)

960 SAMPLES AT 4 SAMPLES/SEC FROM 11:15:23 TO 11:19:23

TAG #	MEAN	RMS	MAX	MIN	WARN LIM	MAX LIM
FGPH	12.03	1.98	17.54	7.00		
FGPV	69.61	29.33	162.90	-23.86		
FGSH	-26.14	1.39	-21.03	-30.14		
FGSV	109.50	28.25	199.23	19.94		
FGFH	6.91	3.97	26.19	-3.71		
FGFV	80.68	26.29	165.62	-7.29		
FGAH	-3.71	9.92	13.66	-37.61		
FGAV	80.58	24.43	164.66	-4.43		
GPITCH	-16.06	1.90	-10.76	-20.93	15.00	20.00
GROLL	-9.29	1.57	-6.62	-14.89	15.00	20.00
GHEAVE	161.08	50.53	329.41	-11.52	400.00	500.00
GSURGE	8.12	15.32	49.81	-35.23	160.00	200.00
GSWAY	14.98	12.20	72.50	-3.23	160.00	200.00
GTILT	18.60	1.45	22.77	14.26		
GAZMTH	-149.54	6.01	-132.31	-161.72		
PHEAVE	178.64	57.48	361.53	-4.36		
PTORQ	-9.71	3.44	4.41	-17.48		
LVDT1	0.22	0.02	0.40	-0.18	1.50	2.70
LVDT2	-0.14	0.01	-0.02	-0.37	1.50	2.70
LVDT3	-0.84	0.02	-0.72	-1.06	1.50	2.70
LVDT4	0.00	0.03	0.28	-0.58	1.50	2.70
LVDT5	-0.13	0.02	0.15	-0.35	1.50	2.70
LVDT6	-0.90	0.03	-0.56	-1.29	1.50	2.70
LVDT7	0.27	0.04	0.67	0.10	1.50	2.70
LVDT8	0.23	0.01	0.40	0.12	1.50	2.70
LVDT9	0.19	0.02	0.40	0.03	1.50	2.70
LVDT10	0.52	0.01	0.75	0.42	1.50	2.70
LVDT11	0.28	0.08	1.40	0.06	1.50	2.70
LVDT12	0.20	0.02	0.39	0.00	1.50	2.70
LVDT13	-0.56	0.04	-0.48	-1.10	1.50	2.70
LVDT14	-0.26	0.02	-0.01	-0.48	1.50	2.70
LVDT15	0.34	0.01	0.57	0.25	1.50	2.70
LVDT16	-0.18	0.02	-0.01	-0.37	1.50	2.70
LVDT17	0.19	0.02	0.48	-0.09	1.50	2.70
LVDT18	-0.15	0.02	0.08	-0.26	1.50	2.70
LVDT19	0.01	0.02	0.37	-0.20	1.50	2.70
LVDT20	-0.22	0.02	0.12	-0.40	1.50	2.70
LVDT21	0.35	0.02	0.58	0.16	1.50	2.70
FI13-1	0.00	0.03	0.50	-0.50	1.50	2.70

Figure 3-5. CWP Parameter Group

was available on demand to test personnel and was automatically initiated, superseding any other analysis and display programs, whenever one or more selected parameters were detected exceeding preset limits. This was one of the most significant on-board real-time programs for assessing the operation of the CWP, and it was the source of data for the CWP release procedure in an emergency. Implementation of this analysis is discussed in Appendix Q.

5. Daily Heat Exchanger Performance Summary

Every 6 h, a summary of both the evaporator and condenser significant parameters was printed on hard copy reflecting the 6-h averages. At the end of each day, all four 6-h averages were hard copied. Figures 3-6 and 3-7 show typical day's end printouts.

6. Average of All Parameters

This program summarized all parameters averaged over a 6-h period. Figure 3-8 shows a portion of a typical summary; note that about 360 parameters were being presented.

7. Environmental Data

Once every hour, the key parameters for environmental monitoring on board the OEC were automatically hard copied and then filed for record purposes. Figure 3-9 shows a typical data summary. The purpose of this group was to provide representative values of parameters of interest to the environmental monitoring lead organization. These data were necessary for EPA permit reporting and for trend status evaluations.

8. Daily BCM Data Summary

Once per day, signficant data for each BCM were analyzed, summarized, and hard copied. This program also required some hand entries by test personnel. A typical daily summary is shown in Figure 3-10.

04-MAR-81 00:18:46

OPERATING CONDITIONS	AVERAGE VALUE OVER 6-HOUR PERIOD			
	0-6	6-12	12-18	18-24HRS
WW FLOWRATE	0.9551E+02	0.9621E+02	0.9739E+02	0.9657E+02
T-H2O (WWINLET TEMP)	0.7696F+02	0.7684E+02	0.7718E+02	0.7715E+02
P-NH3 (SHELL SIDE), PSIG	0.1082E+03	0.1082E+03	0.1082E+03	0.1082E+03
T-NH3(SHELL SIDE SAT.TEMP)	0.7639F+02	0.7602E+02	0.7667E+02	0.7746E+02
T-NH3(AMMONIA FEED TEMP)	0.7254E+02	0.7258E+02	0.7198E+02	0.7418E+02
NH3 VAPOR FLOW, LB/HR	0.2227F+05	0.2236E+05	0.5054E+05	0.2286E+05
NH3 FEED RATE	0.7091E+04	0.7064F+04	-.2147E+05	0.7839E+04
CALCULATED PARAMETERS				
UO (UPPER)	-.2961F+02	-.2668F+02	0.4817E+03	0.8298E+02
UO (LOWER)	0.6364E+03	0.4608E+03	-.6692E+04	-.1404E+04
UO (OVERALL)	0.3088E+03	0.2196E+03	0.1510E+04	-.6301E+03
Q (UPPER)	-.5274E+06	-.6752F+06	0.6116F+07	-.7867E+06
Q (LOWER)	0.1171E+08	0.1191E+08	0.1918E+08	0.1227E+08
Q (OVERALL)				
NH3-SIDE BALANCE	0.1119F+08	0.1124E+08	0.2530E+08	0.1148F+08
H2O-SIDE BALANCE	0.1119F+08	0.1124E+08	0.2530E+08	0.1148E+08
X (EXIT QUALITY)	0.9971E+00	0.9971E+00	0.1005E+01	0.9971E+00
SIGMA(REFLUX RATIO)	-.6816E+00	-.6842E+00	-.1425E+01	-.6571E+00
UO FOR 6 AMERTAP LOOPS				
- U01	-.1104F+03	-.7974E+02	0.6275E+08	0.2693E+03
- U02	-.1847E+03	-.1359E+03	0.6073E+08	0.6174E+03
- U03	-.2727E+02	-.1670E+02	0.6116F+08	0.7762E+02
- U04	-.1055E+03	-.7673E+02	-.3323E+03	0.2699E+03
- U05	-.6778F+02	-.4850E+02	0.6393E+08	0.1584E+03
- U06	0.2056E+02	0.1370F+02	0.6140E+08	-.3928F+02
RF FOR AMERTAP LOOPS				
- RF1	-.9436E-02	-.1272E-01	-.8866E-03	0.2632E-02
- RF2	-.6019F-02	-.7854F-02	-.9104E-03	0.6330E-03
- RF3	-.3552E-01	-.5743F-01	-.9058E-03	0.1127F-01
- RF4	-.9816E-02	-.1317E-01	-.3705E-02	0.2645E-02
- RF5	-.1480F-01	-.2033E-01	-.8740E-03	0.5098E-02
- RF6	0.4501E-01	0.6801E-01	-.9031E-03	-.2492E-01
RF FOR 4 DIRTY LOOPS				
- RF1	-.1286E-02	-.1333E-02	-.1272E-02	-.8178E-03
- RF2	-.4632E+00	-.7789E+00	-.8942E-03	-.1059F+00
- RF3	-.2589F-01	-.3623F-01	-.4405E-02	0.1874F-01
RF4	-.9710E-02	-.1321E-01	-.8912E-03	0.2179E-02

Figure 3-6. Daily Heat Exchange Performance (Evaporator)

04-MAR-81 00:18:46

OPERATING CONDITIONS	AVERAGE VALUE OVER 6-HOUR PERIOD 0-6	6-12	12-18	18-24HRS
CW FLOWRATE	0.7172E+02	0.6958E+02	0.6412E+02	0.7022E+02
T-H2O (CWINLET TEMP)	0.7696E+02	0.7684E+02	0.7699E+02	0.7715E+02
P-NH3 (SHELL SIDE), PSIG	0.6225E+02	0.6193E+02	0.6036E+02	0.6108E+02
T-NH3(SHELL SIDE SAT.TEMP)	0.4242E+02	0.4220E+02	0.4116E+02	0.4164E+02
T-NH3(VAPOR INLET TEMP)	0.7270E+02	0.7260E+02	0.7398E+02	0.7516E+02
NH3 CONDENSATE FLOW, LB/HR	-.5320E+02	-.6811E+02	-.3892E+04	-.8075E+02
CALCULATED PARAMETERS				
UO (OVERALL) NH3	0.1307E+04	0.1735E+04	-.2323E+04	0.3939E+04
UO (OVERALL) WATER	0.1307E+04	0.1735E+04	-.2323E+04	0.3939E+04
NH3-SIDE BALANCE	0.1231E+08	0.1236E+08	0.2810E+08	0.1270E+08
H2O-SIDE BALANCE	0.1231E+08	0.1236E+08	0.2810E+08	0.1270E+08
UO FOR 6-AMERTAP LOOPS				
- U01	-.3699E+09	-.3883E+09	-.3307E+09	-.4364E+09
- U02	0.9232E+13	0.9232E+13	0.9232E+13	0.9232E+13
- U03	0.9232E+13	0.9232E+13	0.9232E+13	0.9232E+13
- U04	-.3477E+09	-.3656E+09	-.3041E+09	-.4121E+09
- U05	0.9232E+13	0.9232E+13	0.9232E+13	0.9232E+13
- U06	-.2439E+09	0.9231E+13	0.9224E+13	0.9225E+13
RF FOR 6 AMERTAP LOOPS				
- RF1	-.1173E-02	-.1221E-02	-.1321E-02	-.1338E-02
- RF2	-.1151E-02	-.1200E-02	-.1347E-02	-.1315E-02
- RF3	-.1117E-02	-.1164E-02	-.1268E-02	-.1277E-02
- RF4	-.1174E-02	-.1222E-02	-.1337E-02	-.1339E-02
- RF5	-.1182E-02	-.1231E-02	-.1264E-02	-.1349E-02
- RF6	-.1135E-02	-.1183E-02	-.2876E-02	-.1297E-02
RF FOR 4 DIRTY LOOPS				
- RF1	-.1173E-02	-.1221E-02	-.1321E-02	-.1338E-02
- RF2	-.1117E-02	-.1164E-02	-.1268E-02	-.1277E-02
- RF3	-.1174E-02	-.1222E-02	-.1337E-02	-.1339E-02
- RF4	-.1135E-02	-.1183E-02	-.2876E-02	-.1297E-02

Figure 3-7. Daily Heat Exchanger Performance Summary (Condenser)

SEQ#	TITLE	VALUE	SEQ#	TITLE	VALUE	SEQ#	TITLE	VALUE	SEQ#	TITLE	VALUE
325	TE9-9	0.77416E+02	326	TE9-8	0.77120E+02	327	TE9-7	0.77211E+02	328	TE9-6	0.77098E+
329	TE9-5	0.77146E+02	330	TE9-4	0.77105E+02	331	TE9-3	0.77096E+02	332	TE9-2	0.77143E
333	TE9-1	0.76940E+02	334	TE8-4	0.76956E+02	335	TE7-10	0.77446E+02	336	TE7-9	0.76673E
337	TE7-8	0.77993E+02	338	TE7-7	0.77547E+02	339	TE7-6	0.78471E+02	340	TE7-5	0.77564E
341	TE14-1	0.70136E+02	342	TE16-4	0.41592E+02	343	TE16-3	0.41652E+02	344	TE16-2	0.41428E
345	TE16-1	0.41555E+02	346	PE16	0.11353E+03	347	PE15	0.11818E+03	348	PE8-2	0.73538E
349	PE8-3	0.73795E+01	350	PE8-4	0.72494E+01	351	PE13-3	0.48770E+01	352	PE13-2	0.49119E
353	PE13-1	-.23870E+00	354	PE12-4	0.38856E+01	355	PE12-3	0.38772E+01	356	PE12-2	0.40014E
357	PE12-1	-.12311E+01	358	PDE11	0.50044E+01	359	PDE10	0.49995E+01	360	PE9	0.61079E
361	TE1514	0.41617E+02	362	TE1513	0.41563E+02	363	TE1512	0.41662E+02	364	TE1511	0.41568E
365	TE1510	0.41508E+02	366	TE15-9	0.41567E+02	367	PE103	0.70216E+02	368	TE110	0.70760E
369	TE109	0.44010E+02	370	TE108	0.75158E+02	371	TE21	0.74497E+02	372	TE3	0.73211E
373	TE2	0.74724E+02	374	TE170	-.78184E+02	375	PE107	0.65875E+02	376	PE106	0.10253E
377	FE107	-.26526E+00	378	LE407	0.93000E+02	379	PE402	0.60426E+02	380	PE403	0.62155E
381	PE505	-.75180E+02	382	LE403	-.14184E+02	383	LE402	-.14565E+02	384	TE10-4	0.73136E
385	TE10-3	0.73294E+02	386	TE10-2	0.63733E+02	387	TE10-1	0.73641E+02	388	PE17	0.11851E
389	SPARE	-.12526E+03	390	SPARE	0.96695E+01	391	SPARE	0.24810E+03	392	TE17-5	0.50010E
393	TE17-4	0.50000E+02	394	TE17-3	0.49929E+02	395	TE17-2	0.49973E+02	396	TE17-1	0.49999E
397	TE12	0.73498E+02	398	TE1124	0.77217E+02	399	TE1123	0.77147E+02	400	TE1122	0.77187E
401	TE1121	0.77356E+02	402	TE1120	0.77344E+02	403	TE1119	0.77256E+02	404	TE1118	0.77403E
405	TE1117	0.77131E+02	406	TE1116	0.77269E+02	407	TE1115	0.77156E+02	408	LE4	-.11464E
409	P103	0.88234E+02	410	P101	0.85863E+02	411	LCV1	0.49946E+02	412	LE2	-.21419E
413	FE112	0.17507E+03	414	FT51	0.15939E+02	415	FT41	0.15000E+02	416	FT31	-.50412E
417	FT21	0.43083E+00	418	TE19	0.52016E+02	419	TE1824	0.41833E+02	420	TE1823	0.32219E
421	TE1822	0.34479E+02	422	TE1821	0.41793E+02	423	TE1820	0.41801E+02	424	TE1819	0.42833E
425	TE1818	0.42096E+02	426	TE1817	0.34246E+02	427	TE1816	0.42205E+02	428	FE106	-.65429E
429	FE4	0.21864E+00	430	LVDT1	0.28759E+00	431	LVDT2	-.13299E+00	432	LVDT3	-.83433E
433	LVDT4	0.26944E-02	434	LVDT5	-.12470E+00	435	LVDT6	-.89424E+00	436	MCPRWV	0.47358E
437	MCPRWA	0.31411E+02	438	P100A	0.59581E+03	439	P100V	0.62422E+03	440	SPARE	0.26830E
441	SPARE	0.11155E+03	442	P101A	0.50259E+03	443	P101V	0.63370E+03	444	P103A	0.33050E
445	P103V	0.65530E+03	446	TPA2	0.26004E+02	447	TPV2	0.42249E+02	448	FE2	0.78607E
449	FE1	0.16578E+02	450	LVDT7	0.83154E-01	451	TE711	0.63872E+02	452	TE712	0.78165E
453	TDT711	0.32093E+00	454	TE721	0.64078E+02	455	TE722	0.77807E+02	456	TDT721	0.33816E
457	TE731	0.63761E+02	458	TE732	0.77819E+02	459	TDT731	0.30928E+00	460	TE741	0.42934E
461	TE742	0.42912E+02	462	TDT741	0.15832E-01	463	TE751	0.46747E+02	464	TE752	0.53504E
465	TDT751	0.36016E+00	466	LVDT39	0.23447E+01	467	TE13-1	0.33031E+02	468	TE13-2	0.33138E
469	TE13-3	0.42095E+02	470	TE13-4	0.42794E+02	471	TE13-5	0.42155E+02			

Figure 3-8. Average of All Parameters (Hours 18 to 24)

ONBOARD ENVIRONMENTAL DATA [illegible]-APR-81 00:27:02

AVERAGED DATA FOR JULIAN DAY 102 FROM 000 TO 100 HOURS
SAMPLE SIZE = 59

SEQ#	TAG #	TITLE	VALUE	RMS
74	TE8-1	EVAP, WATERBOX IN, 0'-40' (DEGF)	75.60	0.0446
73	TE8-2	EVAP. INLET WATER BOX 65-90 DEG F	75.78	0.0997
75	TE8-3	EVAP, WATERBOX IN, 0'25' (DEGF)	75.83	0.0590
334	TE8-4	EVAP.INLET WATER BOX,65-90 DEG F	75.46	0.0834
333	TE9-1	EVAP. OUTLET WATER BOX, 65-90 DEG F	75.44	0.0446
332	TE9-2	EVAP. OUTLET WATER BOX, 65-90 DEG F	75.68	0.0669
331	TE9-3	EVAP OUTLET WATER BOX 65-90 DEG F	75.60	0.0772
76	TE9-11	EVAP OUTLET WATER BOX 65-90 DEG F	75.72	0.0669
77	TE9-12	EVAP. OUTLET WATER BOX 65-90 DEG F	75.74	0.0223
78	TE9-13	EVAP OUTLET WATER BOX 65-90 DEG F	75.76	0.0705
79	TE9-14	EVAP OUTLET WATER BOX 65-90 DEG F	75.67	0.0315
330	TE9-4	EVAP OUTLET WATERBOX 65-90 DEG F	75.63	0.0669
329	TE9-5	EVAP OUTLET WATERBOX 65-90 DEG F	75.66	0.0498
328	TE9-6	EVAP OUTLET WATERBOX 65-90 DEG F	75.61	0.0446
327	TE9-7	EVAP. OUTLET WATER BOX 65-90 DEG F	75.74	0.0223
326	TE9-8	EVAP OUTLET WATER BOX 65-90 DEG F	75.64	0.0223
325	TE9-9	EVAP. OUTLET WATER BOX 65-90 DEG F	75.95	0.0223
324	TE9-10	EVAP. OUTLET WATER BOX 65-90 DEG F	75.78	0.0498
345	TE16-1	COND INLET WATERBOX 35-50 DEG F	42.03	0.0568
344	TE16-2	COND, WATERBOX IN, 0'-35' (DEGF)	41.89	0.0402
343	TE16-3	COND, WATERBOX IN, 0'0' (DEGF)	42.11	0.0523
342	TE16-4	DESCRIPTION FOR SEQ# 342	42.06	0.0557
84	TE15-1	COND, WATERBOX OUT, 0' 14.5' (DEGF)	34.29	0.0295
85	TE15-2	COND, WATREBOX OUT, 37' -2' (DEGF)	42.06	0.0534
86	TE15-3	COND. OUTLET WATER BOX 35-50 DEG F	41.99	0.0620
87	TE15-4	COND.WATERBOX OULET 35-50 DEG F	42.12	0.0640
88	TE15-5	COND, WATERBOX OUT, 0'-24' (DEGF)	41.97	0.0486
89	TE15-6	COND OUTLET WATER BOX 35-50 DEG F	42.14	0.0557
90	TE15-7	COND, WATERBOX OUT, -38'-35' (DEGF)	42.28	0.0446
91	TE15-8	COND. OUTLET WATER BOX 35-50 DEG F	42.05	0.0600
366	TE15-9	COND OUTLET WATER BOX 35-50 DEG F	42.04	0.0579
365	TE1510	COND, WATERBOX OUT, 0' -3', (DEGF)	41.97	0.0498
364	TE1511	COND, WATERBOX OUT, -39' -2', (DEGF)	42.04	0.0620
363	TE1512	COND. OUTLET WATER BOX 35-50 DEG F	42.13	0.0446
362	TE1513	COND, WATERBOX OUT, -40' 16', (DEGF)	42.03	0.0446
361	TE1514	COND, WATERBOX OUT, -2' 35', (DEGF)	42.08	0.0568
115	FE101	WARM WATER FLOW:0-100 X 1000 GPM	87.08	1.8870
367	FE103	COLD WATER FLOW:0-100 X 1000 GPM	69.73	2.6268
114	TE113	MIXED WATER DISCHARGE TEMP.	63.42	0.0739
		WINDSPEED, KNOTS	9.1	
		WIND DIRECTION, DEG. FROM MAG. NORTH	33.	

Figure 3-9. Environmental Parameter Group

TEST DATE : 2/21/81
RESPONSIBLE PERSON : QUIRK

TRANSMISSION DATE : 2-21-81
TRANSMISSION TIME : 23:40

1. MAIN SYSTEM

	EVAP	COND	
AMERTAP BALL COUNT :	3809	3478	@ 23:29
CHLORINATION SYSTEM			
AMMETER READING :	710	410	
VOLTMETER READING :	32	31	
CHLORINE ANALYSIS PPM :	.21	.09	
TIME ON :	1647	1543	
TIME OFF :	1750	1650	

2. BCM'S

UNIT # :	1	2	3	4	5	6	7	8
# CURVES	10	5	0	5	5	0	4	4
AVEFV:	6.05	6.18	0.00	6.15	4.79	0.00	5.91	6.01
AVETW:	25.58	25.37	0.00	3.63	6.65	0.00	5.16	5.92
HUNCOR:	1343.0	1379.9	0.0	1382.2	822.0	0.0	1098.2	1087.7
HCREWT:	1222.4	1255.7	0.0	1635.2	936.3	0.0	1269.9	1260.2
RNFOL*E4:	-0.20	-0.39	0.00	6.24	0.50	0.00	7.78	0.14
SRNFOL*E4:	0.12	0.02	0.00	0.06	0.05	0.00	0.06	0.04
AMRTP COUNT:	3809	DNA			DNA			3478
CHLORNTR								
PPM:	DNA	DNA			DNA			DNA
AMP:	DNA	DNA			DNA			DNA
ON:	DNA	DNA		DNA	DNA		DNA	DNA
OFF:	DNA	DNA		DNA	DNA		DNA	DNA

3. COMMENTS:

Figure 3-10. OTEC-1 Daily Biofouling Summary

9. BCM Status Display

This program ran once per hour and indicated the status of the BCMs, such as which ones were operating and their flows and temperatures. This was displayed to permit the operators to detect malfunctions so as to schedule repairs.

10. Real-Time Analysis of BCM Cooldown Data

Once every 2 h, each BCM was subjected to a cooldown cycle to obtain data for fouling resistance. This program both performed the cooldown procedure automatically and analyzed the data. The display provided diagnostics to the ANL specialists to determine what control and calibration corrections might be required.

11. Out-of-Limits Alarm Display

This program indicated when limits were exceeded for key system parameters. It was used by test personnel as an early warning of potential problems.

12. Recall and Display Data from Disc

As indicated above, the DAS disc had a 24-h capacity when sampling and recording all parameters once per minute. This program allowed the recall of any or all of the parameters recorded on the DAS for any period up to the 24 h. Frequency of recall period was also selectable (e.g., every minute, every 15 min). A typical example is shown in Figure 3-11.

13. Strip Chart Display Program

This program allowed test personnel to display any parameter continuously on the strip chart recorders. Up to 16 channels were available for this purpose.

DAY	HR	MN	SC	FGFV	FGAV	GPITCH	GROLL	TE16-4	TF16-3	TE16-2	TE16-1	HEAVE
52	15	0	23	76.255	83.148	-0.440	-0.205	41.778	41.802	41.605	41.737	0.231
52	15	5	23	73.988	80.852	-0.703	0.088	41.925	41.948	41.761	41.892	0.317
52	15	10	23	71.722	77.408	-0.293	-0.352	41.788	41.838	41.614	41.755	0.109
52	15	15	23	84.512	90.856	-0.440	-0.176	41.769	41.811	41.605	41.737	0.172
52	15	20	23	70.750	76.916	-0.440	-0.205	41.696	41.738	41.522	41.663	0.184
52	15	25	23	83.055	88.396	-0.528	-0.117	41.669	41.701	41.504	41.627	0.199
52	15	30	23	76.741	82.492	-0.264	-0.352	41.632	41.664	41.468	41.590	0.113
52	15	35	23	79.007	82.820	-0.469	-0.176	41.778	41.857	41.614	41.755	0.203
52	15	40	23	78.521	82.984	-0.440	-0.176	41.907	41.921	41.715	41.837	0.176
52	15	45	25	70.426	75.276	-0.264	-0.352	41.888	41.930	41.715	41.846	0.191
52	15	49	26	86.131	92.004	-0.469	-0.176	41.898	41.939	41.724	41.856	0.207
52	15	53	29	92.931	95.612	-0.674	-0.088	41.760	41.811	41.587	41.718	0.215
52	15	58	31	70.750	77.408	-0.440	-0.176	41.815	41.866	41.651	41.782	0.258
52	16	3	32	74.474	78.556	-0.264	-0.352	41.806	41.866	41.642	41.764	0.160
52	16	7	34	77.874	82.656	-0.469	-0.176	41.898	41.939	41.733	41.846	0.090
52	16	12	35	73.179	76.424	-0.440	-0.176	41.540	41.600	41.385	41.508	0.332
52	16	16	36	86.293	90.364	-0.440	-0.205	41.614	41.646	41.449	41.567	0.211
52	16	20	37	80.788	83.968	-0.469	-0.176	41.724	41.802	41.550	41.691	0.203
52	16	24	38	93.578	100.368	-0.578	-0.147	41.833	41.893	41.678	41.801	0.149
52	16	28	39	80.464	85.280	-0.440	-0.176	41.888	41.957	41.733	41.856	0.320
52	16	32	40	81.436	67.248	-0.469	-0.176	41.916	41.957	41.751	41.874	0.234
52	16	36	41	72.855	77.080	-0.469	-0.176	41.916	41.976	41.751	41.883	0.152
52	16	40	43	76.093	83.968	-0.440	-0.176	41.907	41.985	41.742	41.883	0.152
52	16	44	44	74.150	82.164	3.752	-8.031	41.879	41.930	41.724	41.837	0.133
52	16	48	45	87.426	92.824	3.166	-4.397	41.843	41.893	41.678	41.801	0.258
52	16	52	46	76.902	80.688	3.224	-2.726	41.815	41.875	41.642	41.773	0.129
52	16	56	48	82.893	86.592	2.521	-2.579	41.797	41.866	41.632	41.746	0.281
52	17	1	1	76.741	81.180	2.521	-3.136	41.797	41.857	41.632	41.764	0.274
52	17	5	3	78.521	84.624	2.609	-1.905	41.769	41.838	41.614	41.727	0.219
52	17	10	3	78.683	83.148	2.550	-0.498	41.714	41.765	41.550	41.672	0.191
52	17	15	4	77.874	83.640	1.993	1.260	41.788	41.838	41.614	41.737	0.254
52	17	20	5	70.103	76.260	4.338	1.026	41.806	41.857	41.632	41.755	0.266
52	17	25	7	79.817	84.132	2.872	2.931	41.742	41.792	41.577	41.691	0.211
52	17	30	7	84.674	88.068	3.810	4.133	41.778	41.820	41.596	41.718	0.125
52	17	35	8	83.379	86.428	3.400	3.078	41.843	41.912	41.669	41.791	0.246
52	17	40	9	80.626	86.756	2.022	3.254	41.778	41.847	41.605	41.727	0.199
52	17	45	10	74.312	78.884	4.866	2.990	41.815	41.912	41.669	41.801	0.129
52	17	50	11	77.712	83.476	2.814	1.260	41.769	41.829	41.587	41.718	0.184
52	17	55	11	83.217	87.576	2.022	-0.088	41.742	41.802	41.559	41.691	0.250
52	18	0	13	76.579	83.312	3.341	-1.905	41.760	41.811	41.577	41.709	0.254
52	18	4	14	81.112	85.608	3.898	-3.810	41.724	41.792	41.550	41.682	0.184
52	18	8	16	84.997	90.036	3.078	-2.960	41.724	41.783	41.550	41.672	0.195
52	18	13	18	66.379	73.800	6.800	-7.650	41.696	41.774	41.522	41.654	0.164
52	18	18	20	47.275	53.956	6.507	-6.126	41.714	41.774	41.541	41.663	0.164
52	18	23	25	78.036	83.148	5.481	-6.742	41.705	41.774	41.532	41.663	0.160
52	18	28	27	75.769	80.852	3.664	-6.888	41.705	41.765	41.532	41.645	0.168
52	18	33	29	81.598	86.756	1.729	-5.628	41.696	41.765	41.513	41.645	0.301
52	18	38	30	79.979	85.280	3.459	-2.433	41.650	41.719	41.468	41.608	0.191
52	18	43	32	84.836	87.576	1.671	-0.938	41.632	41.692	41.458	41.590	0.219
52	18	48	34	78.521	82.492	2.755	-0.352	41.623	41.683	41.440	41.572	0.184

Figure 3-11. Typical Recall and Display Data from Disc (5-min Interval)

14. Engineering Data Plots

In addition to the real-time data displays on board the OEC, the capability existed at ETEC-HQ to prepare, directly from the data tapes, plots of any parameter, or group of parameters, versus time. This allowed a complete history of any event to be continuously plotted and analyzed. Figure 3-12 shows a typical data plot of three ammonia vapor temperatures versus time during one of the test periods. Similar plots were prepared for numerous other parameters. These were forwarded to ANL, LBL, and NOAA to assist in data evaluation. Most of the data obtained during the OTEC-1 deployment has been examined by ETEC and forwarded, as previously discussed.

15. Other Data Records

In addition to the data recorded via the automated DAS, the following records were made:

1) The daily operations logs made by the test crew shift leader
2) The instrumentation logs made by the test crew instrumentation engineer
3) The overall log by the test director
4) The vessel bridge log made by the ship's deck officers
5) The vessel plant log made by the Engineering Department officers.

Copies or originals of all of these logs are on file at ETEC.

C. OPERATIONS

1. Seawater Systems

A major objective of the test plan was to maintain continuous water flow through the heat exchangers to preclude the development of fouling.

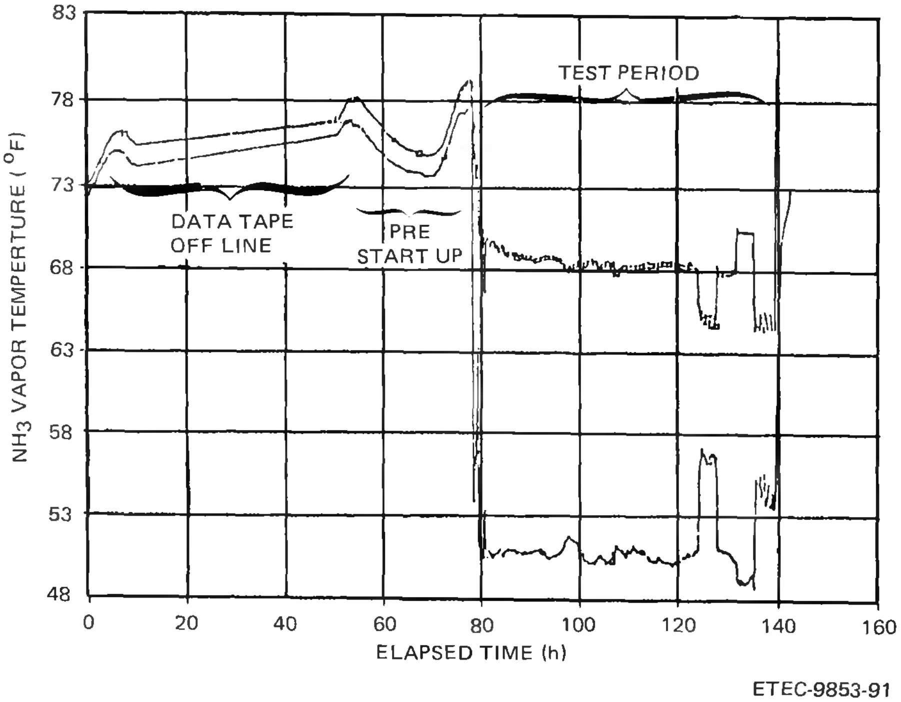


Figure 3-12. Typical Engineering Data Plot - Three NH_3 Vapor Temperatures vs Time

Seawater system operation for testing purposes was initiated in mid-December 1980. The cold water and mixed discharge pumps were started on 13 December 1980. The warm water pump was started on 22 December 1980. Except for short-duration shutdowns and one extended period of 32 h when the OEC was not attached to the moor, the cold and warm water seawater systems operated essentially full time (greater than 96%) after these dates. The mixed water pump was shut down from time to time due to problems with the MWD hose. During these latter periods, the mixed water was discharged directly overboard at the keel line aft of amidships. During these periods, the temperature at the warm water inlet did not change, indicating that none of the discharged mixed water was being recirculated.

Final shutdown of the seawater systems was in the first week of April 1980. This followed special startup and shutdown transient tests made for NOAA to obtain ocean engineering/system effects information and plume study tests made for LBL.

At shutdown, the cold water pump had logged about 2700 h of operation, the warm water pump about 2500 h, and the mixed water pump about 2800 h. Included in these totals is 13 h during which the pumps were operating, but the OEC was not connected to the moor ("grazing" mode).

A significant problem encountered during the OTEC-1 experiment was the failure of the main water flowmeters. The failures of the ultrasonic devices were ultimately diagnosed as having been caused by the void fraction of gases in the seawater having prevented the transmission of the signal through the two-phase fluid. Several experiments were conducted to determine the void fraction (see Refs. 8 and 9); higher powered devices were tested; and different instruments were tried. This failure made it impossible to compute the performance of the heat exchanger directly on the water side and caused the loss of a source signal for closed-loop pump flow control. The performance of the heat exchanger was computed by inferring water flow from a heat balance based on the ammonia system flows and confirmed by using the theoretical head, flow, and speed correlations of the pumps. These techniques yielded less-than-specified accuracies. The control of the system was found to not be difficult by manual, fixed-speed operation. In a commercial OTEC plant, the control problem could be solved easily with other inferential devices. Another problem known before the start of this test program was the difficulty in using the calibration/verification technique of the flowmeters to provide the highly accurate and precise measurements required. Proving the flow to an uncertainty level of 3% or less remains an unsolved problem for large flow rate systems due to the difficulty of controlled laboratory testing in an uncontrollable ocean environment. Computational uncertainties exist at these levels of accuracy. It would appear that devices using other operational principles would be helpful in both the calibrational and operational sense, and some development effort is warranted.

Another problem was encountered in the warm water system, where excessive void fractions were detected. This was caused by inadequate design of the sump itself, which caused the flow to be highly turbulent in passing from the hull intake to the pump intake, causing aeration. ETEC diagnosed this problem and developed an interim solution which involved drawing a vacuum in the chamber to raise the fluid level in the sump by about 10 ft. This increased both the inertial mass of the fluid and the effective capacitance and residence time. This produced a dramatic improvement in the reduction of entrained air but was not sufficient to enable the ultrasonic flowmeters to perform. This type of problem can be prevented by applying well-known sump design criteria. The problem is discussed in detail in Ref. 10.

2. Heat Exchanger Testing/Ammonia System

Initial startup of the complete system was on 31 December 1980. A total of 95 tests was performed with 370 h of ammonia system operation. The heat exchanger test program as performed included:

1) Baseline performance tests to verify design predictions — evaporator and condenser
2) Variable ammonia feed rate tests to determine the optimum reflux radio — evaporator
3) Activation and deactivation tests to study the nucleation characteristics of the high-flux surface enhancement — evaporator
4) Vapor velocity tests to examine liquid entrainment and carry-over — evaporator
5) Off-normal performance tests to evaluate behavior at different heat duties and water flow rates — condenser
6) Zonal and local measurements to assess variations in performance throughout the bundle — evaporator and condenser
7) Waterside pressure drop measurements to verify design predictions — evaporator and condenser.

Although the system was designed to operate continuously, we found that the test program could be run intermittently as thermal equilibrium was achieved within minutes. This reduced the number of personnel that needed to be on duty on both shifts and allowed maintenance to be performed during non-test periods. An excessively noisy throttle valve would have limited test compartment access for maintenance had this intermittent test operation not been possible.

The original plan was to conduct a separate series of tests with the evaporator in the flooded-bundle mode so that thermal performance in both modes (flooded and sprayed) could be compared. Time and budget limitations, however, caused the test in the flooded mode to be deleted.

The heat exchanger test results are discussed in detail in Ref. 11. Ammonia system operating experience is described in Section IV.C. Table 3-2 lists the tested ranges for both the evaporator and condenser during the testing period. Table 3-3 summarizes the baseline test results. Results from the tests are presented in Table 3-4. Of the 95 tests performed, tests 1 through

TABLE 3-2

HEAT EXCHANGER OPERATING RANGES
(From Ref. 2)

	Evaporator	Condenser
Heat duty (MWt)	14 - 46	14 - 46
Seawater flow rate (gpm)	57,000 - 91,000	32,000 - 67,000
Seawater temperature (°F)	76 - 78	41 - 43
Ammonia feed rate[a] (gpm)	400 - 3700	N/A
Ammonia shell side		
Pressure (psia)	128.8 - 133.4	82.7 - 99.7
Saturation temperature (°F)	70 - 72	46 - 56

[a]Total combined feed rate from all nozzles.

TABLE 3-3

BASELINE TEST RESULTS[a]
(From Ref. 2)

Heat Exchanger	U_o (Btu/h·ft^2·°F)		Waterside ΔP (psi)	
	Measured[b]	Predicted	Measured[b]	Predicted
Evaporator				
Plain bundle	490	490	2.7	2.5
Enhanced bundle	600[c]	735	2.7	2.5
Condenser	480	490	d	2.9

[a]Nominal conditions: heat duty = 40 MWt, ammonia feed rate = 3,000 gpm, warm water flow rate = 83,000 gpm, cold water flow rate = 67,000 gpm
[b]Measurement accuracy: U_o ($\pm$10%), ΔP ($\pm$2%)
[c]Partially activated
[d]Pressure transducer out of calibration.

TABLE 3-4

TABULATION OF INDIVIDUAL TEST RUNS
(Sheet 1 of 3)

Test	Description	Heat Duty (MWt)	Warm Water Flow Rate (gpm)	Ammonia Feed Rate (gpm)			U_o (Btu/h·ft^2·°F)		Cold Water Flow Rate (gpm)	U_o (Btu/h·ft^2·°F)
				Top Nozzles		Mid-Plane	Plain (upper)	Enhanced (lower)		
				Low-Pressure	High-Pressure					
1-29	Shakedown tests									
30	Distillation and evacuation	0	78,000	0	0	0	N/A	N/A	55,000	N/A
31	Surface conditioning	0	78,000	0 for dry 1500 for wet	0	0	N/A	N/A	55,000	N/A
32	Baseline	39	78,000	1500	0	0	460	410	55,000	450
33	Surface onditioning	0	82,000	0	0	0	N/A	N/A	55,000	N/A
34	Baseline	37	82,000	2200	0	0	485	565	55,000	455
35	Deluge	35	82,000	2200	0	0	480	560	55,000	455
36	Reflux ratio tests	35	82,000	1500	0	0	475	535	55,000	450
37		35	82,000	1200	0	0	480	505	55,000	455
38		35	82,000	950	0	0	475	410	55,000	455
39		32	82,000	800	0	0	460	310	55,000	455
40		28	82,000	660	0	0	430	165	55,000	450
41		24	82,000	550	0	0	390	80	55,000	450
42	Baseline	35	82,000	2200	0	0	485	420	55,000	450
43	Reflux test	31	82,000	950	0	0	a	a	55,000	445
44	Surface conditioning	0	82,000	1500 for wet 0 for dry	0	0	N/A	N/A	55,000	N/A

TABLE 3-4

TABULATION OF INDIVIDUAL TEST RUNS
(Sheet 2 of 3)

Test	Description	Heat Duty (MWt)	Warm Water Flow Rate (gpm)	Ammonia Feed Rate (gpm)			U_o (Btu/h·ft^2·°F)		Cold Water Flow Rate (gpm)	U_o (Btu/h·ft^2·°F)
				Top Nozzles		Mid-Plane	Plain (upper)	Enhanced (lower)		
				Low-Pressure	High-Pressure					
45	Reflux ratio tests	46	85,000	3000	0	0	490	450	55,000	445
45		45	85,000	1500	0	0	490	395	55,000	450
47		39	85,000	950	0	0	470	250	55,000	455
48		29	85,000	660	0	0	400	75	55,000	455
49		45	85,000	2200	0	0	490	435	55,000	450
50	Reflux ratio tests: mid-plane feed only	18	83,000	0	0	930	N/A	500	55,000	420
51		19	83,000	0	0	795	N/A	450	55,000	420
52		17	83,000	0	0	600	N/A	385	55,000	415
53		14	83,000	0	0	400	N/A	240	55,000	400
54	Reflux ratio tests: top high pressure nozzles only	30	83,000	0	960	0	415	285	55,000	435
55		28	83,000	0	795	0	400	175	55,000	435
56		23	83,000	0	600	0	365	60	55,000	435
57		16	83,000	0	400	0	270	Dryout	55,000	420
58	Reflux ratio tests: nozzle combinations	32	83,000	2730	965	0	475	430	55,000	440
59		32	83,000	2370	970	0	480	425	55,000	445
60		32	83,000	2045	975	0	475	430	55,000	445
61		33	83,000	1520	975	0	470	420	55,000	440
62		34	83,000	2525	0	0	480	430	55,000	440
63		28	83,000	1285	885	0	480	425	55,000	440
64		34	83,000	1355	900	0	480	425	55,000	440
65		41	83,000	1410	930	0	475	415	55,000	450
66		41	83,000	1000	520	0	485	365	55,000	445
67		33	83,000	950	500	0	485	380	55,000	450
68	Repeatability	25	83,000	910	0	475	485	420	55,000	435
69	Surface conditioning	0	83,000	0	0	0	N/A	N/A	55,000	N/A

TABLE 3-4

TABULATION OF INDIVIDUAL TEST RUNS
(Sheet 3 of 3)

Test	Description	Heat Duty (MWt)	Warm Water Flow Rate (gpm)	Ammonia Feed Rate (gpm)			U_o (Btu/h·ft^2·°F)		Cold Water Flow Rate (gpm)	U_o (Btu/h·ft^2·°F)
				Top Nozzles		Mid-Plane	Plain (upper)	Enhanced (lower)		
				Low-Pressure	High-Pressure					
70	Repeatability	34	83,000	2515	0	0	490	N/A	55,000	445
71	Condenser tests	32	83,000	2490	0	0	490	550	55,000	445
72		31	83,000	2505	0	0	485	550	32,000	340
73		31	83,000	2510	0	0	485	545	66,000	485
74		45	83,000	2495	0	0	485	540	68,000	490
75		45	83,000	2490	0	0	480	540	58,000	455
76		44	83,000	2495	0	0	470	530	a	a
77		17	83,000	0	610	380	425	410	32,000	325
78		19	83,000	0	705	475	425	420	57,000	440
79		19	83,000	0	795	580	425	420	67,000	470
80	Repeatability	28	91,000	0	600	365	410	375	57,000	455
81		24	76,000	0	595	450	395	430	44,000	400
82	Activation tests	41	83,000	1005	0	0	460	235	44,000	395
83		21	83,000	1000	0	0	500	425	44,000	385
84		22	83,000	1000	0	0	495	495	44,000	395
85		41	83,000	1000	0	0	480	295	44,000	405
86	Miscellaneous repeatability and reflux ratio tests	38	83,000	800	0	0	590	Dryout	44,000	410
87		38	83,000	0	805	0	495	Dryout	44,000	405
88		22	91,000	0	490	0	232	Dryout	29,000	320
89		17	57,000	1190	0	0	430	370	67,000	470
90		32	83,000	2560	0	920	485	605	44,000	405
91		32	83,000	3025	0	0	485	595	44,000	410
92		32	83,000	1490	0	0	485	565	44,000	410
93		32	83,000	950	0	650	480	555	44,000	410
94		29	83,000	0	800	810	415	530	44,000	410
95		13	79,000	0	810	810	445	490	44,000	380

[a]Insufficient time to reach steady state.
N/A = Not applicable.

29 were considered to be shakedown runs (for debugging the system, checking the instrumentation, and gaining operating experience) and hence are not included in the table. In addition, the water content in the ammonia during these runs was considered too high for valid data (about 0.9% by weight). Online distillation was used to reduce the water content to less than 0.4% by weight, a value the JTG considered satisfactory for runs 30 through 95. A decision was made early in the design phase not to include an ammonia purification system in favor of a resupply/dilution approach based on a water concentration specification range of 0.2 to 2.0%. A later determination that less than 0.5% was necessary dictated that special efforts were required. Little or no continuous contamination with water was observed during the test period.

3. CWP/Gimbal Monitoring

Although the CWP assembly was not considered a test article, its successful operation was critical to the OTEC test program. It had certain operating limitations of angles and forces based on design considerations. Since the CWP was critical to the total operation, continuous monitoring of various parameters was required so that appropriate actions could be taken when operating limits were approached (see Figure 3-4 and 3-5). During test operations, these actions ranged from a minimum of maneuvering the test platform (OEC), to a maximum of actually releasing the OEC from the moor with the CWP remaining attached. At no time was it necessary to disconnect the CWP from the platform as a result of excessive environmentally induced conditions.

During the test period, the cone angle between the CWP and the OEC rarely exceeded 10° (maximum limit along fixed axes was 30°); the CWP heave load was normally about +180 kips (maximum limit ±500 kips), and the CWP surge/sway loads were normally about 20 kips (maximum limit ±200 kips). However, on 4 March 1981, the cone angle reached the 30° limit (Figure 3-13) due to higher-than-normal currents (estimated current magnitudes are discussed in Ref. 4). Verification of the gimbal reaching its mechanical stops is

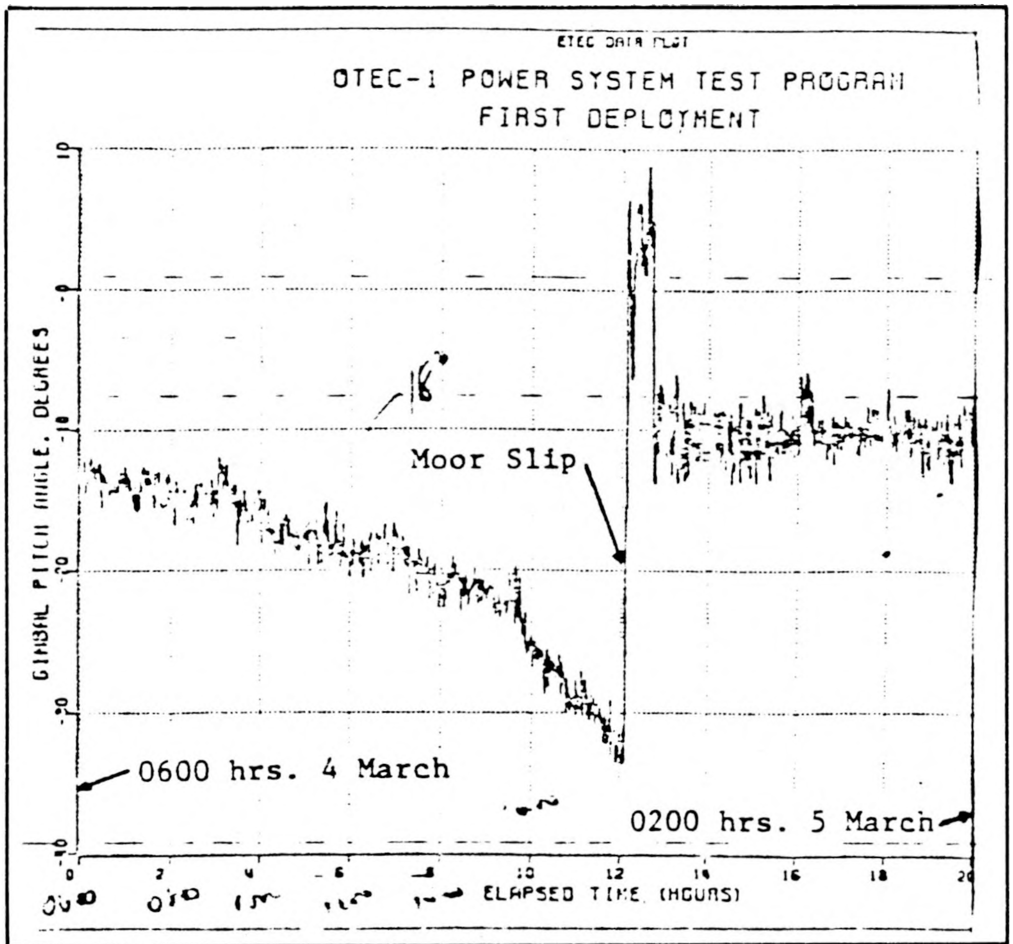


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Figure 3-13. Pitch Record for 20-h Period on March 4 & 5, 1981 illustrated in Figure 3-14, where the load cells show "spikes." Rather than release the CWP at this point (a known test program interruption), the OEC was released from the moor as a first step in attempting to accommodate the current and reduce the cone angle. This reduced the angle to about 10° (as shown in Figure 3-13) because the pipe and ship moved downstream as a unit. The seawater systems remained in operation for about 13 h while the OEC drifted in the "grazing" mode. All systems were then shut down (for an additional 32 h) while the OEC steamed back to the moor. During movement of the OEC back to the moor site, it was necessary to limit the cone angle to below 30°. To return the OEC to the moor required waiting for the current to weaken; and once reattachment was made, the cone angle returned to the 10° range. Table 3-5 shows a chronology of the "grazing" mode. A detailed report of this incident is provided in Refs. 4 and 12. The only other incident of any significance occurred on 22 February 1981 when a sudden vertical gimbal load was observed. A noticeable increase in cone angle occurred simultaneously. A series of OEC maneuvers reduced these values to normal. Two additional events occurred over the next 48 h (see Figure 3-15). The reason for these increases is not known, but one possibility is that the CWP collided with the moor system. No equipment was on board to determine the precise location of the OEC relative to the moor. Subsequently, precision navigation gear was installed which enabled a well-defined operational watch circle to be established and monitored.

4. Biofouling Control Systems

The two methods for heat exchanger biofouling control during testing were chlorination (chemical) and Amertap (mechanical).

An Englehard electrolytic sodium hypochlorite generator was used to chlorinate both the evaporator and the condenser. The maximum dosage to either unit was 0.50-ppm chlorine concentration for 1 h per day. By chlorinating one unit and mixing its discharge with the unchlorinated flow stream from the other unit, a maximum concentration of 0.20 ppm was discharged

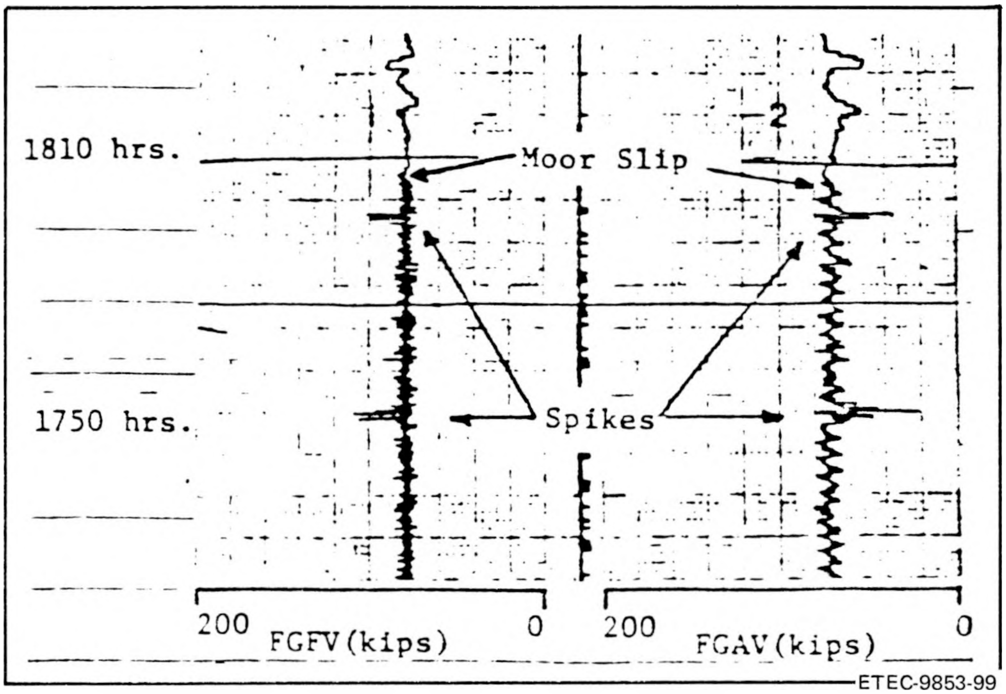

Figure 3-14. Gimbal Loads During Period of Moor Slip

TABLE 3-5

OTEC-1 GRAZING OPERATION

4 March	
1200	Gimbal angle 18° aft.
1600	Gimbal angle 25° aft; moor tension 80 kip.
1620	Gimbal angle 28° aft; dumped MWD pipe to obtain stbd list coupled with hard right rudder and thrusters 300 rpm.
1730	GPITCH aft over 30°; no spikes on pin loads.
1750	400% increase in vertical pin load (spike).
1805	Dropped off moor; maneuvering with thruster.
1915	Heading 190°; ship making 350°.
5 March	
0000	Thruster azimuth 190° at 300 rpm; vessel setting 330° at 0.45 knots, cold water pump at 60%, warm water pump at 60%.
0310	Course change to 140° to stay over plateau; OEC 3.2 nautical miles NW of moor.
0645	C/C to 170°T.
0949	Secured OTEC pumps; began reducing thruster rpm. GPITCH 12° aft.
0952	GPITCH 0°.
0954	Thrusters at 0 rpm. GPITCH 4° forward.
1000	Switch from OTEC to marine mode. OEC 5.3 nautical miles north of moor.
1020	Dead slow ahead, right full rudder.
1059	Slow ahead.
1102	GPITCH 13-14° aft.
1115	Increase speed to 45 rpm.
1130	GPITCH 17° aft.
1147	Speed 47 rpm, GPITCH 24° aft, course 185°.
1710	Reduce speed to 45 rpm, GPITCH 28°.
2217	Course change to 180°.
6 March	
0000	Still in marine mode, course 180°, 46 rpm.
0605	Adjacent to moor.
0815	Return to OTEC mode for thruster operation.
0825	Maneuvering with thrusters at 225 rpm.
1057	Secured thruster.
1120	Return to marine mode.
1126	Slow ahead 35 rpm, 200°.
1422	Hawser along port bow; support vessel PAUL LANGEVIN III maneuvering to assist recovery.
1511	OEC moored.
1541	Engine secured.
1850	Shift to power mode.
2250	Restart warm, mixed, and cold water pumps.

5004K/sjd

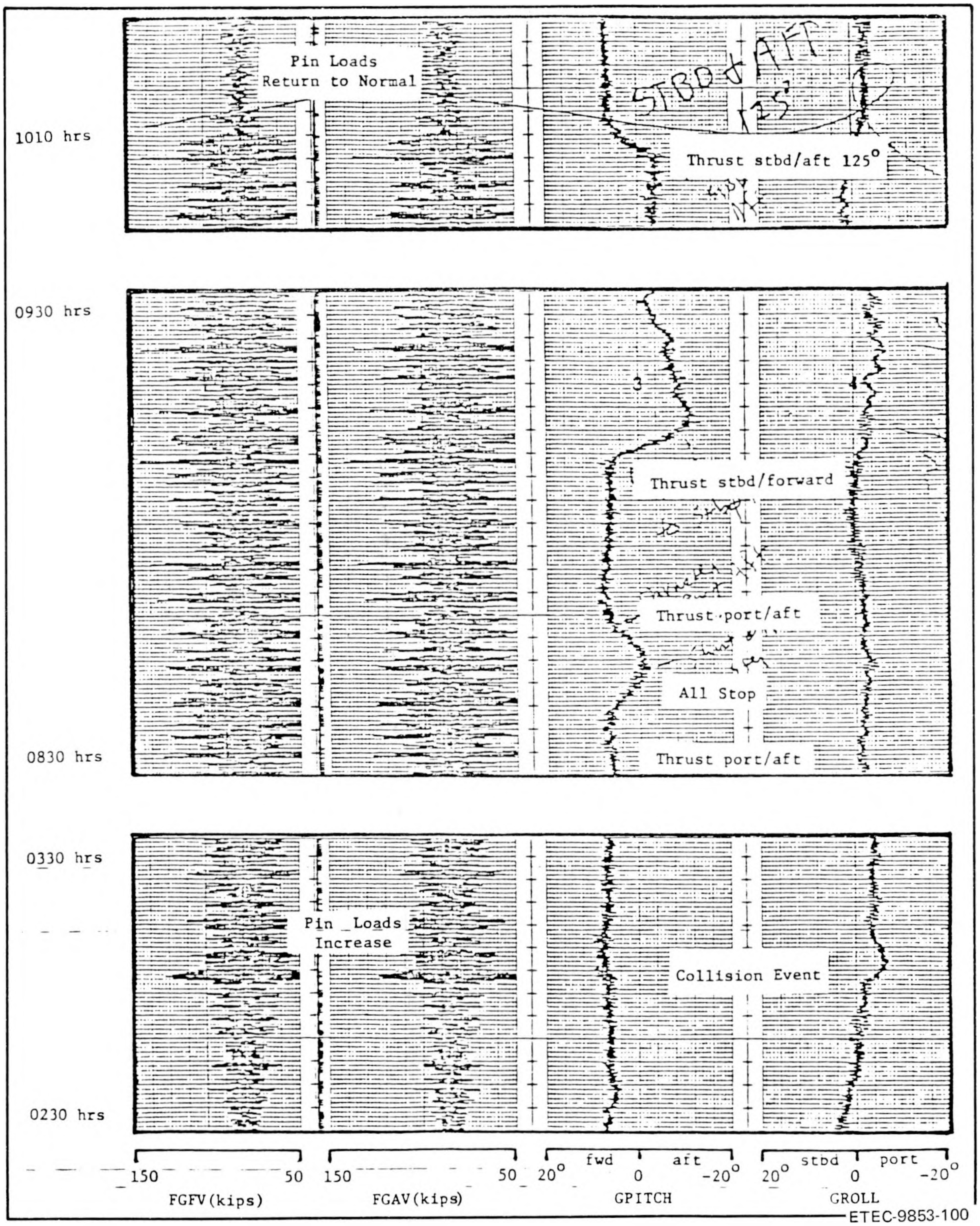

Figure 3-15. Strip Chart Record of Vertical Gimbal Loads and Gimbal Angles for Three Periods on 22 February 1981

to the open sea. Thus, the total chlorine concentration discharged was 0.20 ppm for 2 h in a 24-h period (the EPA permit maximum). This value was only exceeded four times (with ±0.05-ppm tolerance) from a total of 206 chlorine applications of the heat exchangers. Not accurately knowing the seawater flow rate of each system complicated making the chlorination concentration adjustments. Also, the warm water concentration readings were initially masked because of iron oxide in the system and sample line. Details of the chlorination system operating experience are given in Section IV.E. The chlorine concentration was measured by the AECOS laboratory technician in a sample because the on-line instrumentation was never fully functional.

One experimental variable was the concentration of chlorine necessary to control fouling. The test period did not last long enough to reach the reduction initiation step. The parasitic loads on a commercial OTEC facility would not be significant at the EPA maximum limit, however. The Amertap system utilized biodegradable sponge-rubber balls to mechanically clean the inside of the heat exchanger tubes. The system was operated for about 3 months during ammonia system operation with a ball consumption rate of approximately 210 balls (35% of the inventory) and 415 balls (70% of the inventory) per week for the evaporator and condenser, respectively. The system was stopped about 5 weeks before the chlorination, and the seawater systems were shut down at the end of the first deployment. Details of the Amertap system operating experience are given in Section IV.D.

The heat exchanger titanium tubes received posttest visual inspection (see Sections V.A and V.B) and were found to be clean and in excellent condition. Thus, early shutdown of the Amertap system did not seem to affect tube biofouling, at least for the 5-week period.

5. Biofouling and Corrosion Modules

Testing with the BCMs began in November 1980 with the startup of the two heat exchanger tracking modules (BCMs 1 and 8). The warm and cold seawater free-fouling modules were placed on-line in the middle of January 1981 (BCMs 2 and 5). The remaining modules using various biofouling countermeasure schemes were started in the middle of February 1981. All units were shut down on 12 April 1981, just before final system shutdown.

At shutdown, over 3,000 tests (cooldown curves) had been completed and recorded by the DAS. This was the method used to determine changes in the fouling resistance (R_f) of the seawater side of the BCM tubes due to biofouling. Although the time available for obtaining biofouling data was limited, preliminary results from these BCMs indicated the following (see Ref. 14):

1) There was no evidence of heat exchanger tube-side fouling, as inferred from measurements with BCMs 1 and 8. This result was confirmed by the heat exchanger test results, which showed no performance degradation with time.[11]
2) No indication of an increase in fouling resistance was noted in the cold untreated raw seawater module (BCM 5).
3) There were indications of some fouling of the warm untreated raw seawater module (BCM 2). This result was confirmed when manual brush cleaning of the BCM restored the fouling factor to zero. This was just before the final shutdown in April 1981.

After shutdown, sections of tubing were removed from the various BCMs and transferred to the University of Hawaii for analysis under ANL cognizance. No coating of the inside of the tubes was noted by visual inspection. Final, detailed laboratory results are discussed in Ref. 14.

The water system piping and heat exchanger water boxes were inspected for macrofouling by the U of H personnel (see Ref. 14).

D. ONBOARD ENVIRONMENTAL MONITORING

Onboard environmental monitoring and water quality measurements were performed by AECOS, a subcontractor to LBL, utilizing onboard instrumentation and the OEC Environmental Laboratory.

Twenty-one effluent streams were measured on the OEC in compliance with the EPA permit (NPDES Permit No. HI0110272). Residual chlorine in the seawater systems was of critical importance, as noted in Section III.C.4. This analysis was performed real-time in the Environmental Laboratory. In addition, numerous shipboard environment-related measurements were made and logged, including wind speed and direction, barometric pressure, air temperature and dew point, etc. (see Figure 3-16). Also, the abundance of fish in the vicinity of the OEC was visually monitored. As expected, the OEC, the moor, and its buoys attracted many fish, as evidenced by the increasing population of fishing boats in the area and estimates of their daily catch.

A wave-rider buoy attached to one of the three moored current meter strings around the OEC transmitted wave height data via a telemetry link directly to the OEC. During the test period, the maximum wave height experienced was about 15 ft. The normal range was about 3 to 6 ft.

Although not a part of the planned environmental monitoring, the U.S. Navy conducted a "noise" characterization of the OEC, with all water systems operating, for the purpose of acoustic identity.[20]

The only major problem encountered on board the OEC from an environmental standpoint was the loss of the MWD pipe. This made it necessary to notify the Region IX EPA, since the EPA permit specified discharge of the mixed seawater at 73 m below the ocean surface. The EPA allowed continued operation while a fix to the system was being designed. This fix was not completed due to the early termination of the test program. However, plume studies performed just before final shutdown to track the dispersion pattern of the MWD, utilizing fluorescent dyes, indicated that the discharge submerged and dissipated very rapidly.[5, 28]

TE / ME	OBSERVER'S INITIALS	WIND (1) SPEED	WIND (1) DIRECTION	SHIPS (1) HEADING	WAVE RIDER AMPLITUDE	[illegible] TEMP.	WET BULB TEMP.	BAROMETRIC PRESSURE	CURRENT (2) SPEED	CURRENT (2) DIRECTION	+P -S	+F -A	REMARKS	CWP AND BRG° (GEN)/DIST (FT).
EB 81 00	JJa	5	301	021	1.1	84	74	1016.4	NOT OPERABLE		+3	-4	5.0	211°/200
330	JJa	10	297	357	0.8	85	74	1016.1			+6	-3	6.7	206°/195
800	JJa	9	303	348	0.8	81	74	1016.1			+6	-3	6.7	207°/185
[illegible]	JJa	12	000	340	1.0	76	71	1016.4			+3/-1	-2	2.7	198°/195
200	JJa	10	010	345	0.8	75	71	1016.8			+2/-1	-2	2.1	195°/160
FEB 81 000	MK	8	020	000°	0.4	76	71	1016.8			+3	+1	3.4	200°/160
200	MK	8	090	008	1.1	75	69	1014.5			+4	+1	4.1	190°/210
400	MK	6	085	005	2.0	75	70	1014.5			+4	+1	4.1	205°/190
600	MK	4	080	000	1.6	75	69	1014.5			+3	0	3.0	150°/200
800	MK	16	045	010	2.2	76	70	1017.2			-2	+1	2.4	160°/110
1000	MK	8	045	014	1.8	82	72	1018.0			+4/-4	0	0	155°/130
1200	JJa	22	031	031	2.0	82	71	1017.0			+3/-2	+2	2.1	168°/105
1400	JJa	25	015	025	2.1	83	72	1015.6			+5/-2	-2	2.5	155°/135
1600	JJa	22	024	024	1.7	80	71	1015.2			+3/-2	-2	2.1	166°/200
1800	JJa	8	053	023	1.8	78	71	1015.2			+2/-1	0	0.5	198°/170
2000	JJa	15	017	032	1.5	76	70	1016.1			+2	+4	4.5	210°/120
2200	JJa	12	037	032	1.6	75	68	1016.5			+2	+4	4.5	203°/140
FEB 81 0000	MK	16	075	042	1.0	75	68	1016.2			0	+5	5.0	195°/110
0200	MK	18	065	065	1.5	75	67	1015.8			+2	+4	4.5	210°/150'
0400	MK	10	085	051	1.0	74	68	1015.5			+1	+3	3.4	200°/170'
0600	MK	10	085	036	1.0	74	67	1015.8			+2	+5	5.4	200°/150'
0800	MK	6	085	016	1.0	76	70	1014.5			+2	+2	2.8	210°/140

Figure 3-16. Environmental Data Collection

E. CONCLUSIONS

Major conclusions include the following:

1) The predictions of the performance of the heat exchanger smooth tubes were validated; the enhanced tube ammonia side performance was highly susceptible to contaminants.
2) The biofouling countermeasures, as applied, were effective in controlling growth, although the measures may have been more intensive than necessary.
3) The OTEC-1 operations had little or no measurable effect on the environment, and the facility withstood the rigors imposed by the environment during the most severe season of the year.
4) The key features of OTEC-1 were demonstrated to be practical solutions to the specified requirements, including: mooring, CWP, platform operations at sea, and ship/shore logistics.
5) The major objectives that were not achieved were related to the limited test time with respect to biofouling countermeasure optimization, corrosion sample exposure duration, and long-term environmental effects. This excludes the failure of the MWD pipe, which was inadequate in design.

5004K/jbv

IV. TEST OPERATIONS EXPERIENCE

A. GENERAL

Operation of the OEC for over 5 months produced valuable information pertinent to the operation of future OTEC plants. Overall, the entire system of this ocean-based platform operated successfully, and thermal-hydraulic performance data of the 1-MWe shell-and-tube evaporator and condenser heat exchangers were obtained. The short-term effectiveness of the Amertap system with intermittent chlorination for controlling microfouling was evaluated. Data for determining the effect of the OTEC-1 platform and the operation of the power system on the ambient ocean environment were obtained.

The test operations experience was summarized using the OTEC-1 Weekly Flash Report (shown in Figure 4-1). Summaries and recurring problems for the various systems are discussed below.

1. Seawater Systems

The warm, cold, and mixed seawater systems were operated at the mooring site over a period of about 5 months. These pumps were operated during OTEC-mode tests; these tests yielded heat transfer test data for both the evaporator and the condenser heat exchangers. The pumped seawater was also used for BCM studies and posttest system condition results.

Problems in starting the warm and mixed water pumps were eliminated by changing the procedure used for starting the pumps. The problem of entrained air in the pumped seawater was a recurring one. Although air content was drastically reduced by raising the water level in the warm water sump, enough entrained air bubbles were present to prevent the ultrasonic flowmeters from functioning properly.

OTEC-1 Weekly Flash Report
(Week Ending ____________)

To: ETEC Headquarters, P.O. Box 1449, Canoga Park, CA
From: Test Director, OEC, Hawaii

1. Warm Water Pump:
2. Cold Water Pump:
3. Mixed Water Pump:
4. NH_3 System:
5. Chlorination System:
6. Amertap System:
7. Biofouling & Corrosion Modules:
8. Sea Conditions:
   a) Maximum wave amplitude: ____________
   b) Nominal wave amplitude: ____________
   c) Current data: ____________
   d) Maximum wind velocity: ____________
   e) Nominal wind velocity: ____________
9. Gimbal Assembly:
   a) Maximum roll: ____________
   b) Nominal roll: ____________
   c) Maximum pitch: ____________
   d) Nominal pitch: ____________
   e) Maximum vertical load: ____________
   f) Nominal vertical load: ____________
10. Ship:
    a) Maximum roll: ____________
    b) Nominal roll: ____________
    c) Maximum pitch: ____________
    d) Nominal pitch: ____________

____________ Test Director ____________ Date

11. Ship's Systems

____
____
____

____________ Tracor Marine ____________ Date

Figure 4-1. OTEC-1 Weekly Flash Report

2. Ammonia System

The ammonia system was operated over a period of about 3 months. The 106 tests conducted produced heat transfer data and provided valuable experience in the operation of an OTEC plant.

Recurring problems with noise, contamination, leakage, and ammonia sampling were encountered. Recommendations and standard operating procedures were developed and are presented.

3. Amertap System

The Amertap system, which circulated biodegradable sponge-rubber balls, performed as designed over its scheduled operating period of about 4 months. Using the Amertap system in conjunction with the chlorination system appears to be effective for biofouling protection. The Amertap system was stopped 5 weeks before the end of testing. The heat exchangers remained clean using Amertap and chlorination. It was not determined if either Amertap or chlorine alone would have kept the heat exchangers clean.

4. Chlorination System

This unit performed satisfactorily over the entire operational period of about 5 months. Target values of 0.4- to 0.5-ppm chlorine concentration for 1 h/day at the inlets of each heat exchanger and maximum concentration of 0.2 ppm at the MWD were usually obtained. Out of the 206 chlorine applications, the MWD limit (with $\pm$0.05-ppm tolerance) was exceeded only four times.

5. Biofouling and Corrosion Modules

Eight BCM units (four warm and four cold) were put in operation; but because of problems with the seawater supply pump, only six units were used to obtain data. Since the sample tubes exposed to seawater remained clean throughout the experiment, it was not possible to correlate fouling to heat transfer performance. A rust film covered the ID of some of the warm water tube samples. This is attributed to the rusting of various components in the warm water loop.

6. Instrumentation and Control

Problems were uncovered with the I&C system. Once these were corrected, testing and data acquisition were performed to determine heat exchanger performance. Numerous I&C problems were corrected, and recommendations were developed for minimizing problems on future OTEC plants. A copper block technique to verify resistance temperature detector (RTD) calibrations was developed and used.

7. Environmental Monitoring

Environmental studies conducted aboard the OEC followed the requirements of National Pollutant Discharge Elimination System (NPDES) permit HI0110272 (effluent limitations and monitoring requirements). Effluents measured included evaporator, condenser, mixed water, deck drainage, sanitary wastes, domestic wastes, ballast water, bilge water (OTEC compartment), engine cooling water, seawater from fire pumps, boiler blowdown, distillation plant brine, and refrigerator cooling water. Meteorological data included wind speed and direction, wet and dry bulb temperatures, and barometric pressure. Samples were evaluated aboard the OEC using the environmental laboratory or were sent to shore for analysis.

8. Cold Water Pipe

The CWP was installed on the OEC and was used for about 5 months to supply cold seawater to the condenser. The system performed successfully. During one episode when high currents and sea conditions made it necessary to release the mooring line, the OEC performed under the "grazing" mode.

9. Mixed Water Discharge

The MWD hose did not perform as designed. The flexible hose material would tear apart as discharged seawater inflated it. The design was modified and stronger materials were used, but the hose continued to tear. After numerous attempts, the MWD hose was eliminated and the seawater was released directly under the ship's hull. This is discussed in more detail in Section IV.J. The NPDES permit (HI0110272) was modified to permit MWD release effectively at the ocean surface.

10. Stationkeeping

For over 5 months, the FOC performed station-keeping of the OEC. During one period of about 2 days, the ship left its mooring site because of large gimbal angles caused by high currents. Originally, it was not possible to determine the location of the mooring line and mass anchor with respect to the CWP. Use of a mini-ranger system improved this situation. During heavy seas, high currents, and strong winds, the two thrusters were not able to position the ship as required.

B. SEAWATER SYSTEMS

The seawater systems, which comprise the warm, cold, and mixed water systems, were operated over a period of about 5 months. Running the OTEC-1 seawater systems produced valuable knowledge and experience in the operation of an OTEC plant. Problems with air entrainment and pump startup are discussed. Recommendations and standard operating procedures were developed and are presented. These systems generally performed satisfactorily over the entire operational period.

1. Test Operations

This section describes the test operations and experience obtained during checkout and operation of the warm, cold, and mixed water systems.

a. Warm Water System

The operational log for the warm water pump (P-101) is given in Table 4-1. The system began operation on 6 August 1980 and was shut down on 12 April 1981 after 2535.7 h of actual operation. The warm water system generally operated as required. Two problem areas were pump startup and entrained air in the pumped seawater.

(1) Pump Startup

The warm water circuit was designed as a syphon (Figure 2-4). Originally, the pump was started at low speed (about 10% power), then pump power was slowly increased until the ducting and evaporator were filled with water. Air from the loop was vented through the high-point vent valves (V-180, V-183, V-184, and V-187). The pump was then brought up to 100% power to remove any remaining air by sweep entrainment.

During startup checkout tests, the pump operated at a flow rate/speed ratio (Q/N) much lower than its design or best-efficiency point (BEP). This increased the net positive suction head (NPSH) requirement or critical NPSH, causing pump cavitation and high mixing losses, which in turn caused severe pump vibrations. These vibrations continued until syphon was established, at which time the pump operated quietly at about design (Q/N). The duration of startup — about 5 min — was reduced by starting the pump at 20% power then quickly increasing power to 100%. Appendix A gives the standard operating procedure used for warm water startup during the OTEC-1 program.

Startup of the warm water pump was aided, when possible, by raising the warm water sump water level and reducing the mixed water sump water level (thus reducing the back pressure). The level of the warm water sump was raised by pulling a vacuum on the sump compartment. This raised the water level about 10 ft. If the cold water pump was operational, vacuum was provided by using a cold water outlet vent valve (Figure 2-5). If the mixed

TABLE 4-1

WARM WATER PUMP (P-101) OPERATIONAL LOG
(Sheet 1 of 2)

Date	Pump Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
06 Aug 80	0834	0903	0.48	Checkout test and MWD pipe verification testing
07 Aug 80	0950	0958	0.13	
08 Aug 80	1200	1215	0.25	Evaporator drained, HX tube leak discovered
11 Nov 80	1600			Continue checkout and MWD pipe verification testing
12 Nov 80		1025	18.42	Sonic flowmeter and level sensor checkout
	1327			
13 Nov 80		0941	20.23	Evaporator drained, pump/motor coupling checked, power switchover
	1841			
14 Nov 80		1420	19.65	24 V to SCR off
	1433			
15 Nov 80		1404	23.52	Evaporator drained, SCR checked
18 Nov 80	1356			SCR repaired
19 Nov 80		1200	22.07	Ship lost power
	1237			
21 Nov 80		1405	49.46	Ship lost power
	1410			
25 Nov 80		1848	100.63	Evaporator drained, Chloropac pump reworked
12 Dec 80	1431			Chloropac pump repaired
13 Dec 80		0617	15.77	Planned shutdown
	0810	1105	2.92	Evaporator drained, RTD and instrument loop reworked
21 Dec 80	0919			
22 Dec 80		0845	23.43	Pump water seal supply line replaced
	0902			

TABLE 4-1

WARM WATER PUMP (P-101) OPERATIONAL LOG
(Sheet 2 of 2)

Date	Pump Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
24 Dec 80		0805	47.04	Level sensor hookup
	0920			
25 Dec 80		0808	22.80	Ship lost power
	0900			
03 Jan 81		0420	211.33	Ship lost power
	0440			
14 Jan 81		0603	265.38	Hookup of air conditioning ducts to SCRs
	0740			
19 Jan 81		1500	127.33	Inadvertent pump trip during terminal board work
	1505			
02 Feb 81		1320	334.25	Repaired level sensor and motor fan; inspected chlorine distributor manifold in warm water sump
	1610			
10 Feb 81		1144	187.57	Pump dropout, cause unknown
	1150			
01 Mar 81		1307	456.95	Ship lost power
	1325			
		1336	0.18	Ship lost power
	1410			
05 Mar 81		0946	91.60	Evaporator drained, ship on marine power
06 Mar 81	2229			Back to moor, ship off marine power
02 Apr 81		1520	639.33	Evaporator drained, inspect ammonia nozzles
10 Apr 81	0930			MWD plume studies
12 Apr 81		1628	54.97	Planned system shutdown, evaporator drained
Total			2535.69 (3.75 months)	

5005K/sjd

water pump was operational, the mixed water sump level was lowered. The minimum limit of 18 ft was set for this sump for mixed water pump operation. Once the pump was operating at or near the design flow rate, the pump and syphon performed in agreement with the published head-flow (H-Q) performance curve and the calculated system curve for the syphon.

With three water systems, there were six different start modes. Pump operation was dictated by the requirements of the test plan, and special requirements imposed by the FOC and the experimenters. The best start mode was as follows:

1) Start the mixed water pump. Use the eductor system (described in Section IV.B.1.c.1 to start this pump.
2) Start the cold water pump. Use the mixed water pump to lower the water level in the mixed water sump before starting (described in Section IV.B.1.b.1 below).
3) Start the warm water pump. Use the cold water outlet vent valve to raise the water level in the warm water sump before starting. Using this sequence, reduce starting time and the amount of time spent in off-design pump operation, thereby minimizing pump cavitation and vibration.

(2) <u>System Operation</u>

Generally, this system operated satisfactorily, with tests being conducted as requested by the experimenters and the FOC. One major problem discovered was the presence of entrained air in the water from the warm water sump. The cause was found to be an error in the design of the sump. (This problem is analyzed in Appendix B.) The entrained air caused the sonic flowmeter used to measure warm water flow rate to malfunction. Section IV.G discusses this problem. Using vacuum in the warm water sump raised the water level, which made it easier to start the pump, and drastically reduced the amount of entrained air. Figures 4-2 and 4-3 show the pumped seawater at the first elbow, showing the results obtained before and after the application of

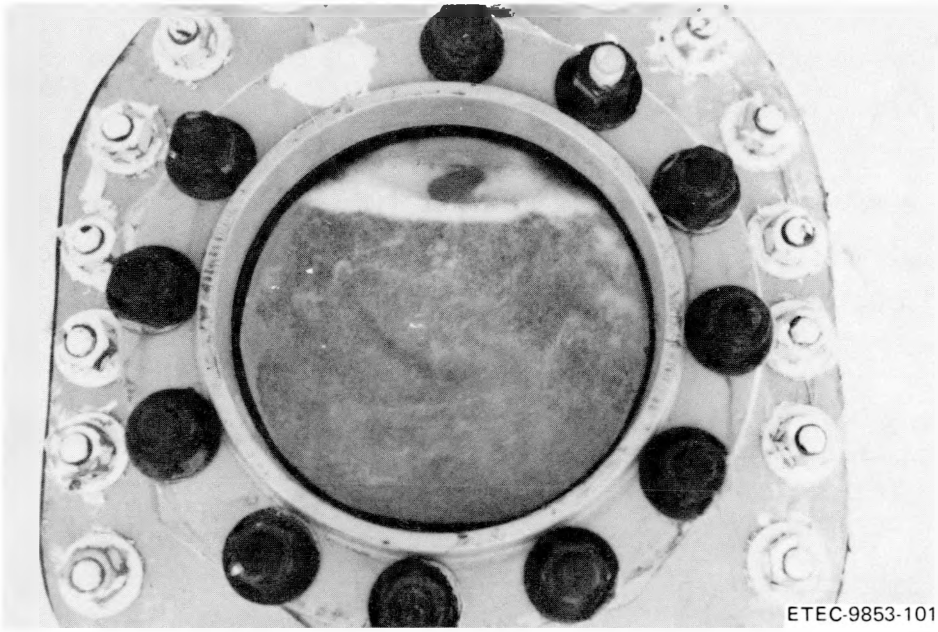

Figure 4-2. Warm Seawater First Elbow Before Vacuum

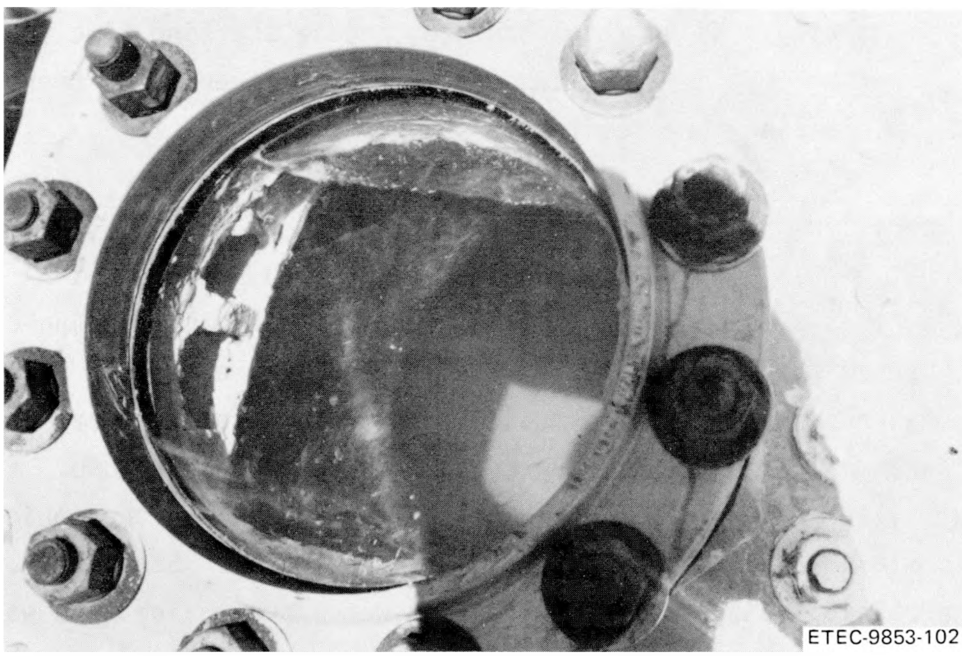

Figure 4-3. Warm Seawater First Elbow After Vacuum

the vacuum. As the figures show, the reduction in air was substantial, but not enough to permit the sonic flowmeter to operate over its full range (it could only go to 60% pump power).

By sealing the warm water sump and running the pump, a self-induced vacuum of 5- to 5.5-in. Hg was maintained. This setup was used during all OTEC-mode operation tests. Table 4-1 gives the operational log of the warm water pump. Several minor problems — loosening of the pump-to-motor coupling bolts, stretching of the pump motor fan belt, and corrosion of the pump seal lubrication line — were encountered that required adjustments or repairs. The first two problems were easily corrected by tightening and readjustment; to correct the third, the corroded 304 SS 1/2-in. tubing was replaced by 316 SS 1/2-in. tubing.

The warm water system (also cold and mixed) was monitored daily by test director contractor (TDC) personnel. Data sheets used by both ETEC shift 1 and shift 2 personnel are found in Tables 4-2 and 4-3, respectively.

The warm water system was drained eight times (see Table 4-1). The standard operating procedure for warm water system shutdown is given in Appendix C. This procedure had to be followed to assure that the system syphon was broken before the evaporator was drained. Otherwise, water from the mixed water sump would continue to flow through the system in the reverse direction. During nonscheduled shutdowns of the warm (or cold) water pump, this reverse flow would carry Amertap balls from the heat exchanger to the inlet sump if the syphon were not broken. Once these balls entered the inlet sump, they would be susceptible to entering and blocking the BCM inlet supply line and filter (see Section IV.F). The evaporator had to be drained if the system was down for more than 2 h (per ANL request). The plume studies were completed on 12 April 1981; the system was then shut down, drained, and secured.

TABLE 4-2

SHIFT 1 DAILY TASKS
(0000 Hours to 1200 Hours)

Date: ____________________

Note: Person taking data will carry walkie talkie and will key to van walkie talkie.

A. Pump Data	WWP (SCR 4)	CWP (SCR 3)	MWP (SCR 6)
1. Time:			
Power (%)			
Volts, V (Seq's. 443, 445, 439)			
Amps, A (Seq's. 442, 444, 438)			
Amertap screen ΔP (in. H_2O)			-
Amertap ball monitor (%)			-
Sump height (ft)			
2. Time:			
Power (%)			
Volts, V (Seq's. 443, 445, 439)			
Amps, A (Seq's. 442, 444, 438)			
Amertap screen ΔP (in. H_2O)			-
Amertap ball monitor (%)			-
Sump height (ft)			
3. Time:			
Power (%)			
Volts, V (Seq's. 443, 445, 439)			
Amps, A (Seq's. 442, 444, 438)			
Amertap screen ΔP (in. H_2O)			-
Amertap ball monitor (%)			-
Sump height (ft)			
4. Time:			
Power (%)			
Volts, V (Seq's. 443, 445, 439)			
Amps, A (Seq's. 442, 444, 438)			
Amertap screen ΔP (in. H_2O)			-
Amertap ball monitor (%)			-
Sump height (ft)			

B. Drain Instru. Air Equip.	Time	
New compressor tank	1st	2nd
Air filter	1st	2nd

Shift Leader Sig. ____________________

TABLE 4-3

SHIFT 2 DAILY TASKS
(1200 Hours to 2400 Hours)

Date: ____________________

Note: Person taking data will carry walkie talkie and will key to van walkie talkie.

A. Pump Data	P-101 WWP (SCR 4)	P-103 CWP (SCR 3)	P-100 MWP (SCR 6)
1. Time: ______			
Power (%)			
Volts, V (Seq's. 443, 445, 439)			
Amps, A (Seq's. 442, 444, 438)			
Amertap screen ΔP (in. H_2O)			
Amertap ball monitor (%)			
Sump height (ft)			
2. Time: ______			
Power (%)			
Volts, V (Seq's. 443, 445, 439)			
Amps, A (Seq's. 442, 444, 438)			
Amertap screen ΔP (in. H_2O)			
Amertap ball monitor (%)			
Sump height (ft)			

B. Drain Instru. Air Equip.	Time	
New compressor tank	1st	2nd
Air filter	1st	2nd

C. Perform HTM Daily Rept. Summary

Time (between 2200 and 2400 hours) ______

Shift Leader Sig. ____________________

b. Cold Water System

The operational log for the cold water pump (P-103) is given in Table 4-4. The system began operation at the mooring site on 12 November 1980 and was shut down on 12 April 1981, after 2711.5 h of total test time. Generally, the cold water system operated as required. But the two problem areas encountered in the warm water system were also found in this system: pump startup and air entrained in the pumped seawater.

(1) Pump Startup

The cold water circuit was also designed as a syphon. The same modified start procedures were used as with the warm water system. Appendix D presents the standard operating procedure for cold water pump startup. By first running the mixed water pump, the mixed water sump level was reduced from a normal 24 ft to 18 ft (minimum). This lower elevation reduced the back-pressure of the cold water system, thus allowing the cold water pump to start and reach its design point quickly. This procedure decreased cold water pump operation in cavitation and vibration modes.

(2) System Operation

Generally, this system operated well, with tests being conducted as requested by the experimenters and the FOC. Voids in the seawater flow prevented the sonic flowmeter from functioning properly (see Section IV.G). With a ship's draft of 24 ft (normal), the moonpool level was normally 21 ft under no-flow conditions due to the specific weight difference between the cold and warm seawater. The seawater level of the moonpool decreased another 4 to 5 ft when the pump was started due to drawdown of the cold water sump. During long periods (over 3 to 4 days) of down time, stagnant seawater in the moonpool and cold water sump would become green due to algae growth. This seawater was pumped overboard to clear out the stagnant water. To prevent this green algae

TABLE 4-4

COLD WATER PUMP (P-103) OPERATIONAL LOG
(Sheet 1 of 2)

Date	Pump Operation Start Time (hours)	Pump Operation Stop Time (hours)	Duration (h)	Remarks
12 Nov 80	1835			Checkout tests
13 Nov 80		0727	12.87	Condenser drained, power switchover
	1240	1314	0.57	Checked pump/motor coupling
	1522	1528	0.10	Lost power to pump motor
	1536			
14 Nov 80		1145	20.15	Lost power to pump motor
	1247			
15 Nov 80		1404	25.28	Condenser drained, SCR (silicon-controlled rectifier) checked
18 Nov 80	1411			SCR repaired
19 Nov 80		1200	21.81	Ship lost power
	1240			
22 Nov 80		1405	49.42	Ship lost power
	1410			
23 Nov 80		2200	55.83	Pump lost prime
24 Nov 80	1154			
25 Nov 80		1848	30.90	Condenser drained, Chloropac pump repaired
11 Dec 80	1014	1045	0.52	Chloropac pump repaired
22 Dec 80	1130			
25 Dec 80		0808	68.63	Ship lost power
	0900			
03 Jan 81		0420	211.33	Ship lost power
	0440			
09 Jan 81		1159	151.32	Condenser drained, sonic flowmeter removed
13 Jan 81	1255			

TABLE 4-4

COLD WATER PUMP (P-103) OPERATIONAL LOG
(Sheet 2 of 2)

Date	Pump Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
02 Feb 81		1255	480.00	Line power off
	1305			
03 Feb 81		1015	21.17	Condenser drained, problems with ship's boilers
04 Feb 81	1300			
16 Feb 81		1600	291.00	Pump lost prime
17 Feb 81	0200			
25 Feb 81		0708	197.13	Investigated noise from moonpool
	0855			
26 Feb 81		0910	24.25	Inspected gimbal socket
	0926			
01 Mar 81		1307	99.93	Ship lost power
	1318	1336	0.30	Ship lost power
	1355			
03 Mar 81		0920	43.42	High-point vent valve opened by experimenters
	0924			
05 Mar 81		0946	48.37	Condenser drained, ship on marine power
06 Mar 81	2250			Back on moor, ship off marine power
12 Mar 81		1910	140.33	Inadvertent pump trip while working on control panel
	1920			
12 Apr 81		1628	741.13	Planned system shutdown, condenser drained
Total			2711.52 (3.71 months)	

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seawater from being pumped through the condenser, this was also done before the system was started up. Similar minor problems as encountered in the warm water system were also met and corrected.

The cold water system was drained seven times (see Table 4-4); the standard operating procedure for cold water system shutdown is given in Appendix E. The shutdown and draining precautions used for the warm water system were also followed. The plume studies were completed on 12 April 1981; the system was then shut down, drained, and secured.

c. Mixed Water System

The operational log for the mixed water pump (P-100) is given in Table 4-5. The system began operation on 5 August 1980 and was shut down on 12 April 1981, after 2804.6 h of total test time. Generally, the mixed water system operated as required. But the two problem areas encountered in the warm and cold water system were also found in this system: pump startup and air entrained in the pumped seawater. The MWD hose, which continued to tear apart, was also a problem and is discussed in Section IV.J.

(1) Pump Startup

To protect the deep water discharge hose from damage and to assist pump startup by priming, an eductor system was installed on the MWD pipe. This system used a venturi pump driven by an existing ship's water pump to decrease the pressure in the mixed water pipe. About a 10-in. Hg vacuum was pulled before the mixed water pump was started. Although this procedure did not solve the problem of damage to the deep water discharge hose, it did facilitate starting the MWD pump quickly and easily, without cavitation and vibration. The standard operating procedure for mixed water pump startup and shutdown is presented in Appendix F.

TABLE 4-5

MIXED WATER PUMP (P-100) OPERATIONAL LOG
(Sheet 1 of 3)

Date	Pump Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
05 Aug 80	1701	1706	0.08	Checkout tests and MWD hose verification tests
	1711	1714	0.05	
06 Aug 80	1300	1306	0.10	Checkout tests
	1410	1415	0.08	Checkout tests
	1440	1500	0.33	Checkout tests
07 Aug 80	0900	0903	0.05	MWD hose failed
02 Oct 80	1152	1210	0.30	Checkout of MWD hose eductor system
03 Oct 80	0825	0910	0.75	Checkout of MWD hose
04 Oct 80	0830	1315	4.75	Facing between fourth and fifth sections of MWD hose failed
07 Oct 80	0848	1325	4.62	Successful MWD hose test, preparing for trip to Honolulu
07 Nov 80	1925			
08 Nov 80		0950	14.42	Lost power to pump motor
	0955			
09 Nov 80		0540	19.75	SCR controller problem
	0930	1113	17.17	Lost signal to SCR
	1118	1730	6.2	24-Vdc power supply turned off causing stoppage
	1735			
10 Nov 80		0730	13.92	SCR controller problem
	1000	1200	3.00	Planned shutdown, MWD hose failed
11 Nov 80	1225			
12 Nov 80		1025	22.00	Sonic flowmeter and level sensor checkout
	1255	1450	1.92	SCR card used for cold water pump start
13 Nov 80	1820			
14 Nov 80		1245	18.42	Lost power to pump motor, checked pump/motor coupling
	1255	1310	0.25	Planned shutdown for SCR work

TABLE 4-5

MIXED WATER PUMP (P-100) OPERATIONAL LOG
(Sheet 2 of 3)

Date	Pump Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
15 Nov 80	1045	1404	3.32	Planned shutdown for SCR repair
18 Nov 80	1417			
19 Nov 80		1200	21.72	Ship lost power
	1243			
21 Nov 80		1405	49.37	Ship lost power
	1410			
25 Nov 80		1848	100.63	Chloropac pump rework
11 Dec 80	1545			MWD hose tests
13 Dec 80		0617	38.53	Planned shutdown
	0810	1105	2.92	Planned shutdown
	1635			
25 Dec 80		0808	279.55	Ship lost power
	0900			
03 Jan 81		0420	212.33	Ship lost power
	0440			
14 Jan 81		0603	265.38	Hookup of air conditioning ducts to SCRs
	0740			
03 Feb 81		1015	482.58	Problem with ship's boilers
04 Feb 81	1125			
10 Feb 81		1212	144.78	Pump dropout, cause unknown
	1220			
16 Feb 81		0841	140.35	Planned shutdown, conserve fuel
19 Feb 81	1307	1620	0.22	Pump started during Amertap ball flushing
21 Feb 81	0220			Sonic flowmeter tests
24 Feb 81		1530	85.17	Starboard list required due to gimbal angle
	1741	1940	1.98	Change of boiler burner heads
	1945			

TABLE 4-5

MIXED WATER PUMP (P-100) OPERATIONAL LOG
(Sheet 3 of 3)

Date	Pump Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
25 Feb 81		0708	11.38	Investigate noise from moonpool
	0855			
28 Feb 81		0010	63.25	Starboard list required
	0720			
01 Mar 81		1307	29.78	Ship lost power
	1325	1336	0.18	Ship lost power
	1410			
04 Mar 81		1630	74.33	Additional power required by ship's thrusters
	1815			
05 Mar 81		0946	15.52	Ship on marine power
06 Mar 81	2243			Back on moor, ship off marine power
12 Mar 81		1910	140.45	Inadvertent pump trip while working on control panel
	1920			
26 Mar 81		1430	331.17	Planned shutdown, conserve fuel
28 Mar 81	0847			
02 Apr 81		1520	126.55	Planned shutdown, pump not required
10 Apr 81	0930			Plume tests
12 Apr 81		1628	54.97	Planned system shutdown
Total			2804.57 (3.84 months)	

(2) System Operation

Generally, this system operated well, except for the failures of the MWD hose (see Section IV.J). Tests were conducted as requested by the FOC and experimenters. During pump operation, the MWD sump could be lowered well below the nominal water line, which facilitated starting the cold and warm water pumps. A minimum level of 18 ft (24 to 26 ft was normal) was set to preclude incipient cavitation of the pump.

The sonic flowmeter for the mixed water pump did not perform satisfactorily because of entrained air. Flow-rate data used for environmental reporting were estimated by adding flow rates of the warm and cold water pumps.

On a few occasions, the MWD pump was used to cause the ship to list quickly. This action was taken when a large gimbal roll (GROLL) angle occurred as a result of high currents and heavy seas. With a GROLL to port, the pump was shut down and the system drained, thereby deballasting the vessel. This technique quickly produced a list of about 12° starboard, which in turn decreased the CWP angle by this amount.

Minor problems similar to those encountered with the warm water system were also encountered. Table 4-5 gives the operational log with reasons for stopping the system. The plume studies were completed on 12 April 1981; the system was then shut down, drained, and secured.

2. Recommendations

The experience gained during test operations led to the following recommendations for future pumped seawater OTEC plants:

1) For syphon-type water flow systems, incorporate a line-priming system for pump startup.

2) Eliminate entrained air from the water systems by proper sump design.
3) Where syphon-type water systems are being considered, the absolute pressure of the water should take into account the enhanced evolution of dissolved or entrained gases, which could affect fluid mechanics, pumps, and instruments downstream.
4) Incorporate viewing windows or ports for observing pump sumps and water flow through the system ducting.
5) Use 316 SS material for seawater-exposed applications where corrosion or failure of the component is critical to the operation of the system.
6) For syphon-type water systems, consider the outlet high-point vents as a source of vacuum.
7) Install inlet screens on all seawater inlet supply lines from the inlet sump. The screens should be of low resistance and sized to keep objects like Amertap balls and shrimp from entering the system.
8) Put flowmeters in ducting where the ducting is assured to have full seawater flow for accurate data acquisition.
9) Provide means for changing sump seawater if system is shut down more than 3 to 4 days. This will prevent algae, formed in the stagnant seawater, from entering the system.

C. AMMONIA SYSTEM

1. Summary

The ammonia system was operated over a period covering about 3 months. Performance data from the shell-and-tube heat exchanger were obtained using the simulated 4-MWe configuration. A total of 106 tests (checkout, shakedown, and performance) were conducted with a total ammonia system test duration of 395 h. Running the OTEC-1 test facility produced valuable experience in operating an OTEC plant. Problems were encountered with contamination, noise, and ammonia sampling. Recommendations and standard operating procedures were developed and are presented. Results of the heat exchanger performance tests are given in Ref. 11.

2. Test Operations

The history of the ammonia system, including test operations, is given in Table 4-6. OTEC-mode operation was initiated on 31 December 1980 and completed on 18 March 1981, during which period 395 h of operating experience was accumulated. Shakedown tests were conducted before OTEC-1 test operations (test series I through VI). After these six test series were complete, the ammonia was transferred to the storage tanks and offloaded. The ammonia system was then purged with gaseous nitrogen and secured. Each phase of the operation and the problems encountered with noise, ammonia sample taking, and oil ingestion are discussed below.

a. Initial OTEC-Mode Operation

During a water flow test of the MWD hose, ETEC detected a seawater leak at an evaporator tube. The leak contaminated the ammonia system. The evaporator, drain tank, and accompanying ducting had to be flushed with fresh water and air-blown dry. The leaky tube was plugged, as were 19 other tubes identified as questionable. The ammonia transfer pump (P-402) and blowdown pump (P-403) failed after very short operational periods due to contamination. Both were close-clearance vane-type pumps. These pumps were removed from the ammonia system and not replaced. Ammonia was transferred using the pressure differential created by venting the tank that was to be filled. Using vacuum also provided a positive means of achieving an ammonia atmosphere that was free of moisture and noncondensables. OTEC-mode operation[16] began on 31 December 1980. The F-1 filter, located between the drain tank and the reflux pumps, was cleaned, including any piping found to be dirty. The contamination removed from the piping was analyzed by the ETEC Chemistry Laboratory and found to be primarily magnetite (Fe_3O_4) with some alpha iron and $Fe_2O_3H_2O$. The ammonia power loop was also modified by adding a strainer

TABLE 4-6

AMMONIA SYSTEM HISTORY
(Sheet 1 of 4)

Date	Ammonia System Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
08 Aug 80				Leak of an enhanced tube discovered during warm water pump tests. Evaporator, drain tank, and adjacent ammonia lines flushed out with fresh water and low-point lines opened for drainage. F-1 filter also cleaned out. Entire system air blown dry.
07-09 Sep 80				TAC onsite to examine evaporator tubes
15-19 Sep 80				TAC plugged 5 tubes
13-15 Oct 80				TAC plugged 13 tubes
22-23 Oct 80				TDC epoxied 2 tubes
20 Nov 80				Began loading ammonia into power loop
22 Nov 80				Ammonia removed from power loop and loop vented
27 Nov 80				Ammonia loaded into evaporator drain tank (T-1)
01 Dec 80				Reflux pump P-1 frozen, pump P-2 with electrical problems
02 Dec 80				Replaced bad power supply board on P-2 pump controller, pump operational
03 Dec 80				Transfer pump P-402 frozen
04 Dec 80				Blowdown pump P-403 frozen
06 Dec 80				Pump P-403 removed
07 Dec 80				Pump P-402 removed
08 Dec 80				Pump P-106 (seal replaced) and pump P-1 (weld bead removed from impeller) repaired
16 Dec 80				Ammonia lines cleaned
23 Dec 80				New ammonia filter system installed; inlet trap for pump P-106 installed

TABLE 4-6

AMMONIA SYSTEM HISTORY
(Sheet 2 of 4)

Date	Ammonia System Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
29 Dec 80				Ammonia strainer system checked out
31 Dec 80				Ammonia loaded into power loop
31 Dec 80	2047	2100	0.22	Initial checkout test using P-1 and P-106
02 Jan 81	1415	1505	0.83	Stopped to clean NH_3 strainer
	2100	2335	2.58	Stopped to clean NH_3 strainer; F-1 filter also cleaned on 20 Jan 81
21 Jan 81	1245	1551	3.10	Checked oil seals on P-1 and P-106
23 Jan 81	1120			Test series I started
25 Jan 81		0116	37.93	Pump P-2 required oil
	0300			
26 Jan 81		1205	33.08	Test series I completed; oil added to pump P-2; noise measurements taken
29 Jan 81				NH_3 sample taken from drain tank at 1000 hours, 0.98% moisture
04 Feb 81	2110	2245	1.58	Test series II started; pump P-2 did not start; throttle control board heat sensitive
05 Feb 81	1731	2347	6.26	Dryout of evaporator initiated
06 Feb 81	0935			Dryout completed
09 Feb 81		1440	77.08	Test series II completed
12 Feb 81				Dumped NH_3 from low points
				Began loading NH_3 into system
13 Feb 81				Finished loading NH_3 into system (720 gal total from 24 bottles)
13 Feb 81	1700	1705	0.08	Checkout of NH_3 system instrumentation
	1805			Test series III started
16 Feb 81		0600	59.92	Test series III completed

TABLE 4-6

AMMONIA SYSTEM HISTORY
(Sheet 3 of 4)

Date	Ammonia System Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
16 Feb 81				NH_3 sample taken from drain tank at 1500 hours, 0.62% moisture
20 Feb 81				Dumped NH_3 from low points at 2030 hours
21 Feb 81				NH_3 sample taken from drain tank at 1200 hours, 0.49% moisture
				Distilled NH_3 and dumped residue at 1610 hours
	1831			Test series IV started
23 Feb 81		0830	37.98	Test D completed, test stopped per test procedure
	1315	2315	10.0	Test E completed, test stopped per test procedure
24 Feb 81	0033	0807	7.57	Test series IV completed (testing stopped after test B-1 due to high winds, currents, and seas)
27 Feb 81				NH_3 sample taken from drain tank at 2100 hours, 0.34% moisture
03 Mar 81				Distilled NH_3 and dumped residue at 1650 hours
07 Mar 81				Loaded NH_3 into storage tanks (1800 gal total from 6 tanks)
10 Mar 81	2219			Test series V started
11 Mar 81		1730	19.18	Test 5H completed
	1929	2333	4.07	Test series V completed
13 Mar 81				NH_3 sample taken from drain tank, sample bomb rupture disk failed
14 Mar 81	0815			Test series VI started
17 Mar 81		0620	70.08	Test 80 completed, dryout of evaporator initiated
	0930			Dryout completed

TABLE 4-6

AMMONIA SYSTEM HISTORY
(Sheet 4 of 4)

Date	Ammonia System Operation		Duration (h)	Remarks
	Start Time (hours)	Stop Time (hours)		
18 Mar 81		0900	23.5	Test series VI completed, NH_3 system shut down
Total			395.04	
20 Mar 81				Initiated transfer of NH_3 to storage tanks
21 Mar 81				Completed transfer of NH_3 to storage tanks; initiated venting of NH_3 vapor from power loop
22 Mar 81				Initiated GN_2 purge of NH_3 power loop
27 Mar 81				Initiated pulling vacuum on NH_3 power loop and backfilling with GN_2
30 Mar 81				Vacuum and GN_2 purging secured; removed manway covers to drain tank and evaporator
27 Apr 81				NH_3 sample taken from aft storage tank, no moisture determination due to excessive oil
21 May 81				NH_3 sample taken from aft storage tank, bomb rupture disk leaked
22 May 81				Initiated offloading of NH_3 from forward storage tank
26 May 81				NH_3 sample taken from aft storage tank, 0.53% moisture
29 Mar 81				Completed offloading of NH_3 from both storage tanks
01 Jun 81				Initiated purging storage tanks with GN_2
02 Jun 81				Completed purging storage tanks with GN_2; secured NH_3 system.

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system and a downcomer trap at the inlet to pump P-106. Various instruments were repaired and recalibrated, and ammonia leaks were sealed.

b. Shakedown Tests

Shakedown tests were conducted on 2 and 21 January 1981 (see Table 4-6). During this period, the new ammonia strainer system was cleaned twice, and the F-1 filter was cleaned a second time. Contamination from the loop removed from these filters had an estimated total weight of about 5 lb. Section V.C shows some of the contamination, which consisted mostly of rust scale.

c. Test Operations

Six test series were completed; the results are listed in Table 4-6. These tests were specified by ANL and are tabulated in Table 4-7. Subtotal test periods for each test series are shown in Table 4-8, with a grand total of 365.8 h for all six test series. Table 4-8, the OTEC-mode test operations log, also gives the start and stop dates and times.

(1) OTEC-Mode Noise

The throttle valve (V-111) located in the vapor line between the evaporator and condenser was very noisy during OTEC-mode operation. During the first test series, noise measurements were taken at various locations in and out of the test compartment. The highest reading, 102 dB, was obtained inside the test compartment on the upper-level platform about 15 ft from the throttle valve. This amount of noise made communications between personnel impossible and made mandatory the use of soundproof ear protectors inside the test compartment during testing.

The noise was diagnosed to be typical for a butterfly configuration valve used for throttling. The valve supplier has noise suppression equipment options. Since the valve was an experimental simulation for the turbine,

TABLE 4-7

OTEC-1 TEST OPERATIONS
(Sheet 1 of 4)

Test No.	Evaporator: Approx. Warm Water Flow (gpm, calc.)	Evaporator: Avg. Warm Water Temp. In (°F)	Evaporator: Avg. Warm Water Temp. Out (°F)	Evaporator: Approx. NH_3 Temp. (°F)	Condenser: Approx. Cold Water Flow (gpm, calc.)	Condenser: Avg. Cold Water Temp. In (°F)	Condenser: Avg. Cold Water Temp. Out (°F)	Condenser: Approx. NH_3 Temp. (°F)	Avg. NH_3 Reflux: Low-Press. Top Nozzles (gpm)	Avg. NH_3 Reflux: Mid-Flange Nozzles (gpm)	NH_3 Flow, Cond. to Evap. (gpm)	Remarks
TEST SERIES I (23-26 Jan 81)												
3	82,500	78.6	75.3	72	55,000	42	43	58	2500	0	820	Condenser had noncondensables
3A	82,500	78.4	74.8	72	55,000	42	46	51.5	2500	0	820	Vented noncondensables
4	67,500	78.5	74.4	71	55,000	42	46	51.4	2500	0	820	Evaporator flow reduced
5	82,500	78.4	74.8	72	55,000	42	46	51.5	2500	0	820	Return to baseline
6	82,500	78.2	77.0	76	55,000	42.3	43	47.5	0	450	300	Enhanced tubes only
7	82,500	78.2	74.6	71.6	55,000	42	46	51.4	2050	450	820	Split reflux
8	82,500	78.2	74.6	72	55,000	42.6	46.1	51.6	1650	0	820	Reduced reflux to top only
TEST SERIES II (4-9 Feb 81)												
1	83,000	78	75	71.5	55,000	41.3	44.5	50	2500	0	800	Erratic results due to low-NH_3 inventory
2	83,000	78	74.5	72	55,000	41.5	44	55	0	970	480	Enhanced bundle only
3	83,000	78	74.5	72	55,000	41.6	45	50	950	950	820	Low-pressure top nozzles + midplane nozzles
4	83,000	77.8	74.7	73	55,000	41.5	45.4	50	850	850	800	High-pressure top nozzles + midplane nozzles
5	83,000	77.7	77.7	-	55,000	42.3	42.3	-	0	0	-	Bakeout of enhanced tubes
6	83,000	77.7	76.1	73	55,000	41.2	43	46.5	0	950	430	Enhanced bundle only after bakeout
7	83,000	77.7	76.1	74	55,000	41.6	43.5	47.4	0	800	430	Reduced enhanced bundle flow
8	83,000	77.7	76.1	74	55,000	41.9	43.7	47.6	0	650	440	Further reduced enhanced bundle flow
9	83,000	77.7	76.1	74	55,000	41.7	43.6	47.8	0	500	460	Further reduced enhanced bundle flow
10	83,000	77.6	76.4	73	55,000	41.6	43.4	46.8	0	340	430	Erratic results due to low flows
11	83,000	77.6	74.3	71	55,000	42.6	46.4	51.3	1500	0	800	Baseline low-pressure top nozzles only
12	83,000	77.8	74.6	72	55,000	41.3	45.4	50	1000	0	800	Reduced top bundle reflux
13	83,000	77.8	74.7	70	55,000	41.5	45.3	49.6	800	0	750	Further reduced top bundle reflux
14	83,000	77.8	74.7	72	55,000	41.7	45.4	50.3	650	500	770	Low-pressure top nozzles + midplane nozzles
15	83,000	77.6	74.7	72	55,000	41.3	45.2	50.3	500	500	800	Low-pressure top nozzles + midplane nozzles
16	96,000	77.5	74.3	71	55,000	42.1	46.0	51	1500	0	800	Low-pressure top nozzles and warm water flow at maximum
17	83,000	77.5	75.4	73	55,000	41.4	43.6	47.7	1500	0	500	Warm water flow nominal (80 to 85%) and 60% heat duty
18	83,000	77.5	75.4	73	55,000	41.6	44.0	48.1	1000	0	500	Reduced reflux
19	83,000	77.4	75.5	74	55,000	41.8	44.0	47.9	800	0	500	Further reduced reflux
20	83,000	77.4	74.0	71	55,000	41.9	45.9	50.7	1500	0	820	Baseline 100% heat duty

TABLE 4-7

OTEC-1 TEST OPERATIONS
(Sheet 2 of 4)

Test No.	Evaporator: Approx. Warm Water Flow (gpm, calc.)	Evaporator: Avg. Warm Water Temp. In (°F)	Evaporator: Avg. Warm Water Temp. Out (°F)	Evaporator: Approx. NH_3 Temp. (°F)	Condenser: Approx. Cold Water Flow (gpm, calc.)	Condenser: Avg. Cold Water Temp. In (°F)	Condenser: Avg. Cold Water Temp. Out (°F)	Condenser: Approx. NH_3 Temp. (°F)	Avg. NH_3 Reflux: Low-Press. Top Nozzles (gpm)	Avg. NH_3 Reflux: Mid-Flange Nozzles (gpm)	NH_3 Flow, Cond. to Evap. (gpm)	Remarks
TEST SERIES III (13-16 Feb 81)												
1	86,600	77.4	74.2	71.7	55,000	42.0	45.8	50.5	1500	0	820	Baseline repeat of previous test
2	86,600	77.4	73.8	70.8	55,000	42.0	46.2	51.5	2950	950	930	Evaporator deluge before test 3
3	86,600				55,000							Vented noncondensables from condenser
2A	86,600	77.2	73.7	70.9	55,000	42.1	46.3	50.3	2950	950	930	Evaporator deluge after test 3
4	86,600	77.7	74.4	69.6	55,000	41.9	46.5	50.7	0	950	950	Reduce evaporator pressure to 100 psig and run midplane nozzles only
5	86,600	77.6	74.0	70.6	55,000	41.4	45.9	50.1	2950	950	950	Evaporator deluge after test 4
6[a]	86,600	77.5	75.3	72.1	55,000	41.6	44.6	47.8	0	1000	320	Midplane only with evaporator drain tank bypassed
7	86,600	77.5	74.7	68.4	55,000	41.7	46.3	49.5	0	1000	930	Same as test 6 with evaporator pressure reduced to 100 psig
TEST SERIES IV (21-24 Feb 81)												
A	78,000	77.4	73.7	70.3	55,000	41.9	47.5	50.8	1500	0	820	Baseline (top feed only)
B	82,000	77.0	73.8	70.5	55,000	41.5	46.7	49.8	2000	900	800	Dryout evaluation
C-1	82,000	77.9	75.9	71.7	55,000	41.8	45.3	47.2	0	900	490	Activation studies
C-2	82,000	78.2	75.8	71.3	55,000	41.7	46.3	49.2	0	900	650	Activation studies
D	82,000	77.6	74.1	70.8	55,000	41.7	47.3	50.7	2000	900	800	Repeat dryout
E	82,000	78.0	74.7	71.6	55,000	41.6	47.1	50.2	2000	900	800	Repeat dryout
B-1	82,000	77.7	74.4	71.5	55,000	41.6	46.9	49.9	2000	900	720	Repeat dryout
TEST SERIES V (10-11 Mar 81)												
5A	82,000	76.6	73.7	71.3	55,000	41.8	46.5	49.1	2200	0	640	Baseline (top feed only)
5B	82,000	76.7	73.7	71.2	55,000	42.2	46.8	49.5	1500	0	643	Reflux ratio tests
5C	82,000	76.7	73.8	71.3	55,000	42.3	46.8	49.5	1200	0	648	Reflux ratio tests
5D	82,000	77.1	74.2	71.3	55,000	41.9	46.4	49.1	950	0	636	Reflux ratio tests
5E	82,000	77.1	74.5	71.3	55,000	41.9	46.2	48.7	800	0	587	Reflux ratio tests
5F	82,000	77.4	75.3	71.2	55,000	42.0	45.8	48.0	650	0	540	Reflux ratio tests
5G	82,000	77.2	75.5	71.3	55,000	41.9	45.2	47.0	550	0	422	Reflux ratio tests
5H	82,000	77.0	74.1	71.3	55,000	41.7	46.3	48.4	2200	0	663	Baseline (top feed only)
6	85,000	77.5	73.7	69.9	55,000	42.2	48.2	49.8	2956	0	855	Reflux ratio tests
6A	85,000	77.5	73.9	69.9	55,000	42.2	48.1	49.9	1500	0	840	Reflux ratio tests
6B	85,000	77.5	74.4	69.9	55,000	42.0	47.2	49.3	950	0	715	Reflux ratio tests
6C	85,000	77.5	75.4	69.9	55,000	42.2	46.0	48.1	650	0	519	Reflux ratio tests
6D	85,000	77.2	73.6	69.9	55,000	42.1	47.9	49.8	2200	0	851	Baseline (top feed only)

TABLE 4-7

OTEC-1 TEST OPERATIONS
(Sheet 3 of 4)

Test No.	Evaporator: Approx. Warm Water Flow (gpm, calc.)	Evaporator: Avg. Warm Water Temp. In (°F)	Evaporator: Avg. Warm Water Temp. Out (°F)	Evaporator: Approx. NH_3 Temp. (°F)	Condenser: Approx. Cold Water Flow (gpm, calc.)	Condenser: Avg. Cold Water Temp. In (°F)	Condenser: Avg. Cold Water Temp. Out (°F)	Condenser: Approx. NH_3 Temp. (°F)	Avg. NH_3 Reflux: Low-Press. Top Nozzles (gpm)	Avg. NH_3 Reflux: Mid-Flange Nozzles (gpm)	NH_3 Flow, Cond. to Evap. (gpm)	Remarks
TEST SERIES VI (14-18 Mar 81)												
50A	83,000	77.1	75.5	71.5	55,000	41.8	44.3	45.7	0 (0[b])	931	306	Reflux ratio tests, midplane feed only
50B	83,000	76.8	76.2	74.7	55,000	41.8	42.8	45.8	0 (0[b])	940	97	Reflux ratio tests, midplane feed only
50C	83,000	76.9	75.4	71.2	55,000	41.8	44.2	46.3	0 (0[b])	930	301	Reflux ratio tests, midplane feed only
51	83,000	77.1	75.6	71.2	55,000	42.0	44.5	46.1	0 (0[b])	800	314	Reflux ratio tests, midplane feed only
52	83,000	77.1	75.8	71.3	55,000	42.0	44.4	45.9	0 (0[b])	600	289	Reflux ratio tests, midplane feed only
53	83,000	76.9	75.9	71.3	55,000	41.9	43.8	45.1	0 (0[b])	400	252	Reflux ratio tests, midplane feed only
54	83,000	76.9	74.6	71.3	55,000	41.7	45.7	48.2	0 (956[b])	0	556	Reflux ratio tests, top high-pressure nozzles only
55	83,000	76.8	74.9	71.2	55,000	42.0	45.7	48.0	0 (800[b])	0	507	Reflux ratio tests, top high-pressure nozzles only
56	83,000	76.7	75.4	71.2	55,000	42.1	45.2	47.1	0 (598[b])	0	401	Reflux ratio tests, top high-pressure nozzles only
57	83,000	76.7	75.8	71.2	55,000	42.2	44.4	45.8	0 (399[b])	0	267	Reflux ratio tests, top high-pressure nozzles only
58	83,000	76.7	74.0	71.2	55,000	42.1	46.4	49.0	2745 (968[b])	0	582	Reflux ratio tests, top nozzle combinations
59	83,000	76.6	73.9	71.2	55,000	41.8	46.1	48.7	2381 (975[b])	0	588	Reflux ratio tests, top nozzle combinations
60	83,000	76.7	73.9	71.2	55,000	42.0	46.2	48.8	2027 (971[b])	0	613	Reflux ratio tests, top nozzle combinations
61	83,000	76.8	74.1	71.3	55,000	42.0	46.4	48.9	1524 (981[b])	0	592	Reflux ratio tests, top nozzle combinations
62	83,000	77.0	74.1	71.3	55,000	42.1	46.5	49.2	2500 (0[b])	0	623	Reflux ratio tests, top nozzle combinations
63	83,000	77.4	75.0	72.6	55,000	42.3	48.3	48.3	1300 (875[b])	0	517	Reflux ratio tests, top nozzle combinations
64	83,000	77.1	77.4	71.3	55,000	42.1	46.6	49.4	1350 (900[b])	0	628	Reflux ratio tests, top nozzle combinations
65	83,000	76.9	73.4	69.9	55,000	41.9	47.3	50.6	1400 (925[b])	0	773	Reflux ratio tests, top nozzle combinations
66	83,000	76.9	73.6	69.9	55,000	41.8	47.1	50.4	1000 (525[b])	0	755	Reflux ratio tests, top nozzle combinations
67	83,000	76.9	74.2	71.3	55,000	42.0	46.4	49.0	950 (500[b])	0	598	Reflux ratio tests, top nozzle combinations
68	83,000	76.9	74.8	72.6	55,000	42.1	45.4	47.5	911 (476[b])	0	474	Repeatability
69	83,000	76.7	76.7	67.3	55,000	42.0	42.1	42.5	0 (0[b])	0	0	Surface conditioning
70	83,000	76.8	73.9	71.5	55,000	41.8	46.3	49.0	2506 (0[b])	0	626	Repeatability
71	83,000	76.8	74.1	71.9	55,000	41.5	45.7	48.2	2506 (0[b])	0	587	Condenser tests

TABLE 4-7

OTEC-1 TEST OPERATIONS
(Sheet 4 of 4)

	Evaporator				Condenser				Avg. NH_3 Reflux			
Test No.	Approx. Warm Water Flow (gpm, calc.)	Avg. Warm Water Temp. In (°F)	Avg. Warm Water Temp. Out (°F)	Approx. NH_3 Temp. (°F)	Approx. Cold Water Flow (gpm, calc.)	Avg. Cold Water Temp. In (°F)	Avg. Cold Water Temp. Out (°F)	Approx. NH_3 Temp. (°F)	Low-Press. Top Nozzles (gpm)	Mid-Flange Nozzles (gpm)	NH_3 Flow, Cond. to Evap. (gpm)	Remarks
TEST SERIES VI (14-18 Mar 81) (Continued)												
72	83,000	76.9	74.3	72.1	32,000	42.3	49.4	52.2	2504 (0[b])	0	586	Condenser tests
73	83,000	77.0	74.5	72.3	66,000	42.1	45.5	47.8	2500 (0[b])	0	579	Condenser tests
74	83,000	77.0	73.3	70.1	68,000	42.3	47.1	50.4	2500 (0[b])	0	829	Condenser tests
75	83,000	76.9	73.2	70.0	58,000	42.4	48.0	51.6	2500 (0[b])	0	843	Condenser tests
76	83,000	76.8	73.2	70.0	42,000	42.3	50.0	55.9	2500 (0[b])	0	840	Condenser tests
77	83,000	76.7	75.3	73.7	32,000	42.3	46.4	48.0	0 (600[b])	375	334	Condenser tests
78	83,000	76.6	75.1	73.4	57,000	42.1	44.6	46.2	0 (706[b])	472	332	Condenser tests
79	83,000	76.5	75.1	73.4	67,000	42.6	44.7	46.2	0 (795[b])	582	353	Condenser tests
80	91,000	76.5	74.5	71.6	57,000	42.5	46.2	48.6	0 (598[b])	375	522	Repeatability
81	76,000	76.4	74.1	71.9	44,000	42.2	46.3	48.3	0 (578[b])	452	445	Repeatability
82	83,000	76.4	73.1	68.1	44,000	42.2	49.0	52.3	1006 (0[b])	0	792	Activation tests
83	83,000	76.4	74.6	72.8	44,000	42.7	46.3	48.0	1001 (0[b])	0	391	Activation tests
84	83,000	76.4	74.4	72.8	44,000	42.7	46.5	48.4	994 (0[b])	0	410	Activation tests
85	83,000	76.3	73.0	68.7	44,000	42.5	49.2	52.4	994 (0[b])	0	742	Activation tests
86	83,000	76.3	73.5	67.4	44,000	42.4	48.5	51.3	820 (0[b])	0	681	Activation tests
87	83,000	76.3	73.8	67.4	44,000	42.3	48.5	51.5	0 (804[b])	0	662	Miscellaneous repeat and reflux ratio tests
88	91,000	76.2	75.0	67.4	29,000	42.4	47.9	49.8	0 (490[b])	0	406	Miscellaneous repeat and reflux ratio tests
89	57,000	76.2	74.1	72.7	67,000	42.1	43.9	45.1	1190 (0[b])	0	294	Miscellaneous repeat and reflux ratio tests
90	83,000	76.1	73.3	71.2	44,000	42.2	47.6	50.3	2506 (0[b])	920	578	Miscellaneous repeat and reflux ratio tests
91	83,000	76.1	73.3	71.3	44,000	42.5	47.6	50.1	3031 (0[b])	0	595	Miscellaneous repeat and reflux ratio tests
92	83,000	76.1	73.4	71.2	44,000	42.7	47.8	50.3	1504 (0[b])	0	577	Miscellaneous repeat and reflux ratio tests
93	83,000	76.1	73.4	71.2	44,000	42.4	47.4	50.0	950 (0[b])	649	554	Miscellaneous repeat and reflux ratio tests
94	83,000	76.1	73.6	71.3	44,000	42.2	47.1	49.4	0 (805[b])	809	504	Miscellaneous repeat and reflux ratio tests
95	79,000	76.1	75.0	73.9	44,000	41.9	44.2	45.4	0 (808[b])	811	208	Miscellaneous repeat and reflux ratio tests

[a]Vented noncondensables from condenser during test 6; seemed to improve U_0 considerably.
[b]Values in parentheses are for high-pressure top nozzles.

TABLE 4-8

OTEC-MODE TEST OPERATIONS LOG
(Sheet 1 of 5)

Test	Start Date	Start Time (hours)	Stop Date	Stop Time (hours)	Duration (h)
Test Series I					
3	23 Jan 81	1120	23 Jan 81	2226	11.10
3A	23 Jan 81	2240	24 Jan 81	0825	9.75
4	24 Jan 81	0825	24 Jan 81	1640	8.25
5	24 Jan 81	1640	25 Jan 81	0130	8.83
6	25 Jan 81	0300	25 Jan 81	1030	7.50
7	25 Jan 81	1030	25 Jan 81	2200	11.50
8	25 Jan 81	2200	26 Jan 81	1205	14.08
			Subtotal		71.01
Test Series II					
1	04 Feb 81	2110	04 Feb 81	2245	1.58
2	05 Feb 81	1731	05 Feb 81	2215	4.73
3	05 Feb 81	2215	05 Feb 81	2300	0.75
4	05 Feb 81	2300	05 Feb 81	2347	0.78
5	05 Feb 81	2347	06 Feb 81	0935	9.8
6	06 Feb 81	0935	06 Feb 81	1400	6.42
7	06 Feb 81	1400	06 Feb 81	1721	3.35
8	06 Feb 81	1721	06 Feb 81	2030	3.15
9	06 Feb 81	2030	06 Feb 81	2230	2.00
10	06 Feb 81	2230	06 Feb 81	2400	1.50
11	07 Feb 81	0000	07 Feb 81	0838	8.63
12	07 Feb 81	0914	07 Feb 81	1230	3.27
13	07 Feb 81	1230	07 Feb 81	1705	4.58
14	07 Feb 81	1705	07 Feb 81	2000	2.92
15	07 Feb 81	2150	07 Feb 81	2400	2.17
16	08 Feb 81	0000	08 Feb 81	0840	8.67
17	08 Feb 81	0945	08 Feb 81	1154	2.15

TABLE 4-8

OTEC-MODE TEST OPERATIONS LOG
(Sheet 2 of 5)

Test	Start Date	Start Time (hours)	Stop Date	Stop Time (hours)	Duration (h)
18	08 Feb 81	1200	08 Feb 81	1500	3.00
19	08 Feb 81	1515	08 Feb 81	1915	4.00
20	08 Feb 81	1950	09 Feb 81	1440	19.50
			Subtotal		85.89
Test Series III					
1	13 Feb 81	1805	14 Feb 81	0155	7.83
2	14 Feb 81	0155	14 Feb 81	1420	12.42
3	14 Feb 81	1420	14 Feb 81	1423	0.05
2A	14 Feb 81	1423	15 Feb 81	1435	24.20
4	15 Feb 81	1435	15 Feb 81	1825	3.83
5	15 Feb 81	1825	15 Feb 81	2225	4.00
6	15 Feb 81	2225	16 Feb 81	0200	3.58
7	16 Feb 81	0200	16 Feb 81	0600	4.00
			Subtotal		59.91
Test Series IV					
A	21 Feb 81	1831	22 Feb 81	0128	6.95
B	22 Feb 81	0235	22 Feb 81	0922	6.78
C-1	22 Feb 81	1008	22 Feb 81	1451	4.72
C-2	22 Feb 81	1545	22 Feb 81	2140	5.92
D	23 Feb 81	0028	23 Feb 81	0723	5.92
E	23 Feb 81	1605	23 Feb 81	2107	4.03
B-1	24 Feb 81	0133	24 Feb 81	0744	6.18
			Subtotal		40.50

TABLE 4-8

OTEC-MODE TEST OPERATIONS LOG
(Sheet 3 of 5)

Test	Start Date	Start Time (hours)	Stop Date	Stop Time (hours)	Duration (h)
Test Series V					
5A	10 Mar 81	2220	11 Mar 81	0723	9.05
5B	11 Mar 81	0726	11 Mar 81	0841	2.25
5C	11 Mar 81	0841	11 Mar 81	1206	3.78
5D	11 Mar 81	1206	11 Mar 81	1247	0.68
5E	11 Mar 81	1247	11 Mar 81	1331	0.73
5F	11 Mar 81	1331	11 Mar 81	1404	0.58
5G	11 Mar 81	1404	11 Mar 81	1432	0.53
5H	11 Mar 81	1432	11 Mar 81	1730	3.47
6	11 Mar 81	1929	11 Mar 81	2007	0.63
6A	11 Mar 81	2008	11 Mar 81	2031	0.38
6B	11 Mar 81	2031	11 Mar 81	2102	0.52
6C	11 Mar 81	2105	11 Mar 81	2130	0.42
6D	11 Mar 81	2130	11 Mar 81	2233	1.55
			Subtotal		24.57
Test Series VI					
50A	14 Mar 81	0932	14 Mar 81	1223	2.83
50B	14 Mar 81	1223	14 Mar 81	1232	0.17
50C	14 Mar 81	1235	14 Mar 81	1335	1.00
51	14 Mar 81	1340	14 Mar 81	1540	2.00
52	14 Mar 81	1542	14 Mar 81	1742	2.00
53	14 Mar 81	1740	14 Mar 81	1942	2.03
54	14 Mar 81	1950	14 Mar 81	2150	2.00
55	14 Mar 81	2151	14 Mar 81	2351	2.00
56	14 Mar 81	2352	15 Mar 81	0204	2.20
57	15 Mar 81	0205	15 Mar 81	0410	2.08
58	15 Mar 81	0430	15 Mar 81	0630	2.00
59	15 Mar 81	0631	15 Mar 81	0830	2.00

TABLE 4-8

OTEC-MODE TEST OPERATIONS LOG
(Sheet 4 of 5)

Test	Start Date	Start Time (hours)	Stop Date	Stop Time (hours)	Duration (h)
60	15 Mar 81	0832	15 Mar 81	1032	2.00
61	15 Mar 81	1034	15 Mar 81	1234	2.00
62	15 Mar 81	1235	15 Mar 81	1435	2.00
63	15 Mar 81	1437	15 Mar 81	1637	2.00
64	15 Mar 81	1640	15 Mar 81	1845	2.08
65	15 Mar 81	1847	15 Mar 81	2047	2.00
66	15 Mar 81	2055	15 Mar 81	2255	2.00
67	15 Mar 81	2258	16 Mar 81	0130	2.53
68	16 Mar 81	0143	16 Mar 81	0342	2.00
69	16 Mar 81	0400	16 Mar 81	0600	2.00
70	16 Mar 81	0620	16 Mar 81	0824	2.07
71	16 Mar 81	0830	16 Mar 81	1034	2.07
72	16 Mar 81	1035	16 Mar 81	1235	2.00
73	16 Mar 81	1243	16 Mar 81	1450	2.12
74	16 Mar 81	1500	16 Mar 81	1700	2.00
75	16 Mar 81	1705	16 Mar 81	1905	2.00
76	16 Mar 81	1910	16 Mar 81	2110	2.00
77	16 Mar 81	2135	16 Mar 81	2335	2.00
78	16 Mar 81	2359	17 Mar 81	0200	2.02
79	17 Mar 81	0204	17 Mar 81	0404	2.00
80	17 Mar 81	0420	17 Mar 81	0620	2.00
81	17 Mar 81	1015	17 Mar 81	1225	2.17
82	17 Mar 81	1250	17 Mar 81	1355	1.08
83	17 Mar 81	1425	17 Mar 81	1528	1.05
84	17 Mar 81	1600	17 Mar 81	1712	1.20
85	17 Mar 81	1740	17 Mar 81	1843	1.05
86	17 Mar 81	1909	17 Mar 81	2010	1.02
87	17 Mar 81	2020	17 Mar 81	2123	1.05

TABLE 4-8

OTEC-MODE TEST OPERATIONS LOG
(Sheet 5 of 5)

Test	Start Date	Start Time (hours)	Stop Date	Stop Time (hours)	Duration (h)
88	17 Mar 81	2135	17 Mar 81	2240	1.08
89	17 Mar 81	2305	18 Mar 81	0008	1.05
90	18 Mar 81	0045	18 Mar 81	0245	2.00
91	18 Mar 81	0250	18 Mar 81	0450	2.00
92	18 Mar 81	0500	18 Mar 81	0600	1.00
93	18 Mar 81	0610	18 Mar 81	0710	1.00
94	18 Mar 81	0731	18 Mar 81	0830	1.00
95	18 Mar 81	0831	18 Mar 81	0900	0.48
			Subtotal		83.43
	Grand Total for Test Series I through VI				365.8

5005K/sjd

damage was not expected, and the compartment was not normally manned, no action was taken to improve the situation. Future applications for turbine bypass valves should not be of a butterfly configuration.

(2) Ammonia Leakage

Minor ammonia leaks were observed and stopped within the ammonia system. Whenever possible, the leaks were sealed without inerting the leak area. Where this was not possible, the leak area was vented and purged with gaseous nitrogen prior to repairs.

The leakage areas and corrective actions taken are listed below:

1) Area: blanked flanges, including evaporator manways and condenser top flange.
   Action: steam fitters reinstalled manways, and condenser top flange was tightened.
2) Area: unions, especially on ammonia pump drain lines.
   Action: disassembled and cleaned union contact surfaces before assembly; tightening leaky unions caused leakage rate to increase.
3) Area: pumps, especially ammonia feed pump (P-106).
   Action: tightened packing around shaft seal; the oil seal on pump P-106 was replaced.
4) Area: F-1 filter delta pressure fitting on cover and also cover flange.
   Action: capped fitting hole; cover gasket replaced with single J-M gasket.
5) Area: instrument lines to pressure transducers.
   Action: tightened fittings.
6) Area: nitrogen supply control panel regulator.
   Action: began to install blocking valve to isolate nitrogen and ammonia when nitrogen not in use; this modification was not completed because of time restrictions.

During the entire operation of the ammonia system, minor ammonia leakage continued and was accommodated by personnel using canister-type face masks. The breathing air systems (both self-contained and umbilical models) were not required. Ammonia vapor was continuously exhausted from the test compartment by the ventilation system. Also, ammonia leakage was controlled by scheduled preventive maintenance (PM). Tables 4-9 and 4-10 give the PM procedures used for the ventilation verification and for the ammonia pumps, respectively.

(3) Ammonia Sampling

Ammonia samples were taken on various occasions from the drain tank and the aft storage tank. Moisture content analysis was done by Brewer Analytical Laboratories, Honolulu, Hawaii. Table 4-11 gives the results obtained for the nine samples taken. Three samples were not analyzed, two because the rupture disk on the sample bomb failed, and one because of oil contamination. Laboratory analyses of the samples analyzed are given in Appendix G. From Tables 4-6 and 4-11, ammonia moisture concentration can be obtained for each of the test series. Therefore, the effects of moisture on the performance of the heat exchanger can be accounted for during analysis of the data.

Because of the difficulties experienced in obtaining the ammonia sample, a standard operating procedure for obtaining ammonia samples (Appendix H) was prepared, checked, and used.

TABLE 4-9

WEEKLY PREVENTIVE MAINTENANCE FOR

VENTILATION VERIFICATION

1.	Observation air lock supply	1-60-5S[a]
2.	Observation room supply	1-60-3S
3.	Observation air lock exhaust	1-60-4E
4.	Observation room exhaust	1-60-2E
5.	Forward air lock supply	1-70-1S
6.	Forward air lock exhaust	1-69-1E
7.	Reflux pumps supply	1-71-3S
8.	Machinery space supply, normal	1-60-1S
9.	Machinery space supply, high	1-60-1S
10.	Machinery space supply, normal	1-71-1S
11.	Machinery space supply, high	1-71-1S
12.	Machinery space supply, normal	1-71-2S
13.	Machinery space supply, high	1-71-2S
14.	Machinery space exhaust, normal	1-64-1E
15.	Machinery space exhaust, high	1-64-3E
16.	Machinery space exhaust, normal	1-64-2E
17.	Machinery space exhaust, high	1-64-4E
18.	Time, date, and initials	

[a]ID Number

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TABLE 4-10

DAILY PREVENTIVE MAINTENANCE
FOR AMMONIA PUMPS

1. Reflux pump P-1
    a. Oil seal reservoir level
    b. Gear box oiler level
    c. Motor blower operation
2. Reflux pump P-2
    a. Oil seal reservoir
    b. Gear box oiler level
    c. Motor blower operation
3. Feed pump P-106
    a. Oil seal reservoir
    b. Gear box oiler level
4. Ammonia catch tank
5. Time, date and initials

5005K/jbv

TABLE 4-11

AMMONIA SAMPLING LOG

Sample	Sampling Date	Moisture Content	Oil and Grease (ppm)	Remarks
1	26 Jul 80	0.18 vol %	-	First sample taken from storage tank by GMDI
2	29 Jan 81	0.98 wt. %	335.3	Second sample taken from drain tank after initial OTEC-mode operation
3	16 Feb 81	0.62 vol %	716	Third sample taken from drain tank after residue dump (12 Feb 81) adding ~720 gal NH_3 (12-13 Feb 81), and OTEC-mode operation
4	21 Feb 81	0.49 vol %	865.5	Fourth sample taken from drain tank after NH_3 residue dump (20 Feb 81)
5	27 Feb 81	0.34 vol %	-	Fifth sample taken from drain tank after NH_3 distillation, residue dump, and OTEC-mode operation
6	13 Mar 81	Rupture disc on sample bomb failed	-	Sixth sample taken from drain tank NH_3 distillation, residue dump, adding ~1800-gal NH_3, and OTEC-mode operation
7	27 Apr 81	Too much oil in sample to permit analysis	-	Seventh sample taken from aft storage tank after OTEC-mode operation and NH_3 transferred from power loop
8	21 May 81	Rupture disc on sample bomb leaked	-	Eigth sample taken from aft storage tank
9	26 May 81	0.53 vol %	-	Ninth sample taken from aft storage tank

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(4) Oil Ingestion

During OTEC-1 operation, 12-1/2 gal of pump lubricating oil leaked into the ammonia power loop through both the reflux and the ammonia feed oil seals. The majority of this oil ended up in the evaporator side of the power loop because of the evaporator's distilling characteristic. Photographs of the ammonia side evaporator posttest condition showing oil contamination are given in Section V.C.

This lubricating oil also fouled the ammonia moisture analyzer. The unit operated for only a short period, then failed. The evaporator shell and plain and enhanced tubes were also fouled with oil. Section V.C discusses this fouling.

Initially, both reflux pumps (P-1 and P-2) and the oil tanks (3-gal capacity each) for the ammonia feed pump (P-106) were filled with refrigeration-type oil before the ammonia power loop operational tests at Portland, Oregon. These tests were conducted by operating the pumps for only a short period, about 2 to 3 h. During these tests, pump P-106 lost its oil externally into its drip pan. There was no external leakage from either pipes P-1 or P-2; any leakage that occurred was internal. Once on site in Hawaii, oil continued to be lost externally from pump P-106 until the pump was repaired in mid-December 1980; from then on, all oil leakage was internal.

The additions of lube oil are summarized in Table 4-12. This table shows that 15-1/2 gal of oil was added to the ammonia pumps, but the first 3 gal added, on 27 November 1980, was not included in the amount ingested because the leakage was external. Therefore, the total amount ingested was 12-1/2 gal.

Repairs to the ammonia pump oil seals were completed on 23 January 1981 after confirmation of incorrect oil seal vent installation. The pump oil reservoir was rerouted to vent to the atmosphere for proper oil seal operation. After this modification, the ammonia pumps (3) consumed a total of

TABLE 4-12

LUBRICATION OIL ADDED TO AMMONIA PUMPS P-1, P-2, AND P-106 AFTER INITIAL FILL

Date	Pump	Amount of Oil Added to Reservoir (gal)	Comments
27 Nov 80	P-106	3	External leakage (not added to total; added into ammonia power loop)
31 Dec 80	P-2	3	Light turbine-type oil used from here on
11 Jan 81	P-106 P-1	1 1	
21 Jan 81	P-106 P-2	1-1/2 1-1/2	ANL authorized up to 10 additional gal of oil into NH_3 loop
25 Jan 81	P-2	1-3/4	
21 Feb 81	P-1 P-2	1/2 1/2	
10 Mar 81	P-2	1-3/4	
Total		15-1/2	

NOTE: An estimated total of 12-1/2 gal of lube oil was added into the ammonia power loop.

5005K/jbv

4-1/2 gal of oil. This equates to 12 oz/day leakage into the system for 388.31 h of test operations which occurred over the period 23 January to 10 March 1981.

During mid-January 1981, the experimenter (ANL) was queried as to the amount of additional oil permitted into the ammonia loop. They recommended that no more than 10 gal be permitted in addition to what was already in the loop. From that time, only a total of 7-1/2 gal was added into the ammonia loop (Table 4-12).

d. System Deactivation

When all scheduled OTEC-mode tests were complete, the system was shut down on 18 March 1981. The power loop was inerted by transferring the liquid ammonia into the storage tanks and purging the ammonia loop with gaseous nitrogen. Liquid ammonia was offloaded into water tanker trucks at Pier 39, Honolulu, Hawaii, to be used as fertilizer by Oahu Sugar Company. During the offloading process, liquid ammonia was dumped into a 6000-gal-capacity truck tanker that was about 2/3 full of water. As ammonia was added to the water, additional water was used to stir up the tanker contents and also blanket the ammonia vapor that was generated. The rate of dumping was kept low to assure that the temperature rise of the tanker and its contents would be low. Six tanker truck loads were needed to empty both storage tanks. The estimated ammonia offloaded was between 4500 and 5000 gal. The storage tanks were then vented and purged with GN_2 and the system was secured.

3. Recommendations

Based on experience gained from the test operations, the following recommendations for future OTEC plants were developed:

1) Minimize contamination and fouling of the ammonia power loop. Ways to prevent contamination are listed in Section V.C.

2) Do not use close-clearance pumps (i.e., vane type) for ammonia applications. Contamination can cause pumps to become inoperative.
3) Incorporate an ammonia vapor transfer compressor (nonlubricated) for moving ammonia within the system. Use of a vapor compressor would greatly reduce ammonia and gaseous nitrogen (GN_2) losses from venting vapor and GN_2 purge gas.
4) Incorporate a vacuum system to provide an ammonia atmosphere that is free of moisture and noncondensables. Be sure the ammonia system is compatible with the vacuum system and can withstand a vacuum (up to 29 in. Hg).
5) If a throttle valve must be used, change the design or insulate the unit for noise reduction. It is hazardous to have loud noises in the test compartment — they can interfere with communications during operation.
6) Leaky pipe unions should not be tightened but should be disassembled and cleaned before assembly, or replaced.
7) With good ventilation, minor leaks can be repaired using canister-type face masks instead of breathing air systems. For major leaks, the breathing air system would still be required.
8) Because of difficulties encountered in obtaining ammonia samples for moisture content determination, a standard operating procedure was prepared and checked out. Use of a procedure whenever ammonia samples are required is highly recommended.
9) The allowable moisture content of the ammonia system must be defined during the design phase to optimize the method for purity maintenance, detection, and control. Decreasing the allowable purity level for a system during operation will severely overburden the system.
10) If oil seals are used on ammonia system components, proper operation should be verified before the system is exposed to possible oil contamination.

11) Particulate screens should be located throughout the system with removable inserts to capture contamination. The inserts can be removed to improve performance after contamination capture amounts become negligible.

12) Two-part epoxy was found to be a good sealant for ammonia gaskets, plugs, and adhesive applications. It is also a handy field applied material.

D. AMERTAP SYSTEM

1. Summary

The Amertap system was used to mechanically clean the inside of the seawater side tubes of the heat exchanger by physical removal of material adhering to the walls. A second method, chlorination, was also used (see Section V.E). Titanium tubes from the heat exchanger were posttest inspected and found to be clean and in excellent condition (see Sections V.A and V.B). It is not known whether it was the Amertap balls, the chlorination, or a combination of the two that prevented the tubes from fouling. As a step toward determining whether countermeasures were needed, the Amertap system was turned off about 5 weeks before the chlorination and seawater systems were finally shut down.

Amertap Corporation's estimated ball consumption or replacement rate of 200 balls per week was obtained in the evaporator (actually 210 balls/week), but the condenser replacement rate was more than double the estimated rate, at 413 balls/week. No satisfactory explanation was provided for this excessive rate.

2. Test Operations

During OTEC-1 test operations, the Amertap units were used for both heat exchangers. These units were operated from 11 November 1980 through 3 March

1981, when they were shut down as planned. Plain biodegradable sponge-rubber balls from the Amertap Corporation were used. The standard operating procedures used during the test operations are attached as Appendices I and J (Amertap SOP and collection and sizing of balls, respectively).

a. Checkout Tests

Preoperational testing in early August 1980 resulted in a higher-than-predicted pressure drop across the collector screen of the evaporator. The Amertap representative recommended that the distance between the pressure taps be increased from 1 ft to 4 ft. Even after this modification had been made for both the evaporator and condenser Amertap units (see Figures 4-4 and 4-5, respectively), the pressure drop (ΔP) across the collector screen remained higher than predicted. Originally, the O&M manual (Ref. 17) had specified that the screens were to be backwashed after ball collection if ΔP reached 10 in. of water in the evaporator/condenser. The screens were to be backwashed immediately if 20 in. of water was reached in either unit. These limits were increased (with Amertap's concurrence) as follows: backflush after ball collection if ΔP reaches 22/14 in. of water (evaporator/condenser) and backflush immediately if ΔP reaches 30/24 in. of water (evaporator/condenser). No explanation of the anomalous ΔP readings was provided. It is not known if the ΔP was actually excessive or if the instrumentation was erroneous. No fouling on the screens was ever observed to confirm a real ΔP.

Another concern during preoperational testing was the loss of balls in the stagnation zones in the waterboxes. Nets had originally been installed by the TAC to block off these zones. But these nets were removed after initial sea trial tests showed that balls were being trapped and caught in the netting.

A bypass system was installed from the inlet waterbox to the outlet waterbox to permit balls which stagnated in the bottom of the inlet waterbox to be bypassed through to the outlet waterbox. Figure 4-6 shows the evaporator 2-in. bypass line, view section, and control valve. During operation of the Amertap system it was determined that only a few balls were being trapped at the bottom of the inlet waterbox in the bypass line stagnant area.

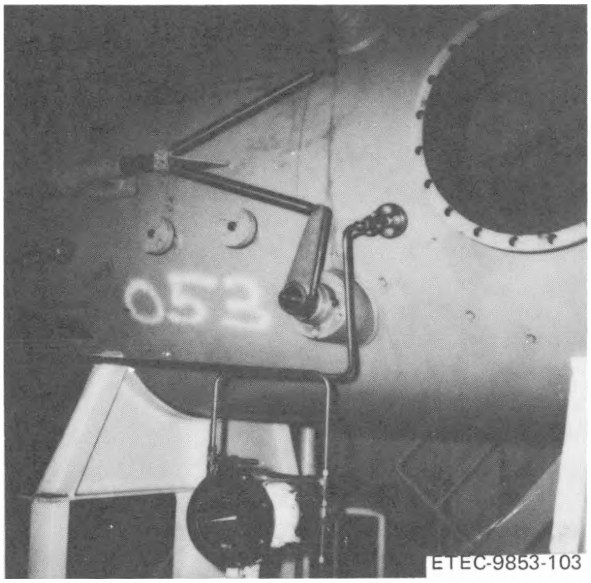

Figure 4-4. Evaporator Amertap Unit Showing Pressure Taps

Figure 4-5. Condenser Amertap Unit Showing Pressure Taps

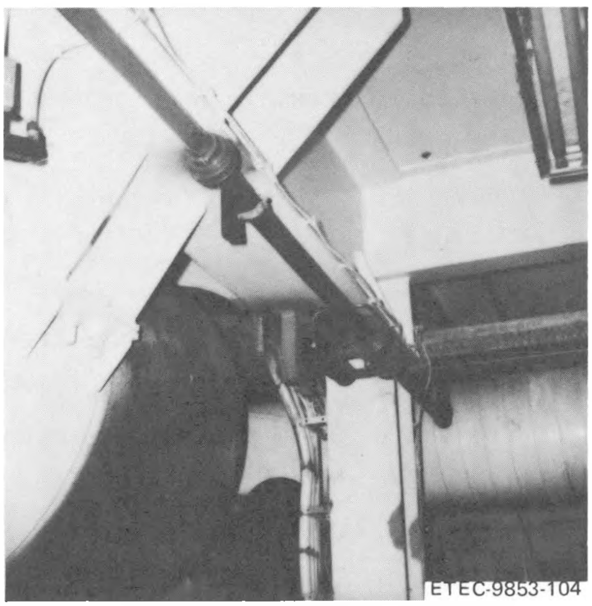

Figure 4-6. Evaporator 2-in. Bypass Line

b. System Operation

The operational histories of the evaporator and condenser Amertap systems in Hawaii are summarized in Tables 4-13 and 4-14, respectively. These tables show the total number of balls recovered and the number of reusable balls recovered after grading for size. All balls used to recharge the system were 27 mm (1.063 in.) in diameter. The titanium tubes had a 1-in. OD, a 0.028-in. wall thickness, and a 0.944-in. ID. Therefore, the total interference fit of these sponge-rubber balls was 0.119 in. Used balls were graded for size and were rejected (considered consumed) if their OD was 0.944 in. or less. Tables 4-13 and 4-14 present the recovery data for the total and reusable (good) balls. The average return and reusable rate was higher for the evaporator system than for the condenser. Amertap representatives were contacted, but they could give no reason for the condenser having a higher rate of ball consumption. It is suspected that the colder water of the condenser may have caused its sponge-rubber balls to embrittle more quickly and thereby to wear out sooner (denied by Amertap) or that the condenser circuit may have had sharp edges or other wear accelerating features.

Because operating times between recharging (with 600 balls) and collecting the Amertap balls varied, the data were reviewed to attempt to determine the consumption rates. These data gave general consumption trends since seawater operating conditions had varied throughout the test program. No clearly defined ball consumption rate was established.

The item numbers from Tables 4-13 and 4-14 were examined; these data are presented in Table 4-15. Days of Amertap operation per fresh ball charge varied from less than 1 day to 14 days. The general observation that can be made is that a high consumption occurs very soon after charging and the rate of loss is lowered as the ball inventory is reduced. This mechanism is not explained. The collection, grading, and recharging interval recommended by Amertap is weekly. Dividing the consumed balls by seven to achieve a daily

TABLE 4-13

EVAPORATOR AMERTAP SYSTEM OPERATIONAL HISTORY
(Sheet 1 of 2)

Item No.	Date	Remarks	Total Number of Balls Recovered	Number of Reusable Balls Recovered
	11 Nov 80	WW pump system started, charged with 600 balls		
	12 Nov 80	Collected balls, then released balls	355	-
	13 Nov 80	WW pump stopped, system drained, WW pump started		
	15 Nov 80	Collected 255 balls (partial), WW pump stopped, system drained		
	18 Nov 80	WW pump started, collected balls, released 600 balls	443	-
1	23 Nov 80	Collected balls, recharged with 600 balls	342	90
	25 Nov 80	Collected balls, WW pump stopped, system drained	523	-
	12 Dec 80	WW pump started, recharged with 600 balls		
	13 Dec 80	Collected balls (not counted), WW pump stopped, system drained		
	21 Dec 80	WW pump started, released caught balls		
2	31 Dec 80	Collected balls, recharged with 600 balls	700	52
3	13 Jan 81	Collected balls, recharged with 600 balls	205	49
4	13 Jan 81	Collected balls, recharged with 600 balls	527	393

5005K/jbv

TABLE 4-13

EVAPORATOR AMERTAP SYSTEM OPERATIONAL HISTORY
(Sheet 2 of 2)

Item No.	Date	Remarks	Total Number of Balls Recovered	Number of Reusable Balls Recovered
5	20 Jan 81	Collected balls, recharged with 600 balls	486	380
6	27 Jan 81	Collected balls, recharged with 600 balls	465	355
7	02 Feb 81	Collected balls	739	414
	04 Feb 81	Recharged with 600 balls		
8	10 Feb 81	Collected balls, recharged with 600 balls	492	240
	15 Feb 81	Collected balls, recharged with 596 balls	435	-
	19 Feb 81	Collected balls (not counted)		
	21 Feb 81	Released caught balls		
9	24 Feb 81	Collected balls	627	464
	25 Feb 81	Recharged with 600 balls		
10	03 Mar 81	Collected balls, system shut down	422	308
		Average	481	274

5005K/jbv

TABLE 4-14

CONDENSER AMERTAP SYSTEM OPERATIONAL HISTORY
(Sheet 1 of 2)

Item No.	Date	Remarks	Total Number of Balls Recovered	Number of Reusable Balls Recovered
	13 Nov 80	CW pump started, charged system with 600 balls		
	15 Nov 80	Collected 289 balls (partial), stopped CW pump, system drained		
	18 Nov 80	CW pump started, collected 220 more balls, released 600 balls	509	-
1	23 Nov 80	Collected balls, recharged with 618 balls	80	29
	25 Nov 80	Collected balls, CW pump stopped, system drained	497	-
	22 Dec 80	CW pump started, recharged with 600 balls		
2	24 Dec 80	Collected balls	457	225
	25 Dec 80	Released 600 balls		
3	08 Jan 81	Collected balls, recharged with 606 balls	271	106
4	09 Jan 81	Collected balls, CW pump stopped, system drained	448	348
	13 Jan 81	CW pump started, recharged with 600 balls		
5	20 Jan 81	Collected balls, recharged with 600 balls	292	220
6	27 Jan 81	Collected balls, recharged with 600 balls	410	165
7	03 Feb 81	Collected balls, CW pump stopped, system drained	349	196

TABLE 4-14

CONDENSER AMERTAP SYSTEM OPERATIONAL HISTORY
(Sheet 2 of 2)

Item No.	Date	Remarks	Total Number of Balls Recovered	Number of Reusable Balls Recovered
	04 Feb 81	CW pump started, recharged with 600 balls		
8	10 Feb 81	Collected balls, recharged with 600 balls	531	239
	19 Feb 81	Collected balls (not counted)		
	21 Feb 81	Released caught balls		
9	24 Feb 81	Collected balls	144	102
	25 Feb 81	Released 600 balls		
10	03 Mar 81	Collected balls, system shut down	338	307
		Average	360	194

5005K/jbv

TABLE 4-15

EVAPORATOR AND CONDENSER AMERTAP BALL CONSUMPTION

Item No.	Evaporator Interval (Days)	Evaporator Balls Consumed	Condenser Interval (Days)	Condenser Balls Consumed
1	5	510	5	571
2	10.68	548	2	375
3	12.75	551	14	494
4	0.82	207	0.91	258
5	7	220	6.62	380
6	7	245	7	435
7	6	186	6.88	404
8	5.6	360	6	361
9	7	136	12.27	498
10	5.54	292	5.54	293
Total	67.4	3,255	66.2	4,069

5005K/jbv

average rate is not meaningful due to the early high rate, and the estimated tube cleaning frequency is also not meaningful over a several-day cleaning interval.

When considering ball consumption, one must realize that balls were lost at various locations within the flow loop. As the balls lost diameter, they became more able to pass through the collector screen and out through the MWD. Small spaces tended to trap balls, and once a ball was trapped in an opening that had some flow, additional balls would get trapped in the same opening. This was found in the condenser inlet when CWP weld flash was caught in the inlet tubesheet and also in some of the drain lines in the waterboxes. Trapped balls were found in some of the heat exchanger instrumented tube open loops. The orifice plates and some of the ball counter paddles had trapped balls. Once a ball became caught, additional balls would jam together upstream from the initially caught ball. Amertap balls were also found in the BCM cold seawater filter (see Section IV.F). These balls were transported into the inlet sump by reverse flow through the heat exchanger during inadvertent pump shutdowns prior to breaking the syphon (see Section IV.B).

3. <u>Recommendations</u>

Based on experience gained from test operations, the following recommendations for future OTEC plants using the Amertap system were developed:

1) Eliminate flow passage restrictions where balls can get caught or trapped. Once a ball is trapped, additional balls will jam into the remaining space and seal the flow path.
2) Design heat exchanger inlet plenums for ball distribution.
3) Bypass systems between waterboxes are not required (especially if item 2 is followed).
4) Operate the seawater pumps at design flow rate before and during ball collection and during backflushing of the collector screens.

5) Development of a design-specific maintenance cycle will be necessary.

6) When loading balls into the system, operate the unit in the ball-catch mode for 15 min to eliminate the need to squeeze the balls under water for air removal.

7) When obtaining the ball inventory, assume that the condenser unit will require at least twice as many balls.

E. CHLORINATION SYSTEM

1. Summary

The Englehard electrolytic sodium hypochlorite generator, or Chloropac unit, was used for about 5 months to chlorinate both the evaporator and condenser heat exchangers and their respective seawater loops to prevent or minimize biofouling. This system usually achieved the target values of 0.4- to 0.5-ppm chlorine concentration for 1 h/day at the inlets of each heat exchanger, and maximum concentration of 0.2 ppm at the MWD. Out of 206 chlorine applications, the MWD limit (with ±0.05-ppm tolerance) was exceeded only four times. Not accurately knowing the seawater flow rates of the warm, cold, and mixed water systems made the chlorination concentration adjustments difficult. Concentration readings at the warm water inlet were initially masked by the presence of iron oxide in the system. The chlorination unit generally performed satisfactorily over the entire operational period. The seawater systems were posttest inspected and found to be clean and in excellent condition (see Sections V.A and V.B).

2. Test Operations

During OTEC-1 operations, the Chloropac unit was successfully used from 14 November 1980 through 10 April 1981 to chlorinate both heat exchangers.

Data from the operational log of the Chloropac unit and on chlorination concentrations at the heat exchanger inlets, outlets, and at the MWD pipe are discussed below. Also, problems with iron oxide (rust) and sample tap location are discussed. The standard operating procedure used for the chlorination system is attached as Appendix K.

a. Checkout Tests

While the system was being checked out, it was discovered that the seawater supply pump, located on the main deck, cavitated because the available NPSH was too low. The pump was moved to the lower level of the forward pump room, where a total flow rate of about 160 gpm was obtained. Because this was 20% lower than the design flow rate of 200 gpm,[18] it decreased the 1850-lb/day available chlorine capacity by about 20%. This reduction did not compromise the operation of this unit or the test program.

Because of operational problems with the Delta Scientific online-feedback chlorine analyzer, the daily chlorine dosage was controlled by manually setting the current to the chlorine generators. The residual oxidant chlorine level was determined by AECOS personnel, the onboard environmental monitor contractor. An amperometric titrator was used for this purpose. The starboard generator was assigned to the condenser and the port generator to the evaporator. This assignment eliminated having to reset the current daily. Of the generator capacity available, the condenser used about 20% and the evaporator about 60%, leading to the observation that the chlorine demand of the warm water system is two to three times that of the cold water system.[19] The current was adjusted and set based on: (1) the residual oxidant chlorine level at the heat exchanger inlets and at the MWD and (2) on the operating condition of all three seawater pumps (warm, cold, and mixed). The target chlorine concentration for each heat exchanger inlet was 0.4 to 0.5 ppm for 1 h/day with a maximum MWD concentration of 0.2 ppm during chlorination. This resulted in a maximum discharge concentration of 0.2 ppm for 2 h in a 24-h period.

b. System Operation

The warm and mixed water pumps were started on 11 November 1980, and the cold water pump was started on 12 November 1980. The Chloropac unit was started on 14 November 1980; adjustments to the unit were made on 14, 18, 19, and 20 November 1980. Operational data of the Chloropac unit began on 21 November 1980 using the OTEC-1 Chlorination System Standard Operating Procedure No. OTEC-1-OP-900 (Appendix K). The operation of the Chloropac unit is summarized in Table 4-16. This table gives the chlorination start and stop times, flow rate, voltage, current, and the heat exchanger inlet and MWD chlorination levels. On 2 February 1981, the Chloropac evaporator flowmeter (FE-201) stopped operating. When the unit was checked, two vanes were found to be missing from the stainless steel turbine rotor. Crevice corrosion had apparently been the cause of the failure. Table 4-16 also shows that out of the 206 chlorine applications, the MWD limit (with ± 0.05 tolerance) was exceeded only four times. Not accurately knowing the seawater flow rates of the warm, cold, and mixed water pumps made the chlorination concentration adjustments difficult.

OTEC-1 residual oxidant data (Table 4-17) were obtained from AECOS. Results of the water quality monitoring service by AECOS are given in Ref. 19. This table shows for the entire test period the chlorine residual oxidant levels in ppm for both heat exchanger inlets and outlets and MWD pipe covering. From 12 December 1980 through 5 January 1981, chlorine level was higher at the evaporator inlet than at the evaporator outlet, showing chlorine demand. From 6 January 1981 through 26 February 1981, the reverse was true. This result was very puzzling since it indicated that additional chlorine was being generated in the evaporator. Various checks of the facility were made, including chlorine and ammonia analysis procedural techniques. On 2 February 1981, ETEC and Tracor Marine divers examined the PVC distribution manifold in the warm water sump for breaks which could have caused streaming of the injected chlorine. None were found.

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 1 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
21 Nov 80	Cond	1330	1415	84.1	29.8	430	a	a
21 Nov 80	Evap	1415	1545	90	34	1000	0.44	0.21
22 Nov 80	Evap	1406	1510	90	35	1000	0.45	0.20
22 Nov 80	Cond	1525	1625	84	29	430	0.40	0.11
23 Nov 80	Cond	1335	1437	84	29	430	0.50	0.06
23 Nov 80	Evap	1443	1543	88.9	33.5	1000	0.35	0.17
24 Nov 80	Evap	1538	1645	88	33	950	0.27	0.16
24 Nov 80	Cond	1646	1750	83	29	430	0.42	0.05
12 Dec 80	Evap	2157	0015	37	30	500	0.10	0.13
21 Dec 80	Evap	1322	1532	86	33	750	0.32	0.25
22 Dec 80	Evap	1349	1524	87	35	1000	0.42	0.21
22 Dec 80	Cond	1542	1705	83.5	30	430	0.39	0.08
23 Dec 80	Cond	1335	1443	83.5	30	430	0.38	0.09
23 Dec 80	Evap	1549	1705	87	35	1000	0.43	0.21
24 Dec 80	Evap	1420	1530	84.5	35	960	0.39	0.18
24 Dec 80	Cond	1540	1650	83.5	29	440	0.39	0.08
25 Dec 80	Cond	1520	1626	83.6	30	430	0.38	0.07
25 Dec 80	Evap	1650	1755	86.5	34	960	0.42	0.19
26 Dec 80	Evap	1245	1400	87	34	960	0.44	0.22
26 Dec 80	Cond	1400	1525	79	30	430	0.19	0.09
27 Dec 80	Cond	1330	1430	86.4	30	430	0.35	0.08
27 Dec 80	Evap	1430	1530	87	34	960	0.46	0.23
28 Dec 80	Evap	1230	1330	86.4	34	960	0.44	0.22
28 Dec 80	Cond	1330	1445	76	30	430	0.32	0.09
29 Dec 80	Cond	1256	1410	83	29	430	0.42	0.08
29 Dec 80	Evap	1415	1520	87	34	960	0.46	0.21
30 Dec 80	Evap	1335	1440	87	35	960	0.40	0.21
30 Dec 80	Cond	1450	1550	84	30	430	0.42	0.13

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 2 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
31 Dec 80	Cond	1315	1432	84	30	430	0.39	0.08
31 Dec 80	Evap	1443	1543	87	34.5	950	0.40	0.20
01 Jan 81	Evap	1305	1400	87	35	960	0.42	0.21
01 Jan 81	Cond	1410	1510	83	30	440	0.43	0.07
02 Jan 81	Cond	1320	1440	84	30	430	0.40	0.08
02 Jan 81	Evap	1440	1530	83	34	960	0.43	0.21
03 Jan 81	Evap	1315	1440	87.5	34	960	0.44	0.21
03 Jan 81	Cond	1440	1540	83.5	30	430	0.41	0.08
04 Jan 81	Cond	1300	1405	84	30	430	0.37	0.10
04 Jan 81	Evap	1405	1505	87	34	960	0.43	0.23
05 Jan 81	Evap	1230	1330	87	34	960	0.60	b
05 Jan 81	Cond	1230	1430	84	30	340	0.42	b
06 Jan 81	Cond	1320	1420	83	30	340	0.49	b
06 Jan 81	Evap	1420	1520	87	34	775	0.39	b
07 Jan 81	Evap	2255	2355	87.5	36	960	0.37	b
07 Jan 81	Cond	2355	0055	83	30	440	0.39	b
08 Jan 81	Cond	1425	1530	83.5	30	440	0.39	0.13
08 Jan 81	Evap	1537	1645	87	36	960	0.36	0.27
09 Jan 81	Cond	0950	1050	83	30	440	0.43	0.12
09 Jan 81	Evap	1140	1240	87.5	36	960	0.36	0.26
10 Jan 81	Evap	1355	1455	84	38	900	0.32	0.46
11 Jan 81	Evap	1636	1736	84	31	450	0.10	0.20
12 Jan 81	Evap	1619	1719	85.5	31	450	0.15	0.20
13 Jan 81	Evap	1855	1955	87	38	900	0.32	0.25
13 Jan 81	Cond	2015	2115	84	30	425	0.42	0.12
14 Jan 81	Cond	1429	1529	84	30	420	0.38	0.12
14 Jan 81	Evap	1540	1646	84	36	856	0.21	0.24

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 3 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
15 Jan 81	Evap	1555	1655	86	36	750	0.20	0.19
15 Jan 81	Cond	1710	1810	83	31	450	0.46	0.13
16 Jan 81	Cond	1447	1547	84	31	430	0.43	0.11
16 Jan 81	Evap	1600	1700	85	34	740	0.23	0.21
17 Jan 81	Evap	1415	1519	82	34	740	0.22	0.20
17 Jan 81	Cond	1530	1633	83	30	440	0.39	0.12
18 Jan 81	Cond	1447	1550	83	30	440	0.37	0.09
18 Jan 81	Evap	1555	1658	81	34	750	0.16	0.19
19 Jan 81	Evap	1553	1653	77	34	740	0.16	0.17
19 Jan 81	Cond	1910	2010	84	30	430	0.20	0.09
20 Jan 81	Cond	1506	1619	83	30	430	0.34	0.11
20 Jan 81	Evap	1626	1747	71	34.5	750	0.14	0.17
21 Jan 81	Evap	1730	1830	73	34.5	750	0.24	0.16
21 Jan 81	Cond	1845	1948	83	30	440	0.38	0.10
22 Jan 81	Cond	1721	1821	83	30	370	0.27	0.07
22 Jan 81	Evap	1836	1936	73	34	640	0.13	0.09
23 Jan 81	Evap	1441	1545	73	36	750	0.19	0.22
23 Jan 81	Cond	1607	1703	83	30	410	0.39	0.12
24 Jan 81	Cond	1310	1410	83	30	410	0.41	0.10
24 Jan 81	Evap	1422	1522	72	34	700	0.28	0.15
25 Jan 81	Evap	1658	1758	71	34	700	0.12	0.15
25 Jan 81	Cond	1900	2000	83	30	410	0.38	0.10
26 Jan 81	Cond	1305	1405	83	30	410	0.39	0.11
26 Jan 81	Evap	1418	1518	72	34	700	0.19	0.12
27 Jan 81	Evap	1300	1410	72	34	700	0.25	0.18
27 Jan 81	Cond	1505	1605	82	31	410	0.48	0.10
28 Jan 81	Cond	1310	1405	82	30	410	0.45	0.10
28 Jan 81	Evap	1520	1620	72.7	35	700	0.13	0.17

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 4 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
29 Jan 81	Evap	1410	1510	72.5	34	700	0.11	0.17
29 Jan 81	Cond	1555	1655	83	30	410	0.40	0.10
30 Jan 81	Cond	1545	1645	83	30	410	0.44	0.16
30 Jan 81	Evap	1655	1810	73	34	700	0.12	0.10
31 Jan 81	Evap	1237	1337	72.5	34	700	0.14	0.17
31 Jan 81	Cond	1345	1445	83	31	420	0.45	0.11
01 Feb 81	Cond	1310	1410	83	31	410	0.40	0.08
01 Feb 81	Evap	1435	1535	72	34	700	0.07	0.15
02 Feb 81	Evap	1507	1623	b	34	700	0.09	0.14
02 Feb 81	Cond	1635	1737	83	31	420	0.45	0.08
03 Feb 81	Evap	1135	1228	70	34	700	a	a
04 Feb 81	Evap	1250	1428	b	35	700	0.16	0.09
04 Feb 81	Cond	1440	1540	83	30.5	410	0.39	0.08
05 Feb 81	Cond	1445	1545	83	30	420	0.38	0.11
05 Feb 81	Evap	1600	1700	b	34	710	0.18	0.17
06 Feb 81	Evap	1300	1400	b	34.3	710	0.10	0.20
06 Feb 81	Cond	1408	1508	82.6	30.5	420	0.39	0.07
07 Feb 81	Cond	1335	1435	84	31.5	410	0.39	0.08
07 Feb 81	Evap	1440	1540	b	34	700	0.09	0.18
08 Feb 81	Evap	1312	1412	b	32	700	0.11	0.16
08 Feb 81	Cond	1415	1515	84	31	410	0.37	0.09
09 Feb 81	Cond	1404	1504	84	35	400	0.39	0.09
09 Feb 81	Evap	1510	1610	b	32	710	0.12	0.15
10 Feb 81	Evap	1345	1445	b	31.5	710	0.23	0.23
10 Feb 81	Cond	1500	1600	82.5	35.5	410	0.46	0.15
11 Feb 81	Cond	1423	1523	82.9	35.2	410	0.55	0.13
11 Feb 81	Evap	1530	1630	b	32	710	0.11	0.23

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 5 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
12 Feb 81	Evap	1418	1540	b	31.5	710	0.03	0.30
13 Feb 81	Evap	1414	1514	b	32	780	0.11	0.20
13 Feb 81	Cond	1555	1655	82.4	31	410	0.30	0.11
14 Feb 81	Cond	1233	1333	82	31	410	0.41	0.10
14 Feb 81	Evap	1410	1510	b	32	780	0.11	0.19
15 Feb 81	Evap	1352	1452	b	34	780	0.09	0.19
15 Feb 81	Cond	1500	1600	82	30.5	400	0.38	0.10
16 Feb 81	Cond	1433	1533	82	28	150	0.03	b
16 Feb 81	Evap	1930	2030	b	30	500	0.18	b
17 Feb 81	Evap	1240	1340	b	30	465	0.09	b
17 Feb 81	Cond	1400	1500	83	27.5	140	0.91	b
18 Feb 81	Cond	1420	1520	83	26	90	0.72	b
18 Feb 81	Evap	1530	1630	b	27	230	0.42	b
19 Feb 81	Evap	1405	1510	b	33	710	0.16	0.12
19 Feb 81	Cond	1520	1620	81.9	31	410	0.51	0.07
21 Feb 81	Cond	1543	1647	83	31	410	0.46	0.09
21 Feb 81	Evap	1640	1750	b	32	710	0.13	0.21
22 Feb 81	Evap	1535	1635	b	32	710	0.18	0.20
22 Feb 81	Cond	1640	1740	82	30.5	375	0.44	0.11
23 Feb 81	Cond	1612	1713	83	30.5	340	0.43	0.09
23 Feb 81	Evap	1718	1818	b	31.5	710	0.14	0.21
25 Feb 81	Evap	1420	1520	b	32	710	0.07	0.13
25 Feb 81	Cond	1528	1628	83	30.5	340	0.37	0.06
26 Feb 81	Cond	1603	1704	83	30.5	340	0.34	0.07
26 Feb 81	Evap	1710	1819	b	32	710	0.10	0.18
28 Feb 81	Evap	1352	1500	b	32	710	0.31	0.18
28 Feb 81	Cond	1506	1610	81	30	350	0.34	0.07

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 6 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
01 Mar 81	Cond	1513	1613	81	30	350	0.40	0.07
01 Mar 81	Evap	1615	1715	b	32	710	0.30	0.17
02 Mar 81	Evap	1406	1513	b	33	710	0.32	0.14
02 Mar 81	Cond	1524	1625	81	30	350	0.32	0.08
03 Mar 81	Cond	1327	1427	82	30	350	0.33	0.06
03 Mar 81	Evap	1435	1535	b	32	710	0.31	0.15
07 Mar 81	Evap	2030	2130	b	33	710	0.34	0.21
07 Mar 81	Cond	2137	2237	81.5	30	340	0.37	0.12
08 Mar 81	Cond	1528	1628	83	30	345	0.37	0.10
08 Mar 81	Evap	1639	1739	b	33	625	0.36	0.23
09 Mar 81	Evap	1330	1430	b	32	630	0.33	0.19
09 Mar 81	Cond	1439	1539	81	30	345	0.40	0.08
10 Mar 81	Cond	1456	1556	83	30	345	0.37	0.09
10 Mar 81	Evap	1607	1707	b	32	625	0.29	0.18
11 Mar 81	Evap	1846	1943	b	32.5	620	0.26	0.17
11 Mar 81	Cond	1946	2046	82	32	340	0.35	0.09
12 Mar 81	Cond	1553	1720	83	30	340	0.37	0.09
12 Mar 81	Evap	1730	1830	b	32	625	0.27	0.17
13 Mar 81	Evap	1304	1404	b	32	625	0.25	0.17
13 Mar 81	Cond	1415	1515	83	30	340	0.39	0.08
14 Mar 81	Evap	1424	1524	b	32	625	0.29	0.16
14 Mar 81	Cond	1530	1630	83	30	340	0.42	0.08
15 Mar 81	Cond	1500	1600	82	30	340	0.41	0.09
15 Mar 81	Evap	1618	1718	b	32	625	0.24	0.16
16 Mar 81	Evap	1611	1711	b	32	620	0.22	0.15
16 Mar 81	Cond	1715	1815	81	30	340	0.39	0.08
17 Mar 81	Cond	1446	1546	82	30.5	360	0.48	0.11
17 Mar 81	Evap	1547	1647	b	31	630	0.21	0.19

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 7 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
18 Mar 81	Evap	1345	1445	b	33	630	0.35	0.20
18 Mar 81	Cond	1500	1600	81	30	350	0.52	0.11
19 Mar 81	Cond	1307	1408	81.5	30	350	0.51	0.11
19 Mar 81	Evap	1430	1532	b	32	625	0.33	0.21
20 Mar 81	Evap	1323	1423	b	32	625	0.36	0.17
20 Mar 81	Cond	1426	1528	81	31	350	0.49	0.15
21 Mar 81	Cond	1303	1404	80	30	350	0.51	0.13
21 Mar 81	Evap	1412	1509	b	32	625	0.37	0.22
22 Mar 81	Evap	1308	1408	b	32	625	0.26	0.20
22 Mar 81	Cond	1418	1518	82	31	350	0.47	0.12
23 Mar 81	Cond	1343	1442	82	31	300	0.43	0.11
23 Mar 81	Evap	1450	1542	b	32	625	0.36	0.18
24 Mar 81	Evap	1306	1408	b	32	625	0.34	0.19
24 Mar 81	Cond	1457	1556	81	30	300	0.44	0.09
25 Mar 81	Cond	1400	1500	81	30	260	0.36	0.09
25 Mar 81	Evap	1503	1603	b	33	625	0.33	0.18
26 Mar 81	Evap	1610	1710	b	33	625	0.41	0.17
26 Mar 81	Cond	1809	1909	81	30	280	0.51	0.13
27 Mar 81	Cond	1400	1500	81	29	220	0.37	0.12
27 Mar 81	Evap	1536	1636	b	32	625	0.40	0.18
28 Mar 81	Evap	1820	1920	b	32	625	0.36	0.21
28 Mar 81	Cond	1923	2023	81	30	230	0.37	0.11
29 Mar 81	Cond	1510	1610	81	30	250	0.37	0.10
29 Mar 81	Evap	1618	1718	b	32	625	0.34	0.19
30 Mar 81	Evap	1433	1533	b	32	540	0.34	0.20
30 Mar 81	Cond	1537	1637	81	28.5	180	0.43	0.08
31 Mar 81	Cond	1214	1314	82	29	180	0.41	0.10
31 Mar 81	Evap	1317	1520	b	32	540	0.32	0.23

TABLE 4-16

CHLOROPAC UNIT OPERATIONAL LOG
(Sheet 8 of 8)

Date	Test Article	Start Time (hours)	Stop Time (hours)	Flow (gpm)	Voltage (V)	Current (A)	Test Article Inlet (ppm)	MWD (ppm)
01 Apr 81	Evap	1630	1730	b	32	540	0.29	0.19
01 Apr 81	Cond	1735	1835	81	29	180	0.41	0.08
02 Apr 81	Evap	1111	1211	b	32	540	0.40	0.06
02 Apr 81	Cond	1328	1428	81.5	29	180	0.33	0.18
03 Apr 81	Cond	1605	1705	82	27.5	90	0.17	0.14
04 Apr 81	Cond	1325	1505	81	27	90	0.16	0.15
05 Apr 81	Cond	1315	1416	81	27	90	0.20	0.15
06 Apr 81	Cond	1415	1515	81	27	90	0.19	0.16
07 Apr 81	Cond	1330	1430	81	27	90	0.15	0.13
08 Apr 81	Cond	1345	1445	81	27	90	0.17	0.16
09 Apr 81	Cond	1330	1430	82	27	90	0.15	0.15
10 Apr 81	Cond	1345	1445	82	29	180	0.22	0.03
10 Apr 81	Evap	1455	1600	b	31	540	0.29	0.15

[a]No samples taken
[b]Not in service

5005K/jbv

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 1 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
14 Nov 80	Evaporator	0.00	0.00	0.00	a	a		a	a	
18 Nov 80	Evaporator	0.11	a	0.11	a	a		a	a	
	(varying	0.31	a	0.31	a	a		a	a	
	Chlorpac	0.50	0.41	0.45	a	a		a	a	
	inputs)	0.54	0.50	0.52	a	a		0.18	0.11	0.15
19 Nov 80	Condenser	0.66	0.65	0.65	a	a		a	a	
	(varying	0.29	0.29	0.24	a	a		a	a	
	input)	0.49	0.46	0.47	a	a		a	a	
20 Nov 80	Condenser	0.00	0.00	0.00	a	a		a	a	
	Evaporator	0.00	0.00	0.00	a	a		a	a	
	Evaporator	0.53	0.51	0.52	a	a		0.21	0.19	0.20
	Condenser	0.44	0.26	0.35	a	a		0.09	0.06	0.08
21 Nov 80	Condenser	0.42	0.39	0.41	a	a		a	a	
	Evaporator	0.34	0.26	0.30	0.47	0.40	0.44	0.22	0.20	0.21
22 Nov 80	Evaporator	0.20	a	0.20	0.47	0.42	0.45	0.23	0.16	0.20
	Condenser	0.41	0.38	0.40	0.27	a	0.27	0.11	a	0.11
23 Nov 80	Condenser	0.50	a	0.50	0.34	a	0.34	0.06	a	0.06
	Evaporator	0.35	a	0.35				0.17	a	0.17
24 Nov 80	Evaporator	0.27	a	0.27	0.47	a	0.47	0.16	a	0.16
	Condenser	0.42	a	0.42	0.34	a	0.34	0.05	a	0.05
12 Dec 80	Evaporator	0.10	0.11	0.10	0.19	0.16	0.17	0.13	0.13	0.13
21 Dec 80	Evaporator	0.31	0.33	0.32	0.30	0.29	0.30	0.24	0.26	0.25
22 Dec 80	Evaporator	0.41	0.43	0.42	0.42	0.44	0.43	0.20	0.21	0.21
	Condenser	0.40	0.37	0.39	0.29	0.30	0.29	0.07	0.08	0.08
23 Dec 80	Condenser	0.38	0.38	0.38	0.36	0.38	0.37	0.09	0.08	0.09
	Evaporator	0.42	0.43	0.43	0.44	0.46	0.45	0.22	0.20	0.21
24 Dec 80	Evaporator	0.39	0.38	0.39	0.40	0.40	0.40	0.18	0.17	0.18
	Condenser	0.38	0.39	0.39	0.35	0.36	0.36	0.07	0.08	0.08

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 2 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
25 Dec 80	Condenser	0.37	0.38	0.38	0.32	0.32	0.32	0.07	0.07	0.07
	Evaporator	0.42	0.43	0.42	0.38	0.40	0.39	0.20	0.18	0.19
26 Dec 80	Evaporator	0.43	0.45	0.44	0.42	0.42	0.42	0.22	0.21	0.22
	Condenser	0.20	0.19	0.19	0.15	0.15	0.15	0.09	0.09	0.09
27 Dec 80	Condenser	0.34	0.35	0.35	0.29	0.30	0.30	0.08	0.08	0.08
	Evaporator	0.46	0.45	0.46	0.40	0.41	0.41	0.23	0.23	0.23
28 Dec 80	Evaporator	0.45	0.43	0.44	0.42	0.43	0.43	0.21	0.22	0.22
	Condenser	0.32	0.32	0.32	0.32	0.32	0.32	0.09	0.09	0.09
29 Dec 80	Condenser	0.42	0.42	0.42	0.36	0.38	0.37	0.08	0.08	0.08
	Evaporator	0.46	0.46	0.46	0.41	0.42	0.42	0.21	0.21	0.21
30 Dec 80	Evaporator	0.40	0.40	0.40	0.45	0.43	0.44	0.21	0.21	0.21
	Condenser	0.41	0.41	0.42	0.38	0.40	0.39	0.13	0.13	0.13
31 Dec 80	Condenser	0.39	a	0.39	0.35	a	0.35	0.07	0.08	0.08
	Evaporator	0.40	a	0.40	0.38	a	0.38	0.20	0.19	0.20
01 Jan 81	Evaporator	0.42		0.42	0.43		0.43	0.21	0.20	0.21
	Condenser	0.42	0.44	0.43	0.33	0.35	0.34	0.06	0.08	0.07
02 Jan 81	Condenser	0.40	a	0.40	0.38	a	0.38	0.07	0.08	0.08
	Evaporator	0.42	a	0.42	0.42	a	0.42	0.21	0.21	0.21
03 Jan 81	Evaporator	0.42	0.45	0.44	0.45	0.35	0.40	0.21	0.20	0.21
	Condenser	0.40	0.41	0.41	0.39	0.37	0.38	0.08	0.08	0.08
04 Jan 81	Condenser	0.38	0.36	0.37	0.34	0.35	0.35	0.09	0.11	0.10
	Evaporator	0.42	0.43	0.43	0.36	0.37	0.37	0.23	0.23	0.23
05 Jan 81	Evaporator	0.58	0.61	0.60	0.49	0.51	0.50	b		
	Condenser	0.43	0.40	0.42	0.40	0.39	0.40	b		
06 Jan 81	Condenser	0.49	0.48	0.49	0.44	0.42	0.43	b		
	Evaporator	0.39	a	0.39	0.38	0.40	0.39	b		
07 Jan 81	Evaporator	0.37	a	0.37	0.40	0.40	0.40	b		
	Condenser	0.39	0.39	0.39	0.36	0.36	0.36	b		

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 3 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
08 Jan 81	Condenser	0.38	0.39	0.39	0.37	0.37	0.37	0.12	0.13	0.13
	Evaporator	0.38	0.33	0.36	0.41	0.42	0.42	0.27	0.27	0.27
09 Jan 81	Condenser	0.40	0.46	0.43	0.35	0.34	0.35	0.13	0.11	0.12
	Evaporator	0.30	0.43	0.36	0.36	0.43	0.40	0.28	0.24	0.26
10 Jan 81	Evaporator	0.28	0.36	0.32	0.39	0.40	0.40	0.46	0.47	0.46
	Condenser	b								
11 Jan 81	Condenser	b								
	Evaporator	0.12	0.08	0.10	0.13	0.13	0.13	0.20	0.21	0.20
12 Jan 81	Evaporator	0.15	0.14	0.15	0.19	0.17	0.18	0.19	0.21	0.20
	Condenser	b								
13 Jan 81	Evaporator	0.32	0.32	0.32	0.37	0.39	0.38	0.24	0.25	0.25
	Condenser	0.41	0.42	0.42	0.31	0.31	0.31	0.13	0.11	0.12
14 Jan 81	Condenser	0.36	0.42	0.38	0.30	0.32	0.31	0.12	0.11	0.12
	Evaporator	0.29	0.13	0.21	0.35	0.34	0.35	0.23	0.26	0.24
15 Jan 31	Evaporator	0.17	0.23	0.20	0.27	0.26	0.27	0.17	0.20	0.19
	Condenser	0.48	0.44	0.46	0.38	0.37	0.38	0.13	0.13	0.13
16 Jan 81	Condenser	0.46	0.40	0.43	0.37	0.35	0.36	0.11	0.11	0.11
	Evaporator	0.31	0.14	0.23	0.24	0.24	0.24	0.21	0.21	0.21
17 Jan 81	Evaporator	0.42	0.14	0.22	0.27	0.27	0.27	0.19	0.21	0.20
	Condenser	0.37	0.41	0.39	0.33	0.33	0.33	0.11	0.13	0.12
18 Jan 81	Condenser	0.34	0.40	0.37	0.31	0.31	0.31	0.10	0.08	0.09
	Evaporator	0.17	0.15	0.16	0.29	0.32	0.31	0.19	0.18	0.19
19 Jan 81	Evaporator	0.16	0.16	0.16	0.17	0.17	0.17	0.18	0.16	0.17
	Condenser	0.20	a	0.20	0.22	0.22	0.22	0.10	0.08	0.09
20 Jan 81	Condenser	0.32	0.36	0.34	0.33	0.33	0.33	0.10	0.11	0.11
	Evaporator	0.16	0.12	0.14	0.13	0.13	0.13	0.16	0.18	0.17
21 Jan 81	Evaporator	0.24	a	0.24	0.12	0.12	0.12	0.15	0.16	0.16
	Condenser	0.40	0.36	0.38	0.27	0.31	0.29	0.10	0.10	0.10

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 4 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
22 Jan 81	Condenser	0.30	0.24	0.27	0.19	0.17	0.18	0.07	a	0.07
	Evaporator	0.10	0.15	0.13	0.00	0.00	0.00	0.06	0.12	0.09
23 Jan 81	Evaporator	0.18	0.20	0.19	0.10	0.10	0.10	0.21	0.23	0.22
	Condenser	0.38	0.39	0.39	0.27	0.23	0.25	0.11	0.13	0.12
24 Jan 81	Condenser	0.40	0.41	0.41	0.30	0.32	0.31	0.10	0.10	0.10
	Evaporator	0.27	0.28	0.28	0.11	0.14	0.13	0.15	0.15	0.15
25 Jan 81	Evaporator	0.12	0.12	0.12	0.12	0.12	0.12	0.16	0.13	0.15
	Condenser	0.39	0.37	0.38	0.31	0.30	0.31	0.12	0.07	0.10
26 Jan 81	Condenser	0.40	0.37	0.39	0.35	0.35	0.35	0.11	0.10	0.11
	Evaporator	0.18	0.19	0.19	0.25	0.25	0.25	0.08	0.15	0.12
27 Jan 81	Evaporator	0.21	0.29	0.25	0.24	0.24	0.24	0.19	0.17	0.18
	Condenser	0.50	0.46	0.48	0.37	0.39	0.38	0.10	0.10	0.10
28 Jan 81	Condenser	0.43	0.47	0.45	0.37	0.39	0.38	0.10	0.10	0.10
	Evaporator	0.10	0.15	0.13	0.22	0.25	0.24	0.17	0.17	0.17
29 Jan 81	Evaporator	0.13	0.08	0.11	0.25	0.25	0.25	0.16	0.17	0.17
	Condenser	0.40	0.40	0.40	0.36	0.35	0.36	0.10	0.10	0.10
30 Jan 81	Condenser	0.46	0.42	0.44	0.37	0.39	0.38	0.16	0.16	0.16
	Evaporator	0.10	0.14	0.12	0.24	0.25	0.25	0.10	0.10	0.10
31 Jan 81	Evaporator	0.12	0.15	0.14	0.27	0.28	0.28	0.16	0.17	0.17
	Condenser	0.46	0.44	0.45	0.36	0.39	0.38	0.10	0.11	0.11
01 Feb 81	Condenser	0.42	0.37	0.40	0.38	0.37	0.38	0.09	0.07	0.08
	Evaporator	0.06	0.08	0.07	0.19	0.21	0.20	0.14	0.16	0.15
02 Feb 81	Evaporator	0.09	0.09	0.09	0.17	0.22	0.20	0.15	0.12	0.14
	Condenser	0.45	0.45	0.45	0.28	0.29	0.29	0.08	0.08	0.08
03 Feb 81	Condenser	b								
	Evaporator	b								
04 Feb 81	Evaporator	0.13	0.19	0.16	0.21	0.21	0.21	0.09	0.09	0.09
	Condenser	0.36	0.42	0.39	0.26	0.27	0.27	0.07	0.08	0.08

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 5 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
05 Feb 81	Condenser	0.39	0.36	0.38	0.31	0.31	0.31	0.11	0.11	0.11
	Evaporator	0.16	0.19	0.18	0.24	0.23	0.24	0.16	0.17	0.17
06 Feb 81	Evaporator	0.09	0.10	0.10	0.17	0.17	0.17	0.21	0.18	0.20
	Condenser	0.36	0.42	0.39	0.33	0.33	0.33	0.07	0.06	0.07
07 Feb 81	Condenser	0.38	0.39	0.39	0.29	0.30	0.30	0.05	0.11	0.08
	Evaporator	0.09	0.09	0.09	0.16	0.15	0.16	0.17	0.18	0.18
08 Feb 81	Evaporator	0.14	0.07	0.11	0.24	0.24	0.24	0.16	0.16	0.16
	Condenser	0.36	0.38	0.37	0.30	0.32	0.31	0.09	0.09	0.09
09 Feb 81	Condenser	0.39	0.39	0.39	0.29	0.30	0.30	0.10	0.08	0.09
	Evaporator	0.08	0.15	0.12	0.27	0.27	0.27	0.14	0.16	0.15
10 Feb 81	Evaporator	0.11	0.34	0.23	0.16	0.27	0.22	0.23	0.23	0.23
	Condenser	0.43	0.48	0.46	0.43	0.44	0.44	0.15	0.14	0.15
11 Feb 81	Condenser	0.56	0.53	0.55	0.46	0.45	0.46	0.12	0.14	0.13
	Evaporator	0.14	0.09	0.11	0.32	0.32	0.32	0.22	0.23	0.23
12 Feb 81	Condenser	0.01	0.05	0.03	0.00	0.01	0.01	0.30	0.30	0.30
	Evaporator	a	a		a	a		a	a	
13 Feb 81	Evaporator	0.10	0.12	0.11	0.30	0.31	0.31	0.21	0.18	0.20
	Condenser	0.30	0.29	0.30	0.26	0.41	0.34	0.10	0.11	0.11
14 Feb 81	Condenser	0.42	0.39	0.41	0.30	0.31	0.31	0.09	0.10	0.10
	Evaporator	0.11	0.10	0.11	0.34	0.36	0.35	0.19	0.19	0.19
15 Feb 81	Evaporator	0.09	0.09	0.09	0.31	0.28	0.30	0.19	0.19	0.19
	Condenser	0.39	0.37	0.38	0.27	0.28	0.28	0.11	0.09	0.10
16 Feb 81	Condenser	0.03	a	0.03	0.04	0.03	0.04	b		
	Evaporator	0.20	0.16	0.18	0.54	0.53	0.54	b		
17 Feb 81	Evaporator	0.08	0.10	0.09	0.39	0.41	0.41	b		
	Condenser	0.90	0.91	0.91	0.71	0.69	0.70	b		
18 Feb 81	Condenser	0.70	0.73	0.73	a	a		b		
	Evaporator	0.51	0.33	0.42	0.09	0.09	0.09			

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 6 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
19 Feb 81	Evaporator	0.16	0.16	0.16	0.29	0.30	0.30	0.12	0.12	0.12
	Condenser	0.51	a	0.51	0.39	0.42	0.41	0.05	0.08	0.07
20 Feb 81	Evaporator	c								
	Condenser	c								
21 Feb 81	Condenser	0.47	0.44	0.46	0.32	0.32	0.32	0.09	0.09	0.09
	Evaporator	0.15	0.10	0.13	0.34	0.30	0.32	0.22	0.20	0.21
22 Feb 81	Evaporator	0.14	0.21	0.18	0.31	0.31	0.31	0.19	0.21	0.20
	Condenser	0.45	0.42	0.44	0.32	0.32	0.32	0.11	0.10	0.11
23 Feb 81	Condenser	0.43	0.42	0.43	0.29	0.30	0.30	0.09	0.09	0.09
	Evaporator	0.11	0.17	0.14	0.27	0.28	0.28	0.20	0.21	0.21
24 Feb 81	Evaporator	c								
	Condenser	c								
25 Feb 81	Evaporator	0.06	0.07	0.07	0.25	0.22	0.24	0.12	0.13	0.13
	Condenser	0.36	0.38	0.37	0.24	0.26	0.25	0.06	0.05	0.06
26 Feb 81	Condenser	0.35	0.33	0.34	0.26	0.26	0.26	0.05	0.08	0.07
	Evaporator	0.10	0.10	0.10	0.24	0.25	0.25	0.17	0.19	0.18
27 Feb 81	Condenser	c								
	Evaporator	c								
28 Feb 81	Evaporator	0.30	0.32	0.31	0.28	0.28	0.28	0.17	0.18	0.18
	Condenser	0.35	0.33	0.34	0.23	0.30	0.27	0.08	0.06	0.07
01 Mar 81	Condenser	0.41	0.39	0.40	0.28	0.27	0.28	0.08	0.06	0.07
	Evaporator	0.30	0.29	0.30	0.27	0.24	0.26	0.16	0.17	0.17
02 Mar 81	Evaporator	a	0.32	0.32	0.29	0.28	0.29	0.14	0.14	0.14
	Condenser	0.32	0.32	0.32	0.27	0.27	0.27	0.07	0.08	0.08
03 Mar 81	Condenser	0.32	0.33	0.33	0.20	0.23	0.22	0.05	0.06	0.06
	Evaporator	0.30	0.32	0.31	0.25	0.24	0.25	0.14	0.15	0.15
04 Mar 81	c									
05 Mar 81	d									

TABLE 4-17
AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 7 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
06 Mar 81	d									
07 Mar 81	Evaporator	0.33	0.34	0.34	0.32	0.31	0.32	0.21	0.20	0.21
	Condenser	0.38	0.36	0.37	0.25	0.27	0.26	0.12	0.11	0.12
08 Mar 81	Condenser	0.38	0.35	0.37	0.32	0.31	0.32	0.10	0.09	0.10
	Evaporator	0.36	0.36	0.36	0.36	0.33	0.35	0.23	0.22	0.23
	e	0.34	0.33	0.34	0.29	0.29	0.29	0.19	0.19	0.19
09 Mar 81	Evaporator	0.32	0.33	0.33	0.25	0.25	0.25	0.19	0.19	0.19
	Condenser	0.41	0.38	0.40	a	0.28	0.28	0.08	0.07	0.08
10 Mar 81	Condenser	0.39	0.35	0.37	0.27	0.25	0.26	0.09	0.09	0.09
	Evaporator	0.29	0.29	0.29	0.25	0.27	0.26	0.17	0.18	0.18
11 Mar 81	Evaporator	0.24	0.28	0.24	0.26	0.24	0.25	0.17	0.17	0.17
	Condenser	0.33	0.37	0.35	0.25	0.26	0.26	0.09	0.09	0.09
12 Mar 81	Condenser	0.36	0.38	0.37	0.31	0.32	0.32	0.08	0.09	0.09
	Evaporator	0.28	0.26	0.27	0.23	0.24	0.24	0.16	0.17	0.17
13 Mar 81	Evaporator	0.25	a	0.25	0.23	0.24	0.24	0.16	0.17	0.17
	Condenser	0.39	0.39	0.39	0.31	a	0.31	0.08	0.08	0.08
14 Mar 81	Evaporator	0.28	0.30	0.29	0.25	0.28	0.27	0.14	0.18	0.16
	Condenser	0.40	0.43	0.42	0.26	0.27	0.27	0.08	0.07	0.08
15 Mar 81	Condenser	0.42	0.40	0.41	0.29	0.30	0.30	0.09	0.08	0.09
	Evaporator	0.22	0.25	0.24	0.24	0.23	0.24	0.17	0.15	0.16
16 Mar 81	Evaporator	0.21	0.22	0.22	0.28	0.27	0.28	0.14	0.16	0.15
	Condenser	0.40	0.38	0.39	0.30	0.33	0.32	0.07	0.09	0.08
17 Mar 81	Condenser	0.48	0.48	0.48	0.40	0.41	0.41	0.11	0.10	0.11
	Evaporator	0.21	0.20	0.21	0.26	0.25	0.26	0.20	0.17	0.19
18 Mar 81	Evaporator	0.36	0.33	0.35	0.27	0.27	0.27	0.19	0.20	0.20
	Condenser	0.54	0.50	0.52	0.41	0.39	0.40	0.10	0.11	0.11
19 Mar 81	Condenser	0.54	0.48	0.51	0.45	0.46	0.46	0.12	0.10	0.11
	Evaporator	0.34	0.32	0.33	0.28	0.28	0.28	0.21	0.21	0.21

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 8 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
20 Mar 81	Evaporator	0.36	0.35	0.36	0.23	0.23	0.23	0.17	0.17	0.17
	Condenser	0.49	0.49	0.498	0.43	0.43	0.43	0.15	0.15	0.15
21 Mar 81	Condenser	0.51	0.51	0.51	0.48	0.49	0.49	0.14	0.12	0.13
	Colormetric	a	a		a	a		0.15	0.18	0.17
	Evaporator	0.35	0.39	0.37	0.33	0.33	0.33	0.21	0.22	0.22
	Colormetric	a	a		a	a		0.21	0.24	0.23
22 Mar 81	Evaporator	0.25	0.26	0.26	0.31	0.30	0.31	0.19	0.20	0.20
	Condenser	0.48	0.45	0.47	0.37	0.37	0.37	0.12	0.12	0.12
23 Mar 81	Condenser	0.43	0.42	0.43	0.37	0.39	0.38	0.10	0.12	0.11
	Evaporator	0.38	0.34	0.36	0.29	0.27	0.28	0.18	0.18	0.18
24 Mar 81	Evaporator	0.33	0.34	0.34	0.31	0.32	0.32	0.19	0.19	0.19
	Colormetric	a	a		a	a		0.19	0.20	0.20
	Condenser	0.44	0.43	0.44	0.35	0.36	0.36	0.09	0.09	0.09
	Colormetric	a	a		a	a		0.12	0.14	0.13
25 Mar 81	Condenser	0.35	0.36	0.36	0.30	0.28	0.29	0.10	0.08	0.09
	Colormetric	a	a		a	a		0.06	0.11	0.08
	Evaporator	0.31	0.35	0.33	0.30	0.31	0.31	0.18	0.18	0.18
	Colormetric	a	a		a	a		0.15	0.21	0.18
26 Mar 81	Evaporator	0.44	0.38	0.41	0.32	0.32	0.32	0.16	0.17	0.17
	Colormetric	a	a		a	a		0.21	0.18	0.20
	Condenser	0.50	0.51	0.51	0.44	0.44	0.44	0.13	0.12	0.13
	Colormetric	a	a		a	a		0.17	0.18	0.18
27 Mar 81	Condenser	0.38	0.36	0.37	0.31	0.29	0.30	0.13	0.11	0.12
	Colormetric	a	a		a	a		0.16	0.15	0.16
	Evaporator	0.41	0.39	0.40	0.35	0.36	0.36	0.18	0.18	0.18
	Colormetric	a	a		a	a		0.24	0.23	0.24
28 Mar 81	Evaporator	0.37	0.34	0.36	0.27	0.26	0.27	0.22	0.19	0.21
	Colormetric	a	a		a	a		a	0.23	0.23
	Condenser	0.37	0.36	0.37	0.32	0.29	0.31	0.12	0.09	0.11
	Colormetric	a	a		a	a		0.16	0.15	0.16

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 9 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
29 Mar 81	Condenser	0.36	0.37	0.37	0.29	0.29	0.29	0.09	0.10	0.10
	Colormetric	0.13	0.10	0.12	a	a		0.13	0.10	0.12
	Evaporator	0.31	0.36	0.34	0.25	0.25	0.25	0.19	0.18	0.19
	Colormetric	a	a		a	a		0.16	0.20	0.18
30 Mar 81	Evaporator	0.34	0.34	0.34	0.31	0.30	0.31	0.20	0.19	0.20
	Colormetric	a	a		a	a		0.20	0.20	0.20
	Condenser	0.43	0.42	0.43	0.36	0.35	0.36	0.07	0.08	0.08
	Colormetric	a	a		a	a		0.12	0.18	0.15
31 Mar 81	Condenser	0.42	0.40	0.41	0.37	0.37	0.37	0.10	0.10	0.10
	Colormetric	a	a		a	a		0.13	0.07	0.10
	Evaporator	0.32	0.31	0.32	0.30	0.29	0.30	0.24	0.21	0.23
	Colormetric	a	a		a	a		0.19	0.20	0.20
01 Apr 81	Evaporator	0.27	0.30	0.29	0.28	0.27	0.28	0.17	0.20	0.19
	Colormetric	a	a		a	a		0.23	0.21	0.22
	Condenser	0.41	0.40	0.41	0.31	0.31	0.31	0.07	0.08	0.08
	Colormetric	a	a		a	a		0.15	0.05	0.10
02 Apr 81	Condenser	0.41	0.38	0.40	0.33	0.32	0.33	0.06	0.06	0.06
	Evaporator	0.33	0.33	0.33	0.29	0.28	0.29	0.20	0.16	0.18
03 Apr 81	Condenser	0.16	0.18	0.17	0.12	0.12	0.12	0.14	0.14	0.14
	Colormetric	a	a		a	a		0.15	0.11	0.13
	Evaporator	d								
04 Apr 81	Condenser	0.15	0.17	0.16	0.11	0.09	0.10	0.15	0.15	0.15
	Colormetric	a	a		a	a		0.13	0.11	0.12
	Evaporator	d								
05 Apr 81	Condenser	0.18	0.21	0.20	0.12	0.12	0.12	0.14	0.15	0.15
	Evaporator	d								
06 Apr 81	Condenser	0.18	0.19	0.19	0.12	0.14	0.13	0.15	0.17	0.16
	Evaporator	d								
07 Apr 81	Condenser	0.15	0.15	0.15	0.08	0.10	0.09	0.13	0.13	0.13
	Evaporator	d								
08 Apr 81	Condenser	0.17	0.17	0.17	0.11	0.11	0.11	0.16	0.16	0.16
	Evaporator	d								

TABLE 4-17

AECOS, INC., CHLORINATION LEVEL DATA
[Residual Oxidants (mg/liter)]
(Sheet 10 of 10)

Date	System	Inlet			Outlet			MWD		
		1	2	Avg	1	2	Avg	1	2	Avg
09 Apr 81	Condenser	0.14	0.15	0.15	0.12	0.11	0.12	0.13	0.16	0.15
	Evaporator	d								
10 Apr 81	Condenser	0.21	0.22	0.22	0.15	0.14	0.15	0.03	0.02	0.03
	Evaporator	0.29	0.29	0.29	0.23	0.22	0.23	0.13	0.16	0.15
11 Apr 81		c								
12 Apr 81		c								

[a]No samples taken
[b]Not operating
[c]Not chlorinated
[d]All systems shut down
[e]Reset Chloropac to lower output for evaporator

5005K/jbv

During this period, it was observed that the Tygon tube used to obtain the evaporator inlet sample (located at 6:00 o'clock) was being stained with iron oxide. On 28 February 1981, AECOS personnel were requested to leave the sample port open to permit continuous seawater flow. From then on, most of the results showed that there was a chlorine demand in the evaporator. The cause of the incorrect chlorine level readings at the evaporator inlet was attributed to iron oxide, which was concentrated at the lower half of the inlet pipe. The evaporator outlet port was located at 9:00 o'clock, as were the MWD pipe (Figure 4-7) and both the inlet and outlet sample ports of the condenser. In Table 4-17, two sets of data are presented beginning with 21 March 1981. Before this date, all data had been obtained using the amperometric titrator. But beginning on that date, a second method using a colorimeter (color) was added for comparison.

Figure 4-7. MWD Sample Port

The last day of chlorination was 10 April 1981, and the seawater pumps (warm, cold, and mixed) were shut down on 12 April 1981.

3. Recommendations

Based on the experience gained, the following recommendations for future OTEC plants using chlorination systems were developed:

1) For a system with an intermittent chlorination regimen, an automated, on-line instrumented feedback control system is unnecessarily complicated. A daily dosage with indication of concentrations, periodically verified by chemical analysis of samples, is a practical, simple, manual task.
2) Protect seawater loops, especially inlet screen frames and any other carbon steel components exposed to seawater, by coating them using proper application techniques and a good coating material to prevent or at least minimize iron oxide formation in the system. Iron oxide formation in the seawater loop can cause erroneous chlorine concentration readings.
3) Locate seawater sample ports for chlorine analysis to reduce drawing contaminants into sample water. Do not have sample ports located at the bottom of the pipes.
4) Flowmeters selected for use with the chlorination system must be compatible (chemically) with the chlorine concentrations and preferably should be located upstream from where the chlorine is generated (Figure 2-12).
5) Use a chlorination system. It is an effective technique for preventing biofouling of the seawater loops and heat exchangers. Although the Amertap system was also used in conjunction with the chlorination system, it was shut down on 3 March 1981. Therefore, during the last 5 weeks of testing, only the chlorination system was used for biofouling control. Posttest inspection results have shown that both heat exchanger critical surfaces were clean and in excellent condition (see Sections IV.A and IV.B).

6) The use of an electrolytic on-line generator was found to be a reliable, flexible, and effective method for chlorination and one that eliminates the need to store chemicals.

F. BIOFOULING AND CORROSION MODULES

1. Summary

The ANL BCMs were operated for 5 months to obtain biofouling and corrosion data. All conclusions and observations regarding fouling and corrosion are taken from Ref. 14. The two biofouling countermeasures (0.4 to 0.5 ppm chlorine, 1 h/day; Amertap balls) were sufficient to prevent any detectable increase in fouling. The only module to experience significant fouling was the warm water free-fouling (no countermeasures) module. The corrosion of aluminum specimens was considerably less in cold water than in warm water. Using Amertap balls every 15 min considerably increased the amount of metal loss in warm water but not in cold water. The inside diameter of the aluminum tubes was 0.074 in. less than that of the titanium tubes for which the Amertap balls were specified.

Microfouling studies indicated the biofouling levels of the tracking module tubes of both the evaporator and condenser to be low and near the limits of detection. Insufficient biofouling data prevented any correlations with heat transfer data. Numerous modifications to and changes of the hardware, requested by ANL and made by ETEC, necessitated changes (by ETEC) in the computer software. Operational problems and design flow capacity regarding the seawater supply pumps limited the number of modules that could be operated simultaneously to six rather than the eight that had been installed.

2. Test Operations

The operational log for the BCM system is presented in Table 4-18. This section discusses the modifications to the hardware, instrumentation, and software that were completed in Hawaii. The operation of the modules and the problems encountered, especially with the seawater supply system, are also covered.

a. Pretest Checkout

The SIC (GMDI) structurally mounted four ANL BCMs and the three seawater supply pumps in the forward end of the test compartment (warm water) and the same number in the observation compartment (cold water). The TDC (ETEC) was given the responsibility to complete the construction, which included mechanical, electrical, and instrumentation hookups and the conversion/installation of the ANL software to be compatible with the on-board central processing unit.

Changes specified by ANL were necessary to make these units perform as required and were completed by ANL and TDC personnel. These changes included:

1) Adding chlorinators to the supply lines of units 3, 4, 5, 6, and 7 and wiring them into the system
2) Adding a three-way valve to the calibration manifold
3) Replacing the motor-operated ball transfer valve (BTV) with a pneumatic-piston-operated BTV
4) Installing a side stream valve and hose to bilge
5) Installing an air supply to the pneumatic valves and wiring them to the BCM system
6) Adding inlet pressure gages to all eight units
7) Installing heat transfer monitors
8) Adding five Amertap enable relays
9) Relocating eight heater relays
10) Adding six HTM ball counters

TABLE 4-18

BCM OPERATIONAL LOG

Date	Remarks
10 Jul 80	Initiated mechanical and electrical hookup and repairs of racked modules
17 Aug 80	Initiated checkout of controllers in van and pulling of wires from modules to van
23 Aug 80	Wiring drawing problems in van corrected and drawings completed
27 Aug 80	Started software loading and checkout in computer
04 Sep 80	Construction and software of original design completed; functional demonstration checkout and walkthrough for ANL site representative completed; results of computer printout given to site representative
15 Sep 80	Hardware changes by ANL necessitated modifying software
12 Nov 80	Module 1 (evaporator tracking) on line
18 Nov 80	Module 8 (condenser tracking) on line
21 Jan 81	Module 4 (evaporator with Amertap and chlorine) on line
29 Jan 81	Modules 2 and 5 (evaporator and condenser free fouling) on line
18 Feb 81	Module 7 (condenser with Amertap and chlorine) on line
01 Mar 81	Module 3 (changed to free fouling) on line
03 Mar 81	Aluminum specimens installed on module 7; modules 4 and 6 taken off line and secured; Amertap application stopped and system secured
06 Mar 81	First BCM sample tubes removed from modules 1, 2, 5, and 8
02 Apr 81	Module 1 shut down and secured; second BCM sample tubes removed from modules 2 and 3
03 Apr 81	Second BCM sample tubes removed from module 1
09 Apr 81	Second BCM sample tubes removed from modules 2, 3, 5, 7, and 8
11 Apr 81	HTM tubes for modules 2 and 5 cleaned per ANL instructions
12 Apr 81	Remaining modules (2, 3, 5, 7, and 8) shut down and secured

5005K/sjd

11) Adding eight pressure switches to digital input
12) Completing other integral control box changes
13) Adding structural supports to racks
14) Installing ultrasonic ball detector electronics
15) Relocating BCM low-flow transmitter wires and removing unidentified wires from terminals
16) Modifying electrical interface controls to seawater supply pumps
17) Deleting remote start/stop switches and remote indicator lights for seawater supply pumps

The ANL BCM software was converted by TDC for use with the existing computer system. The program also had to be modified because of the various hardware changes listed above. The software changes required included:

1) Accommodating the Amertap enable/disable relays
2) Modifying the addressing because of the relocation of the heater relays
3) Implementing chlorinator additions, control, and flowmeter interactions
4) Implementing control action for added pressure switches
5) Accommodating Amertap ball counters
6) Implementing cooldown/heater operations and intervals.

When the mechanical and electrical hookups were complete, the system was turned over to ANL. A walk through and functional demonstrations with source codes and example runs were given to the ANL site representative on 4 September 1980.

b. Test Operations

Continual software changes were required because of continued hardware changes. System operation and instrumentation calibrations were performed by ANL; manpower support for maintaining the system was supplied by the TDC and the FOC. Because no standard operating procedure was available, the BCMs were run by ANL personnel. The TDC occasionally assisted in repairing and maintaining equipment and shutting down the system.

The electronics for the BCMs was supplied as a self-contained unit equipped with a master timer, individual HTM timers, chlorinators, Amertap BTV, and other control devices. Many of the timing and control functions were reassigned to the on-board computer to alleviate problems in starting the BCM. The computer also required data from the HTMs and flowmeters; it calculated heat transfer coefficients on-line and printed the results on hard copy and recorded them on magnetic tape.

The BCM operational log (Table 4-18) lists the start and stop dates for the eight modules. Modules 4 and 6 were taken off line and secured on 3 March 1981. Module 1 was shut down on 2 April 1981, and the remaining modules were shut down on 12 April 1981.

The two biofouling countermeasures used on OTEC-1 were 0.4-ppm chlorine 1 h/day and the Amertap system. Amertap balls (initially) were sufficient to prevent any detectable increase in the fouling factor (R_f). The only module in which significant fouling was observed was module 2, the warm water free-fouling module, in which no countermeasures were used.[14] The aluminum specimens corroded much less in cold water than in warm water.[14] Using the Amertap balls on a 15-min schedule considerably increased the amount of metal loss in warm water, but not in cold water. The inside diameter of the aluminum tubes was 0.074 in. less than that of the OTEC-1 titanium tubes for which the Amertap balls had been specified. The balls used for the aluminum tubes were therefore considerably larger than would normally be used, and therefore the action of the balls was not prototypic.

Tube samples were removed and examined by Dr. L. R. Berger of the University of Hawaii at Manoa. Results of the microfouling studies are given in Appendix N and summarized below:

1) Biofouling levels were low and near the limits of detection for the tracking module tubes of both the evaporator and the condenser.
2) A film of rust (iron oxide or iron hydroxide) covered several samples from the warm water side.
3) There were insufficient biofouling data to correlate biofouling and heat transfer. One BCM was shut down but not drained because there was no standard operating procedure for BCM draining.

The microfouling studies indicated that insufficient test time was accumulated for biofouling levels to be measured. The rust film on the evaporator side was attributed to the many carbon steel parts (inlet sump screen frames, ducting, etc.) that had been used and were heavily rusted (see Section V.A) rather than to chlorination. Macrofouling examinations of both the cold and warm seawater systems were conducted by Dr. E. A. Kay of the University of Hawaii at Manoa. Results are presented in Sections V.A and V.B.

3. Operational Problems

The following pump arrangements were designed for the three warm and three cold water supply systems: (1) one pump to supply heat exchanger inlet seawater to the tracking module, (2) one pump to supply sump seawater to the remaining three modules, and (3) one pump to act as backup which could be used to supply seawater to (1) or (2) above.

In preparing, checking, and operating the BCMs, several hardware and operational problems were discovered. This section discusses several of these problems.

In actual operation, the one pump that was to supply three modules was not capable of supplying a steady flow without air bubbles. Because of air in the seawater, the BCM ultrasonic flowmeter did not function. To correct this problem, the pump was used to supply only two modules (one module was shut down and taken off line). The original module assignment list (see Table 4-19) was modified (Table 4-20) on 3 March 1981 to provide for this change in pumping arrangement.

The supply pumps were made of plastic (volute, impeller, and inlet casing) and were very unreliable. The pumps could not be dead-head started and failed often during operation. Common failure modes included: impeller-to-shaft connection, inlet casing, volute, and seal leakage.

The ball transfer valve (BTV) was replaced with a pneumatic BTV. Two problems were encountered: Amertap balls were cut by the valve and the actuator failed due to corrosion. The ball-cutting problem was corrected by changing the operating procedures.

During the first test, the cold water sump supply line plugged and had to be cleared before seawater pump operation. During operation, the in-line duplex filter would become plugged with deep sea shrimp and Amertap balls.

Because no standard operating procedures had been provided with the system, operation (including startup and shutdown) was difficult and inconsistent when personnel unfamiliar with the system were operating the BCMs.

4. Recommendations

Based on experience gained from the test operations, the following recommendations for future OTEC plants using BCMs were developed:

1) Devices such as the OTEC-1 BCMs were of a developmental nature and required excessive attention, modification, and delicate handling. The application of laboratory-type devices to an industrial field installation invites problems such as were encountered.

TABLE 4-19

ORIGINAL BCM ASSIGNMENT

BCM	Assignment/Seawater Supply Location	Fouling Countermeasure
Evaporator		
1	Tracking/evaporator inlet	Same as evaporator
2	Free fouling/warm water sump	None
3	/Warm water sump	Chlorine and Amertap
4	/Warm water sump	Chlorine and Amertap
Condenser		
5	Free fouling/cold water sump	None
6	/Cold water sump	Chlorine and Amertap
7	/Cold water sump	Chlorine and Amertap
8	Tracking/condenser inlet	Same as condenser

TABLE 4-20

REVISED BCM ASSIGNMENT
(effective 3 March 1981)

BCM	Assignment/Seawater Supply Location	Fouling Countermeasure
Evaporator		
1	Tracking/evaporator inlet	No Amertap
2	Free fouling/warm water sump	None
3	Free fouling/warm water sump	No countermeasures per ANL
4	Shutdown	-
Condenser		
5	Free fouling/cold water sump	None
6	Shutdown	-
7	Aluminum HTM/cold water sump	No countermeasures
8	Tracking/condenser inlet	No Amertap

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2) Future application of such equipment should not be considered unless: the equipment has been satisfactorily operated previously, has dedicated personnel assigned to it, is completely self-sufficient, and experimental importance is defined with respect to priorities.

3) Select seawater supply pumps that are durable and capable of fulfilling the requirements of the system. It would be best to have one reliable pump per module. The pump selected would therefore be sized for one operating point, which would be its best-efficiency point. If one pump supplies three modules, then the pump would be operating at off-design conditions when one or two modules are shut down. For the OEC, it appeared that the pump selected had been sized to supply two modules (satisfactory operation). When the third module was put on line, flow fluctuated and air was ingested. Although the pump map may show high-flow operation, running at this condition usually requires high NPSH. At high flow rates, the pump discharge pressure was low, which permitted air to be easily entrained in the seawater.

4) Provide low system resistance inlets (conservative design) to the seawater supply pumps. Lines should be large, and in-line filters should have low-pressure drop. Also, a delta pressure gage should be provided across the filter to determine when the filter needs cleaning.

5) Install an inlet screen at each seawater inlet supply line. Although screens are provided between the ocean inlet and sump, objects like shrimp and Amertap balls may enter the system. Shrimp are small enough to pass through the sump screen, and Amertap balls may enter the sump area by reverse flow due to syphoning of the seawater loops (see Section IV.C). This condition of reverse syphoning existed during unscheduled shutdowns when the Amertap system was in operation and before the reverse flow and syphon could be stopped.

6) Provide standard operating procedures to facilitate the proper operation of the BCM system.
7) Minimize additions and modifications to systems that are operated and controlled by computer. Changes in the hardware required changes in the software.
8) If changes are required, have an interface/configuration control system to assure that all drawings and documents are updated and controlled.

G. INSTRUMENTATION AND CONTROL

1. Summary

The original instrumentation and control systems were designed and installed on the OEC by TRW. After the sea trials, responsibility was turned over to ETEC for completing, checking, verifying, and operating these systems. Numerous problems were discovered and corrected on the basis of priority to permit continued testing and data acquisition. A copper block technique was developed in which a quartz thermometer was used for verifying RTD calibrations. Both ice bath and copper block calibration/verification procedures are dicussed. Many instrumentation and control problems were never solved.

2. Test Operations

This section discusses the I&C van, instrument identification, critical and other instrumentation problems, additions and modifications that were completed in Hawaii, control system experience and problems, and RTD calibration.

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a. I&C Van

To protect the equipment from shock and vibration, this 40-ft-long by 8-ft-wide van was spring mounted at its four corners. But during high sea conditions and when the ship was in transit, the van had a high-amplitude, low-frequency (about 3- to 5-Hz) vibration. The work space in the van was a narrow aisle the length of the van. During testing, it was difficult to walk by the CRT/keyboard operator or the control panel operator.

b. Instrument Identification

The instruments used during the Phase III testing are listed in Table 4-21. This list was specified in the Test Plan[2] with modifications. Each parameter was assigned a sequence number for easy identification and control by the operators and the on-board central processing units (CPUs). The parameters for OTEC-1 are listed by sequence number in Tables 4-22 and 4-23 for analogic (analog to digital converter) 0 and 1, respectively. A total of 332 parameters were identified, recorded on magnetic tape, and available for examination on CRT or display on strip charts.

Of these parameters, the 80 listed in Table 4-24 were identified as critical instrumentation by ANL. These instruments were given special attention so that data were acquired for evaluating heat exchanger performance. Problems were encountered with a few of these instruments and are discussed in Section IV.G.2.c below.

Strip chart direct-inking graphic recorders (DIGRs) were used to monitor selected parameters and to obtain continuous hard-copy records. Sixteen channels were available, with channels 9 through 16 permanently assigned to record gimbal assembly and ship's motions. An example of the strip chart assignment is given in Table 4-25.

TABLE 4-21

INSTRUMENTATION LIST
(Sheet 1 of 3)

Description (Number of Sensors)	Location	Range	Instrument System Accuracy	Tag Number
Evaporator				
Seawater temperature (2)	Inlet and outlet water lines[a]	-	-	-
Seawater temperature (4)	Inlet water box	65-90°F	±0.127°F	TE-8
Seawater temperature (14)	Outlet water box	65-90°F	±0.127°F	TE-9
Seawater pressure (4)	Inlet water box	5-20 psig	±0.051 psig	PE-7
Seawater pressure (4)	Outlet water box	5-20 psig	±0.051 psig	PE-8
Ammonia temperature (10)	Shell interior	65-80°F	±0.127°F	TE-7
Ammonia temperature (1)	Drain tank	40-80°F	±0.127°F	TE-21
Ammonia vapor ΔP (1)	Upper region	0-5 in. H_2O	±0.0027 in. H_2O	PDE-3
Ammonia vapor ΔP (1)	Lower region	0-5 in. H_2O	±0.0027 in. H_2O	PDE-4
Water temperature (1)	Closed-loop inlet	65-90°F	±0.127°F	TE-12
Water flow rate (1)	Closed-loop tubes	0-15 gpm	±1.0% ft/s	FT-31
Water temperature (6)	Closed-loop outlet	65-90°F	±0.127°F	TE-10
Seawater temperature (24)	Open-loop outlet	65-90°F	±0.127°F	TE-11
Ammonia reflux flow rate	Pump P-1 discharge	1000-4000 gpm	±1.0%	FE-1
Ammonia reflux temperature	Pump P-1 discharge	40-80°F	±0.127°F	TE-2
Ammonia reflux flow rate	Pump P-2 discharge	0-2000 gpm	±1.0%	FE-2
Ammonia reflux temperature	Pump P-2 discharge	40-80°F	±0.127°F	TE-3
Ammonia reflux flow rate	Pump P-2 discharge	0-2000 gpm	±1.0%	FE-3
Seawater flow rate (1)	Open-loop tube	0-15 gpm	±1.0%	FT-21
Ammonia vapor pressure (1)	Shell interior	110-140 psig	±0.25 psig	PE-2
Ammonia liquid pressure (1)	Evaporator sump	110-140 psig	±0.25 psig	PE-2
Ammonia liquid level (1)	Evaporator sump	6-54 in. H_2O	±0.501 in. H_2O	LE-1
Condenser				
Seawater temperature (2)	Inlet and outlet water lines[a]	-	-	-
Seawater temperature (4)	Inlet water box	35-50°F	±0.127°F	TE-16
Seawater temperature (14)	Outlet water box	35-50°F	±0.127°F	TE-15
Seawater pressure (4)	Inlet water box	5-20 psig	±0.051 psig	PE-13
Seawater pressure (4)	Outlet water box	5-20 psig	±0.051 psig	PE-12
Ammonia temperature (2)	Shell interior	40-80°F	±0.127°F	TE-14
Ammonia temperature (5)	Drain pipes[a]	-	-	-
Ammonia vapor ΔP (1)	Top-bottom, aft	0-5 in. H_2O	±0.0027 in. H_2O	PDE-10
Ammonia vapor ΔP (1)	Top-bottom, fore	0-5 in. H_2O	±0.0027 in. H_2O	PDE-11
Water flow rate (1)	Closed-loop tubes	9-15 gpm	±1.0%	FT-51
Seawater flow rate (1)	Open-loop outlet	9-15 gpm	±1.0%	FT-41
Water temperature (1)	Closed-loop inlet	32-52°F	±0.127°F	TE-19
Water temperature (6)	Closed-loop outlet	35-50°F	±0.127°F	TE-17
Seawater temperature (24)	Open-loop outlet	35-50°F	±0.127°F	TE-18
Ammonia flow rate (5)	Drain lines	0-250 gpm	±1.0%	FE-13
Ammonia vapor pressure (1)	Shell, central, center	58-85 psig	±0.25 psig	PE-9
Ammonia liquid level (1)	Drain pot	0-14 in.	±1.0%	LE3-3
Vapor temperature (4)	Noncondensables vent lines[a]	-	-	-

TABLE 4-21

INSTRUMENTATION LIST
(Sheet 2 of 3)

Description (Number of Sensors)	Location	Range	Instrument System Accuracy	Tag Number
Ammonia Loop				
Ammonia flow rate (1)	Downstream/throttle valve	4,777,200-61,470,800 scfh	±0.255%	FT-106
Ammonia temperature (2)	Upstream/throttle valve	65-80°F	±0.127°F	TE-6
Ammonia vapor pressure (1)	Downstream/phase separator	0-150 psig	±0.503%	PE-6
Ammonia temperature (1)	Feed pump P-106/outlet	40-80°F	±0.255%	TE-110
Ammonia liquid flow rate (1)	Phase separator liquid/outlet	0-6 gpm	±1.0%	FT-4
Ammonia liquid flow rate (1)	Feed pump P-106/outlet	40-90 gpm	±0.503%	FT-107
Throttle valve position (1)	Throttle valve	0-100%	±0.53%	ZT-111
Ammonia vapor pressure (1)	Throttle valve/downstream	58-85 psig	±0.25 psig	PE-14
Ammonia liquid flow rate (1)	Phase separator drain	0-60 gpm	±1.0%	FT-4
Ammonia liquid level (1)	Phase separator drain	0-100%	±1.0%	LT-2
Ammonia liquid pressure (1)	Pump P-1/outlet	120-150 psig	±0.5 psig	PE-15
Ammonia liquid pressure (1)	Pump P-2/outlet	120-225 psig	±0.5 psig	PE-16
Ammonia liquid pressure (1)	Pump P-2/outlet	100-150 psig	±1.0%	PE-17
Ammonia temperature (2)	Phase separator/liquid ret.[a]	-	-	-
Cold Water System				
Water flow rate (1)	Cold water line to condenser	60,000-100,000 gpm	±0.503%	FT-103
Water level (1)	Cold water sump	0-35 ft	±1.0%	LT-103
Warm Water System				
Water flow rate (1)	Warm water line to evaporator	60,000-100,000 gpm	±0.503%	FT-101
Water level (1)	Warm water sump	0-35 ft	±1.0%	LT-101
MWD				
Water flow rate (1)	Discharge line from sump	120,000-175,000 gpm	±0.503%	FT-112
Water level (1)	MWD sump	0-40 ft	±1.0%	LT-104
Water temperature (1)	Mixed discharge line[a]	-	-	-
BCMs				
Delta temperature	Module 1	0-10°F	±0.05°F	TDT-711
Delta temperature	Module 2	0-10°F	±0.05°F	TDT-721
Delta temperature	Module 3	0-10°F	±0.05°F	TDT-731
Delta temperature	Module 4	0-10°F	±0.05°F	TDT-741
Delta temperature	Module 5	0-10°F	±0.05°F	TDT-751
Delta temperature	Module 6	0-10°F	±0.05°F	TDT-761
Delta temperature	Module 7	0-10°F	±0.05°F	TDT-771
Delta temperature	Module 8	0-10°F	±0.05°F	TDT-781
Air temperature	Module 1	40-90°F	±0.1°F	TT-711
Air temperature	Module 2	40-90°F	±0.1°F	TT-721
Air temperature	Module 3	40-90°F	±0.1°F	TT-731
Air temperature	Module 4	40-90°F	±0.1°F	TT-741
Air temperature	Module 5	40-90°F	±0.1°F	TT-751

TABLE 4-21

INSTRUMENTATION LIST
(Sheet 3 of 3)

Description (Number of Sensors)	Location	Range	Instrument System Accuracy	Tag Number
BCMs (Continued)				
Air temperature	Module 6	40-90°F	±0.1°F	TT-761
Air temperature	Module 7	40-90°F	±0.1°F	TT-771
Air temperature	Module 8	40-90°F	±0.1°F	TT-781
Water temperature	Module 1	40-80°F	±0.1°F	TT-712
Water temperature	Module 2	40-80°F	±0.1°F	TT-722
Water temperature	Module 3	40-80°F	±0.1°F	TT-732
Water temperature	Module 4	40-80°F	±0.1°F	TT-742
Water temperature	Module 5	40-80°F	±0.1°F	TT-752
Water temperature	Module 6	40-80°F	±0.1°F	TT-762
Water temperature	Module 7	40-80°F	±0.1°F	TT-772
Water temperature	Module 8	40-80°F	±0.1°F	TT-782
Water flow	Module 1	0-35 gpm	±1.0%	FT-701
Water flow	Module 2	0-35 gpm	±1.0%	FT-702
Water flow	Module 3	0-35 gpm	±1.0%	FT-703
Water flow	Module 4	0-35 gpm	±1.0%	FT-704
Water flow	Module 5	0-35 gpm	±1.0%	FT-705
Water flow	Module 6	0-35 gpm	±1.0%	FT-706
Water flow	Module 7	0-35 gpm	±1.0%	FT-707
Water flow	Module 8	0-35 gpm	±1.0%	FT-708
Platform Monitoring				
Gyro compass heading (2)	Gyro room	0-360°	±3.0%	HDGSIN, HDGCOS
Pitch gyro (1)	OTEC-1 compartment	±30°	±1.0%	PITCH
Roll gyro (1)	OTEC-1 compartment	±30°	±1.0%	ROLL
Heave accelerometer (1)	OTEC-1 compartment	±2 g	±2.0%	HEAVE
Surge accelerometer (1)	OTEC-1 compartment	±2 g	±2.0%	SURGE
Sway accelerometer (1)	OTEC-1 compartment	±2 g	±2.0%	SWAY
CWP displacement (1)	CWP	±2200 ft or 220 ft	±1.0%	DISPFA
CWP displacement (1)	CWP	±2200 ft	±1.0%	DISPPS
CWP				
Gimbal position-pitch (2)	GWP gimbal	±30°	±0.5°	GPITCH
Gimbal position-pitch (2)	CWP gimbal	±30°	±0.5°	GROLL
Gimbal loads (2)	Gimbal bearing, inner	±140,280 kips	±5.0%	IGS
Gimbal loads (2)	Gimbal bearing, outer	±140,280 kips	±5.0%	OGS
LVDT (42)	CWP	±0.500 in.	N/A	LVDT-1 to -42

[a]Provision for temporary measurement was made.

TABLE 4-22

OTEC PARAMETER LIST FOR ANALOGIC 0
(Sheet 1 of 4)

31-MAR-81 19:29:27

SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COEF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
1	FE707	0	133236	-0.63450E+01	0.14808E-01	23.967	-6.3450	HTM #1 FLOW, 0 TO 24 GPM
2	FE708	0	133230	-0.61650E+01	0.14453E-01	23.420	-6.1650	HTM #8 FLOW, 0 TO 24 GPM
3	FE701	0	133142	-0.61930E+01	0.14356E-01	23.194	-6.1930	HTM #1 FLOW, 0 TO 24 GPM
4	V701	0	133140	-0.89810E+01	0.21486E-01	35.000	-8.9810	V701 SETPOINT
5	V707	0	133234	-0.89810E+01	0.21485E-01	35.000	-8.9810	V707 SETPOINT
6	V708	0	133226	-0.89810E+01	0.21485E-01	35.000	-8.9810	V708 SETPOINT
7	SPARE/	0	101636	0.00000E+00	0.10000E+01	2046.0	0.00000	SPARE CHAN. NO CARD/
8	SPARE	0	101634	0.00000E+00	0.10000E+01	2046.0	0.00000	SPARE CHAN NO CARD
9	SPARE	0	101632	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN NO CARD
10	SPARE	0	101630	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN NO CARD
11	SPARE	0	101626	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
12	SPARE	0	101624	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
13	SPARE	0	101622	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
14	SPARE	0	101620	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
15	SPARE	0	101616	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
16	SPARE	0	101610	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
17	SPARE	0	101612	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
18	SPARE	0	101614	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
19	SPARE	0	101606	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
20	SPARE	0	101604	0.00000E+00	0.10000E+01	2046.0	0.00000	SPARE CHAN. NO CARD
21	SPARE	0	101602	0.00000E+00	0.10000E+01	2047.0	0.00000	SPARE CHAN. NO CARD
22	HDGSIN	0	101570	-0.10000E+01	0.97700E-03	0.99992	-1.0000	SHIPS HEADING, SIN :-1 TO +1 (0-10 V IN)
23	HDGCOS	0	101566	-0.10000E+01	0.97700E-03	0.99894	-1.0000	SHIPS HEADING, COS :-1 TO +1 (0-10 V IN)
24	PITCH	0	101564	-0.66230E+00	0.59920E-01	19.950	-19.957	SHIP PITCH: BOW UP IS + RANGE +/-30 DEG
25	ROLL	0	101556	-0.73770E+00	0.60060E-01	19.983	-19.957	SHIP ROLL: STBD UP IS + RANGE +/-30 DEG
26	HEAVE	0	101560	0.00000E+00	0.39080E-02	0.19931	-0.19931	SHIP ACCEL: UP IS + RANGE +/-2 G
27	SURGE	0	101562	0.00000E+00	0.39080E-02	0.19931	-0.19931	SHIP ACCEL: FWD IS + RANGE +/-2 G
28	SWAY	0	101554	0.00000E+00	0.39080E-02	0.19931	-0.19931	SHIP ACCEL: STBD IS + RANGE +/-2 G
29	GPITCH	0	101576	0.00000E+00	0.29311E-01	14.978	-14.978	GMBL PITCH:CWP FWD IS +: RNG +/-30 DEG
30	GROLL	0	101574	0.00000E+00	0.29311E-01	14.978	-14.978	GMBL ROLL:CWP TO STBD IS +:RNG +/-30 DEG
31	FGFV	0	110324	0.00000E+00	0.16190E+00	199.95	-199.95	GMBL LOAD, FWD VERT. +/-280KIPS; UP=+
32	FGFH	0	120334	0.20150E+01	0.80600E-01	99.944	-99.944	GMBL LOAD, FWD HORIZ. +/-140KIPS STBD=+
33	FGPV	0	111134	0.34760E+01	0.15800E+00	149.94	-149.94	GMBL LOAD,PORT VERT. +/-280KIPS UP=+
34	FGPH	0	121124	0.26550E+01	0.80460E-01	99.931	-99.931	GMBL LOAD,PORT HORIZ. +/-140 KIPS AFT=+
35	TE10-5	0	133076	0.58950E+02	0.15266E-01	90.185	58.950	EVAP, TUBE G, CLOSED, ROW56,94L (DEGF)
36	TE10-6	0	133074	0.58847E+02	0.15266E-01	90.081	58.847	EVAP, TUBE K, CLOSED, ROW57,47R (DEGF)
37	TE11-1	0	133072	0.58744E+02	0.15266E-01	89.993	65.094	EVAP, TUBE BB, DIRTY, ROW 11,47L (DEGF)
38	TE11-2	0	133070	0.58716E+02	0.15266E-01	89.966	58.716	EVAP, TUBE AA, CLEANED, ROW17,47L (DEGF)
39	TE11-3	0	133066	0.58851E+02	0.15266E-01	90.100	58.851	EVAP, TUBE Z, CLEANED, ROW 9,26L, (DEGF)
40	TE11-4	0	133064	0.58806E+02	0.15266E-01	90.056	58.806	EVAP, TUBE Y, CLEANED, ROW9,4L, (DEGF)
41	TE11-5	0	133062	0.58772E+02	0.15266E-01	90.022	58.772	EVAP, TUBE X, CLEANED, ROW3,4L (DEGF)
42	TE11-6	0	133060	0.58747E+02	0.15266E-01	89.996	58.747	EVAP, TUBE W, CLEANED, ROW16,4L (DEGF)
43	TE11-7	0	133056	0.58746E+02	0.15266E-01	89.996	58.746	EVAP, TUBE V, CLEANED, ROW25,26L (DEGF)
44	TE11-8	0	133054	0.58836E+02	0.15266E-01	90.086	58.836	EVAP, TUBE U, CLEANED, ROW25,4L (DEGF)
45	TE11-9	0	133052	0.58862E+02	0.15266E-01	90.096	58.862	EVAP, TUBE S, DIRTY, ROW32,50R (DEGF)
46	TE1110	0	133050	0.58798E+02	0.15266E-01	90.032	58.798	EVAP, TUBE R, CLEANED, ROW32,53L (DEGF)
47	TE1111	0	133046	0.58750E+02	0.15266E-01	90.000	58.750	EVAP, TUBE Q, CLEANED, ROW56,4L (DEGF)
48	TE1112	0	133044	0.58855E+02	0.15266E-01	90.090	58.855	EVAP, TUBE P, CLEANED, ROW40,26L (DEGF)
49	TE1113	0	133042	0.58892E+02	0.15266E-01	90.127	58.892	EVAP, TUBE O, CLEANED, ROW40,4L (DEGF)
50	TE1114	0	133040	0.58813E+02	0.15266E-01	90.063	58.813	EVAP, TUBE N, CLEANED, ROW56,26L (DEGF)

TABLE 4-22

OTEC PARAMETER LIST FOR ANALOGIC 0
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COEF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
51	TE17-6	0	133136	0.31202E+02	0.91597E-02	49.934	31.202	COND, TUBE CC, CLOSED, ROW8,37L (DEGF)
52	TE18-1	0	133134	0.31178E+02	0.91597E-02	49.910	31.178	COND, TUBE A, CLEANED, ROW10,35L (DEGF)
53	TE18-2	0	133132	0.31202E+02	0.91597E-02	49.952	31.202	COND, TUBE B, CLEANED, ROW8,19L (DEGF)
54	TE18-3	0	133130	0.31190E+02	0.91597E-02	49.922	31.190	COND, TUBE C, CLEANED, ROW8,3L (DEGF)
55	TE18-4	0	133126	0.31250E+02	0.91597E-02	49.982	31.250	COND, TUBE D, CLEANED, ROW24,4L (DEGF)
56	TE18-5	0	133124	0.31248E+02	0.91597E-02	49.998	31.248	COND, TUBE F, CLEANED, ROW24,24L (DEGF)
57	TE18-6	0	133122	0.31250E+02	0.91597E-02	50.000	31.250	COND, TUBE G, DIRTY, ROW24,20L (DEGF)
58	TE18-7	0	133120	0.31284E+02	0.91597E-02	50.015	31.284	COND, TUBE I, CLEANED, ROW46,22L (DEGF)
59	TE18-8	0	133116	0.31194E+02	0.91597E-02	49.926	31.194	COND, TUBE J, CLEANED, LL CLUSTER (DEGF)
60	TE18-9	0	133114	0.31203E+02	0.91597E-02	49.953	31.203	COND, TUBE K, CLEANED, ROW46,4L (DEGF)
61	TE1810	0	133112	0.31214E+02	0.91597E-02	49.964	31.214	COND, TUBE L, CLEANED, ROW70,10L (DEGF)
62	TE1811	0	133110	0.31298E+02	0.91597E-02	50.030	31.298	COND, TUBE M, CLEANED, ROW64,3L (DEGF)
63	TE1812	0	133106	0.31240E+02	0.91597E-02	49.990	31.240	COND, TUBE N, CLEANED, ROW46,39L (DEGF)
64	TE1813	0	133104	0.31250E+02	0.91597E-02	50.000	31.250	COND.TUBE
65	TE1814	0	133102	0.31250E+02	0.91597E-02	50.000	31.250	COND. TUBE
66	TE1815	0	133100	0.31250E+02	0.91597E-02	50.000	31.250	COND. TUBE
67	TE6-1	0	133210	0.61151E+02	0.92081E-02	80.000	61.151	NH3 PHASE SEP. OUTLET TEMP (DEG F)
68	TE6-2	0	133206	0.61151E+02	0.92081E-02	79.991	61.151	NH3 PHASE SEP. OUTLET TEMP (DEG F)
69	TE7-1	0	132006	0.61194E+02	0.91597E-02	79.925	61.194	EVAP, NH3, VERIFIED (DEGF)
70	TE7-2	0	132004	0.61251E+02	0.91597E-02	80.001	61.251	EVAP, NH3, VERIFIED (DEGF)
71	TE7-3	0	132002	0.61276E+02	0.91597E-02	80.008	61.276	EVAP, NH3
72	TE7-4	0	132000	0.61217E+02	0.91597E-02	79.948	61.217	EVAP, NH3, VERIFIED (DEGF)
73	TE8-2	0	133202	0.59364E+02	0.15266E-01	90.598	59.364	EVAP. INLET WATER BOX 65-90 DEG F
74	TE8-1	0	133204	0.58879E+02	0.15266E-01	90.113	58.879	EVAP, WATERBOX IN, 0°-40° (DEGF)
75	TE8-3	0	133200	0.58565E+02	0.15266E-01	89.815	58.565	EVAP, WATERBOX IN, 0°25° (DEGF)
76	TE9-11	0	132076	0.58696E+02	0.15266E-01	89.946	58.696	EVAP OUTLET WATER BOX 65-90 DEG F
77	TE9-12	0	132074	0.58233E+02	0.15266E-01	89.482	58.233	EVAP. OUTLET WATER BOX 65-90 DEG F
78	TE9-13	0	132072	0.58750E+02	0.15266E-01	90.000	58.750	EVAP OUTLET WATER BOX 65-90 DEG F
79	TE9-14	0	132070	0.58705E+02	0.15266E-01	89.954	58.705	EVAP OUTLET WATER BOX 65-90 DEG F
80	TE14-2	0	132136	0.29997E+02	0.24426E-01	79.997	39.987	COND. SHELL NH3 40-80 DEG F
81	TE14-3	0	132134	0.29883E+02	0.24426E-01	79.883	39.873	COND. SHELL, NH3 40-80 DEG F
82	TE14-4	0	132132	0.29917E+02	0.24426E-01	79.917	39.907	COND. SHELL, NH3 40-80 DEG F
83	TE14-5	0	132130	0.29929E+02	0.24426E-01	79.929	39.919	COND. SHELL, NH3 40-80 DEG F
84	TE15-1	0	132116	0.31165E+02	0.91597E-02	49.896	31.165	COND, WATERBOX OUT, 0° 14.5° (DEGF)
85	TE15-2	0	132114	0.31159E+02	0.91597E-02	49.891	31.159	COND, WATREBOX OUT, 37° -2° (DEGF)
86	TE15-3	0	132112	0.31296E+02	0.91597E-02	50.046	31.296	COND. OUTLET WATER BOX 35-50 DEG F
87	TE15-4	0	132110	0.31131E+02	0.92081E-02	49.971	31.131	COND.WATERBOX OULET 35-50 DEG F
88	TE15-5	0	132106	0.31180E+02	0.91597E-02	49.912	31.180	COND, WATERBOX OUT, 0°-24° (DEGF)
89	TE15-6	0	132104	0.31358E+02	0.91597E-02	50.108	31.358	COND OUTLET WATER BOX 35-50 DEG F
90	TE15-7	0	132102	0.31316E+02	0.91597E-02	50.066	31.316	COND, WATERBOX OUT, -38°-35° (DEGF)
91	TE15-8	0	132100	0.31634E+02	0.91597E-02	50.365	31.634	COND. OUTLET WATER BOX 35-50 DEG F
92	PE6	0	132066	0.10230E+03	0.18416E-01	140.00	102.30	NH3 PHASE SEP. OUTLET (PSIG)
93	PDE3	0	132064	-0.12500E+01	0.30530E-02	4.9964	-1.2500	EVAP. UPPER PSID (NO GOOD)
94	PDE4	0	133004	-0.12500E+01	0.30530E-02	4.9964	-1.2500	EVAP LOWER PSID (NO GOOD)
95	PE1	0	132062	0.10250E+03	0.18319E-01	140.00	102.50	EVAP. UPPER SECT.NH3 110-140 PSIG
96	ZT111	0	133224	0.00000E+00	0.48852E-01	100.00	0.00000	NH3 THROTTLE VALVE: RANGE 0-100%
97	FCV3	0	133164	-0.25660E+02	0.61387E-01	100.00	-25.660	MID-PLANE NOZZ. FLOW CONTROL
98	FCV2	0	133166	-0.25660E+02	0.61387E-01	100.00	-25.660	TOP SMALL NOZZ. FLOW CONTROL
99	FCV1	0	133170	-0.25660E+02	0.61387E-01	100.00	-25.660	TOP LARGE NOZZ. FLOW CONTROL
100	V111	0	132060	0.10200E+03	0.00000E+00	102.00	102.00	THROTTLE VALVE POS. 0-100%

TABLE 4-22

OTEC PARAMETER LIST FOR ANALOGIC 0
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COFF	B-COFF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
101	P100	0	132142	-0.25660E+02	0.61387E-01	99.999	-25.660	MIXED WATER PUMP, PERCENT POWER 0-100%
102	V-114	0	132170	-0.25660E+02	0.61387E-01	99.999	-25.660	COND. OUTLET VALVE POS (0-100%)
103	P2	0	133172	0.11586E+04	0.10559E+01	3320.0	1158.6	DESCRIPTION FOR SEQ# 103
104	P1	0	133174	0.66421E+02	0.79804E+00	1700.0	66.421	DESCRIPTION FOR SEQ# 104
105	PE7-1	0	132056	-0.50330E+01	0.12277E-01	20.099	-5.0330	EVAP,INLET WTRBX,TOP (INOPERATIVE)
106	PE7-2	0	132054	-0.11646E+02	0.12277E-01	13.486	-11.646	EVAP, INLET WTRBX,INBOARD,(PSIG CORRECTE
107	PE7-3	0	132052	-0.91470E+01	0.12277E-01	15.985	-9.1470	EVAP, INLET WTRBX,BOTTOM,(PSIG CORRECTED
108	PE7-4	0	132050	-0.11665E+02	0.12277E-01	13.467	-11.665	EVAP, INLET WTRBX,OUTBOARD,(PSIG CORRECT
109	PE8-1	0	132040	-0.50400E+01	0.12272E-01	20.081	-5.0400	EVAP, OUTLET WTRBX,TOP (DISCONNECTED)
110	PE13-4	0	132176	-0.71170E+01	0.12277E-01	18.015	-7.1170	COND,INLET WTRBX,OUTBOARD,(PSIG CORRECTE
111	PE14	0	132174	0.51250E+02	0.16490E-01	85.005	51.250	OUTLET PRESS OF V-111 58-85 PSIG
112	LE1	0	132046	-0.60000E+01	0.29312E-01	53.972	-6.0000	EVAP. DRAIN TANK LEVEL (6-54")
113	LE3-3	0	132172	-0.35000E+01	0.85490E-02	-3.5000	-3.5000	COND. DRAIN POT LEVEL(0-14")
114	TE113	0	132224	0.29736E+02	0.24555E-01	29.736	29.761	MIXED WATER DISCHARGE TEMP.
115	FE101	0	132140	-0.25000E+02	0.61060E-01	94.983	49.982	WARM WATER FLOW:0-100 X 1000 GPM
116	LE101	0	132154	-0.25000E+01	0.20760E-01	38.293	21.291	WARM WATER SUMP LEVEL, RANGE 6-40 FEET
117	LE103	0	132034	-0.85000E+01	0.20762E-01	23.993	12.989	COLD WATER LEVEL: RANGE 0-34 FEET
118	LE104	0	132144	0.75000E+01	0.15880E-01	36.942	13.995	MIXED WATER LEVEL: RANGE 14-40 FEET
119	TE200	0	132214	0.52500E+02	0.18319E-01	89.999	52.500	CHLORINATOR OUT TEMP: RANGE 60-90F
120	FE202	0	132210	0.12500E+02	0.91597E-01	149.99	74.969	CHLORINE TO COND: RANGE 50-200 GPM
121	FE201	0	132212	0.12500E+02	0.91597E-01	149.99	74.969	CHLORINE TO EVAP: RANGE 50-200GPM
122	Y201	0	132216	-0.25000E+00	0.61065E-03	0.99939	-0.25000	CHLORINATOR OUTPUT: RANGE 0-1 PPM
123	Y202	0	132206	-0.25000E+00	0.61065E-03	0.99939	-0.25000	COND CHLORINE: RANGE 0-1 PPM
124	Y203	0	132204	-0.26410E+00	0.65010E-03	1.0660	-0.26410	EVAP CHLORINE: RANGE 0-1 PPM
125	PE504	0	133010	-0.75000E+02	0.18320E+00	300.01	-75.000	NITROGEN MNFLD PRESS: RANGE 0-300 PSIG
126	PE2	0	132042	0.25000E+01	0.67170E-01	140.00	2.5000	EVAP. LOWER SECT.NH3 30-140 PSIG
127	AE103	0	133176	-0.62500E+00	0.15270E-02	1.9999	-0.45699E-03	WATER IN NH3--RANGE 0-2.5 %
128	PDE2C	0	133156	-0.25570E+01	0.61830E-02	10.100	-2.5570	FWD GMBL DPHRGM DELTA P: RANGE 0-10 PSID
129	PDE3C	0	133154	-0.25370E+01	0.62490E-02	10.248	-2.5370	AFT GMBL DPHRGM DELTA P: RANGE 0-10 PSID
130	AIR-PI	0	132010	-0.10000E+03	0.24426E+00	399.76	299.85	INSTRMNT AIR PRESS: RANGE 0-400 PSIG
131	LINE-T	0	101552	0.00000E+00	0.24426E+00	500.00	0.00000	DESCRIPTION FOR SEQ# 131
132	WNDSPD	0	101544	0.00000E+00	0.58600E-01	29.945	0.00000	WINDSPEED: RANGE 0-120 KNOTS
133	DIRSIN	0	101542	-0.10000E+01	0.97700E-03	0.99894	-1.0000	WIND DIRECTION, SIN :-1 TO +1 (0-10 V IN
134	AIRTMP	0	101550	0.00000E+00	0.24426E-01	50.000	0.00000	AIR TEMP ON MAST: RANGE 0-50 DEG C
135	DIRCOS	0	101540	-0.10000E+01	0.97700E-03	0.99992	-1.0000	WIND DIRECTION, COS :-1 TO +1 (0-10V IN)
136	FE3	0	132032	-0.50000E+03	0.12210E+01	1993.3	-500.00	REFLUX FLOW
137	BOW G	0	101676	-0.69020E+00	0.64530E-02	6.9243	-8.9436	BOW G 0-2G
138	LVDT9	0	101674	0.25320E+00	0.81290E-02	9.9999	-9.9975	CWP STRAIN #9, +/-8.33%
139	LVDT10	0	101672	0.57320E+00	0.81290E-02	0.65449	0.49191	CWP STRAIN #10, +/-8.33%
140	LVDT11	0	101670	-0.27690E+00	0.81190E-02	9.9936	-9.9953	CWP STRAIN #11, +/-8.33%
141	LVDT12	0	101666	0.24310E+00	0.81190E-02	0.32429	0.16191	CWP STRAIN #12, +/-8.33%
142	LVDT13	0	101664	-0.25690E+00	0.81190E-02	-0.17571	-0.33809	CWP STRAIN #13, +/-8.33%
143	LVDT14	0	101662	-0.20490E+00	0.81370E-02	-0.12353	-0.28627	CWP STRAIN #14, +/-8.33%
144	LVDT15	0	101660	0.39510E+00	0.81370E-02	0.47647	0.31373	CWP STRAIN #15,+/-8.33 %
145	LVDT16	0	101656	-0.12690E+00	0.81190E-02	-0.45710E-01	-0.20809	CWP STRAIN #16, +/-8.33%
146	LVDT17	0	101654	0.24310E+00	0.81190E-02	0.32429	0.16191	CWP STRAIN #17, +/-8.33%
147	LVDT18	0	101652	-0.96840E-01	0.81290E-02	-0.15550E-01	-0.17813	CWP STRAIN #18, +/-8.33%
148	LVDT19	0	101650	0.65010E-01	0.81270E-02	0.14628	-0.16260E-01	CWP STRAIN #19,+/-8.33%
149	LVDT20	0	101646	-0.16500E+00	0.81270E-02	-0.83730E-01	-0.24627	CWP STRAIN #20,+/-8.33%
150	LVDT21	0	101644	0.40320E+00	0.81290E-02	0.48449	0.32191	CWP STRAIN #21,+/-8.33%

TABLE 4-22

OTEC PARAMETER LIST FOR ANALOGIC 0
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COFF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
151	FT13-1	0	103310	-0.10000E+03	0.50000E+00	700.00	-100.00	COND. DOWNCOMER FLOW #1, 0-400 GPM
152	FT13-2	0	103312	-0.31600E+03	0.69660E+00	798.56	-316.00	COND. DOWNCOMER FLOW #2, 0-400 GPM
153	FT13-3	0	103314	-0.10000E+03	0.50000E+00	700.00	-100.00	COND. DOWNCOMER FLOW #3, 0-400 GPM
154	FT13-4	0	103316	-0.10000E+03	0.50000E+00	700.00	-100.00	COND. DOWNCOMER FLOW #4, 0-400 GPM
155	FT13-5	0	103320	-0.10000E+03	0.50000E+00	700.00	-100.00	COND. DOWNCOMER FLOW #5, 0-400 GPM
156	FT3001	0	103306	0.00000E+00	0.10000E+01	2047.0	0.00000	EVAP INST TUBE #XXX FLOW
157	FT3009	0	103304	0.00000E+00	0.10000E+01	2047.0	0.00000	EVAP INST LOOP #XXX FLOW
158	FT3010	0	103302	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 158
159	FT3016	0	103300	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 159
160	FT3017	0	103376	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 160
161	FT3019	0	103374	0.00000E+00	0.73280E-02	15.000	0.00000	DESCRIPTION FOR SEQ# 161
162	FT3020	0	103372	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 162
163	FT3022	0	103370	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 163
164	FT3023	0	103366	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 164
165	FT3024	0	103364	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 165
166	FT4001	0	103362	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 166
167	FT4004	0	103360	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 167
168	FT4005	0	103356	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 168
169	FT4006	0	103354	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 169
170	FT4012	0	103352	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 170
171	FT4013	0	103350	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 171
172	FT4014	0	103346	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 172
173	FT4016	0	103344	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 173
174	FT4023	0	103342	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 174
175	FT4024	0	103340	0.00000E+00	0.10000E+01	2047.0	0.00000	DESCRIPTION FOR SEQ# 175
176	LE1A	0	132046	-0.60000E+01	0.29312E-01	-6.0000	-6.0000	DESCRIPTION FOR SEQ# 176

TABLE 4-23

OTEC PARAMETER LIST FOR ANALOGIC 1
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COEF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
301	FE702	0	133174	-0.62460E+01	0.15190E-01	24.848	-6.2460	HTM #2 FLOW, 0 TO 24 GPM
302	FE703	0	133166	-0.67100E+01	0.15740E-01	25.510	-6.7100	HTM #3 FLOW, 0 TO 24 GPM
303	FE704	0	133160	-0.61980E+01	0.15198E-01	24.912	-6.1980	HTM #4 FLOW, 0 TO 24 GPM
304	FE705	0	133152	-0.51870E+01	0.12349E-01	20.091	-5.1870	HTM #5 FLOW, 0 TO 24 GPM
305	FE706	0	133144	-0.82270E+01	0.19250E-01	31.178	-8.2270	HTM #6 FLOW, 0 TO 24 GPM
306	V702	0	133172	-0.89810E+01	0.21485E-01	35.000	-8.9810	DESCRIPTION FOR SEQ# 306
307	V703	0	133164	-0.89810E+01	0.21485E-01	35.000	-8.9810	DESCRIPTION FOR SEQ# 307
308	V704	0	133156	-0.89810E+01	0.21485E-01	35.000	-8.9810	DESCRIPTION FOR SEQ# 308
309	V705	0	133150	-0.89810E+01	0.21485E-01	35.000	-8.9810	DESCRIPTION FOR SEQ# 309
310	V706	0	133142	-0.89810E+01	0.21485E-01	35.000	-8.9810	DESCRIPTION FOR SEQ# 310
311	TDT781	0	101516	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #8 THERMOPILE DIFF. TEMP, DEG F
312	TE782	0	101520	0.37929E+02	0.32598E-01	104.62	37.929	HTM #8 H20 TEMP, DEG F
313	TE781	0	101522	0.40000E+02	0.19541E-01	80.000	40.000	HTM #8 AIR TEMP, DEG F
314	TDT771	0	101524	0.00000E+00	0.31750E-02	6.4992	0.00000	HTM #7 THERMOPILE DIFF. TEMP, DEG F
315	TE772	0	101526	0.39300E+02	0.32696E-01	106.20	39.300	HTM #7 H20 THERMISTER, DEG F
316	TE771	0	101530	0.40000E+02	0.19541E-01	80.000	40.000	AHTM #7 AIR TEMP, DEG F
317	TDT761	0	101532	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #6 THERMOPILE DIFF. TEMP, DEG F
318	TE762	0	101534	0.38163E+02	0.32030E-01	103.73	38.163	HTM #6 H20 TEMP, DEG F
319	TE761	0	101536	0.40000E+02	0.19541E-01	80.000	40.000	HTM #6 AIR TEMP, DEG F
320	FGAV	0	110224	0.98420E+00	0.16400E+00	149.90	-149.90	GMBL LOAD,AFT VERT. +/-280KIPS UP=+
321	FGAH	0	120234	-0.15270E+01	0.80370E-01	99.980	-99.980	GMBL LOAD, AFT HORIZ. +/-140 KIPS PORT=+
322	FGSV	0	110324	0.22520E+01	0.16080E+00	149.87	-149.86	GMBL LOAD,STBD VERT. +/-280KIPS UP=+
323	FGSH	0	120334	0.28780E+01	0.79950E-01	99.937	-99.938	GMBL LOAD,STBD HORIZ. +/-140KIPS FWD=+
324	TE9-10	0	132000	0.58865E+02	0.15266E-01	90.084	58.865	EVAP. OUTLET WATER BOX 65-90 DEG F
325	TE9-9	0	132002	0.58798E+02	0.15266E-01	90.048	58.798	EVAP. OUTLET WATER BOX 65-90 DEG F
326	TE9-8	0	132004	0.58623E+02	0.15266E-01	89.873	58.623	EVAP OUTLET WATER BOX 65-90 DEG F
327	TE9-7	0	132006	0.58686E+02	0.15266E-01	89.936	58.686	EVAP. OUTLET WATER BOX 65-90 DEG F
328	TE9-6	0	132010	0.58771E+02	0.15266E-01	90.020	58.771	EVAP OUTLET WATERBOX 65-90 DEG F
329	TE9-5	0	132012	0.58628E+02	0.15266E-01	89.878	58.628	EVAP OUTLET WATERBOX 65-90 DEG F
330	TE9-4	0	132014	0.58729E+02	0.15266E-01	89.979	58.729	EVAP OUTLET WATERBOX 65-90 DEG F
331	TE9-3	0	132016	0.58608E+02	0.15266E-01	89.857	58.608	EVAP OUTLET WATER BOX 65-90 DEG F
332	TE9-2	0	132020	0.58646E+02	0.15266E-01	89.880	58.646	EVAP. OUTLET WATER BOX, 65-90 DEG F
333	TE9-1	0	132022	0.58736E+02	0.15266E-01	89.970	58.736	EVAP. OUTLET WATER BOX, 65-90 DEG F
334	TE8-4	0	133236	0.58947E+02	0.15266E-01	90.166	58.947	EVAP.INLET WATER BOX,65-90 DEG F
335	TE7-10	0	132024	0.61282E+02	0.91597E-02	80.032	61.282	EVAP, NH3, VERIFIED (DEGF)
336	TE7-9	0	132026	0.61192E+02	0.91597E-02	79.923	61.192	EVAP, NH3, VERIFIED (DEGF)
337	TE7-8	0	132030	0.61232E+02	0.91597E-02	79.964	61.232	EVAP, NH3, VERIFIED (DEGF)
338	TE7-7	0	132032	0.61204E+02	0.91597E-02	79.954	61.204	EVAP, NH3, VERIFIED (DEGF)
339	TE7-6	0	132034	0.61255E+02	0.91597E-02	79.986	61.255	EVAP, NH3, VERIFIED (DEGF)
340	TE7-5	0	132036	0.61223E+02	0.91597E-02	79.954	61.223	EVAP, NH3, VERIFIED (DEGF)
341	TE14-1	0	132040	0.29926E+02	0.24426E-01	79.926	39.916	COND, SHELL NH3 40-80 DEG F
342	TE16-4	0	132042	0.31382E+02	0.91597E-02	50.114	31.382	DESCRIPTION FOR SEQ# 342
343	TE16-3	0	132044	0.31195E+02	0.91597E-02	49.926	31.195	COND, WATERBOX IN, 0'0' (DEGF)
344	TE16-2	0	132046	0.31025E+02	0.91597E-02	49.775	31.025	COND, WATERBOX IN, 0'-35' (DEGF)
345	TE16-1	0	132050	0.31294E+02	0.91597E-02	50.026	31.294	COND INLET WATERBOX 35-50 DEG F
346	PE16	0	132066	0.93750E+02	0.64120E-01	225.00	93.750	PUMP P2 OUTLET PRESS 120-225 PSIG
347	PE15	0	132070	0.11250E+03	0.18320E-01	149.98	112.50	PUMP P1 OUTLET PRESS 120-150 PSIG
348	PE8-2	0	132076	-0.11568E+02	0.12277E-01	13.564	-11.568	EVAP,OUTLET WTRBX,INBOARD,(PSIG CORRECTE
349	PE8-3	0	132074	-0.90970E+01	0.12277E-01	16.035	-9.0970	EVAP,OUTLET WTRBX,BOTTOM,(PSIG CORRECTED
350	PE8-4	0	132072	-0.53350E+01	0.12277E-01	19.797	-5.3350	EVAP,OUTLET WTRBX,OUTBOARD,(PSIG CORRECT

TABLE 4-23

OTEC PARAMETER LIST FOR ANALOGIC 1
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COEF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
351	PE13-3	0	132100	-0.63840E+01	0.12277E-01	18.748	-6.3840	COND, INLET WTRBX,BOTTOM,(PSIG CORRECTED
352	PE13-2	0	132102	-0.70680E+01	0.12277E-01	18.064	-7.0680	COND,INLET WTRBX,INBOARD,(PSIG CORRECTED
353	PE13-1	0	132104	-0.49620E+01	0.12277E-01	20.170	-4.9620	COND. INLET WTRBX,TOP (INOPERATIVE)
354	PE12-4	0	132106	-0.84820E+01	0.12277E-01	16.650	-8.4820	COND,OUTLET WTRBX,OUTBOARD,(PSIG CORRECT
355	PE12-3	0	132110	-0.64450E+01	0.12277E-01	18.687	-6.4450	COND,OUTLET WTRBX,BOTTOM,(PSIG CORRECTED
356	PE12-2	0	132112	-0.82850E+01	0.12277E-01	16.847	-8.2850	COND,OUTLET WTRBX,INBOARD,PSIG CORRECTED
357	PE12-1	0	132114	-0.50270E+01	0.12277E-01	20.105	-5.0270	COND. OUTLET WTRBX,TOP (INOPERATIVE)
358	PDE11	0	132116	-0.12480E+01	0.30544E-02	5.0013	-1.2480	DESCRIPTION FOR SEQ# 358
359	PDE10	0	132120	-0.12500E+01	0.30530E-02	4.9964	-1.2500	DESCRIPTION FOR SEQ# 359
360	PE9	0	132122	0.51250E+02	0.16490E-01	85.005	51.250	COND. NH3 PRESS -- 58-85 PSIG
361	TE1514	0	132124	0.31141E+02	0.91597E-02	49.873	31.141	COND, WATERBOX OUT, -2' 35', (DEGF)
362	TE1513	0	132126	0.31157E+02	0.91597E-02	49.889	31.157	COND, WATERBOX OUT, -40' 16', (DEGF)
363	TE1512	0	132130	0.31072E+02	0.91597E-02	49.822	31.072	COND. OUTLET WATER BOX 35-50 DEG F
364	TE1511	0	132132	0.31142E+02	0.91597E-02	49.873	31.142	COND, WATERBOX OUT, -39' -2', (DEGF)
365	TE1510	0	132134	0.31222E+02	0.91597E-02	49.953	31.222	COND, WATERBOX OUT, 0' -3', (DEGF)
366	TE15-9	0	132136	0.31360E+02	0.91597E-02	50.110	31.360	COND OUTLET WATER BOX 35-50 DEG F
367	FE103	0	132142	-0.25000E+02	0.61060E-01	94.983	49.982	COLD WATER FLOW:0-100 X 1000 GPM
368	TE110	0	132150	0.29736E+02	0.24555E-01	80.000	29.736	P106 OUTLET TEMP (DEG F)
369	TE109	0	132152	0.29736E+02	0.24555E-01	80.000	29.736	P106 INLET TEMP (DEG F)
370	TE108	0	132154	0.29736E+02	0.24555E-01	80.000	29.736	NH3 COND INLET TEMP (DEG F)
371	TE21	0	133234	0.29736E+02	0.24555E-01	80.000	29.736	T1 TANK TEMP (DEG F)
372	TE3	0	132062	0.29736E+02	0.24555E-01	80.000	29.736	P2 OUTLET TEMP (DEG F)
373	TE2	0	132064	0.30000E+02	0.24426E-01	80.000	30.000	P1 OUTLET TEMP (DEG F)
374	TE170	0	132144	-0.78750E+02	0.94651E-01	115.00	-78.750	NH3 QLTY (AE101) TEMP: RANGE -40 TO 115
375	PE107	0	132162	-0.50000E+02	0.12210E+00	199.94	-50.000	P106 OUTLET PRESS 0-200 PSIG
376	PE106	0	132164	-0.25000E+02	0.61060E-01	-25.000	-25.000	P106 INLET PRESS 0-100 PSIG
377	FE107	0	132172	-0.22500E+03	0.54958E+00	-225.00	-221.15	NH3 CONDENSATE FLOW: RANGE 0-900 GPM
378	LE407	0	132200	-0.23250E+02	0.56790E-01	74.997	24.965	NH3 BLWDWN TK LEVL: RANGE 0-93 IN
379	PE402	0	132226	0.00000E+00	0.12213E+00	199.93	0.00000	NH3 STOR TK (AFT) PR: RANGE 50-250 PSIG
380	PE403	0	132224	0.00000E+00	0.12213E+00	199.93	0.00000	NH3 STOR TK (FWD) PR: RANGE 50-250 PSIG
381	PE505	0	133010	-0.76980E+02	0.18416E+00	-74.770	-76.980	DESCRIPTION FOR SEQ# 381
382	LE403	0	132232	-0.24020E+02	0.58660E-01	89.428	16.221	NH3 STOR TK (FWD) LEVL:RANGE 0-96 IN NH3
383	LE402	0	132234	-0.24020E+02	0.58660E-01	89.428	16.221	NH3 STOR TK (AFT) LEVL: RANGE 0-96 IN NH
384	TE10-4	0	133000	0.58789E+02	0.15266E-01	90.023	58.789	EVAP, TUBE T, CLOSED, ROW29,50L (DEGF)
385	TE10-3	0	133002	0.58798E+02	0.15266E-01	90.017	58.798	EVAP,TUBE B,CLOSED,ROW11,4R (DEG F)
386	TE10-2	0	133004	0.58769E+02	0.15266E-01	89.988	58.815	EVAP, TUBE D, CLOSED, ROW29, 4R (DEG F)
387	TE10-1	0	133006	0.58789E+02	0.15266E-01	90.023	58.789	EVAP, TUBE CC, CLOSED, ROW11,51L (DEGF)
388	PE17	0	133022	0.11250E+03	0.18320E-01	149.98	112.50	MID-PLANE NOZ. PRESS 120-150
389	SPARE	0	133026	-0.12830E+03	0.30694E+00	500.00	-128.30	DESCRIPTION FOR SEQ# 389
390	SPARE	0	133030	0.00000E+00	0.10000E+01	1.0000	0.00000	DESCRIPTION FOR SEQ# 390
391	SPARE	0	133032	0.23020E+03	0.18416E+01	4000.0	230.20	DESCRIPTION FOR SEQ# 391
392	TE17-5	0	133040	0.31260E+02	0.91597E-02	49.992	31.260	COND, TUBE E, CLOSED, ROW28,5L (DEGF)
393	TE17-4	0	133042	0.31250E+02	0.91597E-02	49.982	31.250	COND, TUBE H, CLOSED, ROW28,23L (DEGF)
394	TE17-3	0	133044	0.31179E+02	0.91597E-02	49.929	31.179	COND, TUBE W, CLOSED, ROW28,43L (DEGF)
395	TE17-2	0	133046	0.31223E+02	0.91597E-02	49.955	31.223	COND, TUBE S, CLOSED, ROW46,43L (DEGF)
396	TE17-1	0	133050	0.31249E+02	0.91597E-02	49.981	31.249	COND, TUBE Q, CLOSED, ROW70,20R (DEGF)
397	TE12	0	133052	0.58882E+02	0.15266E-01	90.132	58.882	EVAP, CLOSED LOOP IN (DEGF)
398	TE1124	0	133054	0.58866E+02	0.15266E-01	90.116	58.866	EVAP, TUBE H, CLEANED, ROW56,8R (DEGF)
399	TE1123	0	133056	0.58829E+02	0.15266E-01	90.078	58.829	EVAP, TUBE F, DIRTY, ROW31,92L (DEGF)
400	TE1122	0	133060	0.58823E+02	0.15266E-01	90.057	58.823	EVAP, TUBE E, CLEANED, ROW31,2R (DEGF)

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OTEC PARAMETER LIST FOR ANALOGIC 1
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COEF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
401	TE1121	0	133062	0.58898E+02	0.15266E-01	90.133	58.898	EVAP, TUBE A, CLEANED, ROW3,49L (DEGF)
402	TE1120	0	133064	0.58809E+02	0.15266E-01	90.059	58.809	EVAP, TUBE C, CLEANED, ROW11,8R (DEGF)
403	TE1119	0	133066	0.58740E+02	0.15266E-01	89.974	58.740	EVAP, TUBE DD, CLEANED, ROW8,49L (DEGF)
404	TE1118	0	133070	0.58804E+02	0.15266E-01	90.038	58.804	EVAP, TUBE I, CLEANED, ROW64,49L (DEGF)
405	TE1117	0	133072	0.58860E+02	0.15266E-01	90.110	58.860	EVAP, TUBE J, CLEANED, ROW60,49L (DEGF)
406	TE1116	0	133074	0.58827E+02	0.15266E-01	90.077	58.827	EVAP,TUBE L, DIRTY, ROW57,51R (DEGF)
407	TE1115	0	133076	0.58789E+02	0.15266E-01	90.023	58.789	EVAP, TUBE M, CLEANED, ROW50,49L (DEGF)
408	LE4	0	133102	-0.25660E+02	0.61387E-01	100.00	-25.660	POOL BOILING LEVEL: RANGE (TBD)
409	P103	0	132140	-0.25660E+02	0.61387E-01	100.00	-25.660	COLD WATER PUMP,PERCENT POWER 0-100%
410	P101	0	132176	-0.25660E+02	0.61387E-01	100.00	-25.660	WARM WATER PUMP, PERCENT POWER 0-100%
411	LCV1	0	132216	-0.25660E+02	0.61387E-01	100.00	-25.660	DESCRIPTION FOR SEQ# 411
412	LE2	0	132220	-0.35000E+01	0.85490E-02	14.000	-3.5000	NH3 PHSE SEPAR LEVL: RANGE 0-14 INCH
413	FE112	0	132170	-0.43750E+02	0.10690E+00	175.07	-43.750	MIXED WATER FLOW: 0-175 X 1000 GPM
414	FT51	0	133104	-0.75000E+01	0.18320E-01	30.001	-7.5000	COND, CLOSED LOOP 0-30 IN H2O
415	FT41	0	133106	-0.37500E+01	0.91600E-02	15.001	-3.7500	COND, OPEN LOOP 0-15 IN H2O
416	FT31	0	133110	-0.27000E+00	0.65950E-03	1.0800	-0.27000	EVAP.CLOSED INST LOOP: 0-1.08 PSID
417	FT21	0	133112	-0.13530E+00	0.33040E-03	0.54103	-0.13530	EVAP, INST LOOP FLOW: 0-.541 PSID
418	TE19	0	133114	0.27000E+02	0.12221E-01	46.786	39.001	COND, CLSD LP IN TEMP: RANGE 32-50F
419	TE1824	0	133116	0.31250E+02	0.91597E-02	49.982	31.250	COND, TUBE O, DIRTY, ROW70,24R (DEGF)
420	TE1823	0	133120	0.31151E+02	0.92081E-02	49.991	31.151	COND, TUBE P, CLEANED, ROW70,17R (DEGF)
421	TE1822	0	133122	0.31250E+02	0.91597E-02	50.000	31.250	COND, TUBE R, CLEANED, ROW70,10R (DEGF)
422	TE1821	0	133124	0.31250E+02	0.91597E-02	49.982	31.250	COND, TUBE T,CLEANED, ROW46,78L (DEGF)
423	TE1820	0	133126	0.31250E+02	0.91597E-02	50.000	31.250	COND, TUBE U, CLEANED, LR CLUSTER (DEGF)
424	TE1819	0	133130	0.31250E+02	0.91597E-02	49.982	31.250	DESCRIPTION FOR SEQ# 424
425	TE1818	0	133132	0.31250E+02	0.91597E-02	49.982	31.250	DESCRIPTION FOR SEQ# 425
426	TE1817	0	133134	0.31250E+02	0.91597E-02	49.982	31.250	DESCRIPTION FOR SEQ# 426
427	TE1816	0	133136	0.31250E+02	0.91597E-02	49.982	31.250	DESCRIPTION FOR SEQ# 427
428	FE106	0	132174	-0.37500E+01	0.91600E-02	15.001	-3.7500	AMMONIA VAPOR FLOW - PSID
429	FE4	0	132056	-0.15000E+02	0.36639E-01	60.000	-15.000	NH3 PHSE SEPAR FLOW: RANGE 0-60 GPM
430	LVDT1	0	101514	0.42000E+00	0.81070E-02	9.9944	-9.9975	CWP STRAIN #1, +/-8.33%; COMPRESS = +
431	LVDT2	0	101512	-0.15810E+00	0.80950E-02	9.9930	-9.9935	CWP STRAIN #2, +/-8.33%
432	LVDT3	0	101510	-0.86620E+00	0.80930E-02	9.9946	-9.9951	CWP STRAIN #3, +/- 8.33%
433	LVDT4	0	101506	-0.28100E-01	0.81050E-02	9.9978	-9.9972	CWP STRAIN #4, +/-8.33%
434	LVDT5	0	101504	-0.16620E+00	0.81030E-02	9.9950	-9.9951	CWP STRAIN #5, +/-8.33%
435	LVDT6	0	101502	-0.93810E+00	0.80950E-02	9.9982	-9.9964	CWP STRAIN #6, +/-8.33%
436	MCPRWV	0	101444	0.00000E+00	0.24426E+00	500.00	0.00000	DESCRIPTION FOR SEQ# 436
437	MCPRWA	0	101442	0.00000E+00	0.58622E+00	1200.0	0.00000	DESCRIPTION FOR SEQ# 437
438	P100A	0	101446	0.00000E+00	0.48850E+00	799.67	49.827	MIX WATER PUMP CURRENT 0-1000 AMPS
439	P100V	0	101450	0.00000E+00	0.48850E+00	999.96	0.00000	MIX WATER PUMP VOLTAGE 0-1000 VDC
440	SPARE	0	101452	0.00000E+00	0.58622E+00	1200.0	0.00000	SEQUENCE NUMBER NOT IN USE
441	SPARE	0	101454	0.00000E+00	0.39082E+00	800.00	0.00000	SEQUENCE NUMBER NOT IN USE
442	P101A	0	101456	0.00000E+00	0.48850E+00	0.00000	-48.850	WARM WATER PUMP AMPS 0-1000 AMPS
443	P101V	0	101460	0.00000E+00	0.48850E+00	0.00000	14.655	WARM WATER PUMP VOLTAGE 0-1000 VDC
444	P103A	0	101462	0.00000E+00	0.48850E+00	999.96	0.00000	COLD WATER PUMP AMPS 0-1000 AMPS
445	P103V	0	101464	0.00000E+00	0.48850E+00	999.96	0.00000	COLD WATER PUMP VOLTAGE 0-1000 VDC
446	TPA2	0	101466	0.00000E+00	0.58622E+00	1200.0	0.00000	DESCRIPTION FOR SEQ# 446
447	TPV2	0	101470	0.00000E+00	0.39082E+00	800.00	0.00000	DESCRIPTION FOR SEQ# 447
448	FE2	0	132204	-0.51380E+03	0.12280E+01	1999.9	-1.7240	REFLUX FLOW P2 TOP SM. 0-2000 GPM
449	FE1	0	132210	-0.10000E+04	0.24432E+01	3998.8	-1000.0	REFLUX FLOW
450	MID-G	0	101500	-0.11670E+01	0.83400E-02	8.8660	-11.750	MIDSHIP STBD G 0-2G

TABLE 4-23

OTEC PARAMETER LIST FOR ANALOGIC 1
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SEQ#	TITLE	TYPE	MUX ADDRESS	A-COEF	B-COEF	LIMIT HIGH	LIMIT LOW	DESCRIPTION
451	TE711	0	101776	0.40000E+02	0.19541E-01	79.981	40.000	HTM #1 AIR TEMP, 40-80 DEG F
452	TE712	0	101774	0.39750E+02	0.31530E-01	104.23	39.750	HTM #1 H2O TEMP, DEG F
453	TDT711	0	101772	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #1 THERMOPILE DIFF. TEMP, DEG F
454	TE721	0	101770	0.40000E+02	0.19541E-01	79.981	40.000	HTM #2 AIR TEMP, DEG F
455	TE722	0	101766	0.37444E+02	0.33100E-01	105.20	37.444	HTM #2 H2O TEMP, DEG F
456	TDT721	0	101764	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #2 THERMOPILE DIFF. TEMP, DEG F
457	TE731	0	101762	0.40000E+02	0.19541E-01	79.981	40.000	HTM #3 AIR TEMP, DEG F
458	TE732	0	101760	0.37444E+02	0.33100E-01	105.20	37.411	HTM #3 H2O TEMP, DEG F
459	TDT731	0	101756	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #3 THERMOPILE DIFF. TEMP, DEG F
460	TE741	0	101750	0.40000E+02	0.19541E-01	79.981	40.000	HTM #4 AIR TEMP, DEG F
461	TE742	0	101752	0.40000E+02	0.19541E-01	79.981	40.000	HTM #4 H2O TEMP, DEG F
462	TDT741	0	101754	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #4 THERMOPILE DIFF. TEMP, DEG F
463	TE751	0	101746	0.40000E+02	0.19541E-01	80.000	40.000	HTM #5 AIR TEMP, DEG F
464	TE752	0	101744	0.40420E+02	0.30180E-01	102.17	40.420	HTM #5 H2O TEMP, DEG F
465	TDT751	0	101742	0.00000E+00	0.31700E-02	6.4890	0.00000	HTM #5 THERMOPILE DIFF. TEMP, DEG F
466	LVDT39	0	101740	-0.76620E+00	0.81030E-02	-0.68517	-0.84723	CWP STRAIN #39,+/-8.33%
467	TE13-1	0	133300	0.29934E+02	0.24426E-01	79.910	29.934	COND. DWNCMR
468	TE13-2	0	133302	0.30179E+02	0.24426E-01	80.155	30.179	COND. DWNCMR
469	TE13-3	0	133304	0.30102E+02	0.24426E-01	80.078	30.102	COND. DWNCMR
470	TE13-4	0	133306	0.30073E+02	0.24426E-01	80.049	30.073	COND. DWNCMR
471	TE13-5	0	133310	0.30073E+02	0.24426E-01	80.048	30.073	COND. DWNCMR

TABLE 4-24

OTEC-1 CRITICAL INSTRUMENTATION

Identity (Quantity)	Description
PE-7 (4)	Evaporator seawater inlet pressure
PE-8 (4)	Evaporator seawater outlet pressure
PE-12 (4)	Condenser seawater outlet pressure
PE-13 (4)	Condenser seawater inlet pressure
TE-8 (4)	Evaporator inlet water temperature
TE-9 (14)	Evaporator outlet water temperature
TE-15 (14)	Condenser outlet water temperature
TE-16 (14)	Condenser inlet water temperature
TE-7 (10)	Evaporator shell interior ammonia temperature
TE-14 (2)	Condenser shell interior ammonia temperature
FT-101 (1)	Warm seawater inlet flow
FT-103 (1)	Cold seawater inlet flow
FE-1, 2, 3 (3)	Evaporator ammonia feed
PE-9 (1)	Condenser ammonia vapor pressure
PDE-10 (1)	Condenser ammonia vapor ΔP
PDE-11 (1)	Condenser ammonia vapor ΔP
PE-1 (1)	Evaporator ammonia vapor outlet pressure
PE-6 (1)	Demister outlet pressure
TE-6 (2)	Demister temperature
PE-14 (1)	Ammonia pressure at flowmeter FT-106
TE-108 (1)	Ammonia temperature at flowmeter FT-106
FE-4 (1)	Demister liquid flow to drain tank
FE-106 (1)	Vapor flow rate to condenser

5006K/sjd

TABLE 4-25

STRIP CHART ASSIGNMENTS

14-APR-81

CHART #	SEQ #	TAG #	CHART RANGE LEFT LIMIT	CHART RANGE RIGHT LIMIT
1	450	MIO-G	-0.100	0.100
2	132	MGDSPD	0.000	100.
3	23	HDGCOS	-1.00	1.00
4	22	HDGSIN	-1.00	1.00
5	131	LINE-T	0.000	100.
6	342	TE16-4	41.0	43.0
7	31	FGFV	100.	50.0
8	320	FGAV	100.	50.0
9	31	FGFV	200.	0.000
10	320	FGAV	200.	0.000
11	29	GPITCH	30.0	-30.0
12	30	GROLL	30.0	-30.0
13	32	FGFH	50.0	-50.0
14	321	FGAH	50.0	-50.0
15	24	PITCH	30.0	-30.0
16	25	ROLL	30.0	-30.0

STRIP CHART UPDATE RATE = 60.0 SECONDS

c. Critical Instrumentation Problems

Several critical instrumentation problems were uncovered while the OTEC-1 test facility was being prepared, checked out, and operated:

1) The warm and cold seawater ultrasonic flowmeters (FE-101 and FE-103) did not read correctly, which was ascribed to excessive voids in the seawater. Trial use of a temporary Doppler-type flowmeter (Mapco) and a high-source-level, low-frequency transducer (Ocean Research Equipment, Inc.) did not correct the problem. Flow rate output signals (by Mapco ultrasonic devices) were obtained only up to 70% flow from the condenser flowmeter and 60% flow from the evaporator flowmeter. These were not valid signals, however. The investigation of

entrained air is discussed in Section IV.B. The warm and cold seawater flow rates were computed by equating the ammonia-side heat duty (data) to the waterside heat duty (calculated). It is noteworthy that similar ultrasonic devices failed to operate properly in the BCM circuits.

2) Evaporator and condenser inlet and outlet static pressure top taps (PE-1) located at 12:00 o'clock of PE-7, -8, -12, and -13 did not give valid data because air had been trapped in the ullage spaces of the waterboxes. These ports were isolated from the remaining three ports per location, and the computer program was changed to average the remaining three good pressure transducer readings per location. This change was approved by ANL (the test requester), who was solely responsible for acceptance of the OTEC-1 instrumentation.

3) Condenser inlet and outlet static pressure taps (PE-13 and -12, respectively) originally operated as planned. As OTEC-mode tests continued, both inlet and outlet static pressure readings decreased. The difference, or pressure drop, of the condenser also decreased. The pressure transducers were checked out, including recalibration and reverification, but to no avail. The erroneous readings of the condenser waterbox pressure transducers were not the fault of these transducers or of out-of-calibration procedures, but rather were related to the fouling of the static pressure taps in the waterboxes, which was discovered during posttest inspection. Section V.B discusses the fouling problem and recommends procedures for avoiding them on future OTEC plants.

4) The demister liquid flowmeter (FE-4) to the drain tank was suspect, but when it was checked, no apparent problems were found. This sonic flowmeter was an integral unit (not the

strap-on type), which made replacement during operation impossible. Because only a small amount of flow was estimated by ANL, and because of restrictions on test time, no replacement unit was ordered.

d. Other Instrumentation Problems

Several other instrumentation problems were uncovered while the OTEC-1 test facility was being prepared, checked out, and operated:

1) Condenser downcomer flowmeters (FT 13-1, -2, -3, -4, and -5) were added to the list of required instruments (and hence are not listed in Table 4-21) after the OEC arrived in Hawaii. The ammonia downcomer piping had to be cut, and flanges were welded and inspected to USCG and ABS standards before the five flowmeters were installed. Wire for both power and signal had to be run from the test compartment to the I&C van. For this installation, penetrations had to be made through the aft test compartment bulkhead and main deck.

   The original wiring from the signal conditioning unit to the junction box was found to have been improperly installed and was corrected. Problems with high-frequency noise in the high-voltage signal (0 to 10 V) were encountered where signals above about 5 V fluctuated randomly. The representative from the multiplexer vendor (Analogic) checked out the multiplexer (MUX) unit 0 and discovered a grounding problem on the analog-to-digital converter. This problem was corrected, as was a problem with the FT 13-2, which had a bad signal conditioner board. Because of testing being curtailed, time did not permit reverification of the flowmeters.

2) Condenser downcomer RTDs (TE 13-1, -2, -3, -4, and -5) were also added to the list of required instruments after the OEC

arrived in Hawaii. These instruments were wired and checked out and data were obtained.

3) Instrument loop assemblies for both the evaporator and the condenser were completed in Hawaii. The inability to keep the instrumented tube systems on-line was due to leaks caused by hose attachment failures inside the waterboxes, some plugging of loops with Amertap balls at the orifice, the ball counter paddle, rusted return line holes, and the low-priority given to repairs. Hose attachment failure and recommended corrective action are discussed in Section V.A.

4) The moisture analyzer in the ammonia system failed after only a short period of operation. The failure is attributed to oil contamination.

5) The evaporator and condenser inlet chlorine analyzers did operate, but they required a very long stabilization period (over 1 h), and the data obtained were not accurate ($\pm$10%). Because accurate chlorine data were being obtained on a timely basis by AECOS, these units were not repaired.

6) Once all the instruments and pneumatic controllers and actuators were put on-line, the capacity of the instrument air system was insufficient and hence had to be increased. This system had to be flushed out due to moisture and contamination in the lines. The storage and filter systems were modified to eliminate the water contamination problem, and additional compressor capacity was added.

7) Before the ammonia power loop was operated, all electrical terminations and connections (J boxes) were fitted with stuffing boxes and sealed with "Chico" compound per USCG regulations.

8) Of the 36 original RTDs installed in the heat exchanger waterboxes by the TAC, 24 failed when exposed to seawater. Replacement units were ordered, and epoxy was added at the new probe-

to-fitting interfaces, which corrected the problem. Four additional RTDs were replaced in the evaporator-instrumented loops, and one RTD was replaced in the ammonia side.

9) Level sensors that did not function caused problems in starting and controlling the pumps when operation of the pump was controlled by liquid level. The sensors required removing the wire wrap and cleaning the probes after considerable consternation and field visits by the supplier.

10) Ammonia sensors gave erroneous alarm signals when exposed to a very moist or windy environment. The ammonia storage tank sensors produced false alarms during high sea and wind conditions. The port-side airlock compartment sensor also gave false readings. This was attributed to condensation on the outer compartment wall, which was also one of the mixed water tank walls. Drain holes were drilled through the floor of the airlock compartment to correct this problem.

11) The sonic flowmeter on the MWD line did not operate because of voids in the seawater. The voids (entrained air) were from the effluent of both the warm and cold seawater systems. Also, during normal operation, the discharge pipe at the flowmeter location never ran full of water. The mixed water flow rate was estimated by obtaining the sum of the warm and cold water flow rates. This was the same problem as described for the warm and cold water ultrasonic flowmeters.

12) The two evaporator ΔP gages failed during operation. The suspected cause was ammonia leakage past their diaphragms.

13) The bottom pinger position indicator (Honeywell) on the CWP originally operated as designed, with the bottom being off-center from the ship, usually between 100 and 200 ft. After late February 1981, the pinger signal was lost. When the CWP was retrieved from wet storage, the pinger was still attached to the bottom of the CWP.

14) The various pieces of DAS equipment that experienced problems are listed below:

   a) CPU
   b) Signal conditioning equipment (multiplexer and analog-to-digital converter)
   c) Tape recorder
   d) CRT/keyboard
   e) DEC writer
   f) Line printer
   g) Strip chart
   h) J-box channelization
   i) High-frequency noise in signals.

   Because the DAS had two identical systems (primary and backup), there was little down time or loss of data during testing.

15) The original DAS software was completely replaced by a new program, one used at ETEC headquarters but modified for multiplexer compatibility. This program also converted the ANL BCM software for use with the existing computer system. Real-time displays were developed for the heat exchanger, ammonia, and gimbal assembly systems. Subroutines were developed and implemented for calibrating and checking the instrumentation (e.g., copper block calibration). Data tape duplication on board the OEC was developed and used.

16) Because of numerous wiring errors, all instrumentation wires were channelized.

17) Calibration difficulties were experienced on site because of ship movement (roll, pitch, heave, surge, and sway). Calibrating the low-pressure transducers was not possible. Accurate calibration of the instrumented tube flowmeter, using an in-line turbine flowmeter, was not possible because of flow fluctuations caused by the ship's motions.

18) Some of the instruments were located in very difficult to get to positions, which made the instruments difficult to calibrate, verify, or replace. Also, it was time consuming and, at times, unsafe to work on these instruments.
19) Because of the remote location of the test facility, long turnaround time was experienced for required personnel, supplies, instruments, and equipment.
20) High-frequency noise was found on many channels. Capacitive-resistive network filters were made and installed by ETEC. The noise source was never isolated.

e. Instrumentation Additions and Modifications

Several additional instruments were installed and other modifications were completed in Hawaii:

1) Five condenser downcomer flowmeters were installed per ANL request.
2) Five condenser downcomer RTDs were installed per ANL request.
3) Two additional accelerometers were installed at bow and midships (starboard) per NOAA request.
4) Thirty-six additional LVDTs were installed on the CWP per NOAA request.
5) One extra pinger was installed on the CWP per NOAA request.
6) One current meter was installed on the ship per LBL request.
7) Three Doppler flowmeters were installed on the warm, cold, and mixed water pipes.
8) High-source-level, low-frequency transducers were installed on the warm and cold water ultrasonic flowmeters.
9) Twenty Validyne ΔP transducers were installed for flow measurement on the instrumented tubes.
10) A backup 24-Vdc power supply was installed for all 24-V instruments.

11) A separate 10-Vdc power supply was installed for the gimbal assembly strain gage load cells.
12) Calibration ports were added on level sensor assemblies to permit the calibration of these units.
13) The static pressure gage PE-2 was moved from evaporator-side center to lower center on 2 March 1981 per ANL request.
14) The ship's dynamics instrumentation was modified by removing the bias (offset) voltage transformer, which had caused noise in the output signal. A voltage divider was installed in the dc output signal to reduce the voltage signal to the DAS.
15) The ranges of PE-9 and PE-14 were changed from 58 to 75 psig to 58 to 85 psig on 22 January 1981 and 27 January 1981, respectively, per ANL request.
16) The range of FE-3 was changed from 0 to 500 gpm to 0 to 2000 gpm on 27 January 1981 per ANL request.
17) The range of FT-106 was changed from 5.5 to 11.5 psig to 0 to 15 psig on 24 July 1980.

f. Control System Experience

The existing control system located in the I&C van used sets of switches with associated display lights to control discrete plant operating components. Local controls were used on some of the plant components. Proportional controllers (Beckman) were also used to provide the appropriate combination of proportional plus differential plus integral control to a given set point. The set points were manually or computer controlled.

g. Control Problems

Several control problems were encountered while the OTEC-1 test facility was being checked out and operated:

1) The control system with its sets of switches and associated display lights was poorly designed and very confusing. No color-coded piping and valving line diagrams with the color-coded lights were available. Therefore, operation of the test faciity was slow and difficult. The high-failure rate of the associated display lights made it difficult to determine the status of the equipment (e.g., on-off, open-closed). To replace a failed light required difficult rewiring procedures.
2) Proportional controllers experienced frequent down time, which caused a loss of data and required many man-hours to keep the system operational.
3) Both ammonia reflux pumps (P-1 and P-2) required a new control system for pump operation. The signal conditioner boards of the original control system were heat sensitive and failed to operate.
4) Because the sonic flowmeter of the MWD pump performed unsatisfactorily, the controller for this pump was modified to operate with sump level rather than flow rate as the process variable. After proper adjustment of the controller (Beckman Model 8000), this system operated satisfactorily.
5) Neither the warm nor the cold water sonic flowmeter functioned properly; therefore, these pump controllers were modified from flow- to manual-mode operation.
6) All three seawater pump SCR units overheated during operation and failed to function. This problem was corrected by providing an air-conditioned environment for these units.
7) Ammonia liquid level in the condenser drain pot (LE 3-3), which controlled the condenser discharge valve (V-114), caused problems because of the original low-level span calibration requirement. The liquid-level range was increased to correct this problem.
8) The ammonia vapor throttle valve between the evaporator and the condenser (V-111) was controlled by either evaporator pressure

or valve position. When switching from one control parameter to the other, the parameter sign changed without any indication on the controller.

h. Resistance Temperature Detector Calibration

The most critical measurement system for OTEC is temperature. No provision for calibration or verification of the temperature measurement systems was made by the designer/constructor (TAC) beyond accepting manufacturer's claims on components. ANL, the experimenter, devised a field procedure and supplied critical equipment to perform the necessary verifications. Instruments were inadequate and required adjustment or replacement.

During the preparation, operation, and posttest inspection of the OEC test facility, RTD calibrations were verified using copper blocks and a quartz crystal thermometer (QCT). This verification was made necessary by the requirement of the OTEC-1 Test Plan[2] that the accuracy of the instrument system be $\pm 0.127°F$. The QCT was calibrated using an ice bath. Ice bath calibration procedures and the copper block technique used for verifying the RTD calibrations are discussed below:

1) Ice bath preparation and calibration procedures are found in Appendix L. Results of the ice bath calibration are listed in Table 4-26.
2) The copper block technique used for verifying the RTD calibrations is given in Appendix M. The calibration/verification procedure first used the manufacturer's calibration data for comparison with the quartz thermometer. A second step was taken, if required, by using the standard average resistance value as a function of temperature: $R = 464.83 + 1.09544T$, where R is resistance (Ω) and T is temperature (°F). A third step was taken, if required, by using the optimum equations for each specified range as follows:

a) 35 to 50°F, $R = 464.63 + 1.0979T$

$R = 503.17$ and 519.52Ω

b) 40 to 80°F, $R = 464.94 + 1.09645T$

$R = 508.65$ and 552.65Ω

c) 65 to 90°F, $R = 465.27 + 1.08868T$

$R = 536.03$ and 563.25Ω

TABLE 4-26

QUARTZ PROBE CALIBRATION CHECK
(Probe S/N 1731A00339, Channel T1)

No.	Date	Time (hours)	Precalibration		Postcalibration		Operator's Name
			Temperature Reading	Dial Setting	Temperature Reading	Dial Setting	
1	13 Oct 80	1020	31.992	506	32.000	513	E. Westerweller
2	14 Oct 80	0930	32.002	513	32.000	512	E. Westerweller
3	20 Oct 80	0958	31.987	512	32.000	520	E. Westerweller
4	21 Oct 80	1100	32.000	520	NC[a]	NC[a]	E. Westerweller
5	23 Oct 80	0900	31.999	520	NC[a]	NC[a]	E. Westerweller
6	25 Oct 80	0900	32.014	520	32.001	512	C. Quirk
7	25 Oct 80	1927	31.992	512	32.001	526	C. Quirk
8	02 Nov 80	1430	31.997	526	31.999	527	A. Drennan
9	04 Nov 80	1023	32.001	527	NC[a]	NC[a]	A. Drennan
10	06 Nov 80	0941	31.999	527	NC[a]	NC[a]	E. Westerweller
11	07 Nov 80	0940	31.997	527	32.000	529	E. Westerweller
12	19 Dec 80	1030	32.010	526	32.000	523	C. Quirk
13	20 Dec 80	0900	32.016	523	32.001	519	C. Quirk
14	17 Feb 81	1400	31.945	519	32.000	551	E. Westerweller
15	16 Apr 81	1100	31.996	525	32.000	528	E. Westerweller

[a]No change

3. Recommendations

Based on experience gained from the test operations, the following general recommendations for future OTEC plants were developed. Instruments (transducers, signal conditioners, readout and analytical systems) that are critical (failure invalidates test or personnel/equipment safety is jeopardized) should be specified and procured with sufficient lead time to be tested in situ to demonstrate function, calibration, and repeatibility. Control systems should be operated (simulated if necessary) during construction to demonstrate function, interlocks, trips, and alarms. Where instruments are included in control systems, they should be considered critical.

Additionally, the following specific recommendations were developed:

1) Have plant operators participate in the design and design review phases of the instrumentation and control systems, including the DAS and software.
2) Design the control center with enough room so that personnel can move about without distracting operators by requiring them to move out of the way.
3) Design the control center installation so as to prevent vibrations (self-induced or external) A vibration-free environment increases equipment life and operator efficiency.
4) Design seawater systems, especially the inlet sumps, to avoid seawater air entrainment. Be conservative in the design so that air ingestion by the seawater pumps is eliminated. Without entrained air in the seawater, ultrasonic flowmeters can be used to obtain flow data; otherwise, other types of flowmeters, types with various disadvantages (pressure drop, moving parts, poor accuracy, etc.), must be used to obtain large seawater flow rates.

5) Static pressure taps must be kept free of rust and contamination for proper operation (see Section V.B).

6) Critical ammonia flowmeters should be designed for easy removal and repair or replacement. Integral types make it necessary to shut down the ammonia system and perform system purging prior to repairs/replacement of the unit.

7) Contamination in the ammonia power loop must be considered (see Sections IV.C and V.C) if an ammonia moisture analyzer is expected to function properly. This unit is necessary in an OTEC plant since moisture in ammonia affects heat exchanger efficiency[15] and some metallic components.

8) If on-line chlorine analyzers are used, the accuracy and analysis time should be checked for system compatibility.

9) Instrument air systems must be designed to have sufficient capacity (conservative design) to supply air to all equipment. The design must have a moisture removal system, preferably automatic, and be capable of operating in a moist environment.

10) RTDs exposed to seawater must be waterproof. A verification test to ensure operation before installation in the test facility is recommended. The use of unions to permit easy installation and removal is also recommended.

11) Ammonia sensors should be located away from very moist areas and also from high-wind locations or be insensitive to those factors.

12) Level sensors must be designed to permit calibration to be performed in situ.

13) Use ammonia ΔP gages that are compatible with ammonia.

14) Instruments sensitive to the ship's motion must be calibrated when the ship is tied up at the pier, not on the mooring site.

15) Locate instruments for accessibility.

16) Minimize additions to and modifications of instruments on site. Working on a moving ship is difficult and hazardous, and the availability of personnel, supplies, and equipment is limited.
17) Have spares on hand to reduce turnaround time.
18) Have pump speed as the output control parameter for the seawater pumps. Pump operation with power as the control parameter was difficult.
19) Incorporate an alarm system that notifies the test operator if the pump motor ventilation fans or pumps stop during operation.
20) Have an alarm system on equipment and at locations to signal failures or avert damage. As a minimum, pump cooling, pump lubrication, and test and observation compartment bilge and forward pump room water levels should be alarmed.
21) Use transistorized proportional controllers.
22) If SCR units are used, provide sufficient cooling for proper operation.
23) To obtain accurate temperature data, use the ice bath and copper block procedures for calibrating/verifying resistance temperature detectors.

H. ENVIRONMENTAL MONITORING

The Marine Sciences Group of Lawrence-Berkeley Laboratory was the lead laboratory for the environmental aspects of the OTEC-1 program. The environmental monitoring contractor (EMC) was EG&G Environmental Consultants, who subcontracted the on-board monitoring to AECOS. Later in the program, AECOS was delegated the responsibility of EMC.

The environmental studies conducted aboard the OEC followed the requirements of National Pollutant Discharge Elimination System (NPDES) permit HI0110272 (effluent limitations and monitoring requirements and taking of meteorological data). Effluents measured included those from the evaporator, condenser, MWD, deck drainage, sanitary wastes, domestic wastes, ballast water, bilge water (OTEC compartment), engine cooling water, seawater from fire pumps, boiler blowdown, distillation plant brine, and refrigerator cooling water. Samples were evaluated aboard the OEC, using the environmental laboratory equipment, or were sent to shore for analysis. Meteorological data (wind speed, wind direction, and air temperature) obtained aboard the OEC were recorded on the OEC's DAS. Barometric pressure and wet and dry bulb air temperatures were measured on the bridge and entered in the environmental log.

1. Test Operations

This section discusses the environmental monitoring during sea trials and the equipment and instrumentation used and the data acquired during the OEC's deployment in Hawaii.

a. Sea Trials

Water-quality sampling was completed during sea trials at Port Angeles Harbor, Washington. Seawater samples were obtained on 7 June 1980 during operation of the warm and cold water systems. The procedure followed is described in Appendix O. The samples were delivered to AM Test, Seattle, Washington, on 8 June 1980; the results are given in Table 4-27.

b. National Pollutant Discharge Elimination System

The NPDES permit, HI0110272, was amended to permit the discharge of mixed water effluent at about 7.3 m beneath the ship instead of the 73 m specified in the Test Plan.[2] This change was necessitated by repeated failures[1] that occurred during checkout operations of the MWD pipe system.

TABLE 4-27

SEA TRIALS SEAWATER ANALYSIS

Laboratory Sample	Sample Location	Laboratory Sample	Sample Taken		Results	
			Date	Time (hours)	Oil and Grease (mg/liter)	Total Suspended Solids (mg/liter)
23857	Condenser inlet	C-1-I 5-ml HCl	07 Jun 80	2130	1.5	-
23858	Condenser outlet	C-1-O 5-ml HCl	07 Jun 80	2130	3.1	-
23859	Evaporator inlet	E-1-I 5-ml HCl	07 Jun 80	1630	3.4	-
23860	Evaporator outlet	E-1-O 5-ml HCl	07 Jun 80	1630	1.0	-
23861	Condenser inlet	C-2-I	07 Jun 80	2130	-	1
23862	Condenser outlet	C-2-O	07 Jun 80	2130	-	7
23863	Evaporator inlet	E-2-I	07 Jun 80	1630	-	6
23864	Evaporator outlet	E-2-O	07 Jun 80	1630	-	6

5006K/sjd

c. Equipment and Instrumentation

The environmental laboratory was a 20-ft-long by 10-ft-wide by 9-ft-high van located aft of the I&C van. This laboratory was furnished with the following analytical equipment, which had been transferred from ETEC to LBL:

		Property Numbers
1)	Induction salinometer, Beckman Model 257	253167
2)	Microscope, Bausch & Lomb Series S	253183
3)	Ionanalyzer, Orion Model 901	253181
4)	Amerometric titrator, Fisher & Porter Model 62410-023	253163
5)	Millipore filter funnels and clamps, filter holder, manifold, and vacuum pump	-
6)	Analytical balance, Sartorius 2842-SR	253178
7)	Auto-analyzer, Technitron Model AA17	253316
8)	Carbon ampule charger, Oceanography International Model 052YPS	253175 and 253176
9)	Triple beam balance, Ohaus 860 W	-

Several other pieces of equipment were installed in the environmental laboratory:

		Property Numbers
1)	Water purifier, Barnstead Nanopure/RO System 10	253179
2)	Incubator, Lab Line Model 3550 BOD	253186
3)	Refrigerator, Lab Line (10 ft^3)	253321
4)	Freezer, Norlake (12 ft^3)	253322
5)	Fume hood, Labcon	253323
6)	Air conditioner	253610
7)	Countertops	-
8)	Four wall cabinets	-

		Property Numbers
9)	Two Lyon cabinets	-
10)	Plumbing	-
11)	Electric power	-
12)	Glassware	-
13)	Sink	-

In response to an LBL request, additional sample taps were installed on the discharge lines of the two sewage plants to sample effluents. Also, sample taps for the warm (two each), cold (two each), and mixed water systems were changed from steel to plastic. Because the discharge taps for the warm, cold, and mixed water systems were located on the main deck, the pressures at these taps were subatmospheric. Various recommendations, including use of a vacuum pump, were made concerning how to take samples at these locations. Tests were conducted using a special sample bottle. Once the bottle was evacuated, the sample water filled the bottle. This arrangement permitted obtaining the sample very quickly and easily. NPDES discharge points on the OEC were as follows:

		Tap Identification
1)	MWD	001
2)	Deck drainage	002
3)	Forward sanitary waste (port)	003
4)	Aft sanitary waste (starboard)	004
5)	Domestic waste (graywater)	005, 006, 007, and 008
6)	Ballast water	010, 011, and 012
7)	OTEC test compartment bilge water	013
8)	Engine cooling water (port and starboard)	014 and 015
9)	Fire pump water	016 and 017
10)	Boiler blowdown	018 and 019

		Tap Identification
11)	Distillation plant brine	020
12)	Refrigerator cooling water	021

d. Additional Data Requirements

During the OEC's deployment at its mooring site, the following additional data were gathered:

1) Data on the quantity of mixed water being discharged during the chlorination period were obtained. This information was supplied by the on-board environmental information where both the warm and cold water computed flow rates were added to give the mixed water flow. The water flowmeters gave erroneous data and therefore were not used.

2) Environmental data were obtained every hour using the on-board environmental data (ENVIR) computer program. Data included heat exchanger waterbox temperatures, warm and cold water flow rates, and wind speed and direction (from magnetic north). Hard copies were given to AECOS for disposition.

3) Also obtained were the following environmental data, hand recorded every 2 h by the FOC, Tracor Marine:
   a) Date and time*
   b) Wind speed and direction*
   c) Ship's heading*
   d) Wave rider amplitude
   e) Air temperature*
   f) Wet bulb temperature
   g) Barometric pressure
   h) Current speed and direction†

---

*Also recorded on DAS.
†Set at 100 ft, if >1 knot, run scan at 100-ft increments to 900 ft every 2 h until <1 knot. Leave sensor at maximum current depth between the 2-h readings.

i) Remarks

j) CWP gimbal angles*

k) CWP bottom pinger bearing and distance from center.

4) Ocean engineering surveys were conducted once a day by Tracor Marine and ETEC personnel using the on-board current meter unit. The current meter sensor, which was normally at a depth of 50 ft, was lowered to 800 ft, where data that included depth, direction and speed of the current, time, and ship's direction were logged. The sensor was then raised in 50-ft increments, and the data were recorded. Many of the current meter data were lost due to operational problems with the Endeco current meter, problems that remained even after efforts by the vendor representative to repair the unit. This current meter assembly was finally replaced by an acoustic Neil-Brown unit.

The acoustic unit was traversed once a day from a depth of 400 ft (rather than 800) with data recorded at 50-ft increments. Except during traverses, the unit was kept at 30 ft. The following data were hand recorded:

a) Depth

b) Time

c) Pressure

d) Cable playout length

e) Speed and direction of the current

f) Water temperature

g) Remarks.

Additional data were then added to the data sheet, including:

a) Start and finish time

b) Start and finish heading

c) Start and finish wind direction and speed

d) Start and finish wave height and direction

e) Start and finish mini-ranger locations

f) Start and finish ship's list and trim

g) Forward and aft thruster position and speed.

5) MWD plume studies were conducted twice without the use of the MWD extension pipe on 7 January and 11-12 April 1981. Results from the 11-12 April survey are given in Ref. 5. Phase III testing was terminated as the second plume study was completed.

2. Recommendations

The environmental monitoring studies aboard the OEC led to the following recommendations for future OTEC plants:

1) Environmental monitoring requirements should be defined before the test platform is deployed. Specifically, the following should be defined:

   a) Sampling stations to permit correct taps to be installed

   b) On-board analysis requirements to ensure that only required analytical equipment is available and installed on-site

   c) On-board environmental monitoring equipment available on a timely basis to permit installation and checkout prior to required usage.

   d) Data requirements to permit instrumentation and data acquisition systems to be installed and checked out.

2) For all water sample ports that are subatmospheric, use the sealed sample bottle technique for obtaining the sample.

3) If current data are required from the test platform, use an acoustic rather than a mechanical type of transducer.

I. COLD WATER PIPE

1. Summary

The CWP was not a test article, but its satisfactory operation was critical to the success of the OTEC-1 mission. The CWP was designed to be mated to the vessel-mounted gimbal and to remain so during operational sea states. During the excessive sea states, the pipe was designed to be rapidly detached from deckside and to free fall to the bottom. There the pipe would reside safely in an upright orientation until conditions permitted its recovery and reattachment. This emergency operation was never implemented, although each of the steps was performed at one time or another. The operational experience of this CWP design was an unconditional success.

2. Preoperational Activities

Before the CWP was deployed into the water, a decision was made to install 36 new linear LVDTs and the associated cabling and signal processing equipment (six units had previously been installed). These devices, which essentially were large-displacement strain gages, were intended to provide the operating personnel with information on the "stress" condition of the pipe material. The locations, critical strain loads, and decision making analyses are available within the ETEC documentation files. The instruments were installed on the pipe exteriors (Figure 4-8) and "zeroed" with the pipe still on rails on the beach. The pipe was launched into the protective harbor and the "zeroes" reverified. Some undetermined damage occurred during the CWP towing operation. Because of difficulties with release of a handling line on the CWP bottom end, the requirement to perform a "drop" test of the CWP, and the changeover from GMDI to Tracor, the LVDT cables were not connected to the signal conditioners and recorders for approximately 4 weeks. When, in attempting to reconcile meaningless data, the instruments were examined by

Figure 4-8. Typical LVDT Installation on CWP

divers, they were found to have failed due to depleted oxygen crevice corrosion. The findings are detailed in Ref. 26. Ultimately, six units (50-ft depth) were reworked by ETEC and reinstalled. The data were recorded but never reduced and analyzed.

The instrumentation that provided the gimbal loads and angles was verified for proper upscale readings prior to pipe attachment as a part of the on site development of computerized system diagnostics and outputs. The onsite NOAA representative provided significant guidance and assistance to this effort.

The "drop" test was satisfactorily conducted on 1 December 1980, with the CWP tethered to the winch, to verify that the quick release hydraulics functioned as designed. The "wet" weight of the CWP assembly was determined to be 105,000 lb by comparing the vertical loads on the gimbal before and after the drop.

Cold water flow was initiated on 12 November 1980, and the water level in the cold water pump, at 6 to 7 ft below the ship's draft, indicted that the calculated ΔP through the pipe was approximately as computed.

3. Test Operations

The CWP was simultaneously monitored for loads and positions, both by the data operators in the van and by the vessel operators on the bridge. The characteristic behavior became familiar: the ship would move relative to the pipe in response to sea surface conditions. It was fortunate that the excessive current situation, discussed below, occurred well after the CWP behavior had become familiar, or the design CWP release option would more likely have been selected as the prudent course of action.

The instrumentation on board that located the bottom end of the CWP was a Honeywell RS-7 unit which displayed offset range and azimuth. This device required the input of "depth" for calibration, so its response was not precise. It indicated that the nominal bottom end was generally aft, at a 200 to 300 ft lateral displacement from the ship's vertical axis. This instrumentation provided little or no information of value.

The major operational event was the excessive deflection of the CWP in response to high surface currents, as discussed in Section IV.K, where the vessel was released from the moor rather than the CWP from the vessel. The details of the procedures and events are available within the references. Figure 4-9 is a composite record of the conditions prevailing before and after the excessive current event and release from the moor.

The figure presents wave heights as logged from a wave rider buoy located approximately one mile from the ship; wind speed recorded on board; and CWP gimbal cone angle. Unfortunately, no measurement of current was available and only inferences[4] can be drawn; in fact, the steady state deflection of the CWP is a measure of the prevailing current. The figure shows that a current pattern was developing from about 24 February to 28 February but appeared to have peaked. The increase in gimbal angle appeared to be related to the wind-driven waves. Note that by March the winds, waves, and gimbal angle were near normal. Beginning in March, the gimbal angle increased dramatically to the allowable limits while the winds and waves were at normal low levels, confirming current as the source of the deflection. A procedure was prepared incorporating the experience gained to enable future operations to consider this option. Appendix Q is a draft of this procedure.

No other events of significance regarding the CWP were recorded, except for the planned release at the conclusion of the first deployment on 13 April 1981. The procedure of release and free fall to the bottom followed by relocation and recovery was not done by the OEC procedures. The CWP was recovered in October 1982, 18 months later. The procedures and findings regarding CWP recovery are discussed in Section VI. It appears that with the loss of buoyancy of the flotation collar, the compression of the polyethylene, and the

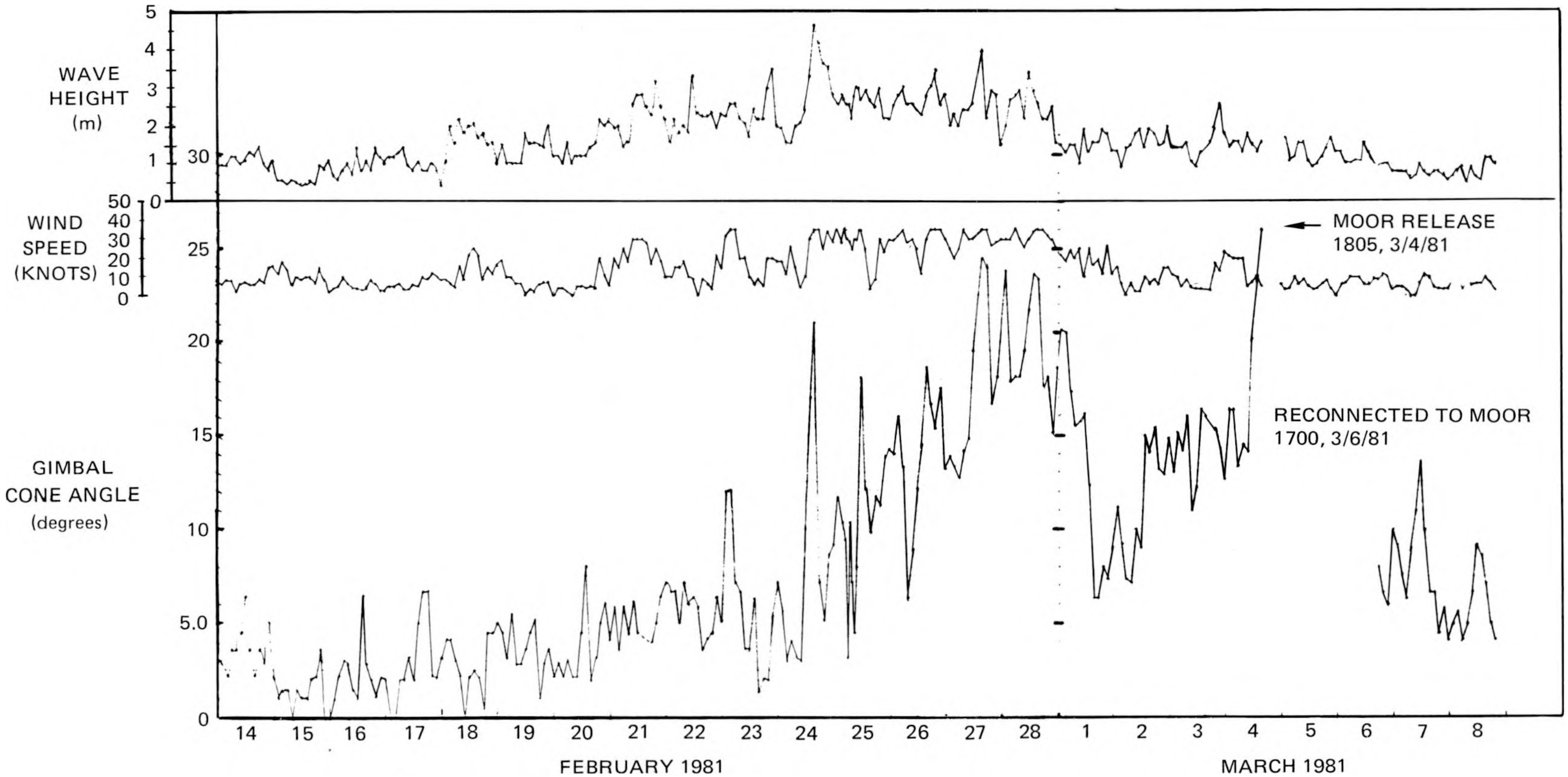

Figure 4-9. Wind Wave and Gimbal Cone Angle Conditions During OEC Release from Moor

bottom weight configuration, the lines at the CWP bottom end became fouled and recovery by the OEC might have been unsuccessful.

4. Recommendations

The operational performance of the OTEC-1 CWP was as close to a total engineering success as is possible for a first-of-a-kind item of this type. The following recommendations result from hindsight:

1) A rigorous analysis should be made to determine the purpose of the instrumentation (e.g., data for real-time decision making, future analysis) and the importance to the program of instrument failure.
2) Based on the difficulties experienced later with recovering the CWP, design features should be provided to accommodate foreseeable events (e.g., mechanical means accessible from the surface to attach to pipe, means to detach CWP from an expendable bottom anchor). Section VI also give specific recommendations.
3) Although in retrospect it might have proven difficult, a calm sea jettison and recovery exercise should have been performed to demonstrate the procedure and to train the crew under unstressful conditions.

J. MIXED WATER DISCHARGE

1. Summary

The MWD subsystem was intended to combine the spent warm and cold seawater flows and to discharge the mixture at a distance from the warm water intake and at a suitable depth from the surface. The design provided for a mixing chamber (port wing tank 5) into which to pipe the warm and cold water and from which to pump the mixed fluid aft for discharge below the surface through a flexible duct attached to the hull (see Figure 2-6 and Figure 4-10).

Figure 4-10. MWD Hose (Illustrates the upper transition section and one of the six 36-ft lengths of hose. The bottom end weight and diffuser are shown on the deck.)

2. Test Operations

During sea trials, it was discovered that the MWD pump was unable to fill and prime the discharge ducting. The system was modified by adding a water-driven eductor to reduce the pressure in the discharge line; this fix proved satisfactory. Testing of the MWD as a subsystem had not specifically been intended, but a series of tests of the redesigned, modified fabric hose was conducted. The hose proved to be inadequate, and operations were resumed without the hose,[1] which required modifying the discharge permit. During acceptance testing in Hawaii, it was determined that the MWD pump had SCR cooling problems as did the other pumps; the problem was ultimately cured by the forced cooling of the SCR cabinets. The operating procedure for the MWD has been included as Appendix F.

The MWD system was intended for continuous operation. When it became desirable to reduce costs, it became evident that operation of the MWD pump (700-hp rating) was not mandatory for heat exchanger testing, and a decision was made to discharge amidships, through the open seavalve in the mixed tank standpipe with the pump off. No evidence of an increase in warm inlet water temperature or recirculation was detected during any of the operations.

An analysis made of the plume trajectory[5] predicted that there would be no reinjestion from the more dense mixture sinking or from velocity effects. This analysis also related to the environmental testing discussed in Section IV.H.1.d.[5]

The inadequate design of the MWD hose coupled with the relatively short first deployment test period precluded a planned subtest program in which the discharge depth would have been varied to evaluate its effect. This deficiency did not affect the prime test program.

3. Recommendations

Should it be determined that a discharge system is required (the OTEC-1 tests neither confirmed nor denied such a determination), the MWD would require as rigorous a design approach as was done for the CWP. The environmental forces that apply to a discharge system are no less significant.

K. STATIONKEEPING SUBSYSTEM

1. Summary

The stationkeeping subsystem (SKS) was a combination of a passive, single-point mooring augmented by two variable-speed, directional thrusters. The design was intended to permit the vessel and its suspended CWP and DWD components to stream aft and away from fouling in the mooring line. The thrusters (rated 1000 hp each) were to provide compensation for rapid changes in wind or current. The array is depicted in Figure 4-11.

Combinations of various wind and current conditions and of various geometries and freeboard of the hull produced instances when full thrusters were unable to provide position control, raising questions about the vessel's precise position in the watch circle.

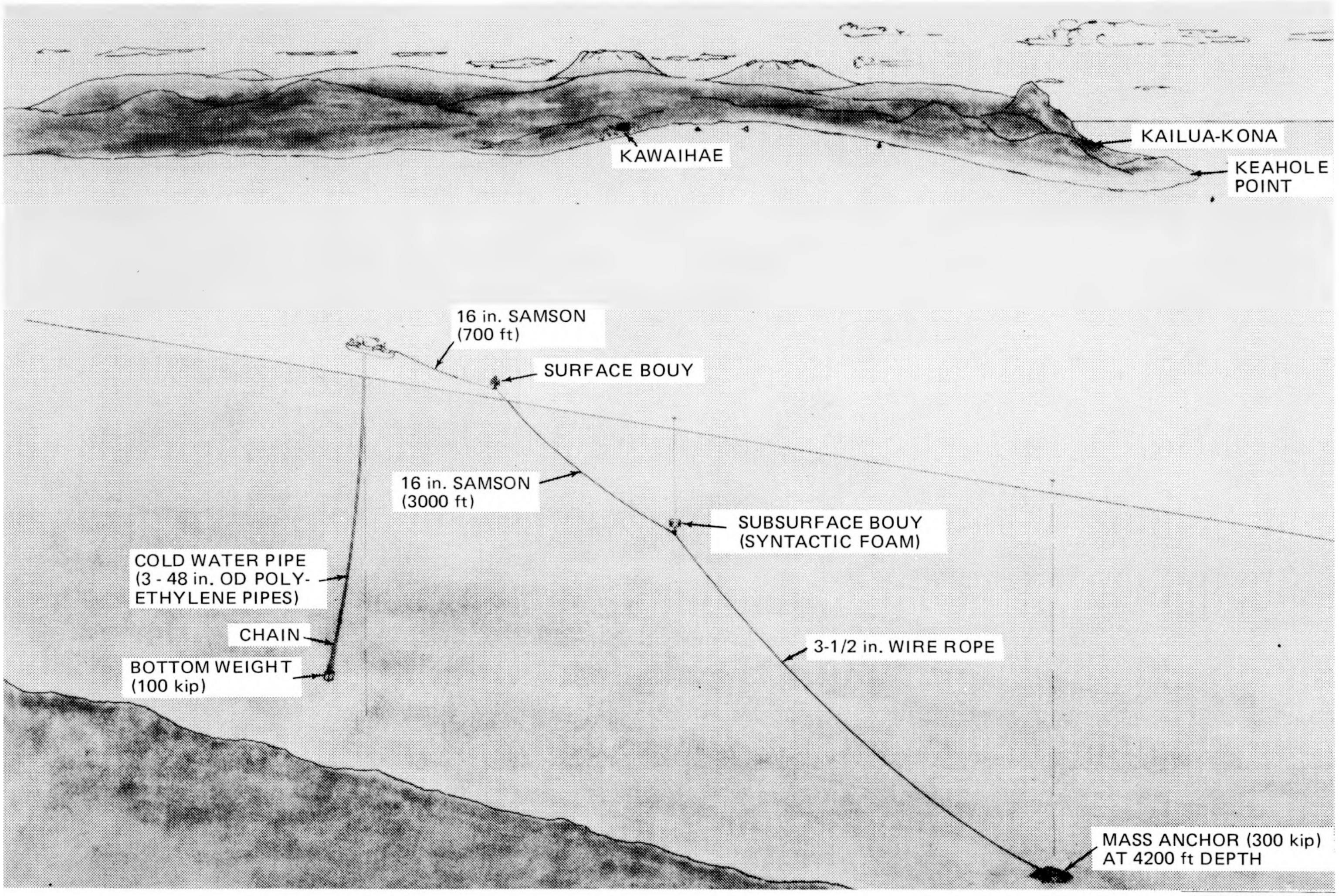

Figure 4-11. Artist's Rendering of OTEC-1 Single Point Moor

2. Test Operations

Although the SKS was not an identified test feature, its satisfactory operation was necessary for operational success. The anchor itself was the largest deepwater moor set. Approximately 150 tons of surplus anchor chain was deployed as a clump mass anchor; it was successfully placed in February 1980. In operation, the bridge was directed to maintain 10,000 lb of tension in the mooring line to ensure that the watch circle was being maintained; this was accomplished by operating the thruster(s) and observing the buoyant line from the ship to the surface buoy.

This mode of operation was satisfactory under most conditions. But instances[23] occurred when the vessel experienced winds and currents that could not be accommodated with full thruster power. These occurrences precipitated the installation of a high-precision positioning system (Motorola Mini-Ranger), which proved to be of great value.

A significant operational event occurred on 4 March 1981 when excessive currents were encountered that deflected the CWP to its extreme limits. The action taken to mitigate this condition was to release the vessel from the moor and, under thruster control, to allow it to drift down current. This reduced CWP deflection and minimized lost test time while retaining the option to jettison the CWP, the primary design mode of accommodation. After the excessive currents had subsided, the vessel was reattached to the moor without difficulty. These events are described and analyzed in Refs. 12, 24, and 25.

Operational data were collected on the DAS. A typical record of mooring tension is given in Figure 4-12; it illustrates the mooring release at 1805 hours on 4 March 1981.

3. Recommendations

The experience during testing led to the following recommendations for future moored plants, especially single-point types:

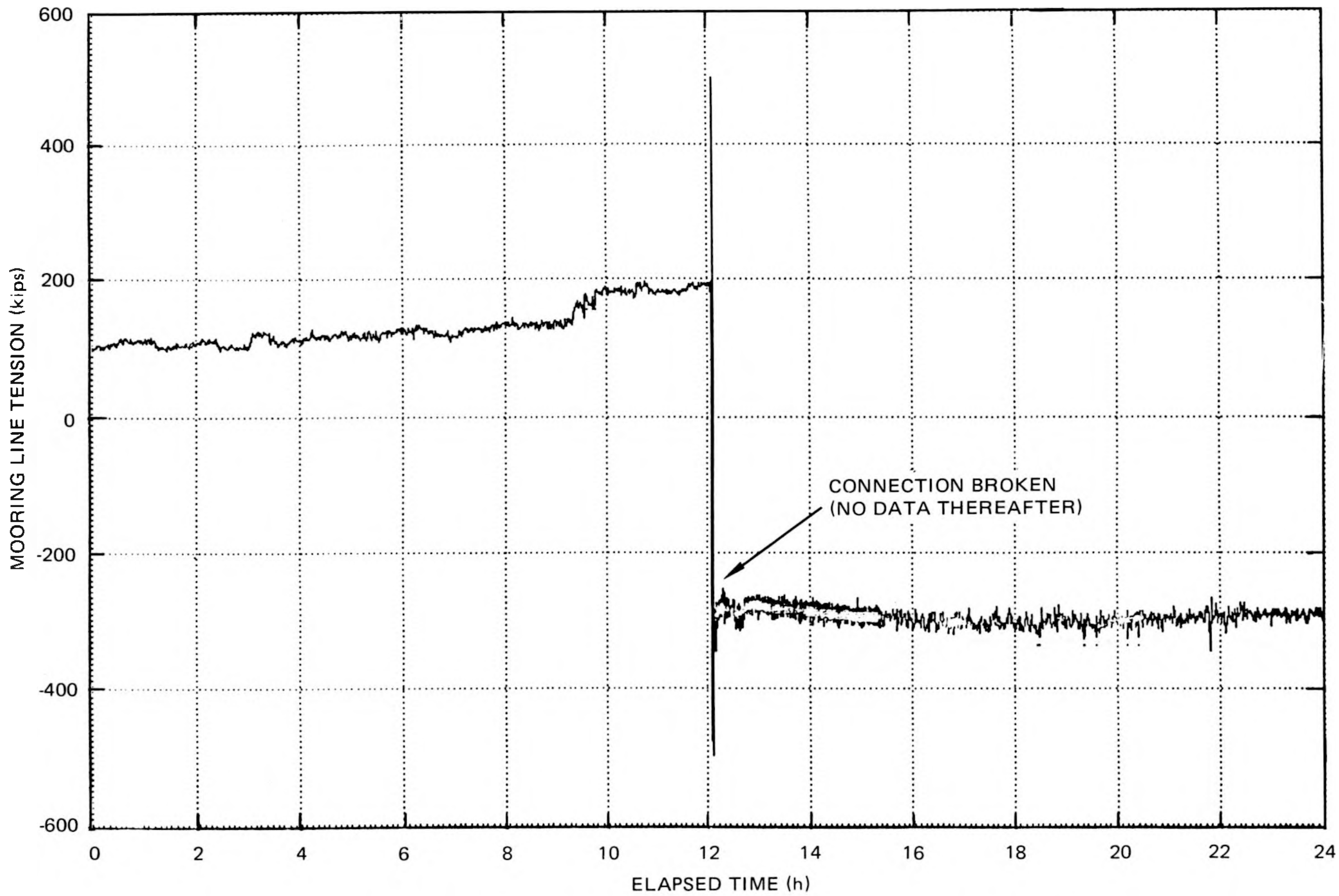

Figure 4-12. Mooring Line Tension Plot at Release Time

1) Analyses that consider winds, waves, and currents occurring simultaneously but from any direction should be performed to size the dynamic positioning equipment.
2) Precision equipment is mandatory to establish the positions of the platform with respect to its appendages and the elements of the mooring system.
3) The utilization of a single-point, weather vaning, dynamic-assist mooring system should be considered a demonstrated state-of-practice technique with no known deficiencies.

L. PLATFORM

1. Summary

The platform system was comprised of those features that, although part of the test system, were mandatory for operation; these include: the crew accommodation facilities, the vessel navigation and communications systems, and the vessel propulsion and utility systems.

2. Test Operations

During the entire period from the departure from Portland, Oregon (June 1980), through the deactivation of the vessel (June 1981), no failures of the platform systems occurred that affected any of the test or deployment activities. This outstanding performance is attributable to the reactivation and refurbishment done by GMDI and the shipyard and the operational maintenance done by Tracor Marine, Inc.

The complement of instrumentation installed to monitor the behavior of the platform included accelerometers and attitude sensors. Data from this instrumentation were recorded and forwarded to NOAA for analysis. No anomalous behavior of the platform initiated special investigations.

3. Recommendations

A serious concern before the test program was the adequacy of the heat exchanger support pedestal designs being subjected to vessel motion loads. It would appear prudent to examine the records for loading history and perhaps perform physical inspections of the structures in question.

The dynamic response of the vessel, as modified for the OTEC-1 application, was predicted during the design phase for structural anlyses. It might be of interest to analyze the data to confirm or reject the design assumptions.

5006K/ljm

V. RESULTS OF POSTTEST INSPECTION

A. EVAPORATOR WATERBOX AND WARM WATER SYSTEM

After about 5 months of seawater operation of the warm water system, the seawater loop and seawater side of the evaporator heat exchanger were inspected and found to be generally clean and in excellent condition. The internal surfaces of the titanium heat exchanger tubes were also clean and in excellent condition. Some loose foreign items were found in the inlet waterbox. Three loose instrumented hoses and an ammonia leak at a weld plug were also found. A small amount of marine growth was observed in the outlet waterbox. Rust was found on nonprotected or poorly coated carbon steel surfaces. The results of this inspection are discussed below.

1. Detailed Inspection Results

The warm seawater pump on the OTEC-1 evaporator began operation on 6 August 1980 and was shut down on 12 April 1981. A chronology of the warm seawater system in Hawaii is given in Table 5-1. The inlet and outlet waterboxes and the warm seawater ducting were inspected on 15 April 1981. Results from the posttest inspection of the waterside evaporator heat exchanger are reported in four sections: (1) inlet waterbox, (2) outlet waterbox, (3) warm seawater ducting and Amertap screen, and (4) warm seawater sump inlet screens.

a. Inlet Waterbox

Inspection of the inlet waterbox (see Figure 5-1) first revealed that the Amertap ball net ring had broken loose from its support points (four bolts) and was resting against the RTD frame (see Figure 5-2). All four bolts had rusted and failed. It was fortunate that the netting had previously been removed. Otherwise, the netting and trapped Amertap balls could have blocked many tubes at the tubesheet face.

TABLE 5-1

WARM WATER PUMP (P-101) OPERATIONAL LOG
(Sheet 1 of 2)

Date	Pump Operation Start Time (hours)	Pump Operation Stop Time (hours)	Duration (h)	Remarks
06 Aug 80	0834	0903	0.48	Checkout test and MWD pipe verification testing
07 Aug 80	0950	0958	0.13	
08 Aug 80	1200	1215	0.25	Evaporator drained, HX tube leak discovered
11 Nov 80	1600			Continued checkout and MWD pipe verification testing
12 Nov 80		1025	18.42	Sonic flowmeter and level sensor checkout
	1327			
13 Nov 80		0941	20.23	Evaporator drained, checked pump/motor coupling, power switchover
	1841			
14 Nov 80		1420	19.65	24 V to SCR off
	1433			
15 Nov 80		1404	23.52	Evaporator drained, SCR checked
18 Nov 80	1356			SCR repaired
19 Nov 80		1200	22.07	Ship lost power
	1237			
21 Nov 80		1405	49.46	Ship lost power
	1410			
25 Nov 80		1848	100.63	Evaporator drained, Chloropac pump reworked
12 Dec 80	1431			Chloropac pump repaired
13 Dec 80		0617	15.77	Planned shutdown
	0810	1105	2.92	Evaporator drained, RTD and instrumented loop reworked
21 Dec 80	0919			
22 Dec 80		0845	23.43	Supply line for pump water seal replaced
	0902			

TABLE 5-1

WARM WATER PUMP (P-101) OPERATIONAL LOG
(Sheet 2 of 2)

Date	Pump Operation Start Time (hours)	Pump Operation Stop Time (hours)	Duration (h)	Remarks
24 Dec 80		0805	47.04	Level sensor hookup
	0920			
25 Dec 80		0808	22.80	Ship lost power
	0900			
03 Jan 81		0420	211.33	Ship lost power
	0440			
14 Jan 81		0603	265.38	Hookup of air conditioning ducts to SCRs
	0740			
19 Jan 81		1500	127.33	Inadvertent pump trip during terminal board work
	1505			
02 Feb 81		1320	334.25	Repaired level sensor and motor fan; inspected C1
	1610			
10 Feb 81		1144	187.57	Pump dropout, cause unknown
	1150			
01 Mar 81		1307	456.95	Ship lost power
	1325			
		1336	0.18	Ship lost power
	1410			
05 Mar 81		0946	91.60	Evaporator drained, ship on marine power
06 Mar 81	2229			Back on moor, ship off marine power
02 Apr 81		1520	639.33	Evaporator drained, inspected ammonia nozzles
10 Apr 81	0930			MWD plume tests
12 Apr 81		1628	54.97	Evaporator drained, system shut down and drained
Total			2535.69 (3.75 months)	

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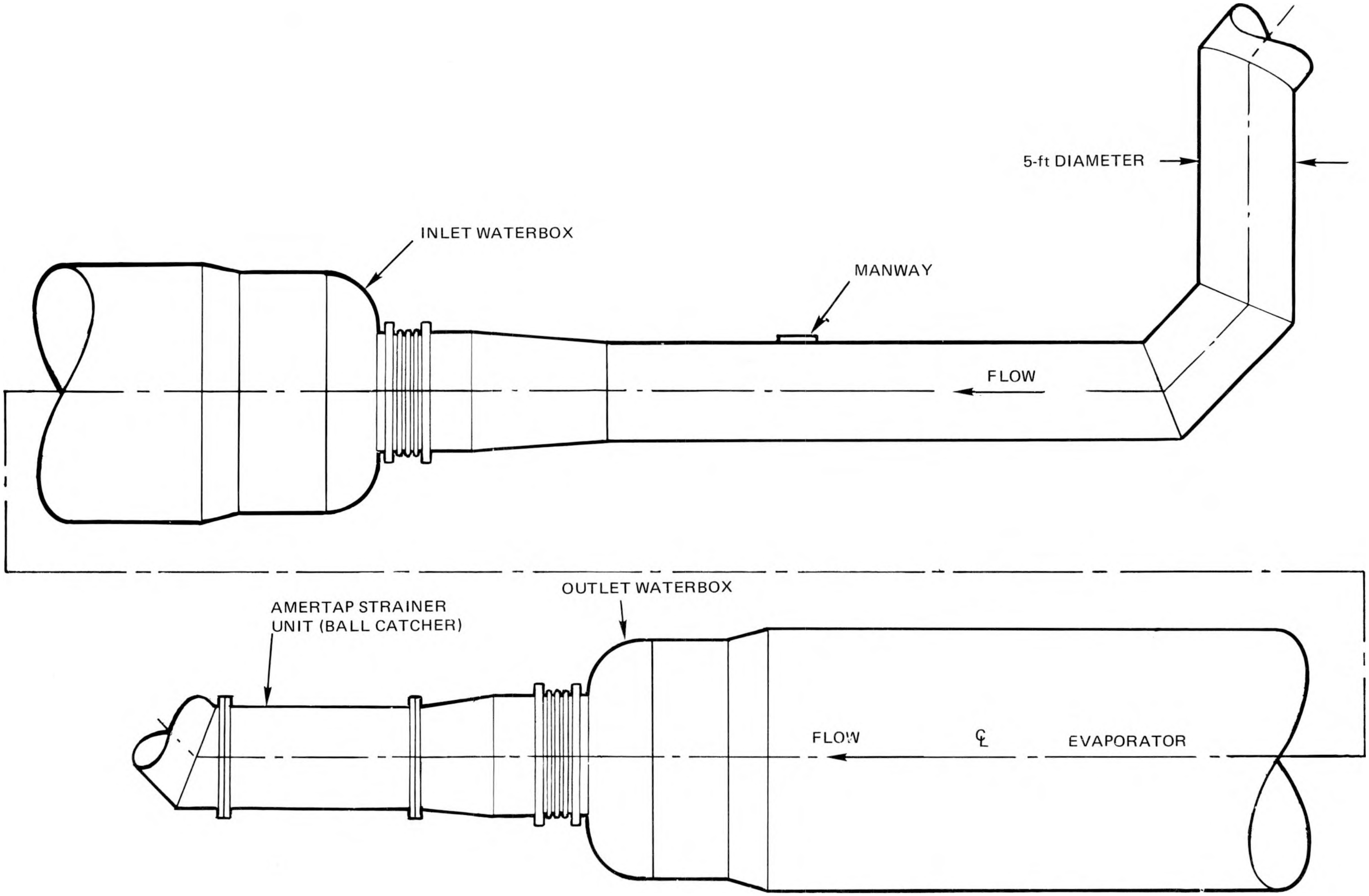

Figure 5-1. Schematic of Inspected Warm Seawater Loop

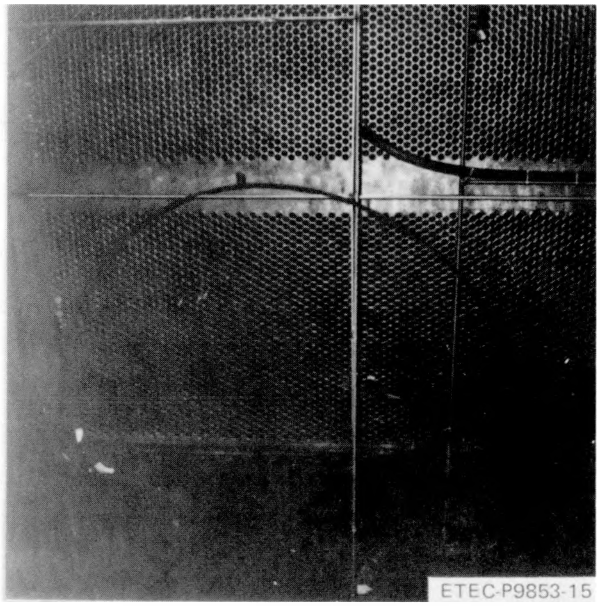

Figure 5-2. Inlet Waterbox with Loose Amertap Net Ring

Other loose items were found in the bottom of the waterbox: (1) three triggerfish, each about a foot long; (2) two small crabs; (3) several pieces of a plastic lid; (4) a piece of 1/4-in. steel plate with approximate dimensions of 3 in. by 1 in.; and (5) about six Amertap balls.

Figure 5-3 shows the bottom of the inlet waterbox in the as-found condition. The three triggerfish (decayed) and the pieces of plastic are visible. Figure 5-4 is a closer view of the bottom with the steel plate next to an RTD. Also, two of the Amertap balls and the two crabs (beyond the fish) are visible.

The fish and the plastic lid had been pumped into the waterbox by the warm water pump. To eliminate air entrainment in the warm water, the sump level had been raised by imposing a vacuum on the sump. Raising its level about 10 ft eliminated most of the ingested bubbles, but allowed some of the incoming water to flow over the inlet screens, bringing fish and other items with it to be pumped into the evaporator.

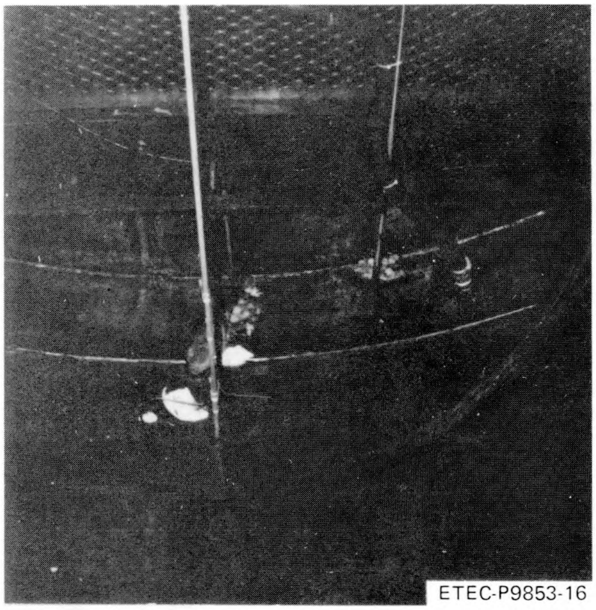

Figure 5-3. Bottom of Inlet Waterbox in the As-Found Condition

Figure 5-4. Closeup of Bottom Inlet Waterbox

The steel plate had also been pumped into the waterbox by the warm water pump. Weld modifications had been made by GMDI in the warm seawater sump when the ship first arrived on site. A piece of the cut plate from the floor had apparently fallen into the sump, from where it had been picked up by the pump and deposited in the inlet waterbox.

An ammonia leak was discovered at the plugged No. 13 (from the bottom) tube of the lower titanium tube bundle on the port (or inboard) side. The leak was obvious: calcium carbonate crystals were caked at the weld joint. This titanium tube had been plugged by TRW during 17-19 October 1980 as part of the general repair following the discovery of a leak during acceptance testing (see Section II.G). Figure 5-5 shows the tube with some of the remaining calcium carbonate crystals. About half of the crystals had previously been removed for analysis. The results of the chemical analysis are given in Table 5-2 under sample 2. The majority of the precipitate was calcium carbonate ($CaCO_3$). Note that the tubesheet and tubes were clean and in excellent condition with only a small amount of rust stain on the tubesheet face.

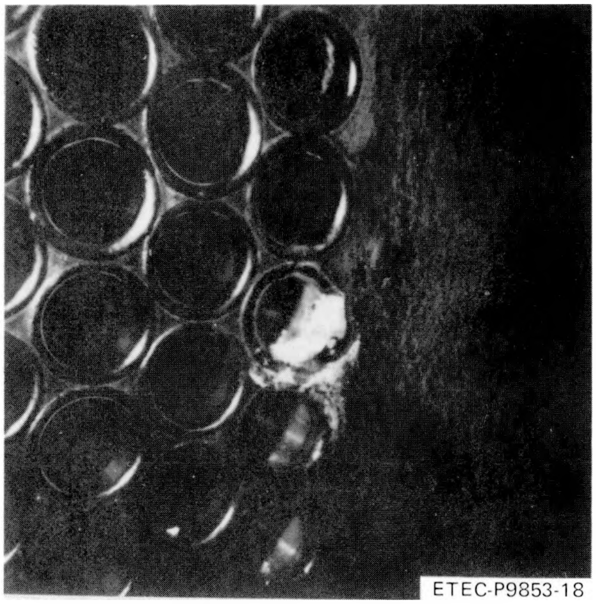

Figure 5-5. Closeup of Leaky Plug Weld on Tube 13

One instrumented loop hose, shown in Figure 5-6, was loose from the upper tube bundle. The hose connector piece is visible just to the right of the dirty instrumented tube screen. The failure of this hose connection is attributed to an inadequate hose connector design combined with turbulence in the inlet waterbox. Figure 5-7 shows the inlet starboard bottom tubesheet with some of its plugged tubes. Figures 5-2 and 5-7 together show that the tubesheet and titanium tubes are clean and in excellent condition. Only small amounts of rust were on these components and on the RTD support brackets.

The 1/2-in.-diameter inlet static pressure taps were also inspected, and rust buildup was found inside the two side taps (at 3:00 and 9:00 o'clock). Figure 5-8 shows the 9:00 o'clock static pressure tap with rust buildup blocking most of the passage. The bottom tap (6:00 o'clock) had an Amertap ball and the top tap (12:00 o'clock), which was usually void of water, was fairly clean. Coating the inside of these pressure taps would require both care and verification to assure that rust would not form at this location. Also, adding a screen would eliminate Amertap ball entrapment at the bottom tap.

TABLE 5-2

ETEC CHEMICAL ANALYSIS REPORT

Energy Technology Engineering Center

CHEMICAL ANALYSIS
REPORT

REQUEST NO. 4986

ORIGINATOR	DEPT.-GRP.	APPROVAL SIG.	DATE OF REPORT
Hoshide, Bob	720/205	R.C. Shepard	10/20/81

CHEMICAL ANALYSIS

Analysis	Method	Investigator	Analysis	Method	Investigator
	EDXRA/XRD	M Klenck			
		M Maeda			

RESULTS OF ANALYSIS

Originator's Sample Number	Analytical Laboratory Number				
#1					
#2					

Energy dispersive x-ray analysis of sample #1 showed major Fe, minor Al, trace Si, P, S, Ca, Cr, Mn & Cu.
X-ray diffraction of sample #1 showed two identifiable crystalline phases - Fe_3O_4, magnetite & γ-Fe_2O_3, maghemite and one or more unidentifiable phase or phases.
Microscopic examination of sample #1 revealed large amounts of what appears to be welding slag.

Energy dispersive x-ray analysis of sample #2 showed major Ca, minor Mg & Sr and trace Na, Al, S, Cl & Fe.

OTHER MEASUREMENT OR PREPARATION

X-ray diffraction of sample #2 showed the presence of one crystalline phase - $CaCO_3$, aragonite.

REMARKS

XRF/XRD file #4986, B Hoshide 10/20/81

EDXRA detection range: Z=11 (Na) to Z=94 (Pu)

SAMPLE #1 - CONTAMINATION FROM NH_3 MIDPLANE NOZZLES

SAMPLE #2 - PRECIPITATE FOUND ON TUBE #13 (FROM BOTTOM) PORT SIDE, INLET EVAP. WATERBOX

FORM 735-A-34 REV 9-78

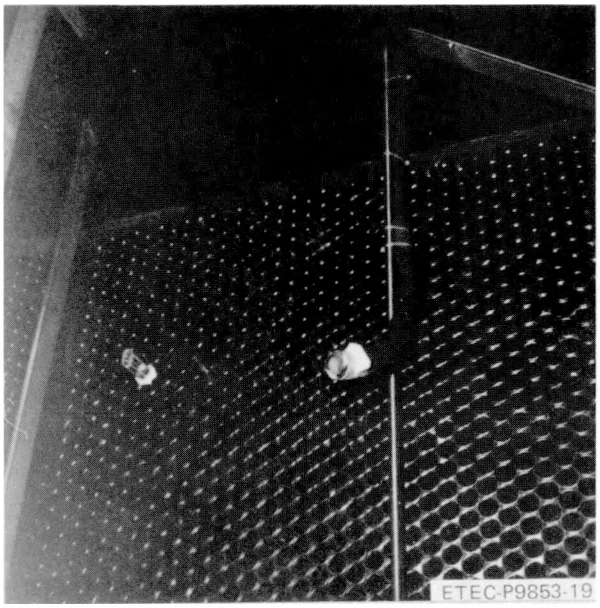

Figure 5-6. Loose Inlet Instrumented Tube Hose

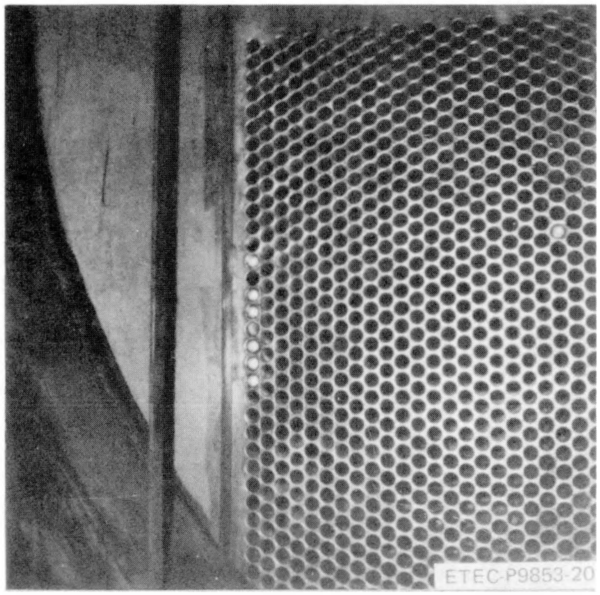

Figure 5-7. Inlet Bottom Tubesheet, Starboard Side

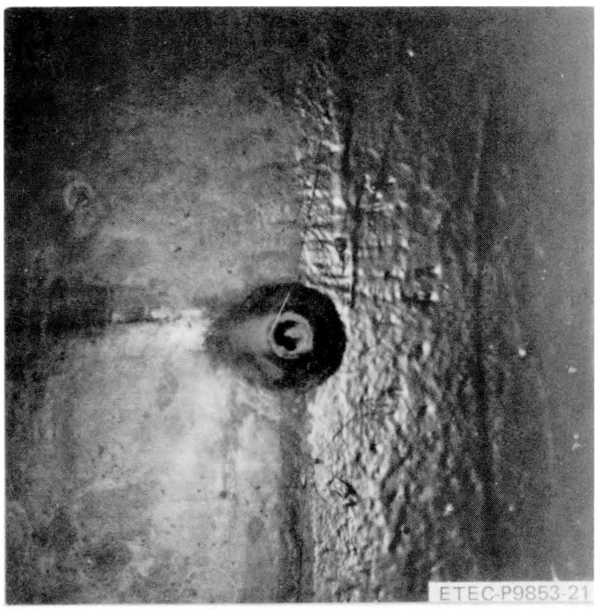

Figure 5-8. Inlet Waterbox Static Pressure Tap

b. Outlet Waterbox

Inside the outlet waterbox, a huge piece of neoprene coating was found hanging from the top of the waterbox (see Figure 5-9). This piece had been one of the layers applied during the fabrication of the evaporator. Fortunately, this piece had remained attached to the waterbox wall during the experiment. Had it not pulled loose and blocked the Amertap ball removal screen, it is possible that it might have caused the screen to collapse.

Figure 5-9. Outlet Waterbox with Loose Neoprene Coating

Two instrumented hoses had come loose from their connector pieces (see Figures 5-10 and 5-11). Note that the titanium tubes were clean and in excellent condition. The RTD and brackets had collected rust scale (see Figures 5-12 and 5-13), with more rust observed at the outlet than at the inlet. The heavier rusting at the outlet is attributed to the stagnation zone of the outlet. The turbulence at the inlet probably kept the support brackets relatively clean.

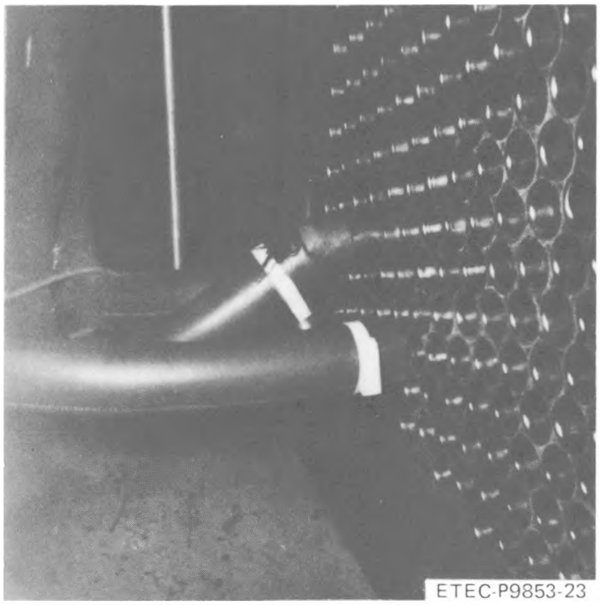

Figure 5-10. Loose Outlet Top Instrumented Tube Hose

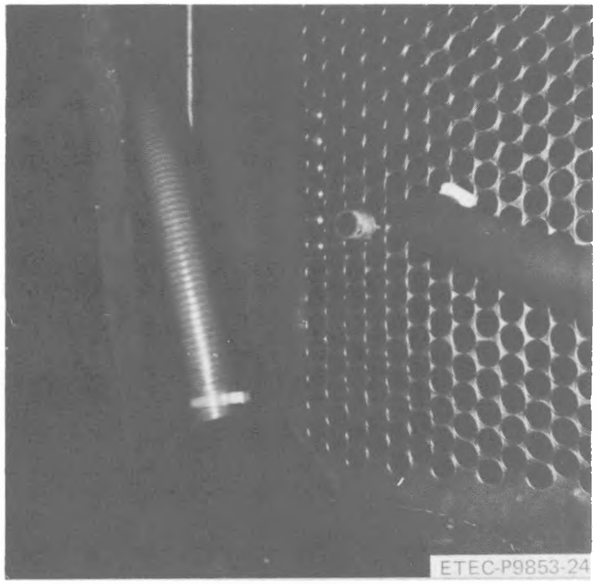

Figure 5-11. Loose Outlet Bottom Instrumented Tube Hose

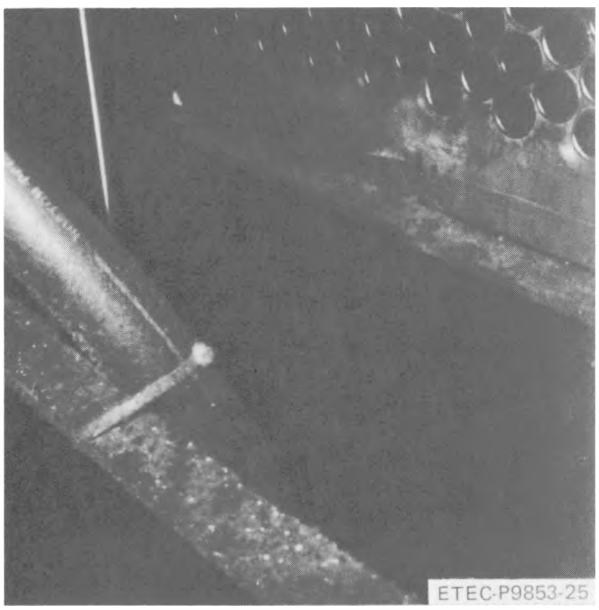

Figure 5-12. Marine Growth on Bottom of Outlet Waterbox, Portside

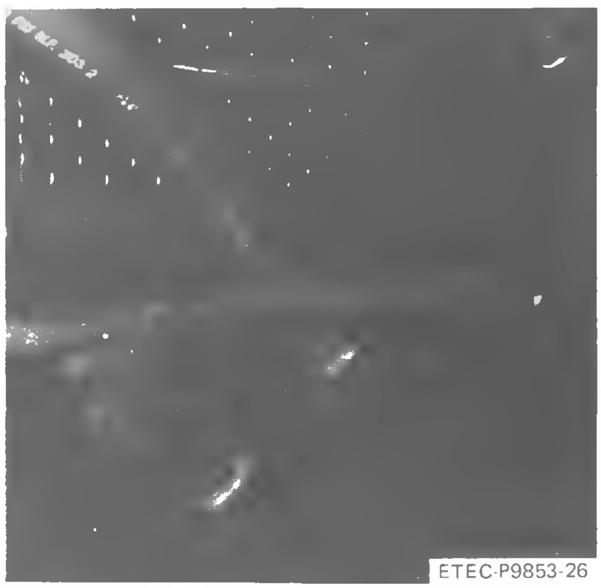

Figure 5-13. Support Bracket at Bottom Outlet Waterbox, Starboard Side

Rust was also found in the outlet pressure taps. Figure 5-14 shows the 3:00 o'clock static pressure tap. The same precautions as described previously for the inlet waterbox should be followed in future designs to prevent the fouling of these types of pressure taps. Keeping these taps clean may require periodic cleaning.

Figure 5-14. Outlet Waterbox Static Pressure Tap

Some marine growth was observed on the bottom of the tubesheet (Figure 5-12). Also, a few very tiny seashells and bivalves were found on the lower portions of the waterbox, and a few small empty crab casings and empty gooseneck clamshells were found on the bottom of the waterbox. It is interesting that these marine growths and sea life grew in a completely dark environment. On 16 April 1981, E. A. Kay from the University of Hawaii obtained marine samples. Her findings are given in Appendix P.

c. <u>Warm Seawater Ducting and Amertap Screen</u>

The inlet ducting was inspected upstream from the waterbox to the first vertical elbow (see Figure 5-1). The internal epoxy coating was in very good condition with some rust stains located mainly on the bottom half of the duct. There was heavy oxidation at the two ultrasonic flowmeter windows, where rust scale and stain had penetrated the epoxy coating. The portside and starboard side flowmeter windows are shown in Figures 5-15 and 5-16, respectively. Note that rust scale had begun to block the holes of both sensors.

Figure 5-15. Ultrasonic Flowmeter Window, Portside

Figure 5-16. Ultrasonic Flowmeter Window, Starboard Side

The heavy rust buildup appeared to be mainly due to the poor application of the epoxy coating. These ports had apparently been installed after the original coating was applied to the inside of the ducting. Welding was required in fabricating the windows. This may have caused the original coating to blister and peel. Upon completion of the windows, these areas would have required touchup. It is obvious from Figures 5-15 and 5-16 that the application technique was different from that used for applying the surrounding coating.

The outlet duct between the Amertap ball removal screen and the outlet waterbox (see Figure 5-1) was also inspected; two areas of rust buildup were found. They were located at the interfaces of the outlet duct with the waterbox and with the Amertap unit. At these interfaces (Figures 5-17 and 5-18),

Figure 5-17. Edge of Outlet Duct at Waterbox Interface

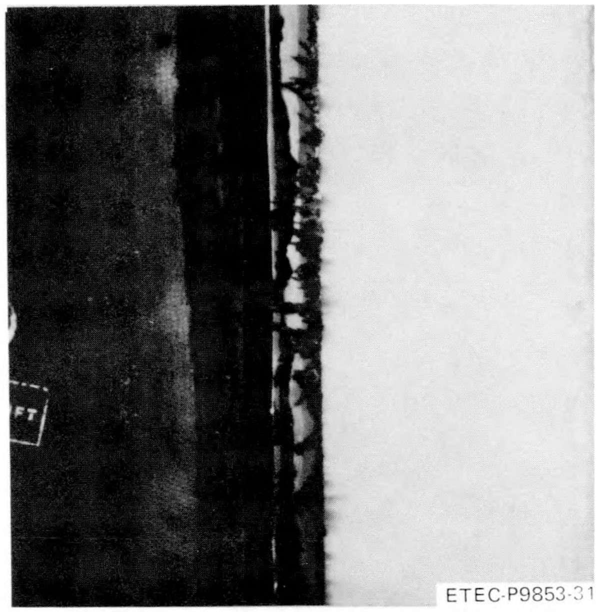

Figure 5-18. Edge of Outlet Duct at Amertap Interface

long rust scale had developed. Again it appears that the protective epoxy coating had not been properly applied. Rust was also found at the interface of the inlet duct and inlet waterbox (Figure 5-19).

Figure 5-19. Edge of Inlet Duct and Waterbox Interface

The Amertap ball collection screens (Figure 5-20) were inspected and found to be very clean and in excellent condition. Only nine undersized Amertap balls and four pieces of fish bone were found wedged in the screen. The screen was normally put in the backwash position (Figure 5-21) after ball collection. This mode flushed most caught objects except the ones that were firmly wedged in the screen.

Figure 5-20. Amertap Ball Collection Screen — Catch Mode

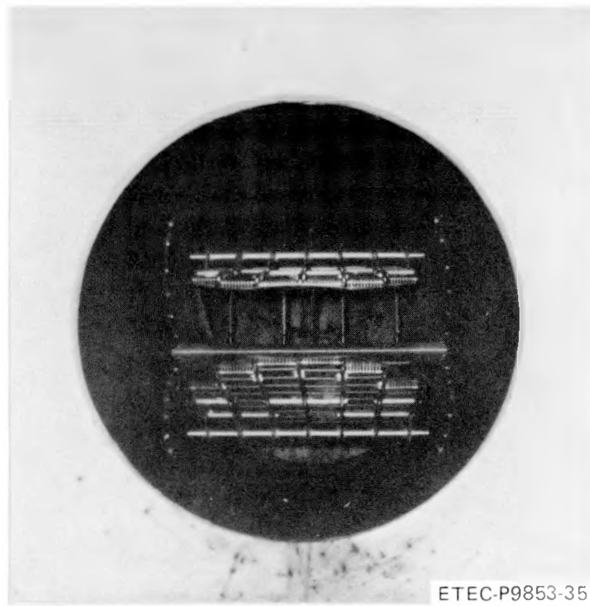

Figure 5-21. Amertap Ball Collection Screen — Backwash Mode

d. <u>Warm Seawater Sump Inlet Screen</u>

The final inspection of the warm seawater loop was a review of the warm seawater sump inlet screens. These screens were raised from their deployed positions to their cleaning positions for inspection. On the whole, the stainless steel screens were clean. Some fuzzy growth (see Appendix P) was observed on the upstream side of the screen. Figures 5-22 and 5-23 show the upstream and downstream sides, respectively, of one of the two sets of inspected screens. Note that the steel frames that held the screens were heavily rusted. A few barnacles and gooseneck clams were found on the downstream side of the screens (Figure 5-23).

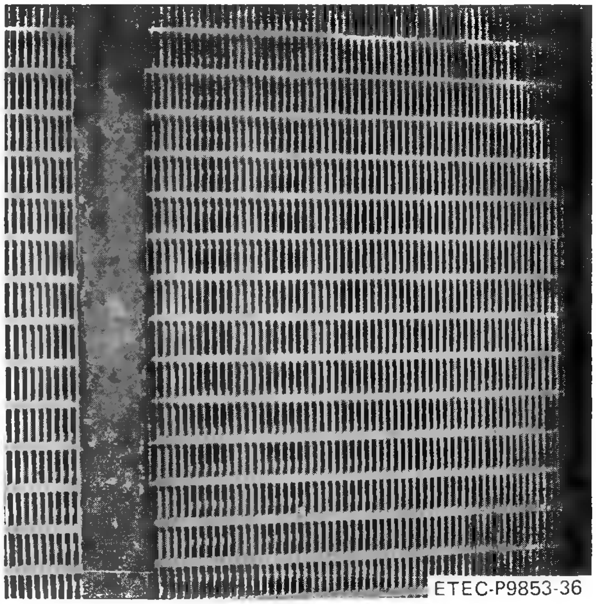

Figure 5-22. Warm Seawater Sump Inlet Screen — Upstream Side

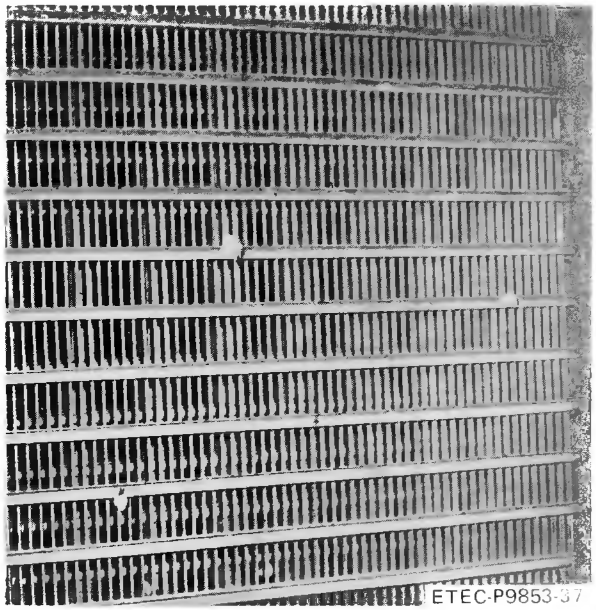

Figure 5-23. Warm Seawater Sump Inlet Screen — Downstream Side

2. Recommendations

Results of the inspections led to the recommendations presented following the condenser water box and cold water system discussion (see Section V.B.2).

B. CONDENSER WATERBOX AND COLD WATER SYSTEM

As with the evaporator, after about 5 months of seawater operation, the cold seawater loop and the seawater side of the condenser were generally very clean and in excellent condition. The critical inside surfaces of the titanium tubes were also found to be clean and in excellent condition. Some plugging of the tubes (27) at the inlet waterbox with CWP weld flash was observed. Only small amounts of rust were observed within the loop.

1. Detailed Inspection Results

The OTEC-1 condenser cold seawater pump began operation on 12 November 1980 and was shut down on 12 April 1981. A chronology of the cold seawater system in Hawaii is given in Table 4-4. On 15 April 1981, the inlet and outlet waterboxes and the cold seawater ducting were inspected. Seawater side condenser posttest inspection results are reported in four sections: (1) inlet waterbox, (2) outlet waterbox, (3) cold seawater ducting and Amertap screen, and (4) cold seawater sump inlet screens.

a. Inlet Waterbox

Inspection of the inlet waterbox (see Figure 5-24) first revealed that 27 titanium tubes were plugged with CWP polyethylene weld flash pieces that had broken loose from the inside of the pipes. Once these weld flash pieces had lodged in the tube entrances, additional plugging occurred when Amertap balls wedged into the remaining space. Figures 5-25 and 5-26 show some of the plugging by the weld flash pieces and Amertap balls. Figure 5-25 shows the portside, while Figure 5-26 shows the starboard side of the inlet tubesheet. The inlet sump screen permitted these weld flash pieces to enter the condenser. Note that the unit appears almost like new.

The only area that showed rust buildup was in the inside of the static pressure taps similar to those in the evaporator (see Section V.A). Figure 5-27 shows the 3:00 o'clock static pressure tap. Erroneous static pressure data are attributed to the fouling of these taps.

b. Outlet Waterbox

The outlet waterbox was also found to be very clean and in excellent condition. Figures 5-28 and 5-29 show the starboard side and portside of the outlet tubesheet, respectively. The tubesheet, tubes, and waterbox walls were very clean with no marine growth observed. The only signs of contamination found in this area were a few red deep-sea shrimp wedged in some of the crevices. Also, rust formation was found in the outlet pressure taps. Figure 5-30 shows the 9:00 o'clock static pressure tap.

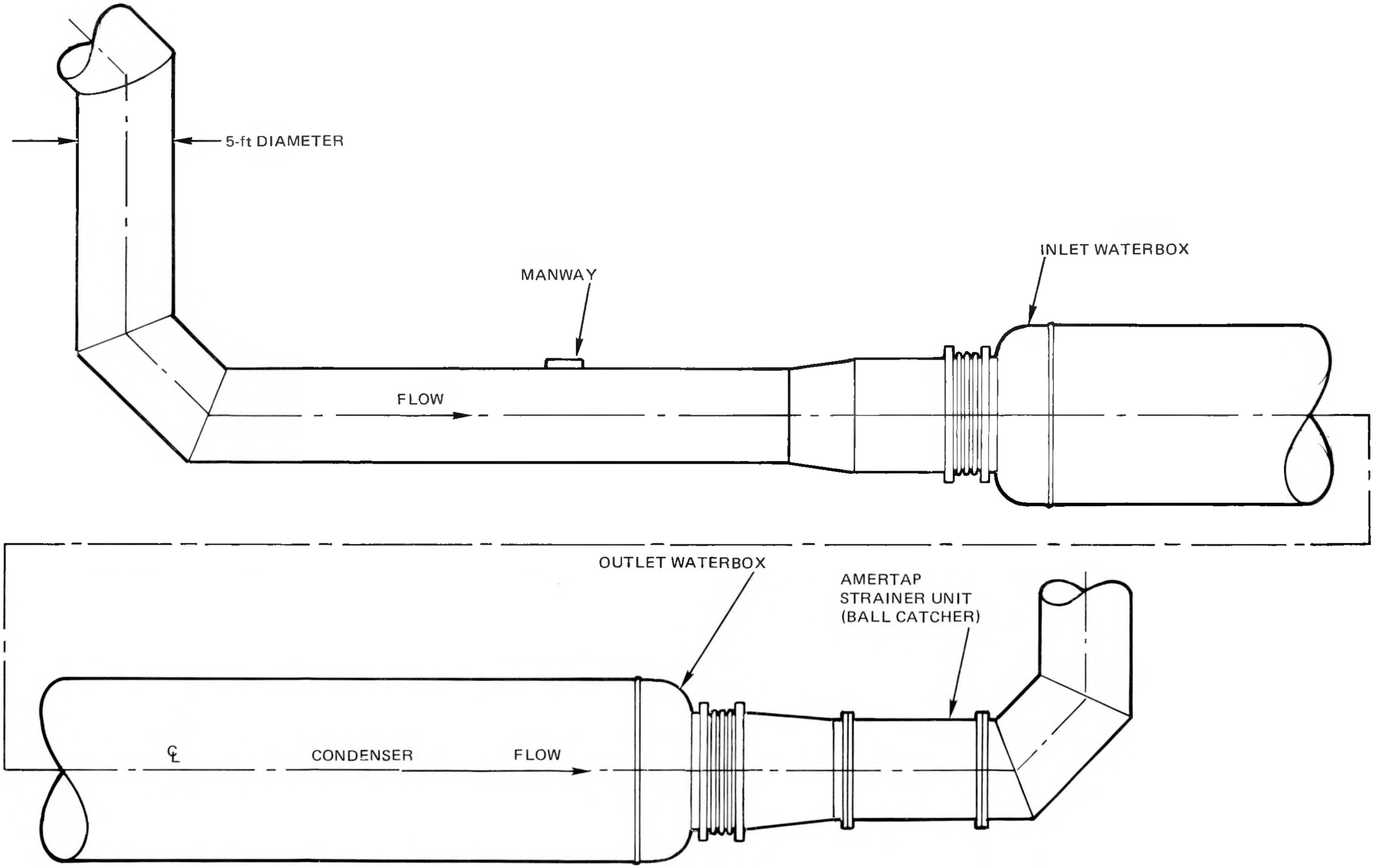

Figure 5-24. Schematic of Inspected Cold Seawater Loop

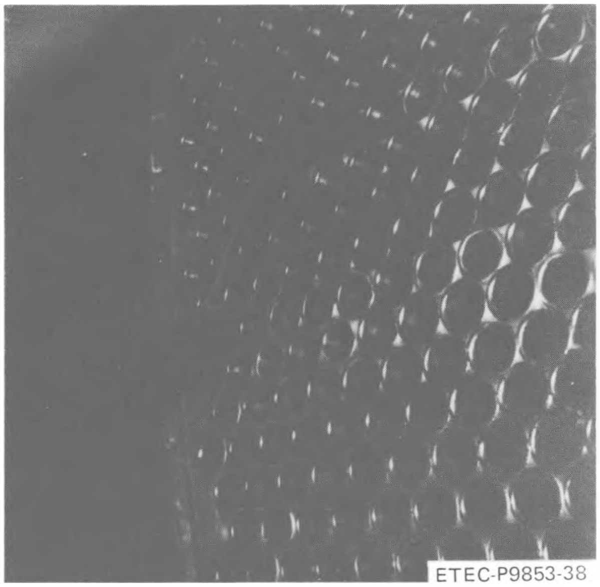

Figure 5-25. Plugging of the Inlet Tubesheet, Portside

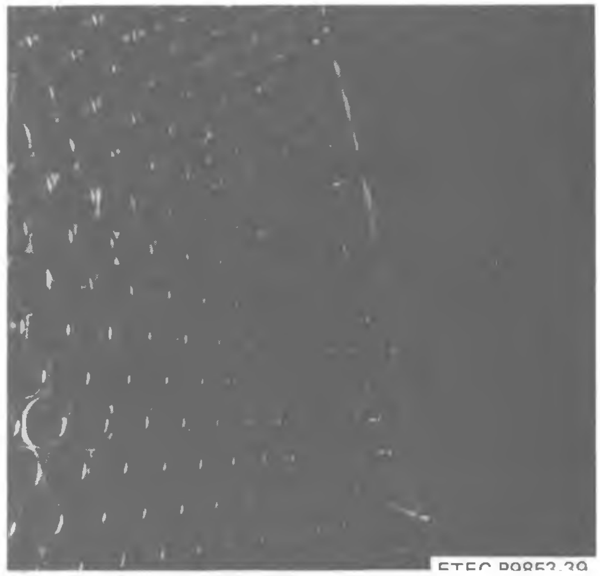

Figure 5-26. Plugging of the Inlet Tubesheet, Starboard Side

Figure 5-27. Inlet Waterbox Static Pressure Tap

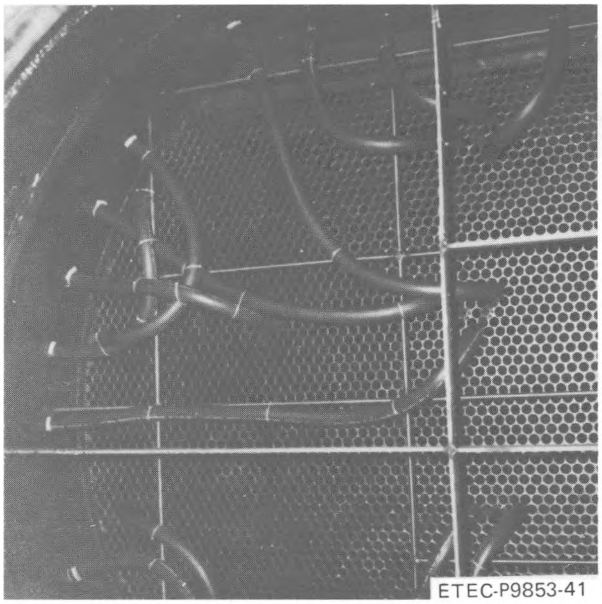

Figure 5-28. Outlet Tubesheet, Starboard Side

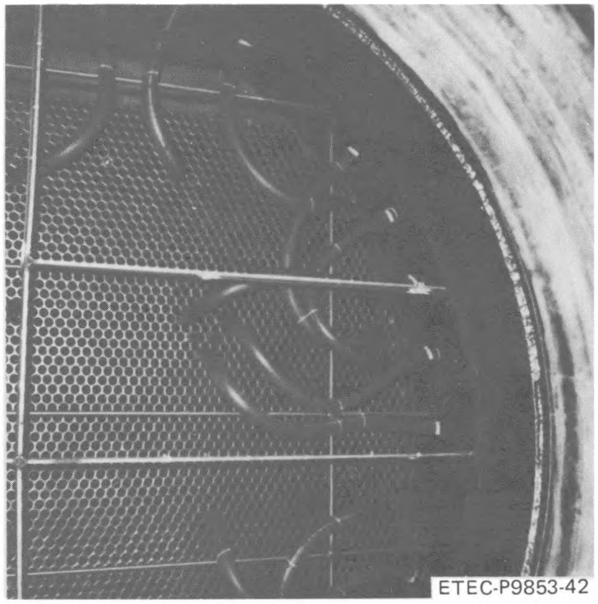

Figure 5-29. Outlet Tubesheet, Portside

Figure 5-30. Outlet Waterbox Static Pressure Tap

On 16 April 1981, E. A. Kay of the University of Hawaii obtained marine samples from the waterboxes. Her results are given in Appendix P.

c. Cold Seawater Ducting and Amertap Screen

The inlet ducting was inspected upstream from the waterbox to the first vertical elbow (see Figure 5-24). The internal epoxy coating was in very good condition with small rust stains located mainly on the bottom half of the duct. Localized blistering of the coating was found at one area. The two ultrasonic flowmeter windows showed very light rust stains, and rust stain had penetrated the epoxy coating. The portside and starboard side flowmeter windows are shown in Figures 5-31 and 5-32, respectively. This rust buildup probably had the same cause as had the rust buildup found in the evaporator duct — the poor touch-up application of the epoxy coating (discussed in Section V.A).

On both interfaces of the outlet duct between the waterbox and the Amertap unit there were only very light rust stains (Figures 5-33 and 5-34, respectively). The Amertap screens were clean and in excellent condition.

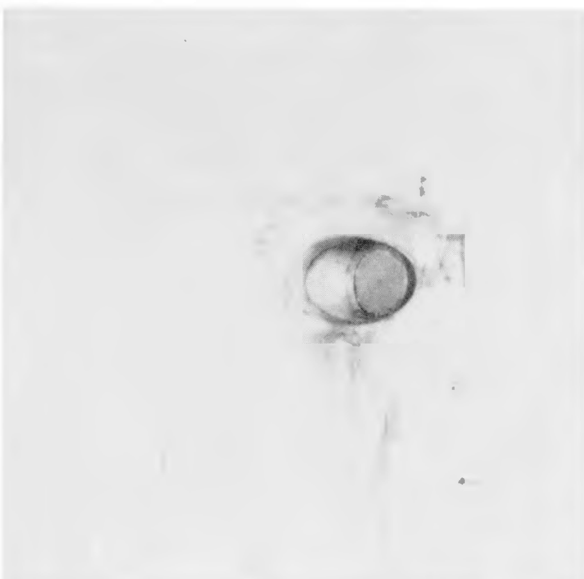
ETEC-P9853-44

Figure 5-31. Ultrasonic Flowmeter Window, Portside


ETEC-P9853-45

Figure 5-32. Ultrasonic Flowmeter Window, Starboard Side

Figure 5-33. Outlet Duct and Waterbox Interface

Figure 5-34. Outlet Duct and Amertap Interface

d. <u>Cold Seawater Sump Inlet Screen</u>

The two inlet screens were removed from their deployed position and placed in their storage rack on the main deck. These stainless steel screens were clean except for a few pieces of CWP weld flash, some red shrimp, and a few wire ties. Figure 5-35 shows the upstream side of the screen with part of its collection. Note that the CWP weld flashes were thin enough to pass through the screen slots (3/8 in. x 3 in.); some ended up on the inlet tubesheet of the condenser. The carbon steel frames that held the screens were lightly rusted, as seen in Figure 5-35.

2. <u>Recommendations</u>

Results of the inspections led to the following recommendations for future OTEC plants:

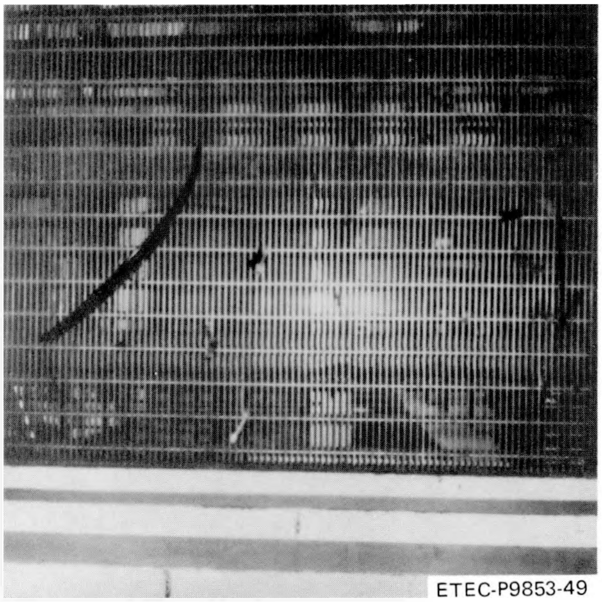

Figure 5-35. Plugging of the Inlet Screen, Upstream Side

1) Special attention must be paid to system cleanliness. All loose items within the water loop, even at the bottom of the water sump, must be removed to prevent these items from being pumped through the water systems.
2) Items that may come loose during operation must be removed or made secure to prevent them from being pumped into the waterbox.
3) Leak detection and inspection procedures are required to determine if any ammonia leaks exist where ammonia is in communication with the seawater system.
4) The chlorination injection system (if used) should be designed so that chlorine is admitted upstream from the water inlet screens.
5) Conduct shakedown tests of the water systems by operating the pumps at their maximum capacity and with the Amertap screen (if used) in the backwash configuration. This procedure will verify the integrity of the coating and of components (screens, support structure, instrumentation, etc.).
6) Carbon steel parts exposed to seawater must be coated using proper coating material and application procedures. These coatings must then be verified to assure that the coated parts

(ducts, ports waterboxes, inlet screen frame, pressure ports, flowmeter windows, support frames, transition pieces, interfaces, etc.) will withstand seawater exposure.

7) If instrumented tubes or any internal hoses are used, provide proper connector design with step groove and sufficient length to prevent hose detachment.

8) Provide screen for bottom pressure tap or drains to prevent blockage.

C. EVAPORATOR AMMONIA SIDE

Inspection of the ammonia side of the evaporator revealed that pump seal lubrication oil had contaminated the bottom of the shell and both the plain and the enhanced tube bundles. Rust stains on the enhanced tubes had changed the color of the tubes to brown from their original white. Of the 37 midplane nozzles inspected, 18 were found to be partially or fully plugged with weld slag and rust scale. The detailed results of this inspection are discussed below.

1. Detailed Inspection Results

OTEC-mode tests began on 31 December 1980 and were completed on 18 March 1981. The ammonia system operations log covering this period is given in Table 4-6. The ammonia side of the evaporator was inspected on 2 April 1981. Only the starboard tubes of this heat exchanger were examined. The portside tubes had had their shrouds installed (4-MWe configuration) and therefore were not inspected. Ammonia side heat exchanger posttest inspection results are reported in four sections: inner shell, plain tubes, enhanced tubes, and midplane nozzles.

a. Inner Shell

The inner shell walls had a thin film of iron oxide. The most obvious contamination was at the bottom of the shell, where oil from the ammonia pumps had accumulated (see Section IV.C). Figure 5-36 shows the bottom of the shell looking aft, and Figure 5-37 is a view looking forward from the starboard manway.

b. Plain Tubes

The surfaces of the plain tubes were fairly clean. About one-third of the surfaces examined were lightly coated with lubricating oil from the ammonia pumps. A small amount of powder that appeared to be rust was on the top part of the tubes examined (Figures 5-38 and 5-39).

c. Enhanced Tubes

The enhanced tube surfaces were very dirty, as shown in Figures 5-40 through 5-42. Figure 5-40 shows the enhanced tube bundle looking aft. The dark spots are oil-coated areas. Figure 5-41 is a view taken closer to the manway, while Figure 5-42 shows the forward end of the enhanced tubes. Note the dark oil spots and also the combined oil- and rust-coated surfaces in Figure 5-42.

On 8 August 1980, a seawater leak into the ammonia side was discovered while the warm water pump was being run. The system was rinsed out with fresh water and air-blown dried. The leaky tube was plugged before seawater was again pumped through the evaporator.

For comparison with Figures 5-40 through 5-42, Figure 5-43, taken on 16 October 1980, shows the enhanced tube bundle as it looked before OTEC-mode operation. Figure 5-43 also shows a bent shroud support frame and the repair of welding a second straight frame adjacent to the bent one. The corrosion products on the enhanced surfaces were analyzed by ETEC and determined to be predominately aluminum hydroxide ($Al(OH)_3$), or bayerite.[11,21]

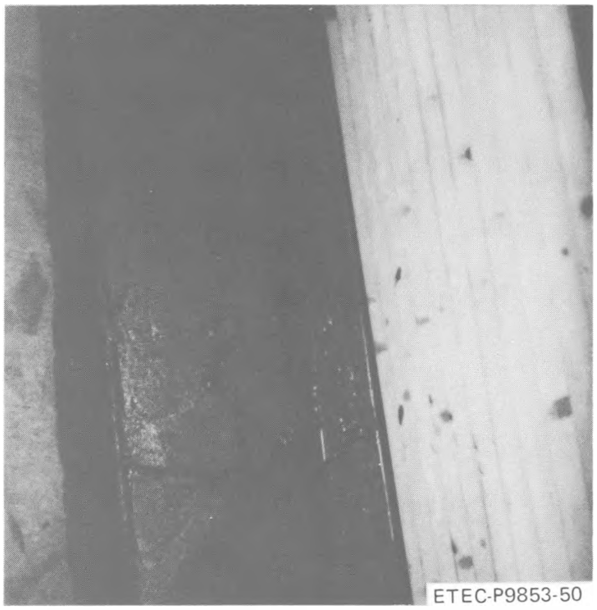

Figure 5-36. Evaporator Shell Bottom Looking Aft, Starboard Side

Figure 5-37. Evaporator Shell Bottom Looking Forward, Starboard Side

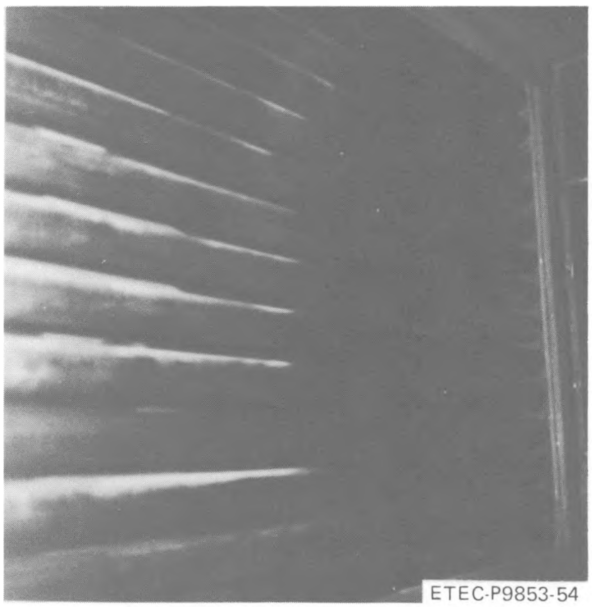

Figure 5-38. Closeup of Evaporator Plain Tube

Figure 5-39. Evaporator Plain Tubes, Bottom Row

Figure 5-40. Evaporator Enhanced Tubes Looking Aft, Starboard Side

Figure 5-41. Evaporator Enhanced Tubes Looking Forward, Starboard Side

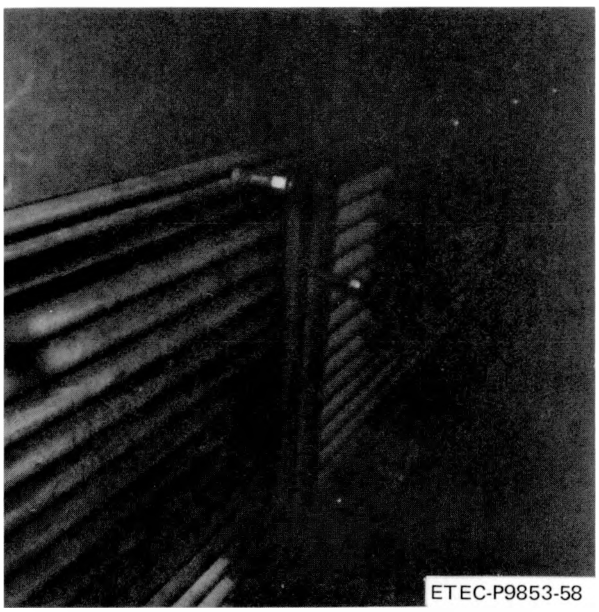

Figure 5-42. Another View of Evaporator Enhanced Tubes Looking Forward, Starboard Side

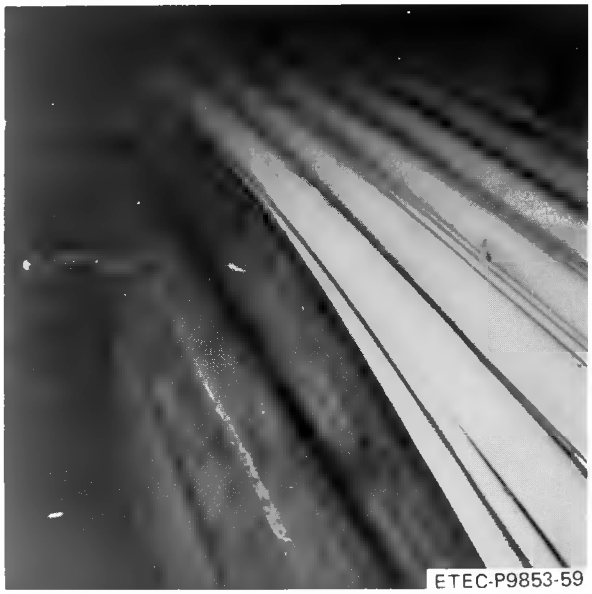

Figure 5-43. Evaporator Enhanced Tubes before OTEC-Mode Operation

d. <u>Midplane Nozzles</u>

From 1 April through 6 April 1981, 37 midplane nozzles were removed and inspected. An ANL representative selected the nozzles to be inspected. The results are as follows:

19 clean
14 one-half plugged
4 completely plugged
37 total inspected

The nozzle design was such that two flow paths 180° from each other permitted liquid ammonia to be sprayed on the enhanced tubes. The 14 nozzles that were one-half plugged had one of the two flow passages blocked with weld slag and rust scale. Nozzles completely plugged had both passages blocked. Note that almost half of the nozzles inspected were either half or fully plugged. Figures 5-44 and 5-45 show the locations of the nozzles removed and the inspection results. Figure 5-44 shows the forward bank of nozzles, and

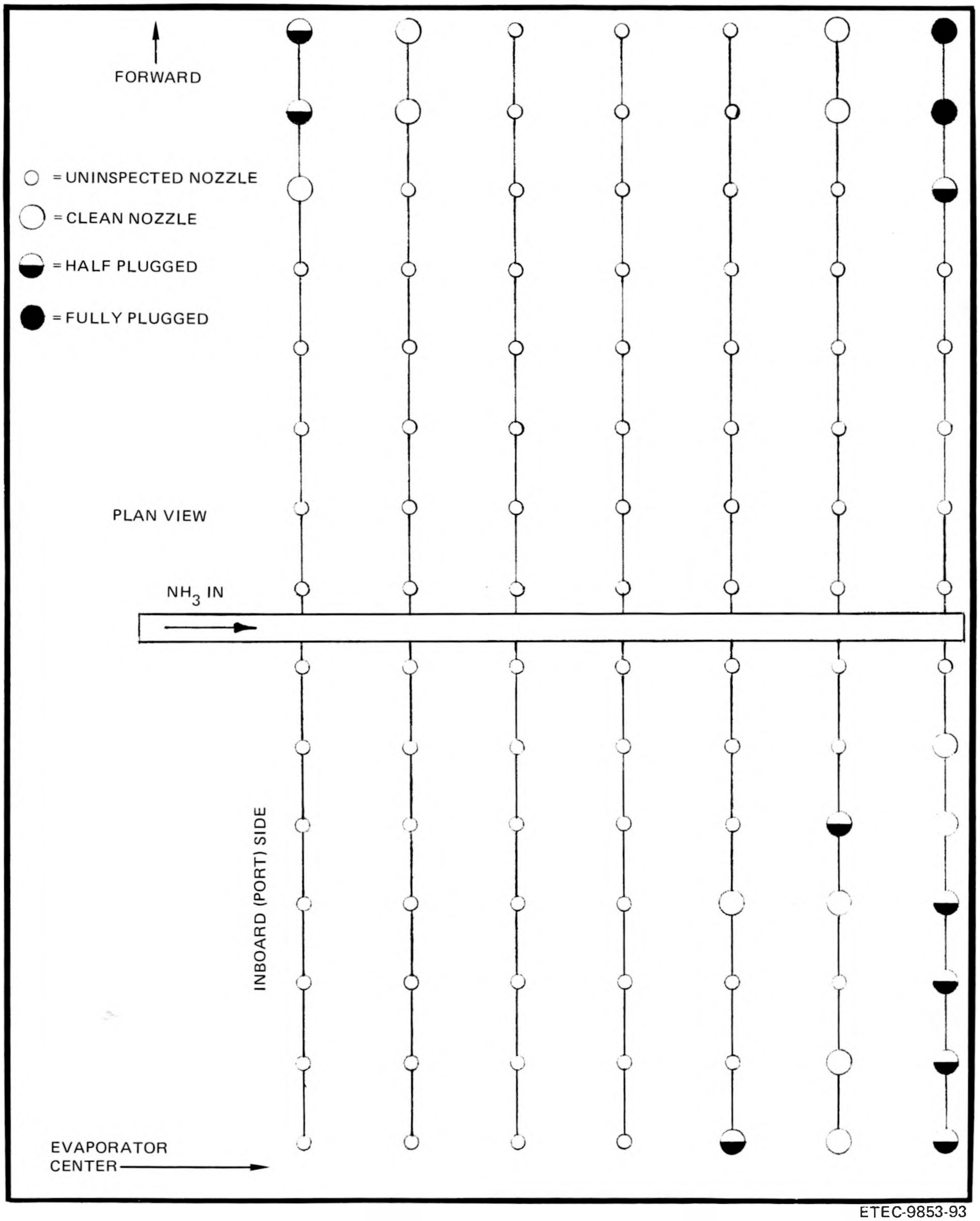

Figure 5-44. Inspected Evaporator Midplane Nozzles and Findings, Forward Section

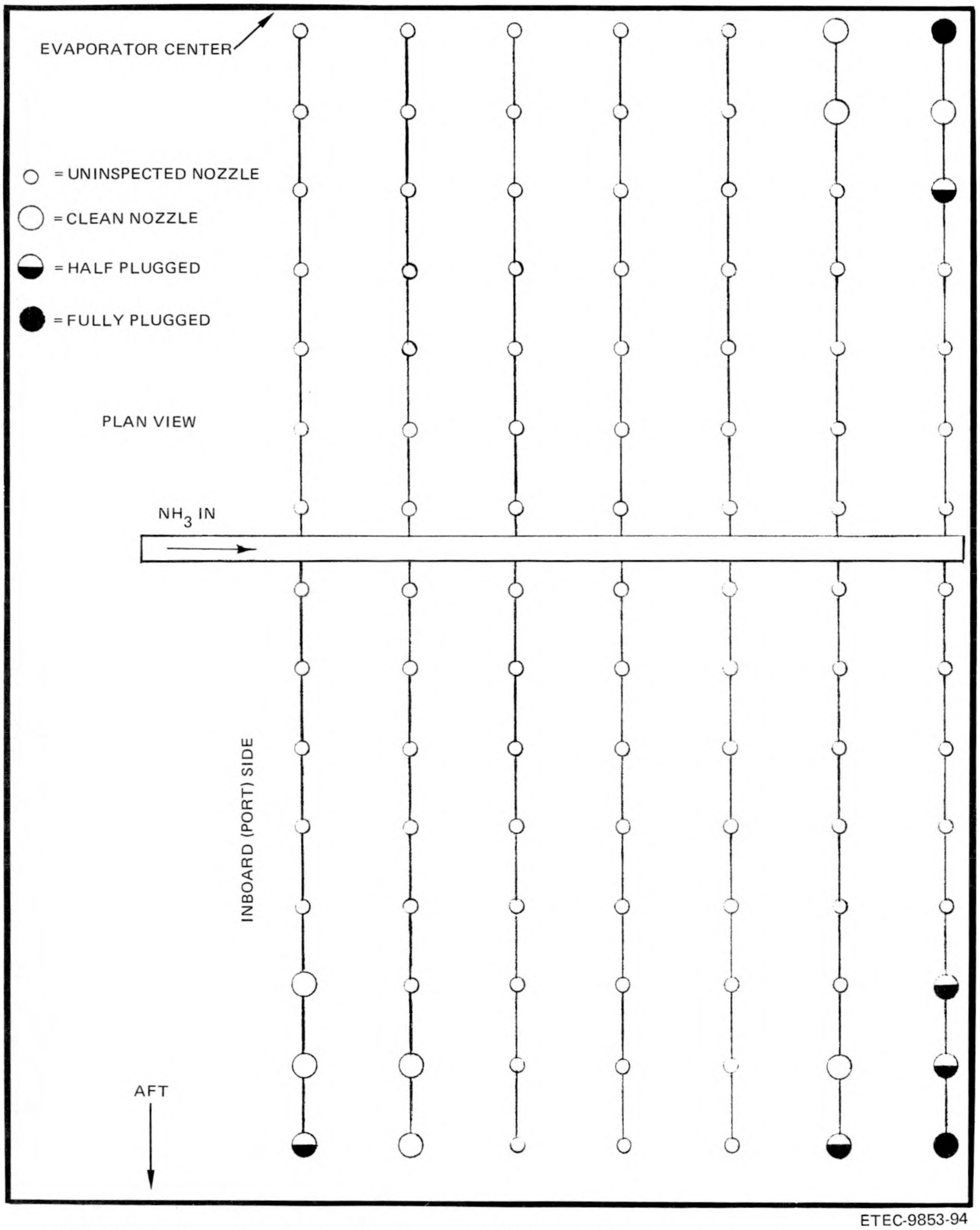

Figure 5-45. Inspected Evaporator Midplane Nozzles and Findings, Aft Section

Figure 5-45 shows the aft bank. Figure 5-46 shows some of the half and fully plugged nozzles. The results from analyzing the contamination are given in Table 5-2 (Section V.A) under sample 1. The majority of the contamination consisted of magnetite and weld slag. The F-1 filter was cleaned during initial OTEC-mode and shakedown tests (Section IV.C). Contamination from the ammonia loop was removed from the F-1 filter and also from the strainer. Figure 5-47 shows some of this contamination, which consisted mostly of rust scale. About 5 lb was removed from the filter.

e. Tube Specimens

Several sections of enhanced tubes were removed (on two separate occasions) from the evaporator and sent to ANL for physical, metallurgical, and thermodynamic testing. Interim results of these tests are discussed in Reference 30.

2. Recommendations

It is important to consider the effect of contamination of the ammonia power loop because of performance and damage. Also, because of the sensitivity to contamination of the enhanced tubes, this type of tube perhaps should not be used for future OTEC plants unless special precautions are taken to prevent fouling of the ammonia loop and/or in-place cleaning or restoration is developed. Since the evaporator is a distillery, contamination will end up in the evaporator and probably on the tube surfaces. Listed below are recommendations regarding contamination of ammonia systems in future OTEC plants.

1) Establish a cleanliness or contamination criterion and review procedures for inspection and implementation as part of a quality assurance program in force during all phases of construction and operations.
2) If modifications like welding of shroud frames are performed on the heat exchanger after it is installed, properly clean the system after the modification.

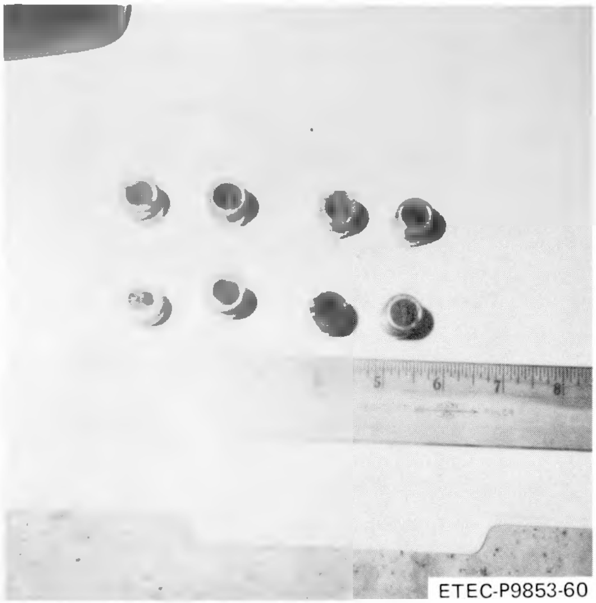

Figure 5-46. Half and Fully Plugged Midplane Nozzles

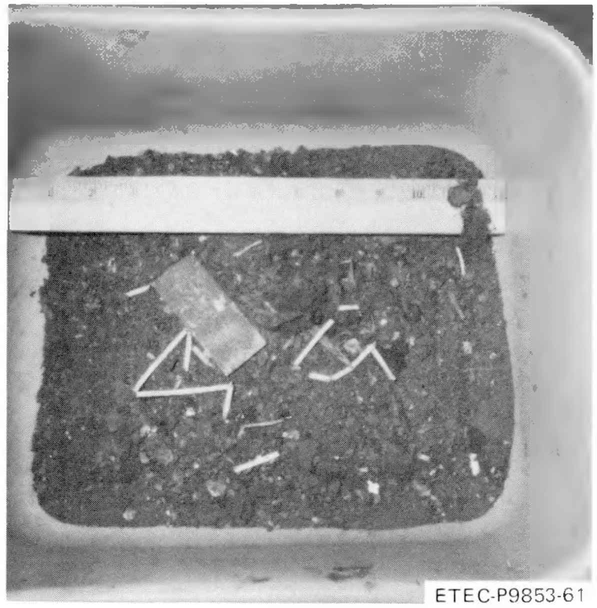

Figure 5-47. Contamination from Ammonia Loop

3) Before loading ammonia, clean the ammonia system using approved flushing and cleaning procedures that have been reviewed for their possible adverse effects on sensitive materials (e.g., did Linde approve water flushing of the enhanced surfaces?).
4) Use isolation valves that are leak proof if a vacuum is to be pulled on the ammonia power loop.
5) Pressure check the heat exchangers during periodic inspections to assure that no leaks exist between the ammonia and seawater sides.
6) When not operating in the OTEC mode, keep the ammonia system at a higher pressure than the seawater side to prevent or at least minimize seawater leakage into the power loop if a leak should occur.
7) Keep the ammonia side isolated from the surrounding atmosphere as much as possible.
8) Install removable filters at key points throughout the ammonia system to protect the equipment.

9) Install an ammonia purification system to keep the ammonia clean and to minimize moisture content.

D. GIMBAL ASSEMBLY

The CWP was attached to the gimbal assembly on 4 November 1980 and was released on 13 April 1981. The gimbal assembly was lifted to the transit position on 15 April 1981 for inspection. Overall, the gimbal was found to be in good condition. Irregular wear patterns were noted on the gimbal ball, especially the aft side.

The aft portside stop had been deformed by metal-to-metal contact. The stop was displaced to the aft direction, as would be expected from the impacts identified prior to the OEC release from the moor in response to excessive currents.

1. Detailed Inspection Results

At the completion of the test program, the CWP gimbal assembly was raised to the transit position, but repeated attempts to raise it to the maintenance position for long-term storage were unsuccessful. The problem was determined to be the torque converter of the 150-ton deck winch. With the gimbal assembly in the transit position, inspection was difficult. Posttest gimbal assembly inspection results are reported in four sections: (1) overall assembly, (2) sacrificial anodes, (3) gimbal ball, and (4) gimbal stops.

a. Overall Assembly

The assembly was in good condition with decayed and dried unidentified algae growth covering the surfaces exposed to the warm seawater. Hangers and supports for hydraulic piping and sensor wiring were firmly fastened with no signs of deterioration. Hydraulic fluid was present in the gimbal pin cylinder relief orifices, apparently the result of minor leaks.

b. Sacrificial Anodes

The four sacrificial anodes located on the upper surface of the gimbal ring showed considerable wastage (about 40%). They all were covered with 1/2 in. of caked powder (zinc oxide). The remaining anodes were not nearly as wasted and did not have the caked powder covering. Use of another material, such as aluminum, should be considered for future applications. Normally, when the gimbal assembly was in the transit position, the lower 9 to 12 in. with zinc anodes remained underwater, providing protection. Because of the reduced draft of the ship (12.1 ft forward, 17.0 ft aft) from the normal 24 ft, the entire assembly, including all hydraulic piping and electrical wiring, was out of water in the storage configuration.

c. Gimbal Ball

The gimbal ball and mating sleeve had apparently been irregularly machined. This was evidenced by the uneven wear marks on the surface of the ball. Some areas had been wiped bright by the sleeve, while on untouched areas there had appeared rust stain and algae growth (Figure 5-48). This figure shows the aftermost side of the ball, which was the area most affected. This is as would be expected from the almost-continuous aft gimbal pitch angle (GPITCH) while on site.

d. Gimbal Stops

Inspection of the two forward and two starboard gimbal stops indicated there had been no contact. The two aft stops, which had previously been inspected by divers and reported to have only "chipped paint," were found to have had definite metal-to-metal contact. Figures 5-49 and 5-50 show the starboard and port positions of the aft stops, respectively. These stop pads were 4 in. wide by 14 in. long by 1 in. thick. They were attached to the gimbal ring with a 1-in.-thick by 14-in.-wide web with a short cantilever; this made these stops very sturdy.

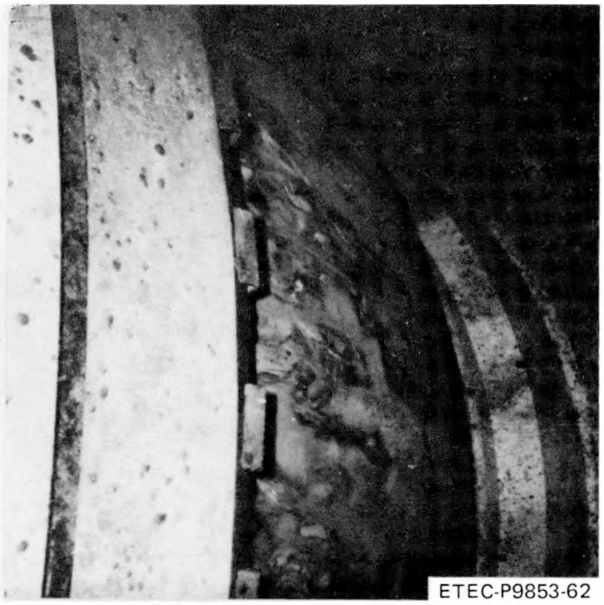

Figure 5-48. Gimbal Ball Showing Wear Marks

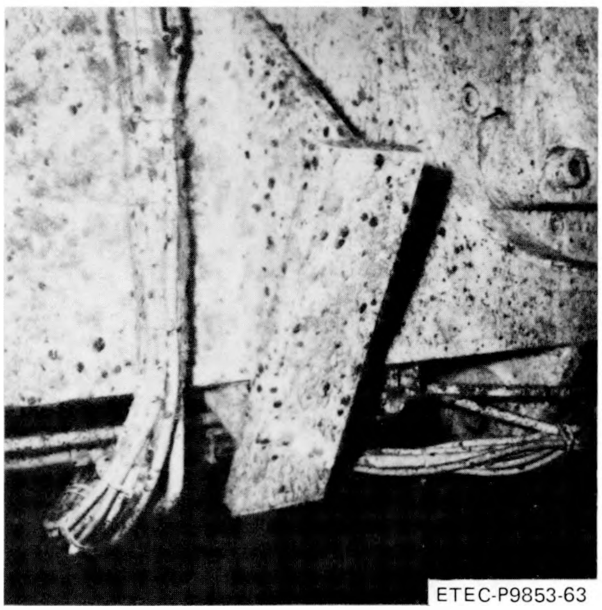

Figure 5-49. Aft Gimbal Stop, Starboard Position Showing Contact

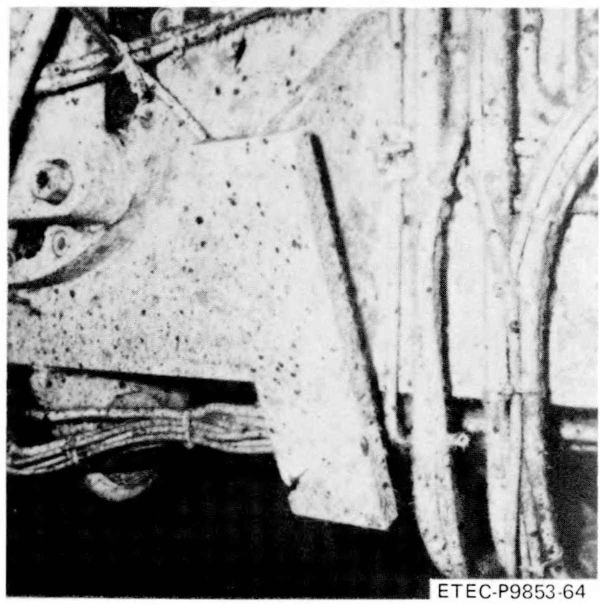

Figure 5-50. Aft Gimbal Stop, Port Position Showing Contact

Inspection of the port stops showed that the forwardmost stop had not been touched (Figure 5-51), but that the aftmost stop had been deformed (Figure 5-52). Figure 5-53 is a closeup of the aftmost stop pad, which was 6 in. wide by 7 in. long by 1/2 in. thick. Note that impact had occurred on the upper left area and metal-to-metal contact at the corner of the pad. This was the only area of contact with the gimbal ring for these port stops. The stop was displaced to the aft direction, as would be expected given the almost-continuous aft GPITCH angle of the assembly while on the site. Figures 5-54 and 5-55 show the before-and-after deformation of the aftmost stop and give approximate dimensions. These stop pads were attached to the gimbal assembly by a 3/8-in.-thick by 6-in.-wide web with a long cantilever (average of 14 in. long), which made these stops susceptible to deformation under side loading.

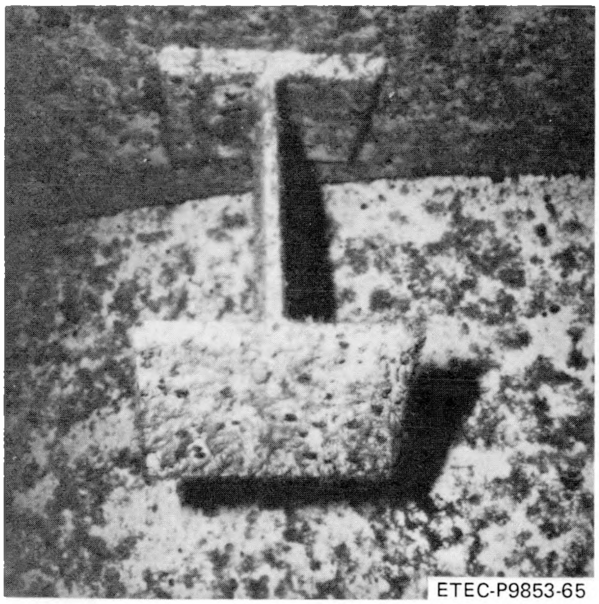

Figure 5-51. Port Gimbal Stop, Forward Position, No Contact

Figure 5-52. Port Gimbal Stop, Aft Position Showing Damage

No visible damage to the diaphragm was noted, but some deformation was probably present based on the misalignment of the diaphragm relative to the main deck observed during the initial attempts to raise the gimbal assembly.

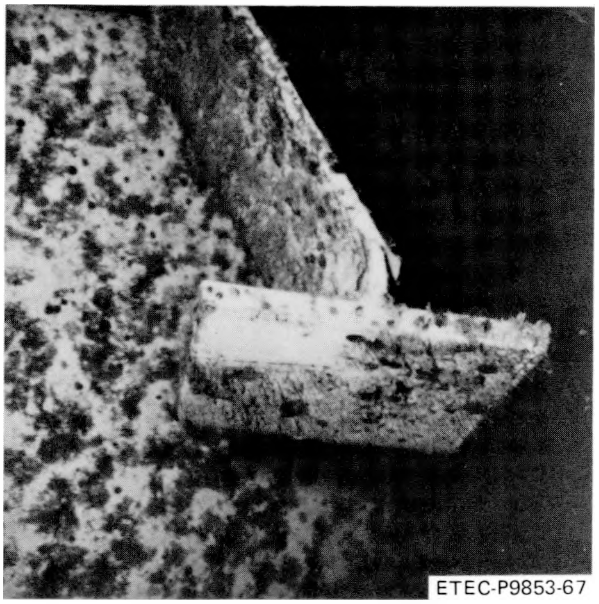

Figure 5-53. Port Gimbal Stop, Aft Position Closeup

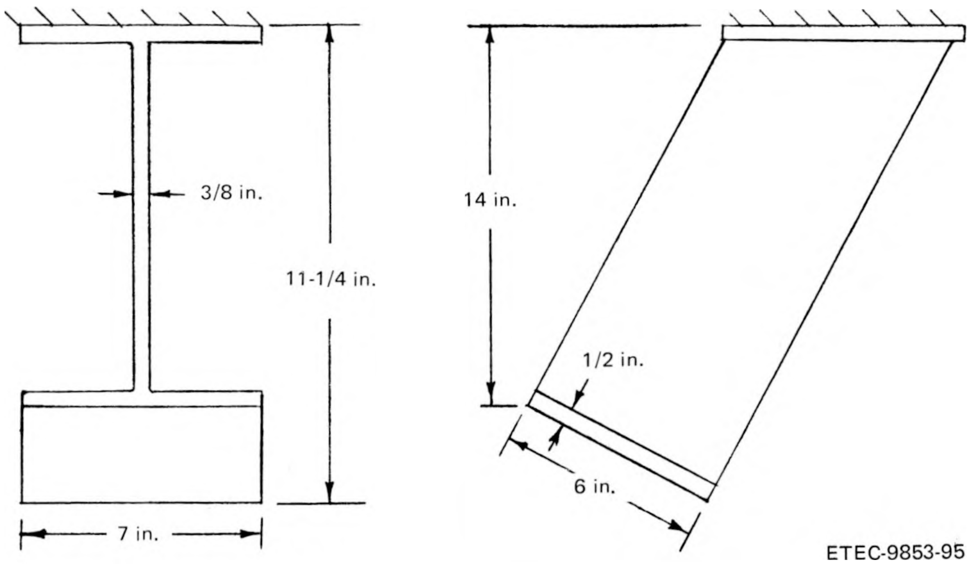

Figure 5-54. As-Built Port Gimbal Stop, Forward Position

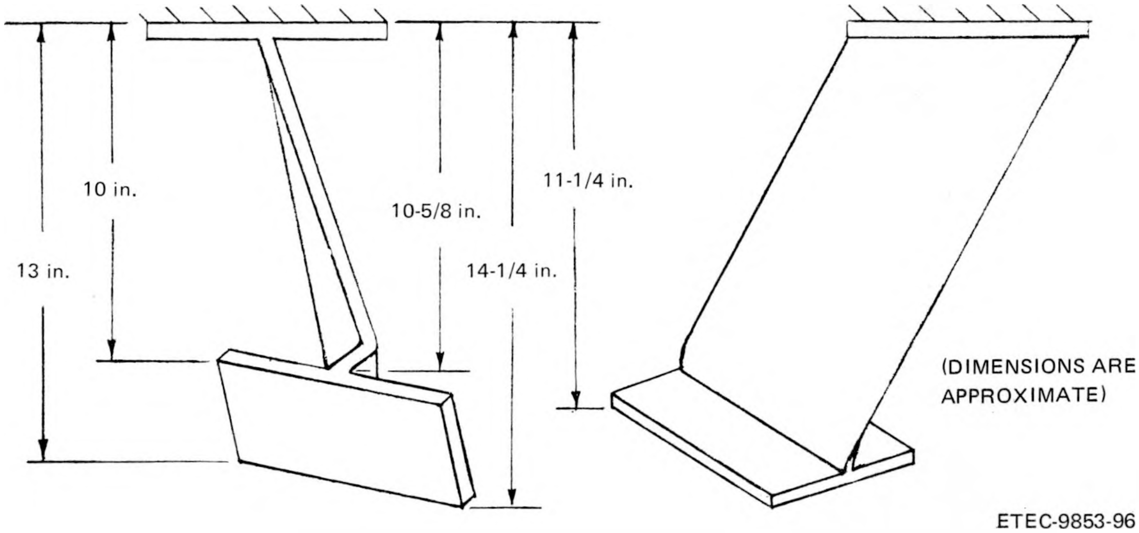

Figure 5-55. Deformed Port Gimbal Stop after Impact, Aftermost Position

2. Recommendations

The inspection results led to the following recommendations for future OTEC plants in which CWP gimbal assemblies are used:

1) Systems requiring the use of gimbal assemblies should use a design similar to the one used here. Overall, the OTEC-1 gimbal assembly performed as designed and was found to be in good condition after over 5 months of operation.
2) The substitution of aluminum anodes for zinc anodes should be considered.
3) The ball/sleeve mating should not have irregular contact surfaces. This would eliminate uneven ball wear and reduce warm seawater leakage into the cold seawater sump.
4) Gimbal stop mounts and adjacent contact surfaces should be designed to accept minor impacts.

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VI. COLD WATER PIPE (CWP) RECOVERY

A. SUMMARY

Since the OTEC-1 program was not to be reinstated, DOE decided to recover the CWP (which had been stored at depth for 18 months) and transfer it to the State of Hawaii for future use by the Natural Energy Laboratory of Hawaii (NELH) at Keahole Point on the Island of Hawaii. A combined effort of DOE, NOAA, and the U.S. Navy, supported by ETEC, resulted in the successful recovery of the CWP and its storage in Kawaihae Harbor on the Island of Hawaii.

Before final storage, the buoyancy collar was removed, as shown in Figure 6-1, to allow the remaining portion of the CWP to be floated and stored in the shallow water section of the harbor.

The CWP was transferred to the State of Hawaii on 9 October 1982, floating in the harbor, attached to buoy/anchors and out of the normal harbor traffic flow, as shown in Figure 6-2.

B. BACKGROUND

When the OTEC-1 first deployment test program was terminated, the CWP was rerigged from the OEC to the buoy/mooring system and dropped to the sea floor at the original test site. (See Section IV for details.) After it was determined by DOE that the OTEC-1 program would not be continued, DOE, in August 1981, gave NOAA the task, through an inter-agency agreement (IAA), to plan and direct the recovery of the CWP. Per agreement between DOE and the State of Hawaii, after recovery the CWP was to be transferred from DOE (ETEC) custody to the State of Hawaii in Kawaihae Harbor for eventual use at NEHL to increase the facility cold water capacity.

Meetings on the CWP recovery program were held in July and August 1982 to develop and finalize a plan-of-action that combined the resources of DOE,

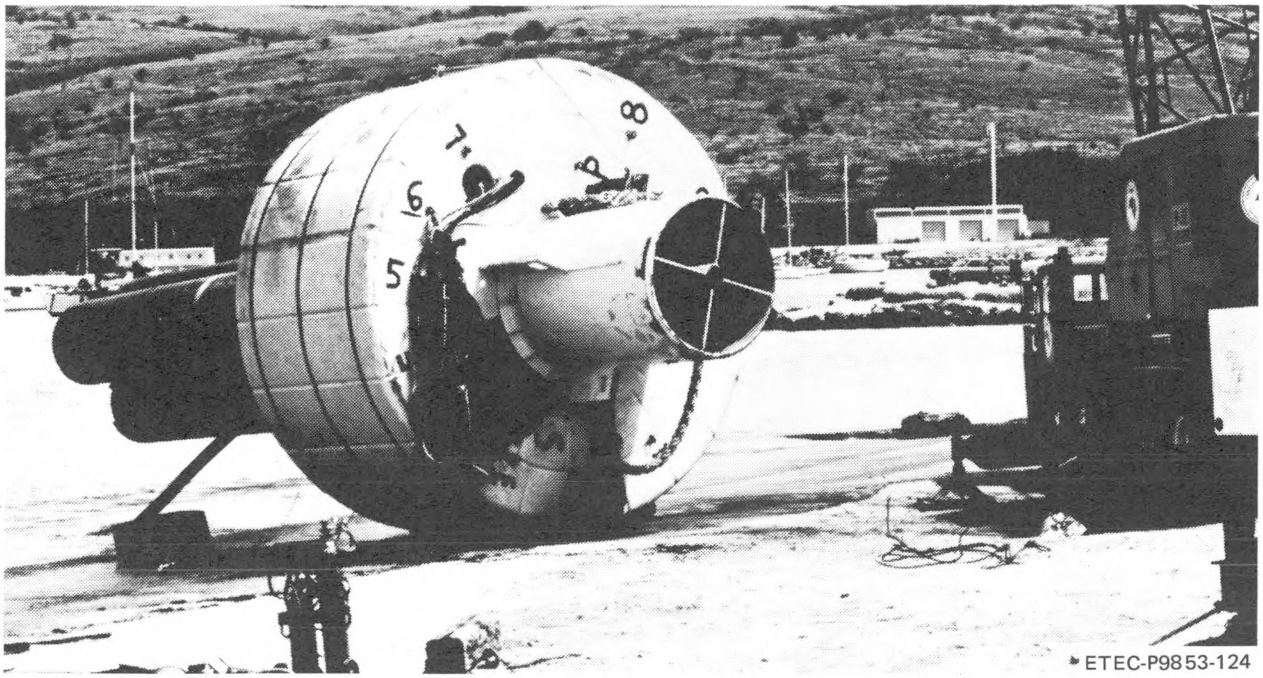


Figure 6-1. Buoyancy Collar, Separated from CWP

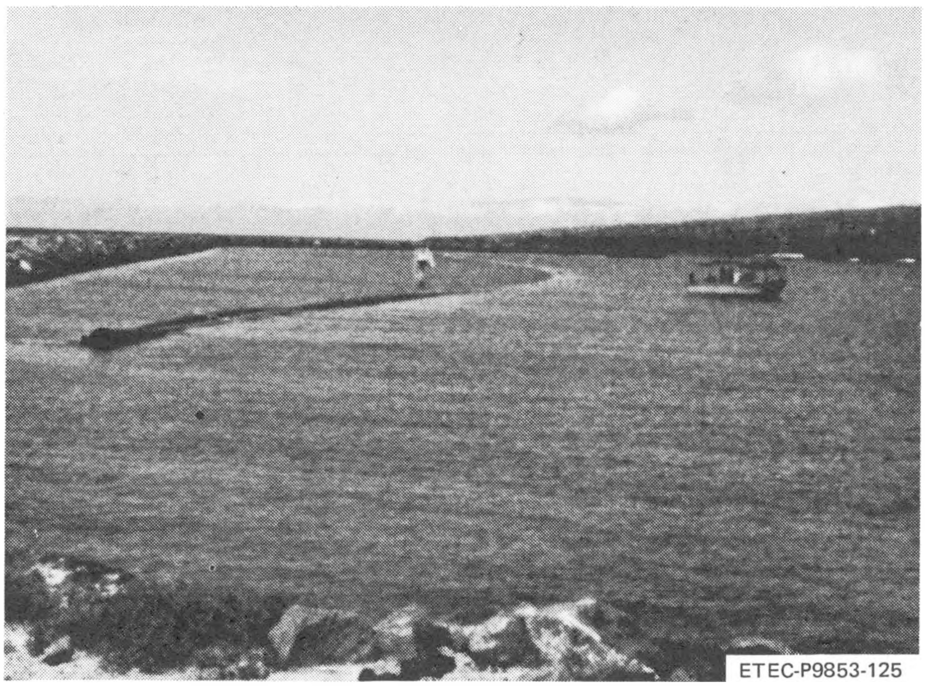


Figure 6-2. CWP in Kawaihae Harbor

NOAA, and both the submarine and salvage branches of the U.S. Navy. ETEC was requested by both DOE and NOAA to support the recovery effort based on previous OTEC-1 CWP experience and available procurement capabilities. Basically, the final plan consisted of 1) modifying a new Navy barge, by installing the large 150-ton capacity CWP handling winch and A-frame removed from the OEC, to allow it to lift the CWP once the bottom weight was removed as shown in Figure 6-3 (the use of the OEC as a "dead ship" barge was considered as an alternate during the planning stages but was rejected in favor of the modified Navy barge); 2) using the Navy's manned deep submergence vessel (DSV) Turtle to set cutting torches on the bottom weight chain and to place lift lines, if necessary (Figure 6-4 shows the DSV Turtle onboard its support vessel Energy Service I, and Figure 6-5 shows the Turtle deployed); 3) severing the bottom weight chain using a THERMOL cutting torch and acoustic system to be developed by Jet Research Center, Inc., (JRC); and 4) using the Navy salvage ship USS Conserver assisted by commercial tugs procured by ETEC to tow the CWP into Kawaihae Harbor once the CWP had been brought to the surface. The USS Conserver would also supply Navy personnel to man the barge.

The actual CWP recovery events were essentially as planned except that the torches were unsuccessful in completely cutting the bottom weight chain. Thus, it was necessary to cut the three bottom weight cables using a cable cutter attached to the DSV Turtle.

Some details of the CWP recovery operation are discussed below. However, a complete report of this program is being prepared by NOAA and will be released in the future.

C. RECOVERY OPERATIONS

Before the detailed CWP recovery plan was made final, numerous tasks were performed to determine such things as 1) the actual location and actual position of the CWP, 2) the near shore bottom terrain in case it became desirable to tow and ground the CWP in shallow water, 3) the ability of the THERMOL

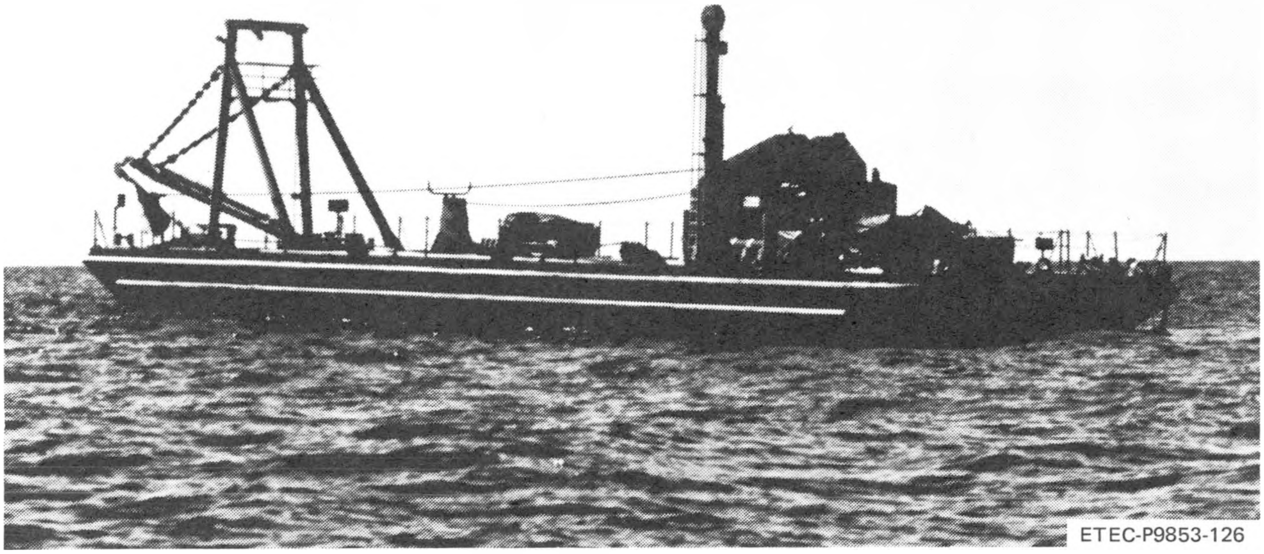


Figure 6-3. Navy Barge Lifting CWP

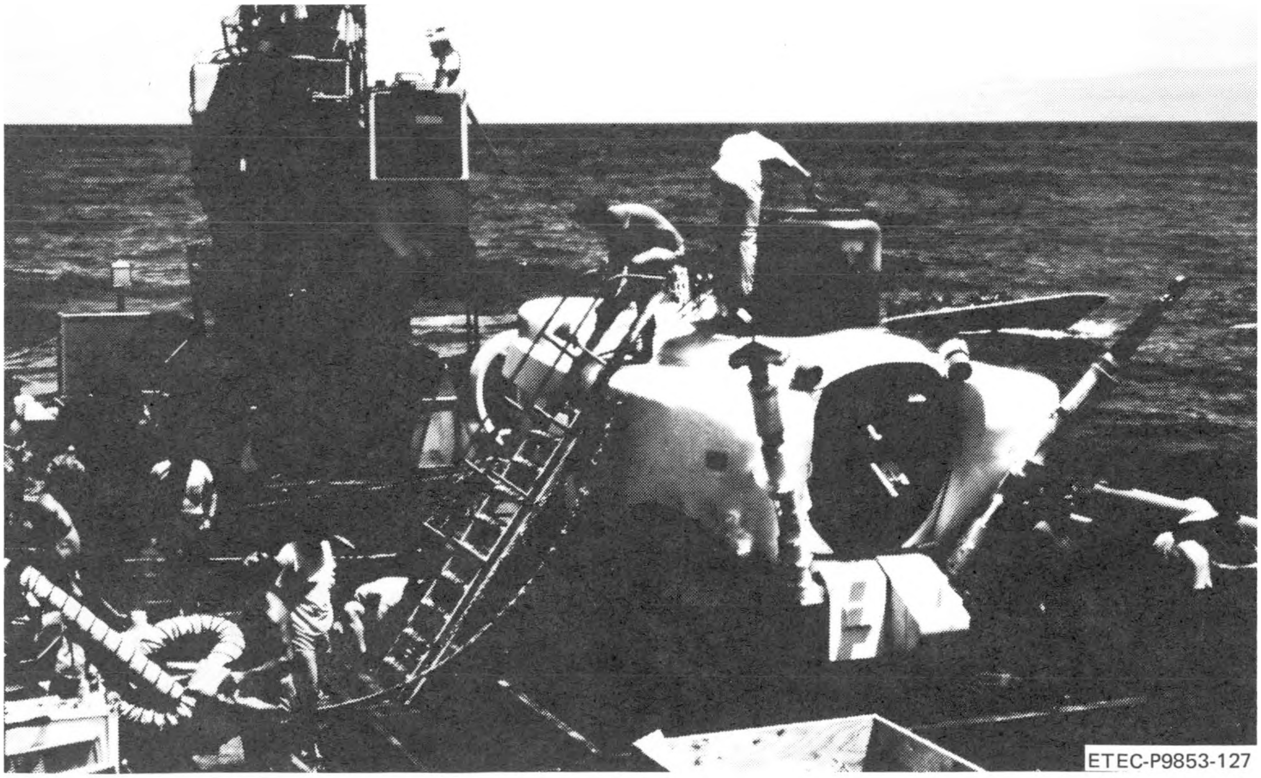


Figure 6-4. Turtle on Support Vessel (USS Conserver)

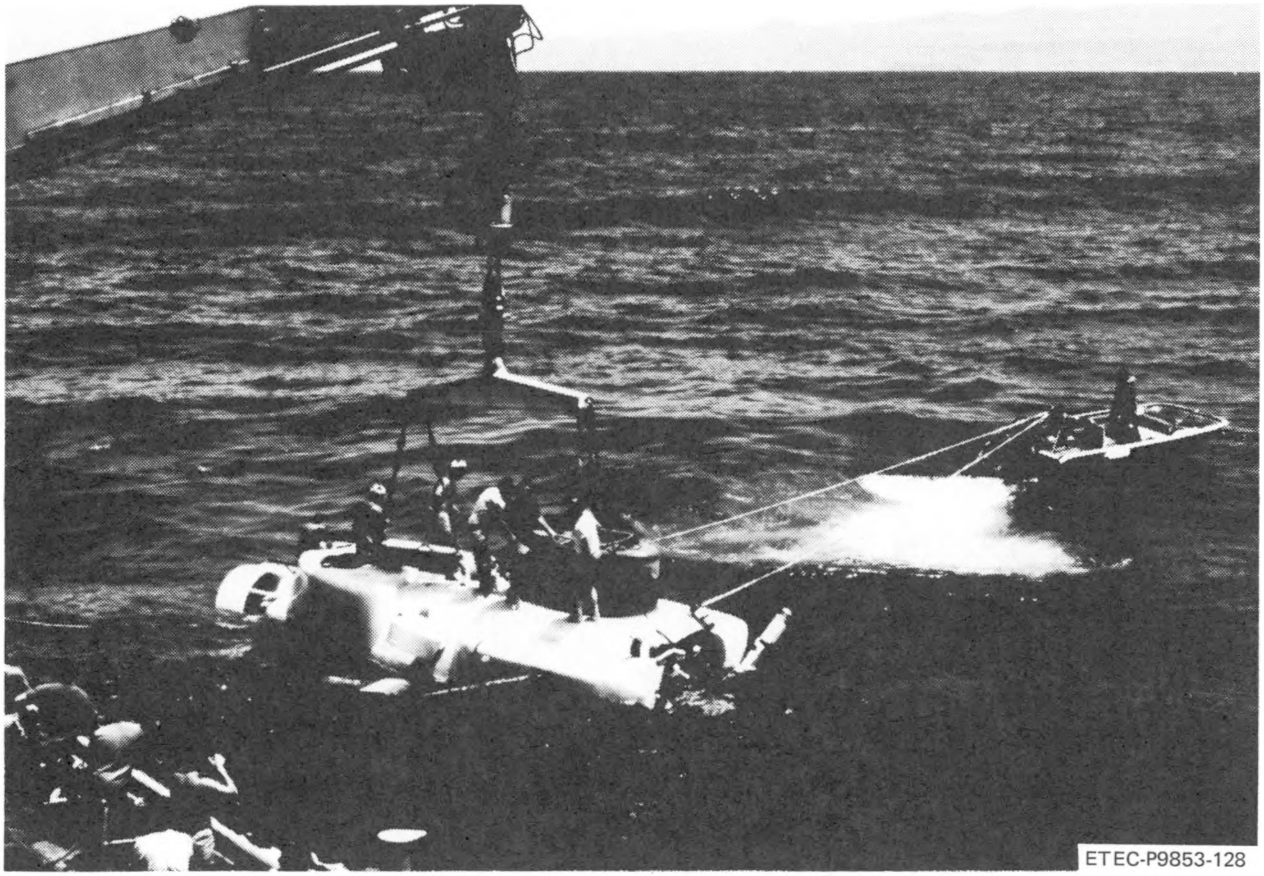


Figure 6-5. Turtle Being Deployed

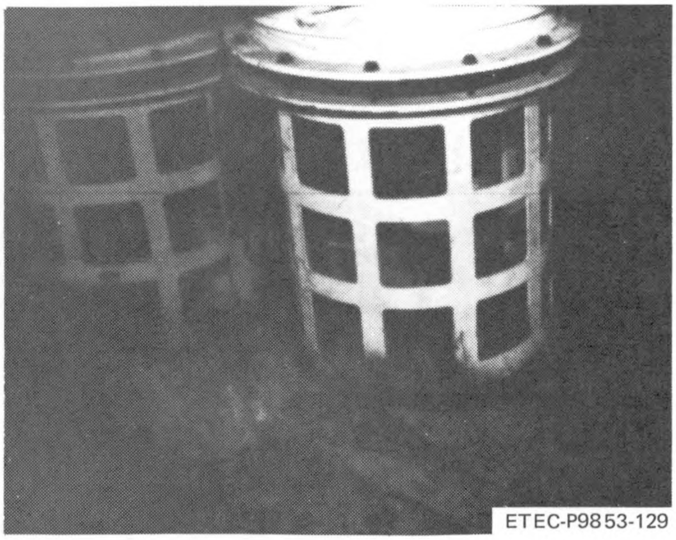


Figure 6-6. CWP Resting on Ocean Floor Showing Strainers

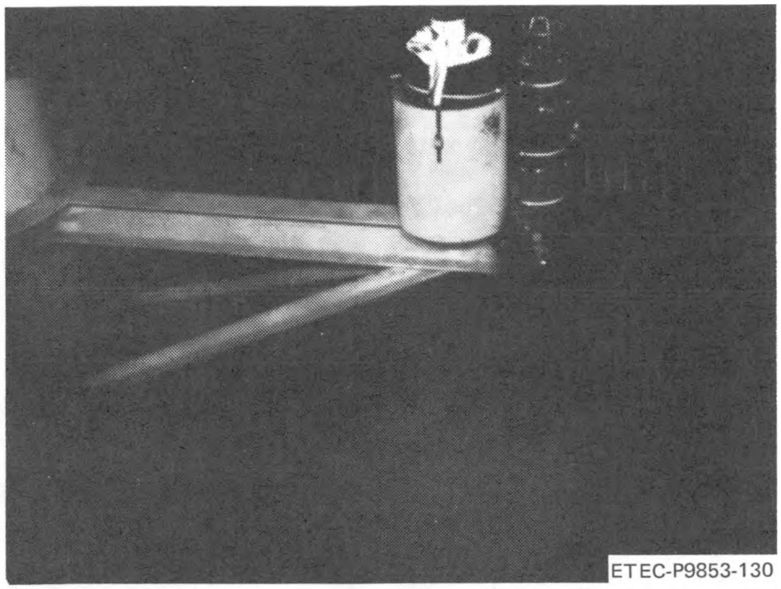
torches to cut the bottom weight chain, 4) methods for attaching and lifting the CWP to the surface, 5) the requirements and modifications needed for the barge to allow safe lifting operations under potentially adverse sea conditions, and 6) CWP storage requirements and methods in Kawaihae Harbor. In addition during this preliminary period, a Kona storm caused the original OTEC-1 surface buoy to break loose from the subsurface buoy. A new surface marker buoy was attached by the USS Conserver after it had successfully grappled for the 3000-ft Samson line between the subsurface buoy and the CWP. Although originally thought to be just another problem, grappling for and then using the Samson line to lift the CWP became a key step in the final recovery plan.

Based on information obtained from the above tasks, the status of the CWP was determined, and the CWP recovery plan was made final.

The CWP was located at essentially the exact original drop site. It was vertical but resting on the bottom as shown in Figure 6-6. It appeared in excellent condition for its full length with no marine growth or structural breaks. The two original transponders were still attached at the bottom transition piece, as shown in Figure 6-7. The Regan post, shackle, and post support arm were missing, but sufficient pad eye remained to allow future attachment to a lifting line (see Figure 6-8).

The final CWP recovery plan consisted essentially of cutting the CWP bottom weight chain with the THERMOL torches, lifting the CWP to the surface using the modified Navy barge, transferring the CWP to the USS Conserver and towing it into shallow water, attaching a lift line from the barge to the bottom of the CWP in shallow water, and towing the CWP into Kawaihae Harbor for removal of the buoyancy collar and final storage. Figures 6-9 through 6-18 show the above sequence of events, and Figure 6-19 shows schematically how the CWP was expected to be stored in the harbor.

Figure 6-7. Transponders on CWP, at Depth



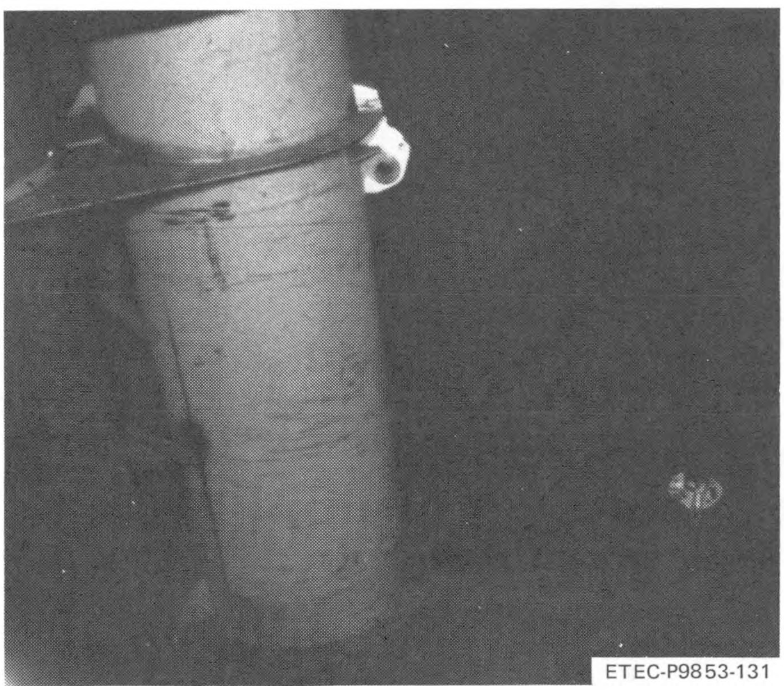


Figure 6-8. Pad Eye at Base of CWP, at Depth

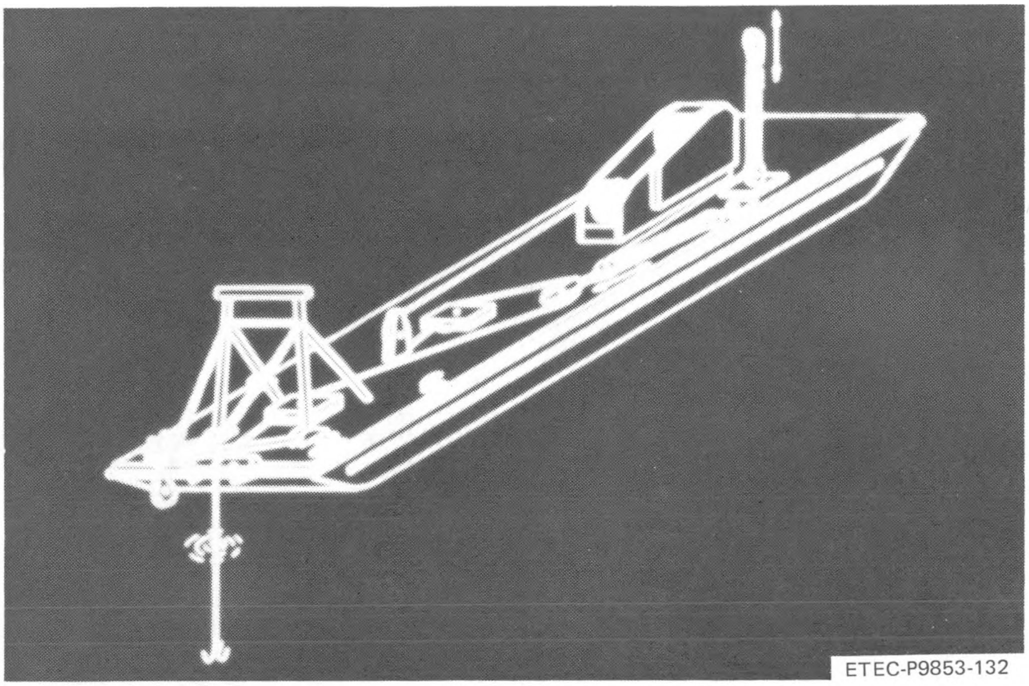


Figure 6-9. YC-1525 Lift Barge — Ramtensioner Rieved for Grapple

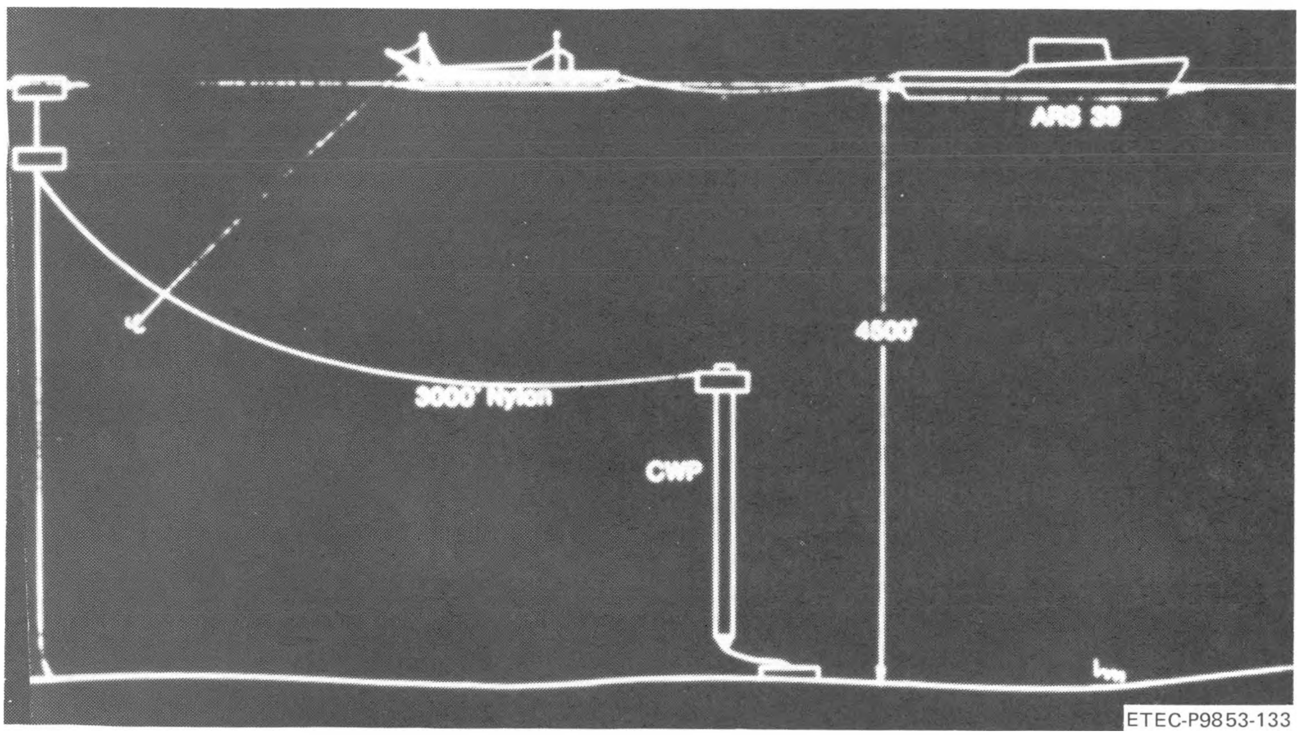


Figure 6-10. Grappling for 16-in. Nylon Line

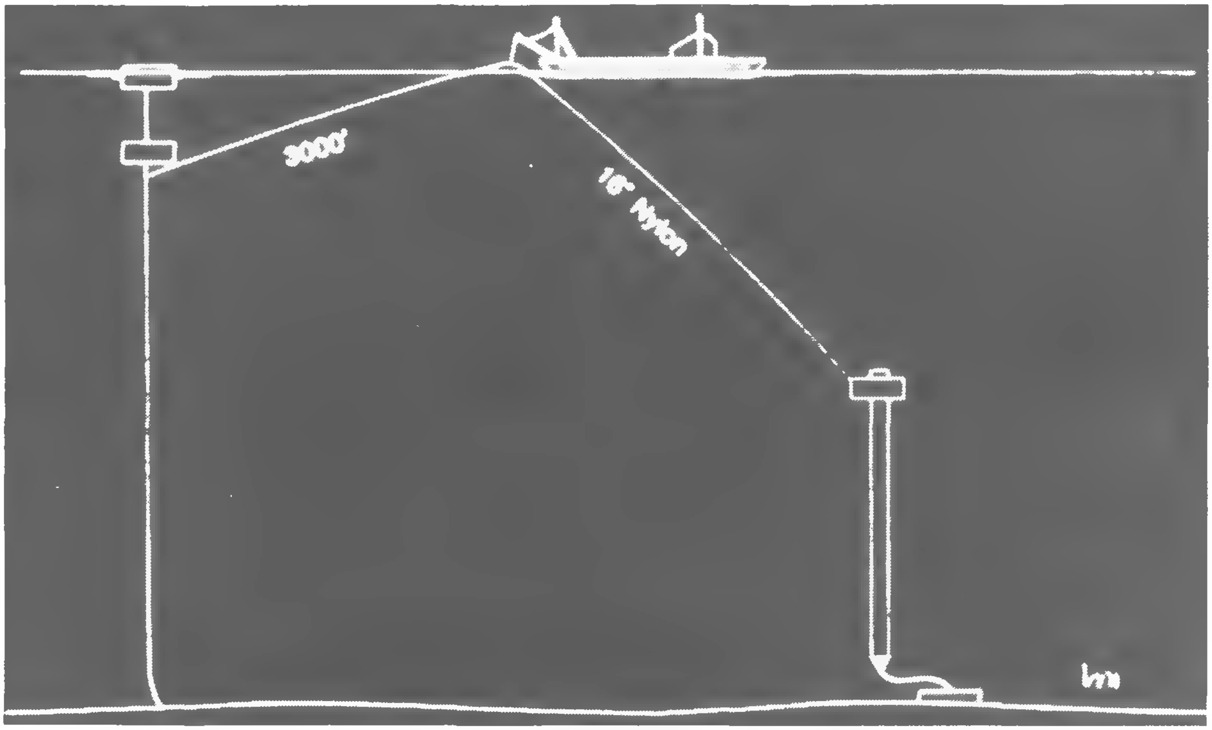


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Figure 6-11. Rendering Along Mooring Line Toward CWP

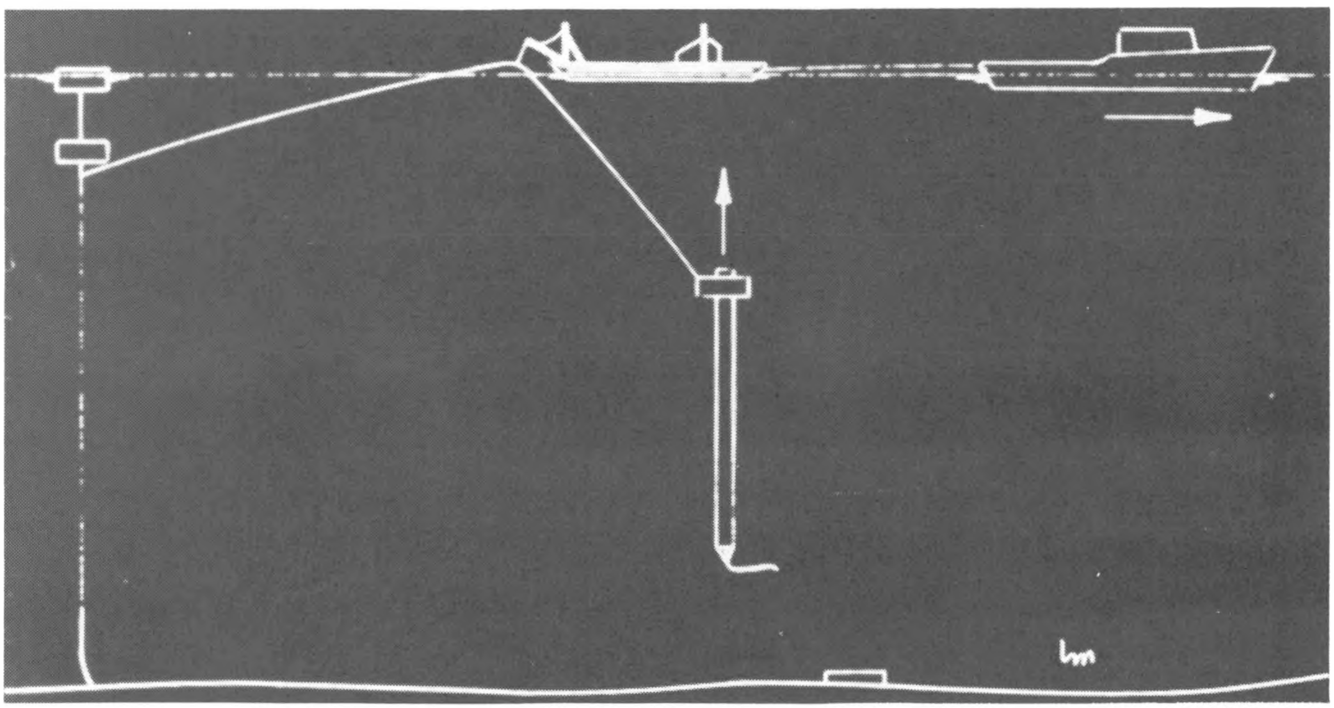

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Figure 6-12. Rendering/Lift of CWP

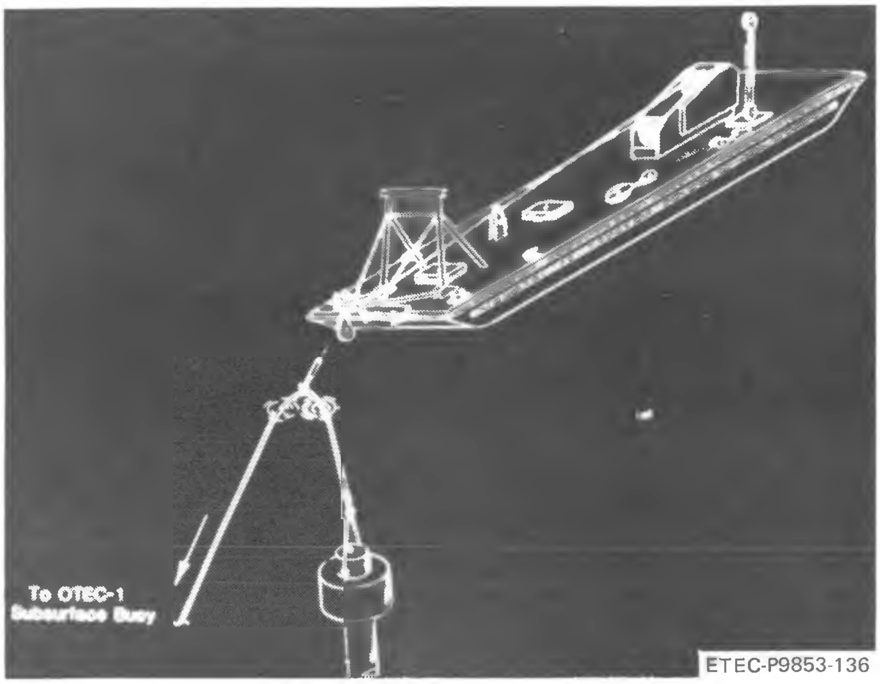

Figure 6-13. CWP Rendered to Barge

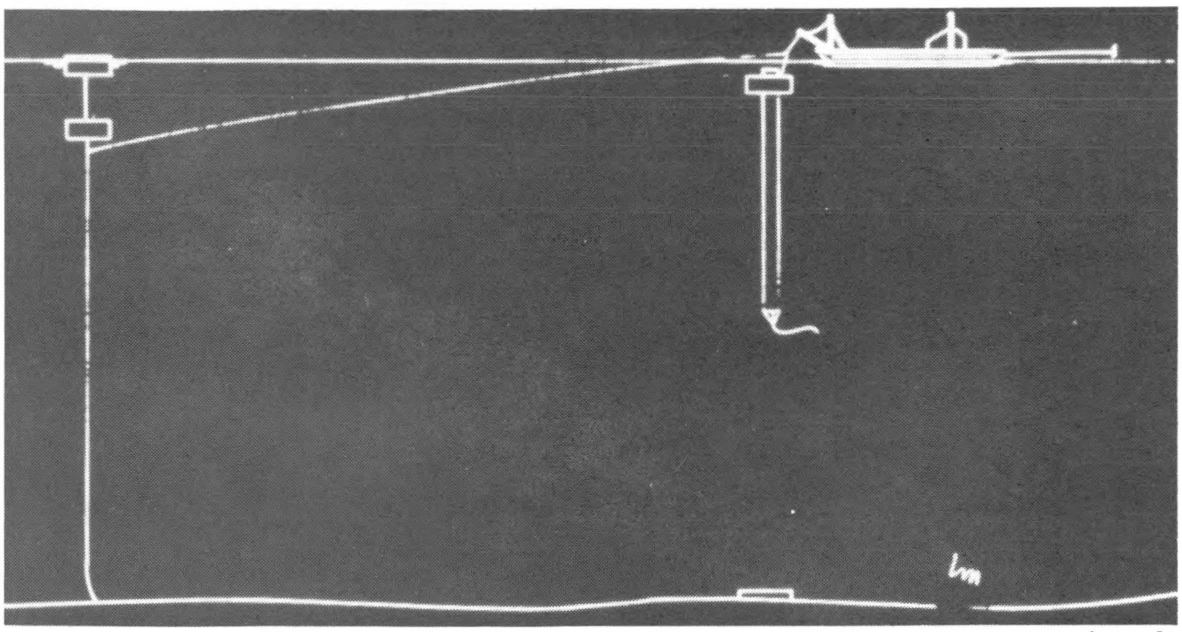

Figure 6-14. CWP at Surface

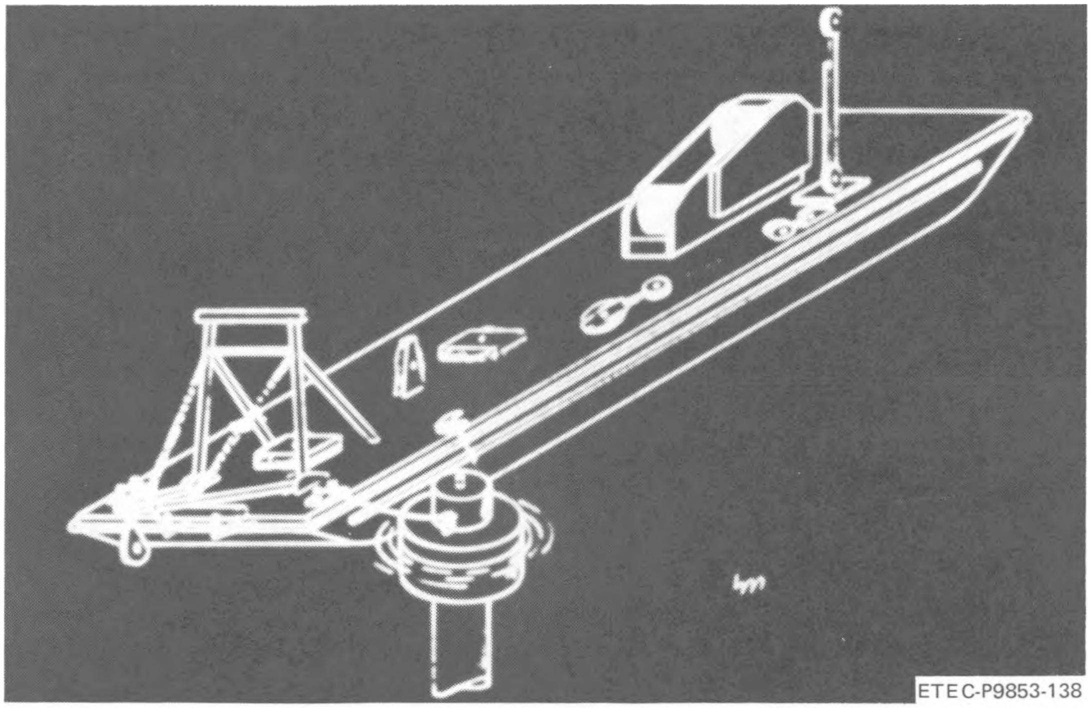

Figure 6-15. CWP Stopped-Off Alongside YC-1525

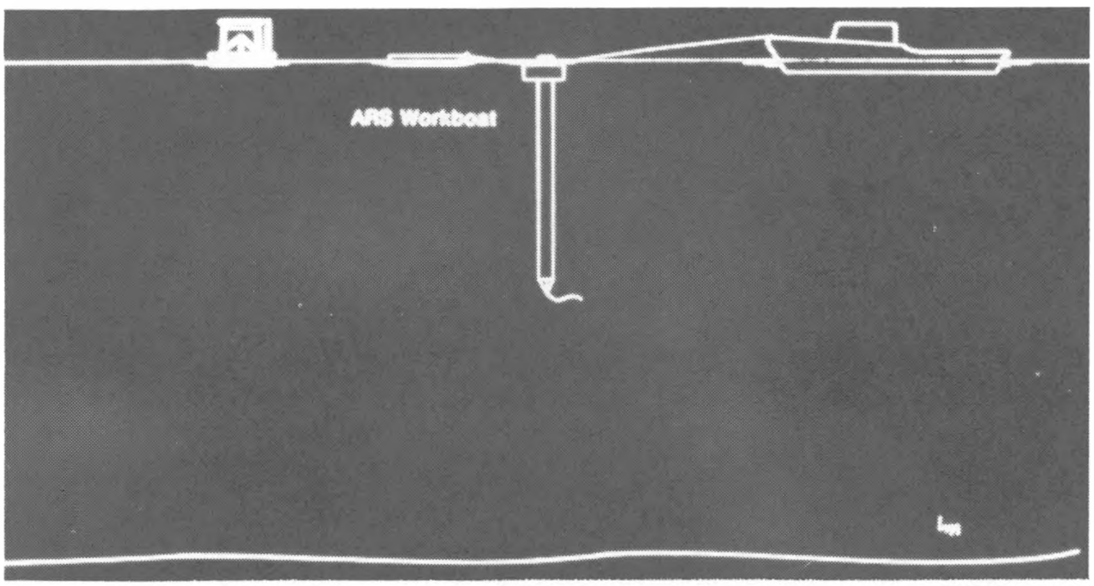

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Figure 6-16. Transfer of CWP From Barge to Conserver

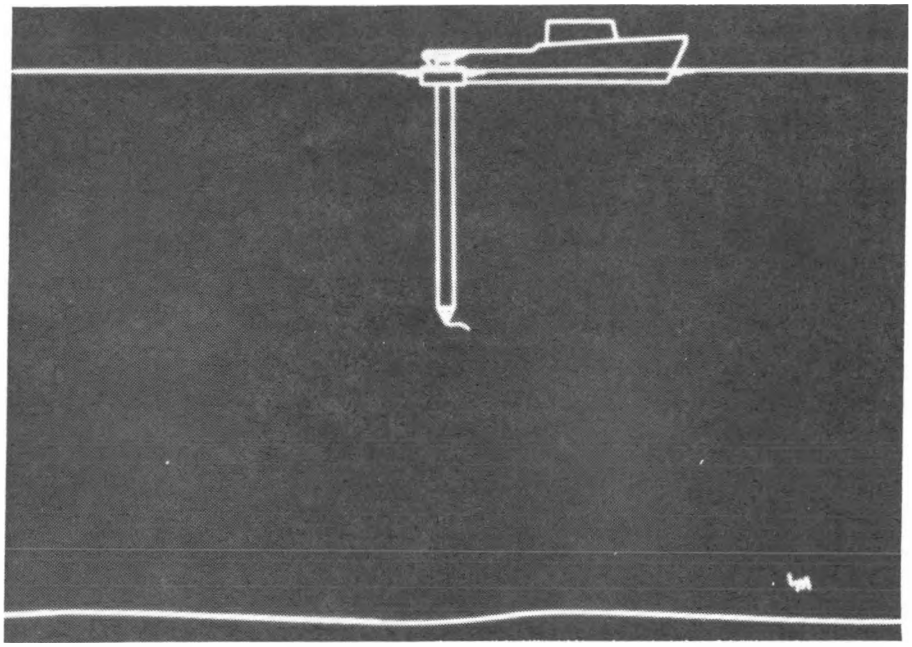

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Figure 6-17. CWP Alongside Conserver

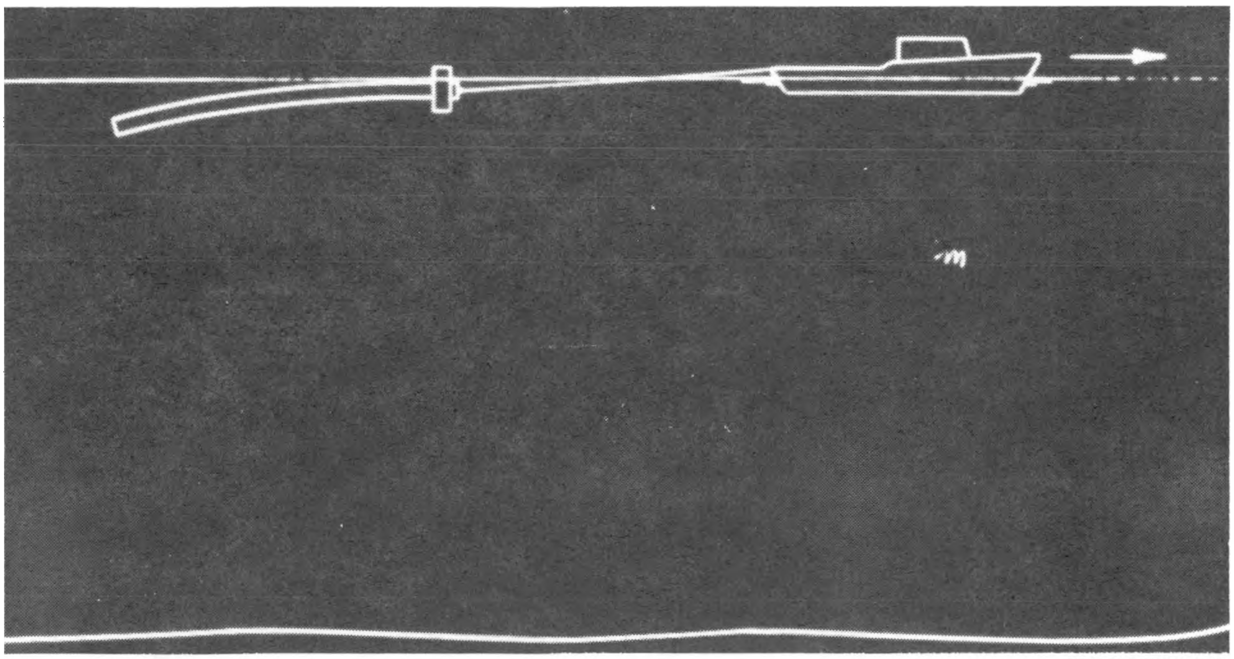

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Figure 6-18. CWP Under Tow

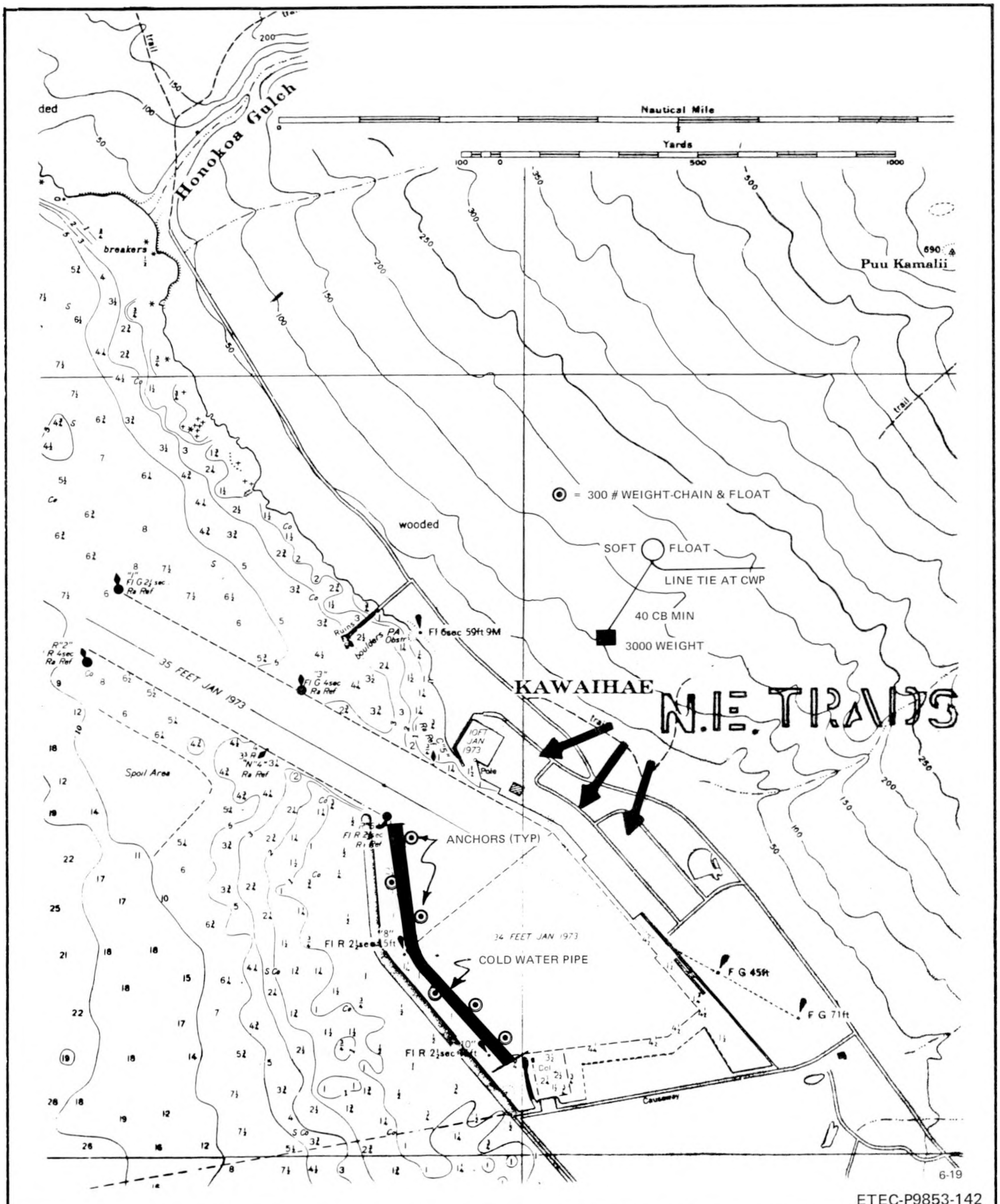

Figure 6-19. Layout of Planned Storage in Kawaihae Harbor

The actual sequence of events happened essentially as planned except for problems with the THERMOL cutting torches. This problem and a brief chronological history of the recovery are discussed below.

1) On 4 October 1982, the cutting torches were attached by the DSV Turtle and the grapple was successfully hooked to the 16-in. Sampson line.
2) At first light on 5 October 1982, the cutting torches were activated. The CWP did not surface. Attempts were made to render (raise) the CWP to the surface. This was unsuccessful and it was decided that the torches had not cut the chain. The DSV Turtle inspected the torches and determined that one-half of a link had been cut through, but that the second half had been only about 90% cut through. Thus, it was decided to cut the three cables that attached the bottom weight chain to the CWP using a cable cutter attached to the DSV Turtle. The cables ran from the lower transition piece to a fish plate from which the anchor chain ran to the bottom weight. The cables were not under tension. One cable had been cut all the way through and a second half way through when the cable cutter blade broke. The DSV Turtle then surfaced.
3) On 6 October 1982, the DSV Turtle returned to the bottom and successfully cut the remaining cables. The CWP did not rise to the surface.
4) On 7 October 1982, the CWP was rendered to the surface (see Figure 6-20). The CWP was transferred to the USS Conserver and towed towards shore. By carefully following the tow path, the CWP was bottomed in about 90 ft of water (diver depth). Figure 6-21 shows the CWP floating near shore while the cable from the barge was attached to the pad eye.
5) On 8 October 1982, the CWP was towed into Kawaihae Harbor, the buoyancy collar was removed, and the CWP was finally anchored near the breakwater and turned over to the State of Hawaii.

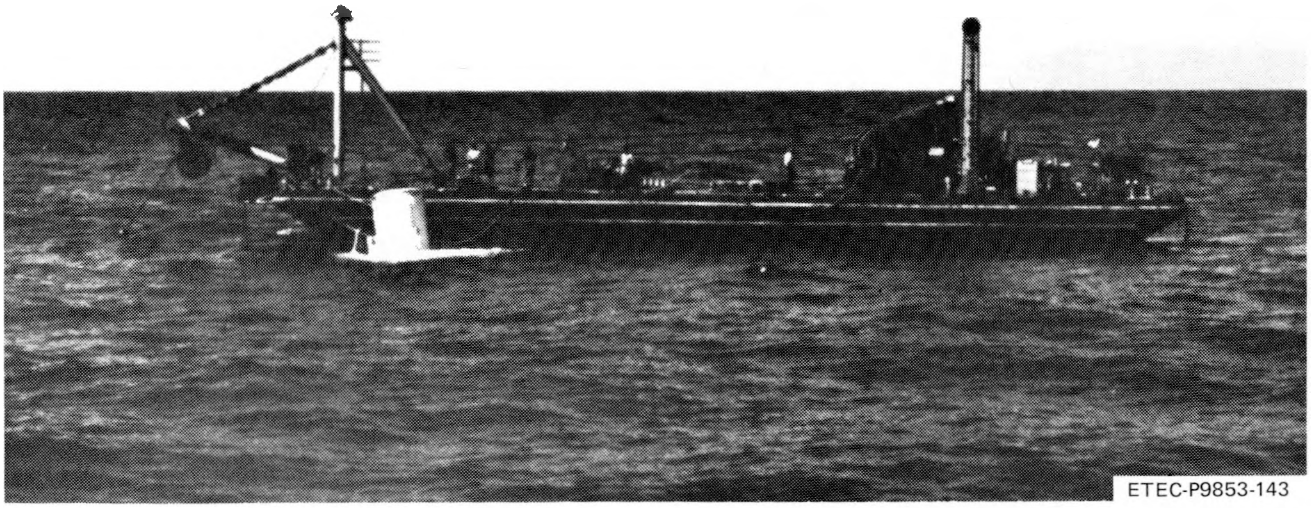

Figure 6-20. Rendering CWP to Surface

Figure 6-21. CWP Being Towed to Kawaihae Harbor

Figure 6-22 shows the CWP pulled onto shore for removal of the buoyancy collar.

The CWP was in extremely good condition with no apparent damage. In fact, an underwater inspection made by NELH indicated nothing more serious than mild surface abrasion for the full length of the three pipes.

The CWP is presently stored in Kawaihae Harbor. The intention is to reinstall it at the NELH at Keahole Point sometime in the future.

The reworked LVDTs near the top of the CWP were removed for possible use on another program; there is no information as to their condition, but visual observation indicated satisfactory integrity (see Figure 6-23).

Material samples of the polyethylene were taken and sent to the original supplier, DuPont of Canada, for analysis. The findings were that the material was significantly affected by hydrostatic pressure or sunlight or both. The material was found to have increased in density and increased in stiffness. A detailed report is available as Ref. 29.

D. RECOMMENDATIONS

The following specific recommendations should be considered for future similar activities:

1) A high priority should be placed during initial design on recovery and reconnection of the CWP since recovery could be time consuming and costly.
2) A positive means should be provided for locating and determining the depth of the dropped CWP from the surface (e.g., long duration transponders at top and bottom, large marker buoys).

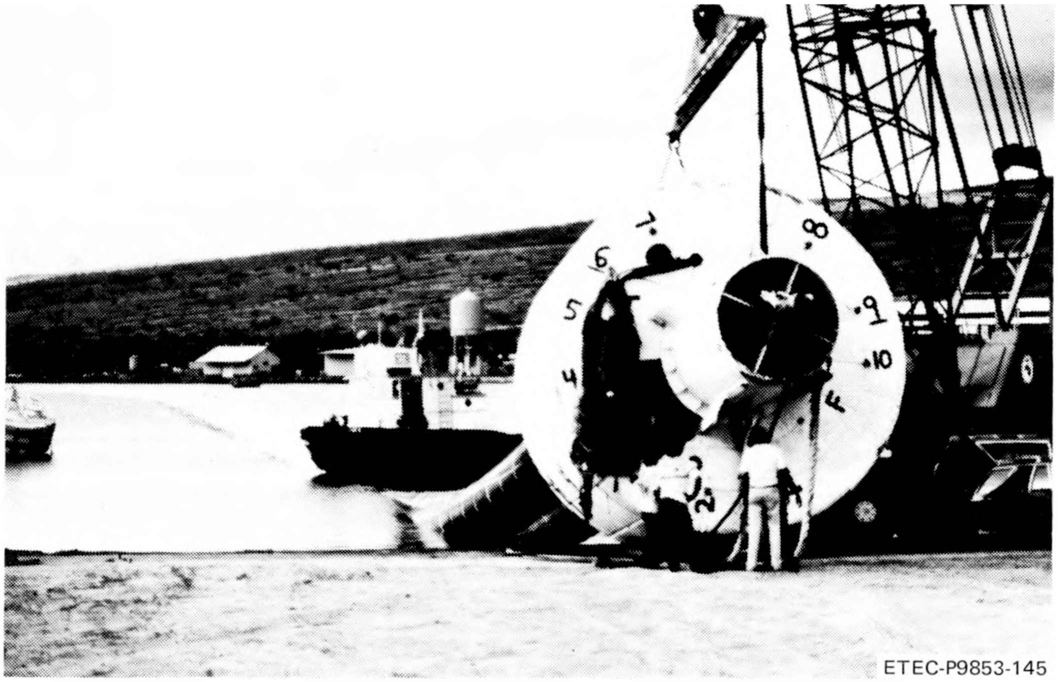

Figure 6-22. Recovered CWP Onshore, Showing Buoyancy Collar

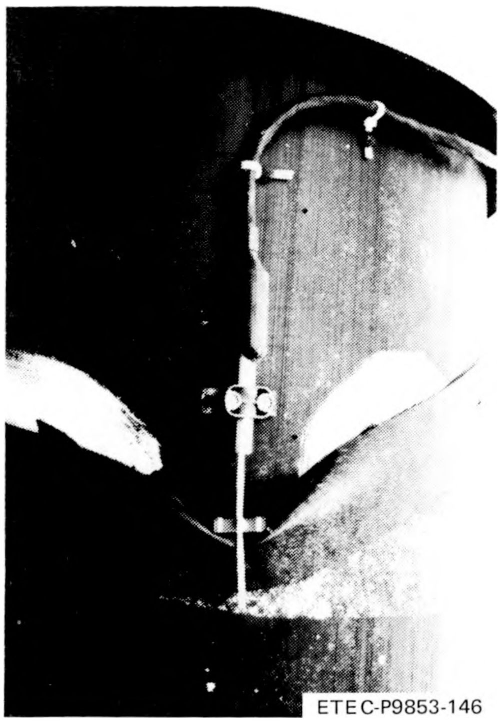

Figure 6-23. Reworked LVTD on CWP at Recovery

3) Marker buoys should be attached to the CWP with positive hard lines. The marker buoy attached to the OTEC-1 CWP with a poly-propolyene line was lost during the first bad weather condition.

4) An expendable bottom weight should be considered. This would allow the CWP to float to the surface for recovery. Additional weights could be stored on shore for reattachment.

5) In the case of Item 6, the vessel could be tethered to the CWP and the CWP towed with the vessel after it was released in bad weather.

6) To assist retrieval, a deballasting feature should be considered. This would require some means of activating buoyancy bags or other devices to assist in raising the CWP to the surface.

7) A means should be provided for attaching a line(s) to the bottom of the CWP from the surface or by using an SMU or some other method. This would allow raising the bottom of the CWP to the surface for reattachment of a bottom weight, maintenance of the pipe or instrumentation, etc.

The above list is by no means complete. It is only provided to generate ideas to be considered for future vertical CWP installations. In any case, considerable thought must be put into the design for CWP recovery operations.

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APPENDIX A

OCEAN THERMAL ENERGY CONVERSION — 1
STANDARD OPERATING PROCEDURE

OTEC-1-OP-400
WARM WATER SYSTEM STARTUP

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to start-up the OTEC-1 Warm Water System.

2. PREREQUISITES

2.1 The DAS and recording instrumentation must be in operation.

2.2 The 24 volt instrumentation power supply must be "ON".

2.3 The control air system must be in operation.

2.4 The oil level in the pump motor must be visible in the sight glass (ball floating).

3. REFERENCES

3.1 Water Circulating System O&M Manual 4086-C401.

3.2 P&I 6850-93-PD-08 Sea Water Support Subsystem Diagram.

3.3 Chlorination Operating Procedure OTEC-1-OP-900.

3.4 Amertap System O&M Manual 4086-0403.

3.5 Amertap System SOP OTEC-1-OP-301.

4. PREPARATION

Date/Time/Initial

4.1 Check warm water inlet screens for cleanliness and innermost screen in down position.

Positioned/Clean ____/____/____

4.2 Seal warm water sump room. Verify all personnel clear of sump room.

Clear & Sealed ____/____/____

4.3 Start-up eductor system, if possible, to draw a vacuum on the warm water sump room.

Started ____/____/____

4.4 Close or verify closed the following valves.

4.4.1 V-181 a 8" drain valve on the condenser outlet pipe.

Closed ____/____/____

Date/Time/Initial

4.4.2 V-182 a 2" drain valve on the condenser outlet water box.

Closed ___/___/___

4.4.3 V-185 a 2" drain valve on the condenser inlet water box.

Closed ___/___/___

4.4.4 V-186 a 8" drain valve on the condenser inlet pipe.

Closed ___/___/___

4.4.5 Condenser pressure transducer drain valves for PE-7 (4 ea) and PE-8 (4 ea).

Closed ___/___/___

4.4.6 Condenser instrumented loop inlet valves (48 ea), and outlet valves (48 ea).

Closed ___/___/___

4.4.7 Amertap delta pressure gage drain lines (2 ea).

Closed ___/___/___

4.4.8 Shut off air supply to amertap ball bypass valve, located in aft observation space port side of air lock entrance.

Air Off ___/___/___

4.5 Open or verify open the following valves.

4.5.1 V-180 a 8" discharge high point vent valve.

Open ___/___/___

4.5.2 V-187 a 8" inlet high point vent valve.

Open ___/___/___

4.5.3 Amertap delta pressure gage, bypass line (1 ea), and supply valves (2 ea).

Open ___/___/___

4.5.4 Sea chest valve in mixed water sump stand pipe.

Open ___/___/___

4.6 Perform or verify performance of the following conditions.

Date/Time/Initial

4.6.1 Initiate pump seal lubrication opening the water flow valve for the pump seal. Located on main deck, mid-ships house, overhead of air pack breathing air bottles. Flush a toilet to verify the water supply is available.

Initiated ___/___/___

Water Supply OK ___/___/___

4.6.2 Amertap ball collecting screens are in the catch position.

Catch ___/___/___

4.7 Notify the following ships stations and personnel of the pending start of the warm water pump.

4.7.1 Bridge - ship's Captain or 1st. Mate.

Notified ___/___/___

4.7.2 Chief Engineer. Notified ___/___/___

4.7.3 Electrical room - ship's electrican to assign the SCR for the warm water pump.

Notified ___/___/___

4.8 After assignment of the SCR, the warm water pump air cooling fan should be running. If not contact the shift leader.

Running ___/___/___

4.9 Deploy 1 person at each of to the high point vent valves V-180 and V-187. Equip them with walkie-talkies to notify the van when they are in position to operate the valves. Caution - do not key walkie-talkies in the van. These operators are to close the valves when vacuum starts or when water starts to flow out of the valves.

Deployed ___/___/___

In Position ___/___/___

5. PUMP START

5.1 Set Beckman L1C-104 for 20 percent as indicated on the black face output meter.

20 Percent ___/___/___

5.2 Press P-101 enable switch at the center consol, right of the CRT. The enable switch should illuminate and the pump should rotate.

Switch "ON" ___/___/___

Date/Time/Initial

5.3 Increase pump power rapidly to 100 percent with L1C-104.

100 Percent ____/____/____

5.4 Close high point vent valves V-180 and V-187 after vacuum starts or when water starts to flow out of the valves.

V-180 Closed ____/____/____

V-187 Closed ____/____/____

5.5 Once full flow is established perform the following.

5.5.1 Bleed air from inlet water box high point 2" vent valve V-184.

Air Bled ____/____/____

5.5.2 Bleed air from outlet water box high point 2" vent valve V-183.

Air Bled ____/____/____

5.5.3 Bleed air from pressure transducer lines PE-7 (4 ea) and PE-8 (4 ea). PE-8-1 may have negative pressure.

Air Bled ____/____/____

5.5.4 Bleed trapped air from Amertap delta pressure gage and close by-pass valve.

Performed ____/____/____

5.5.5 Open 48 condenser instrumented tube inlet valves, and 48 outlet valves.

Performed ____/____/____

5.5.6 Start-up Amertap System per SOP OTEC-1-OP-301.

Started ____/____/____

5.5.7 Perform chlorination of evaporator per OTEC-1-OP-900. Coordinate this operation with AECOS representative.

Started ____/____/____

5.5.8 Start-up BCM"s and DAS program HTM.

Started ____/____/____

5.5.9 Start-up instrumented tubes instrumentation and the associated program (TBD).

Started ____/____/____

Date/Time/Initial

6. Warm water system is now operational.

6.1 Notify the bridge that the warm water system is now on line.

Notified ____/____/____

6.2 For cold water system shut down procedure refer to OTEC-1-OP-400A.

6.3 Manual switch located on hand rail near pump is for local emergency shut down only and should only be used for emergency purpose.

Shift Leader:________________________ Date:__________

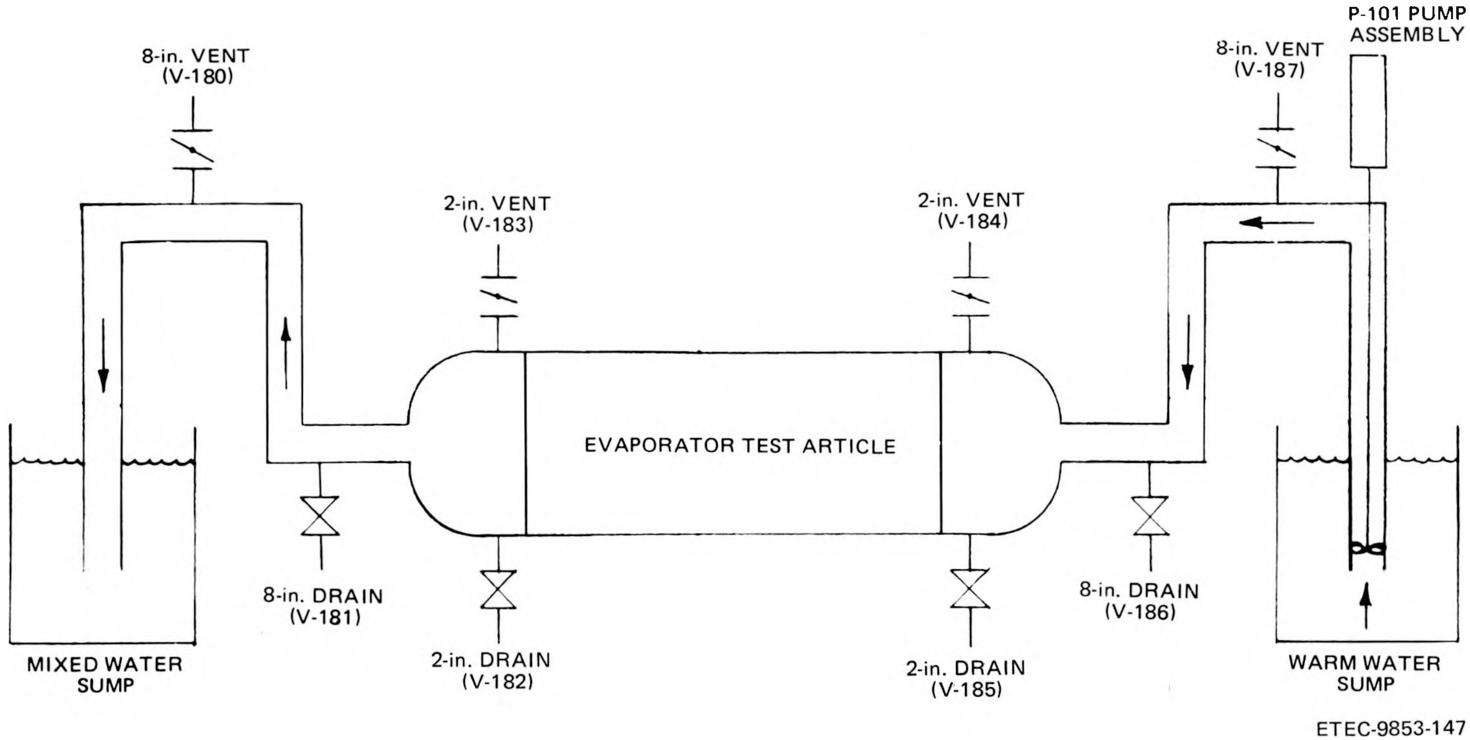

Figure A-1. Warm Water Test Loop Schematic

APPENDIX B

OCEAN THERMAL ENERGY CONVERSION — 1

ETEC REPORT

BUBBLE ENTRAINMENT ON OTEC-1:

IMPLICATIONS FOR FUTURE OTEC DESIGNS

ETEC-82-19

BUBBLE ENTRAINMENT ON OTEC-1: IMPLICATIONS FOR FUTURE OTEC DESIGNS

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ABSTRACT

Problems were experienced in seawater flow measurements aboard the OTEC-1 vessel. Gas bubbles in the seawater systems prevented proper operation of the flowmeters. Air entrainment in the sump and gas evolution were identified as bubble sources.

Remedies included increasing the sump water level and system backpressure. Neither resulted in proper flowmeter operation, however, bubble presence was significantly reduced by the increased sump water level.

Gas evolution and air entrainment can be prevented by appropriate system and sump design such as those provided by Hydraulic Institute Standards. Non-standard sump designs can be verified by scale model testing. Degassing can be minimized by limiting piping elevations and pressure drops. The benefits of bubble elimination must be balanced against the costs of preventing bubbles.

INTRODUCTION

During operation of the OTEC-1 test experiment, problems were experienced in measuring flowrates in the warm, cold, and discharge seawater systems. The ultrasonic flowmeters, designed to measure seawater flowrate to 1% accuracy, were unable to function properly. It was postulated that proper operation of the flowmeters was prevented by gas bubbles interfering with sonic signal transmission through the seawater. Since the gas bubbles could also impact water side heat transfer coefficients and heat exchanger performance, an investigation was initiated to determine the source of the bubbles, methods of bubble elimination, and design practices to prevent similar problems in future installations. The results of the investigation have been detailed in this paper.

BUBBLE SOURCES

The OTEC-1 warm and cold seawater systems, rated at 82,600 gpm and 68,170 gpm respectively, were each driven by a single stage pump taking suction out of a sump. Both warm and cold systems discharged spent fluid to a mixed discharge sump which was emptied by the mixed discharge pump. Ultrasonic flowmeters failed to function in all three systems, however, emphasis was placed on eliminating bubbles in the warm water system where bubble presence was most significant.

Four mechanisms were proposed to account for the presence of bubbles in the warm water system. These were:

1. Air entrainment due to turbulence at the sump water surface.
2. Air entrainment due to vortexing in the sump.
3. Evolution of dissolved gas.
4. Pump cavitation.

Observations of the warm water sump during operation indicated that air entrainment due to surface turbulence was substantial. This entrainment was due to high water velocities and abrupt flow direction changes in the sump.

Warm water entered the sump area through a 5 foot diameter vertical standpipe that extended from the ship's keel to 13 feet (all elevations relative to keel datum). Operating water level in this section of the sump was 22 feet, insufficient to prevent water, exiting from the standpipe, from geysering into the air above the sump surface level resulting in air entrainment (Figure 1). The water then passed through two vertical screens, one in the port direction and one in the forward direction from the standpipe (Figure 2). Downstream of the screens there was additional turbulence and air entrainment particularly downstream of the forward screen where the flow took a sharp left turn to reach pump suction. The seawater experienced a 1 foot head loss across the screens resulting in an operating level of 21 feet downstream of the screens.

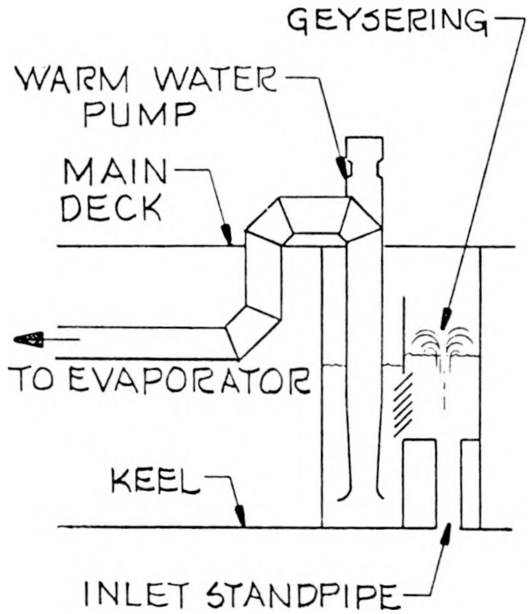

Figure 1
Warm Water Sump Schematic

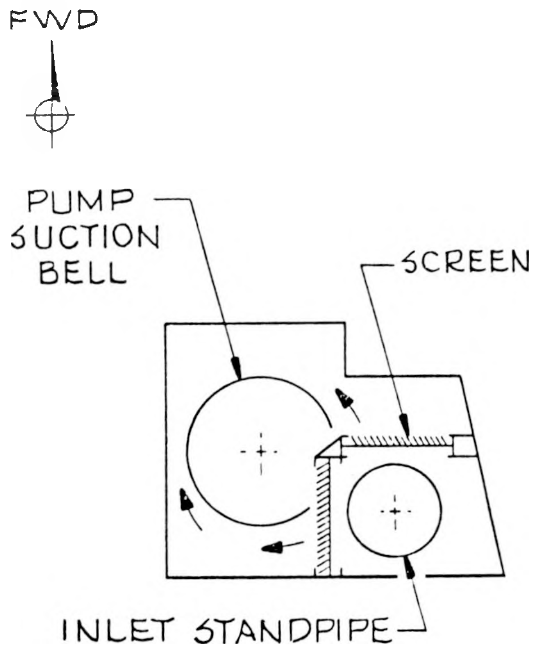

Figure 2
Plan Of Warm Water Sump

At nominal warm water flowrates, the velocity of water through the screens was about 3 feet per second, too high to allow entrained air bubbles to escape. Velocities downstream of the screens were also sufficiently high to keep air bubbles entrained.

Vortex formation around the pump column could not be observed because of difficulty in seeing through the turbulence induced froth on the sump surface. However, there is some evidence that air entraining vorticies could have been forming. Hydraulic Institute Standards (1)* recommend 14 to 15 feet of submergence over the suction bell to prevent vorticies in a sump designed per Hydraulic Institute Standards. Although the nominal water level above the bell was in the 14 to 15 foot range, the design of the sump varied considerably from Hydraulic Institute Standards and consequently the submergence may have not been sufficient.

Vortex formation was also encouraged by uneven flow distribution to the pump suction bell. Observation of the sump showed that the forward side of the pump was "starved" relative to the aft side resulting in high velocity flow around the pump column. Transverse and longitudinal ship support structures below the pump suction bell (Figure 3) may have also contributed to flow disruptions and subsurface vortex formation in the sump. Flow splitters, such as the transverse plate underlying the pump suction bell parallel to incoming flow, normally act as vortex suppressors. However, because of the small clearance between the plate and the suction bell, this plate may have acted to disrupt flow. The "starved" conditions on the forward side of the pump may have been encouraged because this plate prevented flow to the forward side of the pump from the aft side. Flow blockages by the inlet screen support structure provided additional disruptions.

The release of dissolved gas from solution may have also accounted for some of the gas bubbles in the system. Pressures at the center of strong subsurface vorticies may have been low enough to evolve gas from solution in the seawater. The decrease in pressure and severe agitation experienced by the warm water in the piping would also encourage gas evolution.

The water pressure upstream of the flowmeter and evaporator ranged from +24 feet of seawater at the keel (standpipe inlet) to -10.7 feet (gauge) of seawater at the top of pump discharge. The low pressure at the top of pump discharge was a result of the relatively high elevation of the discharge (48 feet above the keel, 24 feet above the nominal sea level). Tests performed aboard the vessel showed that gas came out of solution from seawater under a similar reduction in pres-

*Numbers in parentheses refer to references listed at the end of the paper.

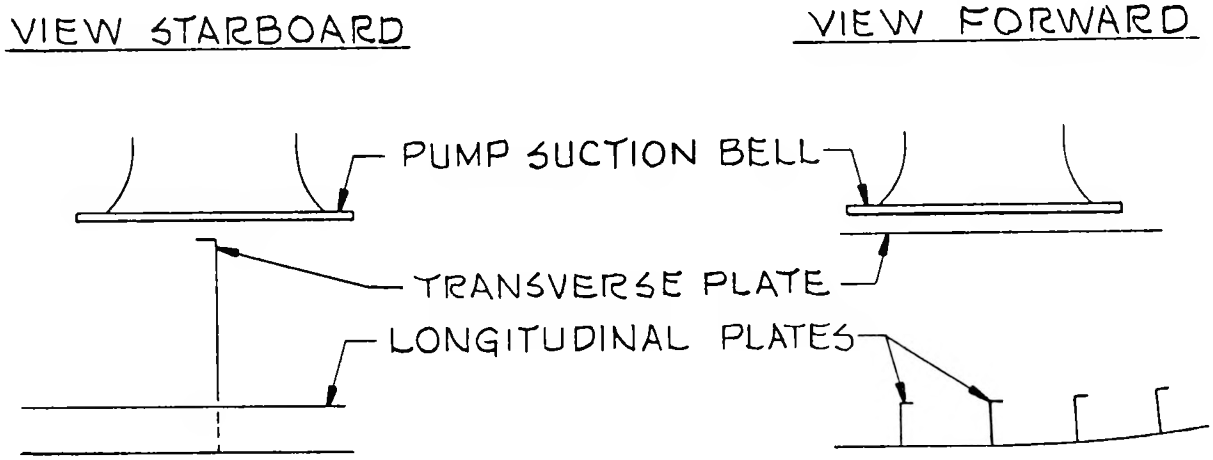

Figure 3

Transverse And Longitudinal Plates Below Pump Suction

sure with mild agitation. Although warm water system pressure increased above atmospheric pressure before reaching the flowmeter due to the drop in warm water pipe elevation, kinetics of gas evolution dictate that gas evolves much quicker than it redissolves and therefore most of the evolved gas would not have redissolved.

Pump cavitation was considered an unlikely source of bubbles since vapor bubbles produced by this phenomena would collapse before reaching the higher pressure region upstream of the ultrasonic flowmeter, and thus not impact flowmeter operation.

ATTEMPTED SOLUTIONS

Since the source of the bubbles was thought to be most likely multifold, a variety of solutions were considered to eliminate the bubbles. Methods that could be implemented relatively quickly with the ship on station were emphasized. However, due to the limited remaining operating time of the vessel, and the desire to accumulate the maximum amount of OTEC operating experience, only two of the proposed solutions were attemped.

The most successful of these solutions was to increase the submergence of the pump suction by pulling a vacuum on the warm water sump. The water level above the suction bell was increased by approximately 11 feet to a 32 foot elevation. The result was a considerable decrease in the warm water system bubble content. The success of this sump level increase indicated that air entrainment, due either to vortexing or surface entrainment, was the major contributor to the bubbles. The increased separation between the pump suction bell and the sump surface was sufficient to calm surface waters and eliminate the geysering above the inlet standpipe. However, the decrease in bubble content was not sufficient to allow proper flowmeter operation.

The second solution, applied to eliminate bubble evolution, was to increase the operating level of the discharge sump. The level rise resulted in an increased warm water system pressure. Qualitative observations indicated little reduction in bubble content and little improvement in flowmeter readings. However, since the resulting pressure rise was insufficient to eliminate all the negative gage pressure areas in the warm water piping, bubble evolution may not have been sufficiently discouraged. In addition, gas evolution in localized low pressure areas such as a subsurface vortex would not be impacted by the discharge sump level rise.

IMPROVED SUMP AND SYSTEM DESIGN

Prevention of gas bubbles in systems such as the OTEC-1 seawater loop can best be accomplished by appropriate sump and system design. Hydraulic Institute Standards provide design guidelines for pump sumps. The recommended design for an 82,600 gpm rated pump is shown in comparison to the actual configuration of the OTEC-1 warm water sump in Figure 4. The most significant difference is the long straight approach channel recommended by the Standards that was nonexistant in the OTEC-1. The long approach channel provides uniform approach velocities, discourages vortex formation, and allows for damping of flow disturbances at the sump inlet. Considerable differences in suction bell to sump floor clearance between the

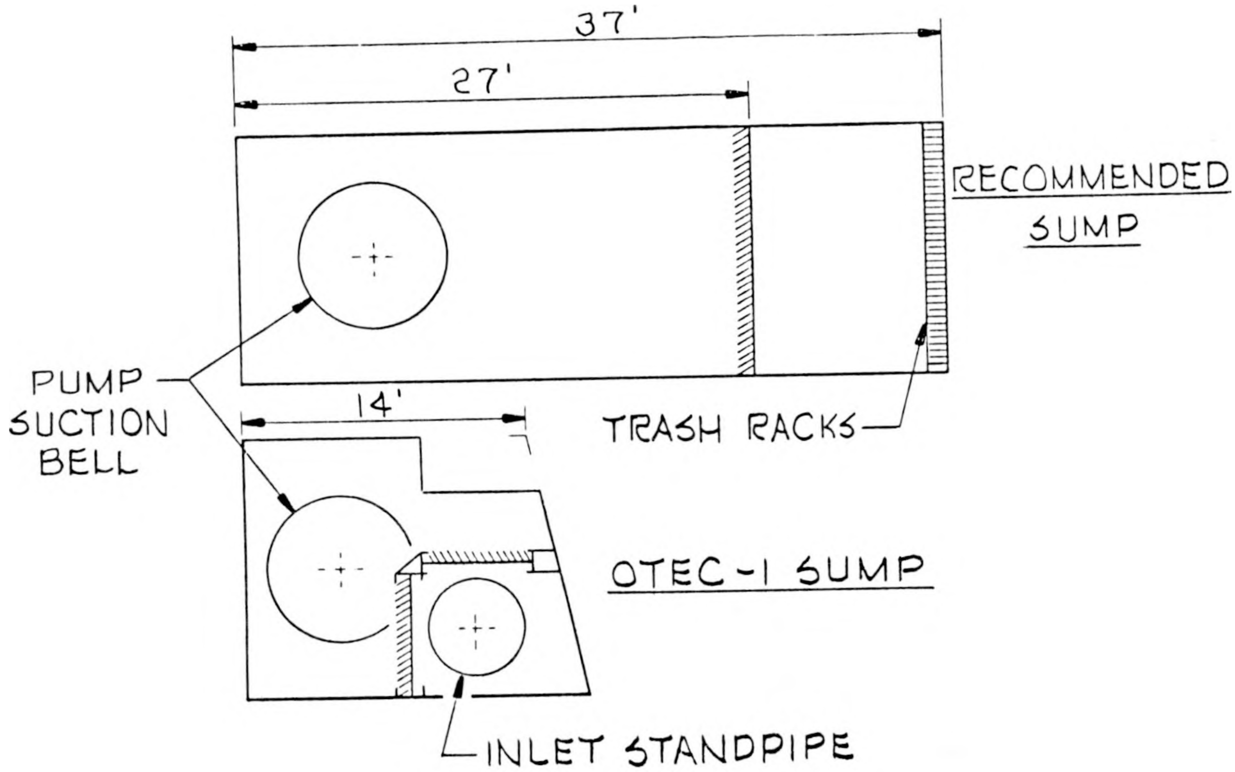

Figure 4
Comparison Of Recomended Sump With OTEC-1 Sump

Hydraulic Institute Standards and the OTEC-1 design were also evident. The OTEC-1 suction bell clearance was about 7 feet as opposed to approximately 3 feet recommended by Hydraulic Institute Standards and clearances of 1/2 the suction bell diameter or 4 feet recommended by others (2, 3,4). The increased floor clearance may have encouraged poor flow distribution and vortex formation at the suction bell inlet. Hydraulic Institute Standards also recommend maintaining sump velocities less than 2 feet per second and minimizing abrupt flow direction changes. Both of these criteria were violated by the OTEC-1 sump design.

Sump design guides such as those provided by Hydraulic Institute Standards may be difficult to follow in ocean based systems due to size and cost limitations. Possible alternatives for a system such as OTEC-1 are elimination of the sump by direct immersion of the suction pipe in the ocean or utilization of a non-standard sump design. Direct immersion of the pump suction pipe could impose pressure fluctuations on the seawater pumps due to the wave induced motion between the ship and the ocean. Constant flowrate would be difficult to maintain even during mild sea states. Hence, this method is not recommended. A non-standard sump design might contain flow baffles, diverters or other fixtures to insure calm and uniform suction bell approach flow. However, these designs are difficult to evaluate analytically and scale model testing is usually required to verify prototype sump adequacy. Sump models commonly range from 1/10 scale to 1/25 scale. Pump flow must be scaled down in the model so that the main flow patterns in the model duplicate those of the prototype. Model pump flow is commonly scaled to maintain the same Froude Modulus in both the model and the prototype. The Froude Modulus relates gravity and inertia forces, both of which can be predominant in open channel flow systems. Scaling flow based on Froude Modulus results in model velocities directly proportional to the square root of the scale factor. However, by basing model velocities on Froude Modulus the assumption is made that other effects such as surface tension and viscosity are unimportant. Some modelers (5, 6, 7) have found better duplication of prototype flow patterns if model flow velocities are increased to prototype values thereby compensating for scale effects. In general, it is prudent to evaluate model sumps at Froude Modulus velocities and higher. Scale values of velocities, flowrates, and areas, based on both Froude and constant velocity criteria, for a 1/10 scale model of the OTEC-1 warm water pump are shown on Table 1.

System designs that minimize piping elevation changes will minimize seawater degassing. To avoid impacting the integrity of bulkheads, OTEC-1 warm and cold seawater piping was routed above the main deck before descending into the condenser and evaporator compartment. This design resulted in low pressure areas that probably encouraged bubble growth in the high elevation piping. If large piping elevation changes cannot be avoided, utilization of an increased pumping head may suffice to eliminate the low pressure regions, however, this option reduces system efficiency by increasing pump parasitic loads.

CONCLUSIONS

Evidence gained from sump observations and the applied solutions suggest a multisource gas bubble origination. Air entrainment due to vortexing and/or surface turbulence predominated but contributions from gas evolution in system low pressure areas also contributed enough to prevent flowmeter operation.

Improved sump and system designs can prevent similar occurrences in future OTEC facilities. Design verification can be obtained by scale model testing. However, the costs associated with designing to eliminate gas bubbles may exceed the benefits derived from bubble elimination. If so, proper test techniques require that provisions for measuring gas bubble content in the fluid streams should be taken.

ACKNOWLEDGEMENTS

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TABLE 1

1/10 SCALE MODEL PARAMETER VALUES FOR FROUDE AND CONSTANT VELOCITY MODEL CRITERIA

PARAMETER	OTEC-1	FROUDE	CONSTANT VELOCITY
LINEAR DIMENSIONS	1	1/10	1/10
AREAS	1	1/100	1/100
VELOCITIES	1	1/3.16	1
FLOW (GPM)	1 (82600)	1/316 (261)	1/100 (826)

6. Fraser, W. H., "Hydraulic Problems Encountered in Intake Structures of Vertical Wet-Pit Pumps and Methods Leading to Their Solution", ASME Transactions, Volume 75, pp. 643-651, 1953.

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APPENDIX C

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-400A

WARM WATER SYSTEM SHUTDOWN

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to shut down the warm water system aboard OTEC-1.

2. PREREQUISITES

2.1 The DAS and recording instruments must be in operation.

3. REFERENCES

3.1 Water Circulating System O&M Manual 4086-C401.

3.2 P&I 6850-93-PD-08 Sea Water Support Subsystem Diagram.

3.3 DAS Operating Procedure P-070E-D40-S0017.

3.4 BCM Operating Procedure (TBD).

3.5 Warm Water System Startup, SOP OTEC-1-OP-400.

3.6 Collection and Sizing the Amertap Balls, SOP OTEC-1-OP-301A.

3.7 Mixed Water Discharge System Startup & Shutdown, SOP OTEC-1-OP-500.

4. PREPARATION

Date/Time/Initial

4.1 Perform an HTM summary per DAS Operating Procedure P-070E-D40-S0017 by executing program "RUN SUMMARY."

Performed ____/____/____

4.2 Collect the Amertap balls from the evaporator by performing SOP OTEC-1-OP-301A.

4.2.1 Notify the Mate on duty of the intent to increase evaporator pump speed.

Notified ____/____/____

4.2.2 Increase the evaporatorr pump P-101 to 85% power for ball collection and screen back washing.

85% ____/____/____

4.2.3 Notify the person in charge (PIC) that the evaporator Amertap system will be off line.

Notified ____/____/____

4.2.4 Close the ball collector flap on the evaporator ball collector basket.

Closed ____/____/____

Date/Time/Initial

4.2.5 Open the evaporator Amertap ball bypass line air actuated valve by opening the air valve located on the bulkhead in the aft observation compartment, left of the lower air lock door. After 5 min. close this air valve and open air vent valve to close the air actuated bypass valve. When closed, close air vent valve.

Performed ____/____/____

4.2.6 Collect the balls for a minimum of 1/2 hour, but no longer than 1 hour.

Time Start ______________ Time Stop __________ ____/____/____

4.2.7 Stop the evaporator Amertap pump by pressing the stop button located on the rail nearest the pump and immediately close the ball collector suction valve.

Performed ____/____/____

4.2.8 Close the ball collector discharge valve and open the vent and drain valves.

Performed ____/____/____

4.2.9 Remove the sight glass cover, count the number of balls collected in the basket.

Total _________________ Performed ____/____/____

4.2.10 Backwash the Amertap screens in the strainer by rotating the hand wheels, marked upper and lower screens, clockwise until the shaft receeds into the housing.

Performed ____/____/____

4.3 Shut down BCM's per ANL Operating Procedure (TBD).

Performed ____/____/____

4.4 Notify Mate on duty of the pending shutdown of the warm water pump (P-101).

Notified ____/____/____

5. PUMP STOP

5.1 Decrease pump speed by decreasing FIC-101 pump power, as indicated on the black face output meter of FIC-101, to 20%.

20% ____/____/____

5.2 Press P-101 stop switch at the center console right of the CRT. The enable light should go "out" and the pump should stop.

Pump Stop ____/____/____

Date/Time/Initial

5.3 The mixed water pump sump level ILE-104) must be monitored to assure a level greater than 20 feet and a pump power greater than 40%. Adjust LIC-104 accordingly to maintain or if necessary shut down the mixed water pump per OTEC-1-OP-500.

Maintained ____/____/____

5.4 Mark Brush recorders with date, time, and event.

Performed ____/____/____

5.5 Open high point vent valves V-180 and V-187.

V-180 Open ____/____/____

V-187 Open ____/____/____

5.6 Notify Mate on duty of the intent to drain the evaporator into the aft observation space.

Notified ____/____/____

5.7 Open V-181, and 8" drain valve in the aft observation space, and drain the evaporator. Have ship's personnel in charge of pumping the bilge stand by during this operation.

Stand By ____/____/____

Drained ____/____/____

5.8 Open V-182 and V-185, 2" evaporator water box drains, and drain the water boxes.

Drained ____/____/____

5.9 Open the calibration "T" valves on transducer lines PE-7 (4 ea) and PE-8 (4 ea.) to drain water from these lines.

Drained ____/____/____

5.10 Drain instrumented loop lines (24 each).

Drained ____/____/____

5.11 Drain Amertap screen delta pressure gage by first opening the bypass valve and then opening the high and low drain valves simultaneously.

Drained ____/____/____

5.12 Drain the Amertap collection bowl (2 valves) for the evaporator.

Drained ____/____/____

Date/Time/Initial

5.13 Close the water flow valve for the pump seal. Located on the main deck, mid-ships house, overhead of air pack breathing air bottles.

Closed ____/____/____

6. Warm water system is now drained and shut down. For restart use Operating Procedure OTEC-1-OP-400.

Shift Leader: ______________________ Date: ____________

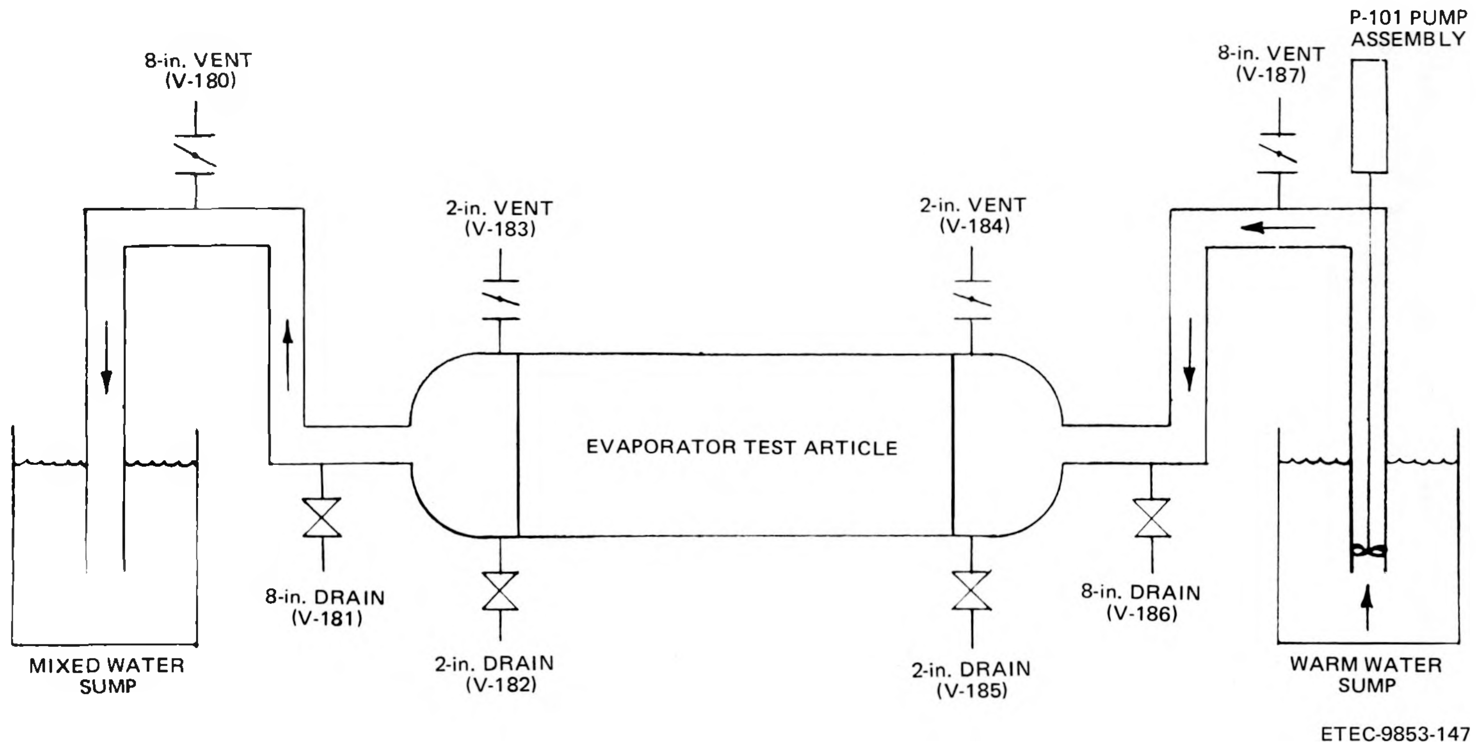


Figure C-1. OTEC-1 — Warm Water Test Loop Schematic

APPENDIX D

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-300

COLD WATER SYSTEM STARTUP

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to startup the OTEC-1 cold water system.

2. PREREQUISITES

2.1 The DAS and recording instrumentation must be in operation.

2.2 The 24 volt instrumentation power supply must be "ON".

2.3 The control air system must be in operation.

2.4 The oil level in the pump motor must be visible in the sight glass (ball floating).

3. REFERENCES

3.1 Water circulating system O&M Manual 4086-C401.

3.2 P&I 6850-93-PD-08 Sea Water Support Subsystem Diagram.

3.3 Chlorination Operating Procedure OTEC-1-OP-900.

3.4 Amertap System O&M Manual 4086-C403.

3.5 Amertap System SOP OTEC-1-OP-301.

4. PREPARATION — Date/Time/Initial

4.1 Check cold water inlet screens for cleanliness and inner most screen in down position.

Position/Cleaned ____/____/____

4.2 Seal cold water sump room. Verify all personnel clear of sump room.

Clear & Sealed ____/____/____

4.3 Close or verify closed the following valves.

4.3.1 V-177 and 8" drain valve on the condenser outlet pipe.

Closed ____/____/____

4.3.2 V-176 a 2" drain valve on the condenser outlet water box.

Closed ____/____/____

4.3.3 V-175 a 2" drain valve on the condenser inlet water box.

Closed ____/____/____

Date/Time/Initial

4.3.4 V-172 an 8" drain valve on the condenser inlet pipe.

Closed ____/____/____

4.3.5 Condenser pressure transducer drain valves for PE-12 (4 each) and PE-13 (4 each).

Closed ____/____/____

4.3.6 Condenser instrumented loop inlet valves (48 each) and outlet valves (48 each).

Closed ____/____/____

4.3.7 Amertap delta pressure gage drain lines (2 each).

Closed ____/____/____

4.3.8 Shut off air supply to Amertap ball bypass valve, locatted in aft observation space port side of lower air lock entrance.

Air Off ____/____/____

4.4 Open or verify open the following valves.

4.4.1 V-178 an 8" discharge high point vent valve.

Open ____/____/____

4.4.2 V-171 an 8" inlet high point vent valve.

Open ____/____/____

4.4.3 Amertap delta pressure gage, bypass line (1 each) and supply valves (2 each).

Open ____/____/____

4.4.4 Sea chest valve in mixed water sump stand pipe.

Open ____/____/____

4.5 Perform or verify performance of the following conditions.

4.5.1 Initiate pump seal lubrication by opening the water flow valve for the pump seal. Located on the main deck port side of cold water pump, overhead, under catwalk. Flush a toilet to verify the water supply is available.

Initiated ____/____/____

Water Supply OK ____/____/____

Date/Time/Initial

4.5.2 Amertap ball collecting screens are in the catch position.

Catch ____/____/____

4.6 Notify the following ship's stations and personnel of the pending start of the cold water pump.

4.6.1 Bridge - ship's captain or first mate.

Notified ____/____/____

4.6.2 Chief engineer. Notified ____/____/____

4.6.3 Electrical Room - ship's electrician to assign the SCR for the cold water pump.

Notified ____/____/____

4.7 After assignment of the SCR, the cold water pump air cooling fan should be running. If not, contact the shift leader.

Running ____/____/____

4.8 Deploy one person at each of the high point vent valves V-171 and equip them with walkie-talkies to notify the van when they are in position to operate the valves. Caution - Do not key walkie-talkies in the van. These operators are to close the valves when vacuum starts or when water starts to flow out of the valves.

Deployed ____/____/____

In Position ____/____/____

5. PUMP START

5.1 Set Beckman FIC-103 for 20 percent as indicated on the black face output meter.

20 Percent ____/____/____

5.2 Press P-103 enable switch at the center consol, right of the CRT. The enable switch should illuminate and the pump should rotate.

Switch "ON" ____/____/____

5.3 Increase pump power rapidly to 100 percent with FIC-103.

100 Percent ____/____/____

Date/Time/Initial

5.4 Close high point vent valves V-171 and V-178 after vacuum starts or water starts to flow out of the valves.

V-171 Closed ____/____/____

V-178 Closed ____/____/____

5.5 Once full flow is established, perform the following.

5.5.1 Bleed air from inlet water box high point 2" vent valve V-173.

Air Bled ____/____/____

5.5.2 Bleed air from outlet water box high point 2" vent valve V-174.

Air Bled ____/____/____

5.5.3 Bleed air from pressure transducer lines PE-12 (4 each) and PE-13 (4 each). PE-12-1 may have negative pressure.

Air Bled ____/____/____

5.5.4 Bleed trapped air from Amertap delta pressure gage and close bypass valve.

Air Bled ____/____/____

5.5.5 Open 48 condenser instrumented tube inlet valves and 48 outlet valves.

Performed ____/____/____

5.5.6 Start up Amertap system per SOP OTEC-1-OP-301.

Started ____/____/____

5.5.7 Perform chlorination of condenser per OTEC-1-OP-900. Coordinate this operation with AECOS representative.

Started ____/____/____

5.5.8 Start up BCM's and DAS program HTM.

Started ____/____/____

5.5.9 Start up instrumented tubes instrumentation and the associated program (TDB).

Started ____/____/____

Date/Time/Initial

6. Cold water system is now operational.

6.1 Notify the bridge that the cold water system is now on line.

Notified ____/____/____

6.2 For cold water system shut down procedure refer to OTEC-1-OP-300A.

6.3 Manual switch located on hand rail near pump is for local emergency shut down only and should only be used for emergency purpose.

Shift Leader: ________________________ Date: ____________________

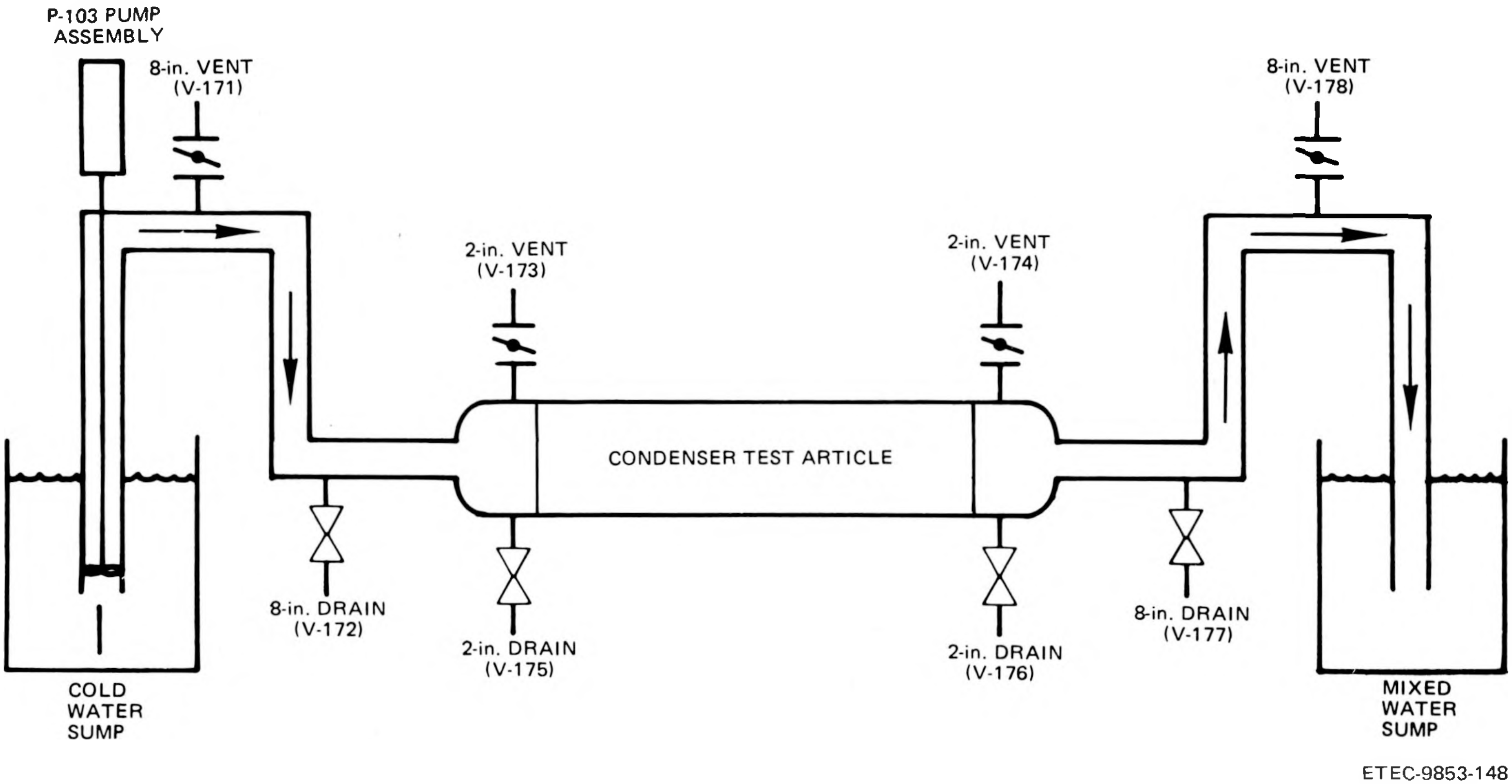


Figure D-1. OTEC-1 — Cold Water Test Loop Schematic

APPENDIX E

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-300A

COLD WATER SYSTEM SHUTDOWN

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to shut down the cold water system aboard the OEC.

2. PREREQUISITES

2.1 The DAS and recording instruments must be in operation.

3. REFERENCES

3.1 Water Circulating System O&M Manual 4086-C401.

3.2 P&I 6850-93-PD-08, Sea Water Support Subsystem Diagram.

3.3 DAS Operating Procedure P-070E-D40-S0017.

3.4 BCM Operating Procedure (TBD).

3.5 Cold Water System Startup SOP OTEC-1-OP-300.

3.6 Collection and Sizing the Amertap Balls SOP OTEC-1-OP-301A.

3.7 Mixed Water Discharge System Startup and Shutdown SOP OTEC-1-OP-500.

4. PREPARATION <u>Date/Time/Initial</u>

4.1 Perform an HTM summary per DAS Operating Procedure P-070E-D40-S0017, by executing program "RUN SUMMARY."

Performed ____/____/____

4.2 Collect the Amertap balls from the condenser by performing SOP OTEC-1-OP-301A.

4.2.1 Notify the mate on duty of the intent to increase condenser pump speed.

Notified ____/____/____

4.2.2 Increase the condenser pump P-103 to 85% power for ball collection and screen back washing.

85% ____/____/____

4.2.3 Notify the person in charge (PIC) that the condenser Amertap system will be off line.

Notified ______/______

4.2.4 Close the ball collector flap on the condenser ball collector basket.

Closed ____/____/____

Date/Time/Initial

4.2.5 Open the condenser Amertap ball bypass line, air actuated valve by opening the air valve located on the bulkhead in the aft observation compartment, left of the lower air lock door. After 5 minutes, close this air valve and open air vent valve to close the air actuated bypass valve. When closed, close air vent valve.

Performed ____/____/____

4.2.6 Collect the balls for a minimum of 1/2 hour, but no longer than 1 hour.

Time Start ____/____/____

Time Stop ____/____/____

4.2.7 Stop the condenser Amertap pump by pressing the stop button located on the rail nearest the pump and immediately close the ball collector suction valve.

Performed ____/____/____

4.2.8 Close the ball collector discharge valve and open the vent and drain valves.

Performed ____/____/____

4.2.9 Remove the sight glass cover, count the number of balls collected in the basket.

Total ____/____/____

Performed ____/____/____

4.2.10 Backwash the Amertap screens in the strainer by rotating the hand wheels, marked upper and lower screens, clockwise until the shaft receeds into the housing.

Performed ____/____/____

4.3 Shut down the BCM's per ANL Operating Procedure (TBD).

Performed ____/____/____

4.4 Notify mate on duty of the pending shut down of the cold water pump.

Notified ____/____/____

5. PUMP STOP

5.1 Decrease pump speed by decreasing FIC-103 pump power, as indicated on the black face output meter of FIC-103, to 20%.

Twenty Percent ____/____/____

Date/Time/Initial

5.2 Press P-103 stop switch at the center console, right of the CRT. The enable light should go "OUT" and the pump should stop.

Pump Stop ____/____/____

5.3 The mixed water pump sump level (LE-104) must be monitored to assure a level greater than 20 feet and a pump power greater than 40%. Adjust LIC-104 accordingly to maintain or if necessary shut down the mixed water pump per OTEC-1-OP-500.

Maintained ____/____/____

Shut Down ____/____/____

5.4 Mark Brush recorders with date, time, and event.

Performed ____/____/____

5.5 Open high point vent valves V-178 and V-171.

V-178 Open ____/____/____

V-171 Open ____/____/____

5.6 Notify mate on duty of the intent to drain the condenser into the aft observation space.

Notified ____/____/____

5.7 Open V-172, an 8" drain valve in the aft observation space, and drain the condenser. Have ship's personnel, in charge of pumping the bilge, stand by during this operation.

Stand By ____/____/____

Drained ____/____/____

5.8 Open V-175 and V-176, 2" condenser water box drains, and drain the water boxes.

Drained ____/____/____

5.9 Open the calibration "T" valves on transducer lines PE-12 (4 each) and PE-13 (4 each) to drain water from these lines.

Drained ____/____/____

5.10 Drain instrumented loop lines (24 each).

Drained ____/____/____

Date/Time/Initial

5.11 Drain Amertap screen delta pressure gage by first opening the bypass valve and then opening the high and low drain valves simultaneously.

Drained ____/____/____

5.12 Drain the Amertap collection bowl (2 valves) for the condenser.

Drained ____/____/____

5.13 Close the water flow for the pump seal, located on Main deck port side of cold water pump, overhead, under catwalk. DO NOT PERFORM THIS STEP IF THE MIXED WATER PUMP IS RUNNING.

Shut Off ____/____/____

Left On ____/____/____

6. The cold water system is now drained and shut down. For restart, use Operating Procedure OTEC-1-OP-300.

Shift Leader: ______________________ Date: ______________________

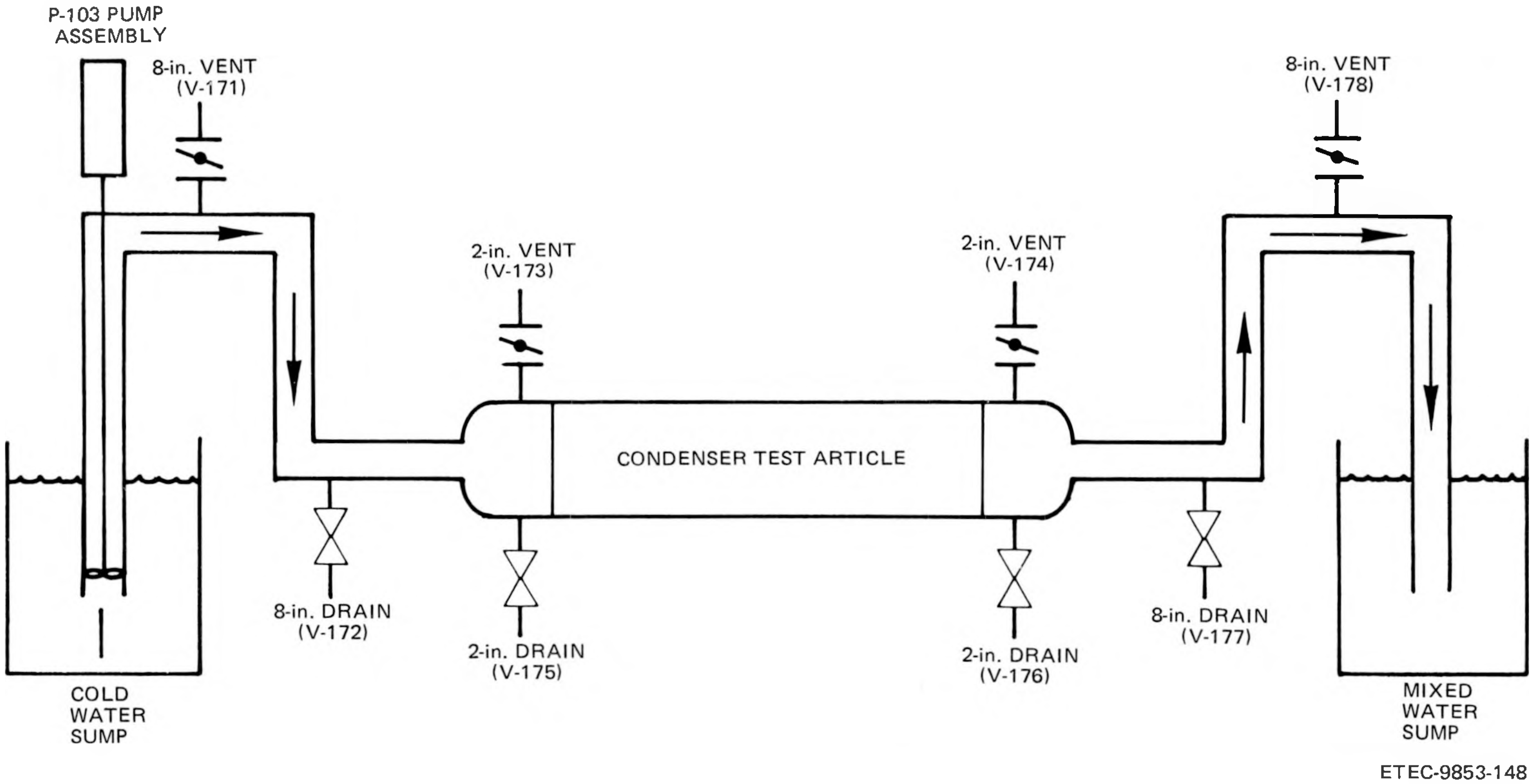


Figure E-1. OTEC-1 — Cold Water Test Loop Schematic

APPENDIX F

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-500

MIXED WATER DISCHARGE SYSTEM STARTUP

AND SHUTDOWN

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to start up the OTEC-1 mixed water system.

2. PREREQUISITES

2.1 The DAS and recording instrumentation must be in operation.

2.2 The 24 volt instrumentation power supply must be "ON".

2.3 The control air system must be in operation.

2.4 The oil level in the pump motor must be visible in the sight glass. (Ball Floating).

3. REFERENCES

3.1 Water Circulating System O&M Manual 4086-C401.

3.2 P&I 6850-93-PD-08 Sea Water Support Subsystem Diagram.

4. PREPARATION

Date/Time/Initial

4.1 Verify mixed water discharge pipe lid is secure and ready for operation.

Ready ____/____/____

4.2 If cold water pump and/or warm water pump is not operating, request Captain to initiate start of mixed water eductor system.

Started or DNA ____/____/____

4.2.1 When 10" of Hg vacuum is established, proceed to paragraph 4.5.3.

Vacuum ____/____/____

4.3 If cold water pump and/or warm water pump is operating, raise level in mixed water sump to 26 or more feet by increasing either cold or warm water pump power. Level is read on LE-104.

Level ____/____/____

Feet ____/____/____

4.4 Open or verify open the following valves.

4.4.1 V-188, an 8" discharge high point vent valve.

Open ____/____/____

Date/Time/Initial

4.4.2 V-178, an 8" inlet high point vent valve.

Open ____/____/____

4.4.3 Sea chest valve in mixed water sump stand pipe.

Open ____/____/____

4.5 Perform or verify performance of the following conditions.

5.4.1 Initiate pump seal lubrication by opening the water flow valve for the pump seal, located on main deck port side of cold water pump, over head, under catwalk. Flush a toilet to verify the water supply is available.

Initiated ____/____/____

Water Supply OK ____/____/____

4.6 Notify the following ship's stations and personnel of the pending start of the mixed water pump.

4.6.1 Bridge ---- ship's Captain or first mate.

Notified ____/____/____

4.6.2 Chief Engineer.

Notified ____/____/____

4.6.3 Electrical Room --- Ship's electrician to assign the SCR for the mixed water pump.

Notified ____/____/____

4.7 After assignment of the SCR, the mixed water pump air cooling fan should be running. If not, contact the shift leader.

Running ____/____/____

4.8 Deploy one person at each of the high point vent valves V-178 and V-188. Equip them with walkie-talkies to notify the van when they are in position to operate the valves. CAUTION --- Do not key walkie-talkies in the van. These operators are to close the valves when vacuum starts.

Deployed ____/____/____

In Position ____/____/____

5. PUMP START

Date/Time/Initial

5.1 Set Beckman LIC-104 for 20 percent as indicated on the black face output meter.

Twenty Percent ____/____/____

5.2 Press P-100 enable switch at the center console, right of the CRT. The enable switch should illuminate and the pump should rotate.

Switch "ON" ____/____/____

5.3 Increase pump power rapidly to 100 percent with LIC-104.

100 Percent ____/____/____

5.4 Close high point vent valves V-178 and V-188 after vacuum starts.

V-178 Closed ____/____/____

V-188 Closed ____/____/____

5.5 Do not allow the mixed water sump level to go below 18 feet as monitored on LE-104. Adjust pump power on cold, warm, and mixed water pumps to achieve 24 to 34 feet in mixed water sump.

Level ____/____/____

Feet ____/____/____

6. MIXED WATER SYSTEM IS NOW OPERATIONAL.

6.1 Notify the bridge that the mixed water system is now on line.

Notified ____/____/____

Shift Leader:______________________ Date:______________

7. FOR MIXED WATER SYSTEM SHUTDOWN PERFORM THE FOLLOWING:

7.1 Notify the following ship's stations and personnel of the pending shutdown of the mixed water system.

7.1.1 Bridge - ship's Captain or first mate.

Notified ____/____/____

7.2 Chief Engineer.

Notified ____/____/____

7.1.3 Electrical Room - Ship's Electrician.

Notified ____/____/____

Date/Time/Initial

7.2 Decrease LIC-104 to 20 percent.

Twenty Percent ____/____/____

7.3 Press P-100 stop switch at the center console, right of the CRT. The enable light in the switch should go "OUT" and the pump should stop.

Pump Stop ____/____/____

7.4 Decrease cold water and warm water pump power on FIC-103 and FIC-101, respectively. Maintain a 24 to 34 foot level in the mixed water sump as read on LIC-104.

Level ____/____/____

Feet ____/____/____

7.5 Open high point vent valves V-178 and V-188 to drain mixed water discharge pipe. Maintain mixed water sump level as per above step.

V-178 Open ____/____/____

V-188 Open ____/____/____

8. MIXED WATER PUMP IS NOW SECURE.

8.1 Notify the bridge that the mixed water system is now on line and to ballast accordingly.

Notified ____/____/____

Shift Leader: ______________________ Date: ________________

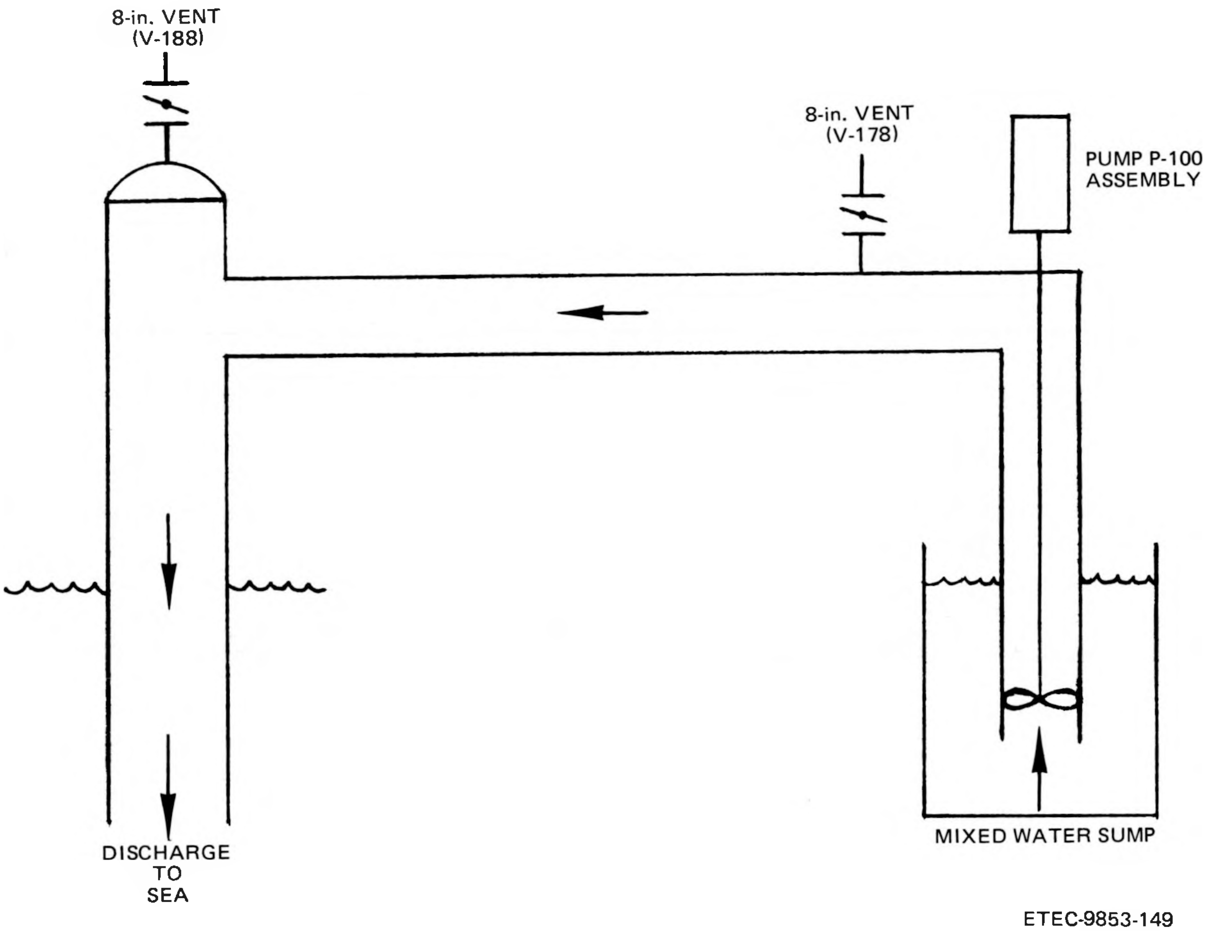


Figure F-1. OTEC-1 — Deepwater Discharge Loop Filling Schematic

APPENDIX G

OCEAN THERMAL ENERGY CONVERSION — 1

LABORATORY ANALYSIS REPORTS OF
ANHYDROUS AMMONIA FROM THE OEC

GLOBAL MARINE DEVELOPMENT INC.

P.O. BOX 3010
NEWPORT BEACH, CALIFORNIA 92663

TELEPHONE 714-752-5050
TELEX 69-2316
CABLE GLOMARDEV
OFFICE 2302 MARTIN ST
IRVINE, CA 92715

August 25, 1980

RECEIVED
AUG 28 1980
DRF 3772

541-80.08.14

Fred Poucher
ETEC
PO Box 1449
Canoga Park, CA 91304

Dear Fred:

Enclosed please find a copy of the Water Concentration Analysis of the ammonia onboard the Ocean Energy Converter.

Sincerely yours,

Jeff Taylor
Project Engineer

BREWER ANALYTICAL LABORATORIES Encl. to DRF 3772

a Department of Brewer Chemical Corporation

TELEPHONE: 533-4411
311 PACIFIC STREET P. O. BOX 46
HONOLULU, HAWAII 96810

August 8, 1980

Mr. Jeff Taylor
EMDI
P. O. Box 4953
Kawaihae, HI 96743

Dear Jeff:

I relayed the results of the analysis to your office by phone. Sorry I didn't realize you would be on the ship from the day after we sampled. Our lab is sending a written report on the analysis.

The residue we got after the evaporation procedure gave a .18% moisture reading. This actually includes some black solids that appeared in the test container along with the sample. I suspect that we picked up this debris from the sampling line we fabricated.

This problem will be solved in the future by the use of these stainless steel fittings I am sending you. I am including a portion of tygon tubing with the fittings. Hopefully, this will make it easier to purge the system adequately prior to sample collection.

We are looking forward to serving your future testing needs.

Sincerely,

Tai Khan

Tai Khan
Laboratory Sales Engineer

TK:su

BREWER ANALYTICAL LABORATORIES

A Department of Brewer Chemical Corporation

TELEPHONE: 533-4411
311 PACIFIC STREET P. O. BOX 48
HONOLULU, HAWAII 96810

1. Sampling - sampling was done on board S/S Ocean Energy Converter on July 26, 1980 by Jeff Taylor (GMDI) and Tai Khan(Brewer Analytical Lab). Some used fittings were used in fabricating the line between the storage tank and sample cylinder. System was purged but perhaps inadequately. Also a separate purge valve was not available on the sampling line.

2. Results - % water analysis of anhydrous ammonia from S/S Ocean Energy Converter

Anhydrous Ammonia purity = 99.82%
% H_2O = .18

Remarks:

1. Small chunks of solids appeared in the test container. This probably accounted for high water % and low purity percentages.

2. It's very likely the sampling line was not adequately purged prior to sample collection. Some old fittings were used on sample collection line. This could be the source of solids impurities.

3. Shipment - because anhydrous ammonia is a restricted item by IATA rules, it could not be flown via passenger airline. Being on a weekend, the DHL cargo office at Kona Airport was closed. The sample did not arrive in the lab until 7/31/80. However, this should not have any effect on the results.

4. Retesting is recommended.

BREWER ANALYTICAL LABORATORIES
a Department of Brewer Chemical Corporation
P.O. BOX 48, HONOLULU, HAWAII 96810, TELEPHONE 533-4411

JOB NO. ______
DATE 2/04/81
PAGE ______ OF ______

LABORATORY ANALYSIS REPORT

TO: E T E C ATTN.: Mr. Bob Hoshide
ADDRESS: OTEC-I Project, Kawaihae, HI 96743 PHONE:
SAMPLES OF: anhydrous ammonia from ocean enegy converter

SAMPLED BY: TKhan & BHoshide SAMPLING DATE: 1/29/81 TIME: 10:00 am
RECEIPT DATE: 1/31/81 TIME: 6:00 a.m.

DATE SAMPLE ANALYZED		1/31/81	2/02/81			
TIME SAMPLE ANALYZED		6:00am	1:00 pm			
SAMPLE TYPE						
SAMPLE DESCRIPTION	UNITS	1st Test	2nd Test	Average		
Water	% wt.	0.89	1.07	0.98		
Oil and Grease	ppm	321.6	349.0	335.3		

LABORATORY REMARKS: Procedures from "Encyclopedia of Industrial Chemical Analysis" Vol. 5, pp 313-314.

cc: Chandar Panchal
Bldg. 362, 9700 S. Cass Avenue
Argonne, IL 60439

Tai Khan

BREWER ANALYTICAL LABORATORIES
a Department of Brewer Chemical Corporation
P.O. BOX 48, HONOLULU, HAWAII 96810, TELEPHONE 533-4411

JOB NO. ____
DATE 3/06/81
PAGE ____ OF ____

LABORATORY ANALYSIS REPORT

TO: Rockwell International ATTN.: Mr. Jack Robeson
ADDRESS: c/o OTEC I, Kawaiahae 96743 PHONE:
SAMPLES OF: anhydrous ammonia

SAMPLED BY: ____ SAMPLING DATE: 2/16/81 RKH TIME: 1200HR RKH
RECEIPT DATE: 2/18/81 TIME:

DATE SAMPLE ANALYZED		2/25/81				
TIME SAMPLE ANALYZED		9:00 am				
SAMPLE TYPE						
SAMPLE DESCRIPTION	UNITS					
Water	%	.62				
Oil and Grease	mg/L	716.0				

LABORATORY REMARKS:

Estelle N. Shiroma

BREWER ANALYTICAL LABORATORIES
a Department of Brewer Chemical Corporation
P.O. BOX 48, HONOLULU, HAWAII 96810, TELEPHONE 533-4411

JOB NO. ____
DATE 3/06/81
PAGE ____ OF ____

LABORATORY ANALYSIS REPORT

TO: Rockwell International ATTN.: Mr. Jack Robeson
ADDRESS: OTEC I, Kawaihae, HI 96743 PHONE:
SAMPLES OF: anhydrous ammonia - Tank I

SAMPLED BY: ____ SAMPLING DATE: 2/21/81 TIME: ____
RECEIPT DATE: 2/25/81 TIME: ____

DATE SAMPLE ANALYZED		2/26/81				
TIME SAMPLE ANALYZED		9:00 a.m.				
SAMPLE TYPE						
SAMPLE DESCRIPTION	UNITS	T-1 Tank				
Water	%	.49				
Oil and Grease	ppm	865.5				

LABORATORY REMARKS: ____

Estelle N Shiroma

ETEC-82-19

BREWER ANALYTICAL LABORATORIES
a Department of Brewer Chemical Corporation
P.O. BOX 48, HONOLULU, HAWAII 96810, TELEPHONE 533-4411

JOB NO. 2316
DATE 3/06/81
PAGE ______ OF ______

LABORATORY ANALYSIS REPORT

TO: Rockwell International ATTN.: Mr. Jack Robison
ADDRESS: c/o OTEC I, Kawaiahae 96743 PHONE:
SAMPLES OF: anhydrous ammonia from OTEC I (T-1 Bottom)

SAMPLED BY: SAMPLING DATE: 2/27/81 TIME: 2100
RECEIPT DATE: 3/04/81 TIME: 1200

DATE SAMPLE ANALYZED		3/06/81				
TIME SAMPLE ANALYZED		9:30am				
SAMPLE TYPE						
SAMPLE DESCRIPTION	UNITS	T-1 Bottom				
Water	%	.34				

LABORATORY REMARKS: Sample has a very light green color. Earlier samples appeared yellowish brown with black residue that stuck to the sides of the test vessel. Only 65 ml of sample was used for actual analysis. (75 ml/sample bomb)

BREWER ANALYTICAL LABORATORIES
a Department of Brewer Chemical Corporation
P.O. BOX 48, HONOLULU, HAWAII 96810, TELEPHONE 533-4411

JOB NO. ______
DATE 6/02/81
PAGE ______ OF ______

LABORATORY ANALYSIS REPORT

TO: Rockwell International ATTN.: Mr. Bob Hoshide
ADDRESS: 8900 DeSoto Avenue, Canoga Park PHONE:
SAMPLES OF: anhydrous ammonia from OTEC 1

SAMPLED BY: Tai Khan SAMPLING DATE: 4/27/81 TIME: 9:00 am
RECEIPT DATE: 4/27/81 TIME:

DATE SAMPLE ANALYZED						
TIME SAMPLE ANALYZED						
SAMPLE TYPE						
SAMPLE DESCRIPTION	UNITS	% Moisture				
Anhydrous Ammonia		*				

LABORATORY REMARKS: *Due to excessive oil transferred to sample cylinder from tank bottom, no moisture determination could be performed.

Estelle N. Shiroma

BREWER ANALYTICAL LABORATORIES
a Department of Brewer Chemical Corporation
P.O. BOX 48, HONOLULU, HAWAII 96810, TELEPHONE 533-4411

JOB NO. ______
DATE 6/02/81
PAGE ____ OF ____

LABORATORY ANALYSIS REPORT

TO: Rockwell International ATTN.: Mr. Bob Hoshide
ADDRESS: 8900 DeSoto Avenue, Canoga Park PHONE:
SAMPLES OF: anhydrous ammonia from OTEC 1.

SAMPLED BY: Tai Khan SAMPLING DATE: 5/26/81 TIME: 11:00 am
RECEIPT DATE: 5/26/81 TIME:

DATE SAMPLE ANALYZED		5/28/81				
TIME SAMPLE ANALYZED						
SAMPLE TYPE						
SAMPLE DESCRIPTION	Tests ~~UNITS~~	%				
% Moisture	1	.53				
% Moisture	2	.53				

LABORATORY REMARKS: Duplicate tests were run giving the same result. Prior to sampling, lines were thoroughly purged to eliminate oil from getting into sample cylinder.

Estelle N. Shiroma

APPENDIX H

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-810

AMMONIA SAMPLE COLLECTION

GENERAL

This procedure has been prepared and modified from knowledge and information gained by actual experiences in obtaining ammonia samples from the ammonia system on the Ocean Energy Converter. Problems encountered included failure of the safety valve on the sample cylinder and contamination in the sampled ammonia. This procedure has been developed by ETEC to minimize ammonia sample contamination and sample cylinder rupture disk failures. Samples were taken at the liquid level sensor high pressure legs of the ammonia drain tank (T-1) and aft storage tank (T-402). The relux pump (either P-1 or P-2) would be started and operated for about 20 minutes prior to taking the sample from the drain tank to assure mixing of the ammonia.

PROCEDURE

1. Obtain tools and equipment including certified sample cylinder (1/2 liter size), drain line (8 ft long), stainless steel fittings, etc.

2. Obtain 5 gallon bucket with 3/4 full of water.

3. Weight outlet of drain line with at least 4 lb weight and submerse outlet to bottom of water bucket. Be sure weight is securely atttached to outlet of drain line.

4. While obtaining ammonia sample, wear gas mask and rubber gloves. Also have a backup person on standby with same safety equipment.

5. Remove cap from bleed valve and connect 1/2-in.-diameter tygon tube drain line to bleed valve (see Figure 1).

6. Crack bleed valve and bleed contaminents, if any, into bucket of water. Be careful since the valve may be plugged. Drain until clean liquid ammonia flows through the drain line.

7. Close bleed valve and remove drain line. Be careful since ammonia will be left in the drain line.

8. Install stainless steel U-tube tubing, sample cylinder (vertical position) with both inlet and outlet valves closed, and drain line with outlet in bucket of water (see Figure 2).

9. Open bleed valve and check for leaks.

10. Open sample cylinder inlet valve.

11. Close sample cylinder inlet valve.

12. Open sample cylinder outlet valve and bleed gaseous ammonia into the bucket of water.

13. Close sample cylinder outlet valve. Be sure to close this valve before water from the bucket works itself back up the tygon drain line.

14. Repeat steps 10, 11, 12 and 13.

15. Open sample cylinder inlet valve.

16. Crack sample cylinder outlet valve and slowly bleed gaseous ammonia through the loop and into the bucket of water.

17. Wait until liquid ammonia flows through the drain line, then close bleed valve and wait 5 minutes.

18. Close sample cylinder inlet valves.

19. Wait until the liquid level in the sample cylinder is 1/2 to 3/4 full, then close the sample cylinder outlet valve. Liquid level is determined by observing frost buildup on the O.D. of the cylinder. Be sure to prevent water from the bucket to work itself up the drain line. If water starts working back into the drain line before 1/2 full level is obtained, remove drain line from water bucket.

20. Observe sample cylinder liquid level which will again be well defined by frost melt at the O.D. of the cylinder. This level should be 1/2 to 3/4 of the cylinder volume.

21. Remove drain line and crack U-tube fitting to clear this tubing. It will take about 5 minutes since this tubing is filled with liquid ammonia.

22. Once the ammonia has cleared out of the tube, remove the sample cylinder and deliver it to the Test Director.

23. The Test Director will identify the cylinder giving sample location, date and time obtained. Caution must be exercised at all times when handling the ammonia cylinder.

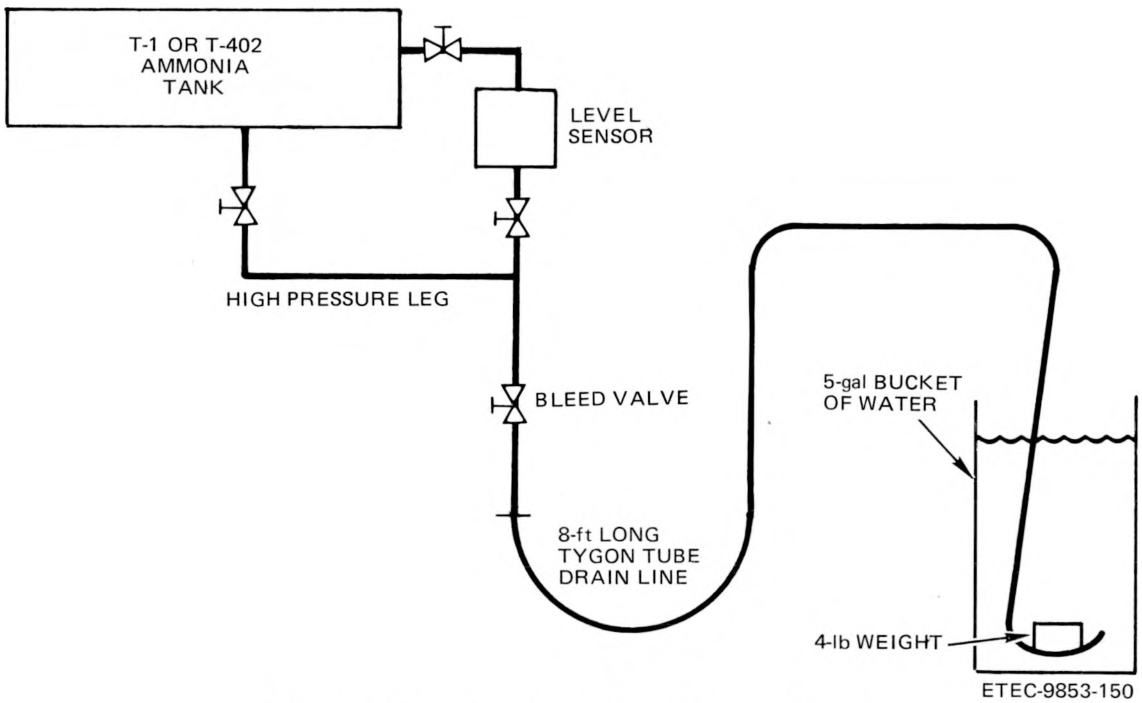


Figure H-1. Setup for Bleeding Ammonia

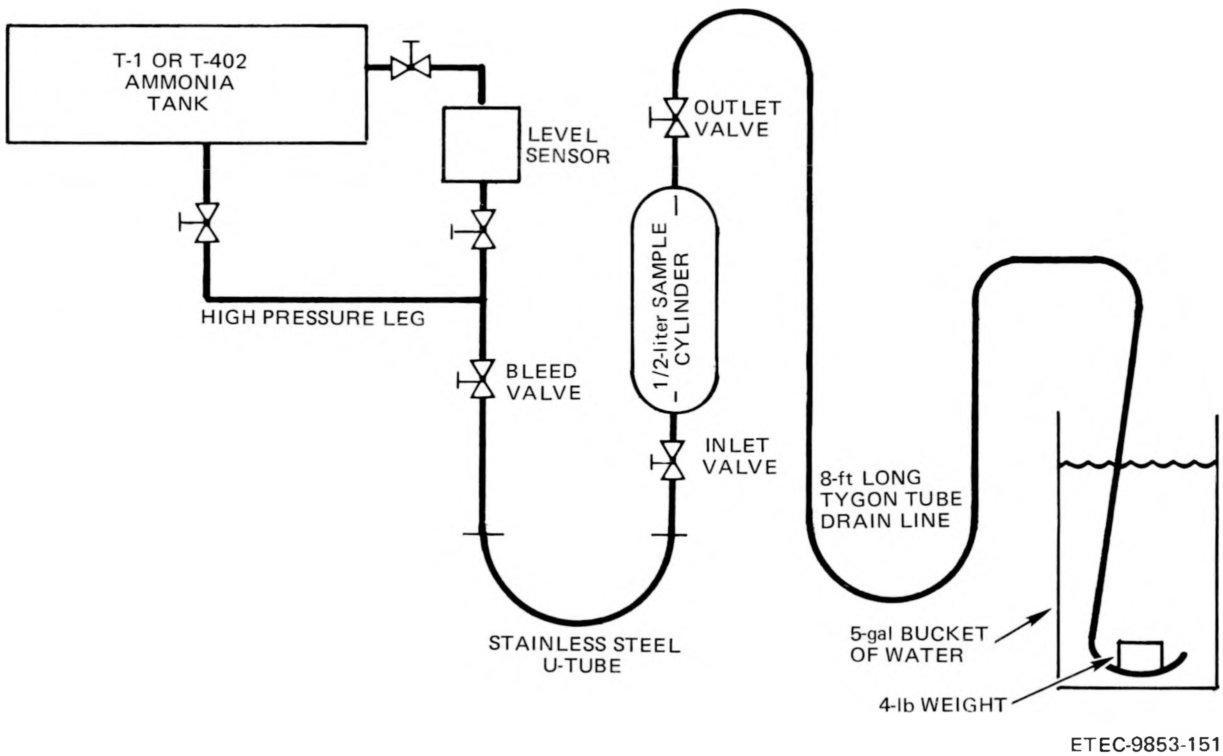


Figure H-2. Setup for Obtaining Ammonia Sample

APPENDIX I

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-301

EVAPORATOR/CONDENSER AMERTAP SYSTEM

(Circle Applicable System)

PURPOSE

The objective of this procedure is to bring on line the Amertap system for the evaporator/condenser.

REFERENCES

1. 6850-93-ES-13, Electrical Interface Control Schematic Evaporator Amertap Subsystem.

2. 6850-93-ES-14, Electrical Interface Control Schematic Condenser Amertap Subsystem.

3. 6850-93-PD-05, Evaporator Amertap Biofouling Control Subsystem Piping and Inst. Dia.

4. 6850-93-PD-10, Condenser Amertap Biofouling Control Subsystem Piping and Inst. Dia.

5. 4086-C403, Amertap System Operating and Maintenance Manual for the OTEC-1.

6. 1679/00/025, Amertap Corp. Operating and Maintenance Technical Manual

PREREQUISITES

1. The warm/cold water system must be in operation per Procedure OTEC-1-OP-400/OTEC-1-OP-300.

2. The DAS and recording instrumentation must be in operation.

3. The recirculating pump gear box oil at the required level.

PROCEDURE		Date/Time/Initial
1.0	Close or verify closed the ball collector discharge valve.	____/____/____
1.1	Close or verify closed the ball collector flap.	____/____/____
1.2	Close or verify closed the ball collector suction valve.	____/____/____
1.3	Close or verify closed the ball collector drain valve.	____/____/____
1.4	Close or verify closed the Amertap bypass valve.	____/____/____

Date/Time/Initial

1.5 Close or verify closed the upper screens in the strainer, at the evaporator/condenser outlet, rotate the hand wheel counter-clockwise until shaft hits the stop.

____/____/____

1.6 Close or verify closed the lower screens in the strainer, at the evaporator/condenser outlet, rotate the hand wheel counter-clockwise until shaft hits the stop.

____/____/____

1.7 Close or verify closed the shut-off flap in the strainer at the evaporator/condenser outlet.

____/____/____

1.8 Close or verify closed the throttle flap in the strainer at the evaporator/condenser outlet.

____/____/____

1.9 Open or verify open the valves (2 ea.) in the ball injection lines at the inlet of the evaporator/condenser and the deflector in the ball distributor is set in the center.

____/____/____

2.0 Open or verify open the valves (2 ea.) at the ball distributor in outlet line of the evaporator/condenser, and deflector is set in the center.

____/____/____

2.1 Remove the ball collector cover and place 600 balls in the basket, reinstall the cover.

____/____/____

2.2 Open the ball collector discharge valve and allow the water to enter the collector, close the vent when the collector is full of water.

____/____/____

2.3 Close or verify closed the breaker, located in the midship house switch gear room, marked evap. Amertap ball recirc. pump, P-351/evap. Amertap ball recirc. pump, P-301/cond.

____/____/____

2.4 Open the ball collector suction valve and contact the control van to start the pump by pressing the start button marked P-351/P-301, allowing the water to circulate through the basket.

____/____/____

NOTE

A stop only button is located at the pump.

Date/Time/Initial

2.5 Before releasing the balls into the system, verify the pressure differential across the evaporator/condenser is greater than 2.45 psid/2.62 psid, subtract the reading of PE8-3/PE12-3 from PE7-3/PE13-3 for the delta pressure, notify the PIC if the delta pressure is less.

___/___/___

2.6 Allow the water circulation to continue for fifteen minutes to remove the air from the balls.

___/___/___

2.7 After fifteen minutes of circulation, shut off the pump and close the suction valve, if the balls sink, all the air has been expelled. If the balls continue to float, repeat step 2.4.

___/___/___

2.8 When all the air is expelled from the balls, with the water circulating, open the ball collector flap (up position), allowing the balls to circulate through the system, and leave the collection flap full open.

___/___/___

2.9 Observe the sight glass cover on the ball collector and verify the balls are returning through the piping and pump.

___/___/___

3.0 Open the cover on the ball monitor and set the switch to manual position and press the reset button, after ten minutes, verify that the ball count is at least 90% of 600 balls per five minutes, set the switch to automatic after satisfactory manual performance, and secure the cover.

___/___/___

CAUTION

The cover will not close with the switch in manual.

3.1 Verify that the balls are flowing equally in both injection lines at the diverters. This is a visual verification. Manual adjustments can be made with the diverter vane.

___/___/___

3.2 Check the pressure differential across the screens at the delta pressure gage located by the Amertap strainer evaporator/condenser outlet. When the screens are closed and in a clean condition, the differential pressure should not exceed 22"/14" of water. If the delta pressure reaches 26"/20" notify PIC. Balls should be collected and screens backwashed. If the delta pressure reaches 30"/24", notify PIC and immediately backwash without collecting the balls.

___/___/___

Shift Leader ________________ Date ______________

APPENDIX J

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-301A

COLLECTION AND SIZING THE AMERTAP BALLS

IN EVAPORATOR/CONDENSER

(Circle Applicable System)

PURPOSE

The objective of the procedure is to collect, count, and size the Amertap balls and recharge the system.

REFERENCES

1. 6850-93-ES-13, Electrical Interface Control Schematic Evaporator Amertap Subsystem.

2. 6850-93-ES-14, Electrical Interface Control Schematic Condenser Amertap Subsystem.

3. 6850-93-PD-05, Evaporator Amertap Biofouling Control Subsystem Piping and Inst. Dia.

4. 6850-93-PD-10, Condenser Amertap Biofouling Control Subsystem Piping and Inst. Dia.

5. 4086-C403, Amertap System Operating and Maintenance Manual for the OTEC-1.

6. 1679/00/025, Amertap Corp. Operating and Maintenance Technical Manual.

PREREQUISITES

1. The warm/cold water system must be in operation per Procedure OTEC-1-OP-400/OTEC-1-OP-300.

2. The Amertap System must be in operation per Procedure OTEC-1-OP-301.

3. The DAS and recording instrumentation must be in operation.

4. Increase the evaporator/condenser pumps P-101/103 to 100% power for ball collection or screen back washing.

PROCEDURE — Date/Time/Initial

1.0 Notify PIC that the evaporator/condenser Amertap system will be off line.

____/____/____

1.1 Close the ball collector flap on the ball collector. This allows the balls to be collected in the basket with the water circulating.

____/____/____

1.2 Open the evaporator/condenser Amertap ball bypass line valve by opening the air valve located on the bulkhead in observation compartment left of lower air lock door. After 5 minutes, close air valve and open vent to close bypass valve.

____/____/____

Date/Time/Initial

1.3 Collect the balls for a minimum of 1/2 hour and maximum of one hour.

____/____/____

Time Start ________________ Time Stop ________________

1.4 Stop the pump by pressing the stop button located on the rail by the pump. Immediately close the ball collector suction valve.

____/____/____

1.5 Close the ball collector discharge valve. Open the vent and drain valves.

____/____/____

1.6 Remove the sight glass cover. Count the number of balls in the basket. Total _________.

____/____/____

1.7 Using the ball gage, check the ball size. The ball gage has holes equal in diameter to the inside diameter of the tubes. Balls that go through the holes are worn down and are ineffective, and must be removed from circulation. Record the count.

Number Returned______ Number Undersize______ ____/____/____

1.8 Charge the collector with used and new balls to a total of 600. Reinstall the cover.

____/____/____

1.9 Close the drain valve, open the ball collector discharge valve and allow water to enter the collector. Close the vent valve when the collector is full of water.

____/____/____

2.0 Open the ball collector suction valve and contact the control van to start the evaporator/condenser pump by pressing the start button marked P-351/P-301, allowing the water to circulate through the basket.

____/____/____

NOTE

A stop only button is located at the pump.

2.1 Allow the water circulation to continue through the ball collector for fifteen minutes to remove the air from the balls.

____/____/____

2.2 Backwash the screens in the strainer by rotating the hand wheels marked upper and lower screens, clockwise until the shaft recedes into the housing.

____/____/____

Date/Time/Initial

2.3 A backwashing period of five to ten minutes is normally sufficient. Turn the hand wheels counter clockwise until the shafts hit the stops, closing both the upper and lower screens. ____/____/____

NOTE

The pressure differential across the screens is normally 22" on the evaporator, 14" on the condenser.

2.4 After fifteen minutes of circulation, shut off the pump and close the suction valve. If the balls sink, all the air has been expelled. If the balls continue to float, repeat step 2.0. ____/____/____

2.5 When all the air is expelled from the balls, restart the pump as in step 2.0. With the water circulating, open the ball collector flap (up position), allowing the balls to circulate through system, and leave the collection flap full open. ____/____/____

2.6 Observe the sight glass cover on the ball collector and verify the balls are returning through the piping and pump. ____/____/____

2.7 Open the cover on the ball monitor, set the switch to manual position and press the reset button. After ten minutes, verify that the ball count is at least 90% of 600 balls per five minutes, set the switch to automatic after satisfactory manual performance, and secure the cover.

CAUTION

The cover will not close with the switch in manual.

____/____/____

Shift Leader ____________________ Date ______________

APPENDIX K
OCEAN THERMAL ENERGY CONVERSION — 1
STANDARD OPERATING PROCEDURE

OTEC-1-OP-900
CHLORINATION SYSTEM

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to start up, operate, and stop the OTEC-1 chloropac system.

2. PREREQUISITES

2.1 The warm water pump P-101 and/or the cold water pump P-103 must be in operation per SOP OTEC-1-OP-400 and OTEC-1-OP-300.

2.2 The mixed water pump P-100 must be in operation per SOP OTEC-1-OP-500.

2.3 The DAS and recording instrumentation must be in operation.

2.4 The chlorine analyzers for both warm and cold water systems must be operational.

3. REFERENCES

3.1 Chloropac Seawater Supply Pump O&M Manual 4086-C402 7/31/80.

3.2 6850-93-ES-04 Elect. Interface Control Schematic for Condenser Cold Water Pump P-103.

3.3 6850-93-ES-PD-06 chlorination biofouling control subsystem piping and instrument diagram.

3.4 6850-93-ES-PD-08 D seawater support subsystem piping and instrument diagram.

3.5 6850-93-ES-PD-12 condenser test loop piping and instrument diagram.

3.6 850-93-PD-13 biofouling module installation piping and instrument diagram.

4. PREPARATION

Verify or set the condition of the following valves:

4.1 V-201 seawater supply valve open. Located on forward weather deck starboard of warm water pump.

Open ________________

4.2 V-202 warm water return valve for evaporator chlorination. Must be open. For condenser chlorination it must be closed. Located under catwalk port side of warm water pump.

Open ________________
Or
Closed ________________

4.3 V-208 cold water return valve---closed for evaporator chlorination, open for condenser chlorination. Located port side of cold water pump.

Open ________________
Or
Closed ________________

4.4 Duplex strainer filter isolation valves open (No I/D), located in bilge of forward pump room.

Open ________________
Or
Closed ________________

4.5 Seawater valve to heater chiller should be open if heater chiller is in operation. Location in forward pump room.

Open ________________
Or
Closed ________________

4.6 Chlorinator seawater supply valves port and starboard should be open. Located inboard of chloropac unit.

Open ________________

4.7 Chloropac evaporator outlet valve for evaporator chlorination should open. For condenser chlorination it should be closed. Located forward end of chloropac unit on the port side.

Open ________________
Or
Closed ________________

4.8 Chloropac condenser outlet valve for condenser chlorination should be open. For evaporator chlorination it should be closed. Located forward end of chloropac unit starboard side.

Open ________________
Or
Closed ________________

4.9 Chloropac breaker "ON". Located in M. G. room in midship house.

On ________________

4.10 Switch pump motor starter breaker to "ON". Located at port side forward on chloropac.

On ________________

4.11 At chloropac to be used, verify circuit breaker CB-2, CB-3, and CB-4 are "ON". Located aft on chloropac in control cabinet.

On ________________

4.12 Close door on control cabinet. Closed ______________

5. OPERATION

5.1 Press the pump start switch located between the two chloropac control boxes.

On ______________

5.2 At the DAS in the I&C van record both flows as follows:

Evaporator FE-201 Seq No. 121 ___________ gpm

Condenser FE-202 Seq No. 120 ___________ gpm

5.3 At the duplex strainer filter, located in the bilge of the forward pump room, record the delta pressure reading.

___________ psid

NOTE: If delta press is 6.0 PSID or greater notify shift leader.

5.4 Energize power switch on right hand side of control box, located aft on chloropac unit in use.

On ______________

5.5 Wait approximately 20 seconds and the status "normal" lamp will light. If not, de-energize power switch and notify shift leader.

Lamp Lit ______________

5.6 Record D.C. amps as indicated on ampmeter in control cabinet

___________ AMPS

f.7 Record D.C. volts as indicated on voltmeter in control cabinet.

___________ VOLTS

5.8 Record date_____________and Time _________Operator ____________

5.9 Notify AECOS that chlorination of evaporator or condenser has started. Give him the amperage, flow rate, and start time of chlorination. He will notify you of the chlorine concentration in ppm.

___________ ppm

5.10 Chlorinate system for one hour and check with AECOS to be sure they have obtained their required samples before stopping system.

6. STOP PROCEDURE

6.1 At the chloropac in use, de-energize the power switch on right-hand side on respective control box.

Off ______________

Time ______________

6.2 On the chloropac at the port side, forward, push the "STOP" button.

Stop ______________

6.3 At the same location turn "PUMP MOTOR STARTER" breaker to "OFF".

Off ______________

DO NOT CLOSE OR REPOSITION ANY VALVES

Shift Leader: ______________________________ Date: ________________

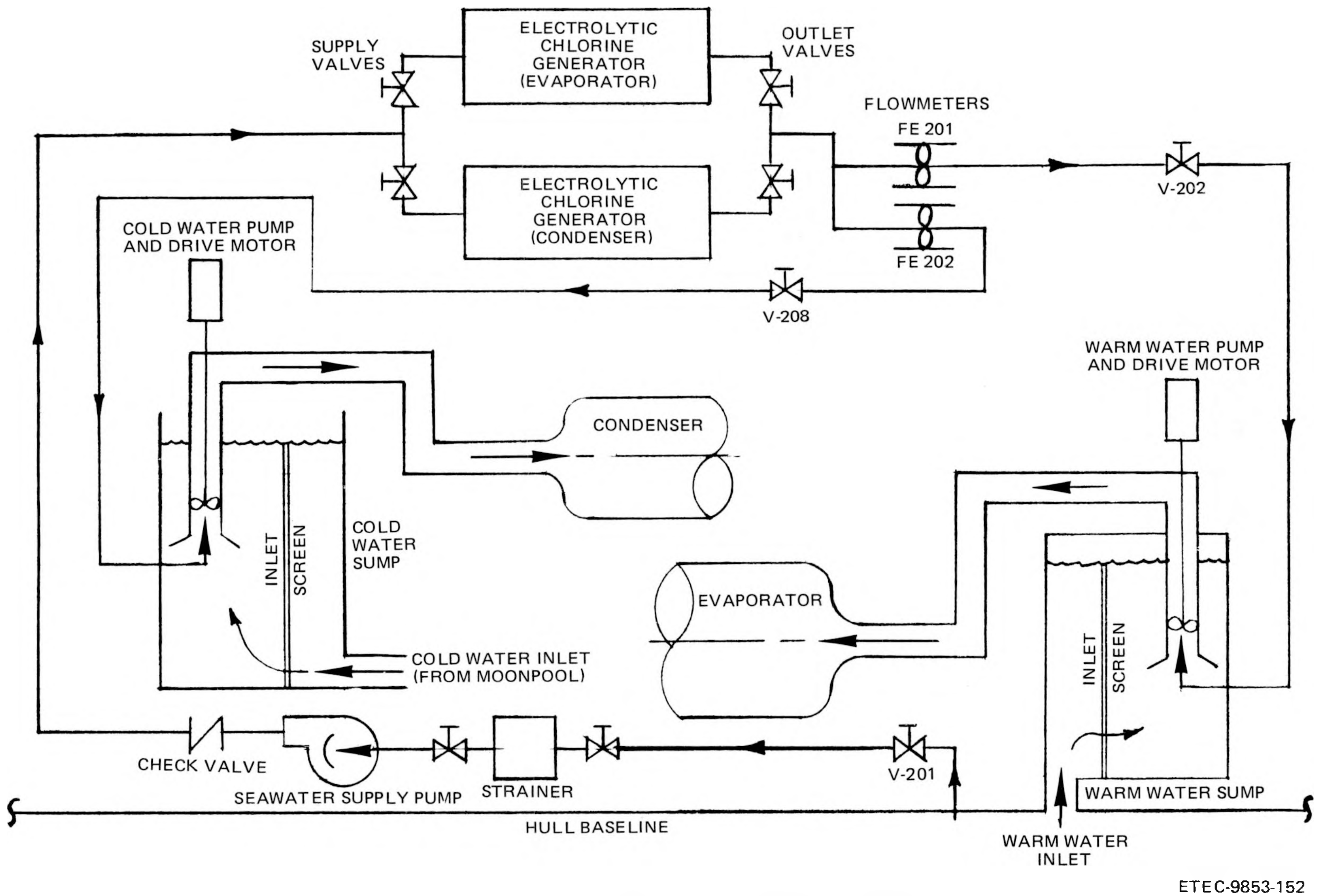


Figure K-1. OTEC-1 Chlorination System

APPENDIX L

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-1120

OTEC-1 ICE BATH PREPARATION AND QUARTZ THERMOMETER CALIBRATION CHECK PROCEDURE

1. INTRODUCTION AND DESCRIPTION

1.1 Scope

This procedure provides instructions necessary to prepare a 32°F ice bath for checking the calibration of the Hewlett Packard Quartz Crystal Thermometer (HP model 2804A) aboard the Ocean Energy Converter (OEC).

1.2 Applicable Documents

1.2.1 "Operating and Service Manual, 2804B Quartz Thermometer," HP 2804A, Hewlett Packard Co., Mountain View, California, 1978.

1.3 Description

1.3.1 Figure 1 is a sketch of the ice bath.

2. REQUIREMENTS

2.1 A high quality ice bath prepared with care, and using distilled water and distilled water ice are required to check the calibration of the quartz thermometer.

2.2 Equipment Requirements

2.2.1 Distilled water.

2.2.2 Plastic ice trays covered with plastic wrap.

2.2.3 Ice crusher.

2.2.4 1/2 inch diameter by 1-1/2 ft long glass or plastic rod.

2.2.5 1 qt wide mouth Dewar flask or thermos.

2.2.6 Isopropyl alcohol.

2.2.7 Quartz probe.

2.2.8 Quartz probe readout instrumentation.

3. PREREQUISITES

3.1 Prepare ice bath in a clean environment aboard the Ocean Energy Converter.

4. SPECIAL PRECAUTIONS

4.1 Care must be taken in handling the quartz probe because it is very fragile. See precautions in manual for Hewlett Packard Moodel 2804A quartz thermometer.

5. PROCEDURE

5.1 Power up quartz thermometer with probe attached to 180 ft RG59U wire with in-line oscillator.

5.2 Wash your hands thoroughly to remove any salts and contamination.

5.4 Rinse Dewar flask and ice crusher with distilled water.

5.5 Crush as much distilled water ice as is needed to pack the Dewar flask full.

5.6 In a separate plastic container that has been rinsed with distilled water, mix distilled water and ice until the mixture is precooled close to the freezing point.

5.7 Pour this water into the Dewar flask, filled in step 5.5, until water level is just below the top of the Dewar flask. This water fills the voids in the ice pack.

5.8 Wash the quartz probe with isopropyl alcohol and then rinse in distilled water. This is very important to minimize contamination of the ice bath.

5.9 Form a pilot hole in the ice pack using the prerinsed clean rod. Then insert the quartz probe into pilot hole (Figure 1).

5.10 Let quartz thermometer system stabilize until no change is noted in the temperature reading, which usually takes about 15 minutes.

5.11 Record pre-cal data on quartz probe calibration check data sheet, (see Table 1).

5.12 Adjust thumbwheel switches to obtain a reading of $32.000^{o}F$ or as close as possible to this value.

5.13 Record this adjusted data (post-cal data), in the data sheet.

5.14 Large difference of greater than 200 in pre-cal to post-cal thumbwheel switch settings will be brought to the attention of the Instrument Cognizant Engineer.

5.15 Refresh ice bath if required.

5.15.1 Drain water out of bottom of Dewar flask when a significant melt has occurred.

5.15.2 Repack the Dewar flask with more distilled water ice.

5.15.3 If needed, add more precooled water as prepared in step 5.6 into Dewar (as in step 5.7) and continue with calibration check procedure.

TABLE 1

QUARTZ PROBE CALIBRATION CHECK DATA SHEET

PROBE S/N: ____________________ CHANNEL: ____________________

DATE	TIME	PRE-CAL		POST-CAL		OPERATOR NAME
		TEMPERATURE READING	DIAL SETTING	TEMPERATURE READING	DIAL SETTING	

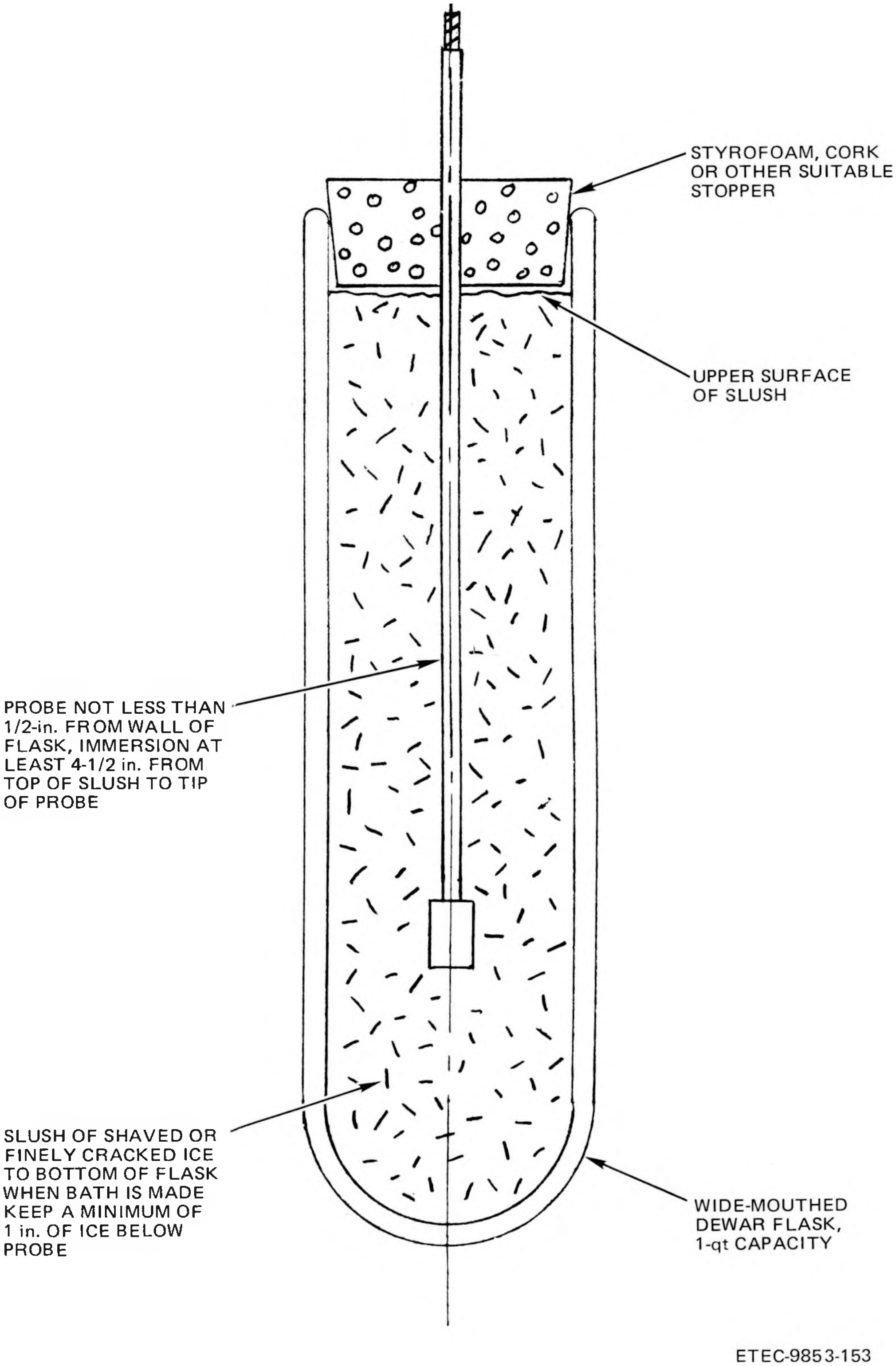


Figure L-1. Ice Bath for Calibrating Quartz Thermometer

APPENDIX M

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-1130

OTEC-1 SYSTEM CALIBRATION/VERIFICATION PROCEDURE — RESISTANCE TEMPERATURE DETECTOR (RTD) COMPARISON TO QUARTZ CRYSTAL THERMOMETER

1. INTRODUCTION AND DESCRIPTION

1.1 Scope

This procedure provides instructions necessary to perform calibration/verification of the following RTD systems by comparing RTD temperature to quartz crystal temperature with both measurement sensors inserted in a copper block.

Tag No.	Range	Description
TE8-1 thru TE8-4	65-90°F	Evap inlet water box
TE9-1 thru TE9-14	65-90°F	Evap outlet water box
TE10-1 thru TE10-6	65-90°F	Evap inst tubes
TE11-1 thru TE11-24	65-90°F	Evap inst tubes
TE12	65-90F	Heater outlet
TE15-1 thru TE15-14	35-50°F	Cond outlet water box
TE16-1 thru TE16-4	35-50°F	Cond inlet water box
TE17-1 thru TE17-6	35-50°F	Cond inst tubes
TE18-1 thru TE18-24	35-50 F	Cond inst tubes
TE19	32-52°F	Chiller outlet

Total = 98 each

1.2 Applicable Documents

1.2.1 Ice bath preparation of quartz thermometer calibration check procedure OTEC-1-OP-1120.

1.3 System Description

1.3.1 Figure 1 provides a simplified sketch of the measurement comparison system.

1.3.2 The approach is to insert a given RTD and the quartz probe along side each other in an insulated copper block chilled to a temperature near the low end of the RTD range. After temperature stabilization occurs, the computer, through program "CALIB", will compare and at operator command, calculate and enter the corrected "A" coefficient. The copper block is then warmed to a temperature near the upper end of the RTD range where the "B" coefficient is calculated and entered to make the RTD display equal to the quartz temperature.

2. CALIBRATION/VERIFICATION REQUIREMENTS

2.1 Prior to performing this procedure the RTD is calibrated-verified by the decade box.

2.2 The quartz crystal thermometer is ice bath calibrated per procedure referenced in paragraph 1.2.1.

2.3 Test Equipment Requirements

The following equipment is used in performing this calibration/ verification. Substitutions may be made, if equipment accuracy, linearity and stability are equal to or better than that specified, but only with approval of the Cognizant Instrument Engineer.

2.3.1 Fluke DVM model 8600R.

2.3.2 Hewlett Packard quartz thermometer 2804A.

2.3.3 Hewlett Packard Lab Probe model 18111A.

2.3.4 Hewlett Packard Ext. Oscillator model 18107A.

3. PREREQUISITES

3.1 All calibration/verification equipment used must be in current calibration with calibration traceable to National Bureau of Standards.

4. SPECIAL PRECAUTIONS

4.1 ± 24 VDC is present at the transmitter terminals and caution is required to avoid touching sensor leads to these terminals during the performance of the procedure.

5. PROCEDURE

Obtain permission from person in charge (PIC) to perform calibration/verification.

PIC ____________________ Date__________________ Time___________

5.1 Record specified information for the ice bath calibration of the quartz crystal thermometer.

Probe S/N ____________________ 1 ______________________ 2

Date and Time of Last Ice Bath Calibration

Date / Time	Date / Time	Date / Time
/	/	/
/	/	/
/	/	/
/	/	/
/	/	/

5.2 Utilizing program "UPDAT" obtain a parameter list and attach to this procedure. Mark it as "per cal A&B coeff."

5.3 <u>For RTD Under Calibration/Verification</u>

5.3.1 Remove the cover from transmitter.

5.3.2 Disconnect the sensor red leads. Do not let lead touch the ± 24 VDC terminals or case ground.

5.3.3 Connect the DVM (+) to red lead.

5.3.4 Connect the DVM (-) to explosion proof housing (ground).

5.3.5 Set DVM as follows: red test lead to "V-ohm," black to "Lo," function to "K ohm," range to "20 megohm", power "ON".

5.3.6 DVM should read +18.888 and blink on and off. Record this reading as 20 megohm. Any other reading, record as displayed.

5.3.7 Record pre-cal reading on data sheet. Readings less than 20 megohms must be brought to the attention of Cognizant Instrument Engineer.

5.3.8 Switch DVM to "off" and disconnect test leads.

5.3.9 Reconnect sensor to transmitter. Red lead to (+) pin 1.

5.3.10 Screw on explosion proof cover.

5.4 <u>Preparing Copper Block</u>

5.4.1 Select the appropriate copper block (Figure 2) having the hole size for the RTD under calibration/verification.

5.4.2 Prepare a container, large enough to hold copper block and ice cubes.

5.4.3 Soak uninsulated copper block in the ice cubes for approximately 2 minutes to cool the block.

5.4.4 While block is cooling, prepare the RTD and the quartz probe by applying a light coating of thermal compound to their probes.

5.4.5 Make a suitable support for the copper block when the RTD and quartz probes are installed.

5.4.6 Remove the copper block from the ice cubes and insert it into insulated sleeve (refer to Figure 1).

5.4.7 Put copper block in the support and very carefully insert the RTD into proper copper block hole until probe bottoms out.

5.4.8 Very carefully insert quartz probe into 7/16 inch diameter hole until probe bottoms out. Secure insulated end pieces to copper block.

5.4.9 To raise the temperature of the copper block, use an air heat gun.

5.4.10 Direct the hot air to the ends of the copper block with the insulated end pieces removed.

5.4.11 If a lower temperature is required, use ice cubes held on the ends of the copper block with the insulated end pieces removed.

5.5 Prequartz / RTD Comparison Procedure

5.5.1 Set A & B coefficients to "standard" values as per Table 1 according to range of RTD.

Table 1

Range	"A"	"B"
35 to 50°F	31.25	0.91597 E-02
40 to 80°F	30.00	0.24426 E-01
65 to 80°F	61.25	0.91597 E-02
65 to 90°F	58.75	0.15266 E-01
65 to 95°F	57.50	0.1832 E-01

5.5.2 Chill copper block to low temperature value.

5.5.3 Run "QUARTZ" program if delta t_o (Quartz - RTD) is less than ± 0.250°F. Proceed to step 5.5.4. If greater than ± 0.250°F, program will exit. Perform RTD calibration/verification per para. 5.6. Use resistance values supplied by Templine. Repeat para. 5.5.

5.5.4 Heat copper block to high temperature value.

5.5.5 Run "QUARTZ" program if delta hi (Quartz - RTD) is less than ± 0.250°F. Proceed through "QUARTZ" program. If greater than ± 0.250°F, program will exit. Perform RTD calibration/verification per para. 5.6. Then repeat 5.5.

5.5.6 Should the final comparison be greater than 0.127°F, tag and flag RTD and continue on. Notify Cognizant Instrument Engineer for resolution of the problem RTD.

5.6 Performing RTD to Quartz Comparison

5.6.1 Inform computer operator that RTD and quartz probes are ready for comparison calibration.

5.6.2 In the I&C van, observe RTD temperature using program "CKOTK" and quartz temperature on readout box for consistent tracking.

5.6.3 When both RTD and quartz temperatures track and are near the end points of the RTD temperature range, record this data on the data sheet as precalibration data.

5.6.4 Execute program "CALIB" to trim the "A" and "B" coefficients to ±0.030°F. Record the results on the data sheet as post-calibration data.

5.6.5 Computer operator notifies copper block personnel that calibration is complete.

5.7 <u>Removing Copper Block</u>

5.7.1 Very carefully remove quartz probe from copper block, clean probe, and store probe in case.

5.7.2 Very carefully remove copper block from RTD probe, clean probe, and prepare copper block for next comparison calibration.

5.8 <u>Post Calibration Resistance Test</u>

5.8.1 Remove the cover from transmitter.

5.8.2 Disconnect the red sensor lead. Do not let head touch the ± 24 VDC terminals or case ground.

5.8.3 Connect the DVM (+) to the red sensor lead.

5.8.4 Connect the DVM (-) to explosion proof housing (ground).

5.8.5 Set DVM as follows: red test lead to "V-ohm," black to "LO,"d function to "K-ohm," range to "20 megohm," power "ON".

5.8.6 DVM should read + 18.888 and blink on and off. Record this reading as 20 megohms. Any other reading, record as displayed.

5.8.7 Record post-cal resistance readings on data sheet. Reading should compare to pre-cal reading and be greater than 20 megohms. Report abnormalities to Cognizant Instrumentation engineer.

5.8.8 Switch DVM to "off" and disconnect test leads.

5.8.9 Reconnect sensor to transmitter. Red lead to (+) pin 1.

5.8.10 Screw on explosion-proof cover.

5.8.11 Notify computer operator to obtain ambient temperature reading if ambient is lower than upper end of RTD under calibration/verification.

6. CALIBRATION/VERIFICATION REPORT

6.1 Utilizing program "UPDAT" obtain a parameter list and attach to this procedure. Mark it as "Post Cal A&B coefficients."

6.2 Person in charge approval.

______________________________ ______________________________
PIC Date

6.3 File this procedure. ____________________

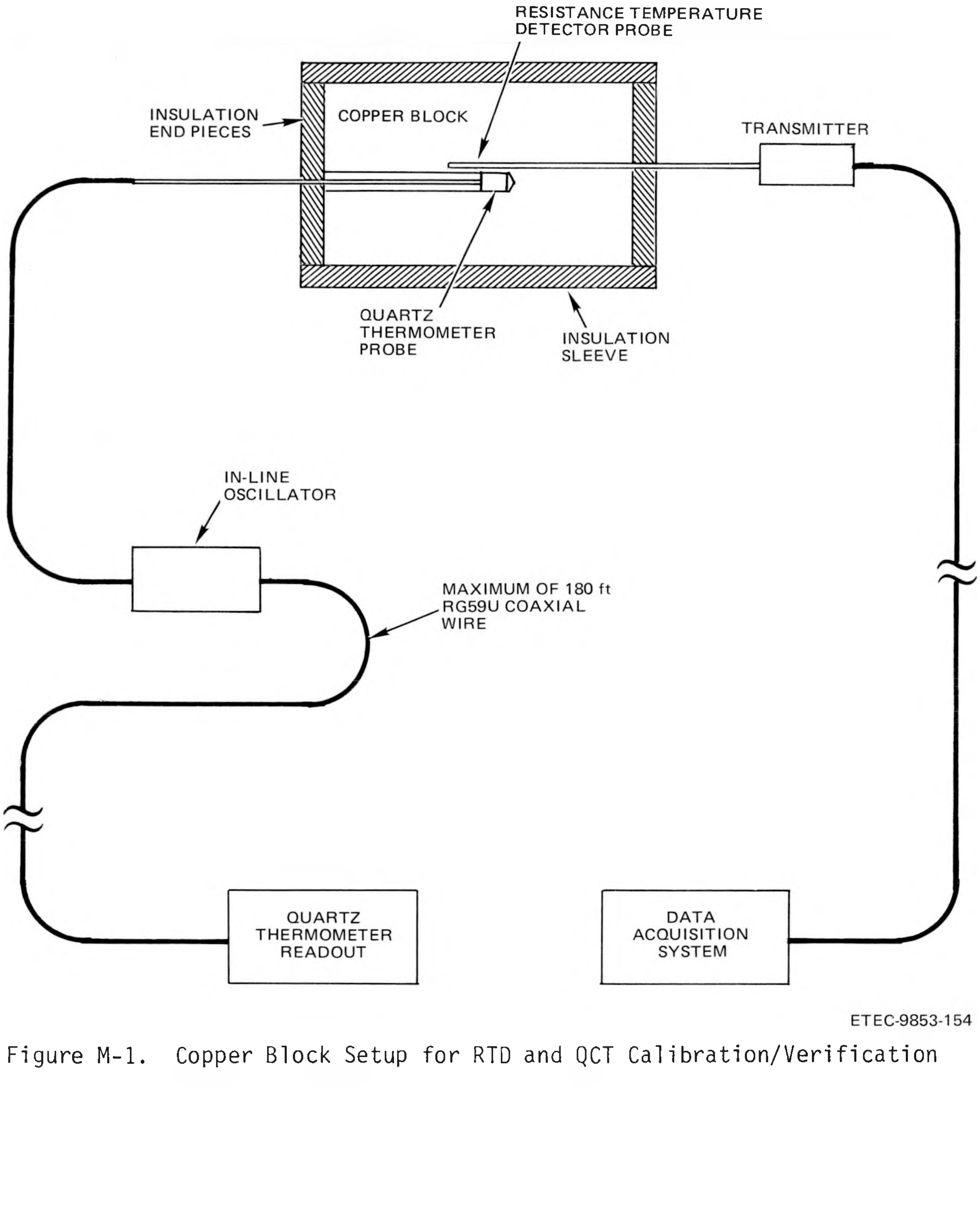


Figure M-1. Copper Block Setup for RTD and QCT Calibration/Verification

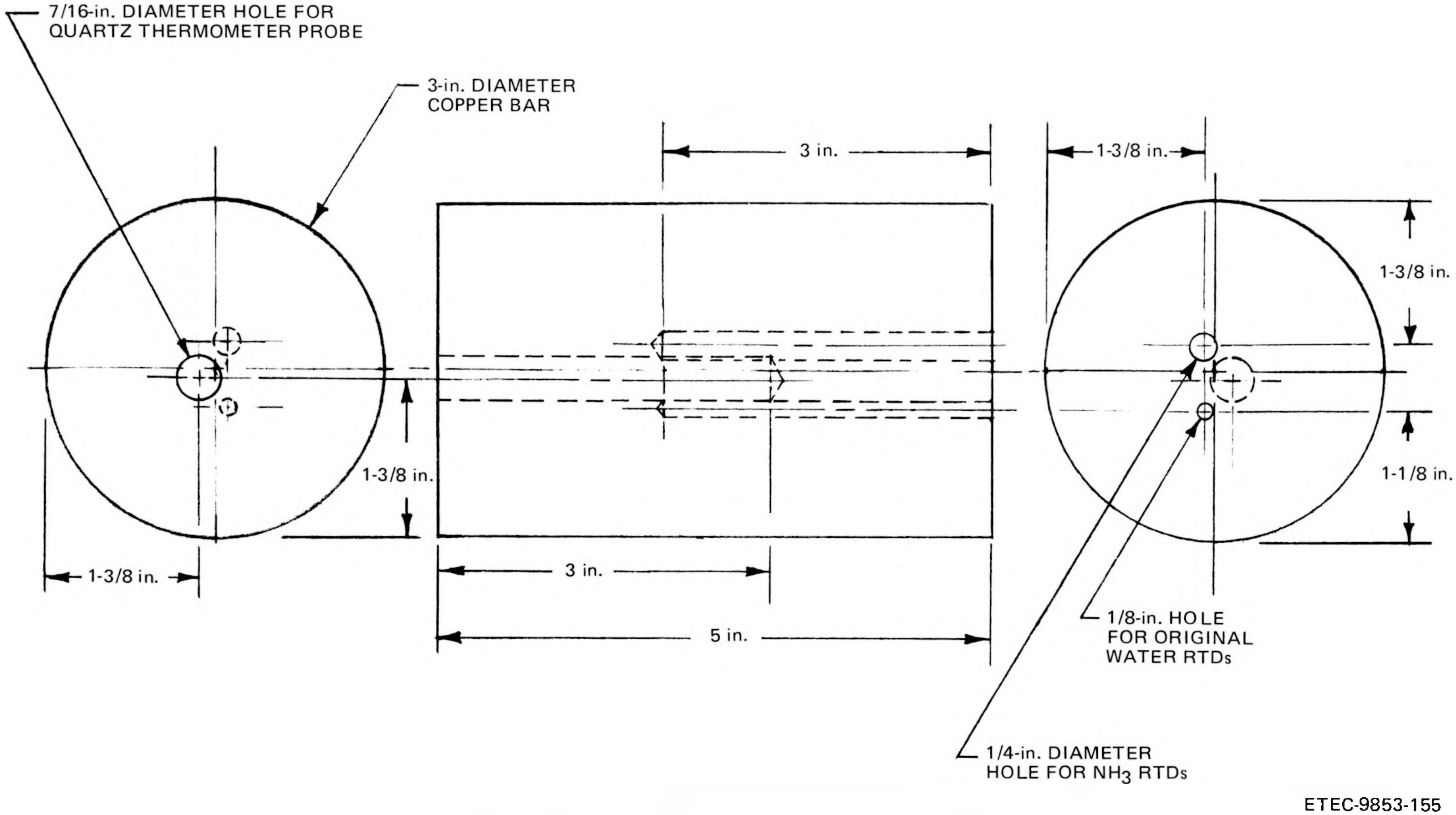


Figure M-2. Typical Copper Block Design

APPENDIX N

OCEAN THERMAL ENERGY CONVERSION — 1

UNIVERSITY OF HAWAII REPORT

BIOFOULING (MACROFOULING) RESULTS FROM OEC

1. MICROFOULING STUDIES

Compiled by L. R. Berger, University of Hawaii
at Manoa, Honolulu, Hawaii

a. Methodology

Sample removal and pretreatment: two 9-inch sections of tubing were removed from each BCM (#1, 2, (3), 5, 7, and 8). One of these tubes was stoppered wrapped in plastic and frozen in dry ice. It was subsequently run through a freeze drier to desiccate the fouling layer. The tube was then plugged with silicone stoppers and sent to Dr. David White for further analyses. From the second tube a one-inch section was cut. The remaining 8-inch piece was dipped gently in filtered distilled water, wrapped in a plastic bag, and frozen. The one-inch section was subjected to the following fixation procedure:

1) 1-hour dip in 4% glutaraldehyde-sea water pH 7.2.

2) 10-minute dips each in 25% ethanol in sea water, 50% ethanol in sea water and 50% ethanol in distilled water.

3) The sample was stored and shipped in aqueous 75% v/v ethanol.

4) Complete dehydration was done in 95% and absolute ethanol in Honolulu. The sample was then critical point dried from abs ethanol in Freon 22.

In Honolulu the biofouling film was removed from the frozen sample and treated as previously reported. Analyses for film dry weight, organic carbon, total nitrogen, protein and total iron were done on acid-hydrolyzed portions of the biofilm.

b. Results

Tables 1 and 2 summarize the results of the microfouling analyses. Several observations need pointing out.

1) In the BCMs which tracked the condenser or evaporator, levels of biofouling were low and near the limits of detection for a number of the assays.

2) A film of iron oxide or iron hydroxide covered a number of samples. It was observed that only the tubes subjected to chlorine showed high level of iron deposit. It is not possible to generalize on the basis of this limited data. There were many potential sources of iron in the OTEC-1 flow system. But, chlorination may have had to direct bearing.

3) There is insufficient heat transfer data and biofouling data to make any correlations one with the other. There were a number of pump failures, not all of which have been documented (to our knowledge). The first set of samples was taken during a pump shut down. One set of BCM's had been drained; the other was filled with stagnant water.

TABLE 1. RESULTS OF FIRST MICROFOULING SAMPLING AT OTEC-I

BCM Unit	Iron	Protein	Dry Weight	Org. Carbon	Nitrogen
#1 Tracker warm (03-06-81)	12.73	3.16 ± 1.17	114.8 ± 8.5	1.19 ± 0.26	1.43 ± 0.23
#2 Free-fouling warm (03-06-81)	0.309	1.60 ± 0.09	58.2 ± 22.0	1.04 ± 0.04	0.81 ± 0.07
#5 Free-fouling warm (03-06-81)	0.071	0.95 ± 0.35	55.7 ± 10.7	0.43 ± 0.23	0.31 ± 0.14
#8 Tracker warm (03-06-81)	0.435	0.53 ± 0.06	49.4 ± 5.1	0.66 ± 0.12	0.47 ± 0.05

All analyses except for total iron were run twice.

All values are give in $\mu g\ cm^{-2}$.

Notes on analyses:

(a) except for dry weights, most results were at the lower end of detectable concentration.

(b) iron is significatly higher in chlorine-treated samples.

(c) in the cold water system, no significant difference is evident at this early stage between cleaned and free-fouling pipes.

(d) pumps were inorperative at time of sampling. The cold system was drained; the warm system contained standing water. The cold system had been off 28.5 hr; the warm system 21 hr

TABLE 2. RESULTS OF SECOND MICROFOULING SAMPLING AT OTEC-I

BCM Unit	Dry Weight ($\mu g\ cm^{-2}$)	Organic Carbon ($\mu g\ cm^{-2}$)	Total N_2 ($\mu g\ cm^{-2}$)	Protein ($\mu g\ cm^{-2}$)	Total Iron ($\mu g\ cm^{-2}$)	Remarks
#1-0 Tracker warm (04/03/81)	220 ± 32	1.75 ± 0.81	2.15 ± 0.77	2.88	Greater than 25	Extract orange, rust hygroscopic
#1-1 Tracker (SS) warm (04/03/81)	174 ± 24	1.41 ± 0.09	2.19 ± 0.16	2.44	Greater than 25	Extract orange, rust hygroscopic
#1-2 Tracker warm (04/03/81)	155 ± 27	1.01 ± 0.09	1.69 ± 0.29	2.23	Greater than 25	Extract orange, rust hygroscopic
#2 Free-fouling warm (04/02/81)	46.8 ± 10	2.84 ± 0.86	2.58 ± 0.79	6.22	0.29	
#2 Free-fouling warm (04/09/81)	206 ± 8	6.95 ± 0.49	6.15 ± 0.54	18.60	Greater than 25	Orange rust hygroscopic
#3 Chlorine, only warm (04/02/81)	39.5 ± 8	1.63 ± 0.31	2.19 ± 0.05	4.52	0.22	
#3 Chlorine warm (04/09/81)	32.3 ± 9	1.18 ± 0.35	1.46 ± 0.24	2.30	0.31	
#5 Free-fouling cold (04/09/81)	12.8	0.33	0.2	0.65	0.16	
#7 Free-fouling cold (04/09/81) Aluminum	172 ± 28	0.75 ± 0.37	0.87 ± 0.30	0.88	0.37	
#8 Tracker cold (04/09/81)*	8.6, 23.8	0.13, 1.36	0.16, 1.13	0.19, 0.82	0	
Untreated tube control - Ti**	27.9	1.72	1.44	-	0	
Untreated tube control S.S.**	23.7	0.55	0.58	-	0	
Untreated tube control - AL**	14.8	1.16	1.03	-	0.01	

Except where noted, analyses were done on two pieces of tubing, or on separate portions of a single piece. Standard deviations reflect differences in distribution of fouling. All analyses were done in duplicate.

*Average values for each set of analyses are given.
**Off-the-shelf tubes were used without cleaning. These "film values" should not be subrated from that of the experimental pieces because it is probable that seal water flow removed the "dirt/film" relatively quickly.

REFERENCES

"OTEC-1 Power System Test Program: Biofouling and Corrosion Monitoring on OTEC-1," ANL/OTEC-BCM-027, Argonne National Laboratory, Argonne, Illinois September 1981.

"OTEC-1 Power System Test Program: Performance of One-Megawatt Heat Exchangers," ANL/OTEC-PS-10, Argonne National Laboratory, Argonne, Illinois, November 1981.

APPENDIX O

OCEAN THERMAL ENERGY CONVERSION — 1

STANDARD OPERATING PROCEDURE

OTEC-1-OP-510

OTEC-1 WATER SAMPLING AND ANALYSIS PROCEDURES

DURING SEA TRIALS

1. PURPOSE

The objective of this procedure is to detail the necessary steps required to obtain and analyze water samples that will be taken from the cold and warm water systems during sea trials.

Grossly characterize the quality of water taken into the evaporator and condenser sea water systems during the trials. This characterization will provide data to document that gross contamination of these systems has not occurred during the trials.

2. PREREQUISITES

2.1 Global Marine Development, Inc., Procedure ST-2-04, "Cold Water System Operational Trial"; procedure will be in operation.

2.2 GMDI Procedure ST-2-05, "Warm Water System Operational Trial;" procedure will be in operation.

3. DRAWINGS, MANUALS, REFERENCES

3.1 Drawing and manual requirements can be found in GMDI ST-2-04 and ST-2-05 procedures.

3.2 Letter, Argonne National Laboratory, J. D. Ditmars, Energy and Environmental Systems Division to F. W. Poucher, Energy Technology Engineering Center, ANL-80-3046, April 29, 1980. Subject: Water Quality Sampling and Analysis During the Sea Trials.

4. SAMPLE CONTAINER CLEANING REQUIREMENTS

All 1-liter samples will be collected in glass bottles cleaned in the ETEC Chem and Met Lab. All bottles will be clearly marked with the location and time when the sample was drawn. In addition, the level of water in the bottle will be marked on the bottle. Samples will be collected during the period of maximum flow rate for both the warm and cold water system. Each container will be well rinsed in sample water and then filled.

Each 20-liter (5 gal) sample will be collected in five 1-gal Cubitaners which have been cleaned in the ETEC Chem and Met Lab by rinsing (at least twice) with a 50/50 solution of Hexane Acetone and then rinsed (at least twice) with distilled water. At sampling, each container will be well rinsed in sample water and then filled about 7/8 full. Do not fill the container completely because the samples will be frozen and enough room must be allowed to permit expansion.

5. PROCEDURE — Date / Initial

5.1 During the cold water system operational trial, ST-2-04, the following water samples will be taken:

5.1.1 Take two 1-liter water samples from the condenser inlet.

Note
Rinse each sample bottle several times with sample water.

____

5.1.2 Mark each sample bottle with sample number, location, time, date and water level.

____

5.1.3 Take two 1-liter water samples from the condenser outlet.

Note
Rinse each sample bottle several times with sample water.

____

5.1.4 Mark each sample bottle with sample number, location, time, date and water level.

____

5.1.5 Take one 20-liter water sample (5 gal) from the condenser outlet.

Note
Rinse each 1-gal Cubitaner several times with sample water and fill only 7/8 full).

____

5.1.6 Mark each sample container with sample number, location, time, date and water level.

____

5.1.7 Place the four glass sample bottles from 5.1.1 and 5.1.3 in the ship's refrigerator prior to shipment for sample analysis.

____

5.1.8 Place the five Cubitaners from 5.1.5 in the ship's freezer prior to shipment for sample analysis.

____

Date / Initial

5.2 During the warm water system operational trial, ST-2-05, the following water samples will be taken:

5.2.1 Take two 1-liter water samples from the evaporator inlet.

Note

Rinse each sample bottle several times with sample water.

____

5.2.2 Mark each sample bottle with sample number, location, time, date and water level.

____

5.2.3 Take two 1-liter water samples from the evaporator outlet.

Note

Rinse each sample bottle several times with sample water.

____

5.2.4 Mark each sample bottle with sample number, location, time, date and water level.

____

5.2.5 Take one 20-liter water sample (5 gal) from the evaporator outlet.

Note

Rinse each 1-gal Cubitaner several times with sample water and fill only 7/8 full).

____

5.2.6 Mark each sample container with sample number, location, time, date and water level.

____

5.2.7 Place the four glass sample bottles from 5.2.1 and 5.2.3 in the ship's refrigerator prior to shipment for sample analysis.

____

5.2.8 Place the five Cubitaners from 5.2.5 in the ship's freezer prior to shipment for sample analysis.

____

Date / Initial

6. REQUIRED ANALYSES

One 1-liter sample from each sampling location will be analyzed for grease and oil, and the other 1-liter sample for total suspended solids. The 20-liter samples may be used for total hydrocarbon scan by GC/MS analysis depending on the results of the grease and oil analysis.

6.1 Place the glass sample bottles from 5.1 and 5.2 in an ice chest, fill with ice (or dry ice) and hand carry to the analysis lab. ____________

6.2 Hold the Cubitaners obtained in 5.1 and 5.2 in the ship's freezer until notified otherwise by the Test Director. ____________

7. PROCEDURE COMPLETED ____________

APPENDIX P

OCEAN THERMAL ENERGY CONVERSION — 1

UNIVERSITY OF HAWAII REPORT

BIOFOULING (MACROFOULING) RESULTS FROM OEC

MACROFOULING STUDIES

By E. A. Kay, Dept. of Zoology, University of Hawaii at Manoa, Honolulu, Hawaii.

Macrofouling determinations on OTEC-1 were made on April 16, 1981. Both cold and warm water inflow pipes were examined. The results are as follows:

Cold Water Inlet

The titanium screens at the cold water inlets were remarkably free of macrofouling, and, indeed, any observable indications of corrosion. No rust or macroscopic growth of any kind was noted. The only biological material found was a single crustacean carapace, about 3 mm in length, and a sponge which had been inserted in one of the screens.

Warm Water Pipes

1. Sump

The only macroscopic fouling around the sump consisted of some fuzzy growth of possibly a blue-green alga on the bars of the sump gate. This material is acellular and its specific nature has not been determined.

2. Main Warm Water Pipe

The frame around the entrance of the main warm water pipe was found to contain most of the macrofouling seen during the survey. Rust accumulated both on the frame and at the base of the frame and served as a substrate for barnacles, oysters and serpulid worms. In addition, bivalve shells, gastropod shells, the carapaces of crabs, and a fish vertebra were found in the rust accumulation. Quantitative determinations of the amount of macrofouling were not feasible but some indication of the sizes and nature of what was there follow.

Observations

Organism	Number and Name
Crustaceans	Barnacles - five oceanic or goose barnacles, Lepas, with capitular plates about 25 mm in length.
	Crabs - three crabs, two of one species, the third of another; carapace diameters about 20 mm.

Mollusks: Bivalves	Pinna muricata - 2 pen shells, 1 juvenile, about 33 mm long, the other a fragment.
	Ostrea hanleyana - Upper valves of 23 Hawaiian oysters found either loose or attached to the frame. Valves ranged in diameter from 7 - 25 mm, with mean diameter of 13 mm. Valves of the larger oysters with seruplid worms.
	Ervilia sandwichensis - 1 small specimen, ca 7 mm in length.
	Malleus regula - 2 small specimens, ca 4 mm in length.
Mollusks: Gastropods	Morula foliacea - 21 shells ranging from 4 - 13 mm in length with a mean length of 9.3 mm.
	Drup ricina - 1 shell ca 10 mm in length.
	Triphoridae - 1 larval shell.

Unidentified blue-green alga - The frame also supported projections of the same ascellular growth as found on the sump gate.

Remarks

The mollusks and crustaceans found in the warm water pipes appeared to have entered the system as larva and grown within the system. All the animals found were those known to have planktonic larval stages. The goose barnacles are well known for their oceanic existence and they are common in clusters on floating objects in the sea. The number of specimens of Morula foliacea is surprising. These mollusks are carnivores and perhaps could have been feeding on the oysters once they had metamorphosed within the pipes, although no drill holes were noted in the oyster shells. Pinna has not previously been recorded from the Kona coast but has a very fast growing shell and larval shells are often abundant in the plankton off Honolulu.

APPENDIX Q

OTEC-1 PROGRAM

CRITERIA FOR DECISIONS IN REGARD TO OTEC-1
OEC CWP DROP, MOOR RELEASE, GRAZING MODE,
AND MAINTENANCE ON STATION

COLD WATER PIPE BEHAVIOR AND RELEASE CRITERA, RECOVERY PROCEDURES

PURPOSE

The purpose of this procedure is to define the CWP's characteristic behavior for the determination of CWP release.

REFERENCES

1. OTEC-1 Acceptance Testing Plan - NOAA, Oct. 10,1980 (ETEC-DRF-4615)
2. On-Board Computer Program "CWPDSP".
3. 4086-C405, Operating and Maintenance Manual for CWP.
4. 4086-B001, 002, and 003, B051, 052, and 053, Mooring System Assys and Details.

INFORMATION

The CWP has functional and operating limits imposed by the designers. These limits are:

1. The Forces at the ship-to-pipe interface (gimbal loads).
2. The Displacement of the ship-to-pipe interface (gimbal angle).
3. The Deformation of the polyethylene plastic pipe material (LVDT's).
4. The Entanglement of the CWP with the components of the mooring.

The factors which cause the CWP system to respond are currents, waves and the ship's attitude. The wind and the mooring influence these interacting factors.

Instruments are available to measure the factors which cause pipe responses (i.e., wind speed and direction, current speed and direction, wave height and ship's attitude and position) but the determinations of CWP release will be made on the basis of measured repsonses.

LOGIC - (see Figure 2)

The basic approach is to set threshold limits to alert the operators of the onset of conditions. After verifying that instruments have not malfunctioned; countermeasures to mitigate effects are implemented, depending upon type of alarm. If this is not effective, radical action is required.

The knowledge of the local bathymetry and the precision of position determination afforded by the miniranger enables the decision to release the ship from the moor to be made as the first course of action. Improved vessel maneuverability is gained after release from the mooring, and most important, no interruption to OTEC operation is necessary as the OEC runs in a grazing mode. After mooring release has been accomplished, the nature of the prevailing situation will determine the extent of drift period and mode. If current direction and magnitude permit thruster control to keep in moor vicinity or over controlled depth plateau operation continues and moor recovery accomplished.

In the event that a combination of environmental conditions prevent retention of the CWP, the release sequence is implemented, followed by a determination of whether to return to port or remain on site. This decision is based on weather forecasts and the changed dynamics of an unencumbered vessel. Return to normal operations is then implemented as the weather improves.

SOURCES OF INFORMATION

The only instruments which are to be used for CWP decisions are:

1. The Angular Sensors: GPITCH and GROLL (see Figure 1).

2. The Load Cells: FGFV; FGFH; FGAV; FGAH; FGPV; FGPH; FGSV; FGSH (see Figure 2).

3. The LVDT's: LVDT1 through 6.

4. The Mini-ranger - ship's position.

These are read on the strip charts, or CRT on-line printer, except for the mini-ranger which is plotted on the bridge.

An analysis program provides a statistical summary of the key parameters enabling the operators to judge the dynamics of the situation. Table 1 illustrates the calculated parameters. Appendix A details the basis of the calculations.

Additional ship's instrumentation is available for confirmation of observations and for correlation of countermeasures effectiveness as follows:

1. Ship's location with respect to shore and mooring - mini-ranger on bridge.

2. Ship's heading - on DAS as HDGSIN and HDGCOS, GYRO on bridge.

3. Wind heading and magnitude - on DAS as DIRSIN, DIRCOS and WNDSPD and AEROVANE on bridge.

4. Mooring line tension - on DAS as LINET and on bridge direct gage.

5. Gimbal angles - on DAS as GPITCH and GROLL, and on bridge direct readout gages.

6. Ship's accelerations - on DAS only, as heave, surge and sway.

7. Ship's attitude - on DAS as PITCH and ROLL and on bridge spirit levels.

Figure 1. Logic Diagram

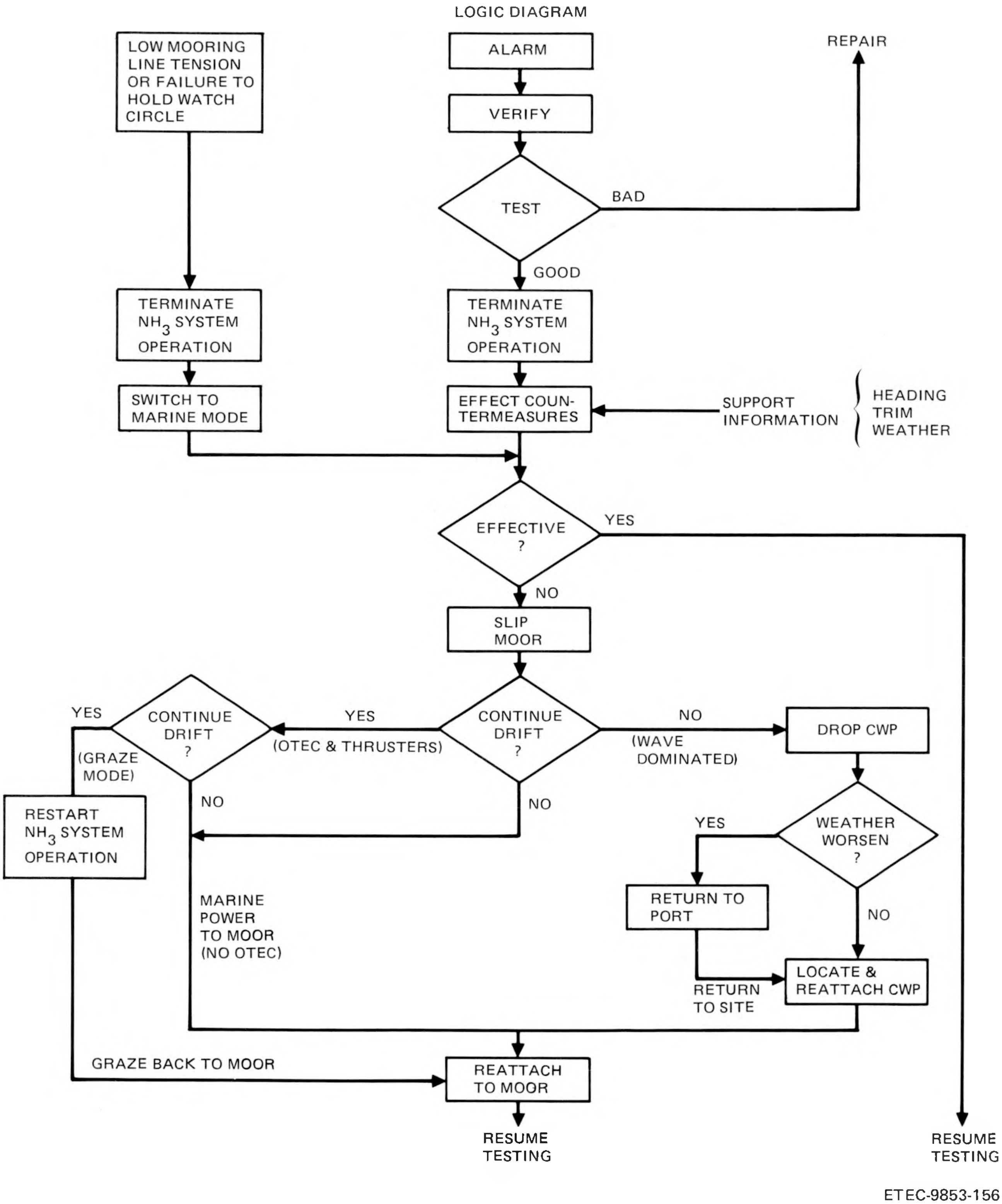


Table 1. Cold Water Pipe Parameter Group
(960 samples at 4 samples/sec from 18:10:12 to 18:14:13, 2/24/81)

Tag No.	Mean	RMS	Max.	Min.	
FGPH	10.87	1.98	15.93	4.99	
FGPV	68.35	8.34	92.43	43.13	
FGSH	-24.22	1.66	-19.75	-28.94	
FGSV	110.35	8.75	135.88	86.67	
FGFH	-18.75	4.86	-8.30	-31.68	
FGFV	81.91	8.81	108.47	56.99	
FGAH	19.40	4.86	30.78	8.28	
FGAV	83.02	7.90	106.60	60.84	
GPITCH	6.84	3.88	13.37	0.00	
GROLL	10.04	3.90	18.73	3.96	
GHEAVE (VERTICAL)	165.46	16.65	215.58	118.23	= FGAV + FGFV
GSURGE (FORE/AFT)	-60.86	12.51	-32.54	-93.82	= PH+SH+Pitch angle comp.
GSWAY (ATHWARTSHP)	-33.71	9.64	-11.74	-57.63	= AH+FH+Roll angle comp.
GTILT	12.28	5.10	22.64	4.42	= Pipe cone angle
GAZMTH	58.05	10.31	90.00	40.22	= Pipe bearing
PHEAVE	178.28	16.99	227.75	129.36	= Axial force on pipe
PTORQ	-9.03	1.64	-4.90	-12.98	= Twist force on pipe

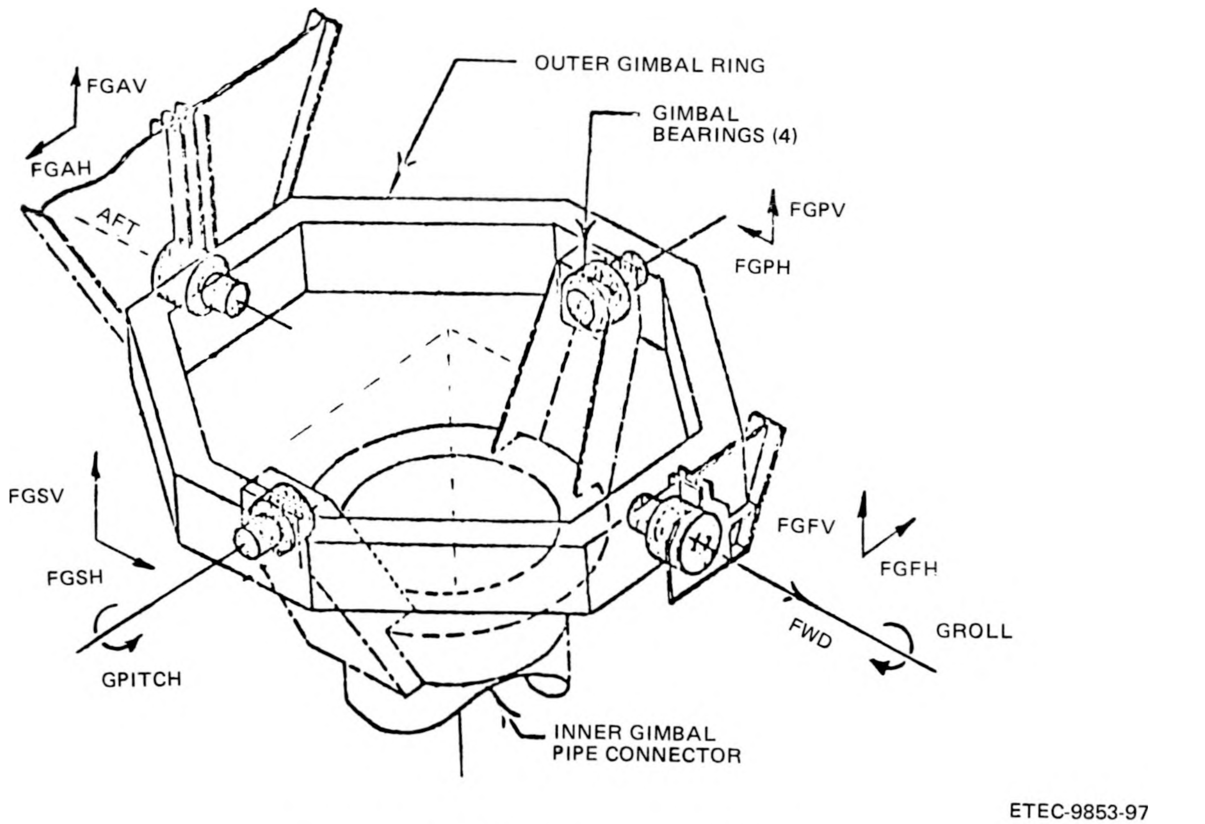


Figure 2. CWP Gimbal Assembly

PROCEDURE

1. In the event that mooring line tension cannot be maintained above 4 kips or mini-ranger indicates a potential CWP interference:

   a. Request the experimenters to terminate ammonia systems operations and secure.

   b. Go to step 5a to implement transition to marine mode.

2. Upon receipt of alarm(s):

   a. Put (or verify) load cells and GPITCH and GROLL on strip charts (Max. write rate 60 per/min).

   b. Initiate (or verify "CWPDSP" analysis program).

   c. Examine line printer for identity of parameter which gave alarm.

3. Examine records for anomalous behavior of instruments (dropouts, abrupt spikes, etc.):

   a. If GPITCH/GROLL is suspected, switch to alternates tranducers on winch console.

   b. Terminate NH_3 system OTEC operations.

NOTE

(If instruments are satisfactory, proceed to identified parameter of step 4.)

4. Identify limiting parameter:

   a. GHEAVE is limited to maximum of 500 kips or a minimum of -500 kips.

      1. Request bridge to operate thrusters so as to change heading towards head or following seas (beam seas increase heaving and rolling) observing gimbal angles and line tension.

      2. If this measure is not effective, pipe may be fouled on mooring or weather is too severe, proceed to step 5b to slip moor, and notify shore base of status.

   b. GSURGE, GSWAY is limited to a max/min of $\pm$ 200 kips.

      (Due to pipe gimbal geometry, these parameters are unlikely to be large before excessive gimbal angles are encountered, or vertical loads become excessive.)

      1. In the event these limits are being approached, proceed to step 5b to slip moor, and notify shore base of status.

c. GROLL is limited to max/min of $\pm 30^{o}$.

1) Request bridge to operate thrusters, so as to change heading to reduce GROLL (GPITCH will increase). The optimum combination has GPITCH and GROLL equal (GAZMTH at $\pm 45^{o}$ or $\pm 135^{o}$).

2) If this is not possible, request bridge to adjust list of vessel to compensate for steady state roll.

a) Mixed water pump operation and/or the sump-discharge system may be modified to add/subtract weight from port side to assist.

b) Reballasting of vessel tanks is required.

3) If these are not possible or sufficient, proceed to step 5b to slip moor. Notify shore base of status.

d. GPITCH is limited to max/min of $\pm 30^{o}$.

1) Request bridge to operate thrusters, so as to change heading to reduce GROLL (GPITCH will increase). The optimum combination has GPITCH and GROLL equal (GAZMTH at $\pm 45^{o}$ or $\pm 135^{o}$).

2) If this is not possible, request bridge to adjust trim of vessel to compensate for steady state pitch by adjusting ballasting.

3) If these are not possible, proceed to step 5b to slip moor. Notify shore base of status.

5. Decision point to remain on watch circle in Marine mode, slip moor, or release.

a. The desire to remain on the watch circle in a marine mode will most likely occur when the mooring line tension is less than 5 kips. (Condition symptoms are increasing thruster power required, and current and wind opposed.)

1) Monitor ship's position on mini-ranger and CWP bottom beacon.

2) Implement OTEC water systems shutdown and switchover to marine mode, per procedures in Ref. 3.

3) Operate main engine to maintain position on watch circle.

4) If conditions worsen, proceed to step 5b to slip moor.

5) If conditions improve, return to OTEC mode, notify shore base of status.

b. Countermeasures are not effective, mooring to be slipped.

1) This action is most likely to occur in a current dominated situation which is characterized by large gimbal angles without significant sea states (6 ft or less), indicates that moor slip is required. Slip mooring as follows:

a) Alert crew of impending actions.

b) Disconnect instrumentation connector from tension link and stow to prevent damage. Insert preventer bar in shackle.

c) Deploy line end marker buoy.

d) Trip pelican hook.

e) Log position and begin plotting bathymetric chart. Maintain course (via thrusters) over plateau regions where depth is 1150 to 1350 meters. Notify shore base of moor status. Notify USCG/USN that OEC if off moor.

f) If drift rate remains high, or maintenance of ship's course/position is not possible, go to step 5c to release CWP.

g) If drift rate reduces, or if ship's course/position is acceptable, go to step 6.

c. Countermeasures are not effective, CWP is to be released. This action is most likely to occur in a wave-dominated situation which is characterized by large dynamic gimbal angles, or by large dynamic gimbal loads without significant current driven components. Limiting angles and loads must be prevented by CWP release as follows:

1) Alert crew of impending actions.

2) Activate and check gimbal hydraulics console (Appendix B).

3) Prepare marker buoy system and secure LVDT cabling (Appendix B).

4) Secure cold water side of experiment (pump, BCM's).

5) Release CWP (Appendix B).

6) Record position at drop and notify shore base of status. Notify USCG/USN that CWP has been emergency released and give coordinates.

7) Return ammonia to deck storage tanks as a standby precaution.

8) Go to step 7 for determination of whether to head for port or stay in seaway.

6. Ship off moor with CWP attached. Ship/pipe assembly is adrift under thruster power. Water system in operation (NH_3 system secured on standby).

   a. If ship is unmanageable with 30 mins, go to step 5c to release CWP. (Time allowed presumes drift toward deep water.)

   b. If desired, experiment can be continued in grazing mode. Restart NH_2 system at Test Director's convenience.

   c. Obtain current condition at mooring site by PLIII before deciding to return.

   d. If rapid return to site is desired, movement in marine mode is performed (maximum propeller speed is 45 rpm). After water system shutdown and coordination with experimenters, go to step 9b.

   e. Return to mooring under thruster power in grazing mode can be performed if desired, step 9a.

7. Ship off moor with CWP detached. Decision to be made whether to seek sheltered port or remain in seaway.

   a. Review "G" loads on test articles for approach to design limits. In the event that heave accels exceed $\pm$ 0.5 G or if surge/sway accels exceeded $\pm$ 0.2 G the HX's should be drained of water. Coordinate with bilge pumping operations. Drain evaporator first, then condenser.

   b. Monitor weather forecasts.

   c. If conditions are predicted to worsen, determine destination and inform shore base of actions planned.

   d. If conditions are predicted to stabilize or improve, remain on alert, then proceed to step 8 to locate and recover CWP.

8. Locate and retrieve CWP and reattach (weather calmed).

   a. Steam OEC to mooring site and determine currents.
   b. Rig top beacon hydrophone on OEC for locating CWP.
   c. Return to CWP drop region.
   d. Recover CWP and reattach per Appendix C. Notify shore base of status.

9. Determine return to site operation mode.

   a. Return in "grazing" mode, under thruster control.
   b. Return in marine power mode. Do not exceed 45 rpm on screw.

10. Reattach OEC to moor.

   a. Attach per Appendix D., notify shore base.
   b. Reconnect load cell.

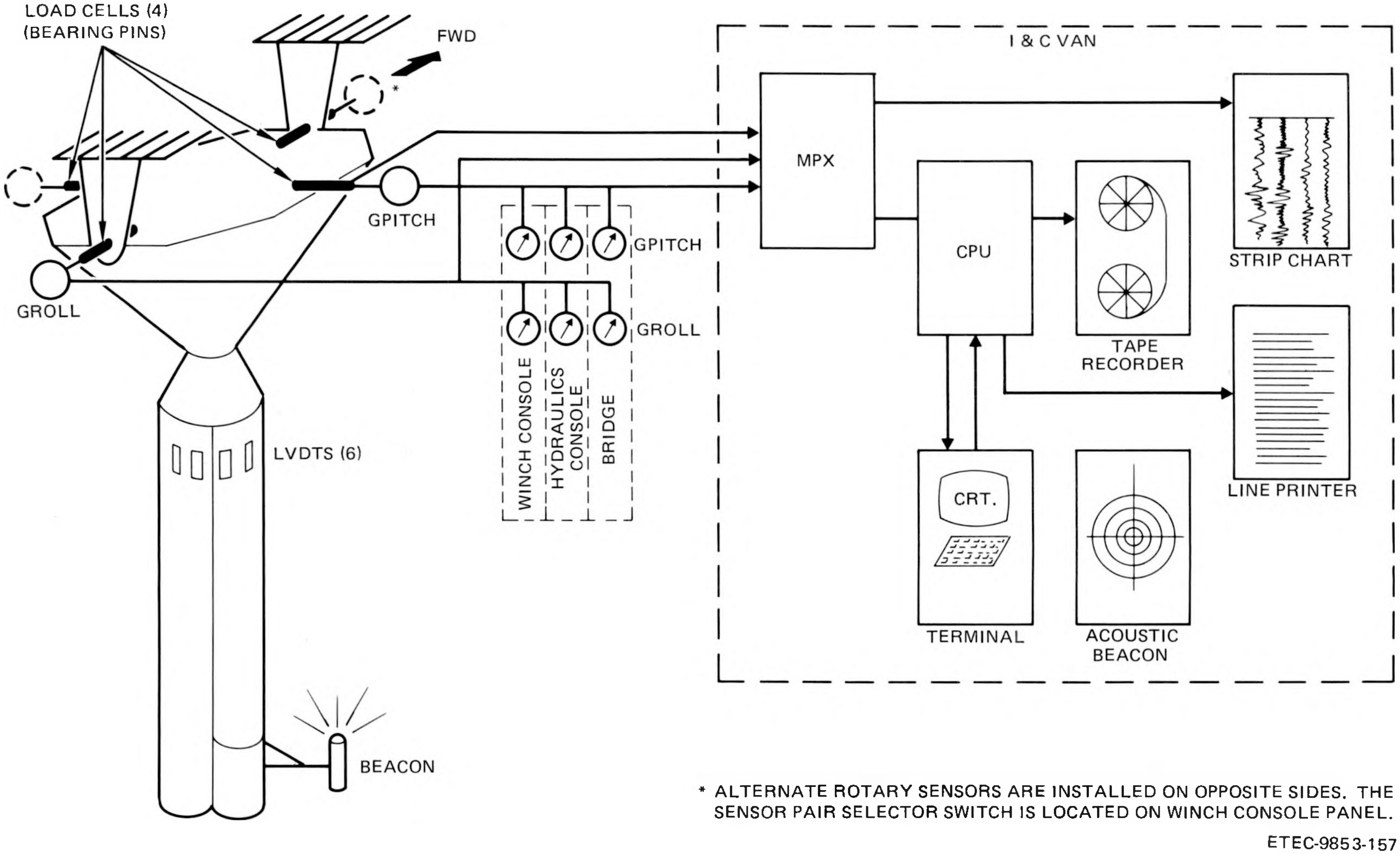
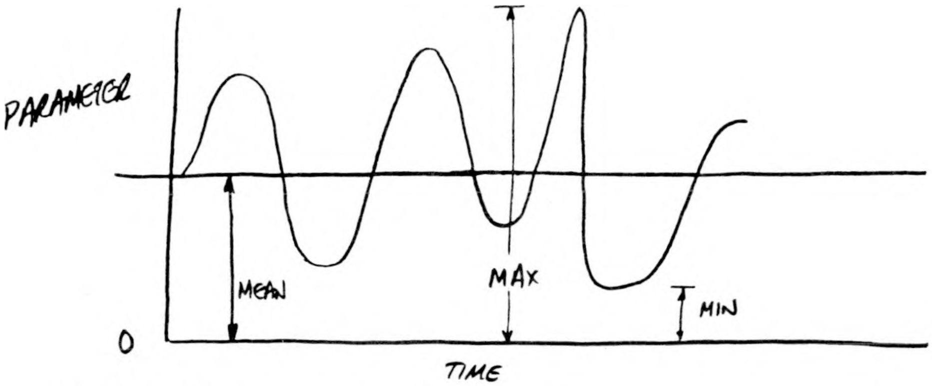


Figure 3. CWP Instrumentation Schematic

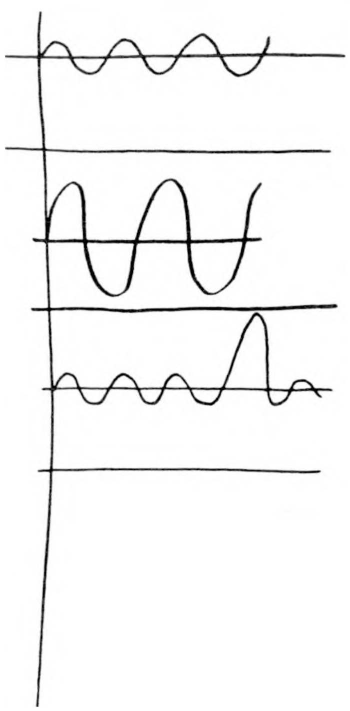
ENCLOSURE 1

COMPUTER PROGRAM PROVIDES CALCULATIONS WHICH PRESENTS STATISTICS TO DEFINE A DYNAMIC SITUATION. THE COMPUTED PARAMETERS ARE AS SHOWN AND HAVE SIGNIFICANCE FOR A CYCLIC PHENOMENON AS FOLLOWS



MEAN - THIS IS THE VALUE OF THE PARAMETER ABOUT WHICH THE VARIATIONS OCCUR (ALSO THE AVERAGE)

RMS - THIS IS A MEASURE OF THE VARIATIONS ABOUT THE MEAN. (NOT ILLUSTRATED, SEE BELOW.)
MAX - THIS IS THE LARGEST VALUE OBSERVED
MIN - THIS IS THE SMALLEST VALUE OBSERVED.



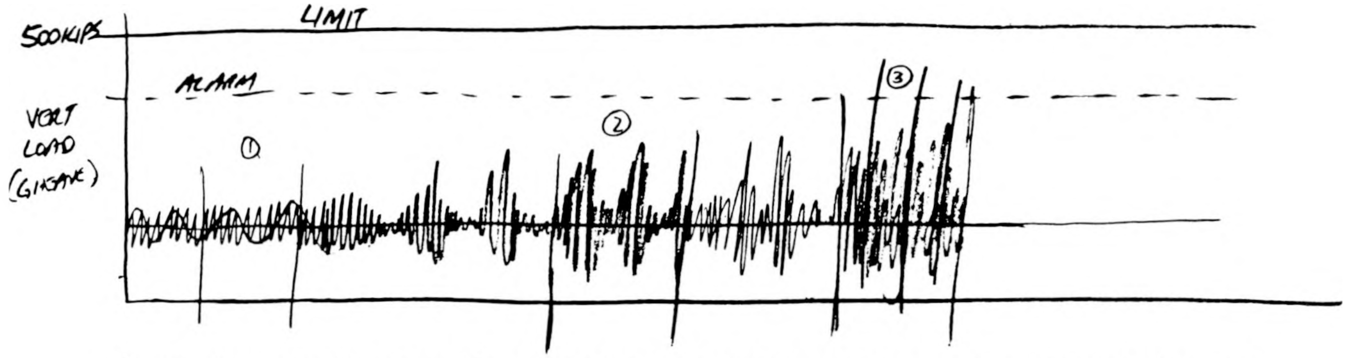
CASE 1 MAX/MIN HAVE SMALL DEVIATIONS ABOUT MEAN, RMS IS SMALL.

CASE 2 MAX/MIN HAVE LARGE DEVIATIONS ABOUT MEAN, RMS IS LARGE

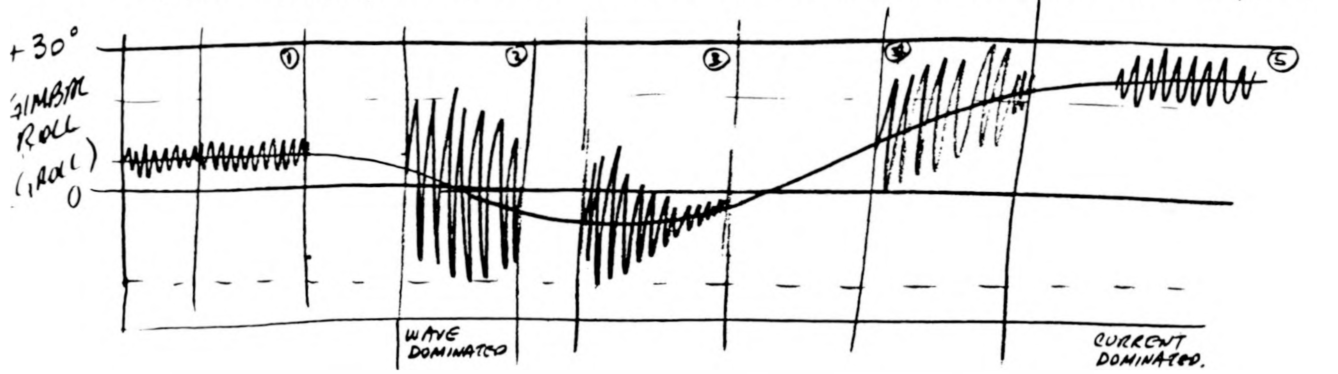
CASE 3 AN OCCASIONAL PEAK GIVES A LARGE MAX, BUT RMS WILL BE SMALL. THE MAXIMUM MAY TRIGGER AN ALARM, BUT DEVIATIONS ARE SMALL

A1

THE ADVANTAGE OF SUCH A PROGRAM IS TO ASSIST IN DETERMINING HOW THE SITUATION IS CHANGING. THE FOLLOWING EXAMPLES ARE GIVEN



GIGAVE IS BEING EXAMINED; THE MEAN VALUE SHOULD NOT CHANGE BECAUSE IT IS THE WEIGHT OF THE CWP ASSY. CASE ① HAS LOW RMS, CASE ② HAS MEDIUM RMS WITH SOME LARGE MAX/MIN, CASE ③ HAS LARGE RMS & HIGH MAX/MIN. THE CYCLES OF LOAD ARE CAUSED BY HEAVING OF THE SHIP DUE TO SWELLS/WAVES.



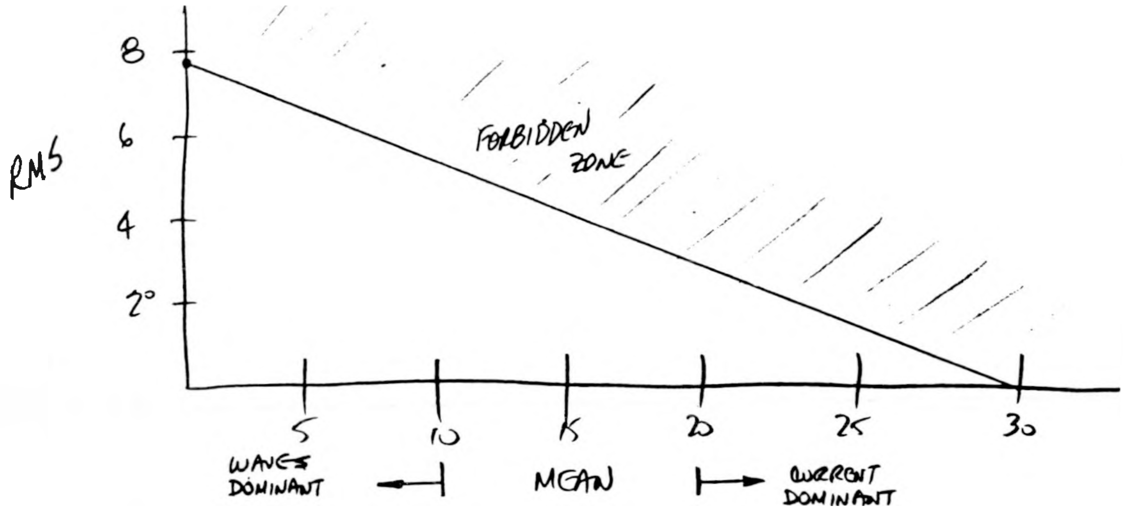
GROLL IS BEING EXAMINED; THE MEAN VALUE SHOWS A LONG TERM ANGULAR SET OF THE PIPE TO SHIP CAUSED BY CURRENTS OR SHIPS LISTING. THE CYCLES ARE CAUSED BY SHIPS ROLL DUE TO WAVES/SWELLS. CASE ① IS SMALL MEAN, SMALL MAX/MIN, SMALL RMS, ② IS VERY SMALL MEAN, ~~MEDIUM~~ MAX/MIN, LARGE RMS, ③ IS SMALL (NEGATIVE SIDE) MEAN, MEDIUM MAX/MIN, MEDIUM RMS ④ LARGE MEAN, LARGE MAX " LARGE RMS. ⑤ MEAN IS LARGE, MAX

THE GIMBAL ANGLE MUST NOT BE PERMITTED TO EXCEED 30°. THIS CAN OCCUR WHEN THE STEADY STATE VALUE IS LARGE & THE DYNAMIC EFFECT SMALL, OR STEADY STATE MODERATE & DYNAMIC MODERATE OR STEADY STATE SMALL & DYNAMIC LARGE. THE TOTAL EXCURSION IS CRITICAL. THE CASE OF A LARGE STEADY STATE COMPONENT IS CALLED "CURRENT DOMINATED", WHILE THE CASE OF LARGE DYNAMIC COMPONENT IS CALLED "WAVE DOMINATED".

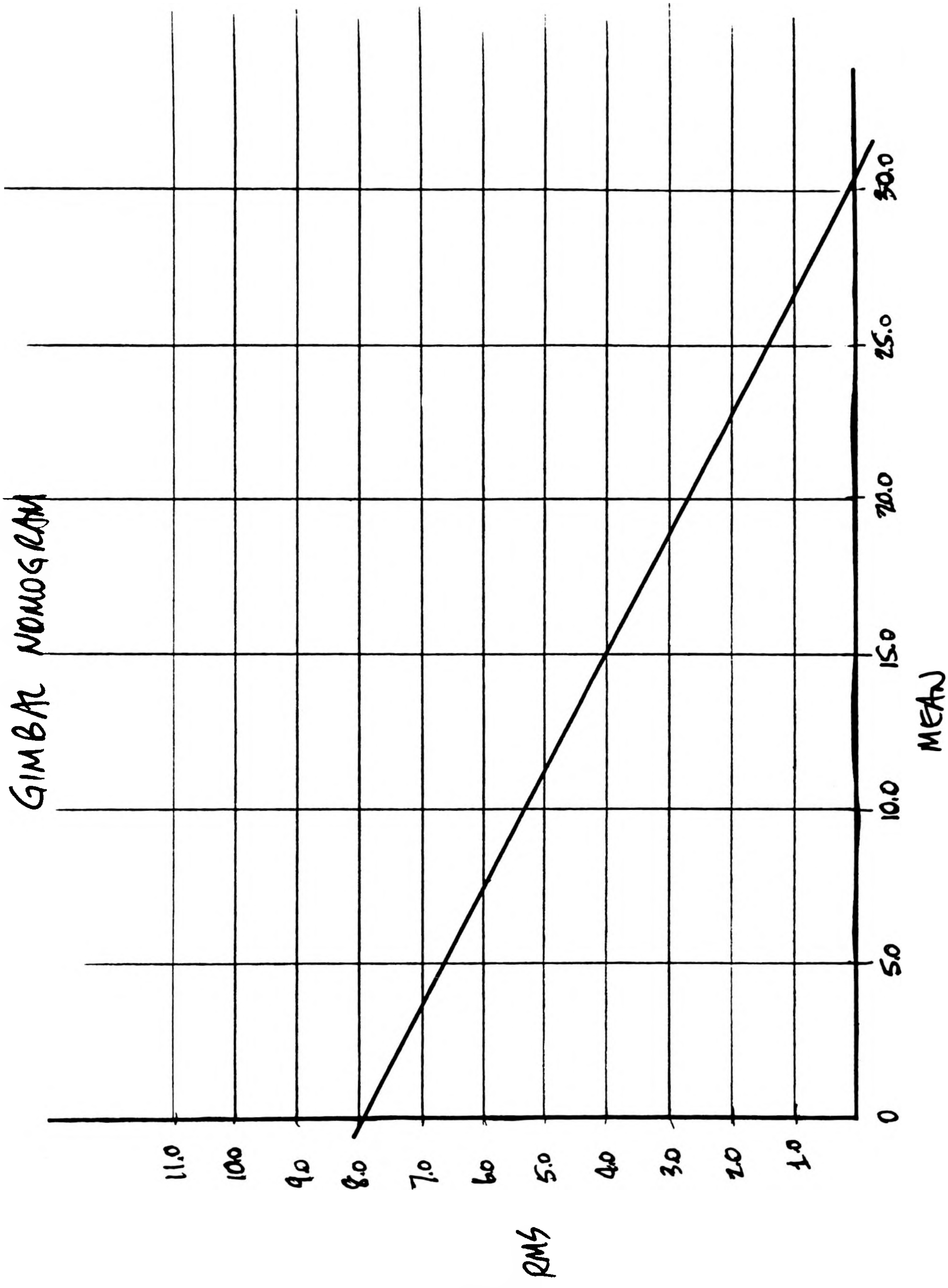
THE GIMBAL IS LIMITED TO 30° MAX ON ANY AXIS (PITCH OR ROLL)

CRITERIA. DEVELOPMENT.

THE STATISTICS FOR WAVE MOTION (RAYLEIGH DISTRIBUTION) INDICATE THAT A PEAK IS EXPECTABLE AT .3.8 x RMS VALUE THERE FORE, THE MEAN + 3.8 RMS ≤ 30°
A NOMOGRAM IS CONSTRUCTED AS FOLLOWS :



PLOT THE DATA INTERVAL RESULTS OF MEAN & RMS & OBSERVE DIRECTION AS TIME CONTINUES. THIS MAY SHOW TREND & WILL GIVE FEEL FOR WHAT IS DEVELOPING.


GIMBAL NOMOGRAM
MEAN
0
5.0
10.0
15.0
20.0
25.0
30.0
RMS
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0

ENCLOSURE 2 DETAILED CWP RELEASE PROCEDURE

In carrying out emergency procedures, it must be kept in mind that the ultimate responsibility for the safety of the ship lies with the ship's master. Everyone concerned should provide the necessary information for the Master to make the final decision on release of the pipe.

ACTION TO BE TAKEN (see Ref. 3, O&M Manual, for supporting information)

1. Unlock the gimbal hydraulics control panel.

2. Check to ensure that the gimbal accumulator is charged 3000 psi, maximum. If not, open charge valve and bring up to pressure.

3. Check adjust L.P. pump compensator to ensure that all system pressures are at 250 psi minimum. If not, charge to this pressure.

4. Adjust H.P. pump compensator to ensure high pressure system is at 3000 psi.

5. Check cold water pipe marker buoy system to ensure the lines are all free and clear.

6. Remove the moon pool cover from the pool and stow.

7. Secure the cold water pump.

8. Unplug the LVDT's and cap the connections.

9. Bundle the LVDT leads and attach a lowering line.

10. Remove the bolts in the slides of the CWP marker buoy launcher in preparation for launching. Be prepared to cut the release lines and release and latch.

11. Cycle all four CWP release pins one at a time to ensure they are all free. (See note at end of Appendix B.)

12. Lower the LVDT's below the baseline with the lowering lines.

13. Remove the rope ties on the cold water pipe marker buoy.

14. Release the marker buoy by cutting the rope ties and pulling the release latch pin.

15. At the signal from the Master, use the following sequence to release:

a. If the cold water pipe is streaming fore or aft (mainly):

*1. Push enable valves forward and aft.

2. Move forward and aft selector to the retract position.

3. Verify pin retraction by appropriate light indication. Also verify retraction by a drop in pressure reading on the low pressure gage.

4. Verify pins to be fully retracted by appropriate light. Also verify full retraction by observing the low pressure gage has returned to normal 250 psi.

5. When the forward and aft pins have been retracted, open the accumulator charge valves for the port and starboard pins.

6. Ensure that 3000 psi is indicated on gage and then close the valves.

*7. Push port and starboard enable valves.

8. Push port and starboard fast fire valves simultaneously (perform on upward vessel motion if possible).

**b. If the cold water pipe is streaming port and starboard (mainly).

1. Push the enable valves port and starboard.

2. Move the port and starboard selector to retract position.

3. Verify pin retraction by appropriate light indication. Also verify retraction by a drop in pressure reading on the low pressure gage.

4. Verify pins to be fully retracted by appropriate light. Also, verify by observing that the low pressure gage has returned to 250 psig.

5. When the port and starboard pins have been retracted, open the accumulator charge valves for forward and aft pins.

6. Ensure that 3000 psi is indicated on the gage and then close the valves.

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*If fore and aft gimbal angle is very high, use fast fire for all four pins. Fore and aft first then port and starboard.

**If port and starboard gimbal angle is high, fast fire fore and aft pins then port and starboard.

7. Push forward and aft enable valves.

8. Push forward and aft fast fire valves simultaneously.

NOTE

Detailed procedure for cycling all release pins to ensure they are free in case emergency release is required is as follows.

1. Unlock the gimbal hydraulics control panel.

2. Charge the gimbal accumulators to 3000 psi maximum.

3. Charge all low pressures to 250 psi using pump adjustment.

4. Adjust H.P. pump compensator to bring high pressure system to 3000 psi.

5. Cycle all four pins using the following procedures.

6. Push the enable valve for the pin involed.

7. Move selector to the retract position.

8. Verify pin retract by appropriate light indication and drop in pressure reading on the low pressure gage.

9. Verify fully retract by appropriate light. Check fully retract also by return of pressure to 250 psi.

10. If pin fails to retract use the 3000 psi unlatch valve (for a second) to try and release.

11. If pin still fails to retract push the auxiliary insert enable valve for the appropriate pin.

12. Move selector to insert position. Verify pin to be fully retracted by appropriate light. Also verify by observing low pressure gage to 250 psi.

13. If all above fails to retract the pin, open the accumulator charge valve and ensure 3000 psi registers on the gage.

14. Push the enable valve and release the pin.

ENCLOSURE 3 CWP RECOVERY

(This appendix provides the procedure for locating the CWP, grappling, rigging for winching, keelhauling, and attachment to the gimbal. Refer to Operation and Maintenance Manual for tools, fixtures, and procedures.)

ENCLOSURE 4 RECONNECTION OF OEC TO MOOR

NOTE

Vessel should be maneuvered in the "marine" mode unless there is no measureable current; in which case thrusters only may be used. Review Ref. 4 documents for additional information.

1. Verify position of the OEC relative to the subsurface buoy utilizing the mini-ranger. CWP must be clear of possible interference with the subsurface buoy.

2. Proceed to the small recovery buoy, lining up with the surface buoy and the mooring line (with floatation).

3. Take aboard the small recovery buoy, passing the 100 ft length of 3/4-in. wire to the "niggerhead" through the "bullnose".

4. Bring the mooring chain aboard. The wire is made fast four links off of the bitter end - this will allow sufficient slack to secure the pelican hook.

5. Bring the larger recovery buoy aboard.

NOTE

Use caution when recovering the 100 ft wire - keep the vessel lined up with the buoy, and the mooring line slack. The best position for the Master is on the fo'c'sle head to keep a constant eye on the mooring as it is necessary to adjust the main drive revolution's via VHF hand set through the Mate on the bridge.