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OCEAN THERMAL ENERGY CONVERSION POWER SYSTEM DEVELOPMENT-I

Preliminary Design Report

Volume 4, Appendix G

December 18, 1978

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Work Performed Under Contract No. EG-77-C-03-1568

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TO
OCEAN THERMAL ENERGY CONVERSION
POWER SYSTEM DEVELOPMENT-I
PHASE I — FINAL REPORT

PRELIMINARY DESIGN REPORT — VOLUME IV
LMSC-D630248 • 18 DECEMBER 1978
CONTRACT EG-77-C-03-1568

Prepared for
UNITED STATES DEPARTMENT OF ENERGY
DIVISION OF SOLAR ENERGY
by
OCEAN SYSTEMS
LOCKHEED MISSILES & SPACE COMPANY, INC.
SUNNYVALE, CALIFORNIA 94086

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OCEAN THERMAL ENERGY CONVERSION POWER SYSTEM DEVELOPMENT-I PRELIMINARY DESIGN REPORT

VOLUME IV

APPENDIX G

18 DECEMBER 1978

CONTRACT EG-77-C-03-1568

Prepared for

**UNITED STATES DEPARTMENT OF ENERGY
DIVISION OF SOLAR ENERGY**

by

**OCEAN SYSTEMS
LOCKHEED MISSILES & SPACE COMPANY, INC.
SUNNYVALE, CALIFORNIA 94086**

FOREWORD

The Lockheed Missile and Space Company, Inc. (LMSC) together with corporate team members and subcontractors, has completed Task 2, Phase I, of the Power System Development (PSD-I) project. This report presents the results of an eight-month study performed for the United States Department of Energy, Division of Solar Energy, under contract EG-77-C-03-1568 and consists of:

- Conceptual design of a 50-MW(e) Commercial plant size Power Module (CPM)
- Preliminary design of a 10-MW(e) Modular Application Power System (MAPS)
- Preliminary design of Heat Exchanger Test Articles (HETA)

The corporate team members were:

- Lockheed Electronics Co., (LEC), Houston, TX
- Lockheed Shipbuilding and Construction Co., (LSCC), Seattle, WA

The subcontractors were:

- AIRCO Cryogenics, Newport Beach, CA
- Bechtel National Inc., (BNI), San Francisco, CA
- Foster Wheeler Energy Corporation (FWEC), Livingstone, NJ
- Rotoflow Corporation, Los Angeles, CA

This report presents a technical description of the closed cycle ammonia power system modules derived for a reference surface platform in an immersed configuration (with two variations) as well as an alternative power system incorporated into a submerged detachable module.

The complete report consists of the following volumes:

Volume I — Preliminary Design Report LMSC D-630248

Volume II — Appendixes:

- Appendix A. System Analysis and Performance (Computer Runs, Sensitivity Analysis, Individual Studies Etc.)
- Appendix B. System and Component Specs for TA and 10 MW Drawings
- Appendix C. General Arrangements Envelope, Flow, Piping, Subsystem, Etc.(Structure Analysis, Stability Analysis)

Volume III — Appendixes:

- Appendix D. System Equipment (Hardware Breakdown, Equipment Tables Maintenance and Support Equipment)
- Appendix E. Heat Exchangers Supporting Data
- Appendix F. Rotating Machinery

Volume IV — Appendix G. Ammonia Cycle and Auxiliaries

Volume V — Appendixes:

- Appendix H. Electrical Power
- Appendix I. Control and Instrumentation
- Appendix J. Module Assembly
- Appendix K. Cost Reporting Tables

Appendix G

AMMONIA CYCLE, AUXILIARIES AND ANCILLARIES

BECHTEL NATIONS, INC.

50 MW(e) COMMERCIAL PLANT POWER MODULE CONCEPTUAL DESIGN DESCRIPTION FOR:

- G1 AMMONIA VAPOR AND CONDENSATE SYSTEM
- G2 AMMONIA STORAGE AND FILL SYSTEM
- G3 NONCONDENSIBLE GAS REMOVAL SYSTEM
- G4 AMMONIA CLEANUP SYSTEM (OTEC AMMONIA CLEANUP ALTERNATIVES)
- G5 AMMONIA UNLOADING SYSTEM
- G6 LEAK DETECTION SYSTEM
- G7 FLUID SAMPLING SYSTEM

10 MW(e) MODULAR APPLICATION POWER MODULE PRELIMINARY DESIGN DESCRIPTION FOR:

- G8 AMMONIA VAPOR AND CONDENSATE SYSTEM
- G9 AMMONIA STORAGE AND FILL SYSTEM
- G10 NONCONDENSIBLE GAS REMOVAL SYSTEM
- G11 AMMONIA CLEANUP SYSTEM
- G12 AMMONIA UNLOADING SYSTEM
- G13 LEAK DETECTION SYSTEM
- G14 FLUID SAMPLING SYSTEM

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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

50 MWe Commercial Plant Power Module
Conceptual Design Description
for the
Ammonia Vapor and Condensate System

Dechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the conceptual design description of the Ammonia Vapor and Condensate System (AVCS) for the 50 MWe OTEC commercial plant power module. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The conceptual design was prepared to identify key features of commercial OTEC power plants which are to be incorporated into an analogous 10 MWe modular application power system. The design is based on generic site conditions.

The AVCS pumps condensate from the condenser to the evaporator, supplies liquid ammonia to the evaporator spray nozzles, and carries ammonia vapor to the turbine.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The functions of the Ammonia Vapor and Condensate System (AVCS) are to:

- Convey ammonia condensate from the condenser to the evaporator sump
- Convey liquid ammonia from the evaporator sump to the evaporator spray nozzles
- Convey ammonia vapor from the evaporator to the turbine.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The AVCS is to permit the operation of the OTEC power cycle with the warm water and cold water temperature combinations shown in Figure 1-1.

At the design point conditions (50 MWe net electric power generation), the condensate flow rate is 4000 lb/sec. The condensate flow will vary over a range of 2580 lb/sec to 4540 lb/sec as part of normal operation. The distribution flow is 150% of the condensate flow rate over the operating range.

Figure 1-1 OTEC OPERATING REGIME

At the design point the condenser operates at 89 psia and the evaporator operates at 129 psia ammonia pressure. The evaporator pressure varies from 114 to 138 psia. The pressure of the condenser varies from 86.5 to 93 psia. The condensate pumps are to deliver the required condensate flow against the condenser-to-evaporator pressure differentials over the whole operating regime of the power system.

1.2.2 Structural Requirements

All lines containing ammonia are to be designed to contain a pressure of 250 psig. Lines are fabricated of carbon steel and are designed for a 30-year plant life. The system piping and components are to be designed to remain operational with vertical acceleration of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary with vertical accelerations of $\pm 0.7g$ (sea state 9). The system is to be designed to withstand transient effects such as those resulting from turbine trip.

1.2.3 System Configuration and Essential Features

The pumps of the AVCS are located in the machinery rooms of the condenser (condensate pumps) and the evaporator (distribution pumps). Pump locations are to be sufficiently below the suction sump liquid level to ensure cavitation-free operation at all operating conditions of Figure 1-1 in sea states with a vertical acceleration of $\pm 0.15g$. Maximum allowable flow velocities are as follows:

Liquid Lines

30 ft/sec

Vapor Lines

160 ft/sec

The evaporator and the condenser are to be separately detachable from the power module. Separable and remakable joints and valves are therefore required above the water line in the evaporator vapor lines, in the turbine exhaust line, and in the condensate line from the condenser to the evaporator sump.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be specified during preliminary and detailed designs.

1.2.5 Level of Technology

Components for the AVCS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Instrument sensors and displays, required to ascertain safe operating status of the system and to indicate nonstandard operating conditions, are to be identified. As a minimum, such instrumentation should include pressure and temperature sensing, flow metering, chemical sampling and analytical capability, electric motor status, and valve position indicators.

Controls are to have sufficient response capability to allow regulation of the ammonia vapor and condensate flows, demanded by the OTEC control system, over the expected operating range. Liquid levels in the evaporator and condenser sumps are to be controlled. Continuous condensate and distribution flow rate signals are to be provided for use in the OTEC control system.

1.2.7 Maintenance Requirements

Maintenance provisions of the AVCS are to be consistent with the overall maintenance plan of the power module. Means of isolation, purging, and disassembly and for lifting and transportation are to be provided to permit maintenance of disabled pumps while the power module is operating. Special tooling, including lifting slings required for maintenance of AVCS equipment, are to be provided. The arrangement of system components is to allow space and access to perform maintenance operations and a safe transit path for equipment removal.

1.2.8 System Reliability

The reliability of the AVCS is to be consistent with the OTEC 90% availability (at 60% confidence) requirement. One redundant condensate pump and one redundant distribution pump are to be installed for operation upon failure of an operating pump. Equipment specifications and rating are to be conservative (e.g., low speeds, heavy walls) to provide maximum durability.

1.2.9 Interface Requirements

The AVCS is functionally a part of the OTEC power cycle, and it interfaces with the:

- Ammonia Storage and Fill System
- Ammonia Unloading System
- Ammonia Cleanup System
- Noncondensable Gas Removal System
- Machinery Room HVAC System
- Plant Control System
- Electrical System
- Fire Protection System.

During normal operation, valves at all interfaces to the Ammonia Unloading System are locked closed. Those valves at the interface with the Ammonia Storage and Fill System which do not function to control ammonia inventory will also be locked closed.

1.2.10 Environmental and Safety-Related Requirements

The AVCS is to be equipped with pressure relief devices to prevent accidental overpressuring of the system. Blowdown from relief valves is to be manifolded for safe discharge through the Ammonia Unloading System.

Warning indicators and alarms are to be provided by the Leak Detection System to alert plant personnel of unsafe conditions,

such as high ammonia concentrations, before the system is opened for maintenance.

Design provisions required by OSHA for plant personnel safety are to be incorporated. In particular, the ammonia vapor concentrations in the pump rooms are to be monitored and maintained below 50 ppm.

Provisions for fire alarm and suppression are to be supplied by the plant fire protection system.

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Section 2

DESIGN DESCRIPTION

The AVCS is a functionally integral part of the OTEC 50 MWe power cycle. The power cycle uses ammonia as the working fluid. The details of the power cycle, the turbine, the evaporator and the condenser are described in other project documentation.

2.1 SYSTEM CONFIGURATION

A flow diagram of the AVCS is shown on Drawing M-502 (Appendix A). A functional and physical description of the system is given below.

An 84-inch diameter suction manifold takes ammonia from the condenser sump and distributes it to three 48-inch diameter suction lines leading to each of the three 50% capacity condensate pumps. These pumps have head and flow capacity to increase the condensate pressure to the operating pressure of the evaporator, satisfy static head requirements, and to overcome line losses. Two pumps are normally operating; the remaining pump is on standby. Each suction line contains a butterfly stop valve and a temporary startup strainer. Each pump discharge line contains a butterfly stop check valve. These valves are used to isolate the pumps for maintenance or to prevent backflow through a standby pump. Elastomeric expansion joints in both the suction and discharge lines serve to minimize thermal expansion stresses in the close-coupled arrangement. The three 20-inch diameter

discharge lines combine to feed a 30-inch diameter main condensate line. This line is routed through the condenser shell to above the water level where the valves and separation flanges, necessary for evaporator and condenser removal, are located. The main condensate line is then routed to the evaporator sump where the condensate is discharged below the liquid surface through a circular sparger. Lines from the bottom of each pump barrel and from the top of each pump discharge port are provided for access to the interfacing systems for the purpose of filling, draining, venting and purging. During normal operation the valves at these connections are locked closed. The line from the top of each pump discharge port is connected with a vapor vent within the condenser. A line which can vent the highest point in the condensate line to the evaporator space is provided to permit draining of the condensate line.

In the distribution loop an 84-inch diameter suction manifold takes ammonia from the evaporator sump and distributes it to four 48-inch diameter lines leading to each of the four 33% capacity distribution pumps. Three pumps are normally operating; the remaining pump is on standby. Each suction line contains a butterfly valve and a temporary startup strainer. Each pump discharge line contains a butterfly stop check valve. Similar to the condensate loops, these valves serve to isolate the pump and to prevent backflow. Elastomeric expansion joints in both the suction and discharge lines of each pump serve to minimize expansion stresses. The four 20-inch diameter discharge lines combine to feed a 36-inch diameter manifold which enters the

bottom of the evaporator shell and is routed to banks of spray nozzles to distribute the ammonia uniformly over the evaporator tube surfaces. Lines from the bottom of each pump barrel and from the top of each pump discharge port are provided for connection to the interfacing systems for the purpose of filling, draining, venting and purging. During normal operation the valves at these connections are locked closed. The line from the top of each discharge port is connected with a vapor vent within the evaporator.

A pair of 75-inch diameter lines carry vapor from the evaporator to the turbine. Each of these lines contains a removable, gasketed flange and a stop valve. Similar flanges and stop valves are provided in the turbine exhaust line. This feature is required to permit removal of either the condenser or the evaporator from the power system without the need for complete draining and purging of the system.

2.2 SYSTEM PERFORMANCE

The range of warm and cold seawater temperatures and the corresponding evaporator and condenser operating pressures are shown in Figure 2-1. The corresponding range of ammonia flow rates (to the turbine and from the condenser) are presented in Figure 2-2. Distribution flow rates exceed those of Figure 2-2 by approximately 50%.

Figure 2-1 HEAT EXCHANGER OPERATING PRESSURES

OPTIMIZED FOR AVAILABLE ΔT

Figure 2-2 AMMONIA FLOW VARIATION

As is evident from Figure 2-2, both the condensate and distribution flows vary from about 60 to 110% of the design point conditions. Based on a comparative study described in Appendix B, a flow control approach, consisting of discharge throttling near the design point and pump speed control below this flow, was selected for meeting the system requirements. This combined control approach will minimize the losses over the entire operating regime. It is noted that the design of the AVCS is based on generic site conditions, and it should be reevaluated in light of the seawater temperature history of the selected OTEC power site.

2.3 SYSTEM ARRANGEMENT

The system arrangement is illustrated by the condensate pump arrangement drawing (Drawing P-501, Appendix A) and the distribution pump arrangement drawing (Drawing P-502, Appendix A).

As shown on Drawing P-501 (Appendix A), the condensate pumps are located in a 32-ft diameter, 45-ft high cylindrical pump room immediately below and attached to the spherical condenser shell. The pumps are located side by side in alignment with the cylinder diameter. The elevation of the pump barrel flange is 116 ft below sea level.

A 10-ton jib crane and nearly 12 ft of overhead clearance are provided for pump and pump-motor replacement. Removed components

are transported by the crane to a 10-ft diameter access tube. The access tube provides for manned access and transport of components to and from the main deck. The tube also serves to house electric cables, HVAC ducts, and lines for other services (e.g., service water, compressed air, etc.).

HVAC ducting entering and leaving the pump room is to provide six changes of air per hour. Supply ducts are pointed at each pump motor and valve motor to lessen the buildup of hazardous ammonia concentrations if leakage occurs.

Each pump room also houses a drain tank with transfer pumps for the Ammonia Unloading System and a bilge tank for storage and removal of waste water and oily wastes that are produced during the course of operation and maintenance. A hydraulic system that is used to actuate the large valves at the pump suction and discharge is also located in this room, together with two instrument cabinets housing control equipment and transmitters.

Relative thermal expansion between the condensate piping and the pump room cylindrical shell tends to create stresses that can be imparted to the pump flanges and the heat exchanger shell. A 44F maximum temperature differential can create an .124-inch displacement in the pump suction flange and an .098-inch displacement of the pump discharge flange. A single convolution, reinforced, elastomeric expansion joint is placed near each pump suction and discharge flange in order to accommodate such movement and avoid the imposition of unwanted forces. It is

expected that a deflection-stress analysis of the pump discharge lines may show that sufficient flexibility can be provided in the discharge line and manifolding arrangement to avoid the need for expansion joints at the pump discharge flanges. This analysis has been deferred to the final design phase when the final line configuration will be better known.

The arrangement of the distribution pump room is the same as that of the condensate pump room except that four pumps are accommodated instead of three. This requires a pump room diameter of 37 ft instead of 32 ft, as shown on Drawing P-502 (Appendix A).

2.4 SYSTEM COMPONENTS

Following is a list of AVCS components:

Condensate Pumps

Quantity:	3
Type:	Vertical centrifugal, multistage
Capacity:	26200 gpm
Head:	215 ft
Power:	1046 shaft hp
Driver - type:	Electric motor
- speed:	705 rpm (max. load)
Power Supply:	Variable frequency
Barrel Diameter:	5 ft 4 in
Height:	18 ft 10 in (without motor)
Weight:	22500 lb (without motor)

It is noted that the condensate and distribution pump designs are similar, and consequently a number of their components are interchangeable.

Condensate Pump Discharge Isolation Valves

Quantity: 3
Type: Butterfly, stop-check
Size: 20-in diameter
Actuation: hydraulic

Condensate Pump Suction Isolation Valves

Quantity: 3
Type: Butterfly
Size: 48-in diameter
Actuation: hydraulic

Condensate Control Valve

Quantity: 1
Type: Butterfly
Size: 30-in diameter
Actuation: hydraulic

Distribution Pumps

Quantity: 4
Type: Vertical centrifugal, single stage
Capacity: 26200 gpm
Head: 96 ft
Power: 462 shaft hp
Driver - type: Electric motor
- speed: 705 rpm (max. load)
Power Supply: Variable frequency
Barrel Diameter: 5 ft 4 in
Height: 15 ft 2 in (without motor)
Weight: 15700 lb (without motor)

Distribution Pump Discharge Isolation Valves

Quantity: 4
Type: Butterfly, stop-check
Size: 20-in diameter

Distribution Pump Suction Isolation Valves

Quantity: 4
Type: Butterfly
Size: 48-in diameter

Condenser Evaporator Liquid Isolation Valve

Quantity: 2
Type: Butterfly
Size: 30-in diameter

Evaporator Vapor Isolation Valves

Quantity:	2
Type:	Butterfly
Size:	75-in diameter
Actuation:	hydraulic

Distribution Control Valve

Quantity:	1
Type:	Butterfly
Size:	36-in diameter
Actuation:	hydraulic

2.5 SPECIAL SUPPORT EQUIPMENT

2.5.1 Hydraulic Actuation Packages

Due to confined space and large valve sizes, air actuation appears to be impractical. Electrical motor actuators would require explosion-proof motors. However, hydraulic actuation can minimize the disadvantages of the above options. It is commonly used in shipboard applications and was selected for the large valves of the AVCS. There is a hydraulic actuation package in each of the two pump rooms. Commercially available, unitized packages, containing a reservoir, hydraulic pumps, controls and auxiliaries are used.

2.5.2 Hoisting and Transport Equipment

Each pump room is equipped with a 10-ton capacity jib crane. Lift coverage extending over all pumps, discharge isolation valves and expansion joints is provided for installation and maintenance lifts. Special transfer carts are provided for

horizontal transport of major components to and from the pump rooms.

2.6 INSTRUMENTATION AND CONTROL

The operation of the AVCS must be controlled to maintain the required liquid ammonia flow rate for the operation of the OTEC power cycle and to maintain appropriate distribution of the liquid ammonia inventory in various parts of the system.

The condensate flow rate to the evaporator is controlled in response to the demand signal of the evaporator sump liquid level sensor. The condenser sump liquid level sensor signal is used to control the valve adding ammonia at low level or the overflow valve which withdraws ammonia from the system. The flow rate to the evaporator spray nozzles is controlled by signals from the power system controls.

The method for controlling the condensate and distribution flows involves separate throttle controls of the condensate and distribution pump discharge flows from maximum down to about 90% of design flow capacity. At flow rates below this level, the control is accomplished by varying the pump speed (using frequency control of the electric current driving the pump motors). This combination of flow control methods was found to be superior to pure throttle control or pure speed control as a result of economic evaluations described in Appendix B.

Special instrumentation includes transducers to measure pump suction and discharge pressures, pump discharge temperatures, and pump vibration, and a condensate flow measurement that is used as an input signal to both the main OTEC control system and the evaporator sump control system. Other instrumentation is provided for monitoring the concentration of ammonia within the pump rooms.

The pump discharge and suction valves are equipped with position indicators that connect to an interlock which prevents operation of the pump motor when the valves are closed. This prevents pump damage due to operation at shutoff or low-flow conditions.

2.7 SYSTEM INTERFACES

Within the power module, the AVCS interfaces with the following systems:

- Power System Active Components - integrated operation of power system
- Power System Central Control - overall control
- Ammonia Storage and Fill System - vapor and liquid for filling and liquid for makeup
- Ammonia Unloading System - drain, vent and purge function
- Ammonia Liquid Cleanup System - removal of seawater and solid reaction products
- Noncondensable Gas Removal System - elimination of noncondensable gases from the system
- Electrical System - pump drive power, startup and standby power

- Module Structures - physical support and space for the AVCS.

The AVCS also interfaces with platform-related systems. The most significant interfaces are as follows:

- The platform Ammonia Storage and Transfer System provides storage capacity for the system ammonia inventory and for ammonia makeup. That system also provides superheated ammonia at 50°F to charge the power system with ammonia vapor from 60 to 90 psia and liquid ammonia to complete the system charging.
- The platform HVAC system provides air supply for 6 air changes per hour in each of the pump rooms.
- The platform nitrogen storage system supplies inert gas for purge/dilution of ammonia.
- The platform air supply provides purge/dilution air to reduce the ammonia to 50 ppm concentration in a purged component.
- The platform electric distribution system provides startup power and standby power.
- The platform fire protection system provides central fire alarm and fire suppression capability.
- The platform utilities system provides portable water and sanitary waste disposal services.

2.8 DESIGN PROVISIONS FOR SAFETY

Safety provisions in the AVCS pump rooms are aimed primarily at maintaining a nontoxic and nonexplosive atmosphere. This is accomplished by providing HVAC design features required by NFPA 70 (ANSI-C1) for Class I, Group D, Division 2 locations. To this end, special ventilation supply ducts are provided in the vicinity of all electric motors. The use of electric devices for valve actuation is minimized. A single hydraulic package in each

pump room provides actuation power to all large valves. The allowable leakage from all valves and fittings within a pump room is specified so as to maintain nontoxic ammonia concentrations of less than 50 ppm when diluted by the six air changes supplied by the HVAC system each hour. The HVAC system is, therefore, a safety-related system which is to incorporate redundant component design features for added reliability and suitable alarms to signal malfunction. The pump rooms must be evacuated upon receipt of alarms signaling malfunction of the HVAC system or high readings from the ammonia concentration monitors of the Leak Detection System.

To prevent personal injury and major economic losses due to fires and explosion, all electric motors are induction-type or explosion-proof wound-rotor type.

Both pump rooms are equipped with deluge-type sprinkler systems and with outlets for water to wash down ammonia spills.

Section 3
SYSTEM OPERATION

3.1 SYSTEM STARTUP

The following sequence of operations accomplishes startup of the AVCS:

1. Verify that the system contains the required ammonia charge.
2. Set all valves as specified for startup and verify positions.
3. Using power from a startup ship or from an operating OTEC module, initiate startup mode operation of the seawater pumps (one warm seawater pump and one cold seawater pump).
4. Start one evaporator distribution pump. Start one condensate pump in recirculating mode.
5. Open turbine valves and allow turbine to accelerate to speed. Synchronize generator output with startup power supply.
6. Upon sufficient lowering of evaporator sump level to create a condensate flow demand signal, start one condensate pump.
7. When the module generator produces enough power for self-sustaining operation, switch from exterior startup power supply to module power.
8. Turn on all remaining seawater pumps, one at a time.
9. Turn on two more evaporator distribution pumps.
10. Turn on one more condensate pump.
11. Start supplying power to platform electric distribution system.

3.2 NORMAL OPERATION

During normal operation, flow demand for the distribution pumps comes from the main OTEC control system. Condensate pump flow is governed by liquid level in the evaporator sump. Inventory is varied as required to maintain liquid level in the condenser sump. Pumping rates are automatically controlled by means of throttling or motor speed control to maintain the required ammonia flow for the desired power level. Failure of a condensate or distribution pump automatically brings a standby pump into operation.

3.3 SHUTDOWN

The following sequence of operations accomplishes shutdown of the AVCS:

1. Unload the turbine/generator.
2. Shut down one of two operating condensate pumps and two of three operating distribution pumps.
3. Allow condensate flow rate to stabilize at a reduced value.
4. Shut down all seawater pumps.
5. Shut down the remaining distribution and condensate pumps.

3.4 INFREQUENT AND ABNORMAL OPERATIONS

Abnormal operation can occur as the result of component or control system failures. Erroneous condensate flow demand

signals can result in flooding or emptying of the evaporator sump. High and low liquid level alarms are provided, should such an event occur. Similar liquid level alarms are provided in the condenser. Failure of a distribution or condensate pump automatically brings a standby pump on line and creates no abnormal operation except for a momentary dip in flow rate. Unintended closure of a pump suction or discharge valve results in shutdown of the associated pump by means of the valve-pump motor interlock feature. In such an instance the standby pump automatically starts. The pumps are tripped on low level indication in the condenser and evaporator.

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Section 4

MAINTENANCE

4.1 DRY DOCK MAINTENANCE

The entire OTEC module is removed to dry dock once each three years for inspection and maintenance. Regular inspection and replacement of relatively short life items such as elastomeric expansion joints and seals occurs at this time. Pumps and valves are overhauled. Piping is inspected for weld cracks, deposits, and signs of leakage, erosion or cavitation.

4.2 OPERATIONAL MAINTENANCE

The AVCS pump rooms are equipped for removal of defective pumps and pump motors while the plant is operating. A 10-ton jib crane and nearly 12 ft of overhead clearance are provided.

Pump removal requires prior closure of suction and discharge isolation valves and the draining and purging of the pump interior until the concentration of ammonia in the purge air falls below 50 ppm.

The removal of a pump entails removal of the motor and removal of the rotor and discharge housing in two pieces. The pump barrel is left in place and remains connected to the suction line. The discharge nozzle flange must be disconnected to remove the top portion of the pump.

The removed sections of the pump are carried to the 10-ft diameter pump room access passage on the jib crane. The equipment is then transported by dolly or monorail along the passageway to an elevator which transports men and equipment to the main deck. There minor pump repair can be conducted. Pumps with major defects are taken ashore for repair.

Appendix A

AMMONIA VAPOR AND CONDENSATE SYSTEM DRAWINGS

Bechtel Drawing M-502, Ammonia Vapor and Condensate
System Flow Diagram

Bechtel Drawing P-501, Condensate Pump Arrangement

Bechtel Drawing P-502, Distribution Pump Arrangement

MODE	PARAMETER	1	2	3	4	5	6	7	8	9	10	11
MAXIMUM	FLOW L/SEC	0	2270	0	2270	4540	0	2270	0	2270	6810	4540
	TEMP. F	52	52	52	52	52	59	59	59	59	59	74
	PRESS. PSIA	93	93	16	161	51	138	138	170	170	850	138
DESIGN	FLOW L/SEC	0	2000	0	2000	4000	0	2000	0	2000	6000	4000
	TEMP. F	50	50	50	50	50	57	57	57	57	57	70
	PRESS. PSIA	89	89	143	143	39	129	129	160	160	150	129
MINIMUM	FLOW L/SEC	0	1290	0	1290	2580	0	1290	0	1290	3870	2580
	TEMP. F	48	48	48	48	48	53	53	53	53	53	63
	PRESS. PSIA	86.5	86.5	126	126	18	114	114	142.5	142.5	132.5	114

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OTEC Power System Development Project

Subcontract YF80C1050M

Appendix B

Evaluation of Alternate Condensate and
Distribution Flow Control Methods

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

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1. PURPOSE

The purpose of this study was to determine the economically most advantageous method for controlling the liquid ammonia flow to the evaporator and to the evaporator distribution header.

2. APPROACH

2.1 Flow Control Methods Considered

Three plausible methods for varying condensate and distribution flow were evaluated in detail. These are:

- Throttling control, where the pumps are driven by constant speed electric motors and the liquid flow rate is varied by throttling the pump discharge.
- Variable speed control, where the pump motor speed is varied using a variable frequency power supply to meet different flow rate demands over the full range of flows.
- Mixed-mode control, where throttling control is used near maximum flow demand and variable speed control is applied for lower flow rates.

An alternate variable speed drive, based on the use of wound rotor motors with variable secondary resistance, was considered but not economically evaluated. Although this system is more efficient than the variable frequency power supply, wound rotor motors are generally much larger than induction motors and also require cumbersome explosion proofing.

A further alternative for varying pump speed, to be evaluated in detail design, is the use of hydraulic motor drives for each

pump. These motors would be driven by a single variable displacement hydraulic pump, driven either from the main turbine-generator shaft or by a separate electric motor. This system may prove to be both more efficient and less expensive than the variable frequency power supply.

Variable pitch pumps, although applicable in principal, do not appear to be appropriate for this specific application.

2.2 Economic Analysis

An economic analysis was done to compare variable speed and mixed-mode flow control with throttling control for both the 50 MWe commercial power module and the 10 MWe modular application system. For each of the two alternative flow control methods, the benefit was calculated as the present worth of the net gain in saleable electrical energy over a 30-year plant life, and the respective costs were evaluated as the present worth of the cost of the additional equipment required for the particular control method.

Plant Operating Basis. For purposes of the analysis, it was assumed that the power plant is designed to operate over the following range of conditions:

- Cold water temperature 32 to 50F
- Warm water temperature 70 to 85F
- Differential temperature range 29 to 44F
- Nominal design point 80F warm water
 40F cold water

At a number of potential sites, the cold water temperature is virtually constant year around, and the warm water temperature varies seasonally, which gives an annual cycle of power available from an OTEC plant. For purposes of this tradeoff study, the annual operating cycle was assumed to consist of the following time fractions:

- Design point - 50% of the time
 Warm water temperature 80F
 Cold water temperature 40F
- Low water temperature - 25% of the time
 Warm water temperature 70F
 Cold water temperature 41F
- High water temperature - 25% of the time
 Warm water temperature 85F
 Cold water temperature 41F

This set of operating conditions provides a realistic allowance for seasonal changes in operating conditions and allows a reasonable approximation of the annual power availability for this study.

Plant life was taken as 30 years and plant availability was assumed to be 90%.

Economic Basis. The following economic assumptions were used for this study:

- Discount rate 8%
- Value of electric energy 40 mills/kWh initially and escalating at 7% annually
- Capital recovery factor 0.128

3. RESULTS

To illustrate the results of this economic comparison, one case (50 MWe mixed mode) is traced step-by-step in the following paragraphs with the complete set of all four cases given in Table 3-1.

3.1 Benefits

For the 50 MWe module with mixed mode control, electric energy amounting to 4,180,000 kWh is saved and available for sale each year compared to throttling control. This saving results from using throttling or variable speed control to achieve maximum efficiency at any flow rate demand thus requiring the least power to drive the pumps. The annual energy saving has a value of \$167,200 at the assumed current value of 40 mills/kWh. Over a 30-year plant life, the total electric energy saved has a present worth of \$4,355,000.

TABLE B-1

BENEFITS AND COSTS FOR ALTERNATIVE FLOW CONTROL METHODS

Module Capacity	50 MWe			10 MWe		
Flow Control Method	Throttling	Variable Speed	Mixed Mode	Throttling	Variable Speed	Mixed Mode
Annual Electric Energy Saving (kWh)	Base Case	2,990,000	4,180,000	Base Case	276,000	536,000
Market Value of Annual Electric Energy Saving at 40 mills/kWh (1st year)	Base Case	\$ 119,600	\$ 167,200	Base Case	\$ 11,040	\$ 21,440
Present Worth of Electric Energy Saving Over 30 year Plant Life	Base Case	\$3,114,000	\$4,355,000	Base Case	\$288,000	\$559,000
Cost of Additional Equipment	Base Case	\$ 898,000	\$ 943,000	Base Case	\$106,000	\$130,000
Present Worth of Cost of Capital for Additional Equipment	Base Case	\$1,294,000	\$1,359,000	Base Case	\$152,000	\$187,000
Net Benefit	Base Case	\$1,820,000	\$2,996,000	Base Case	\$136,000	\$372,000
Benefit/Cost Ratio	Base Case	2.41	3.20	Base Case	1.89	2.99

3.2 Cost

The estimated cost of equipment needed for mixed mode flow control in a 50 MWe module is \$943,000 greater than for throttling control. This added cost includes the electrical equipment needed for supplying the variable frequency current to the pump motors.

The present worth of the cost of capital for this additional equipment is \$1,359,000 assuming an annual capital recovery factor of 0.128.

3.3 Comparison of Benefit and Cost

For the case followed in this illustration, the difference between present worth of the benefit and present worth of the additional equipment cost is \$2,996,000, and the ratio is 3.20.

A ratio greater than unity is usually considered as an attractive investment. However, to this point only equipment costs were considered with no allowance for installation costs. The effects of the installation costs may be assessed by considering the ratio of installation costs to equipment costs and calculating a breakeven value as follows:

For an alternative control method to be financially justified, the installation-to-equipment-cost ratio (IR) must be related to the benefit-to-equipment-present-worth ratio (BR) by the inequality

$$\frac{BR}{1 + IR} > 1$$

This inequality can be rearranged to show that

$$IR < BR - 1$$

for the added equipment to be justified.

Thus, mixed mode flow control for a 50 MWe module is justified for any ratio of installation to equipment cost less than 2.20. For the type equipment needed to implement this control method, the installation to equipment cost ratio is likely to be only a small fraction of that number.

3.4 Comparison of Control Methods

Both the variable speed and the mixed mode flow control approaches are economically beneficial compared to throttling control for both the 50 MWe and 10 MWe module capacity as shown by the benefit-to-cost ratio in Table 3-1, and the mixed mode is decidedly the better of these two alternatives, having a benefit-to-cost ratio of 3.20 compared to 2.41 for a 50 MWe module.

4. RECOMMENDATION

This analysis shows that the mixed mode flow control is economically the best of the three candidate methods, and it should be adopted for purposes of the conceptual and preliminary design work.

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF8CC1050M

50 MWe Commercial Plant Power Module

Conceptual Design Description

for

Ammonia Storage and Fill System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

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INTRODUCTION AND SUMMARY

This document contains the conceptual design description of the module-related portions of the Ammonia Storage and Fill System (ASFS) for the 50 MWe OTEC commercial plant power module. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The conceptual design was prepared to identify key features of a commercial OTEC power module which are to be incorporated into an analogous 10 MWe modular application power system. The design is based on generic site conditions.

The functions of the ASFS are to fill the module with ammonia and to supply ammonia to make up for losses. The complete system consists of tanks, heat exchangers, seawater pumps, interconnecting piping, and appropriate controls. In a commercial size OTEC installation using 50 MWe power modules, the ASFS storage tanks, pumps, and heat exchangers are part of the OTEC platform support facilities. The module provides piping to distribute ammonia to components in the module and to control the ammonia makeup flow rate. This document also describes the interfaces with the platform-related parts of the ASFS.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

Part of the functions of the Ammonia Storage and Fill System (ASFS) are provided by the platform support facilities, and part of the functions are provided by the module.

The platform-related facilities serve the following functions:

- Store ammonia for power module charging and operational makeup reserve
- Provide ammonia in liquid and vapor form for charging
- Supply makeup ammonia during operation.

The ASFS functions provided by the module are:

- Distribute the ammonia to charge the components and the power system
- Control the makeup ammonia flow rate during plant operation.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

Storage Capacity. The ammonia inventory in the 50 MWe module during normal conditions is 720,000 lb. Tankage is to be provided by the platform support facilities for the inventories

of all modules in the plant and some additional reserve amount for makeup to all modules.

Charging Capacity. The ASFS is to charge the power system with superheated ammonia vapor at 50 to 85 F from 60 to 89 psia and with liquid ammonia at ambient temperature. The target time for completing the vapor and liquid charging operations is 24 hr. The ASFS is to charge the power module turbine volume with ammonia vapor from 3 to 89 psia within 4 hr. Heat exchangers needed for vapor charge are provided by the platform facilities.

1.2.2 Structural Requirements

ASFS components and piping are to be designed for .250 psig internal pressure to satisfy CSHA and U. S. Coast Guard requirements for nonrefrigerated storage. The system piping and components are to remain operational with vertical acceleration of 0.15g (sea state 6) and to retain the integrity of the pressure boundary with vertical acceleration of 0.7g (sea state 9). A 30-year plant life is to be used in determining allowances for corrosion.

1.2.3 System Configuration and Essential Features

The ASFS storage tanks and heat exchangers are to be provided by the OTEC support platform. The piping connection joints between the platform facilities and the module distribution piping are to be located above water level. The module distribution piping,

that connects to components located below water level, is to be routed through a "shirt sleeve" environment.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be specified during preliminary and detailed design.

1.2.5 Level of Technology

The components for the ASFS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

All controls are to be provided by the platform. Control signals are to be provided by sensors in the ammonia vapor and condensate system.

1.2.7 Maintenance Requirements

Maintenance provisions of the ASFS are to be consistent with the maintenance plan established for the power module. Maintenance activities are to consist of inspections, preventive maintenance, routine refurbishing, and in-situ repairs. General tooling and special tools are to be provided for shipboard maintenance and for replacement of defective components. The arrangement of system components is to allow space and access to perform

maintenance operations and a safe transit path for component removal.

1.2.8 System Reliability

Equipment required for makeup addition will be essentially in continuous service. The ammonia charging equipment will be used for short periods, intermittently. Safe handling of ammonia requires that the whole system have high reliability. In addition, components in continuous service must support the targeted module availability of 90% (at 60% confidence level). Conservative equipment selection and ratings are to be specified (e.g., low speeds, heavy walls) to provide maximum durability.

1.2.9 Interface Requirements

Within the power module the interfaces between the ASFS distribution piping and the Ammonia Vapor and Condensate System include:

- Vapor charging connections (one each) to the evaporator and condenser
- Liquid charging connections to each of the condensate and distribution pumps
- Makeup liquid connection to the condenser.

The ASFS interfaces with the platform-related ammonia storage tanks and heat exchangers.

All enclosed spaces where ASFS components are installed will be served by the module ventilation system.

1.2.10 Environmental and Safety-Related Requirements

ASFS equipment and components are located in areas normally accessible to personnel without protective clothing or breathing apparatus. Ammonia concentrations in the pump rooms are to be maintained below 50 ppm (OSHA allowable level for 8-hr exposure) by ventilation and by system leaktight integrity.

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Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

The ASFS is used to fill the power system with ammonia working fluid, using tanks, heat exchangers, seawater pumps, and piping. The tanks, heat exchangers, seawater pumps and system controls are part of the platform support facilities. The module provides the piping to distribute ammonia to components in the module and to control ammonia makeup flow rate. A flow diagram for the module system is shown in the Drawing M-503 (Appendix A).

Before the ASFS is used for filling the module evaporator and condenser, these components will have been made ready by other facilities (such as a service ship), where the interiors of the evaporator and condenser are purged and then charged with ammonia vapor to 60 psia at ambient temperature. The ammonia charge also contains 1 psia partial pressure of nitrogen as a result of previous inerting operations.

For filling, the ASFS platform facilities provide a steady flow of ammonia vapor, which is superheated to 50 F, until the evaporator and condenser are charged to 89 psia. The module piping delivers this vapor flow to the evaporator and condenser. When the set-point pressure is reached, the vapor-charging operation is shut down, and liquid delivery is started. The ASFS platform facilities provide a steady flow of liquid ammonia at

ambient temperature. The module piping delivers the liquid flow to the low points in the module piping system, which are the bottom ends of the condensate and distribution pumps. Liquid ammonia is added to the power system until set-point levels are reached in the evaporator and condenser sumps; then the main liquid delivery train is shut down.

The ASFS platform facilities continue to provide a source of pressurized liquid ammonia for makeup. While the power module is operating, liquid ammonia is added to make up for losses and for liquid removed for cleanup.

The ASFS also provides lines to refill any component which has been drained for maintenance with liquid ammonia. The component can then be returned to service.

2.2 SYSTEM PERFORMANCE

The main parameters which describe the ASFS performance are the times required for various operations. The platform venting and purging facilities are used to prepare the power system piping for loading in about 10 hr. The ASFS is used to pressurize the power module evaporator and condenser from 60 to 89 psia in 4 hr and to complete the loading with liquid in one additional hour. The total estimated time for loading is 15 hr.

2.3 SYSTEM ARRANGEMENT

The ammonia storage tanks, seawater pumps and heat exchangers in the ASFS platform facilities are part of, and are located on, the platform. Vapor and liquid distribution lines extend below water level to connect to the power module, but disconnect joints are provided above water level.

2.4 SYSTEM COMPONENTS

The only ASFS component included in the module is piping needed to distribute ammonia vapor and liquid to the module components.

2.5 SPECIAL SUPPORT EQUIPMENT

No special support equipment is required for the ASFS.

2.6 INSTRUMENTATION AND CONTROL

All filling and makeup controls are included in the platform support facility. Temperature elements are provided on the piping to monitor the temperatures during the filling operation.

2.7 SYSTEM INTERFACES

2.7.1 Structures

The ASFS components and piping are supported by structural members of either the module or the platform.

2.7.2 Ammonia Vapor and Condensate System

Evaporator. A permanent pipe connection is furnished for charging vapor to the power module evaporator. The nominal ammonia temperature at the interface point is 50 F, and the pressure varies from 60 to 89 psia during the vapor-charging operation with an ammonia flow rate of 2380 cu ft/sec.

Condenser. A similar piping connection is used for charging vapor to the condenser as described above for the evaporator. The same temperature, pressure, and flow conditions apply.

Pumps. Each of the three condensate pumps and the four distribution pumps is equipped with a permanent pipe connection for charging liquid ammonia to the power module at the lowest points in the power system piping. The piping in the condenser pump room is used to supply makeup liquid ammonia.

At the interface points, the liquid temperature is 50 F and the pressure is 89 psia.

2.7.3 Platform-Related Parts of ASFS

A vapor and a liquid-charging pipeline is connected from the module to the platform-related parts of the ASFS.

2.8 DESIGN PROVISIONS FOR SAFETY

The module-related design of the ASFS includes no special safety items.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

Startup of the system consists of setting the set-points for the required flow rate, pressure and temperature, and setting the flow quantity integrator in the ASFS platform support facility. The valves isolating the Ammonia Vapor and Condensate System and the ASFS are opened.

3.2 NORMAL OPERATION

After startup, the power module loading proceeds until the vapor pressure in the module reaches its target value and until the liquid levels in the condenser and evaporator reach the required levels.

3.3 SHUTDOWN

At shutdown the vapor train is isolated from the power module by block valves. The liquid delivery line remains connected to the power module to make up for losses. All of these operations are connected with the platform-related parts of the ASFS.

3.4

INFREQUENT AND ABNORMAL OPERATIONS

Abnormal operations in the system are announced by alarms in the power module control room. These abnormal operations include low temperature in the vapor and liquid supply lines.

Section 4

MAINTENANCE

The ASFS is maintained in the periods between power module filling operations. The maintenance procedure includes instrumentation and control system calibrations.

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Appendix A

AMMONIA STORAGE AND FILL SYSTEM DRAWINGS

Bechtel Drawing M-503, Ammonia Storage and Fill
System Flow Diagram

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Δ	DATE	DESCRIPTION	BY	DATE	BY	DATE	BY	DATE	BY
BECHTEL SAN FRANCISCO									
OTEC POWER SYSTEM DEVELOPMENT LOCKHEED MISSILES & SPACE COMPANY, INC.									
FLOW DIAGRAM AMMONIA STORAGE & FILL SYSTEM SOMME POWER MODULE									
		JOB No.	2334	TRAINING No.	M-503	REV.	0		

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

50 MWe Commercial Plant Power Module

Conceptual Design Description

for

Noncondensable Gas Removal System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

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INTRODUCTION AND SUMMARY

This document contains the conceptual design description of the Noncondensable Gas Removal System (NCGR) for the 50 MWe CTEC commercial plant power module. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The conceptual design was prepared to identify key features of commercial OTEC power modules which are to be incorporated into an analogous 10 MWe modular application power system. The design is based on generic site conditions.

The function of the NCGR is to remove noncondensable gases from the ammonia power cycle working fluid during power module operation in order to minimize the performance degradation in the condenser due to gas blanketing.

The NCGR compressor, condenser, and automatic controls are part of the OTEC platform support facilities. The module provides the piping to connect components in the module to the support facilities, and the instrumentation sensors to signal the NCGR controllers. This document describes the part of the NCGR associated with the

module and the interfaces with the platform support facilities.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Noncondensable Gas Removal System (NCGR) is to remove noncondensable gases from the ammonia power cycle working fluid and to discharge them to the atmosphere. Noncondensibles are present in the system following purge operations and as a result of seal gas leakage. The module-related parts of the NCGR include the interconnecting vapor and liquid piping between module components and the platform support facility, and the sensors which signal the NCGR controllers.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The NCGR is to remove the noncondensable gases from the power cycle ammonia inventory until their volumetric concentration is reduced below 0.1%. Ammonia extracted with the noncondensable gases is to be returned to the Ammonia Vapor and Condensate System. The NCGR is to be sized for an economical optimum capacity, taking into consideration the loss of generating capacity due to gas blanketing and the capital investment in the NCGR equipment.

1.2.2 Structural Requirements

The structural design pressure of the NCGR is to be 250 psig. The system piping and components are to be designed to remain operational with vertical accelerations of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary with vertical accelerations of $\pm 0.7g$ (sea state 9). A 30-year plant life is to be used in determining allowances for corrosion.

1.2.3 System Configuration and Essential Features

The platform support facilities for separating noncondensable gases from ammonia and discharging the noncondensable gases to the atmosphere will be located on the platform structure above water level. Piping from the platform to module components is to be routed through a "shirt sleeve" environment.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be identified during preliminary and detailed designs.

1.2.5 Level of Technology

Components for the NCGR are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

The control system design is to be based on manual starting and automatic control with provisions for manual override by operators in the control room. Data acquisition/storage and displays are to be provided in the plant control room. Local display and control panels are to be provided at selected locations to assist operators performing routine checkout and maintenance. To the extent feasible, pneumatic or hydraulic control actuators are to be used.

1.2.7 Maintenance Requirements

Maintenance provisions of the NCGR are to be consistent with the overall maintenance plan of the power module. Maintenance of the NCGR components is to be scheduled during periods of normal plant operation when NCGR services are not required by the power module. Maintenance is to consist of inspections, preventive maintenance, routine refurbishing and in situ repairs. General tooling, special tools, lifting devices, and dollies are to be provided for the shipboard maintenance and for replacement of defective components. The arrangement of system components is to provide space and access to perform maintenance operations, and a safe transit path for component removal.

1.2.8 System Reliability

The NCGR will be subject to intermittent and short duration service and has only marginal impact on the power system availability. However, safe handling of ammonia requires that the whole system have high reliability. The availability of the NCGR for service when needed is assured by preventive maintenance during normal plant operation and by redundant installation of rotating equipment, such as pumps and compressors.

1.2.9 Interface Requirements

The NCGR interfaces with the following systems:

- Module Condenser. The NCGR interface with the condenser consists of a piping connection to the gas scavenging system in the condenser.
- Ammonia Vapor and Condensate System (AVCS). The NCGR interface with the AVCS consists of a piping connection to return liquid ammonia.
- Ammonia Unloading System (AUS). The separated noncondensable gases are transferred to the AUS Vent and Purge Subsystem for safe disposal to the atmosphere (platform interface).
- Electrical System. Power for NCGR pumps and compressors is to be supplied by the electrical system (platform interface).
- Control System. The NCGR is to interface with the control system to permit operation of the NCGR from the control room.
- Structure. The NCGR interfaces with the structure consist of equipment mountings and pipe support.

1.2.10 Environmental and Safety-Related Requirements

NCGR equipment and components are located in areas normally accessible to personnel without protective clothing or breathing apparatus. Ammonia concentration in these areas is to be held to less than 50 ppm (OSHA allowable level for 8-hr exposure) by ventilation and by system leaktight integrity. Relays, electric motors and other electrical equipment are to meet NFPA requirements for areas potentially contaminated with ammonia.

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Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

The NCGR removes noncondensable gases from the working fluid in the power module and transfers them to the Ammonia Unloading System Vent and Purge Subsystem. The functional arrangement of the components in the NCGR is shown in Drawing M-505 (Appendix A). As shown in the drawing, a bleed line is connected from the noncondensable gas scavenging system in the power system condenser to the noncondensable gas separation equipment in the platform support facility. The noncondensable gases are discharged to the atmosphere by the platform support facility, and the liquid ammonia is returned to the power system.

2.2 SYSTEM PERFORMANCE

The NCGR reduces the volumetric concentration of noncondensable gases in the power module from approximately 1% to less than 0.1% in 12 hours. This time requirement was based on economic optimizations described in Appendix B.

2.3 SYSTEM ARRANGEMENT

The equipment for the platform support facility is located on the platform structure, above water level. The NCGR module piping

connects to components below water level, but all disconnect joints are above water level.

2.4 SYSTEM COMPONENTS

All components in the NCGR are standard commercial items. None of the equipment requires long lead times for delivery. Active components of the NCGR are part of the platform support facilities. The only NCGR component included in the module is piping.

2.5 SPECIAL SUPPORT EQUIPMENT

There is no special support equipment required for the module related parts of the NCGR.

2.6 INSTRUMENTATION AND CONTROL

The operating instrumentation and controls for the NCGR are provided by the platform support facility. The module provides manually operated isolation valves in the interconnecting piping.

2.7 SYSTEM INTERFACES

The NCGR interfaces physically with the power system, with the AUS Vent and Purge Subsystem, and with the electrical system. The interfaces with the power system are at the valves in the noncondensable gas removal line and in the liquid ammonia return

line. The interfaces with the Vent and Purge Subsystem are at the valves in the vapor bleed and liquid return lines. The Electrical System provides power for the compressors and pumps.

2.8 DESIGN PROVISIONS FOR SAFETY

All design safety provisions for the NCGR are provided in the platform support facility. There are no specific safety items for the portion of the NCGR which is provided by the module.

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Section 3..

SYSTEM OPERATION

3.1 SYSTEM STARTUP

Startup of the NCGR consists of energizing the equipment in the platform support facility and opening the shutoff valves in the vapor bleed line, the gas blowoff line and the ammonia liquid return line. The AUS Vent and Purge Subsystem must be operating to start the NCGR.

3.2 NORMAL OPERATION

After the NCGR is started, it operates under automatic control until measurements indicate that the noncondensable gas concentration has been reduced to the required level.

3.3 SHUTDOWN

After the noncondensable gas concentration has been reduced to the required level, the NCGR is shut down by de-energizing the equipment in the platform support facility and closing the shutoff valves in the module.

Abnormal operations in the system are announced by alarms in the power module control room. These abnormal operations include: equipment not energized, and high temperature readings.

Section 4
MAINTENANCE

Maintenance work on the NCGR is done in the periods between noncondensable gas removal operations. The maintenance procedure includes: system leak checking, equipment startup checks, and control system calibration.

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Appendix A

NONCONDENSIBLE GAS REMOVAL SYSTEM DRAWINGS

Bechtel Drawing M-505, Noncondensable Gas
Removal System Flow Diagram

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A-2
G3

STATION	(1)	(2)
FLOW	1070 CFM	54 CFM
PRESSURE PSIA	89	1190
TEMPERATURE F	50	71

RECHTEL	12384	N-505	0
NONCONDENSIBLE GAS REMOVAL SYSTEM 50 MW POWER MODULE			

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

Appendix B

50 MWe Commercial Plant Power Module

Noncondensable Gas Removal System Capacity Study

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

B-0
G1

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Objective:

The objective of this study is to define the most economical Noncondensable Gas Removal System (NCGR) capacity considering the economic effects of the loss of power generation due to noncondensibles in the power system condenser and the cost of equipment to remove these noncondensibles.

Commercial OTEC Power Plant Configuration:

Net generating capacity	400 MWe
Number of modules	8 @ 50 MWe, each
Number of modules per NCGR	4
N ₂ concentration at start of NCGR Operation	1.62. mole % *

- * Residual N₂ after purge and evacuation to 3 psia followed by full system charge.

Loss of generating capacity per module:

Assume as a first approximation that: $P_{\text{turbine}} \propto W_{\text{turbine}}$
 $Q_{\text{cond.}} \propto U_{\text{cond.}}$

where: P = turbine power
W = vapor flow rate
Q = condenser heat transfer
U = condenser heat transfer coefficient

From steam power plant performance data:

	<u>U actual</u>
	<u>U design</u>
@ Air concentration of:	
2%	.38
1%	.55
0%	1

Using a straight line relationship to quantify the power lost while reducing the N_2 concentration from 1.62 mole % to essentially zero, the equation for power lost is:

$$P_L = 0.368 \times P_{des} \times t^*$$

where: P_L = total power lost,
kWh

P_{des} = design power, kW

t^* = NCGR operating time,
hours

Loss of revenue per module, using present worth calculations.

Assume that the NCGR operates through a full removal cycle 15 times in the 30 year plant life and the initial price of power sold is \$.04 per kWh.

Then the revenue lost over the plant life is:

$$R_L = \bar{P}_L \sum_{i=1}^{30} \left(\frac{1+e}{1+i} \right)^n$$

where: R_L = present worth of
revenue lost over
30 years

$$R_L = 13,426 t^*$$

$\bar{P}_L$ = first year revenue
loss

$$= 515.2 t^*$$

e = annual power cost
escalation, 7%

i = discount rate 8%

Since there are 4 modules per NCGR the revenue lost per NCGR is:

$$R_L^* = 53,704 \times t^*$$

Cost of NCGR equipment from cost estimates:

- 50 hp compressor cost is \$60,000
- from price lists the compressor cost scales as $\left(\frac{hp_1}{hp_2} \right)^{.7}$
- from cost estimates cost of titanium-tubed heat exchangers \$61 per ft^2 .

Equipment requirements for various t^* conditions:

<u>t^* (hours)</u>	<u>Compressor hp</u>	<u>NCGR Cond. Surface Area (ft²)</u>
12	660	1485
24	504	725
48	282	354

Present worth of equipment cost (using 12.8% annual capital charge and 8% discount rate), compared with present worth of revenue lost:

<u>t^* (hours)</u>	<u>Equipment Cost (\$)</u>	<u>Present Worth (\$) (equipment)</u>	<u>Present Worth (\$) (revenue lost)</u>
12	454,300	654,600	644,400
24	346,600	498,600	1,889,000
48	223,000	321,300	2,577,800

Conclusion:

At $t^* > 12$ hours the revenue lost due to sub-design performance exceeds the cost of NCGR equipment; and 12 hours should be used as the design basis.

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OTEC POWER SYSTEM DEVELOPMENT PROJECT

SUBCONTRACT YF80C1050M

50 MWe Commercial Plant Power Module

Conceptual Design Description

for

Ammonia Cleanup System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the conceptual design description of the Ammonia Cleanup System (ACS) for a 50 MWe module of a commercial OTEC power system. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The conceptual design was prepared to identify key features of commercial OTEC power modules which are to be incorporated into an analogous 10 MWe modular application power system. The design is based on generic site conditions.

The function of this system is to remove seawater inleakage from the ammonia working fluid. This is accomplished by treating a liquid sidestream from the evaporator in a continuous process consisting of an evaporation step and a distillation step.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Ammonia Cleanup System (ACS) is to remove water and residual reaction products that result from leakage of seawater into the ammonia working fluid.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The seawater inleakage rate is scaled from estimates during a previous conceptual design study (Reference 1-1). In that work, the rate of seawater inleakage was estimated as 1 gpm for a 25 MWe module. That estimate is scaled up to 2 gpm for the 50 MWe module. The ACS design is to be optimized to maintain water concentration in the ammonia working fluid where the loss of saleable power from the power module is at the minimum.

1.2.2 Structural Requirements

The system piping and components are to be designed to remain operational with vertical accelerations of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary with vertical accelerations of $\pm 0.7g$ (sea state 9).

Materials of construction are to be compatible with ammonia contaminated with seawater and with seawater where it is used as a heat exchange medium. The design life is to be 30 years.

1.2.3 System Configuration and Essential Features

The ACS is to be located in a "shirt sleeve" environment above the water line. Piping connections to the power system components are to be capable of being disconnected above the water line to allow removal of the evaporator or the condenser.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be specified during preliminary and detailed designs.

1.2.5 Level of Technology

Components for the ACS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Sensor instrumentation (such as pressure and temperature elements) is to be furnished as inputs for the control system, and final control elements are to be included in the design. The

control system functions are to be supplied by the power module control computer.

1.2.7 Maintenance Requirements

Maintenance provisions for the ACS are to be consistent with the overall maintenance plan for the power module. Maintenance activities are to consist of inspections, preventive maintenance, routine refurbishing, and in-situ repairs. General tooling, special tooling, lifting devices, and dollies are to be provided for shipboard maintenance and for replacement of defective components. The arrangement of components is to allow space and access for maintenance operations and a safe path for equipment removal.

1.2.8 System Reliability

The reliability of the ACS is to be consistent with the OTEC 90% availability (at 60% confidence) requirement. Equipment specifications and ratings are to be conservative to provide maximum durability.

1.2.9 Interface Requirements

The working fluid for processing by the ACS is to come from the power system, and the purified ammonia is to be returned to the power system. Electric power for operating the ammonia cleanup system is to be supplied by the electrical system.

1.2.10 Environmental and Safety-Related Requirements

Disposal of wastes is to be in compliance with Environmental Protection Agency regulations. The limit of ammonia discharges to natural waters is 100 lb/day for one plant. At present there are no discharge limitations for ammonia vapor.

Safety provisions are controlled by Occupational Safety and Health Agency regulations limiting 8-hr industrial exposure to 50 ppm ammonia in air.

Electrical devices are to comply with the National Fire Protection Association requirements for hazardous areas. The ACS is to be designed to prevent routine escape of ammonia to the ambient air; thus, the hazardous area classification is to be Class I, Group D, Division 2.

Fire protection, in the form of a sprinkler system and manual extinguishers, is to be provided.

Section 2

DESIGN DESCRIPTION

The ACS consists of a vaporization process followed by a distillation step operating on a liquid sidestream from the power system evaporator. In previous conceptual design work (Reference 2-1), a one-step distillation process was proposed for the ACS. The one-step process has the advantage of being simple and straightforward, but it requires a sizeable amount of power for operation. As part of the conceptual design, a study was conducted to develop a more energy-conservative ACS design. The results of this effort are reported in Appendix B. Two systems, requiring the same energy input, are described in Appendix B: two-step evaporation and recompression evaporation with distillation. For this conceptual design work, the two-step evaporation process was selected because of its apparent equipment simplicity. Although the two-step cleanup system described here is more complicated than the one-step distillation process, it allows the net module power output to be increased by 15% due to a combined improvement in turbine electrical output and a reduction in cleanup system power requirement.

2.1 SYSTEM CONFIGURATION

The ACS flow diagram is shown in Drawing M-506 (Appendix A).

A sidestream of liquid ammonia is taken from the liquid dripping off the evaporator tubes to the ACS for processing. The liquid

is drawn from this point because it is expected to have the highest water concentration in the power system. At the estimated seawater inleakage of 2 gpm, the liquid entering the ACS has 1-1/2% seawater and has a flow rate of 28 lb/sec (0.7% of the nominal power system flow rate). The ammonia liquid stream flows into the cleanup system evaporator where 97% of the ammonia is converted to vapor. The evaporator pressure is controlled at 56 psia, resulting in an equilibrium temperature of 40 F. The heat for vaporization in the cleanup system evaporator is furnished by warm seawater.

The ammonia vapor stream from the cleanup system evaporator is compressed to 92 psia to permit its introduction into the power system condenser. As a result of the compression process, the vapor temperature is increased from 40 to 112 F; thus, some of the compression energy can be recovered by heating the liquid stream leaving the evaporator, as described below. The liquid effluent (25% seawater and 75% ammonia) from the evaporator is pumped to 92 psia (slightly greater than the 89 psia in the power system condenser), and is preheated by the compressed vapor stream in an energy recovery evaporator from 40 to 80 F. As a result of this preheating, 43% of the remaining ammonia flashes off. This evaporation step is not reported in Appendix B but was added to recover energy from the compressed vapor stream. The remaining liquid is then introduced into the distillation column.

The overhead ammonia vapor stream from the distillation column is combined with the compressed vapor from the cleanup system evaporator to return it to the power system. Steam to operate the distillation column is generated by vaporizing part of the column liquid bottoms in an electrically heated reboiler. The remainder of the liquid effluent, which is seawater with very little ammonia remaining (400 ppm), is mixed with the seawater return from the cleanup system evaporator for disposal.

There are two areas of technical uncertainty to be resolved by investigation or small-scale operation. First, when seawater and ammonia are mixed, precipitates (mainly calcium carbonate and magnesium hydroxide) are formed. It is expected that these materials will form small particles and will be carried along with the liquid stream and will be removed by the ACS. There is a shortage of reported operating experience with ammonia and seawater; therefore, the actual behavior of the precipitates cannot be predicted with certainty. They may act as purely sludge-forming particles, as described above, or they may deposit on the process evaporator tubes causing tube fouling on the ammonia side. Another potential obstacle to trouble-free operation is posed by the possibility of calcium sulfate precipitation from heated seawater. The inverse solubility of calcium sulfate can cause a scaling problem. A scale inhibitor can be added to control this problem if tests with ammonia and seawater show it to be needed.

2.2

SYSTEM PERFORMANCE

The nominal design operating condition of the ACS is described in the preceding section. The flow rate and concentration of the liquid stream entering the ACS are based on an assumed seawater inleakage rate of 2 gpm for the power module. If the inleakage is less, as is expected when a module is new, the ACS is used intermittently for a few hours each day to remove the actual seawater leakage. If the seawater inleakage is greater than the estimated 2 gpm, the ACS is operated continuously. However, the water concentration will gradually increase and the power system output will ease progressively; eventually, the module must be shut down to repair the leaks.

2.3

SYSTEM ARRANGEMENT

The ACS evaporator, compressor, heat recovery evaporator, and distillation column are grouped together, forming a compact system package. This package is located in a "shirt sleeve" environment above the water line to permit easy access for inspection and maintenance.

2.4

SYSTEM COMPONENTS

The ACS major equipment items are listed in Table 2-1; all items are commercially available, and none of them requires long lead time.

TABLE 2-1
MAJOR EQUIPMENT ITEMS

<u>Description</u>	<u>Number Required</u>
Cleanup system evaporator 10,500 sq ft heat transfer area Titanium tubing	1
Ammonia Compressor and motor 6000 cu ft/min 55 psia inlet pressure 92 psia outlet pressure 875 hp motor	2
Liquid mixture pump and motor 10 gpm 1/2 hp motor Stainless steel pump materials	2
Heat recovery evaporator 4200 sq ft heat exchange area Titanium tubing	1
Distillation column 12 in dia. x 6 ft height Packed column Titanium materials	1
Reboiler 500 kW electric heater Titanium materials	1

2.5

SPECIAL SUPPORT EQUIPMENT

Ventilation is required in the area where the ACS is located to prevent ammonia concentration buildup to breathing hazard or explosive concentrations in case of ammonia leakage. This area is monitored for ammonia concentration by the Leak Defection System.

2.6

INSTRUMENTATION AND CONTROL

The ACS control is accomplished using the plant control computer for control mode implementation. The controlled variables and the methods for controlling them are given in Table 2-2. Key operating variables are monitored by the plant control computer.

TABLE 2-2
CONTROLLED VARIABLEES

<u>Variable</u>	<u>Control Method</u>
Sidestream bleed to cleanup system	Pressure control on cleanup system evaporator
Cleanup evaporator pressure	Pressure control valve
Cleanup evaporator liquid level	Pump on-off control
Reboiler liquid level	Level control valve
Compressor back-pressure	Automatic compressor bypass (pressure regulator)
Liquid effluent ammonia content	Cascade control on reboiler temperature

2.7 SYSTEM INTERFACES

The ACS interfaces with other systems are listed in Table 2-3.

2.8 DESIGN PROVISIONS FOR SAFETY

The ACS piping and vessels are designed in accordance with ANSI 31.1, Power Piping. Motors and other electrical devices comply with requirements for National Fire Protection Association hazardous area classification for Class I, Group D, Division 2.

The airborne ammonia concentration is continuously monitored in the vicinity of the ACS, and alarms are sounded at a concentration of 50 ppm. The monitoring is provided by the Leak Defection System. Prior to opening the system, the ammonia is purged out to 50 ppm maximum, and portable sensors are used to verify this concentration before personnel are permitted to approach the system, once opened up.

The area of the cleanup system is covered by an automatic sprinkler system, and manual ABC fire extinguishers are located within easy access.

To meet requirements for liquid effluent, the distillation column is designed to purify the liquid bottoms stream to less than 400 ppm ammonia which is equivalent to 10 lb/day ammonia discharge from each 50 MWe power module. Thus, eight 50 MWe modules in one plant would release 80 lb/day ammonia in the

TABLE 2-3

AMMONIA CLEANUP SYSTEM INTERFACES

<u>System</u>	<u>Interface</u>
Power system evaporator	Sidestream liquid takeoff from evaporator, ammonia vapor return to condenser
Electrical system	Heater power, compressor power, and liquid mixture pump power
Plant control computer	Transducer inputs and control loops
Warm seawater supply	15,000 gpm
Ammonia storage and fill system	Piping connections to withdraw liquid ammonia from storage
Ammonia unloading system	Piping connections to permit venting the vapor and filling with atmospheric air
HVAC system	Ventilation air to keep ammonia concentration less than 50 ppm
Fire protection system	Sprinkler coverage

liquid effluent which is less than the 100 lb/day maximum allowed by present Environmental Protection Agency regulations.

Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

The initial condition before startup is as follows:

- Upstream from evaporator pressure control valve--vapor filled at 129 psia
- Downstream from evaporator pressure control valve--vapor filled at 89 psia
- Valve in the vapor line from distillation column is closed.

To start the ACS, the steps below are followed in sequence:

- Seawater flow is started and full flow condition is achieved.
- Ammonia vapor compressor is started.
- After evaporator pressure reaches 40 psia, liquid ammonia flow from the evaporator is started.
- After evaporator liquid reaches normal operating level, liquid solution pump is started.
- After distillation column pressure reaches 92 psia, valve in column vapor line is opened.
- After liquid in reboiler reaches 50% of normal operating level, reboiler heaters are turned on, completing the startup sequence.

3.2 NORMAL OPERATION

Once the ACS is brought to nominal operating condition, as described in the preceding section, its operation is completely automatic and requires no operator manipulation. Monitoring of

the ACS process temperatures, pressures, and levels is required to be sure that the system is operating properly.

Off design operation is expected if the seawater inleakage is less than the 2 gpm estimate. In that case, the ACS is operated intermittently to remove seawater accumulation. The concentration of seawater in the working fluid is indicated by the Fluid Sampling System.

3.3 SHUTDOWN

The ACS shutdown procedure consists of shutting down the various equipment in the following order:

- Reboiler
- Ammonia flow to cleanup system evaporator
- Liquid solution pump
- Seawater flow
- Compressor.

After the shutdown sequence is completed, the valve in the vapor line from the distillation column is closed.

3.4 INFREQUENT AND ABNORMAL OPERATIONS

3.4.1 Air Evacuation and Ammonia Vapor Fill

After maintenance of the ACS or a component (e.g., a compressor), air at 1 atm pressure is present and the isolation valves to the power system are closed. The Ammonia Unloading System is used to purge the ACS following the sequence given below:

- The ACS is evacuated to 1 psia.
- Nitrogen is injected until the pressure is 15 psia.
- The ACS is once again evacuated to 1 psia.

After evacuation, as described above, ammonia vapor is introduced by slowly opening the valves to the power system.

3.4.2 Ammonia Unloading

The Ammonia Unloading System is used to unload ammonia from the ACS and replace it with atmospheric air. The steps for unloading are summarized as follows:

- Ammonia vapor pressure is reduced to one atmosphere by venting to a stack for safe disposal.
- The vacuum pump is used to reduce the ammonia pressure to 1 psia.
- Nitrogen is injected, increasing the pressure to 1 atm.
- The system is vented with air, reducing the ammonia content to the allowable concentration of 50 ppm.

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Section 4

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

Most of the preventive maintenance for the ACS is accomplished during the scheduled annual maintenance designated as Level 5 in Reference 4-1, p. 5-13. During this shutdown period, heat exchanger tubing is cleaned and inspected, pump rotors are inspected and rebuilt if necessary, control valves are rebuilt, instrumentation transducers are cleaned and calibrated, the reboiler is cleaned of sludge and mineral deposition, and the compressors are inspected for signs of bearing and seal degradation. During the scheduled 3-yr maintenance periods (Level 6), the additional operations consist of replacing bearings on rotating machines and motors.

To do the work indicated for the annual and triennial scheduled maintenance periods, the ACS must have the ammonia removed and the internal volume filled with air at 1 atm pressure, as described in Section 3.4.2.

4.2 CORRECTIVE MAINTENANCE

The ammonia compressors are two 50% capacity units. If one unit requires corrective maintenance, the ACS can continue

in operation at one-half capacity while maintenance is performed on the defective compressor. Two full capacity liquid pumps permit maintenance without interruption of ACS operation. If corrective maintenance is needed, the ACS continues in operation while maintenance work is performed.

If the cleanup system evaporator or the reboiler needs corrective maintenance, the ACS is isolated from the power system. The ammonia is unloaded and replaced with atmospheric air. After that, the ACS is disassembled to the degree necessary for maintenance work on the affected vessel.

REFERENCES

- 1-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978 (LMSC-D566744).
- 2-1 Ibid.
- 4-1 Ibid.

APPENDIX A
AMMONIA CLEANUP SYSTEM DRAWINGS

Bechtel Drawing M-506, Ammonia
Cleanup System Flow Diagram

STATION	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
PRESSURE PSIA	129	56	32	32	56	92	92	92	92	92	92	92
TEMPERATURE °F	100	40	112	40	40	40	80	80	80	120	80	321
DESIGN FLOW RATE, LB/SEC	20.5	27.4	27.1	27.4	1.13	1.13	77					
FLUID	NH3	NH3	NH3	NH3	H2O/H2O2	H2O2/H2O	H2O2/H2O	NH3	NH3	H2O	NH3	H2O
PHASE	VAPOR	VAPOR	VAPOR	VAPOR	L/D	L/D	L/D	VAPOR	VAPOR	L/D	VAPOR	L/D
AMMONIA CONTENT %	98.5	99.95	99.95	99.95	75	75	63	97	39.9	400 PPM	99.5	—

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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

APPENDIX B

Ammonia Cleanup System Alternatives

Bechtel National, Inc.
San Francisco, California

JOB 12384-002

September 1978

Section 1

INTRODUCTION

The Rankine power cycle of an OTEC power module operates with ammonia as the working fluid. Heat exchangers, immersed in seawater, serve as evaporators and condensers in this cycle. Although these heat exchangers use welded construction, there is a finite probability that leaks will develop during the life of these units. At OTEC temperatures, the ammonia saturation pressure is in the order of 90 psia, which is higher than the static pressure of the water at the lowest point of these heat exchangers. However, the combined static pressure and seawater pump head approaches, and in some instances exceeds, the ammonia pressure. This could lead to water inleakage at defects near the bottom of the heat exchangers. Other possible mechanisms causing seawater inleakage include back diffusion phenomena and outright fracture of heat exchanger tubes.

Seawater leakage into the OTEC system has serious degrading effects on the power cycle performance and results in significant loss of power generating capacity. Any seawater that leaks into the power system tends to migrate to, and accumulate in, the evaporator. Unless the water is removed, it will continue to build up in the evaporator and will cause progressive worsening of power module performance.

In previous conceptual design studies, distillation of a sidestream from the OTEC evaporator underflow has been proposed

for water removal (LMSC-D566744). Sidestream distillation is a relatively simple and reliable process, but its energy requirement is very high. For example, energy for vaporizing ninety-nine pounds of ammonia (about 50,000 Btu) is required for the separation of each pound of water.

The objective of the study outlined in this report was to explore the feasibility of using alternative, preferably less energy demanding, water removal techniques for OTEC power systems.

The merits of the alternatives were evaluated based on the following characteristics:

- Technical feasibility
- Energy consumption compared to distillation
- Simplicity and reliability.

This study was confined to the examination of methods for removing water from ammonia. However, it is recognized that seawater also contains a number of dissolved compounds. Many of these will react with ammonia and form soluble and insoluble compounds. Additional evaluations and prototype tests will be required to characterize the behavior of these reaction products and their effects on the power module performance. In particular, any tendency for scale formation on heat exchanger tubes needs to be identified.

The study described in this report is based on the conditions of the 50 MWe commercial OTEC power system module. The conclusions

are, however, also valid for the analogous 10 MWe modular application power system.

Section 2

SUMMARY AND CONCLUSIONS

As shown in Figure 2-1, the presence of water in ammonia causes progressively more serious loss of useful power output as the water concentration increases. Potential methods for water removal to reduce such losses include absorption techniques (such as molecular sieve and silica gel), cold trapping, and various evaporative techniques. Both vapor phase and liquid phase processes were considered; however, the significantly lower water concentration in the vapor phase (.015% water in the vapor is in equilibrium with a liquid solution of 95% ammonia-5% water) makes vapor phase separation a less likely approach.

Absorption techniques were found to require many absorption-desorption stages, because the affinity of the absorbing media to water and ammonia is nearly the same. Little, if any, energy saving would result (in comparison with distillation) due to the expected high energy requirement for vapor compression to overcome pressure drop across the absorption bed and for regeneration of the spent absorbent.

Another potential technique for separating the water from ammonia is cold trapping. However, in mixtures with ammonia concentrations above 80%, the first substance to freeze on cooling will be pure ammonia. In the intermediate range of concentrations, various water-ammonia compounds will freeze out initially. Only when the ammonia concentration is below 32% will

Figure 2-1 EFFECTS OF WATER ON OTEC POWER

pure water freeze out. Consequently, cold trapping does not appear to be a feasible cleanup method for OTEC.

Various evaporation processes have also been considered as potential alternative cleanup methods. These include multiple effect evaporation, vapor recompression evaporation, and combinations of these. The reference cleanup method of the Task 1 conceptual design (simple distillation) is itself an evaporative process.

Although distillation is a simple process, the high energy consumption contributes significantly to the already high auxiliary power load of the OTEC cycle. It also requires energy at about 300 F, which cannot be readily obtained from seawater. The power required for the distillation process may be reduced by pre-enrichment of the distillation column feed. Evaporation or recompression-evaporation stages ahead of the distillation column may serve as pre-enrichment processes. In both cases, the distillation column feed will be enriched to about 25% water. From the energy consumption point of view, both of these combined cleanup methods are approximately the same and both would significantly reduce the energy requirements of the cleanup system.

Figure 2-2 shows the energy losses of the conceptual design reference distillation concept and the two-step evaporation approach as a function of water concentration in ammonia. As is evident from the figure, an energy saving of approximately 5 MWe

Figure 2-2 EFFECTS OF WATER ON OTEC POWER LOSS

(or 10% of the net generating capacity) could be realized with the two-step evaporation method. Potential energy savings of this magnitude certainly warrant some additional complexity and equipment cost. It is therefore recommended that the two-step evaporation cleanup method be selected for continuing design.

Section 3

POTENTIAL AMMONIA CLEANUP METHODS

Ammonia and water form an intimate solution over the whole range of concentrations. Physical properties of both constituents are quite similar, so that simple separation methods such as stratification settling are not feasible. Even complex separation processes require multiple stages to achieve an adequate degree of water removal. This section describes and evaluates the applicable separation processes most often used in the chemical industry.

3.1 TASK 1 REFERENCE DESIGN - SIMPLE DISTILLATION

The reference ammonia cleanup system in the earlier conceptual studies is shown in Figure 3-1. The process, involving distillation of a sidestream from the OTEC evaporator underflow in a distillation column, is a simple one, but it requires considerable electrical energy.

The energy required for conventional distillation of an ammonia-water mixture is primarily the latent heat for evaporation of ammonia. The distillation system of the proposed application requires a heat source with temperature capability above 320 F. Of the several possible heating methods, the reference design uses electric resistance heating.

Figure 3-1 TASK 1 REFERENCE AMMONIA CLEANUP SYSTEM

For a given water leakage rate, the energy requirement can be reduced by increasing the water concentration at the OTEC evaporator; however, high water concentrations reduce the available pressure across the turbine and cause losses in generating capacity as shown in Figure 3-2.

3.2 VAPOR PHASE WATER SEPARATION VS. LIQUID PHASE WATER SEPARATION

A basic initial decision in selecting the ammonia cleanup technique is the choice between vapor and liquid phase processes. Differences between water concentrations in the vapor and liquid phases may be considered as useful indices in this decision. Examination of equilibrium data shows that water concentration in the vapor phase is much less than in the liquid phase. For example, vapor in equilibrium with a 5% water, 95% ammonia mixture contains only 0.015% water at 70 F. This means that if seawater leaks into an OTEC plant at the rate of 2 gpm, over 47% of the vapor flow would have to be treated to achieve adequate water separation in vapor phase processes, while only 0.14% of the evaporator underflow must be treated if liquid phase cleanup processes are to be used. Processing the large vapor flow will result in higher energy requirement. Therefore, liquid phase cleanup processes are more likely to offer a potential for energy saving.

Figure 3-2 EFFECTS OF WATER ON OTEC POWER LOSS

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3.3

MOLECULAR SIEVE AND SILICA GEL ABSORPTION

Separation of water from gaseous or liquid mixtures, using molecular sieve and silica gel selective absorption, is based on the absorbent's high affinity for water. However, molecular sieve and silica gel have virtually the same affinity to water and to ammonia. Because of this similar affinity, separating water from a water-ammonia mixture requires a cascade system of many repeated absorption-desorption units.

The energy requirements for an absorption system include the power to compress a gas to overcome the pressure drop across the absorption beds and the power to regenerate the spent absorbent. The pressure drop in a typical absorption bed is in a range of 5 to 10 psi. During regeneration, heat is required to raise the bed temperature to a range of 350 to 700 F and to provide the latent heat of vaporization of the absorbed ammonia and water. The power requirement for a cascade absorption system consisting of many repeated absorption units will probably exceed the OTEC plant power output. Therefore, the absorption processes are not viable for this proposed application.

3.4

WATER SEPARATION BY COLD TRAPPING

Separation of water from gaseous or liquid mixtures by freezing techniques, such as cold trapping, is practiced in certain industrial processes, such as drying process air and desalting seawater. However, as shown in the phase diagram (Figure 3-3),

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Figure 3-3 NH₃ - H₂O PHASE DIAGRAM

in mixtures with very high ammonia fraction the first constituent solidified upon cooling is ammonia. It is followed by successive solidification of water and ammonia mixtures and finally water. Therefore, freezing of water alone is not possible, and separation of water from a water-ammonia mixture by conventional freezing methods does not appear possible.

3.5 MULTI-EFFECT EVAPORATION

Multi-effect evaporation is used in some industrial evaporation processes to minimize the energy requirement. In a multi-effect evaporation system, the latent heat of condensation of one effect is used to heat and evaporate the liquid of the next effect. For a multi-effect evaporation system to work, the vapor temperature of each lower effect must be lower than that of the preceding effects. In the case of an ammonia-water mixture, when the lowest effect is operated close to the OTEC system pressure (89 to 129 psia), the first effect would have to operate at supercritical ammonia conditions. Accordingly, the water separation from an ammonia-water mixture using a conventional multi-effect evaporation system appears impractical.

3.6 VAPOR RECOMPRESSION EVAPORATION

The energy input to evaporation cleanup systems may be reduced by vapor recompression-evaporation in which condensation of the compressed vapor supplies the evaporation heat.

In the case of a water-ammonia mixture, separation of the mixture into relatively pure water and pure ammonia would require a multi-stage vapor recompression-evaporation system. The number of stages would depend on the required end purity of the ammonia. A multi-stage vapor recompression evaporation system will require repeated compression, and the energy requirement would most likely exceed that of a simple distillation system.

3.7 TWO STEP EVAPORATION (EVAPORATION-DISTILLATION COMBINATION)

The energy required for the ammonia cleanup can be reduced by use of a two-step evaporation system consisting of a cleanup evaporator and a distillation column, as shown in Figure 3-4. The ammonia-water mixture (a sidestream from the OTEC evaporator underflow) is first evaporated at low temperature and low pressure to remove most of the ammonia, using warm sea water as the heat source. Ammonia vapor from the cleanup evaporator is then compressed and returned to the OTEC system. The underflow from the cleanup system evaporator is pumped into a distillation column where the remaining ammonia is stripped off. The vapor compression and distillation heat are the primary energy consumers since warm seawater heat is virtually free. The energy requirements for the two-step evaporation system are shown in Figure 3-5.

The energy reduction in the two-step evaporation system depends on the water concentration of the sidestream, the evaporator

Figure 3-5 EFFECTS OF WATER ON OTEC POWER LOSS

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temperature and pressure, and the operating condition of the distillation column. The effects of these variables on the total energy requirement and an optimum system are discussed in Section 4.

3.8 COMBINED VAPOR RECOMPRESSION-EVAPORATION AND DISTILLATION

As discussed previously, the one-step vapor recompression evaporation is not suited for the OTEC ammonia cleanup, but a combination of vapor recompression-evaporation and distillation, schematically shown in Figure 3-6, may prove to be a promising method for the ammonia cleanup.

The combined vapor recompression-evaporation and distillation system is similar to the two-step evaporation except that the evaporator and compressor of the two-step evaporation system are replaced with a vapor recompression-evaporation system operating at the same temperature and pressure. The energy requirement for a combined vapor recompression-evaporation and distillation system is about the same as that for the two-step evaporation. It appears, however, that this alternative would require more complex equipment and possibly more sensitive controls. Considering all factors, this alternative appears to be inferior to the two-step evaporation and thus will not be considered further.

Figure 3-6 VAPOR RECOMPRESSION EVAPORATION AND DISTILLATION

The above discussions lead to the following conclusions:

- Liquid phase cleanup techniques are preferable since they require less ammonia bypass.
- Simple distillation is the only one-step process viable for the OTEC systems.
- The two-step evaporation technique offers potentially significant power savings at the expense of only modest increase in cost and complexity. It is a viable and desirable alternative to the simple distillation technique, used in the conceptual design.

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Section 4

THE TWO-STEP EVAPORATION SYSTEM ANALYSIS

In comparison with the simple distillation process, the two-step evaporation system shown in Figure 4-1 reduces the high temperature heat requirement considerably by first evaporating the sidestream at a low temperature and low pressure using warm seawater as the heat source. Heat at higher temperature is used only for the final distillation step to separate the remaining ammonia and water. The power requirement for ammonia cleanup depends primarily on the operating temperature and pressure of the cleanup evaporator and the water concentration in the evaporator feed. Parametric studies were conducted to assess the effects of these variables on the power requirements of the two-step evaporation cleanup system. Table 4-1 shows the variations of the cleanup evaporator heat load, the compressor power requirements, and the distillation column heater power as a function of the pressure and temperature of the evaporator. The calculated values are presented in terms of specific power requirement (kW/lb H₂O/min). The table shows the values for 1% water concentration in the ammonia feed to the cleanup system. Similar calculations were made for 5% and 10% water concentrations. The effect of the water concentration on the power requirement is shown in Figure 4-2 and Table 4-2.

The optimum water concentration at inlet to the cleanup system, which requires the least power, must be determined by considering both the energy required to separate the water and the loss of

Figure 4-1 TWO - STEP EVAPORATION

TABLE 4-1

AMMONIA CLEANUP POWER REQUIREMENT*

Evaporator Pressure, psia	Evaporator Temperature, F	Evaporator Heat, kW	Vapor Compressor kW	Distillation kW
12	40	1,634	507	15.6
	50	2,792	864	14.6
	60	--	--	--
	70	--	--	--
24	40	--	--	--
	50	1,525	351	16.6
	60	2,389	557	15.1
	70	14,067	3,312	13.8
32	40	895	192	21.0
	50	1,215	214	18.9
	60	1,602	286	16.9
	70	2,638	475	15.2
40	40	--	--	--
	50	1,130	152	20.7
	60	1,322	180	18.4
	70	1,761	244	16.6
56	40	908	64	39.8
	50	993	72	27.4
	60	1,093	80	22.3
	70	1,268	94	19.5

*Power requirement is based on 1.0 lb/min. water removal from OTEC evaporator sidestream with 1.0% water.

**Figure 4-2 EFFECTS OF WATER ON AMMONIA CLEANUP POWER
(TWO-STEP EVAPORATION)**

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TABLE 4-2

EFFECTS OF WATER ON AMMONIA
CLEANUP POWER REQUIREMENT*

Water, %	Evaporator kW	Vapor Compression kW	Disillation kW
0.5	1,923	141.2	38.1
1.0	895	65.3	38.1
2.0	418	30.5	38.1
3.0	262	19.3	38.1
5.0	141	10.4	38.1
10.0	52.5	3.9	38.1

* Evaporator - 40°F and 56 psia

Distillation Column - 92 psia

Compressor - 56 psia to 92 psia

Power requirement is based on 1.0 lb/min. water removal.

power generation due to water in the working fluid. Figure 4-3 shows the net power loss as a function of the water content for the simple distillation and for the two-step evaporation cleanup systems. As shown in the figure, the optimum water concentration for the two-step cleanup system is about 1.0% while for simple distillation the optimum occurs at about 3.0% water. The figure also shows that the specific power requirements of the two-step evaporation cleanup system are lower than those of the simple distillation by about a factor of three. This represents a significant energy saving.

It is noted that somewhat lower turbine loss due to water leakage into the OTEC system has been reported in the conceptual design report (LMSC-D566744). The difference is apparently due to discrepancies in the ammonia-water equilibrium vapor pressure data used in the two studies. A comparison of power losses calculated from both sets of data is shown in Figure 4-4. It is evident that, although the absolute power savings calculated with the conceptual design data are significantly lower than those in the present study, calculated on the basis of data from Perry's Chemical Engineering Handbook*, the two-step distillation requires less power in either case. The ratio of power used for distillation to that of the two-step evaporation process at the optimum is about the same for either case.

* Perry's Chemical Engineer's Handbook, McGraw-Hill
Fourth Edition 1963

Figure 4-3 EFFECTS OF WATER ON OTEC POWER LOSS

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Figure 4-4 ESTIMATED POWER LOSS COMPARISON

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF8OC1050M

50 MWe Commercial Plant Power Module

Conceptual Design Description

for

Ammonia Unloading System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the conceptual design description of the Ammonia Unloading System (AUS) for the OTEC 50 MWe Commercial Plant Power System. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The conceptual design was prepared to identify key features of commercial OTEC power modules which are to be incorporated into an analogous 10 MWe modular application power system. The design is based on generic site conditions.

The function of the AUS is to transfer the ammonia from the power system to the ammonia storage tanks on the platform and to establish low pressure ammonia or air atmosphere in the system, in preparation for disassembly or maintenance activities. The AUS is also used for removing ammonia from condensate and distribution pumps to allow pump disassembly and maintenance during normal plant operation.

Some operations needed to satisfy these functions (such as vapor recovery, venting, and purge) are performed by platform support facilities which serve all modules; others are performed by

facilities included in each module. This document describes the part of the AUS associated with the module and defines the interfaces with the part associated with the platform support facilities.

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A

Ammonia Unloading System Drawings

A-1

Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Ammonia Unloading System (AUS) is to transfer into storage tanks the ammonia working fluid from the entire power system, or from selected components, after shutdown. Another function of the system is to establish low pressure ammonia or air atmosphere inside the power system and its components in preparation for isolation, maintenance or disassembly activities.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

Ammonia removal from the evaporator and condenser, or ammonia removal and replacement with air for the pumps and turbine, is to be accomplished within a target time limit of 24 hr. Ammonia removed is to be either recovered and stored, or disposed of in a safe and environmentally acceptable manner.

The pressure of the ammonia vapor in the evaporator, condenser, and the ammonia loop associated with each of them is to be reduced to 60 psia in preparation for disconnecting. The air inside individual condensate or distribution pumps and in the

isolated turbine with its associated piping is to contain less than 50 ppm ammonia at the end of the unloading operation.

1.2.2 Structural Requirements

The system piping and components are to remain operational with vertical accelerations of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary with vertical accelerations of $\pm 0.7g$ (sea state 9). The materials for the internals must be compatible with ammonia liquid or vapor (possibly contaminated with seawater) at typical system operating temperatures, and with ammonia contaminated air at atmospheric temperature. The externals are to be appropriate for service in a marine, above-water environment with no shelter from the weather and seawater spray. The plant design life is to be thirty years.

1.2.3 System Configuration and Essential Features

Liquid drain connections are to be located at the lowest points of the power system. Connections for extracting ammonia vapor and for vent/purge are to be located above normal seawater level or in the pump rooms which have a "shirt sleeve" atmosphere. It is desirable to use the same connections for charging and for unloading the ammonia. Of the components required to perform the unloading function, only the drain collection tanks with their pumps and the vapor and liquid piping connecting the module to the remaining system components are part of the module.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be identified during preliminary and detailed designs.

1.2.5 Level of Technology

Components for the AUS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumental and Control Requirements

The control system is to be designed for manual operation with data acquisition/storage and displays in the control room. Local display and control panels are to be provided at selected locations to assist operators performing routine checkout and maintenance. To the extent feasible, pneumatic or hydraulic control actuators are to be used.

1.2.7 Maintenance Requirements

The maintenance provisions of the AUS are to be consistent with the overall maintenance plan established for the power module. Maintenance activities consist of inspections, preventive maintenance, routine refurbishing and in-situ repairs. General tooling, special tools, and lifting devices are to be provided for shipboard maintenance and for replacement of defective components. The arrangement of system components is to allow

space and access for maintenance operations and a safe transit path for component removal.

1.2.8 System Reliability

The AUS is not used during normal plant operation; therefore, its function is not critical to power plant availability. However the functioning of the ammonia vent and purge subsystem is important for safety of personnel; thus, its reliability must be high. The availability of the AUS, when needed, is to be assured by preventive maintenance performed during periods of normal plant operation, and by redundant installation of rotating equipment, such as pumps and compressors.

1.2.9 Interface Requirements

The AUS has interface requirements with the following systems:

- Ammonia Vapor and Condensate System (AVCS). The AUS interfaces with the AVCS consist of appropriately located pipe connections to allow drainage of liquid ammonia and venting of ammonia vapor.
- Ammonia Storage and Fill System (ASFS). The AUS interfaces with the ASFS to store ammonia vapor which is recovered from the power system.
- Electrical System (ES). Power for AUS pumps is to be supplied by the ES.
- Control System (CS). The AUS is to interface with the CS to permit operation of the AUS from the control room.

- Structure. The AUS interfaces with the structure consist of equipment mountings and pipe supports.

1.2.10 Environmental and Safety-Related Requirements

The module-related parts of the AUS do not directly communicate with the atmosphere or with natural water. Consequently, apart from accidental and unplanned ammonia releases, no adverse environmental effects are expected.

The AUS is to operate in a manner which keeps the ammonia concentration at safe levels inside manned compartments. The present OSHA 8-hr exposure limit is 50 ppm.

All motors in the AUS which are located inside the machinery rooms are to be suitable for NFPA Class I, Group D, Division 2 installations.

Purging of ammonia vapor is to be done in a way which assures that an explosive mixture of ammonia in air (16%) is never present inside piping or vessels and that the concentration of ammonia in air inside any system or component is to be less than 50 ppm at the end of the unloading operation.

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Section 2

DESIGN DESCRIPTION

To remove the ammonia working fluid from the power system, the AUS is used for three distinct functions:

- Draining liquid ammonia from the power system and transferring it to storage
- Recovering ammonia vapor from the power system, condensing it, and transferring the resulting liquid to storage
- Venting and purging residual ammonia vapor from the power system, leaving the system filled with air at atmospheric pressure.

For convenience in considering the equipment for accomplishing these three functions, each subsection of the Design Description is broken down to describe the following three subsystems:

- Ammonia Drain Subsystem (module-related)
- Ammonia Vapor Recovery Subsystem (platform-related)
- Ammonia Vent and Purge Subsystem (platform-related).

2.1 SYSTEM CONFIGURATION

2.1.1 Ammonia Drain Subsystem

The Ammonia Drain Subsystem provides the means for draining liquids from the power system, using piping, collection tanks and transfer pumps. The Ammonia Drain Subsystem transfers the collected drains to the ammonia storage tanks on the platform. The functional arrangement of the components in the system is

shown in Drawing M-504 (Appendix A). As shown in the diagram, a drain line is connected to the bottom of each condensate pump and each distribution pump, as well as at the low points of pipe lines, so that all pumps, lines, and the condenser and evaporator sumps can be drained. In addition, vent lines connect the high point on each pump to the vapor space in either the condenser or the evaporator to promote gravity draining.

A drain collection tank is provided for the condenser segment of the power module, and another collection tank is provided for the evaporator segment. This arrangement is necessary because of the segmented nature of the module.

Two parallel, 50% capacity transfer pumps are provided in each collection tank, so that the drain function is available, even if one transfer pump fails. The space in each collection tank is sufficient to store the volume of one condensate or distribution pump. When a larger volume, e.g., the condenser sump, is to be drained, the transfer pumps must be activated to transport the excess ammonia to the storage tanks.

2.1.2 Ammonia Vapor Recovery Subsystem

The Ammonia Vapor Recovery Subsystem, which is included in the platform support facilities to serve all modules, transfers ammonia vapor from the power module to liquid-storage tanks in the ASFS. Each module includes piping to connect components to the Ammonia Vapor Recovery Subsystem in the platform support

facility. The functional arrangement of the subsystem is also shown in Drawing M-504. As shown in the drawing, a vapor recovery line is connected to each component in the power module which contains a significant amount of vapor to be recovered. Each recovery line connects to a header which leads to the platform support facility. The vapor is condensed by the Ammonia Vapor Recovery Subsystem and stored in the ASFS platform support facilities so that the liquid can be used for refilling or makeup.

2.1.3 Ammonia Vent and Purge Subsystem

The Ammonia Vent and Purge Subsystem, which is part of the platform support facilities, disperses economically not recoverable quantities of ammonia vapor and noncondensable gases from the power module to the atmosphere. Each module includes piping to connect components to the Ammonia Vent and Purge Subsystem in the platform support facility. Drawing M-504 shows the functional arrangement of the subsystem. As shown in the drawing, a vent and purge line is connected to each component in the power module except the evaporator and condenser. All vent lines connect to a header which leads to the platform support facility. All purge lines connect to a header which leads to supplies of nitrogen and clean atmospheric air, which are furnished by the platform support facilities.

2.2 SYSTEM PERFORMANCE

The main parameter which describes the Ammonia Drain Subsystem performance is the time required to complete its performance. The target criterion given for unloading ammonia from the power module is 24 hr. This target has been achieved as shown below.

2.2.1 Ammonia Drain Subsystem

The drain function, which is the first step in unloading the power system, is completed in 1 hr.

2.2.2 Ammonia Vapor Recovery Subsystem

This subsystem is designed to reduce the ammonia vapor pressure in the power system to 60 psia in 12.5 hr while recovering and storing the extracted ammonia.

2.2.3 Ammonia Vent and Purge Subsystem

The time required for the Ammonia Vent and Purge Subsystem to reduce the ammonia concentration in the air inside the turbine and associated piping to 50 ppm is 10.5 hr from the time of starting the nitrogen purge. Since the turbine and piping is the largest volume to be purged, this is the maximum time for any component.

2.3 SYSTEM ARRANGEMENT

2.3.1 Ammonia Drain Subsystem

The drain collection tank and transfer pumps associated with the condenser segment of the power module are located at the lowest level of the condenser equipment room. Another collection tank and pair of transfer pumps are located similarly in the evaporator equipment room. All drain system lines run within the equipment rooms, except for the pipe connecting to the ammonia storage tanks, which is located on the platform.

2.3.2 Ammonia Vapor Recovery Subsystem

The equipment for the Ammonia Vapor Recovery Subsystem, which is part of the platform support facilities, is located on the platform structure above water level. All vapor recovery lines from the platform facility connect to the power module piping at locations which are above water level.

2.3.3 Ammonia Vent and Purge Subsystem

The equipment for the Ammonia Vent and Purge Subsystem, which is part of the platform support facilities, is located on the platform structure above water level. Vent and purge ducting connect to all components in the power system, except the evaporator and condenser, and to all components in the platform

support facilities which handle ammonia. All disconnect joints are above water level.

2.4 SYSTEM COMPONENTS

2.4.1 Ammonia Drain Subsystem

All components in the Ammonia Drain Subsystem are standard commercial items. None of the equipment requires long lead times for delivery. A list of the major components is given below:

- Collection Tanks (2) horizontal, cylindrical
 7ft 6in dia x 14ft long,
 250 psig, 80 F
- Transfer pumps (4) vertical, centrifugal sump
 type, 280 gpm, 150ft head,
 15 hp

2.4.2 Ammonia Vapor Recovery Subsystem

All major components in the Ammonia Vapor Recovery Subsystem are provided as part of the platform support facilities. The module provides the interconnecting piping between the power system components and the platform support facility.

2.4.3 Ammonia Vent and Purge Subsystem

All major components in the Ammonia Vent and Purge Subsystem are provided as part of the platform support facilities. The module provides the interconnecting piping between the power system components and the platform support facility.

2.5 SPECIAL SUPPORT EQUIPMENT

There is no special support equipment required for the AUS.

2.6 INSTRUMENTATION AND CONTROL

2.6.1 Ammonia Drain Subsystem

The drain collection tanks have liquid-level limit switches to start the transfer pumps at high liquid level and stop them when the tanks are nearly empty. The operating status of the pumps is indicated in the module control room.

2.6.2 Ammonia Vapor Recovery Subsystem

The operating instrumentation and controls for the Ammonia Vapor Recovery Subsystem are provided by the platform support facility. The module provides manually operated isolation valves in the interconnecting piping.

2.6.3 Ammonia Vent and Purge Subsystem

The operating instrumentation and controls for the Ammonia Vent and Purge Subsystem are provided by the platform support facility. The module provides manually operated isolation valves in the interconnecting piping.

2.7 SYSTEM INTERFACES

2.7.1 Ammonia Drain Subsystem

The Ammonia Drain Subsystem interfaces physically with the ammonia storage tanks and with the power system. The interface with the storage system is at a shutoff valve near the tanks. The interfaces with the power system are at the drain valves in the lines to the individual components.

2.7.2 Ammonia Vapor Recovery Subsystem

This platform related subsystem interfaces physically with the module ammonia vapor withdrawal manifold.

2.7.3 Ammonia Vent and Purge Subsystem

The Ammonia Vent and Purge Subsystem interfaces physically with the platform vent and purge manifold.

2.8 DESIGN PROVISIONS FOR SAFETY

All design safety provisions for the AUS are provided in the platform support facility. There are no specific safety items for the portion of the AUS which is provided by the module.

Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

Startup of the Ammonia Drain Subsystem consists of opening the pressure equalizing vent line, followed by opening the drain valve on the component to be drained. The transfer pumps are automatically started by the high liquid level switch.

Startup of the Vapor Recovery Subsystem consists of energizing the equipment in the platform support facility and manually opening valves in the vapor recovery line from the components in the power module which have been previously drained.

Startup of the Vent and Purge Subsystem consists of energizing the equipment in the platform support facility and manually operating shutoff valves in the vent and purge ducting.

3.2 NORMAL OPERATION

After the Ammonia Drain Subsystem is started, the liquid drains from the component by gravity. The transfer pumps operate automatically when the high-level limit switches in the collection tanks are tripped. The operation is continued until the selected component is drained and the transfer pumps stop.

After the Vapor Recovery Subsystem is started, the equipment in the platform support facility runs until the suction pressure is reduced to the set pressure (60 psia for the condenser and evaporator and 15 psia for the turbine).

After startup, the Vent and Purge Subsystem operates until the stack gas ammonia concentration measurement indicates that the power system component, which is being serviced, contains a safe ammonia concentration.

3.3 SHUTDOWN

After the drain operation is completed and the transfer pumps stopped, the drain and vent valves are closed.

After the vapor recovery operation is completed, the vapor recovery line isolation valves are closed, and the equipment in the support facility is de-energized.

After the vent and purge operation is completed, shutoff valves are manually closed, and the equipment in the platform support facility is de-energized.

3.4 INFREQUENT AND ABNORMAL OPERATIONS

Abnormal operations in the AUS are announced by alarms in the power module control room. These abnormal operations include:

high ammonia concentration in the stack, pumps not energized, and high temperature in the condenser.

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Section 4

MAINTENANCE

Maintenance work on the AUS is done during the periods between power system unloading operations. The checking and maintenance consist of the following operations:

- Ammonia Drain Subsystem. Check pump and valve seals for leaktightness and check the liquid level controls for proper operation.
- Ammonia Vapor Recovery Subsystem. Check subsystem for leaks and perform equipment startup checks.
- Ammonia Vent and Purge Subsystem. Perform equipment startup checks.

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Appendix A

AMMONIA UNLOADING SYSTEM DRAWINGS

Bechtel Drawing M-504, Ammonia
Unloading System Flow Diagram

A-2
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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF8OC1050M

50 MWe Commercial Plant Power Module

Conceptual Design Description

for

Leak Detection System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the conceptual design description for the Leak Detection System (LDS) for the 50 MWe OTEC Commercial Plant Power System. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions.

The function of this system is to detect ammonia leakage to air by continuous monitoring and alarming at three potentially dangerous ammonia concentration levels: industrial exposure level, lethal concentration, and explosive concentration. The first and second levels are monitored by infrared analyzers, and the third is measured by a combustible gas detection system.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Leak Detection System (LDS) is to detect and record the presence of ammonia in the air occupying various enclosures of the power module, and to provide alarm signals at critical levels of concentrations.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The LDS is to continuously monitor and record the concentrations of ammonia in room air at various locations in a power system module. Sensors are to cover the concentration range from about 10 ppm to the lower explosive limit. Alarm signals are to be provided with location indication to the module control computer at the following concentration levels:

- Industrial exposure level
(50 ppm for 8 hr exposure)
- Lethal concentration
(1700 ppm for 1/2 hr exposure)
- Explosive concentration
(lower explosive limit--16%).

1.2.2 Structural Requirements

The system piping and components are to be designed to remain operational with vertical acceleration of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary (and survive) with vertical accelerations of $\pm 0.7g$ (sea state 9).

1.2.3 System Configuration and Essential Features

Ammonia detection sensors are to be located and permanently installed in various compartments in a power system module, including the following:

- Condensate pump room
- Distribution pump room
- Control room
- Auxiliary machinery room
- Auxiliary pipe chase
- Elevator shafts and access tubes.

In addition, portable detectors are to be provided for local monitoring during maintenance operations and leak tracing. Portable detectors are to provide local alarm signals.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be specified during preliminary and detailed designs.

1.2.5 Level of Technology

Components for the LDS are to be selected from state-of-the-art, commercially available designs, requiring no development work.

1.2.6 Instrumentation and Control Requirements

Does not apply.

1.2.7 Maintenance Requirements

Maintenance provisions for the LDS are to be consistent with the overall maintenance plan of the power module. Tooling is to be available for in-situ maintenance and for replacement of defective components. The LDS equipment is to be accessible for calibration and corrective maintenance without disrupting the power system operation.

1.2.8 System Reliability

The LDS is to be functioning at all times when ammonia is present in the module. The required high system reliability and availability may be achieved either by redundant installations or by stocking enough spare units for quick changeout of defective parts.

1.2.9 Interface Requirements

The LDS is to be supplied with uninterruptable electric power, and it is to transmit measurement signals to the module control computer.

1.2.10 Environmental and Safety-Related Requirements

The LDS electrical equipment is to be approved for use in Class I, Group D, Division 2 hazardous locations.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

2.1.1 Industrial Exposure Level and Lethal Concentration

Infrared analyzers are used to measure ammonia concentration in air at hazard breathing levels. This type analyzer is commonly used in industrial environments for monitoring a single potentially harmful vapor. The analyzer operates by comparing the infrared absorption of a sampled gas with that of a reference cell. The sampled gas flows continuously through the analyzer, and the analyzer produces a continuous output signal. Changes in ammonia concentration are indicated (90% response) typically within 5 sec. Numerous output voltage and current options are available. A complete analyzer typically weighs 100 lb.

2.1.2 Explosive Concentration

A combustible gas detection system is specified for monitoring ammonia vapor in air at potentially explosive concentrations. The combustible component in the air is burned by a heated catalytic cell, and a temperature rise in the cell is sensed by a bridge circuit producing a continuous dc voltage level output signal proportional to the percent of lower explosive level present in the air. The combustible gas detection system, in an

enclosure for Class I, Group D, Division 2 service, measures 17 x 14 x 10 in.

2.2 SYSTEM PERFORMANCE

Each detector system specified for the LDS has an electrical output proportional to the concentration of ammonia in air. The detector output signals are used as inputs to the power module control computer for recording and alarm functions. The concentration signals for the industrial exposure level measurements are recorded to provide permanent personnel exposure records. Any concentration which exceeds a preselected value triggers a warning alarm in both the control room and the module compartment where the high concentration is detected.

2.3 SYSTEM ARRANGEMENT

The locations and numbers of LDS detectors are given in Table 2-1 below:

TABLE 2-1

LOCATIONS OF LEAK DETECTION SYSTEM DETECTORS

<u>Location</u>	<u>Number of Detectors</u>		
	<u>Industrial Exposure Level</u>	<u>Lethal Concentration</u>	<u>Explosive Concentration</u>
Condensate pump room	2	1	1
Distribution pump room	2	1	1
Control room	1		
Auxiliary machinery room	1		
Auxiliary ammonia systems deck	2	2	2
Auxiliary pipe chase	1	1	1
Elevator Shaft and Access Tubes	1	1	1

2.4 SYSTEM COMPONENTS

The major equipment items for the LDS are given in Table 2-2. None of this equipment requires long lead time, and all are items commercially available.

TABLE 2-2
SYSTEM COMPONENTS

<u>Description</u>	<u>No. Required</u>
Infrared ammonia analyzer 0-300 ppm	10
Infrared ammonia analyzer 0-3000 ppm	6
Combustible gas detection system	6

2.5 SPECIAL SUPPORT EQUIPMENT

None Required.

2.6 INSTRUMENTATION AND CONTROL

None required.

2.7 SYSTEM INTERFACES

TABLE 2-3
LEAK DETECTION SYSTEM INTERFACES

<u>System</u>	<u>Interface description</u>
Electric	Requires 115 vac, 60 Hz, 7 kW
Module control computer	Receives 22 electrical input signals Records 22 signal inputs and alarms for 12 inputs

2.8

DESIGN PROVISIONS FOR SAFETY

The LDS components are designed to meet the requirements for Class I, Group D, Division 2 hazards.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP, NORMAL OPERATION, AND SHUTDOWN

For the LDS the startup and shutdown procedures consist of turning on and off the electrical power to each unit. Normal operation is completely automatic; the analyzer and detector units detect the ammonia concentration in air and transmit proportional signals to the module control computer without operator actions.

3.2 INFREQUENT AND ABNORMAL OPERATIONS

The LDS analyzers and detectors require annual calibration.

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Section 4

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

The LDS preventive maintenance schedule is compatible with the Level 5 (Reference 4-1, pp. 5-13) schedule for the power system. Annual inspection, test, repair, and calibration work is performed. However, rather than do this work during the scheduled annual shutdown, it is started immediately following resumption of power generation. By using one spare unit of each type, the LDS monitors are sequentially replaced and serviced.

In addition to the annual preventive maintenance described above, the combustible gas detection system catalytic burner units are replaced once every 3 yr.

4.2 CORRECTIVE MAINTENANCE

If one of the ammonia-in-air monitoring units should fail in service, it is removed and replaced with a spare unit. This is done in less than 1 hr. The nonfunctioning unit is then taken to an instrument repair area or to shore for repair.

REFERENCES

1-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978, (LMSC-D566744)

4-1 Ibid.

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF8OC1050M

50 MWe Commercial Plant Power Module

Conceptual Design Description

for

Fluid Sampling System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the conceptual design description for the Fluid Sampling System (FSS) for a 50 MWe commercial plant power module. It reflects the system definition after completion of the conceptual design of the OTEC Power System Development Program, Phase I, Task 2. The conceptual design was prepared to identify key features of commercial OTEC power modules which are to be incorporated into an analogous 10 MWe modular application power system. The design is based on generic site conditions.

The functions of this system are to measure seawater or impurity concentration in liquid ammonia and to measure noncondensable gas concentration in ammonia vapor. The results of analyses of the liquid and gas phase constituents are used to determine the need for operating the ammonia cleanup or the noncondensable gas removal system, respectively.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The Fluid Sampling System (FSS) has the following functions:

- Measure seawater concentration in the liquid ammonia in the evaporator
- Measure concentration of noncondensable gas in the condenser ammonia vapor
- Withdraw liquid and gaseous ammonia samples from the power cycle for wet chemistry or other chemical analyses to determine all constituents in both phases.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

Seawater Concentration. The nominal concentration is 1% seawater in saturated ammonia liquid at 70 F (129 psia). The measurement system is to have adequate sensitivity over a range of 0.1 to 10% seawater in ammonia.

Noncondensable Gas Concentration. The maximum concentration of noncondensable gases in the condenser is 2% with normal concentration being 0.1%. The measurement system is to have adequate sensitivity over a range of 0.05% to 20% noncondensibles in ammonia vapor.

1.2.2 Structural Requirements

The FSS is to operate with vertical acceleration of $\pm 0.15g$, and it is to survive $\pm 0.7g$ vertical acceleration with no permanent damage.

The liquid ammonia is at pressures from 142 to 170 psia with temperatures from 53 to 59 F depending on operating conditions. The ammonia vapor is at pressures from 86 to 93 psia with temperatures from 48 to 52 F. The measuring units are to function at these conditions, or sample conditioning systems are to be provided to establish fluid pressures and temperatures compatible with the measuring units.

1.2.3 System Configuration and Essential Features

The seawater concentration is to be measured directly in the evaporator sump or with samples taken from that region. The noncondensable gas concentration is to be measured in the condenser vapor space or in samples taken from the noncondensable gas scavenging header. The measuring instruments are to generate continuous output signals for recording and control purposes. Connections for withdrawing liquid and vapor samples for wet chemistry are to be provided near the respective measuring points.

1.2.4 Codes and Standards

Applicable national and industrial codes are to be specified during preliminary and detailed designs.

1.2.5 Level of Technology

Components for the FSS are to be selected from the state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Does not apply.

1.2.7 Maintenance Requirements

Maintenance provisions for the FSS are to be consistent with the overall maintenance plan of the power module. General and special tooling is to be available for in-situ maintenance and for replacement of defective parts. The FSS equipment is to be accessible for corrective maintenance and calibration without disrupting the power system operation.

1.2.8 System Reliability

The FSS is to be in operation any time the plant is operating, but it is not essential for plant functioning. Therefore, short

outages of up to 2-hr duration can be tolerated for component repair or replacement.

1.2.9 Interface Requirements

The FSS is to be supplied with electric power, and it is to transmit measurement signals to the module control computer.

1.2.10 Environmental and Safety-Related Requirements

The FSS electrical equipment is to be approved for use in Class I, Group D, Division 2 hazardous locations.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

2.1.1 Seawater Concentration

Seawater concentration in liquid ammonia is measured with an electrical conductivity cell installed in the ammonia distribution pump discharge manifold. The cell is cable-connected to a conductivity converter which in turn transmits an electrical dc signal to the module control computer for recording and control. The electrical conductivity cell and converter are commercially available.

2.1.2 Noncondensable Gas Concentration

The noncondensable gas concentration is measured with a thermal conductivity (TC) cell. To accomplish the measurement, a small stream of vapor is bled from the noncondensable gas scavenging header, passed through the TC cell, and vented to the stack. The sample stream has a flow rate of 100 standard cm³/min, which is less than 100 lb/year of ammonia vented to the atmosphere. The TC cell is electrically connected to a readout unit which produces a continuous electrical dc signal for recording and control use. The thermal conductivity cell and readout unit are commercially available.

2.2 SYSTEM PERFORMANCE

Each of the measurement devices for the FSS generates a continuous electrical output signal indicating concentration. These signals are used as inputs to the power module control computer for recording and control purposes.

2.3 SYSTEM ARRANGEMENT

The seawater-in-ammonia measuring probe is installed in the distribution pump discharge line located in the machinery room beneath the evaporator. The signal converter is located nearby in the same room. The noncondensable gas measuring cell and its readout package are located above the condenser near the noncondensable gas scavenging header.

2.4 SYSTEM COMPONENTS

The major equipment items for the FSS are given in Table 2-1. All of the equipment is commercially available, and none of it requires long lead time.

TABLE 2-1
SYSTEM COMPONENTS

<u>Description</u>	<u>No. Required</u>
Electrical conductivity cell and converter	1
Thermal conductivity cell and readout	1

2.5 SPECIAL SUPPORT EQUIPMENT

None required.

2.6 INSTRUMENTATION AND CONTROL

None required.

2.7

SYSTEM INTERFACES

TABLE 2-2

FLUID SAMPLING SYSTEM INTERFACES

<u>System</u>	<u>Interface Description</u>
Ammonia vapor and condensate	Requires tap for installing electrical conductivity cell in distribution pump discharge line Requires bleed tap for thermal conductivity cell in noncondensable gas scavenging header outlet
Electrical	Requires 115V ac, 60 Hz, 200 W
Module control computer	Receives and processes 2 electrical input signals

2.8

DESIGN PROVISIONS FOR SAFETY

The FSS components are designed to meet requirements for Class I, Group D, Division 2.

Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP, NORMAL OPERATION, AND SHUTDOWN

For the FSS the startup and shutdown procedures consist of turning on and off the electrical power to each unit. Once energized, the FSS operates automatically. The measuring devices produce continuous output signals for transmission to the module control computer.

3.2 INFREQUENT AND ABNORMAL OPERATIONS

The FSS measuring equipment requires annual calibration.

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Section 4

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

The FSS preventive maintenance schedule is compatible with the Level 5 (Reference 4-1, p. 5-13) schedule for the power system. Annual inspection, test, repair, and calibration work is performed during the time that the power system is down for routine annual maintenance.

4.2 CORRECTIVE MAINTENANCE

Either of the measuring units in the FSS can be shut down and removed without interrupting the power system operation. A defective unit can be repaired or replaced, as necessary, for corrective maintenance.

REFERENCES

- 1-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978, (LMSC-D566744)
- 4-1 Ibid.

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module
Preliminary Design Description
for the
Ammonia Vapor and Condensate System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Ammonia Vapor and Condensate System (AVCS) for the 10 MWe OTEC Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of AVCS were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The AVCS pumps condensate from the condenser to the evaporator, supplies liquid ammonia to the evaporator spray nozzles, and carries ammonia vapor to the turbine.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The functions of the Ammonia Vapor and Condensate System (AVCS) are to:

- Convey ammonia condensate from the condenser sump to the evaporator sump
- Convey liquid ammonia from the evaporator sump to the evaporator spray nozzles
- Convey ammonia vapor from the evaporator to the turbine.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The AVCS is to permit the operation of the OTEC power cycle with the warm water and cold water temperature combinations shown in Figure 1-1.

At the design point conditions (10 MWe net electric power generation), the condensate flow rate is 800 lb/sec. The condensate flow will vary over a range of 516 to 908 lb/sec as part of normal operation. The distribution flow is 150% of the condensate flow rate over the operating range.

Figure 1-1 OTEC OPERATING REGIME

At the design point the condenser operates at 89 psia, and the evaporator operates at 129 psia ammonia pressure. The evaporator pressure varies from 114 to 138 psia. The pressure of the condenser varies from 86.5 to 93 psia. The condensate pumps are to deliver the required condensate flow against the condenser-to-evaporator pressure differentials over the whole operating regime of the power system.

1.2.2 Structural Requirements

All lines containing ammonia are to be designed to contain a pressure of 250 psig. Lines are fabricated of carbon steel and are designed for a thirty-year plant life. The system piping and components are to be designed to remain operational with vertical acceleration of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary with vertical accelerations of $\pm 0.7g$ (sea state 9). The system is to be designed to withstand transient effects such as those resulting from turbine trip.

1.2.3 System Configuration and Essential Features

The pumps of the AVCS are located in the machinery rooms of the condenser (condensate pumps) and the evaporator (distribution pumps). Pump locations are to be sufficiently below the suction sump liquid level to ensure cavitation-free operation at all operating conditions of Figure 1-1 in sea states with a vertical acceleration of $\pm 0.15g$. Maximum allowable flow velocities are as follows:

Liquid Lines

30 ft/sec

Vapor Lines

160 ft/sec

The evaporator and the condenser are to be separately detachable from the power module. Separable and remakable joints and valves are therefore required above the water line in the evaporator vapor lines, in the turbine exhaust line, and in the condensate line from the condenser to the evaporator sump.

1.2.4 Codes and Standards

A tentative selection of codes and standards for the design, construction and operation of the AVCS is given below. Applicability of specific sections and the need for any additional standards are to be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	- ANSI B31.1 - 1974 Code for Power Piping
Electric Motors	- National Electric Code, NFPA 70 - NEMA Standards
Pumps	- Hydraulic Institute Standards
Ammonia Properties	- Bureau of Standards Cir- cular No. 142. Tables of Thermodynamic Properties of Ammonia

Component/Requirement

Standard

Safety

- American National Standard for the Storage and Handling of Anhydrous Ammonia (K 61.1)
- OSHA Standards, Section 1910.11, Storage and Handling of Anhydrous Ammonia
- National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the AVCS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Instrument sensors and displays, required to ascertain safe operating status of the system and to indicate nonstandard operating conditions, are to be identified. As a minimum, such instrumentation should include pressure and temperature sensing, flow metering, chemical sampling and analytical capability, electric motor status, and valve position indicators.

Controls are to have sufficient response capability to allow regulation of the ammonia vapor and condensate flows, demanded by the OTEC control system, over the expected operating range. Liquid levels in the evaporator and condenser sumps are to be

controlled. A continuous condensate and distribution flow rate signal is to be provided for use in the OTEC control system.

1.2.7 Maintenance Requirements

Maintenance provisions of the AVCS are to be consistent with the overall maintenance plan of the power module. Means of isolation, purging, and disassembly and for lifting and transportation are to be provided to permit maintenance of disabled pumps while the power module is operating. Special tooling, including lifting slings required for maintenance of AVCS equipment, are to be provided. The arrangement of system components is to allow space and access to perform maintenance operations and a safe transit path for equipment removal.

1.2.8 System Reliability

The reliability of the AVCS is to be consistent with the OTEC 90% availability (at 60% confidence) requirement. One redundant condensate pump and one redundant distribution pump are to be provided and made available for operation upon failure of an operating pump. Equipment specifications and ratings are to be conservative (e.g., low speeds, heavy walls) to provide maximum durability.

1.2.9 Interface Requirements

The AVCS is functionally a part of the CTEC power cycle, and it interfaces with the:

- Ammonia Storage and Fill System
- Ammonia Unloading System
- Ammonia Cleanup System
- Noncondensable Gas Removal System
- Machinery Room HVAC System
- Plant Control System
- Electrical System
- Fire Protection System.

During normal operation, valves at all interfaces to the Ammonia Unloading System are locked closed. Those valves at the interface with the Ammonia Storage and Fill System which do not function to control ammonia inventory will also be locked closed.

1.2.10 Environmental and Safety-Related Requirements

The AVCS is to be equipped with pressure relief devices to prevent accidental overpressuring of the system. Blowdown from relief valves is to be manifolded for safe discharge through the Ammonia Unloading System.

Warning indicators and alarms are to be provided by the Leak Detection System to alert plant personnel of unsafe conditions,

such as high ammonia concentrations, before the system is opened for maintenance.

Design provisions required by OSHA for plant personnel safety are to be incorporated. In particular, the ammonia vapor concentrations in the pump rooms are to be monitored and maintained below 50 ppm.

Provisions for fire alarm and suppression are to be supplied by the plant fire protection system.

Section 2

DESIGN DESCRIPTION

The AVCS preliminary design for the 10 MWe Modular Application Power System described in this section was derived from and is analogous to the conceptual design prepared for the 50 MWe commercial power system. The AVCS is a functionally integral part of the OTEC 10 MWe power cycle. It consists of pumps, piping, and associated equipment used to convey ammonia liquid from the condenser to the evaporator, and ammonia vapor to the turbine shutoff valve. The details of the power cycle and a description of the turbine, the condenser and the evaporator are presented in other project documentation. (Reference to be furnished by LMSC.)

2.1 SYSTEM CONFIGURATION

The flow diagram and the system piping and instrumentation diagram are shown on Drawings M-102 and M-107 (Appendix A), respectively.

A 36-inch diameter suction manifold takes ammonia from the condenser sump and distributes it to three 24-inch diameter suction lines leading to each of the three 50% capacity condensate pumps. These pumps have head and flow capacity to increase the condensate pressure to the operating pressure of the evaporator, satisfy static head requirements, and overcome line losses. Two pumps are normally operating; the remaining pump is

on standby. Each suction line contains a butterfly stop valve and a temporary startup strainer. Each pump discharge line contains a butterfly stop check valve. These valves are used to isolate the pumps for maintenance or to prevent backflow through a standby pump. Elastomeric expansion joints in both the suction and discharge lines serve to minimize thermal expansion stresses in the close-coupled arrangement. The three 12-inch diameter discharge lines combine to feed a 12-inch diameter main condensate line. This line is routed through the condenser shell to above the water level where the valves and separation flanges, necessary for evaporator and condenser removal, are located. The main condensate line is then routed to the evaporator sump where the condensate is discharged below the liquid surface through a circular sparger. Lines from the bottom of each pump barrel and from the top of each pump discharge port are provided for access to the interfacing systems for the purpose of filling, draining, venting and purging. Vents for the pump suction barrel are also provided to assist filling. During normal operation the valves at these connections are locked closed. The line from the top of each pump discharge port is connected with a vapor vent within the condenser. A line which can vent the highest point in the condensate line to the evaporator space is provided to permit draining of the condensate line. A recirculation line is provided for establishing condensate pump flow during startup.

In the distribution loop a 48-inch diameter suction manifold takes ammonia from the evaporator sump and distributes it to four 24-inch diameter lines leading to each of the four 33% capacity

distribution pumps. These pumps have head and flow capabilities to lift the ammonia to the discharge nozzles and to provide the required pressure at the spray nozzles. Three pumps are normally operating; the remaining pump is on standby. Each suction line contains a butterfly valve and a temporary startup strainer. Each pump discharge line contains a butterfly stop check valve. Similar to the condensate loops, these valves serve to isolate the pump and to prevent backflow. Elastomeric expansion joints in both the suction and discharge lines of each pump serve to minimize expansion stresses. The four 12-inch diameter discharge lines combine to feed a 16-inch diameter manifold which enters the bottom of the evaporator shell and is routed to banks of spray nozzles to distribute the ammonia uniformly over the evaporator tube surfaces.

Lines from the bottom of each pump barrel and from the top of each pump discharge port are provided for connection to the interfacing systems for the purpose of filling, draining, venting and purging. Again, suction can vents are also provided. During normal operation the valves at these connections are locked closed. The line from the top of each discharge port is connected with a vapor vent within the evaporator.

A pair of 36-inch diameter lines carry vapor from the evaporator to the turbine. Each of these lines contains a removable, gasketed flange, and a stop valve. Similar flanges and stop valves are provided in the turbine exhaust line. This feature is required to permit removal of either the condenser or the

evaporator from the power system without the need for complete draining and purging of the system.

2.2 SYSTEM PERFORMANCE

The range of warm and cold seawater temperatures and the corresponding evaporator and condenser operating pressures are shown in Figure 2-1. The corresponding range of ammonia flow rates (to the turbine and from the condenser) are presented in Figure 2-2. Distribution flow rates exceed those of Figure 2-2 by approximately 50%.

As is evident from Figure 2-2, both the condensate and distribution flows vary from about 60% to 110% of the design point conditions. Based on a comparative study, Reference 2-1, a flow control approach, consisting of discharge throttling near the design point and pump speed control below this flow, was selected for meeting the system requirements. This combined control approach will minimize the losses over the entire operating regime. It is noted that the design of the AVCS is based on generic site conditions, and it should be reevaluated in light of the seawater temperature history of the selected OTEC power site.

Figure 2-1 HEAT EXCHANGER OPERATING PRESSURES

OPTIMIZED FOR AVAILABLE ΔT

Figure 2-2 AMMONIA FLOW VARIATION

2.3

SYSTEM ARRANGEMENT

The system arrangement is illustrated by the condensate pump arrangement drawing (Drawing P-101, Appendix A) and the distribution pump arrangement drawing (Drawing P-102, Appendix A).

As shown on Drawing P-101 (Appendix A), the condensate pumps are located in a 20-ft diameter, 28-ft high cylindrical pump room immediately below and attached to the spherical condenser shell. The pumps are located side by side in alignment with the cylinder diameter. The elevation of the pump barrel flange is 71 ft below sea level.

A 5-ton jib crane and nearly 10 ft of overhead clearance are provided for pump and pump-motor replacement. Removed components are transported by the crane to a 10-ft diameter access tube. The access tube provides for manned access and transport of components to and from the main deck. The tube also serves to house electric cables, HVAC ducts, and lines for other services (e.g., service water, compressed air, etc.).

HVAC ducting entering and leaving the pump room is to provide six changes of air per hour. Supply ducts are pointed at each pump motor and valve motor to lessen the buildup of hazardous ammonia concentrations if leakage occurs.

Each pump room also houses a drain tank with transfer pumps for the Ammonia Unloading System and a bilge tank for storage and removal of waste water and oily wastes that are produced during the normal course of operation and maintenance. A hydraulic system that is used to actuate the large valves at the pump suction and discharge is also located in this room together with two instrument cabinets housing control equipment and transmitters.

Relative thermal expansion between the condensate piping and the pump room cylindrical shell tends to create stresses that can be imparted to the pump flanges and the heat exchanger shell. A 44F maximum temperature differential can create an .071-inch displacement in the pump suction flange and an .058-inch displacement of the pump discharge flange. A single convolution, reinforced, elastomeric expansion joint is placed near each pump suction and discharge flange in order to accommodate such movement and avoid the imposition of unwanted forces. It is expected that a deflection-stress analysis of the pump discharge lines may show that sufficient flexibility can be provided in the discharge line and manifold arrangement to avoid the need for expansion joints at the pump discharge flanges. This analysis has been deferred to the final design phase when the final line configuration will be better known.

The arrangement of the distribution pump room is the same as that of the condensate pump room except that four pumps are accommodated instead of three. This requires a pump room

diameter of 22 ft instead of 20 ft, as shown on Drawing P-102 (Appendix A).

2.4 SYSTEM COMPONENTS

2.4.1 List of AVCS Components

Condensate Pumps

Quantity:	3 (50% each)
Type:	Vertical centrifugal, multistage
Capacity:	5240 gpm
Head:	241 ft
Power:	233 shaft hp
Driver - type:	Electric motor
- speed:	1160 rpm (max. load)
Power supply:	variable frequency
Weight:	6500 lb (without motor)
Barrel Diameter:	3 ft
Height:	11 ft (without motor)

It is noted that the condensate and distribution pump designs are similar, and consequently a number of their components are interchangeable.

Condensate Pump Discharge Isolation Valves

Quantity:	3
Type:	Butterfly, stop-check
Size:	12-inch diameter
Actuation:	hydraulic

Condensate Pump Suction Isolation Valves

Quantity:	3
Type:	Butterfly
Size:	24-inch diameter
Actuation:	hydraulic

Condensate Control Valve

Quantity: 1
Type: Butterfly
Size: 12-inch diameter
Actuation: hydraulic

Distribution Pumps

Quantity: 4 (33% each)
Type: Vertical centrifugal, single stage
Capacity: 5240 gpm
Head: 75 ft
Power: 72 shaft hp
Driver - Type: Electric motor
- Speed: 1160 rpm (max. load)
Power Supply: Variable frequency
Weight: 15700 lb (without motor)
Barrel Diameter: 3 ft
Height: 7-1/2 ft (without motor)

Distribution Pump Discharge Isolation Valves

Quantity: 4
Type: Butterfly, stop-check
Size: 12-inch diameter
Actuation: hydraulic

Distribution Pump Suction Isolation Valves

Quantity: 4
Type: Butterfly
Size: 24-inch diameter
Actuation: hydraulic

Condenser/Evaporator Liquid Isolation Valve

Quantity: 2
Type: Butterfly
Size: 12-inch diameter
Actuation: hydraulic

Evaporator Vapor Isolation Valves

Quantity: 2
Type: Butterfly
Size: 36-inch diameter
Actuation: hydraulic

Distribution Control Valve

Quantity: 1
Type: Butterfly
Size: 16-inch diameter
Actuation: hydraulic

2.4.2 Failure Modes and Reliability Assessment

Ammonia Pumps Failure Modes. Failure modes of the ammonia pumps specified for OTEC may be grouped as shown in Table 2-1.

TABLE 2-1
FAILURE MODES OF AMMONIA PUMPS

<u>Cause</u>	<u>Percentage of Total Failures</u>	<u>Effects</u>
1. Vibration from:		Bearing, seal or bush- ing failure, rotor rub; failure of internal parts or support pedestals
a. Misalignment	25	
b. Unbalance	5	
c. Other	<u>5</u>	
	35	
2. Ingestion of foreign materials	10	Erosion; plugging of small passages and bushings; abrasion of bushing, shaft, and impellers
3. Miscellaneous: lubrication, flow slugging, improper operating proce- dure, liquid pulsations, corrosion, piping strain, cavitation, faulty installa- tion	35	Bearing or seal failure, thrust bearing failure, coupling failure, fatigue failures
4. Design or manufac- turing errors	20	Faulty rotor dynamics, improper clearances and fits, deficient hydraulic performance, etc. - all of which could cause failures
	<u>100%</u>	

Failure Modes of Other AVCS Equipment. Failure modes of other AVCS equipment are listed in Table 2-2.

TABLE 2-2
FAILURE MODES OF OTHER AVCS EQUIPMENT

<u>COMPONENT/EQUIPMENT</u>	<u>FAILURE MODES</u>	<u>EFFECTS</u>
Electric Drive Motors	excessive vibration	bearing failure, parts rubbing, overheating, coupling damage
	loss of lubrication	overheating, bearing failure, loss of serviceability
	electric fault	overheating, fire, loss of serviceability
Electrical Switchgear	overload	overheating, breaker open, loss of serviceability
	circuit short	loss of serviceability
	ground short	loss of serviceability
Control Valves	stem leakage	ammonia loss
	operator failure	loss of serviceability
Shutoff Valves	stem leakage	ammonia loss
	seat failure	ammonia loss, loss of function
	operator failure	loss of serviceability

Reliability Considerations. The principal pumping services are ammonia cycle condensate and ammonia distribution. The severity of these services is considered average. Accordingly, the pump design would have an ordinary degree of sophistication, with

individual pump reliabilities in excess of 98%, consistent with usual service experience using this type of equipment. The arrangement of the ammonia cycle condensate service consists of two 50% pumps plus one spare pump of the same size. For the ammonia distribution service, the arrangement consists of three 33-1/3% pumps and one identical spare. The redundancy of the spare pump results in an overall high reliability in the range between 99-100% for each service.

It is estimated that the potential availability of each pump service would surpass 98.5% based on an overhaul at three-year intervals. It is probable that plant downtime for overhaul of other components will exceed the downtime required for the pumps; therefore, no significant downtime would be actually chargeable against these pumps.

2.5 SPECIAL SUPPORT EQUIPMENT

2.5.1 Hydraulic Actuation Packages

Due to confined space and large valve sizes, air actuation appears to be impractical. Electrical motor actuators would require explosion proof motors. However, hydraulic actuation can minimize the disadvantages of the above options. It is commonly used in shipboard applications and was selected for the large valves of the AVCS. There is a hydraulic actuation package in each of the two pump rooms. Commercially available, unitized

packages containing a reservoir, hydraulic pumps, controls, and auxiliaries are used.

2.5.2 Hoisting and Transport Equipment

Each pump room is equipped with a 5-ton capacity jib crane with lift coverage extending over all pumps, discharge isolation valves, and expansion joints to provide for installation and maintenance lifts. Special transfer carts are provided for horizontal transport of major components to and from the pump rooms.

2.6 INSTRUMENTATION AND CONTROL

The operation of the AVCS must be controlled to maintain the required liquid ammonia flow for the operation of the OTEC power cycle and to maintain appropriate distribution of the liquid ammonia inventory in various parts of the system. The required control arrangement is shown on Drawing M-107 (Appendix A).

The condensate flow to the evaporator is controlled in response to the demand signal of the evaporator sump liquid level sensor. The condenser sump liquid level sensor signal is used to control the valve adding makeup ammonia at low level or the overflow valve which withdraws ammonia from the system. The flow to the evaporator spray nozzles is controlled by signals from the power system controls.

The method for controlling the condensate and distribution flows involves throttle control of the discharge flow from the maximum down to about 90% of design flow. At flow rates below this level, the control is accomplished by varying the pump speed (using frequency control of the electric current driving the pump motors). This combination of flow control methods was found to be superior to pure throttle control or pure speed control as a result of economic evaluations described in Reference 2-1.

The distribution flow to the evaporator spray nozzles is controlled by a demand signal from the module power system control room based on the turbine vapor requirement. Flow control in the distribution loop employs the same combined method as the condensate loop described above.

Special instrumentation includes pump suction and discharge pressures, pump discharge temperatures, pump vibration pickups, and a condensate flow measurement that is used as an input signal to both the main OTEC control system and the evaporator sump control system. Other instrumentation is provided for monitoring the concentration of ammonia within the pump rooms.

The pump discharge and suction valves are equipped with position indicators that connect to an interlock which prevents operation of the pump motor when the valves are closed. This measure prevents pump damage due to operation at shutoff or low-flow conditions. Other interlocks will be identified in detailed design.

Within the power module, the AVCS interfaces with the following systems:

- Power System Active Components - integrated operation of the power system
- Power System Central Control - overall control
- Ammonia Storage and Fill System - vapor and liquid for filling and liquid for makeup
- Ammonia Unloading System - drain, vent and purge function
- Ammonia Liquid Cleanup System - removal of seawater and solid reaction products
- Noncondensable Gas Removal System - elimination of noncondensable gases from the system
- Electrical System - pump drive power, startup and standby power
- Module Structures - physical support and space for the AVCS.

The AVCS also interfaces with platform-related systems. The most significant interfaces are as follows:

- The platform HVAC system provides air supply for 6 air changes per hour in each of the pump rooms.
- The platform electric distribution system provides startup power and standby power.
- The platform fire protection system provides central fire alarm and fire suppression capability.
- The platform utilities system provides potable water and sanitary waste disposal services.

Safety provisions in the AVCS pump rooms are aimed primarily at maintaining a nontoxic and nonexplosive atmosphere. This is accomplished by providing HVAC design features required by NFPA 70 (ANSI-CI) for Class I, Group D, Division 2 locations. To this end, special ventilation supply ducts are provided in the vicinity of all electric motors. The use of electric devices for valve actuation is minimized. A single hydraulic package in each pump room provides actuation power to all large valves. The allowable leakage from all valves and fittings within a pump room is specified so as to maintain nontoxic ammonia concentrations of less than 50 ppm when diluted by the six air changes supplied by the HVAC system each hour. The HVAC system is, therefore, a safety-related system which is to incorporate redundant design features for added reliability and suitable alarms to signal malfunction. The pump rooms must be evacuated upon receipt of alarms signaling malfunction of the HVAC system or high readings from the ammonia concentration monitors of the Leak Detection System.

To prevent personal injury and major economic losses due to fires and explosion, all electric motors are induction type or explosion-proof wound rotor type.

Both pump rooms are equipped with deluge type sprinkler systems and with outlets for water to wash down ammonia spills.

Section 3
SYSTEM OPERATION

3.1 SYSTEM STARTUP

The following sequence of operations accomplishes startup of the AVCS:

1. Verify that the system contains the required ammonia charge.
2. Align all valves, as shown in the System P&ID (Drawing M-107, Appendix A), and verify positions.
3. Using power from the startup ship or from an operating OTEC module, initiate startup mode operation of the seawater pumps (one warm seawater pump and one cold seawater pump).
4. Start one evaporator distribution pump. Start one condensate pump in recirculating mode.
5. Open turbine valves and allow turbine to accelerate to speed. Synchronize generator output with startup power supply.
6. Upon sufficient lowering of evaporator sump level to create a condensate flow demand signal, open condensate flow control valve.
7. When the module generator produces enough power for self-sustaining operation, switch from exterior startup power supply to module power.
8. Turn on all remaining seawater pumps, one at a time.
9. Turn on two more evaporator distribution pumps.
10. Turn on the second condensate pump.
11. Start feeding power to platform electric distribution system.

3.2 NORMAL OPERATION

During normal operation, flow demand for the distribution pumps comes from the main OTEC control system. Condensate pump flow is governed by liquid level in the evaporator sump. Inventory is varied, as required, to maintain liquid level in the condenser sump. Pumping rates are automatically controlled by means of throttling or motor speed control to maintain the required ammonia flow for the desired power level. Failure of a condensate or distribution pump automatically brings a standby pump into operation in "run" mode.

3.3 SHUTDOWN

The following sequence of operations accomplishes shutdown of the AVCS:

1. Unload the turbine/generator.
2. Shut down one of two operating condensate pumps and two of three operating distribution pumps.
3. Allow condensate flow rate to stabilize at a reduced value.
4. Shut down all seawater pumps.
5. Shut down the remaining distribution and condensate pumps.

3.4 INFREQUENT AND ABNORMAL OPERATION

Abnormal operation can occur as the result of component or control system failures. Erroneous condensate flow demand

signals can result in flooding or emptying of the evaporator sump. High and low liquid level alarms are provided, should such an event occur. Similar liquid level alarms are provided in the condenser. Failure of a distribution or condensate pump automatically brings a standby pump on line and creates no abnormal operation except for a momentary dip in flow rate. Unintended closure of a pump suction or discharge valve results in shutdown of the associated pump by means of the valve-pump motor interlock feature. In such an instance the standby pump automatically starts. The pumps are tripped on low level indication in the condenser and evaporator.

*Back-up
Blank*

Section 4

MAINTENANCE

4.1 DRY DOCK MAINTENANCE

The entire OTEC module is removed to dry dock once each three years for inspection and maintenance. Regular inspection and replacement of relatively short life items such as elastomeric expansion joints and seals occurs at this time. Pumps and valves are overhauled. Piping is inspected for weld cracks, deposits, and signs of leakage, erosion or cavitation.

4.2 OPERATIONAL MAINTENANCE

The AVCS pump rooms are equipped for removal of defective pumps and pump motors while the plant is operating. A 5-ton jib crane and nearly 10 ft of overhead clearance are provided.

Pump removal requires prior closure of suction and discharge isolation valves and the draining and purging of the pump interior until the concentration of ammonia in the purge air falls below 50 ppm.

The removal of a pump entails removal of the motor and of the rotor and discharge housing in two pieces. The pump barrel is left in place and remains connected to the suction line. The discharge nozzle flange must be disconnected to remove the top portion of the pump.

The removed sections of the pump are carried to the 10-ft diameter pump room access passage on the jib crane. The equipment is then transported by dolly or monorail along the passageway to an elevator which transports men and equipment to the main deck. There minor pump repair can be conducted. Pumps with major defects are taken ashore for repair.

REFERENCES

- 2-1 Liquid Flow Control Alternatives, 50 MWe Commercial
Plat Power Module, Conceptual Design Description
for the Ammonia Vapor and Condensate System.
OTEC Power System Development Project, subcontract
YF80C1050M

Appendix A

AMMONIA VAPOR AND CONDENSATE SYSTEM DRAWINGS

Bechtel Drawing M-102, Ammonia Vapor and Condensate
System Flow Diagram

Bechtel Drawing M-107, Ammonia Vapor and Condensate
System P&ID

Bechtel Drawing P-101, 10 MWe Power Module -
Condensate Pump Arrangement

Bechtel Drawing P-102, 10 MWe Power Module -
Distribution Pump Arrangement

A-2
C8

- NOTES
1. RELIEF VALVES THROUGHOUT. A RELIEF VALVE IS PROVIDED FOR EACH VESSEL OF AMMONIA SYSTEMS IN BEING CONSIDERED.
 2. TURN ON GENERATOR AND TURNING TO CONDENSER DURING TO BE SUPPLIED BY AMMONIA PUMP.
 3. AMMONIA PUMPED FROM STORAGE TANKS TO CONDENSER.

REVISIONS	
NO.	DESCRIPTION
1	AS SHOWN
BECHTEL SAN FRANCISCO POWER SYSTEM DEVELOPMENT LOCKHEED WILCOX & SPACE COMPANY, INC.	
PIPING AND INSTRUMENT DIAGRAM AMMONIA VAPOR AND CONDENSATE SYS TO INS POWER MODULE	
DESIGNED BY 1238-1	DRAWN BY M 107
CHECKED BY 0	APPROVED BY 0

A-3
G8

[illegible]

NOTES
1 0 FT. ELEVATION AT NOMINAL WATER
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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module
Preliminary Design Description
for
Ammonia Storage and Fill System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Ammonia Storage and Fill System (ASFS) for the 10 MWe CTEC Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of the ASFS were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The functions of the ASFS are to store the ammonia needed to fill the power system, to charge the power system with ammonia, and to supply ammonia to make up for losses.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The functions of the Ammonia Storage and Fill System (ASFS) are to:

- Receive ammonia supply from a supply ship and return contaminated ammonia to a similar receiving ship
- Provide ammonia storage for power module ammonia inventory and operational makeup reserve
- Provide means to fill the power module (or selected components of the module) with ammonia
- Supply makeup ammonia during operation on demand from the Ammonia Vapor and Condensate System.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

Storage Capacity. The ammonia inventory in the 10 MWe module during normal conditions is 120,000 lb. Tankage is to be provided for 150% of module inventory with 10% freeboard allowance. The storage volume is to be calculated for ammonia saturation conditions at ambient air temperature. Manifolded multiple tanks are to be provided to ease the installation of the large storage volume and to maintain a reasonable tank wall thickness.

Charging Capacity. Power system charging time, from 1 psia to full charge at warm soak saturation pressure, is to be less than 24 hours. The ASFS is to charge the power module with superheated ammonia vapor and with liquid. Vapor is to be admitted to the module at 50 to 85F to reduce the thermal shock hazard to the condenser or evaporator.

1.2.2 Structural Requirements

System components and piping are to be designed for 250 psig internal pressure to satisfy OSHA and U. S. Coast Guard requirements for nonrefrigerated ammonia storage. Mechanical restraints and supports are to be provided such that the system can remain operational against $\pm 0.15g$ vertical acceleration (sea state 6) and can retain leaktight integrity under $\pm 0.7g$ vertical acceleration (sea state 9). The internal surfaces are to be compatible with ammonia vapor or liquid (possibly contaminated with sea water) at typical system operating temperatures and with air at ambient temperatures (possibly contaminated with ammonia vapor). External surfaces are to be compatible with service in a marine, above seawater environment. A 30-year plant life is to be used to determine corrosion allowances.

1.2.3 System Configuration and Essential Features

The ASFS ammonia storage tanks and heat exchangers are to be located in the power module structure above seawater level. Any piping connections which will be uncoupled during operation or

maintenance are also to be located above water level. Distribution piping, that connects to components located below water level, is to be routed through a "shirt sleeve" environment.

1.2.4 Codes and Standards

Codes and standards tentatively selected for the design, construction, and operation of equipment in the ASFS are listed below. Applicability of specific code sections and the need to include additional codes will be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	<ul style="list-style-type: none">- ANSI B31.1 - 1974 Code for Power Piping- American Water Works Association Standards (seawater pipes)
Electric Motors	<ul style="list-style-type: none">- National Electric Code (NFPA 70)- NEMA Standards
Pumps	<ul style="list-style-type: none">- Hydraulic Institute Standards
Heat Exchangers	<ul style="list-style-type: none">- Tubular Exchanger Manufacturers Association (TEMA) standards
Tanks	<ul style="list-style-type: none">- ASME Code, Section VIII, unfired pressure vessels
Ammonia Properties	<ul style="list-style-type: none">- Bureau of Standards Circular No. 142. Tables of Thermodynamic Properties of Ammonia

Component/Requirement

Standard

Safety

- American National Standard for the Storage and Handling of Anhydrous Ammonia (K 61.1)
- OSHA Standards Section 1910.11, Storage and Handling of Anhydrous Ammonia
- National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the ASFS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

The control system is to provide automated control, following manual initiation, for the vapor and liquid filling operations. Data acquisition/storage, data displays, and manual control system override are to be available in filling operations. Local display and control panels are to be provided at selected locations to assist operators performing routine checkout and maintenance. Liquid makeup is to be an automatic operation.

To the extent feasible, pneumatic or hydraulic control actuators are to be used. A list of sensors and controls required for system operation and sensors to provide additional data required

by the pilot plant nature of the 10 MWe module are to be identified during detailed design.

1.2.7 Maintenance Requirements

Maintenance of the ASFS components is to be scheduled during periods of normal plant operation when the ASFS is not required. ASFS maintenance is to consist of inspections, preventive maintenance, routine refurbishing and in situ repairs. General tooling, manufacturer-provided special tools, lifting devices, and dollies are to be provided for shipboard maintenance and for replacement of defective components. The arrangement of system components is to allow space and access to perform maintenance operations and a safe path for component removal.

1.2.8 System Reliability

The ammonia storage tanks and the equipment required for operating makeup addition will be essentially in continuous service. The ammonia charging equipment will be subject to intermittent and short-duration service. Safe handling of ammonia requires that the whole system have high reliability. In addition, components in continuous service must support the targeted module availability of 90% at 60% confidence level. Where components of limited life expectancy or tendency for frequent breakdowns must be used, equipment will be derated, redundant units will be installed, or spare parts will be kept on hand.

1.2.9 Interface Requirements

The ASFS components are supported by structural members of the module platform. Wave-caused motion is transmitted to the ASFS at support points.

The interfaces with the Ammonia Vapor and Condensate System include:

- Vapor charging connection (one each) to the condenser and the evaporator
- Liquid charging connections to each of the condensate and distribution pump charging headers
- Makeup liquid connection to the condenser.

The module electrical system provides energy to power electrically operated controls and instrument transmitters.

The module ventilation system circulates air through enclosed spaces occupied by ASFS components.

1.2.10 Environmental and Safety-Related Requirements

ASFS equipment and components are located in areas normally accessible to personnel without protective clothing or breathing apparatus.

Design provisions required by OSHA for plant personnel safety are to be incorporated. In particular, the ammonia vapor

concentrations in the pump rooms are to be monitored and maintained below 50 ppm.

The ASFS is to be equipped with pressure relief devices to prevent accidental overpressuring of the system. Blowdown from relief valves is to be manifolded for safe discharge through the Ammonia Unloading System.

Warning indicators and alarm signals are to be provided by the Leak Detection System to alert plant personnel of unsafe conditions such as high ammonia concentrations, before the system is opened for maintenance.

Provisions for fire alarm and suppression are supplied by the plant fire protection system.

Relays, electric motors, and other electrical equipment are to meet NFPA requirements for enclosed spaces containing ammonia-filled equipment.

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Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

The ASFS is used to fill the power module with ammonia working fluid, using tanks, heat exchangers, and piping, as shown in the system flow diagram, Drawing M-103 (Appendix A).

Liquid ammonia is stored in a set of four cylindrical storage tanks having a total capacity of 180,000 lb (36,000 gal). The tanks are manifolded to function as two rather than four tanks. During the filling operation, two tanks are drained completely, and two are emptied of one-third their contents. The two empty tanks are then used to store ammonia which has been in use (and possibly contaminated) and is returned from the power system. The latter two tanks contain clean ammonia which is used as makeup fluid. The vapor spaces and the liquid spaces in each pair of storage tanks are interconnected so that a common liquid level is maintained. The tanks are uninsulated so the ammonia temperature tends toward the ambient air temperature, and the pressure in the vessels is the vapor pressure of ammonia at the storage temperature. The vapor pressure in the vessels provides the motive force for transferring ammonia to the power module.

Before initiating the ammonia charging operation, the power module is prepared by the Ammonia Unloading System (AUS) Vent and

Purge Subsystem by removing air from the interior of the power module and replacing it with nitrogen gas at 1.0 psia.

As seen in the Drawing M-103, the valve on the discharge line from the tanks at Station 1 is used to control the flow charging rate. As the flow passes through the flow control valve, some of the liquid flashes to vapor with the flashed fraction depending on the pressure at Station 2. When the module is being pressurized with vapor, all valves on the liquid fill line are closed, and the pressure in the evaporator, Station 2, is controlled by the valve at Station 3. The flow is completely vaporized in the evaporator using warm seawater as the heat source. The temperature of the flow downstream of the pressure-control valve depends on the module pressure at Station 3. The flow is superheated in the following heat exchanger, and the stream temperature at Station 4, just as it enters the module, is controlled constant at 50F. When the vapor pressure in the module reaches the set pressure, 89 psia, the vapor delivery train is shut off, and the remainder of the charge is loaded through the liquid delivery line. The temperature of the liquid flow into the module adjusts itself to stay in equilibrium with the vapor pressure in the module. When the liquid levels in the power module condenser and evaporator reach prescribed levels, the filling function is complete, and the ASFS is shutoff.

The ASFS also provides a flow of ammonia liquid to make up for liquid drawn off for cleanup and lost because of leakage. The makeup flow is delivered by the line at Station 5L and is

controlled by a valve in the Ammonia Vapor and Condensate System in response to a signal from a liquid level measurement in the power module condenser.

The ASFS also provides lines to fill any component which has been drained for maintenance with liquid ammonia. The component can then be returned to service.

2.2 SYSTEM PERFORMANCE

The main parameters which describe the ASFS performance are the times required for the various operations. To prepare for ASFS operation, the AUS Vent and Purge Subsystem is used to prepare the power module for loading in about ten hours. The ASFS pressurizes the power module from one to 89 psia in four hours and completes the loading with liquid in one additional hour. The total estimated time for loading is 15 hours, which is well within the 24-hour criterion given.

2.3 SYSTEM ARRANGEMENT

The ammonia storage tanks, control valves, and heat exchangers in the ASFS are located on the module structure above water level. Vapor and liquid delivery lines extend below water level to connect to the power module pumps, but disconnect joints are provided above water level. Ammonia liquid lines to the pump rooms are routed through appropriately isolated sections of the elevator and access tubes.

2.4 SYSTEM COMPONENTS

All components in the ASFS are standard commercial items. None of the equipment requires long lead times for delivery. A list of the major components is given below:

Storage Tanks

Quantity:	4
Type:	cylindrical
Dimensions - Diameter:	8 ft 6 in
Height:	25 ft
Design Pressure:	250 psig
Design Temperature:	80 F
Capacity:	40,000 lb of ammonia
Free board:	10%

Fill Evaporator

Quantity:	1
Duty:	1,600,000 Btu/hr
Type:	shell and tube
Heat transfer surface:	212 ft
Dimensions - Diameter:	1 ft 10 in
Length:	9 ft

Fill Superheater

Quantity:	1
Duty:	62,000 Btu/hr
Type:	shell and tube
Heat transfer surface:	44 ft
Dimensions - Diameter:	12 in
Length:	8 ft

2.5 SPECIAL SUPPORT EQUIPMENT

No special support equipment is required for the ASFS.

The system controls are shown in the piping and instrumentation diagram, Drawing M-108 (Appendix-A). Flow rate, pressure, and temperatures are measured and controlled during operation of the ASFS. Flow is controlled to a set rate by a valve on the liquid discharge line from the storage tanks. The flow rate is integrated to determine the amount of charge loaded. The pressure in the fill evaporator is controlled by a valve in the vapor discharge line. Vapor temperature entering the power module is controlled by a valve which regulates the liquid flow to the evaporator.

2.7

SYSTEM INTERFACES

2.7.1

Ammonia Vapor and Condensate System

Heat Exchangers. Permanent pipe connections to the turbine exhaust and evaporator vapor outlet lines are furnished for charging vapor to the power module heat exchangers. The nominal ammonia temperature at the interface point is 50F, and the pressure varies from one psia to 89 psia during the vapor charging operation with an ammonia flow rate of 11 gpm.

Pumps. Each of the three condensate pumps and the four distribution pumps is equipped with a manifolded, permanent pipe

connection for charging liquid ammonia to the power module at the lowest points in the power system piping.

At the interface, the liquid temperature is 50F, and the pressure is 89 psia, with a nominal flow rate of 400 lb/hr.

2.7.2 Ammonia Unloading System

The ASFS interface with the Ammonia Unloading System (AUS) consists of a liquid transfer connection to pumps in the liquid ammonia collection tanks. The temperature at the interface point is the same as the ambient air temperature with pressure of 153 psig and flow rate of 400 lb/hr. Additional connections with the AUS are provided for purging and venting the ASFS.

2.7.3 Compressed Air System or Hydraulic Actuation Package

Compressed air or hydraulic actuating fluid is needed to operate five control valves during the ammonia-filling operation and one pneumatic control valve during normal plant operation.

2.7.4 Ammonia Cleanup System

Warm seawater flow of 192 gpm to heat the fill evaporator and superheater is provided by the Ammonia Cleanup System.

2.7.5 Structures

The ASFS components and piping are supported by structural members of the module.

2.8 DESIGN PROVISIONS FOR SAFETY

The design of the ASFS includes no specific safety items. Since warm seawater is used to heat the ammonia, safe operating pressures are maintained even under the most adverse conditions. Nevertheless, dead-ended portions of the system and the ammonia tanks are equipped with safety relief valves which are connected to a vent manifold.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

Startup of the system consists of starting the seawater flow, setting the set-points for flow rate, pressure, and temperature, and setting the flow quantity integrator. The valves isolating the Ammonia Vapor and Condensate System and the ASFS are opened.

3.2 NORMAL OPERATION

After ASFS startup, the power module loading proceeds until the vapor pressure in the module reaches its set value and until the liquid levels in the condenser and evaporator sumps reach the set levels.

3.3 SHUTDOWN

At shutdown the vapor pressurization train is isolated from the power module by block valves, and the seawater flow is stopped. The liquid delivery line remains connected to the power module to make up for losses. Makeup delivery is automatically controlled by a signal from the liquid level sensor in the condenser.

Abnormal operations in the system are announced by alarms in the power module control room. These abnormal operations include: low level in storage tanks, loss of seawater flow, low temperature in the evaporator, and low temperature in the superheater discharge.

Section 4

MAINTENANCE

The ASFS is maintained in the periods between power module filling operations. The maintenance procedure includes: checking pump and valve seals for leak tightness, heat exchanger cleanliness, and instrumentation and control system calibrations.

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Appendix A

AMMONIA STORAGE AND FILL SYSTEM DRAWINGS

Bechtel Drawing M-103, Ammonia Storage and
Fill System Flow Diagram

Bechtel Drawing M-108, Ammonia Storage and
Fill System Piping and Instrument Diagram

STATION	(1)	(1L)	(2)	(2L)	(3)	(4)	(5L)	(5)	(7)	(8)	(9)
PRESSURE PSIA	153	53.1/07	89	95	1.0/09	1.0.09	89	□	57	60	57
TEMPERATURE °F	80	00/67	53.3	53.3	11/53.3	53.3	50	□	63	60	70
DESIGN FLOW RATE GPM	11	400		400			400	152	192	25	25
FLUID	N ₂	N ₂	N ₂	N ₂	N ₂	N ₂	N ₂	SEAWATER	SEAWATER	SEAWATER	SEAWATER
PHASE	LIQUID	LIQUID	X+.06	X+.06-.03	VAPOR	VAPOR	X+.06/.03	LIQUID	LIQUID	LIQUID	LIQUID
OPERATION DURATION HRS	4	1	4	1	4	4	4	4	4	4	4
OPERATION	PRESSURIZING	LIQUID FILLING	PRESSURIZING	LIQUID FILLING	PRESSURIZING	PRESSURIZING	LIQUID FILLING	PRESSURIZING	PRESSURIZING	PRESSURIZING	PRESSURIZING

X = QUALITY, LB-VAPOR/LB-FLUID

[illegible]

NOTES																																					
1	RELIEF VALVE SYMBOL IS SYMBOLIC, A RELIEF VALVE IS REQUIRED FOR EACH PORT ON THE AMMONIA STORAGE TANKS BY NAME CLOSING OFF																																				
2	CONNECTIONS INDICATED FOR ATTACHING A PORTABLE PUMP ARE SHOWN																																				
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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module

Preliminary Design Description

for

Noncondensable Gas Removal System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Noncondensable Gas Removal System (NCGR) for the 10 MWe OTEC Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of the NCGR were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The function of the NCGR is to remove noncondensable gases from the ammonia power cycle working fluid during power module operation in order to minimize the performance degradation in the condenser due to gas blanketing. The NCGR uses a compressor, condenser, piping, and automatic controls to perform its function.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Noncondensable Gas Removal System (NCGR) is to remove noncondensable gases from the ammonia power cycle working fluid and to discharge them to the atmosphere. Noncondensibles are present in the system following purge operations and as a result of seal gas leakage.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The NCGR is to remove the noncondensable gases from the power cycle ammonia inventory until their volumetric concentration is reduced below 0.1%. Ammonia extracted with the noncondensable gases is to be returned to the Ammonia Vapor and Condensate System. The NCGR is to be sized for an economical optimum capacity, taking into consideration the loss of generating capacity due to gas blanketing and the capital investment in the system equipment.

1.2.2 Structural Requirements

The structural design pressure for the NCGR is 250 psig. NCGR equipment is to be designed to remain operational with vertical accelerations of up to ± 1.15 (sea state 6) and is to retain the leaktight integrity of the pressure boundary with vertical accelerations of up to $\pm 1.7g$ (sea state 9). A 30-year plant life is to be used in determining allowances for corrosion.

1.2.3 System Configuration and Essential Features

The NCGR equipment is to be located on the module structure above water level. Piping to module components will be routed through a "shirt sleeve" environment.

1.2.4 Codes and Standards

A tentative selection of codes and standards for the design, construction, and operation of the equipment in the NCGR is given below. Applicability of specific sections and the need for any additional codes and standards are to be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	<ul style="list-style-type: none">- ANSI B31.1 - 1974 Code for Power Piping- American Water Works Association Standards (seawater pipes)

<u>Component/Requirement</u>	<u>Standard</u>
Electric Motors	- National Electric Code NFPA 70
	- NEMA Standards
Pumps	- Hydraulic Institute Standards
Compressors	- API Standard 618
	- Tubular Exchanger Manufacturers Association (TEMA) Standards
Tanks and Vessels	- ASME Code, Section VIII Unfired Pressure Vessels
Ammonia Properties	- Bureau of Standard Cir- cular No. 142. Tables of Thermodynamic Properties of Ammonia
Safety	- American National Stan- dard for the Storage and Handling of Anhydrous Ammonia (K 61.1)
	- OSHA Standards Section 1910.11, Storage and Handling of Anhydrous Ammonia
	- National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the NCGR are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

The control system design is to be based on manual starting and automatic control with provisions for manual override by operators in the control room. Data acquisition/storage and displays are to be provided in the plant control room. Local display and control panels are to be provided at selected locations to assist operators performing routine checkout and maintenance. To the extent feasible, pneumatic or hydraulic actuators are to be used. Sensors to provide additional data which may be required by the pilot plant nature of the 10 MWe module will be identified in the detailed design phase of this project.

1.2.7 Maintenance Requirements

Maintenance provisions of the NCGR are to be consistent with the overall maintenance plan of the power module. Maintenance of the NCGR components is to be scheduled during periods of normal plant operation when NCGR services are not required by the power module. Maintenance is to consist of inspections, preventive maintenance, routine refurbishing and in-situ repairs. General tooling, manufacturer-provided special tools, lifting devices and dollies are to be provided for shipboard maintenance and replacement of defective components. The arrangement of system components is to provide space and access to perform maintenance operations and a safe transit path for component removal.

1.2.8 System Reliability

The NCGR will be subject to intermittent and short duration service; therefore, its function is not critical to power plant availability. However, safe handling of ammonia requires that the whole system have high reliability. Where components of limited life expectancy or tendency for frequent breakdowns must be used, equipment is to be derated, redundant units are to be installed and/or spare parts are to be kept on hand.

1.2.9 Interface Requirements

The NCGR interfaces with the following systems:

- Module Condenser. The NCGR interface with the condenser consists of a piping connection to the gas scavenging system in the condenser.
- Ammonia Vapor and Condensate System (AVCS). The NCGR interface with the AVCS consists of a piping connection to return liquid ammonia to the power system.
- Ammonia Unloading System (AUS). The separated noncondensable gases are transferred to the AUS Vent and Purge Subsystem for safe disposal to the atmosphere.
- Electrical System (ES). Power for NCGR pumps and compressors is to be supplied by the ES.
- Control System. The NCGR is to interface with the control system to permit operation of the NCGR from the control room.
- Structure. The NCGR interfaces with the structure consist of equipment mountings and pipe support.

1.2.10 Environmental and Safety-Related Requirements

NCGR equipment and components are to be located in areas normally accessible to personnel without protective clothing or breathing apparatus. The NCGR is to be equipped with pressure relief devices to prevent accidental overpressuring of the system. Blowdown from relief valves is to be manifolded for safe discharge through the Ammonia Unloading System.

Warning indicators and alarms are to be provided by the Leak Detection System to alert plant personnel of unsafe conditions, such as high ammonia concentrations before the system is opened for maintenance.

Design provisions required by OSHA for plant personnel safety are to be incorporated. In particular, the ammonia vapor concentrations in enclosed compartments are to be monitored and maintained below 50 ppm.

Provisions for fire alarm and suppression are supplied by the plant fire protection system.

All motors of the NCGR which are located inside compartments having ammonia piping are to be suitable for NFPA Class 1, Group D, Division 2 installations.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

The NCGR removes noncondensable gases from the working fluid in the power system and transfers them to the AUS Vent and Purge Subsystem, using compressors, a heat exchanger and piping. The functional arrangement of the components in the NCGR is shown in Drawing M-105 (Appendix A). As shown in the diagram, a bleed line is connected from the noncondensable gas scavenging system in the power module condenser to the suction of the NCGR compressors. These compressors discharge the compressed gas-vapor mixture into a seawater-cooled gas removal condenser. Most of the ammonia from the mixture is condensed and subcooled in this heat exchanger and is returned to the ammonia vapor and condensate system for continued use. The remaining noncondensable vapors are discharged from the subcooler to the vent and purge subsystem of the Ammonia Unloading System. Two 50% capacity compressors in parallel are provided so the NCGR function is available even if one compressor fails.

2.2 SYSTEM PERFORMANCE

The main parameter which describes the NCGR system performance is the time required to complete its operation. The NCGR reduces the volumetric concentration of noncondensable gases in the power module from approximately 1% to less than 0.1% in 12 hours.

2.3 SYSTEM ARRANGEMENT

The compressors, condenser-subcooler and controls for the NCGR are located on the platform structure, above water level. The NCGR piping connects to the power module at points below water level, but all disconnect joints are above water level.

2.4 SYSTEM COMPONENTS

All components in the NCGR are standard commercial items. None of the equipment requires long lead times for delivery. A list of the major components is given below:

Compressor

Quantity:	2
Type:	reciprocating, pressurized crank case
Capacity:	85 cfm
Compression ratio:	2:1
Discharge pressure:	165 psig
Motor horsepower:	5 hp

Gas Removal Condenser

Quantity:	1
Type:	shell and tube heat exchanger
Duty:	850,000 Btu/hr
Heat transfer surface:	116 ft ²
Dimensions - Diameter:	1 ft - 8 in
Length:	4 ft - 0 in
Materials - Tubes:	titanium
Shell:	carbon steel

Seawater Pump

Quantity:	2
Type:	centrifugal
Capacity:	600 gpm
Head:	100 ft
Motor horsepower:	20 hp

2.5 SPECIAL SUPPORT EQUIPMENT

There is no special support equipment required for the NCGR.

2.6 INSTRUMENTATION AND CONTROL

As shown in the P&ID, Drawing M-110 (Appendix A), the major control point in the NCGR system is the gas removal condenser pressure which is controlled by a regulating valve on the gas discharge line to the AUS Vent and Purge Subsystem. Liquid level in the condenser-subcooler is controlled by a regulating valve in the liquid ammonia return line. The NCGR performance is monitored by measuring the noncondensable gas concentration in the vapor stream from the condenser gas scavenging system.

2.7 SYSTEM INTERFACES

The NCGR interfaces physically with the power module, with the AUS Vent and Purge Subsystem, and with the Electrical Subsystem. The interfaces with the power module are at the valves in the compressor suction line and in the liquid ammonia return line. The interface with the ammonia unloading system, vent and purge subsystem, is at the valves in the gas delivery and vent lines. The electrical system provides power for the compressors and pumps.

The NCGR system includes a safety pressure relief valve connected between the compressor discharge and suction lines. The compressor drive motors are suitable for NFPA Class I, Group D, Division 2 service. Other module systems provide ammonia monitoring, ventilation and fire protection for this system.

Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

Startup of the NCGR consists of energizing the cooling seawater pumps; opening the shutoff valves in the compressor suction lines, the gas blowoff line and the ammonia liquid return line; and energizing the compressors. The AUS Vent and Purge Subsystem exhausters are also started.

3.2 NORMAL OPERATION

After the NCGR is started, the system operates under automatic control until measurements indicate that the noncondensable gas concentration is reduced to the required level.

3.3 SHUTDOWN

After gas samples indicate that the noncondensable gas concentration is reduced to the required level, the NCGR is shut down by de-energizing the compressors, closing the shutoff valves, and de-energizing the cooling water pumps.

3.4

INFREQUENT AND ABNORMAL OPERATIONS

Abnormal operations in the system will be announced by alarms in the power module control room. These abnormal operations include: pumps not energized, compressors not energized, and high pressure in the condenser.

Section 4
MAINTENANCE

The NCGR is maintained in the periods between noncondensable gas removal operations. The maintenance procedure includes: system leak checking, equipment startup checks, and control system calibration.

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Appendix A

NONCONDENSIBLE GAS REMOVAL SYSTEM DRAWINGS

Bechtel Drawing M-105, Noncondensable Gas
Removal System Flow Diagram

Bechtel Drawing M-110, Noncondensable Gas
Removal System Piping and Instrument Diagram

A-2
G10

NOTES

1. RELIEF VALVE DESIGN IS TYPICAL. A RELIEF VALVE IS REQUIRED FOR EACH OF THE DRAINING POINTS LISTED OR BEING FOLLOWED BY.
2. CONNECTIONS PROVIDED FOR ATTACHING A GAS-HOLDING PUMP AIR LINE.

REVISION	DATE	BY	CHKD

BECHTEL
SAN FRANCISCO

PROJECT: SYSTEM
LOCATION: MODULAR GAS REMOVAL SYSTEM

PIPING AND INSTRUMENT DIAGRAM
NONCONDENSIBLE GAS REMOVAL SYSTEM
ICVW TEST MODULE

JOB NO.	DESIGN NO.	REV.
3384	M-110	0

A-3
G10

REVISIONS		DATE	
1	AS SHOWN	12/15/64	12/15/64
BECHTEL SAN FRANCISCO			
TITLE NONCONDENSABLE GAS REMOVAL SYSTEM FLOW DIAGRAM TOWNE TEST MODULE			
DESIGNED BY 12154	CHECKED BY Y-105	DRAWN BY G	DATE 12/15/64

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G10

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module

Preliminary Design Description

for

Ammonia Cleanup System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Ammonia Cleanup System (ACS) for the 10 MWe OTEC Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of the ACS were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The function of this system is to remove seawater inleakage from the ammonia working fluid. This is accomplished by withdrawing a liquid ammonia sidestream from the evaporator and purifying it in a continuous process consisting of an evaporation step and a distillation step.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Ammonia Cleanup System (ACS) is to remove seawater and residual reaction products that result from leakage of seawater into the ammonia working fluid.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The design basis seawater inleakage rate is scaled from an estimate in a previous conceptual design study report (Reference 1-1), where the rate of seawater inleakage was estimated as 1 gpm for a 25 MWe module. For the 10 MWe module, an inleakage rate of .4 gpm was established by direct ratio of the power levels. The ACS design is to be optimized to maintain water concentration in the ammonia working fluid where the loss of saleable power from the power module is at the minimum.

1.2.2 Structural Requirements

The ACS is to remain operational with $\pm 0.15g$ vertical acceleration (sea state 6) and to survive $\pm 0.7g$ vertical acceleration (sea state 9) without loss of leaktight integrity.

Materials of construction are to be compatible with ammonia (contaminated with seawater) and with seawater, where it is used as a heat exchange medium. Carbon steel, titanium-clad carbon steel and titanium are acceptable materials depending on service conditions and on the seawater concentration. The design life is to be 30 years.

1.2.3 System Configuration and Essential Features

The ACS is to be located in a "shirt sleeve" environment above the water line. Piping to the power system must be capable of being disconnected above the water line to allow removal of the evaporator or the condenser.

1.2.4 Codes and Standards

A tentative selection of codes and standards for the design, construction, and operation of the ACS is given below. Applicability of specific sections and the need for any additional standards are to be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	<ul style="list-style-type: none">- ANSI B31.1 Power Piping- American Water Works Association Standards (seawater pipes)

<u>Component/Requirement</u>	<u>Standard</u>
Electric Motors	- National Electric Code (NFPA 70)
	- NEMA Standards
Pumps	- Hydraulic Institute Standards
Compressors	- API Standard 618
Heat Exchangers	- Tubular Exchanger Manufacturers Association (TEMA) Standards
Tanks and Vessels	- ASME Code, Section VIII, Unfired Pressure Vessels
Ammonia Properties	- Bureau of Standards Circular No. 142. Tables of Thermodynamic Properties of Ammonia
Safety	- American National Standard for the Storage and Handling of Anhydrous Ammonia (K 61.1)
	- OSHA Standards Section 1910.11, Storage and Handling of Anhydrous Ammonia
	- National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the ACS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Instrument sensors for control system inputs and final control elements are to be furnished. The control system functions and command signals are to be supplied by the power module control computer.

1.2.7 Maintenance Requirements

Maintenance provisions of the ACS are to be consistent with the overall maintenance plan of the power module. Means of isolation, purging, and disassembly and for lifting and transportation are to be provided to permit maintenance of disabled components while the power module is operating. Special tooling, including lifting slings, required for maintenance of ACS equipment are to be provided. The arrangement of system components is to allow space and access to perform maintenance operations and a safe path for equipment removal.

1.2.8 System Reliability

The reliability of the ACS is to be consistent with the OTEC 90% availability requirement at 60% confidence. The ammonia cleanup system is to be available for full capacity operation any time the power system is operating. Equipment specifications and ratings are to be conservative to provide maximum durability.

1.2.9 Interface Requirements

The ACS is to have piping connections to the power system evaporator and to the ammonia storage tanks to permit reprocessing ammonia from either source. Clean ammonia vapor is to be returned to the power system condenser. The seawater pumps supply warm seawater to the evaporator and superheater of the ammonia storage and fill system. Ammonia drain and purge service to the ACS is provided by the ammonia unloading system.

Electric power for operating the ammonia cleanup system is to be supplied by the electrical system.

1.2.10 Environmental and Safety-Related Requirements

The ACS equipment is located in areas normally accessible by personnel without protective clothing or breathing apparatus.

Disposal of wastes is to be in compliance with Environmental Protection Agency regulations. The limit of ammonia discharges to natural waters is 100 lb/day for one plant. At present there are no discharge limitation for ammonia vapor.

Electrical devices are to comply with the National Fire Protection Association requirements for hazardous areas. The ACS is to be designed to prevent routine escape of ammonia to the ambient air; thus, the hazardous area classification is to be Class I, Group D, Division 2.

The ACS is to be equipped with pressure relief devices to prevent accidental overpressuring of the system. Blowdown from relief valves is to be manifolded for safe discharge through the Ammonia Unloading System.

Warning indicators and alarms are to be provided by the Leak Detection System to alert plant personnel of unsafe conditions, such as high ammonia concentration, before the system is opened up for maintenance.

Design provisions required by OSHA for plant personnel safety are to be incorporated. In particular, the ammonia vapor concentrations in the pump rooms are to be monitored and maintained below 50 ppm.

Provisions for fire alarm and suppression are supplied by the plant fire protection system.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

As shown in the flow diagram, Drawing M-106 (Appendix A), the contaminated ammonia supply to the ACS is taken from the liquid dripping off the evaporator tubes. The liquid, drawn from this point, is expected to have the highest water concentration in the power system. At the estimated seawater inleakage of .4 gpm, the liquid ammonia entering the ACS has 1-1/2% seawater. The nominal supply flow rate is 5.7 lb/sec (0.7% of the nominal power system flow rate). The ammonia liquid stream flows into the cleanup system evaporator where 97% of the ammonia is converted to vapor. The evaporator pressure is controlled at 56 psia, resulting in an equilibrium temperature of 40F. The heat for vaporization in the cleanup system evaporator is furnished by warm seawater to take advantage of this low-cost heat source.

The ammonia vapor stream from the cleanup system evaporator is compressed to 92 psia to permit its flow into the power system condenser. As a result of the compression process, the vapor temperature is increased from 40 to 112F. Some of the compression energy is used to preheat the liquid stream before entering the distillation column. The water rich ammonia (25% seawater and 75% ammonia) from the cleanup system evaporator is pumped to 92 psia (slightly greater than the 89 psia in the power system condenser), and is preheated by the compressed vapor from

40 to 80F. As a result of this preheating, 43% of the remaining ammonia flashes off. This evaporation step is added to the two-step vaporization for improved energy efficiency.

The overhead ammonia vapor stream from the distillation column is combined with the compressed vapor from the cleanup system evaporators to return it to the power system. Steam to operate the distillation column is generated by vaporizing part of the column bottoms in an electrically heated reboiler. The remainder of the effluent, which is water with very little ammonia remaining (400 ppm), is mixed with the seawater return from the cleanup system evaporator for disposal.

There are two areas of technical uncertainty to be resolved by investigation or small-scale operation. First, when seawater and ammonia are mixed, precipitates (mainly calcium carbonate and magnesium hydroxide) are formed. It is expected that these materials will form small particles and will be carried along with the liquid stream and will be removed by the ACS. There is a shortage of reported operating experience with ammonia and seawater; therefore, the actual behavior of the precipitates cannot be predicted with certainty. They may act as purely sludge-forming particles, as described above, or they may deposit on the process evaporator tubes causing tube fouling on the ammonia side. Another potential obstacle to trouble-free operation is posed by the possibility of calcium sulfate precipitation from heated seawater. The inverse solubility of calcium sulfate can cause a scaling problem. A scale inhibitor

can be added to control this problem if tests with ammonia and seawater show it to be needed.

2.2 SYSTEM PERFORMANCE

The nominal design operating condition of the ACS is described in the preceding section. The flow rate and concentration of the liquid stream entering the ACS are based on a seawater inleakage rate of .4 gpm for the power module. If the inleakage is less, as is expected when a module is new, the ACS is operated intermittently for a few hours each day. If the seawater inleakage is greater than the estimated .4 gpm, the ACS is operated continuously at capacity but the power system output will progressively decrease and eventually it must be shut down to repair the leaks.

2.3 SYSTEM ARRANGEMENT

The ACS evaporator, compressor, heat recovery evaporators, and distillation column are grouped together, forming a compact system package. This package is located in a "shirt-sleeve" environment above the water line to permit easy access for inspection and maintenance.

In addition to this main ACS equipment package, seawater pumps are used to take water from the warm seawater plenum and supply it to the ACS evaporator and to the storage and fill system. Two full-capacity pumps are used to assure continuous ACS operation.

A third, smaller capacity pump is used to supply warm seawater to the ammonia storage and fill system.

2.4 SYSTEM COMPONENTS

The ACS major equipment items are listed in Table 2-1; all items are commercially available, and none of them requires long lead time.

2.5 SPECIAL SUPPORT EQUIPMENT

Ventilation is required in the area where the ACS is located to prevent hazardous ammonia concentration buildup. This area is monitored for ammonia concentration.

2.6 INSTRUMENTATION AND CONTROL

The ACS control is accomplished using sensing and final control elements as shown in the piping and instrumentation diagram (Drawing M-111, Appendix A). Data acquisition and control mode implementation are furnished by the plant control computer. The controlled variables and the methods for controlling them, are given in Table 2-2.

TABLE 2-1

MAJOR EQUIPMENT ITEMS

Cleanup System Evaporator

Quantity:	1
Type:	shell and tube heat exchanger
Shellside fluid:	ammonia
Tubeside fluid:	warm seawater
Heat transfer surface:	2100 ft ²
Material - Tubes:	titanium
Shell:	carbon steel
Shell pressure rating:	250 psig

Heat Recovery Evaporator

Quantity:	1
Type:	shell and tube heat exchanger
Heat transfer surface:	120 ft ²
Materials - Tubes:	titanium
Shell:	carbon steel
Shell pressure rating:	250 psia

Ammonia Compressor

Quantity:	2
Type:	reciprocating, pressurized crank case
Capacity:	1200 cfm
Inlet pressure:	56 psia
Discharge pressure:	92 psia
Motor horsepower:	175 hp

Ammonia Pump

Quantity:	2
Type:	centrifugal
Flow:	2 gpm
Suction pressure:	56 psia
Discharge pressure:	92 psia
Motor horsepower:	1/2 hp

Seawater Pump

Quantity:	2
Type:	centrifugal
Capacity:	3000 gpm
Head:	100 ft
Motor horsepower:	125 hp

TABLE 2-1 (CONT'D)

Seawater Pump

Quantity:	1
Type:	centrifugal
Capacity:	250 gpm
Head:	100 ft
Motor horsepower:	10 hp

Distillation Column

Quantity:	1
Type:	packed column
Dimensions - Diameter:	5 in
- Length:	6 ft
Material:	titanium (internals)

Reboiler

Quantity:	1
Type:	electrically heated
Heater rating:	100 kW
Material:	titanium (internals)

TABLE 2-2
CONTROLLED VARIABLEES

<u>Variable</u>	<u>Control Method</u>
Sidestream bleed to cleanup system	Pressure control on cleanup system evaporator
Cleanup evaporator pressure	Pressure control valve
Cleanup evaporator liquid level	Level control valve
Reboiler liquid level	Level control valve
Compressor back-pressure	Automatic compressor bypass
Liquid effluent ammonia content	Cascade control on reboiler temperature

Transducers are used to monitor the following parameters: evaporator temperature, pressure, and liquid level; compressor backpressure and outlet temperature; distillation column inlet temperature and pressure; reboiler temperature and liquid level; liquid effluent ammonia content; seawater pump outlet pressure; and seawater discharge temperature.

2.7 SYSTEM INTERFACES

The ACS interfaces with other systems are tabulated in Table 2-3.

TABLE 2-3

AMMONIA CLEANUP SYSTEM INTERFACES

<u>System</u>	<u>Interface</u>
Power system	Sidestream liquid takeoff from evaporator, ammonia vapor return to condenser
Electrical system	Heater power, compressor power, ammonia and seawater pump power
Ammonia storage and fill system	Piping connections to withdraw liquid ammonia from storage
Ammonia unloading system	Piping connections to permit draining liquid, venting the vapor, and filling with atmospheric air
HVAC system	Ventilation air to keep ammonia concentration less than 50 ppm
Fire protection system	Fire alarm and suppression
Plant control computer	Provisions for twelve transducer inputs and four control loops

The ACS piping and vessels are designed in accordance with ANSI B31.1, Power Piping. Motors and other electrical devices comply with requirements for National Fire Protective Association hazardous area classification for Class I, Group D, Division 2.

To meet requirements for liquid effluent, the distillation column is designed to purify the liquid bottoms stream to less than 400 ppm ammonia in accord with requirements stated in Reference 2-1. This maximum limit is needed to demonstrate that a commercial OTEC power plant, consisting of eight 50 MWe power modules could be operated without exceeding the 100 lb/day discharge limit.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

The initial conditions before startup are as follows:

- Upstream from evaporator pressure control valve--vapor filled at 129 psia
- Downstream from evaporator pressure control valve--vapor filled at 89 psia
- Valve in vapor line from distillation column is closed.

The sequence of operations required to startup the ACS are as follows:

- Seawater pump is started and full flow condition is achieved.
- Ammonia vapor compressor is started.
- After evaporator pressure reaches 40 psia, liquid ammonia flow from the evaporator is started.
- After evaporator liquid reaches normal operating level, liquid pump is started.
- After distillation column pressure reaches 92 psia, valve in column vapor line is opened.
- After liquid in reboiler reaches 50% of normal operating level, column heaters are turned on, completing the startup sequence.

3.2 NORMAL OPERATION

Once the ACS is brought to nominal operating condition, as described in the preceding section, its operation is completely

automatic and requires no operator manipulation. Monitoring of the ACS process temperatures, pressures, and levels is required to be sure that the system is operating properly.

Off design operation is expected if the seawater inleakage is less than the .4 gpm estimate. In that case, the ACS is operated intermittently to remove seawater accumulation. The concentration of seawater in the working fluid is indicated by the Fluid Sampling System.

3.3 SHUTDOWN

The ACS shutdown procedure consists of shutting down the various equipment in the following order:

- Reboiler
- Ammonia flow to cleanup system evaporator
- Liquid solution pump
- Seawater flow
- Compressor.

After the shutdown sequence is completed, the valve in the vapor return line from the distillate column is closed.

3.4 INFREQUENT AND ABNORMAL OPERATIONS

3.4.1 Air Evacuation and Ammonia Vapor Fill

After maintenance of the ACS or a component (a compressor for example), air at one atmosphere pressure is present and the isolation valves to the power system are closed. The Ammonia Unloading System (Reference 3-1) is used to purge the ACS, following the sequence given below:

- The ACS is evacuated to 1 psia.
- The internal pressure is increased to 15 psia with nitrogen.
- The ACS is once again evacuated to 1 psia.

After evacuation as described above, ammonia vapor is introduced by opening the valves to the power system.

3.4.2 Ammonia Unloading

The Ammonia Unloading System is used to remove ammonia from the ACS and replace it with atmospheric air. The steps for unloading and purge are summarized as follows:

- Ammonia vapor pressure is reduced to one atmosphere by venting to a stack for safe disposal.
- The vacuum pump is used to reduce the ammonia pressure to 1 psia.
- Nitrogen is injected, increasing the pressure to one atmosphere.
- The system is vented with air until the ammonia concentration is reduced to the allowable 50 ppm concentration.

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Section 4

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

Most of the preventive maintenance for the ACS is accomplished during the scheduled annual maintenance designated as Level 5 in Reference 4-1, p. 5-13. During this shutdown period, heat exchanger tubing is cleaned and inspected, pump rotors are inspected and rebuilt if necessary, control valves are rebuilt, instrumentation transducers are cleaned and calibrated, the reboiler is cleaned of sludge and mineral deposition, and the compressors are inspected for signs of bearing and seal degradation. During the scheduled three-year maintenance periods (Level 6) the additional operations consist of replacing bearings on rotating machines and motors.

To do the work indicated for the annual and triennial scheduled maintenance periods, the ACS must have the ammonia removed and the internal volume filled with air at one atmosphere pressure, as described in Section 3.4.2.

4.2 CORRECTIVE MAINTENANCE

The ammonia compressors are two 50% capacity units. If one unit requires corrective maintenance, the ACS can continue in operation at one-half capacity while maintenance is performed on

the defective compressor. Two full-capacity liquid pumps permit maintenance without interruption of ACS operation. If corrective maintenance is needed, the ACS continues in operation while maintenance work is performed.

If a heat exchanger or the reboiler should need corrective maintenance, the ACS is valve isolated from the power system. The ammonia is unloaded and replaced with atmospheric air. After that, the ACS is disassembled to the degree necessary for maintenance work on the affected vessel.

With the ACS shut down as indicated in the previous paragraph, the seawater concentration in the module working fluid will increase, and the power system output will diminish. However, this will not require power system shutdown unless the ACS is out of service for a very long time. This would require approximately 25% seawater in the evaporator ammonia liquid, which would occur in 66 hours with seawater inleakage at the design rate of 0.4 gpm.

REFERENCES

- 1-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978 (LMSC-D566744).
- 2-1 Bechtel National, Inc., 50 MWe Commercial Plant Power Module Conceptual Design Description for Ammonia Cleanup System, San Francisco, California, September 1978.
- 3-1 Bechtel National, Inc., 10 MWe Modular Application Power Module Preliminary Design Description for Ammonia Inloading System, San Francisco, California, September 1978.
- 4-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978 (LMSC-D566744).

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Appendix A

AMMONIA CLEANUP SYSTEM DRAWINGS

Bechtel Drawing M-106, Ammonia Cleanup System
Flow Diagram

Bechtel Drawing M-111, Ammonia Cleanup System
Piping and Instrument Diagram

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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module

Preliminary Design Description

for

Ammonia Unloading System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Ammonia Unloading System (AUS) for the OTEC 10 MWe Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of the AUS were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The function of the AUS is to remove the ammonia working fluid from the power system after shutdown, and to purge and fill it with air at 1 atm to allow safe disassembly of the equipment. The AUS is also used for removing ammonia from condensate or distribution pumps to allow pump disassembly and maintenance during normal plant operation.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The functions of the Ammonia Unloading System (AUS) are to transfer the ammonia from the power system into storage tanks and to replace it with atmospheric pressure air following a nitrogen purge. These functions are available to the whole power system after shutdown, or to selected condensate and distribution pumps during normal plant operation.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

Ammonia removal and replacement with air for the complete power system is to be accomplished within a target time limit of 24 hr. Ammonia removed from the power system must be either recovered and stored, or disposed of in a safe and environmentally acceptable manner.

1.2.2 Structural Requirements

System components and piping are to be designed for 250 psig internal pressure to satisfy OSHA and U. S. Coast Guard requirements for handling and storage of unrefrigerated ammonia. Mechanical restraints and supports are to be provided such that

the system can remain operational against $\pm .15g$ vertical acceleration (sea state 6) and can retain leaktight integrity under $\pm .7g$ vertical acceleration (sea state 9). Materials for internal surfaces are to be compatible with ammonia vapor or liquid (possibly contaminated with seawater) at typical system operating temperatures and with air at atmospheric temperature (possibly contaminated with ammonia vapor). External surfaces are to be appropriate for service in an above-water, marine environment. A 30-year plant life is to be used to determine corrosion allowances.

1.2.3 System Configuration and Essential Features

Liquid drain connections are to be located at the lowest points of the power system. Connections for extracting ammonia vapor and for purge/vent are to be located above normal seawater level (if external) or in the pump rooms which have a "shirt sleeve" atmosphere. To the extent practical, the piping connections to the ammonia vapor and condensate system are to be used for ammonia charging and unloading operations.

1.2.4 Codes and Standards

Codes and standards tentatively selected for the design, construction, and operation of the AUS are listed below. Applicability of specific code sections and the need to include additional codes is to be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	<ul style="list-style-type: none"> - ANSI B31.1 - 1974 Code for Power Piping - American Water Works Association Standards (sea-water pipes)
Electric Motors	<ul style="list-style-type: none"> - National Electric Code (NFPA 70) - NEMA Standards
Pumps	<ul style="list-style-type: none"> - Hydraulic Institute Standards
Compressors	<ul style="list-style-type: none"> - API Standard 618
Heat Exchangers	<ul style="list-style-type: none"> - Tubular Exchanger Manufacturers Association (TEMA) Standards
Tanks and Vessels	<ul style="list-style-type: none"> - ASME Code, Section VIII Unfired Pressure Vessels
Ammonia Properties	<ul style="list-style-type: none"> - Bureau of Standards Circular No. 142. Tables of Thermodynamic Properties of Ammonia
Safety	<ul style="list-style-type: none"> - American National Standard for the Storage and Handling of Anhydrous Ammonia (K 61.1) - OSHA Standards Section 1910.11, Storage and Handling of Anhydrous Ammonia - National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the AUS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumental and Control Requirements

The control system is to be designed for manual operation with data acquisition/storage and displays in the control room. Local display and control panels are to be provided at selected locations to assist operators in performing routine checkout and maintenance. To the extent feasible, pneumatic or hydraulic control actuators are to be used.

1.2.7 Maintenance Requirements

Maintenance of AUS components is to be scheduled during periods of normal plant operation when the AUS is not required. Maintenance is to consist of inspections, preventive maintenance, routine refurbishing and in-situ repairs. General tooling, manufacturer-provided special tools, lifting devices and dollies are to be provided for shipboard maintenance and for replacement of defective components. The arrangement of system components is to allow space and access to perform maintenance operations and a safe path for component removal.

1.2.8 System Reliability

The AUS is not used during normal plant operation; therefore its function is not critical to power plant availability. However, the functioning of the ammonia vent and purge subsystem is important for safety of personnel; thus, its reliability must be high. Reliability of the AUS is to be assured in two ways:

- Preventative maintenance on the AUS is to be performed during periods of normal plant operation to assure that the AUS will be operable when needed.
- Rotating equipment such as pumps and compressors are to have multiple unit installations, such that in case of a single failure, unloading operations can be completed, at a slower rate, using only one unit.

1.2.9 Interface Requirements

The AUS has interface requirements with the following systems:

- Ammonia Vapor and Condensate System (AVCS). The AUS interfaces with the AVCS consist of appropriately located pipe connections to allow drainage of liquid ammonia, recovery and venting of ammonia vapor, and purging.
- Ammonia Cleanup System (ACS). The AUS is to provide venting and purging facilities for the ACS.
- Ammonia Storage and Fill System (ASFS). The AUS interfaces with the ASFS to receive and store the ammonia which is recovered from the power system, and it is to provide venting and purging facilities for the ASFS.
- Noncondensable Gas Removal System (NCGR). The AUS is to provide venting and purging facilities for the NCGR.
- Electrical System (ES). Power for the AUS pumps and compressors is supplied by the ES.
- Control System (CS). The AUS interfaces with the CS to permit operation of the AUS from the control room.
- Structure. The AUS interfaces with the structure consist of equipment mountings and pipe supports.

1.2.10 Environmental and Safety-Related Requirements

The AUS will discharge ammonia vapor into the air for short periods of time during maintenance operations. There is presently no restriction on the rate or amount of ammonia which can be dispersed into the atmosphere. However, the concentration of ammonia in the effluent must be limited to assure personnel safety, in case atmospheric conditions cause the discharge plume to remain near the platform.

All motors in the AUS, which are located inside the machinery rooms, must be suitable for NFPA Class I, Group D, Division 2 installations.

Purging of ammonia vapor must be done in a way which assures that an explosive mixture of ammonia in air (16%) is never present inside piping or vessels and that the concentration of ammonia in the air inside the system or component is less than 50 ppm at the end of the unloading and purging operation.

The AUS is to be equipped with pressure relief devices to prevent accidental overpressuring of the system. Blowdown from relief valves is to be manifolded for safe discharge.

Warning indicators and alarms are to be provided by the Leak Detection System to alert plant personnel of unsafe conditions, such as high ammonia concentrations before a power system component is opened for maintenance.

Design provisions required by OSHA for plant personnel safety are to be incorporated. In particular, the ammonia vapor concentrations in the pump rooms are to be monitored and maintained below 50 ppm.

Provisions for fire alarm and suppression are supplied by the plant fire protection system.

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Section 2

DESIGN DESCRIPTION

To remove the ammonia working fluid from the power system, the AUS is used for three distinct functions:

- Draining liquid ammonia from the power system and transferring it to storage (performed by the Ammonia Drain Subsystem)
- Recovering ammonia vapor from the power system, condensing it, and transferring the resulting liquid to storage (performed by the Ammonia Vapor Recovery Subsystem)
- Venting and purging residual ammonia vapor from the power system, leaving the system filled with air at atmospheric pressure (performed by the Ammonia Vent and Purge Subsystem).

2.1 SYSTEM CONFIGURATION

2.1.1 Ammonia Drain Subsystem

The Ammonia Drain Subsystem provides the means for draining liquids from the power system using piping, collection tanks, and transfer pumps. The Drain Subsystem transfers the collected drains to the ammonia storage tanks. The functional arrangement of the components in the subsystem is shown in Drawing M-104 (Appendix A). As shown in the flow diagram, a drain line is connected to the bottom of each condensate pump and each distribution pump, as well as at the low points of pipe lines so that all components can be drained. The drain lines are manifolded for connection to the drain collection tanks. In addition, manifolded vent lines connect the high point on each

pump to the vapor spaces in either the condenser or the evaporator, so that gravity draining is not restricted.

Due to separate pump rooms, a drain collection tank is provided for the condenser segment of the power module, and another collection tank is provided for the evaporator segment. Drain collection tanks and transfer pumps are necessary because the adverse elevation differential and the higher ammonia pressure in the storage tanks would prevent draining of the power system without low-level collection and pumping provisions.

Two parallel, 50% capacity transfer pumps are provided in each collection tank, so that the drain function is available, even if one transfer pump fails. The space in a collection tank is sufficient to store the volume of one condensate or distribution pump. When a larger volume, for example the condenser sump, is drained, the transfer pumps must be activated to transfer the excess ammonia to the storage tanks.

2.1.2 Ammonia Vapor Recovery Subsystem

The Ammonia Vapor Recovery Subsystem transfers ammonia vapor from the power system to liquid storage tanks in the ASFS using compressors, a condenser and piping. The functional arrangement of the components in the subsystem is also shown in Drawing M-104. As shown in the drawing, a vapor recovery line is connected to the condenser and evaporator vapor spaces, and to the vapor piping from the evaporator to the turbine. These

contain significant amounts of vapor to be recovered. Each recovery line connects to a header which leads to the suction of the vapor recovery compressor. The compressor discharge is condensed against cold seawater and transferred to the liquid storage. The liquid drains from the recovery condenser to the storage tanks by gravity. Two parallel, 50% capacity compressors are provided so that at least partial vapor recovery function is available, even if one compressor fails.

Ammonia vapor contained in smaller components, such as the ammonia pumps, cannot be economically recovered. Instead it is vented to the atmosphere after suitable dilution by the Vent and Purge Subsystem.

2.1.3 Ammonia Vent and Purge Subsystem

The Ammonia Vent and Purge Subsystem disperses ammonia vapor and noncondensable gases from the power module to the atmosphere using vacuum pumps, exhausters, blowers, ducting, and a stack. The functional arrangement of the components in the system is shown in Drawing M-104. As shown in the diagram, vent and purge lines are connected to every component in the power module. The vent lines connect to a header which leads to the inlets of vacuum pumps and the exhausters. Clean air, for diluting the stream before it is released to the atmosphere, is admitted to the suction ports of the exhausters. All purge lines are connected to a purge header, which supplies nitrogen from tanks or low pressure air from the blowers for the purging operations.

Two parallel, 50% capacity vacuum pumps, exhausters, and blowers are provided so that the Vent and Purge Subsystem function is available, even if one of these components fails.

2.2 SYSTEM PERFORMANCE

The main parameter which describes the Ammonia Unloading System performance is the time required for draining, vapor recovery, and purging. The target criterion given for unloading ammonia from the power module is 24 hr. The drain function, which is the first step in the unloading sequence, is completed in one hour. The subsequent vapor recovery function takes 9.5 hr. Finally, the vent and purge function requires 12 hr. The total time for the three functions of the AUS, performed on the complete power system, is 22.5 hr. Notably, the unloading of parts of the power module is accomplished in significantly less time.

2.3 SYSTEM ARRANGEMENT

2.3.1 Ammonia Drain Subsystem

The drain collection tank and transfer pumps associated with the condenser segment of the power module are located at the lowest level of the condenser pump room. The second collection tank and pair of transfer pumps are located similarly in the evaporator pump room. All drain system lines run within these pump rooms. The lines from the drain collection tanks to the ammonia storage

tanks are routed through the service shafts. The disconnect joints in these lines are located above water level.

2.3.2 Ammonia Vapor Recovery Subsystem

The compressors, vapor recovery condenser, and controls for the Ammonia Vapor Recovery Subsystem are located on the module structure above water level. All vapor recovery lines connect to the power system at locations which are above water level.

2.3.3 Ammonia Vent and Purge Subsystem

The vacuum pumps, exhausters, blowers, stack and high-pressure nitrogen storage for the Ammonia Vent and Purge Subsystem are located on the module structure above water level. Vent and purge ducting are connected to all components in the power system, including those which are below water level, but all disconnect joints are above water level.

2.4 SYSTEM COMPONENTS

All components in the AUS are standard commercial items. None of the equipment requires long lead times for delivery. A list of the major components is given below:

2.4.1 Ammonia Drain Subsystem

- Collection Tanks

Quantity:	2
Configuration:	horizontal, cylindrical
Capacity:	200 ft ³
Dimensions - Diameter:	5 ft
Length:	10 ft
Design Pressure:	250 psig
Design Temperature:	80F

- Transfer Pumps

Quantity:	4
Type:	vertical centrifugal sump
Flow:	150 gpm
Discharge Head:	100 ft
Motor Horsepower:	10 hp

2.4.2 Ammonia Vapor Recovery Subsystem

- Compressor

Quantity:	2
Type:	reciprocating, pressurized crankcase
Capacity:	75 cfm
Compression Ratio:	11:1
Discharge Pressure:	180 psig
Motor Horsepower:	40 hp

- Recovery Condenser

Quantity:	1
Type:	shell and tube heat exchanger
Duty:	1,750,000 Btu/hr
Heat Transfer Surface:	113ft ²
Dimensions - Diameter:	16 in
- Length:	6 ft

2.4.3 Ammonia Vent and Purge Subsystem

- Vacuum Pump

Quantity:	2
Type:	rotating cylinder
Capacity:	140 cfm
Vacuum capacity:	1 psia
Motor Horsepower:	10 hp

- Exhauster

Quantity:	2
Type:	low pressure centrifugal
Suction Pressure:	3 in water
Capacity:	100,000 cfm
Motor Horsepower:	100 hp

- Blower

Quantity:	2
Type:	centrifugal
Capacity:	4800 cfm
Discharge pressure:	15 in water
Motor Horsepower:	15 hp

- Stack

Dimensions - Diameter:	6 ft 8 in
- Height:	100 ft

- Nitrogen Storage Tanks

Quantity:	10
Dimensions - Diameter:	2 ft
- Length:	40 ft
Charged Pressure:	2000 psig
Capacity:	30,000 lb

2.5 SPECIAL SUPPORT EQUIPMENT

There is no special support equipment required for the AUS.

2.6 INSTRUMENTATION AND CONTROL

2.6.1 Ammonia Drain Subsystem

The drain collection tanks have liquid-level limit switches to start the transfer pumps at high level and stop them when the tanks are nearly empty. The operating status of the pumps is indicated in the module control room. There are no automatic flow rate, temperature or pressure controls on the Ammonia Drain Subsystem. All valves are manually operated.

2.6.2 Ammonia Vapor Recovery Subsystem

The major control point in the Ammonia Vapor Recovery Subsystem is the recovery condenser pressure which is controlled by a pressure relief valve connected between the compressor discharge and suction lines.

2.6.3 Ammonia Vent and Purge Subsystem

The major control point in the Ammonia Vent and Purge subsystem is the ammonia concentration of the stack gas, which is controlled by regulating the rate of ammonia addition to the dilution air stream. This is done by manually adjusting louvers in the blower outlets or by manipulation of the vacuum pumps. The flow from the high-pressure nitrogen storage is controlled by an automatic pressure regulating valve. There are no flow controls on the vacuum pumps and exhausters. All other valves in

the system are for shutoff only, and they are manually operated. The system instrumentation includes pressure gages on the nitrogen gas storage and discharge line, and an instrument to measure stack gas ammonia concentration. There is no temperature or flow instrumentation.

2.7 SYSTEM INTERFACES

2.7.1 Ammonia Drain Subsystem

The Ammonia Drain Subsystem interfaces physically with the power system at the component drain shutoff valves.

2.7.2 Ammonia Vapor Recovery System

The Ammonia Vapor Recovery Subsystem interfaces physically with the power system and the Ammonia Storage and Fill System. The interface with the Ammonia Storage and Fill System is at a valve in the delivery line to the liquid-holding tanks. The interfaces with the power system are at the valves in each vapor recovery line.

2.7.3 Ammonia Vent and Purge Subsystem

The Ammonia Vent and Purge Subsystem interfaces physically with the power system at valves in the purge and vent lines to each component.

Design safety provisions for the AUS include the following:

- A safety pressure relief valve, connected between the compressor discharge and suction lines, for the Ammonia Vapor Recovery Subsystem
- A safety pressure relief valve on the discharge line of the nitrogen supply for the Ammonia Vent and Purge Subsystem.

Section 3

SYSTEM OPERATION

3.1 AMMONIA DRAIN SUBSYSTEM

Startup of the Ammonia Drain Subsystem consists of opening the pressure equalizing vent lines followed by opening the drain valves from the component to be drained. The liquid drains from the component by gravity, and the transfer pumps operate automatically when the liquid-level limit switches in the collection tanks are tripped. The operation continues until the selected component is drained, and the transfer pumps are stopped by the low level limit switch. After the drain operation is completed and the transfer pumps are de-energized, the drain and vent valves are closed.

3.2 VAPOR RECOVERY SUBSYSTEM

Startup of the Vapor Recovery Subsystem consists of starting the cooling seawater flow, manually opening valves in the line to the storage tanks and in the vapor recovery line from the components in the power module, and energizing the compressors. The compressors run until the suction pressure is reduced to 15 psia. The compressors are then stopped completing the vapor recovery operation. The vapor recovery line isolation valves are closed, and the cooling seawater flow is discontinued. The condenser well drains to storage by gravity, and then the valve in the drain line is closed.

Startup of the Vent and Purge Subsystem consists of energizing the vacuum pumps, blowers and exhausters, as required, and manually operating shutoff valves in the vent and purge ducting. The first of three vent and purge steps consists of using the vacuum pumps to evacuate the power system to 1 psia. The ammonia vapor withdrawn by the vacuum pumps is mixed with a stream of dilution air entering the exhausters. The combined stream is vented through the stack for safe discharge of the ammonia. After the power system internal pressure reaches 1 psia, the vent valves are closed, and the vacuum pumps are shut off. During the second step, nitrogen is admitted to the power system until the internal pressure is 15 psia. The nitrogen flow is then discontinued.

The final vent and purge step consists of venting the power system internals with air using the blowers and exhausters. With the exhausters operating, the vent valves are opened, and the blowers are started. The stream of ammonia vapor, nitrogen and air from the power system is mixed with dilution air before disposal through the stack. After the stack gas ammonia concentration measurement indicates that the power system interior contains a safe ammonia concentration, the blowers and exhausters are shut off.

Abnormal operations in the AUS are announced by alarms in the power module control room. These abnormal operations include: high ammonia concentration in the stack, pumps not energized, and high temperature in the condenser.

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Section 4

MAINTENANCE

Maintenance work on the AUS is done during the periods between power system unloading operations. The checking and maintenance consist of the following operations:

- Ammonia Drain Subsystem. Check pump and valve seals for leaktightness and check the liquid level controls for proper operation.
- Ammonia Vapor Recovery Subsystem. Check subsystem for leaks and perform equipment startup checks.
- Ammonia Vent and Purge Subsystem. Perform equipment startup checks.

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Appendix A

AMMONIA UNLOADING SYSTEM DRAWINGS

Bechtel Drawing M-104, Ammonia Unloading System
Flow Diagram

Bechtel Drawing M-109, Ammonia Unloading System
Piping and Instrument Diagram

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OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module

Preliminary Design Description

for

Leak Detection System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Leak Detection System (LDS) for the 10 MWe OTEC Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of the LDS were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The function of this system is to detect ammonia leakage to air by continuous monitoring and alarming at three potentially dangerous ammonia concentration levels: industrial exposure level, lethal concentration, and explosive concentration. The first and second levels are monitored by infrared analyzers, and the third is measured by a combustible gas detection system.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The function of the Leak Detection System (LDS) is to detect and record the presence of ammonia in the air, occupying various enclosures of the power module, and to provide alarm signals at critical levels of concentrations.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The LDS is to continuously monitor and record the concentrations of ammonia in room air at various locations in a power system module. Sensors are to cover the concentration range from about 10 ppm to the lower explosive limit. Alarm signals are to be provided with location indication to the module control computer at the following concentration levels:

- Industrial exposure level
(50 ppm for 8 hour exposure)
- Lethal concentration
(1700 ppm for 1/2 hour exposure)
- Explosive concentration
(lower explosive limit--16%).

1.2.2 Structural Requirements

The system piping and components are to be designed to remain operational with vertical accelerations of $\pm 0.15g$ (sea state 6) and to retain the integrity of the pressure boundary (and survive) with vertical accelerations of $\pm 0.7g$ (sea state 9).

1.2.3 System Configuration and Essential Features

Ammonia detection sensors are to be located and permanently installed in various compartments in a power system module, including the following:

- Condensate pump room
- Distribution pump room
- Control room
- Auxiliary machinery room
- Auxiliary pipe chase
- Elevator shafts and access tubes.

In addition, portable detectors are to be provided for local monitoring during maintenance operations and leak tracing. Portable detectors are to provide local alarm signals.

1.2.4 Codes and Standards

A tentative selection of codes and standards for the design, construction and operation of the AVCS is given below.

Applicability of specific sections and the need for any additional standards are to be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	- ANS B31.1 - 1974 Code for Power Piping
Electric Motors	- National Electric Code NFPA 70 - NEMA Standards
Ammonia Properties	- Bureau of Standards Circular No. 142. Tables of Thermodynamic Properties of Ammonia
Safety	- American National Standard for the Storage and Handling of Anhydrous Ammonia (K 61.1) - OSHA Standards Section 1910.11, Storage and Handling of Anhydrous Ammonia - National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the LDS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Does not apply.

1.2.7 Maintenance Requirements

Maintenance provisions of the LDS are to be consistent with the overall maintenance plan for the power module. Tooling is to be available for in-situ maintenance and for replacement of defective components. The LDS equipment is to be accessible for calibration and corrective maintenance without disrupting the power system operation.

1.2.8 System Reliability

The LDS is to be functioning at all times when ammonia is present. The required high system reliability may be achieved either by stocking enough spare units for quick changeout or by redundant installations.

1.2.9 Interface Requirements

The LDS is to be supplied with uninterruptable electric power, and it is to transmit measurement signals to the module control computer.

1.2.10 Environmental and Safety Related Requirements

The LDS electrical equipment is to be approved for use in Class I, Group D, Division 2 hazardous locations.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

2.1.1 Industrial Exposure Level and Lethal Concentration

Infrared analyzers are used to measure ammonia concentration in air at breathing hazard levels. This type analyzer is commonly used in industrial environments for monitoring a single potentially harmful vapor. An infrared analyzer operates by comparing the infrared absorption of a sampled gas with that of a reference cell. The sampled gas flows continuously through the analyzer, and the analyzer produces a continuous output signal. Changes in ammonia concentration are indicated (90% response) typically within 5 sec. Numerous output voltage and current options are available. A complete analyzer typically weighs 100 lb.

2.1.2 Explosive Concentration

A combustible gas detection system is specified for monitoring ammonia vapor in air at potentially explosive concentrations. The combustible component in the air is burned by a heated catalytic cell, and a temperature rise in the cell is sensed by a bridge circuit producing a continuous dc output signal proportional to the percent of lower explosive level present in the

air. The combustible gas detection system in an enclosure for Class I, Group D, Division 2 service measures 17 x 14 x 10 in.

2.2 SYSTEM PERFORMANCE

Each detector system specified for the LDS has an electrical output proportional to the concentration of ammonia in air. The detector output signals are used as inputs to the power module control computer for recording and alarm functions. The concentration signals for the industrial exposure level measurements are recorded to provide permanent personnel exposure records. Any concentration which exceeds a preselected value triggers a warning alarm in both the control room and the module compartment where the high concentration is detected.

2.3 SYSTEM ARRANGEMENT

The locations and number of LDS detectors are given in Table 2-1 below:

TABLE 2-1

LOCATIONS OF LEAK DETECTION SYSTEM DETECTORS

<u>Location</u>	<u>Industrial Exposure Level</u>	<u>Number of Detectors</u>	
		<u>Lethal Concentration</u>	<u>Explosive Concentration</u>
Condensate pump room	2	1	1
Distribution pump room	2	1	1
Control room	1		
Auxiliary machinery room	1		
Auxiliary ammonia systems deck	2	2	2
Auxiliary pipe chase	1	1	1
Elevator shaft and access tubes	1	1	1

2.4 SYSTEM COMPONENTS

The major equipment items for the IDS are given in Table 2-2. None of this equipment requires long leadtime, and all items are commercially available.

TABLE 2-2
SYSTEM COMPONENTS

<u>Description</u>	<u>No. Required</u>
Infrared ammonia analyzer 0-300 ppm	10
Infrared ammonia analyzer 0-3000 ppm	6
Combustible gas detection system	6

2.5 SPECIAL SUPPORT EQUIPMENT

None Required.

2.6 INSTRUMENTATION AND CONTROL

None required.

2.7 SYSTEM INTERFACES

TABLE 2-3
LEAK DETECTION SYSTEM INTERFACES

<u>System</u>	<u>Interface description</u>
Electric	Requires 115 vac, 60 Hz, 7 kW
Module control computer	Receives 22 electrical input signals
Module control computer	Records 22 signal inputs and alarms for 12 inputs

2.8

DESIGN PROVISIONS FOR SAFETY

The LDS components are designed to meet the requirements for Class I, Group D, Division 2 hazards.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP, NORMAL OPERATION AND SHUTDOWN

For the LDS, the startup and shutdown procedures consist of simply turning on and off the electrical power to each unit. Once energized, the LDS equipment operates automatically. Each sensing unit generates a continuous signal and transmits a proportional dc signal voltage to the module control computer.

3.2 INFREQUENT AND ABNORMAL OPERATIONS

The LDS analyzers and detectors require annual calibration.

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Section 4

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

The LDS preventive maintenance schedule is compatible with the Level 5 (Reference 4-1, pp. 5-13) schedule for the power system. Annual inspection, test, repair, and calibration work is performed. However, rather than do this work during the scheduled shutdown, it is started immediately following resumption of power generation. By using one spare unit of each type, the LDS monitors are sequentially replaced and serviced.

In addition to the annual preventive maintenance, the combustible gas detection system catalytic burner units are replaced once every three years.

4.2 CORRECTIVE MAINTENANCE

If one of the ammonia-in-air monitoring units should fail in service, it is removed and replaced with a spare unit. This is done in less than an hour. The nonfunctioning unit is then taken to an instrument repair area or to shore for repair.

REFERENCES

- 1-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978, (LMSC-D566744)
- 4-1 Ibid.

OTEC POWER SYSTEM DEVELOPMENT PROJECT

Subcontract YF80C1050M

10 MWe Modular Application Power Module

Preliminary Design Description

for

Fluid Sampling System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Fluid Sampling System (FSS) for the 10 MWe OTEC Modular Application Power System. It reflects the system definition after completion of the preliminary design of the OTEC Power System Development Program, Phase I, Task 2. The design is based on generic site conditions and was prepared to serve as a basis for the Phase II detailed design effort of the Power System Development Program. Significant features of the FSS were derived from, and are analogous to, the 50 MWe OTEC commercial power plant conceptual design also developed during the above Task 2 effort.

The functions of this system are to measure seawater or impurity concentration in liquid ammonia and to measure noncondensable gas concentration in ammonia vapor. The results of analyses of liquid and gas phase constituents are used to determine the need for operating the ammonia cleanup or the noncondensable gas removal system, respectively.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The Fluid Sampling System (FSS) has the following functions:

- Measure seawater concentration in the liquid ammonia in the evaporator
- Measure concentration of noncondensable gas in the condenser ammonia vapor
- Withdraw liquid and gaseous ammonia samples from the power cycle for wet chemistry or other chemical analyses to determine all constituents in both phases.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

Seawater Concentration. The nominal concentration is 1% seawater in saturated ammonia liquid at 70F (129 psia). The measurement system is to have adequate sensitivity over a range of 0.1 to 10% seawater in ammonia.

Noncondensable Gas Concentration. The maximum concentration of noncondensable gases in the condenser is 2% with normal concentration being 0.1%. The measurement system is to have adequate sensitivity over a range of 0.05 to 20% noncondensibles in ammonia vapor.

1.2.2 Structural Requirements

The FSS is to operate with vertical acceleration of $\pm 0.15g$, and it is to survive $\pm 0.7g$ vertical acceleration with no permanent damage.

The liquid ammonia is at pressures from 129 to 156 psia with temperatures from 53 to 59 F depending on operating conditions. The ammonia vapor is at pressures from 86 to 93 psia with temperatures from 48 to 52 F. The measuring units are to function at these conditions, or sample conditioning systems are to be provided to establish pressures and temperatures compatible with the measuring units.

1.2.3 System Configuration and Essential Features

The seawater concentration is to be measured directly in the evaporator sump or with samples taken from that region. The noncondensable gas concentration is to be measured in the condenser vapor space or in samples taken from the noncondensable gas scavenging header. The measuring instruments are to generate continuous output signals for recording and control purposes. Connections for withdrawing liquid and vapor samples for wet chemistry are to be provided near the respective measuring points.

1.2.4 Codes and Standards

A tentative selection of codes and standards for the design, construction, and operation of the FSS is given below. Applicability of specific sections and the need for any additional standards are to be evaluated during detailed design.

<u>Component/Requirement</u>	<u>Standard</u>
Piping	- ANSI B31.1 - 1974 Code for Power Piping
Electric Motors	- National Electric Code (NFPA 70) - NEMA Standards
Pumps	- Hydraulic Institute Standards
Ammonia Properties	- Bureau of Standards Circular No. 142. Tables of Thermodynamic Properties of Ammonia
Safety	- American National Standard for the Storage and Handling of Anhydrous Ammonia (K 61.1) - OSHA Standards, Section 1910.11, Storage and Handling of Anhydrous Ammonia - National Fire Protection Association Rules and Practices

1.2.5 Level of Technology

Components for the FSS are to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

Does not apply.

1.2.7 Maintenance Requirements

Maintenance provisions for the FSS are to be consistent with the overall maintenance plan of the power module. General and manufacturer-provided special tooling is to be available for in-situ maintenance and for replacement of defective parts. The FSS equipment is to be accessible for corrective maintenance and calibration without disrupting the power system operation.

1.2.8 System Reliability

The FSS is to be in operation any time the plant is operating, but it is not essential for plant functioning. Therefore, short outages of up to 2-hr duration can be tolerated for component repair or replacement.

1.2.9 Interface Requirements

The FSS is to be supplied with electric power, and it is to transmit measurement signals to the module control computer.

1.2.10 Environmental and Safety-Related Requirements

The FSS electrical equipment is to be approved for use in Class I, Group D, Division 2 hazardous locations.

Section 2
DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

2.1.1 Seawater Concentration

Seawater concentration in liquid ammonia is measured with an electrical conductivity cell installed in the ammonia distribution pump discharge manifold. The cell is cable-connected to a conductivity converter which in turn transmits an electrical, dc signal to the module control computer for recording and control. The electrical conductivity cell and converter are commercially available.

2.1.2 Noncondensable Gas Concentration

The noncondensable gas concentration is measured with a thermal conductivity (TC) cell. To accomplish the measurement, a small stream of vapor is bled from the noncondensable gas scavenging header, passed through the TC cell, and vented to the stack. The sample stream has a flow rate of 100 cm³/min, which is less than 100 lb/year of ammonia vented to the atmosphere. The TC cell is electrically connected to a readout unit which produces a continuous electrical, dc signal for recording and control use. The thermal conductivity cell and readout unit are commercially available.

2.2 SYSTEM PERFORMANCE

Each of the measurement devices for the FSS generates a continuous electrical output signal indicating concentration. These signals are used as inputs to the power module control computer for recording and control purposes. In addition to the operating unit, a complete unit is kept in the spare parts inventory for both the seawater and noncondensibles measuring systems to assure continuity of service in the event of equipment failure.

2.3 SYSTEM ARRANGEMENT

The seawater-in-ammonia measuring probe is installed in the distribution pump discharge line located in the machinery room beneath the evaporator. The signal converter is located nearby in the same room. The noncondensable gas measuring cell and its readout package are located above the condenser near the noncondensable gas scavenging header.

2.4 SYSTEM COMPONENTS

The major equipment items for the FSS are given in Table 2-1. All of the equipment is commercially available, and none of it requires long lead time.

TABLE 2-1
SYSTEM COMPONENTS

<u>Description</u>	<u>No. Required</u>
Electrical conductivity cell and converter	2
Thermal conductivity cell and readout	2

2.5 SPECIAL SUPPORT EQUIPMENT

None required.

2.6 INSTRUMENTATION AND CONTROL

None required.

2.7 SYSTEM INTERFACES

TABLE 2-2
FLUID SAMPLING SYSTEM INTERFACES

<u>System</u>	<u>Interface Description</u>
Ammonia vapor and condensate	Requires tap for installing electrical conductivity cell in distribution pump discharge line
	Requires bleed tap for thermal conductivity cell in noncondensable gas scavenging header outlet
Electrical	Requires 115V ac, 60 Hz, 200 W
Module control computer	Receives and processes 2 electrical input signals

2.8

DESIGN PROVISIONS FOR SAFETY

The FSS components are designed to meet requirements for Class I, Group D, Division 2.

Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP, NORMAL OPERATION, AND SHUTDOWN

For the FSS the startup and shutdown procedures consist of simply turning on and off the electrical power to each unit. Once energized, the FSS operates automatically. The measuring devices produce continuous output signals for transmission to the module control computer.

3.2 INFREQUENT AND ABNORMAL OPERATIONS

The FSS measuring equipment requires annual calibration.

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Section 4

MAINTENANCE

4.1 PREVENTIVE MAINTENANCE

The FSS preventive maintenance schedule is compatible with the Level 5 (Reference 4-1, p. 5-13) schedule for the power system. Annual inspection, test, repair, and calibration work is performed during the time that the power system is down for routine annual maintenance.

4.2 CORRECTIVE MAINTENANCE

Either of the two measuring units in the FSS can be shut down and removed without interrupting the power system operation. A defective unit can be repaired or replaced, as necessary, for corrective maintenance.

REFERENCES

- 1-1 Lockheed Missiles and Space Company, Ocean Thermal Energy Conversion (OTEC) Power System Development Conceptual Design, Sunnyvale, California, January 1978, (LMSC-D566744)
- 4-1 Ibid.

Appendix G15

FIRE SUPPRESSION SYSTEM

The fire suppression system on the power system module has been designed following best state of the art of marine commercial practice, incorporating methods used at sea on hazardous explosive cargos, and in accordance with the latest requirements of the applicable regulatory agencies. Information and advice supplied by Chemetron Fire Systems has been used to develop a cost effective system offering maximum safety for the operating personnel and the power system itself.

The primary fire suppression medium is a low pressure CO₂ flooding system, arranged for multiple hazard control and supplied with a dual charge for redundancy. Use of a CO₂-based fire control system provides maximum protection for the large amount of electrical equipment in the power system module. In addition, low pressure CO₂ provides an easy and convenient method for recharging the system, as it can be pumped aboard in bulk, eliminating the handling and weighing of numerous individual high pressure cylinders. Finally, CO₂ was chosen over Halon for the fire control system as being more cost effective and providing a greater abundance of supply sources.

Low pressure CO₂ storage tanks are located on the weather decks of each half of the upper machinery space. Each tank has been sized to provide two full charges of CO₂ for all spaces protected by that subsystem. The protected areas for the evaporator side include the upper machinery area and the lower Machinery Room. The protected areas on the condenser side are the Control Room, the transformer and switchgear area, and the lower Machinery Room. The systems are designed for automatic operation, with manual overrides both for CO₂ release and prevention of CO₂ release. The system fire detectors are arranged to be redundant. When a fire is detected and confirmed an alarm sounds to alert personnel to evacuate the danger zone prior to the delayed release of CO₂. Delays can be selected separately for each compartment protected. The system shuts down ventilation to the fire area and feeds its location into the DACS/Alarm System as well as its own master control panel, located in the

Control Room. As already stated, multiple fires can be suppressed simultaneously, and a 100% backup reserve capacity is included in the storage tanks, capable of instantaneous release on demand should the fire start anew. The arrangement of the fire suppression system may be seen in LMSC Dwg. 5531932. (APPEN. B)

Appendix G16

AMMONIA WASHDOWN SYSTEM

OTEC power plants using ammonia cycles must make provision for ammonia dilution systems, as ammonia is a poisonous gas which can form explosive and lethal mixtures in the atmosphere in the event of a leak in the working fluid system. Ammonia gas being highly soluble in water, a high density water spray system can reduce the level of free ammonia in the atmosphere to acceptable levels very quickly. Consequently, fresh water was chosen as the primary washdown medium. A fresh water dilution system also offers the additional advantage of minimizing cleanup problems after an emergency. Finally, the fresh water system can also serve as a supplemental means of fire suppression, in addition to the primary low pressure CO₂ system described in Appendix F-19, in those areas with little or no electrical equipment where water does not itself represent a danger during fire suppression.

The ammonia washdown system consists of two large, pressurized, weather deck-mounted fresh water storage tanks which feed a system of sprinkler heads distributed in appropriate areas of the power module. Pressure is supplied to the tanks from the platform air system; in the event of loss of air pressure, the head of water available between the storage tanks and the sprinkler heads will still permit a washdown deluge. In addition, a seachest seawater supply is available in each lower Machinery Room providing further ammonia washdown redundancy for those spaces. The system is zoned so that individual areas can be washed down by tripping the appropriate electrically actuated valves; simultaneous washdown capability for any combination of areas is provided by the system. Manual override is available on all valves. The arrangement of the washdown/deluge system may be found in LMSC Dwg. 5531932 (see Appendix B).

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Appendix G17
PERSONNEL WASHDOWN

In addition to the dangers of ammonia vapor in the atmosphere, the liquid is irritating to the skin, as are concentrated vapors. In the event that a major spill should involve direct contact with operating personnel, some means should be available for dissipating the ammonia rapidly.

This purpose is served by use of standard commercial shower/eyewash stations located appropriately. There is one located near the archway leading out of each Machinery Room below, one by the top of each access trunk and one additional at the opposite end of the upper machinery space from the access trunk. These units are equipped for foot and hand operation as found in modern chemical plants today. In addition, hose reels are located adjacent to each eyewash/shower station to facilitate additional washdown of personnel or equipment as required.

The arrangement of the eyewash/shower system may be found in LMSC Dw. 5531932.

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Appendix G18

HEATING, VENTILATION AND AIR CONDITIONING (HVAC)

Modern industrial practice is to provide a large amount of conditioned air throughout the plant, to increase operator efficiency and comfort.

There is no firm rationale for LMSC to provide an air conditioning plant on the PSM. The platform is required to furnish a specific quantity and quality of clean, dry, cool air for the LMSC PSM. The ducting system will distribute the air primarily to areas of heat producing equipment, such as the electronics and electrical switch gear and transformers, and pumps and compressors. Areas where operating personnel will spend considerable time are identified and treated accordingly. All areas are furnished with pressure positive ventilation.

The Control Room and electrical switch gear space on the evaporator side of the PSM are supplied with cooled conditioned air, with a natural exhaust to the atmosphere. Fire dampers are installed to deal with emergencies. The upper Machinery Space on the condenser side of the PSM is spot cooled in way of heat producers and operating locations, with natural exhaust to the atmosphere and fire dampers as necessary. The ducting for the lower Machinery Rooms has a booster fan installed to insure positive ventilation. The ducting penetrates the watertight/fumetight bulkhead into a Access Compartment, via a watertight damper. Supply air only is ducted down the Access Trunks to the Machinery Rooms. Return air flows naturally up the Access Trunk to a natural exhaust in the roof of the Access Compartment.

The ventilation system fans are tied into the fire and ammonia alarm systems for shut down in an emergency, which gives maximum safety for both the operating personnel and the plant itself. The audio alerts will distinguish the nature of the hazard to insure that proper steps are taken to deal with the emergency.