OCEAN THERMAL ENERGY CONVERSION POWER SYSTEM
DEVELOPMENT— I. PRELIMINARY DESIGN REPORT

Phase I—Final Report

Volume 5. Appendixes H, I, J, and K

MASTER

December 18, 1978

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

Lockheed Missiles & Space Company, Inc.
Ocean Systems
Sunnyvale, California

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

PRELIMINARY DESIGN REPORT – VOLUME V
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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Printed in the United States of America

Available From

National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22161

Prices:

Document	Printed Copy	Microfiche
Final Report	\$ 4.50	\$3.00
Conceptual Design Report	9.00	3.00
Preliminary Design Report		
Volume I	11.75	3.00
Volume II	10.75	3.00
Volume III	8.00	3.00
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OCEAN THERMAL ENERGY CONVERSION POWER SYSTEM DEVELOPMENT-I PRELIMINARY DESIGN REPORT

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APPENDIXES H, I, J, AND K
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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 H

ELECTRICAL SYSTEM

- H.1 50 MWe Commercial Plant Power Module Conceptual
Design Description for Electrical System
- H.2 10 MWe Modular Application Power Module
Preliminary Design Description for
Electrical System

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OTEC Power System Development Project
Subcontract YF80C1050M

Appendix H1

50 MWe Commercial Plant Power Module
Conceptual Design Description
for
Electrical 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 Electrical System (ES) for a 50 MWe OTEC commercial power plant 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 ES provides distribution of electric power needed to operate the commercial power module and furnishes connections to the platform electric power distribution system. Normal ac, standby ac, and emergency dc power are provided to the module.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The functions of the module Electrical System (ES) are as follows:

- Distribute power within the power module
- Provide emergency power for control and instrumentation, turbine auxiliaries, and emergency lighting
- Provide interface with the platform standby and startup power systems
- Connect the module electrical system to the platform distribution system.

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The module ES is to provide adequate, safe, reliable, and efficient power for a power module in the following modes of operation:

- Startup
- Normal
- Standby
- Emergency.

1.2.2 Structural Requirements

The electrical equipment items are to be installed in accordance with the general requirements for shipboard electric installation as specified in IEEE-45 (Ref. 1-1), including the following requirements:

- Momentary 30 degrees roll, and 10 degrees pitch and permanent inclination of 15 degrees.
- Continuous exposure to severe moisture, salt-laden atmosphere, and high wind velocity.

The system is to remain operational with vertical accelerations of $\pm 0.15g$ (sea state 6) and to survive vertical accelerations of $\pm 0.7g$ (sea state 9).

1.2.3 System Configuration and Essential Features

In general, switchgear, transformers, load centers, and motor control centers are to be located in ammonia-free areas and are to be suitable for marine service. The use of oil-immersed equipment within the module is to be limited.

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

The equipment for the ES is to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

The instrumentation and control for the electrical system is to be consistent with module computer control, with additional local start-stop control stations provided for individual motors.

1.2.7 Maintenance Requirements

Maintenance requirements of the ES are to be consistent with the maintenance plan established for the power module. 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 reliability of the ES is to be consistent with the OTEC 90% availability (at 60% confidence) requirement. Standby and emergency power sources are to be provided to assure operating continuity of vital or safety-related functions in the event of failure of the normal power source.

1.2.9 Interface Requirements

The module electrical system is to interface functionally and physically with the platform electrical system in the following areas:

- 115 kV connection to the module main transformer
- 4.16 kV connection to the module buses for startup power
- 480 V standby power connection
- 480 V normal power connection
- System grounding requirements for 4.16 kV startup power, and 480 V standby power
- Protective relaying.

The symmetrical interrupting capacity, current and voltage rating of the platform electrical system and the module ES are to be of the same ratings at the interface points.

1.2.10 Environmental and Safety-Related Requirements

Areas within the module are to be classified in accordance with the degree of hazard involved. Electrical equipment located in areas with ammonia containing equipment are to be classified as Class I, Group D, Division 2. Electrical equipment of the ventilation system serving hazardous areas is to be treated as safety related. A high resistance grounding system is to be employed to limit ground current and to limit shock hazards.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

The block diagram of the ES is shown in Drawing E-502 (Appendix A), and the module electrical system is shown in the plant electrical single line diagram, Drawing E-503 (Appendix A). The diagram is shown for variable frequency drive control for the seawater and power system ammonia pumps.

2.1.1 Medium Voltage Switchgear

The switchgear employed in the design are vacuum-type metal-clad switchgear. Feeder breakers are arranged in a two-high arrangement. This design is space-effective considering the number of breakers required for the system.

2.1.2 Variable Frequency Pump Drives

The design incorporates the latest available industrial variable frequency pump drive. This approach is adopted to implement the mixed-mode flow control by allowing pump speed control for:

- Cold seawater pumps
- Warm seawater pumps
- Ammonia condensate pumps
- Ammonia distribution pumps.

To date, variable frequency drive systems using silicon controlled rectifiers (SCR) for converter and inverter are only available at 480 V level in the United States. It may be possible to bring this level of technology to a higher voltage (4.16 kV) by employing technology already in existence in continental Europe. The design may then be revised by deleting stepdown and stepup transformers for each drive system.

2.1.3 Electrical System Grounding

Normally, in a Class I, Group D, Division 2 environment, Section 43 of IEEE 45 (Ref. 2-1) recommends an ungrounded neutral system. However, a high-resistance grounding system was selected because it minimizes shock hazard and steady-state overvoltage conditions associated with an ungrounded system. A backup ground detection system is also adopted for alarm on low leakage and trip on high ground leakage. This method has been accepted and advantageously employed in most petroleum and process industries. The same method of grounding and detection is adopted for the variable frequency drive systems. Special features of this approach are:

- The system operates as virtually an ungrounded system.
- Early detection and alarm avoids serious consequences.

2.2 SYSTEM PERFORMANCE

The ES is designed to operate under four modes of operation:

- Startup mode - (a) when shipboard power is available

(b) when platform power is available

- Normal mode - operation at part or full power under normal operating conditions
- Standby mode - operation with complete loss of all normal power sources
- Emergency mode - operation with loss of normal as well as standby power source.

Under normal sea-state conditions, a module can be operated at part or full power level. Operational performance is described in detail under Section 3.

2.3 SYSTEM ARRANGEMENT

Equipment of the ES is located on the above-water decks of the module. The standby power generators are located on the platform.

2.4 SYSTEM COMPONENTS

The ES components and equipment are listed in Appendix B, which also includes the tentative hazardous area classification of the equipment.

2.5 SPECIAL SUPPORT EQUIPMENT

No special support equipment is needed. Lifting slings and general maintenance tools are to be provided by the platform maintenance system.

H1

2.6

INSTRUMENTATION AND CONTROL SYSTEM

The ES instrumentation and controls are generally similar to those used in conventional power generating stations. Listing and specifications of the required instrumentation will be defined in later phases of design.

2.7

SYSTEM INTERFACES

Interfaces with the module systems and the platform power distribution system are shown on the single line diagram, Drawing E-503 (Appendix A).

2.7.1

Main Transformer Connection

All power modules for one platform are connected to a common high voltage bus at 115 kV. A main transformer is provided on the platform for each module to step up the module-generated voltage from 13.8 kV to 115 kV. The transformer is a nonflammable liquid immersed type. The required capacity of the main and auxiliary transformers imposes a need to employ an oil-insulated transformer. The main transformer and the unit auxiliary transformer are located in the platform. The interconnection between the generator and the main transformer is in 4000 A, 4.16 kV, nonsegregated phase-insulated bus ducts.

2.7.2 Startup Power Source Connection

The connections between the module 4.16 kV buses and the platform startup buses are in 3000 A, 4.16 kV, nonsegregated phase-insulated bus ducts. The startup transformer has high-resistance grounding with a ground detection and alarm system. Since the startup transformer is shared among all platform-connected modules, its output is interlocked such that only one module can utilize the startup transformer at any time.

2.7.3 Standby Power Connection

Two feeder connections at 480 V are provided for connections to the two standby power buses in the platform. Each feeder is rated for 250 kVA, 480 V, 3Ø - 60 Hz. The standby power system has a high resistance grounding system with ground detection and alarm.

2.7.4 Normal Power Connection

Two feeder connections are provided in each power module for supplying power to the platform auxiliary loads. Each feeder is rated to carry 300 kVA - 480 V - 3Ø - 60 Hz.

2.7.5 Protective Relaying

Protective relaying for the system features, described in Sections 2.7.1 through 2.7.4, requires detailed analysis and will be specified at a later design phase.

2.8 DESIGN PROVISIONS FOR SAFETY

2.8.1 Ventilation System

Normal and standby power supply is provided for powering all safety-related ventilation systems.

2.8.2 Ammonia Leak Detection System

The leak detection and monitoring system is supplied with normal and emergency power to ensure uninterrupted service under all modes of module operation.

2.8.3 System Grounding

To avoid shock hazard and excessive ground current, a high resistance grounding system is adopted. This system provides the following features:

- Low leakage current (normally less than 4 amp)
- Early detection of insulation failure
- Prevention of unsafe touch-voltage situations

- Prevention from fire hazards resulting from high-ground current.

2.8.4 Fire Protection System

An emergency power supply is provided for this system such that smoke detection and alarm are possible under all modes of module operation. Cabling and routing for the fire protection system is such that disabling from failure of other cables is not possible.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

At startup, no power is available within the module to operate the process pumps and other auxiliary loads. Hence, an external power source is required to start up the process pumps until the power system can generate enough power to supply its own auxiliaries. The module can be started from two external power sources:

- Shipboard power source from a support ship
- Platform power source generated by another OTEC plant power module.

3.1.1 Shipboard Power Source

In startup operation from a shipboard power source, the platform startup power buses are connected to the shipboard power. By operation of associated disconnecting switches on these buses, the module 4.16 kV buses are energized by closing the normally open breakers.

Prior to closing the startup power breakers, all the breakers must be in the open position. After the 4.16 kV buses are energized, the system is started from either one of the 4.16 kV energized buses by closing the startup power breakers. Then, the 480 V load center breakers are closed to supply power to all

auxiliary systems necessary to establish safe prestart conditions. The ventilation and ammonia leak detection systems must function properly. On receipt of permissive signals indicating satisfactory operation of these systems, the cold seawater pumps, warm seawater pumps, ammonia distribution and condensate pumps are started one at a time in a planned sequence. These pumps can be started either across the line at rated speed, or with the variable frequency drive control at slow speed. The former is employed with a stiff-power systems, and the latter is employed with a soft power systems. It is probable that the shipboard power source will perform as a soft system.

After the generator is brought to rated speed, voltage and frequency, the unit auxiliary breaker is closed, and the module is put in parallel operation with the shipboard power system. This initial startup operation can be executed with one 4.16 kV bus. The startup power supply breaker is then opened.

Once self-sustaining operation is achieved, the second 4.16 kV bus can be supplied with power from within the module by closing the unit auxiliary supply breaker. The second set of process pumps on this bus can then be started in the same sequence as described above. The power system is then ready to close the main transformer breaker and to start power delivery to the platform distribution system.

3.1.2 Platform Power Source

When one or more power modules are generating enough power to supply power to the platform, the startup operation of additional modules will not require external shipboard power. The startup power buses are energized from the common startup transformer, and the additional module can be started with power from an operating module. With power available at the startup power supply breaker, the subsequent startup operations are the same as described in Section 3.1.1.

To maintain a module at a certain power level, the process pumps can be operated at a speed between 50 - 100% speed range. Speed control is achieved by varying the input frequency supply to the pump motors. Motors can be switched to direct 60 Hz operation, if desired, without system disturbance. Instrumentation is provided for continuous monitoring of the motor operating conditions. Any unsafe conditions are annunciated and alarmed in the control room.

3.2 NORMAL OPERATION

In normal operation, the module generator supplies power to the unit auxiliary transformer and the main transformer. The unit auxiliary transformer distributes power via the 4.16 kV buses. Each of the buses is rated for half the module auxiliaries. Motors of over 200 hp are operated from 4.16 kV buses, and motors

rated from 75 to 200 hp are operated from 480 V. Motors smaller than 75 hp are operated from motor control centers.

The main transformer supplies power at 115 kV to the platform.

3.3 SHUTDOWN

The module is shutdown in a definite orderly sequence of steps for reasons of safety; however, emergency shutdown of all loads at the same time is also possible.

For planned shutdown, an interlock system is incorporated in the electrical system so that the load shedding sequence of operations is executed in a safe manner.

3.4 INFREQUENT AND ABNORMAL OPERATIONS

Power module conditions that cause an immediate shutdown include:

- Natural phenomena such as severe storms
- Unsafe ammonia concentration in a pump room
- Protective relay operation
- Ventilation system failure
- Fire alarm operation.

Operations which are infrequently performed during the lifetime of a plant include:

- Process interruption
- Filling and draining

- Corrective and preventative maintenance.

In any situation where the module is not generating enough power for self sustaining operations, it is provided with standby and emergency power from the platform. On loss of normal power within the module, the load centers connected with standby power feeders will be supplied from standby diesel power units designed to start and to supply power within 20 sec following a loss of normal power. The standby power supply is considered as a platform function. Following loss of the normal power sources, the turbine generator is brought to a safe shutdown.

A separate 125 V dc battery power system is provided in each module to supply power for the:

- 4.16 kV switchgear
- 480 V load center switchgear
- Instrumentation and control
- Fire protection system
- Gas detection system.

Upon loss of normal ac power, a 125 V dc battery serves the emergency loads via an inverter system. The transition of power sources from normal ac to dc battery is accomplished without interruption in power supply to the critical systems listed above.

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Section 4

MAINTENANCE

Standard power plant maintenance planned for corrective and preventive measures is considered adequate.

REFERENCES

- 1-1 IEEE-45, IEEE Recommended Practice for Electric Installation on Shipboard
- 2-1 Ibid.

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Appendix A

ELECTRICAL SYSTEM DRAWINGS

Bechtel Drawing E-502, Electrical Power Block Diagram

Bechtel Drawing E-503, Electrical Single Line Diagram

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Appendix B

ELECTRICAL EQUIPMENT LIST FOR A POWER MODULE

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
1.	1A1 - 4.15 kV Medium Voltage Switchgear 4.16 kV - 350 MVA Class 3Ø - 60 HZ (Vacuum-type) Marine service - Metal-Clad Switchgear 3 - 3000 A Incoming Main Breakers 14 - 1200 A Feeder Breakers	324"L x 109"W x 111"H	7750 lbs. 4750 lbs.	15,500 lbs. 61,750 lbs.	Per standards IEEE-45 CG-259 ABS rules. Located in unclassified area
2.	1A2 - 4.16 kV - Medium Voltage Switchgear 4.16 kV - 350 MVA Class 1Ø - 60 HZ (Vacuum-type) Marine Service - Metal Switchgear 2 - 3000 A Incoming Main Breakers 5 - 1200 A Feeder Breakers	324"L x 109"W x 111"H	7750 lbs. 4750 lbs.	15,500 lbs. 61,750 lbs.	Per standards IEEE-45 CG-259 ABS rules. Located in unclassified area
3.	1AV3 - 4.16 kV - Medium Voltage Switchgear Variable Frequency 4.16 kV - 350 MVA Class 3Ø - 60 HZ (Vacuum-type) 1 - 1200 A Incoming Breaker 2 - 1200 A Feeder Breaker	72"L x 109"W x 111"H	7750 lbs. 4750 lbs.	12,500 lbs.	Per standards IEEE-45 CG-259 ABS rules. Lineup with item 1D9 located in unclas- sified area
4.	1AV4 - 4.16 kV - Medium Voltage Switchgear Variable Frequency Same as Item 1AV3	72"L x 109"W x 111"H	7750 lbs. 4750 lbs.	12,500 lbs.	Same as item 1AV3. Lineup with item 1D10 located in unclassified area
5.	1AV5 - 4.16 kV - Medium Voltage Switchgear Variable Frequency Same as Item 1AV3	72"L x 109"W x 111"H	7750 lbs. 4750 lbs.	12,500 lbs.	Same as item 1AV3 lineup with item 1D10 located in unclassified area

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
*1A.	1A1 - 4.16 kV - Medium Voltage Switchgear 4.16 kV - 350 MVA Class 3Ø - 60 HZ (vacuum-type) Marine Service - Metal-Clad Switchgear 2 - 3000 A - Incoming Main Breakers 9 - 1200 A - Feeder Breakers	252"L x 109"W x 111"H	7750 lbs. 4750 lbs.	15,500 lbs. 47,000 lbs.	Per standards IEEE-45, CG-259 and ABS rules. Located in unclassified area. *For constant speed drive system. This item replaces: 1A1, 1AV3, 1AV5, 1D1, 1D3, 1D5, 1D7, 1D9 and 1D11.
*2A.	1A2 - 4.16 kV - Medium Voltage Switchgear 4.16 kV - 350 MVA Class 3Ø - 60 HZ (Vacuum-type) Marine Service - Metal-Clad Switchgear 2 - 3000 A - Incoming Main Breakers 9 - 1200 A - Feeder Breakers	252"L x 109"W x 111"H	7750 lbs. 4750 lbs.	15,500 lbs. 47,500 lbs.	Per standards IEEE-45, CG-259 and ABS rules. Located in unclassified area. *For constant speed drive system, this item replaces: 1A2, 1AV4, 1D2, 1D4, 1D6, 1D8, 1D10, and 1D12.
6.	1B6 - 480 V - 30,000 ALC - 480 V - 3Ø - 60 HZ Marine Service Switchgear 1 - 1600 A - Incoming Main Breaker 1 - 1600 A - Tie-Breaker 6 - 600 A - Feeder Breaker	84"L x 68"W x 90"H	2004 lbs. 1724 lbs.	5732 lbs.	Per standards IEEE-45, CG-259 and ABS rules. Located back-to-back with item 1B7 in unclassified area.
7.	1B7 - 480 V - 30,000 ALC - 480 V - 3Ø - 60 HZ Marine Service Switchgear 1 - 1600 A - Incoming Main Breaker 1 - 1600 A - Tie-Breaker 6 - 600 A - Feeder Breakers	84"L x 68"W x 90"H	2004 lbs. 1724 lbs.	5732 lbs.	Per standards IEEE-45, CG-259 and ABS rules. Located back-to-back with item 1B6 in unclassified area.

* 1A and 2A apply to constant speed drive system only.

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
8.	1B8 - 480 V - Motor Control Center 600 A - 22,000 AIC Marine Service Motor Control Center 6 - Nema Size 1 Starters FVNR 6 - Nema Size 2 Starters FVNR 2 - Nema Size 3 Starters FVNR 4 - Nema Size 1 Starters FVR 2 - 30 KVA - 480Y-208/120 V Transformer 2 - 208Y/120 V NAB Dist. Panels	140"L x 20"W x 90"H	1000 lbs.	6000 lbs.	Per standards IEEE-45, CG-259 ABS rules located back-to-back with item 1B9 in unclassified area.
9.	1B9 - 480 V Motor Control Center 600A - 22,000 AIC Marine Service Motor Control Center 6 - Nema Size 1 Starters FVNR 6 - Nema Size 2 Starters FVNR 2 - Nema Size 3 Starters FVNR 4 - Nema Size 1 Starters FVR 2 - 30 KVA 480 V 208Y/120 V Transformer	140"L x 20"W x 90"H			Same as item 1B8.
10.	1C1 Main Process Control Panel (a) Main Control Console (b) Main Process Control Panel	160"L x 48"W x 72"H 160"L x 48"W x 72" H	1600 lbs. 1600 lbs.	3200 lbs.	Per standards IEEE-45, CG-259 ABS rules. Main control room.
11.	1D1 - 4160 V 3500 HP Variable Frequency Drive Control (a) 3500 HP 4160 V 3Ø - 60 HZ Rectifier/Inverter Variable Frequency Control Unit (b) 3750 KVA Step-Down Insulation Transformer. 4160 V-480 V - 3Ø - 60 Dry-Type (c) 3750 KVA Step-Up Insulation Transformer. 4160 V - 480 V - 3Ø - 60 HZ Dry-Type (d) 1200 A - 350 MVA Class Vacuum-Type Marine Service Metal-Clad Switchgear	240"L x 20" W x 90"H 36"L x 55"W x 90"H 36"L x 55"W x 90"H 36"L x 109"W x 111"H	47,000 lbs. 17,500 lbs. 17,500 lbs. 4750 lbs.	86,750 lbs.	Per standards IEEE-45, CG-259 ABS rules. Install lengthwise (b), (a), (c) and (d) order. Located in unclassified area.

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
12.	1D2 4160 V - 3500 HP Variable Frequency Drive Control Same as Item 1D1	Same as Item 1D2	Same as Item 1D1	86,750 lbs.	Same as Item 1D1.
13.	1D3 - 4160 V - 3500 HP Variable Frequency Drive Control Same as Item 1D1	do	do	do	Same as Item 1D1.
14.	1D4 - 4160 V - 3500 HP Variable Frequency Drive Control Same as Item 1D1	do	do	do	Same as Item 1D1.
15.	1D5 - 4160 V - 2500 HP Variable Frequency Drive Control (a) 2500 HP - 4160 V - 3Ø - 60 HZ Rectifier/Inverter - Variable Frequency Control Unit (b) 2500 kVA Step-Down Isolator Transformer 4160 V - 480 V, 3Ø - 60 HZ Dry-Type (c) 2500 kVA - Step-Up Isolation Transformer - 4160 V - 480 V - 3Ø - 60 HZ Dry-Type (d) 1200 A - 350 MVA Class Vacuum-type Marine Service Metal-Clad Switchgear	180"L x 20"W x 90"H 84"L x 55"W x 90"H 84"L x 55"W x 90"H 36"L x 109"W x 111"H	44,000 lbs. 15,000 lbs. 15,000 lbs. 4,750 lbs.	78,750 lbs.	Per standards IEEE-45, CG-259 ABS rules. Install lengthwise (b), (a), (c), and (d) order. Located in unclassified area.
16.	1D6 - 4160 V - 2500 HP Variable Frequency Drive Control Same as 1D5	do	do	do	Same as 1D5.

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
17.	1D7 - 4160 V - 2500 HP Variable Frequency Drive Control Same as 1D5	Same as 1D5	Same as 1D5	78,750 lbs.	Same as Item 1D5.
18.	1D8 - 4160 V - 2500 HP Variable Frequency Drive Control Same as 1D5	dc	do	do	Same as Item 1D5.
19.	1D9 - 125 V DC Emergency Power System (120 V AC Power Supply) (a) 1 - 1000 AH - 125 V DC Battery Cells and Marine Service battery rack (b) 1 - 150 A Battery Charger 480 V 0 3Ø - 60 HZ Input 125 V DC Output (c) 1 - 15 kVA Regulated Power Transformer 480 V AC Input 120 V AC Output (d) 1 - 15 kVA - 125 V DC/120 V AC Inverter Unit	130"L x 180"W x 100"H 50"L x 25"W x 60"H 36"L x 30"W x 90"H 55"L x 33"W x 90"H	3000 lbs. 4800 lbs. 2200 lbs. 2400 lbs.	3000 lbs. 4800 lbs. 2200 lbs. 2400 lbs.	Per standards IEEE-45, CG-259 ABS rules. 125 V dc power supplies power to: • 125 V dc control • 125 V dc inverter system for 120 V ac output.
20.	1D10 - 250 V DC Emergency Power System (a) 1 - 1000 AH - 250 V DC Battery Cells and Marine Service Battery Rack (b) 1 - 100 A Battery Charger 480 V - 3Ø - 60 HZ Input 250 V DC Output	180"L x 180"W x 100"H 30"L x 30"W x 90"H	6000 lbs. 1640 lbs.	6000 lbs. 1640 lbs.	Per standards IEEE-45, CG-259 ABS rules. 250 V power supplies power to: • Turbine generator lube/seal system.
21.	1G1 - NH ₃ Turbine Generator (By others)				

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
22.	<u>1X1 - Main Transformer</u> 41.7/55 MVA. - OA/FA. - 55°C. 11.5 kV - 13.8 kV: 30 - 60 HZ Z = 7% (41.7 MVA base) Nonflammable liquid immersed type transformer suitable for marine service.	380"L x 250"W x 180"H	310,000 lbs.	310,000 lbs.	Per standards IEEE - 45 CG - 259 ABS - Rules. Step-up generated voltage to connect to common hi-voltage AC-BUS located in platform.
23.	<u>1X2 - Unit Auxiliary Transformer</u> 22.29.26 MVA. - OA/FA. - 55°C. 3 windings transformer X = Y = 11/14.63 MVA - OA/FA - 55°C. 13.8 kV - 4.16 kV - 30 - 60 HZ Z _{Hx} = Z _{Hy} = % (22MVA - Base). Non-flammable liquid immersed type transformer suitable for marine service.	250"L x 85"W x 180"H	175,000 lbs.	175,000 lbs.	Per standards IEEE - 45 CG - 259 ABS - Rules. Step down transformer supplies power to module auxiliary loads. Located in platform.
24.	<u>1X3 - Generator Grounding Transformer</u> 13.8 kV - 120/240 V - 10 - Dry Type distribution transformer and ground detection unit.	64"L x 40"W x 102"H	3,000 lbs.	3,000 lbs.	Generator ground fault protection. part of generator package
25.	<u>1X21/1X22: - 4.16kV - System Grounding Transformer</u> 2 - 4.16kV - 120/240V 10 - Dry type distribution transformer and ground leakage current detection unit.	64"L x 40"W x 102"H (each)	3,000 lbs.	6,000 lbs.	16.4kV - System ground leakage current detection unit.

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
26.	CX1 - Common Startup Transformer (Platform Related Item) 22/29.26 MVA - OA/FA - 55C 3 - Winding Transformer with Delta Tertiary X = Y = 11 / 14.63 MVA - OA/FA - 55C 13.8 kV - 4.16 kV - 4.16 kV - 3Ø - 60 HZ Z _{HX} = Z _{HY} = % (22 MVA - Base) Nonflammable liquid immersed type trans- former suitable for marine service. CX2 / CX3 - 4.16 kV System Grounding Transformers 2 - 4.16 kV - 120/240 V - 1Ø Dry-Type Distribution Transformer and Ground Detection Unit.	250"L x 185"W x 180"H 64"L x 40"W x 102"H	175,000 lbs. 3,000 lbs.	175,000 lbs. 6,000 lbs.	Per standards IEEE-45, CG-259 ABS rules. Step- down transformer to supply an alter- nate power source to module auxiliary loads. This is plat- form related and located in plat- form. 4.16 kV system ground leakage current detection unit. Part of item CX1.
27.	LX6 - 480 V Load Center Transformer 750 kVA - AA - 150C 4.16 kV - 480 Y/277 V - 3Ø - 60 HZ Z = 5.75% Dry-Type LX6G Grounding Transformer 5 kVA - 480 V - 120/240 V - Ø Dry-type Transformer with Ground Detection Unit.	108"L x 58"W x 90"H 64"L x 40"W x 102"H	5,800 lbs. 1,500 lbs.	4,800 lbs. 1,500 lbs.	Load center trans- former for LB6. 480 V system ground leakage detection unit. Located in unclassified area.
28.	LX7 - 480 V - Load Center Transformer Same as Item LX6. LX7G Grounding Transformer	108"L x 58"W x 90"H 64"L x 40"W x 102"H	5,800 lbs. 1,500 lbs.	5,800 lbs. 1,500 lbs.	Load center trans- former for LB7. 480 V system ground leakage detection unit. Located in unclassified area.

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
29.	2500 A - 350 MVA - 4.16 kV - 3Ø - 60 HZ Startup Bus #1 10 - 2500 A - 4.16 kV - 3Ø Non-Load Break Disconnecting Switches	400"L x 70"W x 90"H	3,000 lbs.	30,000 lbs.	Startup power feeders discon- necting switches. Platform related item and located in platform.
30.	2500 A - 350 MVA - 4.16 kV - 3Ø - 60 HZ Startup Bus #2 Same as Item 32	400"L x 70"W x 90"H	3,000 lbs.	30,000 lbs.	Startup power feeders discon- necting switches. Platform related item and located in platform.

NOTE: All items except 1A and 2A apply to variable speed drive system of one power module only.

OTEC Power System Development Project
Subcontract YF80C1050M

Appendix H2

10 MWe Modular Application Power Module
Preliminary Design Description
for
Electrical System

Bechtel National, Inc.

San Francisco

Job 12384-002

September 1978

Revision 0

H2

H2

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INTRODUCTION AND SUMMARY

This document contains the preliminary design description of the Electrical System (ES) 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 ES 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 ES provides distribution of the electric power needed to operate the power module, and connection to the platform electric power distribution system. Normal ac, standby ac, and emergency dc power are provided to the module.

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Section 1

FUNCTIONS AND REQUIREMENTS

1.1 FUNCTIONS

The functions of the module electrical system (ES) are to:

- Provide power distribution within the power module
- Provide emergency power for
 - Control and instrumentation
 - Turbine auxiliary
 - Emergency lighting
- Supply power to platform auxiliary systems
- Provide interface with the platform
 - AC power transmission
 - Standby power system
 - Startup power system

1.2 REQUIREMENTS

1.2.1 Operational Requirements

The module ES is to provide adequate, safe, reliable, and efficient power supply for the operation of the power module in the following modes of operation.

In the startup mode of operation, the module requires an external power source to operate most of its auxiliaries.

During normal mode of operation, the module is generating and supplying power to its own auxiliaries and also to the platform switchgear and platform auxiliaries.

In the standby mode of operation, only safety-related auxiliaries of the module are running from power provided by the platform diesel-generating units. The transition time from normal to a standby mode is approximately 20 sec.

In the emergency mode of operation, only the emergency power source is available to the module. This mode occurs during the transitional period between normal and standby mode and on loss of standby power.

1.2.2 Structural Requirements

The electrical equipment is to be installed in accordance with the general conditions of shipboard marine service specified under Section 1.5 of IEEE-45 (Ref. 1-1), including the following requirements:

- Momentary 30 degrees roll, 10 degrees pitch and permanent inclination of 15 degrees
- Continuous exposure to severe moisture, salt-laden atmosphere, and high wind velocity.

The system is to remain operational with vertical accelerations of $\pm 0.15g$ (sea state 6) and to survive vertical accelerations of $\pm 0.7g$ (sea state 9).

1.2.3 System Configuration and Essential Features

In general, switchgear, transformers, load centers, and motor control centers are to be located in ammonia-free areas and are to be suitable for marine service. The use of oil-immersed equipment within the module is to be limited.

1.2.4 Codes and Standards

The latest editions of the following codes and standards are to be used in the design of the module electrical system:

United States Coast Guard.

USCG 259 Electrical Engineering Regulations

American Bureau of Shipping.

Rules for Building and Classing Steel Vessels

Institute of Electrical and Electronic Engineers (IEEE) Standards.

No. 45 - Recommended Practice for Electric Installations on Shipboard

No. 450 - Recommended Practice for Maintenance, Testing, and Replacement of Large Stationary Type Power Plant and Substation Lead Storage Batteries

No. 484 - Recommended Practice for Installation Design and Installation of Large Lead Storage Batteries for Generating Stations and Substations.

Insulated Power Cable Engineers Association (IPCEA) Standards.

- P-32-382 - Short Circuit Characteristics of Insulated Cable
- P-45-482 - Short Circuit Performance of Metallic Shielding and Sheaths of Insulated Cable
- P-46-426 - Power Cable Ampacities, Vol. 1 Copper Conductors, and Cumulative Errata Sheets (1966)
- P-54-440 - Ampacities - Cables in Open-top Cable Trays
- S-19-81 - Rubber Insulated Wire and Cable for the Transmission and Distribution of Electric Energy
- S-28-357 - Asbestos, Asbestos-Varnished Cloth and Asbestos-Thermoplastic Insulated Wires and Cables
- S-66-524 - Cross-linked Polyethylene Insulation for Power Cables Rated 0-600 volts
- S-68-516 - Cables Rated 0-35,000 volts and Having Ozone-Resistant Ethylene-Propylene Rubber Insulation.

National Electronic Manufacturers Association (NEMA) Standards.

- No. AB - Molded Case Circuit Breakers
- No. MB - Motors and Generators
- No. PB-1 - Panelboards
- No. PB-2 - Switchboards, Dead Front Distribution
- No. SG-5 - Power Switchgear Assemblies
- No. S-61-402 Thermoplastic-Insulated Wire and Cable for Transmission and Distribution of Electric Energy
- No. TR-1 - Transformers, Regulators and Reactors
- No. VE-1 - Ventilated Cable Trays

- No. WC-3 - Rubber-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
- No. WC-5 - Thermoplastic-Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
- No. WC-7 - Cross-Linked-Thermosetting - Polyethylene - Insulated Wire and Cable for the Transmission and Distribution of Electrical Energy
- No. WC-8 - Cables Rated 5000 Volts and Less and Having Ozone-Resistant Ethylene-Propylene Rubber Integral Insulation and Jacket
- No. 151 - Recommended Motor Starting Currents
- No. 201 - Primary Unit Substations
- No. 210 - Secondary Unit Substations

American National Standards Institute (ANSI) Standards.

- No. C37.010 - AC High Voltage Circuit Breakers Rated on a Symmetrical Current Basis
- No. C37.13 - Low Voltage AC Power Circuit Breaker
- No. C50.12 - Salient Pole Synchronous Generators and Condenser, Requirements for
- No. C57.12.00 Distribution, Power, and Regulating Transformers and Shunt Reactors, General Requirements for
- No. C84.1 - Voltage Ratings for Electric Power Systems and Equipment

National Fire Protection Association (NFPA) Standards.

- NFPA No. 70 - National Electrical Code
- NFPA No. 321 - Basic Classification of Flammable and Combustible Liquids
- NFPA No. 325M - Fire-Hazard Properties of Flammable Liquids, Gases and Volatile Solids

- NFPA No. 77 - Static Electricity
- NFPA No. 496 - Purged and Pressurized Enclosures for Electrical Equipment in Hazardous Locations

American Petroleum Institute (API) Standards.

- API-RP500B - Recommended Practice for Classification of Areas for Electrical Installations at Drilling Rigs and Production Facilities on Land and on Marine Fixed and Mobile Platforms
- API-RP500A - Recommended Practice for Classification of Areas for Electrical Installations in Petroleum Refineries
- API-RP2003 - Recommended Practice for Protection Against Ignitions Arising Out of Static, Lightning and Stray Currents

Design Guides. The following power industry design practices are to be employed in the design of the electrical system:

- Lighting system
- Communication system
- Cable derating practices
- Conduit and tray installation
- Short circuit calculations
- Voltage drop and regulation calculations
- Transformer rating selection
- Marine electric equipment installation

1.2.5 Level of Technology

The equipment for the ES is to be selected from state-of-the-art, commercially available designs, requiring no development.

1.2.6 Instrumentation and Control Requirements

The instrumentation and control for the electrical system is to be consistent with module computer control with additional local start-stop control stations provided for individual motors.

1.2.7 Maintenance Requirements

Maintenance provisions of the ES are to be consistent with the overall maintenance plan of the power module. General tooling, special tools supplied by the manufacturers, 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 to perform maintenance operations and a safe transit path for equipment removal.

1.2.8 System Reliability

The reliability of the ES is to be consistent with the OTEC 90% availability (at 60% confidence) requirement. Standby and emergency power sources are to be provided to assure operating continuity of vital or safety-related functions in the event of failure of the normal power source.

1.2.9 Interface Requirements

The module electrical system interfaces functionally and physically with the platform electrical system in the following areas:

- 13.8 kV cable connection to 13.8 kV switchgear
- 13.8 kV feeder cable connection to unit auxiliary transformer
- 4.16 kV startup power feeder connection
- 480 V standby power connection
- 480 V normal power connection.

Other subsystem interfaces are shown in Table 1-1.

1.2.10 Environmental and Safety-Related Requirements

Areas within the module are to be classified in accordance with the degree of hazard involved. Electrical equipment located in areas with ammonia containing equipment is to be classified as Class I, Group D, Division 2. The ventilation system providing ventilation air to hazardous areas is to be treated as safety related. A high resistance grounding system is to be employed to limit ground current and to limit shock hazards.

TABLE 1-1
INTERFACE REQUIREMENTS

ELECTRICAL SYSTEM REQUIREMENTS				
NO.	STANDBY POWER SYSTEM	INTERFACE SYSTEM	ELECTRICAL SYSTEM	REMARKS
1.	Fire Protection System	<p>(a) CO₂ Flooding and CO₂ Portable Extinguisher</p> <ul style="list-style-type: none"> o Control Room o Switchgear Room o Generator/Exciter <p>(b) Water Spray System</p> <ul style="list-style-type: none"> o Main Transformer o Unit Auxiliary Transformer <p>(c) Flooding Halon 1301 System</p> <ul style="list-style-type: none"> o Relay Room o Computer Room <p>(d) Fire and Smoke Monitoring, Detection and Alarm System. Ionization Detection System to be Used Extensively.</p>	<p>(a) 120 V ac Emergency Power</p> <ul style="list-style-type: none"> o Fire Detection System o Fire Alarm System <p>(b) Seawater Pumps are Furnished with Two Sources of Power:</p> <ul style="list-style-type: none"> o Normal Power o Standby Power <p>(c) Flame Retardant Materials are Used for Cables and Wires</p> <p>(d) Non-Flammable Liquid is Used for Transformer</p>	<p>This system shall have a well balance between:</p> <ul style="list-style-type: none"> o Prevention o Detection o Extinguishing o Mitigation of Consequences
2.	Standby Power System	<p>Test Module Requires:</p> <p>250 KVA - 480V - 3Ø - 60 HZ Power. Power shall be available in 20 seconds following a lost of normal power.</p>	<p>480V - 3Ø - 60 HZ. Feeder connection is provided for connection to standby diesel generator. Provided on shipboard.</p>	<p>Provide power:</p> <ul style="list-style-type: none"> o Essential Services o Safety Related Ventilation and Exhaust System o Life Support and Signalling System
3.	Compressed Air System	<p>None. Air motor may be used where electric motor application is not possible.</p>	<p>Normal 480V - 3Ø - 60 HZ ac power for compressor motors.</p> <p>120V - ac - standby and emergency power for solenoid control valves.</p>	<p>Pneumatic drive and control instrumentation</p>

TABLE 1-1
INTERFACE REQUIREMENTS

ELECTRICAL SYSTEM REQUIREMENTS				
NO.	STANDBY POWER SYSTEM	INTERFACE SYSTEM	ELECTRICAL SYSTEM	REMARKS
4.	Cooling Water System	None.	Normal 480V - 3Ø - 60 HZ. AC supply is furnished for pump drive.	
5.	Hydraulic Pressure System	None.	Normal 480V - 3Ø - 60 HZ. AC supply is furnished for pump drives.	
6.	Heating, Ventilation and Air Conditioning System	<p>Redundant ventilation system shall be provided for classified areas.</p> <p>Ventilation system provided for classified areas shall be interlocked to the process generation.</p>	<p>Ventilation system related to the classified areas are furnished with 480V - 3Ø - 60 HZ.</p> <ul style="list-style-type: none"> o Normal, and o Standby Power 	<p>Safe and proper operation of plant by providing:</p> <ul style="list-style-type: none"> o Life Support System o Safe Area Classification
7.	Cathodic Protection	Provide adequate protection during the design life of the plant.	<p>Anode and cathode lead wires are provided.</p> <p>480V - 3Ø - 60 HZ or 120V - 1Ø - 60 HZ. Power Supply are furnished for the rectifier.</p>	Protect metal structure from corrosion.

Section 2

DESIGN DESCRIPTION

2.1 SYSTEM CONFIGURATION

The module ac electrical power block diagram is shown on Drawing E-102 (Appendix A). The system is designed for four distinct modes of operation, as shown in Table 2-1. The electrical single line diagram is shown in Drawing E-103 (Appendix A). The diagram shows the system designed to operate the ammonia and seawater pump drives in variable frequency drive control or in constant 60 Hz ac motor current mode.

The variable frequency motor speed control requires a separate rectifier-inverter which operates at 480 V. This voltage is the present upper limit with equipment supplied by US manufacturers. Although 4.16 kV equipment is available from European suppliers and will be used in the US utility industry in the near future, there is no significant US experience with this high voltage equipment as yet. Therefore, it was not used in the present design.

The implication of the lower rectifier-inverter voltage is that when large electric motors (above 200 hp) are used, the required 4.16 kV ac current is obtained by transformation from the 4.16 kV source bus to 480 V to feed the rectifier-inverter. The output current is then transformed back to 4.16 kV.

TABLE 2-1
MODES OF OPERATION

NO.	MODE OF OPERATION	POWER REQUIREMENT	SOURCE OF POWER	REMARKS
1.	STARTUP		(a) 13.8 kV 3Ø - 60 Hz shore power, or (b) 13.8 kV, 3Ø - 60 Hz second module power, or (c) 4.16 kV 3Ø - 60 Hz ship-board power.	At peak t power generated = 5400 kVa @ 0.8 PF vs.
2.	NORMAL	6000 kVa @ 0.85 PF module house load at peak.	4.16 kV - 3Ø - 60 Hz from unit-auxiliary transformer	At peak t , generate 16.5 MVA @ 0.9 PF with maximum house load = 6000 kVa @ 0.85 PF.
3.	STANDBY	150 kW or 200 kVa - 480V - 3Ø - 60 HP	Standby diesel generators at 480V - 3Ø - 60 HP	Supply power to: (a) essential services (b) life support system (c) safety ventilation system
4.	EMERGENCY	30 kW - 125V-dc system - 250V-dc system	125V-dc and 250V-dc system - dc battery and inverter located in power module	Supply power to: (a) 125V-dc control power (b) 120V-ac inverter system instrumentation (c) 250V-dc turbine lube and seal system.

2.2 SYSTEM PERFORMANCE

Under normal sea-state conditions, the module can function at part or full capacity. At a given differential seawater temperature, the seawater pumps and the ammonia pumps can be set for a speed to give maximum power system net power output. The system electrical losses are somewhat greater when operating in the variable frequency mode, with efficiencies in the 80% range. Economic studies indicated, however, that this speed control mode is preferable in the lower seawater and ammonia pump flow ranges.

2.3 SYSTEM ARRANGEMENT

The transformers, switchgear, and the rectifier cabinets are located on the above-water decks of the module. The standby generators are on the platform.

2.4 SYSTEM COMPONENTS

The power module system components and equipment are tabulated in Appendix B. The equipment for the system is installed in essentially two main electrical area classifications:

- Unclassified area (nonhazardous)
- Classified area (Class I, Group D, Division 2).

The equipment list in Appendix B identifies the classification for each item.

2.5 SPECIAL SUPPORT EQUIPMENT

None required. Lifting slings and general tooling are provided with the platform maintenance system.

2.6 INSTRUMENTATION AND CONTROL SYSTEM

Instrumentation and control are provided for the safe operation of the plant. The required readout and controls are generally the same as those used in normal power plant applications. Instrument listing and specifications will be prepared in the detailed design phase.

2.7 SYSTEM INTERFACES AND CONNECTIONS

The interfaces for the power module are:

- Generator cable connections to the platform switchgear
- Unit-auxiliary transformer main feeder connection
- Startup power feeder connection
- 480 V feeder connections for
 - Standby power source
 - Normal power source
- System protective relaying.

These interfaces and the module equipment served by the ES are shown on the single line diagram, E-103 (Appendix A) .

2.7.1 Generator Cable Connection

The generator supply cables supplying power to the 13.8 kV switchgear are:

6 - 1/c - 750 kcmil - metal-clad-type - 15 kV - power cables.

2.7.2 Unit-Auxiliary Transformer

The unit-auxiliary transformer supply feeder cables are:

3 - 1/c - 500 kcmil - metal-clad-type - 15 kV - power cables.

2.7.3 Startup Power Feeder Connection

The startup power feeder cables are:

3 - 1/c - 750 kcmil - metal-clad-type - 5 kV - power cables.

2.7.4 480V - Feeder Connections

The power module has two 480 V supply feeder connections:

(a) The supply feeder cables for supplying normal power to the platform are:

6 - 1/c - 350 kcmil - metal-clad-type - 600 V
- power cables.

(b) The supply feeder cables for supplying standby power to the power module are:

3 - 1/c - 350 kcmil - metal-clad-type - 600
V - power cables.

2.7.5 System Protective Relaying

Protective relays installed for the generator breaker and the feeder breakers require a detailed analysis, to be performed during detailed design.

2.8 DESIGN PROVISIONS FOR SAFETY

2.8.1 Ventilation System

Normal and standby power supply is provided for the safety-related ventilation system. It is further interlocked to the power system such that on failure of the ventilation system, coupled with high ammonia gas leakage detection, the power system is shut down.

2.8.2 Ammonia Leak Detection System

This system is supplied with normal and emergency power. It is operational under all modes of module operation. It is further interlocked to the power system such that operation of the power system is not possible in areas where a high concentration of gas leakage is present.

2.8.3 System Grounding

In an ac electric system, a constant flow of ground current is present due to capacitive coupling. However, high ground leakage current would cause overheating of bare grounding conductors. Such a condition is potentially dangerous in Class I areas. To minimize such hazards, high-resistance system grounding is adopted. This system provides the following features:

- Low leakage current, normally less than 5 amp
- Early detection of insulation failure
- Prevents unsafe touch voltage situation
- Prevents explosion resulting from high energy ground current.

2.8.4 Fire Protection System

Normal and emergency power is provided for the fire protection system such that smoke detection and monitoring is possible under all modes of module operation. Cables for the system are routed in a separate raceway system to assure the functioning of the fire protection system.

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Section 3

SYSTEM OPERATION

3.1 SYSTEM STARTUP

During system startup, no power is available within the module to operate the process pumps. Hence, an external power source is needed to operate the process pumps until the power system can generate enough power to supply its own auxiliaries. Three external power sources are available for system startup:

- Shipboard power source from a support ship
- Platform power source generated by another OTEC power module
- Shore power source.

3.1.1 Shipboard Power Source

In startup operation from a shipboard power source, the platform startup power bus is connected to the shipboard power. The module 4.16 kV bus is energized by closing a normally open breaker.

Prior to closing this startup power breaker, all the breakers must be in the open position. After the 4.16 kV bus is energized, the 480 V load center breakers are closed to supply power to all auxiliary systems necessary to establish safe prestart conditions. The ventilation and ammonia leak detection

systems must function properly to allow a safe prestart condition.

On receipt of permissive signals indicating satisfactory operation of these systems, the cold seawater pumps, warm seawater pumps, ammonia distribution and condensate pumps are started one at a time in a planned sequence. These pumps can be started either across the line at rated speed, or with the variable frequency drive control at slow speed. The former is employed with a stiff power system, and the latter is employed with a soft power system. It is probable that the shipboard power source will represent a soft system.

After the generator is brought up to rated speed, voltage and frequency, the generator bus breaker is closed. Then the unit auxiliary breakers are closed, putting the module in parallel operation with the shipboard power system. The startup power supply breaker is then opened.

3.1.2 Platform Power Source

If a second power module is in operation at the same time on the platform, power is available on the platform to start up the module. To start up with platform power, the module 4.16 kV bus is supplied with power from 13.8 kV switchgear through the unit-auxiliary transformer. The startup sequence of operation after the power is available on the 4.16 kV bus is the same as described in Section 3.1.1.

3.1.3 Shore Power Source

The 13.8 kV switchgear is directly connected to the shore substation. The same transmission line can feed the shore power back to the platform. The unit auxiliary transformer can be energized from the 13.8 kV switchgear in the same manner as described in Section 3.1.2. The sequence of operations that follow will be the same as described in Section 3.1.1.

3.2 NORMAL OPERATION

In the normal operation of the power module, the generator supplies power to the 13.8 kV platform bus which distributes power to the shore substation and also back to the module unit auxiliary transformer.

During normal operation of the power system, the electric motors are provided with the following protection:

- Motor winding or circuit failure
- Overload
- Loss of power supply
- Phase current unbalance
- Single phase operation
- Phase reversal.

The parameters are continuously monitored, and any unsafe condition is annunciated in the module control room.

3.3 SHUTDOWN

The module is shutdown in a definite orderly sequence of steps for reasons of safety; however, emergency shutdown of all loads at the same time is also possible.

For a planned shutdown, interlocks are incorporated in the electrical system so that the load shedding sequence of operations is executed in a safe manner.

3.4 INFREQUENT AND ABNORMAL OPERATIONS

Power module conditions that cause immediate shutdown include:

- Natural phenomena such as severe storms
- Unsafe ammonia concentration in a pump room
- Protective relay operation
- Ventilation system failure
- Fire alarm operation.

Operations which are infrequently performed during the lifetime of a plant include:

- Process interruption
- Filling and draining in the event of a pipe rupture
- Corrective maintenance.

Upon loss of normal ac auxiliary power, a 125 V dc battery serves the emergency loads via an inverter system. The transition from

normal ac to the emergency power supply is accomplished without interruption in power to the critical systems listed below:

- 4.16 kV switchgear
- 480 V load center switchgear
- Instrumentation and control
- Fire protection system
- Leak detection system.

The emergency power supply allows operation of these critical units until a standby power system can be started and brought on line. This standby power is furnished by diesel generator units which are designed to start and supply power within 20 sec following loss of normal power. The standby power supply system is a platform function.

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Section 4

MAINTENANCE

The electrical components and equipment specified in the design of the module electrical system (listed in Appendix B), are highly reliable, standard industrial quality, and certified for marine installation. Preventive maintenance and refurbishing requirements will be established on the basis of manufacturers' specifications. Scheduled maintenance will be done in accordance with the overall module operating and maintenance plans.

REFERENCES

- 1-1 IEEE-45-1977, IEEE Recommended Practice for Electric Installations on Shipboard.

Appendix A

ELECTRICAL SYSTEM DRAWINGS

Bechtel Drawing E-102, Electrical Power Block
Diagram

Bechtel Drawing E-103, Electrical Single Line
Diagram

Δ	1/12/74	ISSUED FOR REPORT	ST	CHS	BSCH	ENG	PROG
NO.	DATE	REVISIONS	ST	CHS	BSCH	ENG	PROG
SCALE NONE		DESIGNED	DRAWN				
<p align="center">BECHTEL SAN FRANCISCO</p>							
<p align="center">QTEC POWER SYSTEM DEVELOPMENT LOCKHEED MISSILES & SPACE COMPANY, INC.</p>							
<p align="center">ELECTRICAL POWER BLOCK DIAGRAM 10 MW_g POWER MODULE</p>							
		JOB NO.	DRAWING NO.				
		12584	E-102

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Appendix B

**ELECTRICAL EQUIPMENT LIST FOR THE
10 MWe POWER MODULE**

No.	Description	Dimensions	Unit Wt. (lbs.)	Ttl. Wt. (lbs.)	Remarks
1	<u>1A1 - 13.8 kV - MEDIUM VOLTAGE SWITCHGEAR</u> 13.8 kV - 580 MVA - Class 3Ø - Co HZ - (Vacuum Type) Marine Service Metal Clad Switchgear 1 - 1200 A Incoming Breaker with Auxiliary Compartment 1 - 1200 A Outgoing Breaker with an Auxiliary Compartment 1 - 1200 A Feeder Breaker	72"L x 109"W x 111"H	7750 lbs. 4750 lbs.	20,200 lbs.	Per Standards - CG-259 IEEE-45 & ABS Rules located in platform
2	<u>1A2 - 4.16 kV - MEDIUM VOLTAGE SWITCHGEAR</u> <u>MAIN MODULE SWITCHGEAR</u> 4.16 kV - 250 MVA - Class 3Ø - Co HZ - (Vacuum Type) Marine Service Metal Clad Switchgear 1 - 1200 A Incoming Breaker with Auxiliary Compartment 8 - 1200 A Feeder Breakers	216"L x 109"W x 111" H	7750 lbs. 4750 lbs.	31,750 lbs.	Per Standards - CG-259 IEEE-45 & ABS Rules located in unclassified area
2A	<u>1A2 - 4.16 kV - MEDIUM VOLTAGE SWITCHGEAR</u> <u>CONSTANT SPEED DRIVE SYSTEM</u> 4.16 kV - 250 MVA - Class 3Ø - Co HZ - (Vacuum Type) Marine Service Metal Clad Switchgear 1 - 1200 A - Incoming Breaker with Auxiliary Compartment 13 - 1200 A - Feeder Breakers	108"L x 109"W x 111"H	7750 lbs. 4750 lbs.	17,250 lbs.	Item No. 2A replaces Item No. 2, 3, 4 & 5 for con- stant speed drive system
3	<u>1A3 - 4.16 kV - MEDIUM VOLTAGE VARIABLE FREQUENCY</u> <u>SWITCHGEAR</u> 4.16 kV - 250 MVA - Class 3Ø - Co HZ - (Vacuum Type) Marine Type Metal Clad Switchgear 1 - 1200 A Incoming Breaker with Auxiliary Compartment 4 - 1200 A Feeder Breakers	108"L x 109"W x 111"H	7750 lbs. 4750 lbs.	17,250 lbs.	Per Standards - CG-259 IEEE-45 ABS Rules located in un- classified area

NO.	Description	Dimensions	Unit Wt. (lbs.)	Ttl. Wt. (lbs.)	Remarks
4	<p><u>1A4 - 4.16 kV - MEDIUM VOLTAGE VARIABLE FREQUENCY SWITCHGEAR</u></p> <p>4.16 kV - 250 MVA - Class 3Ø - Co HZ - (Vacuum Type) Marine Type Metal Clad Switchgear</p> <p>1 - 1200 A Incoming Breaker with Auxiliary Compartment 4 - 1200 A Feeder Breakers</p>	108"L x 109"W x 111"H	7750 lbs. 4750 lbs.	17,250 lbs.	Sames as 3.
5	<p><u>1A5 - 4.16 kV - MEDIUM VOLTAGE VARIABLE FREQUENCY SWITCHGEAR</u></p> <p>4.16 kV - 250 MVA - Class 3Ø - Co HZ - (Vacuum Type) Marine Type Metal Clad Switchgear</p> <p>1 - 1200 A Incoming Breaker with Auxiliary Compartment 3 - 1200 A Feeder Breakers</p>	108"L x 109"W x 111"H	7750 lbs. 4750 lbs. 4150 lbs.	16,650 lbs.	Same as 3.
6	<p><u>1A6 - EXTERNAL POWER SOURCE DISCONNECTING SWITCH</u></p> <p>600 A - 5 kV - Load Interrupter Switchgear</p>	33"L x 70"W x 100"H	1200 lbs.	1200 lbs.	Platform Equipment Per Standards - CG -259 IEEE-45 ABS - Rules located in platform.
7	<p><u>1B4 - 480 V - LOAD CENTER</u></p> <p>2000 A - 480 V - 3Ø - Co HZ - Load Center Marine Type Switchgear</p> <p>1 - 2000 A Incoming Breaker 4 - 600 A Feeder Breakers 3 - 600 A Motor Feeder Breakers</p>	102"L x 68"W x 90" H	2004 lbs. 1650 lbs.	6,950 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules located in unclassified area.

No.	Description	Dimensions	Unit Wt. (lbs.)	Ttl. Wt. (lbs.)	Remarks
8	<u>1B2 - 480 V - MOTOR CONTROL CENTER</u> 600 A - 22,000 A Symmetrical Marine Type Motor Control Center 7 - NEMA Size - 1, Starters - FVNR 7 - NEMA Size - 2, Starters - FVNR 3 - NEMA Size - 3, Starters - FVNR 10 - NEMA Size - 1, Starters - FVNR 2 - 30 kVA - Transformer 2 - 208Y/120V - NAB - Panels (Back to back arrangement)	120"L x 40"W x 90"H	1000 lbs.	6,000 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules located in unclassified area.
9	<u>1C1 - MAIN PROCESS CONTROL PANEL</u> (a) Main Control Console (b) Main Process Control Panel	108"L x 48"W x 72"H 108"L x 48"W x 90"H	1200 lbs. 1200 lbs.	2400 lbs.	Power Module Main Control Room Equipment
10	<u>1D1 - 4160V - VARIABLE FREQUENCY PUMP DRIVE</u> (a) 1 - 2500 HP - 4160V - 3Ø - Co HZ Adjustable Frequency Converter Only (b) 1 - Step Down - Isolation Transformer 4.16kV - 480V - 3Ø Co HZ. Dry Type. (c) 1 - Step Up - Isolation Transformer 480V - 4.16kV - 3Ø - Co HZ. Dry Type.	180"L x 20"W x 90"H 84"L x 55"W x 50"H 84"L x 55"W x 90"H	44,000 lbs. 15,000 lbs. 15,000 lbs.	74,000 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules installed in (b) (a) (c) order length wise. Located in unclas- sified area.
11	<u>1D2 - 4160V - VARIABLE FREQUENCY PUMP DRIVE</u> (a) 1 - 1600 HP - 4160V - 3Ø - Co HZ Adjustable Frequency Converter Only (b) 1 - Step Down - Isolation Transformer 4.16 kV - 480V - 3Ø - Co HZ. Dry Type. (c) 1 - Step Up - Isolation Transformer 480V - 4.16 kV - 3Ø - Co HZ. Dry Type.	126"L x 20"W x 90"H 84"L x 55"W x 90"H 84"L x 55"W x 90"H	25,000 lbs. 13,500 lbs. 13,500 lbs.	52,000 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules installed in (b) (a) (c) order length wise. Located in unclas- sified area.

No.	Description	Dimensions	Unit Wt. (lbs.)	Ttl. Wt. (lbs.)	Remarks
12	<u>1D3 - 4150V - VARIABLE FREQUENCY PUMP DRIVE</u> (a) 1 - 750 Up - 4160V - 3Ø - Co HZ Adjustable Frequency Converter Only (b) 1 - Step Down - Isolation Transformer 4.16 kV - 480V - 3Ø - Co HZ. Dry Type. (c) 1 - Step Up - Isolation Transformer 490V - 4.16 kV - 3Ø - Co HZ. Dry Type.	80"L x 20"W x 90"H 72"L x 55"W x 90"H 72"L x 55"W x 90"H	15,000 lbs. 6400 lbs. 6400 lbs.	27,800 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules Install in (b) (a) (c) order lengthwise. Located in unclassified area.
13	<u>1D4 - 480V - 160 HP - VARIABLE FREQUENCY PUMP DRIVE</u> (a) 1 - 160 HP - 480V - 3Ø - Co HZ Adjustable Frequency Converter Only (b) 8 - NEMA Size - 3 - Starters 20" Section - Arranged Back to Back	64"L x 20"W x 90"H 40"L x 40"W x 90"H	2750 lbs. 3000 lbs.	5,750 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules Install lengthwise. Located in unclassified area.
14	<u>1D5 - 125V - DC - EMERGENCY POWER SYSTEM</u> (a) 1 - 1000 AH - 125V - DC - Battery Cells and Marine Service Battery Racks (b) 1 - 150 A - Battery Charger 480V - 3Ø - Co HZ Input 125V - DC - Output (c) 1 - 15 KVA - Regulated Power Transformer 480V - AC - Input - 120V - AC Regulated Output (d) 1 - 15 KVA - 125V - DC/ 120V - AC Inverter Unit	180"L x 180"W x 100"H Space 50"L x 25"W x 60"H 36"L x 30"W x 90"H 55"L x 33"W x 90"H	3000 lbs. 4800 lbs. 2200 lbs. 2400 lbs.	3,000 lbs. 4,800 lbs. 2,200 lbs. 2,400 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules 124V - DC Power Supplies Power To: o 125V - DC Control o 125V - DC Inverter System for 120V - AC Output.
14A	<u>1D6 - 250V - DC - EMERGENCY POWER SYSTEM</u> (e) 1 - 1000 AH - 250V - DC - Battery Cells and Marine Service Battery Racks (f) 1 - 100 A - Battery Charger 480V 3Ø - Co HZ - Input 250V DC - Output	180"L x 180"W x 100"H Space 30"L x 30"W x 90"H	6000 lbs. 1640 lbs.	6,000 lbs. 1,540 lbs.	Per Standards - IEEE-45 CG-259 ABS - Rules 250V - DC - Power Supplies Power To: o Turbine Generator Lube/ Seal System

No.	Description	Dimensions	Unit Wt. (lbs.)	Ttl. Wt. (lbs.)	Remarks
15	<u>1X1 - UNIT AUXILIARY TRANSFORMERS</u> 4500/6000 kVA - AA/FA - 150°C 3 - 1500 kVA - 1Ø - Transformer Delta - Wye - Connection 13.8 kV - 4.16 kV - 3Ø - 60 HZ Z - 6% - (4500 kVA - Base) Dry-Type Transformer Transformer Include: 2 - Incoming Line Sections - 2 x 36" Wide for 3Ø Connection	90"L x 68"W x 96"H 72"L x 68"W x 90"H	10,000 lbs. 475 lbs.	13,550 lbs.	Per Standards - CG-259 IEEE-45 ABS - Rules Located in Unclassified Area
16	<u>1X2 - 4.16 kV - GROUNDING TRANSFORMER</u> 25 kVA - 4.16 kV - 120/240V 1Ø - Dry Type Transformer and Detection Unit	64"L x 40"W x 102"H	3,000 lbs.	3,000 lbs.	Ground Leakage Detection Unit on 4.16 kV - System
17	<u>1X3 - 13.8 kV - GROUNDING TRANSFORMER</u> 25 kVA - 13.8 kV - 120/240V 1Ø Dry Type Transformer and Detection Unit	64"L x 40"W x 102"H	3,000 lbs.	3,000 lbs.	Ground Fault Generator Protection. (Part of Generator Package.)
18	<u>1X4 - 480V - LOAD CENTER TRANSFORMER</u> 1000/1333 kVA - AA/FA - 150°C 4.16 kV - 480 Y/277 - 3Ø - 60 HZ Load Center Transformer <u>1X5 - GROUNDING TRANSFORMER</u> 5 kVA - 480V - 120/240V - 1Ø - Dry Type, Ground Current Detection Unit	120"L x 68"W x 96"H 64"L x 40"W x 102"H	12,500 lbs. 3,000 lbs.	12,500 lbs. 3,000 lbs.	Load Center Transformer for 184 480V - System Ground Leakage Detection Unit

No.	Description	Dimensions	Unit Wt.	Tlt. Wt.	Remarks
20.	1D9 - 4160 V 1000 HP Variable Frequency Drive Control (a) 1000 HP 4160 V 3Ø - 60 HZ Rectifier/Inverter Variable Frequency Control Unit (b) 1000 KVA Step-Down Insulation Transformer. 4160 V-480 V - 3Ø - 60 Dry-Type (c) 1000 KVA Step-Up Insulation Transformer. 4160 V - 480 V - 3Ø - 60 HZ Dry-Type	150"L x 20"W x 90"H 72"L x 55"W x 90"H 72"L x 55"W x 90"H	15,000 lbs 6,000 lbs 6,500 lbs	28,000 lbs 	Per standards IEEE-45, CG-259 ABS rules. Install lengthwise (b), (a), (c) 1AV3. Located in unclassified area.
21.	1D10 4160 V - 1000 HP Variable Frequency Drive Control	Same as Item 1D9	Same as Item 1D9	32,750 lbs	Same as Item 1D9, except 1AV4 replaces 1AV3.
22.	1D11 - 4160 V - 2500 HP Variable Frequency Drive Control (a) 2500 HP - 4160 V - 3Ø - 60 HZ Rectifier/Inverter - Variable Frequency Control Unit (b) 2500 kVA Step-Down Isolator Transformer 4160 V - 480 V, 3Ø - 60 HZ Dry-Type (c) 2500 kVA - Step-Up Isolation Transformer - 4160 V - 480 V - 3Ø - 60 HZ Dry-Type				
23.	1D12 - 4160 V 1250 HP Variable Frequency Drive Control (a) 1250 HP 4160 V 3Ø - 60 HZ Rectifier/Inverter Variable Frequency Control Unit (b) 1500 KVA Step-Down Insulation Transformer. 4160 V - 480 V - 3Ø - 60 HZ	150"L x 20"W x 90"H 72"L x 55"W x 90"H	15,000 lbs 6,500 lbs	32,750 lbs	Per standards IEEE-45, CG-259, ABS rules. Install lengthwise (b), (a), (c) and (d) order. Located in unclassified area.

No.	Description	Dimensions	Unit Wt.	Ttl. Wt.	Remarks
23.	LD12 - 4160 V 1250 HP Variable Frequency Drive Control (Continued)				
	(c) 1500 KVA Step-Up Insulation Transformer. 4160 V - 480 V - 3Ø - 60 HZ Dry-Type	72"L x 55"W x 90"H	6,500 lbs.		
	(d) 1200 A - 250 MVA Class Vacuum-Type Marine Service Metal Clad Switchgear	36"L x 109"W x 111"H	4,750 lbs.		

APPENDIX I

CONTROL AND INSTRUMENTATION

- I.1 Control Instrumentation Description
- I.2 Diagnostic Instrumentation Description
- I.3 DACS Hardware Description

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Appendix I

CONTROL AND INSTRUMENTATION

Instrumentation and hardware selected for the power module is described as follows:

- Control Instrumentation
- Diagnostic Instrumentation
- DACS Hardware

I.1 CONTROL INSTRUMENTATION DESCRIPTION

- (1) Ammonia liquid level capacitance probe: An Invalco Process Equipment Model 400 level measuring system has been selected to satisfy the requirements of measuring the evaporator and condenser sump liquid levels. The Model 400 is a continuous level indicator and/or controller for application on liquids and in particular liquid ammonia. The 400 uses the proven capacitance probe principle and features the latest in electronic techniques, such as modular design and solid state circuitry. Features include wide range of adjustment, high sensitivity and stability, and repeatability of 0.1 percent of span. Input power requirements are 6 W @ 115Vac $\pm$ 15 percent, thereby enabling an output of 4-20 mA as required. Figure I-1 shows the selected probe with an explosion proof housing for the measuring unit.
- (2) Turbine Speed. Turbine speed will be measured by a Tachometer-Generator such as the Sticht Model C or equivalent. The Model C dc Tachometer-Generator is a heavy duty totally enclosed unit designed for continuous maintenance free operation. The dc electrical output of the Generator (transmitter) is directly proportional to the rotational speed of the Generator and no outside source of power is required. The speed signal will be brought out to the nearest RTU where it will be conditioned, sampled, quantized and transmitted to the Control Center for display and control purposes. Figure I-2 shows the Sticht Co, Model C, Tachometer Generator.

Fig. I-1 INVALCO Model 400 Liquid Level Probe

Fig. I-2 Sticht Co. - Model C - Tachometer Generator

- (3) Pressure Transducer: To sense Evaporator and Condenser pressures a Druck Ltd, Model PDCR22 bonded strain-gage pressure transducer has been selected. This transducer will obtain its input pressure signal via stainless steel tubing introduced into the appropriate evaporator and condenser locations. Used in conjunction with a Recording Devices Model SCSG/S4-20MA, Signal Conditioner/ Transmitter, the input pressures are mechanically multiplexed using a Scanivalve system and the output 4-20mA signal is transmitted to the appropriate RTU as depicted in dwg. No. 55531926, Preliminary Instrumentation Schematic, OTEC 10-MW(e), MAPS, Appendix C. The Scanivalve system is described in greater detail in Section 4.6.5.

I.2 DIAGNOSTIC INSTRUMENTATION DESCRIPTION

- (1) Thermistor Probe: All ammonia and seawater temperatures to be measured for either control or diagnostic purposes will use the same type sensor. During normal operation, most system temperature changes will be very small; therefore, for an accurate representation of temperature change at the control center, a sensitive, accurate, and reliable sensor has been selected. A Yellow Springs Instrument (YSI) Model 44018 thermistor composite mounted in a Model 710 probe assembly has been chosen as the measuring device. The high degree of sensitivity plus the excellent long term stability characteristics exhibited by thermistors allow low excitation levels and, therefore, linear and reliable output data over the specified temperature range. The thermistor is sheathed in stainless steel as depicted in Fig. I-3 and, consequently, will not be affected adversely by the ammonia or seawater.
- (2) Annubar Primary Flow Sensor: Referring to Dwg. No. 5531926, Appendix C, both seawater and ammonia flow rates will be measured for test and diagnostic purposes. The sensor selected for this measurement is the ANNUBAR primary flow sensor. This sensor is designed to accurately (± 1 percent of flow) sense the velocity of a

Fig. I-3 Model 710 Shielded Thermistor Probe for Ammonia
And Seawater Temperature Measurement Application

fully developed turbulent flow profile and convert it to differential pressure directly proportional to flow rate. The information is converted to an electrical output signal by a Flo - Tek variable reluctance-type transmitter environmentally sealed with adjustable zero and span control. Accuracy of this device is better than ± 1 percent for the selected range. The transmitters will be mounted externally to the ammonia and seawater pipes with appropriate adjacent in-line valving to permit zeroing, calibration, and removal without shutting down. Flow signals will go to the nearest TRU for conversion and/or transmission to the DACS control center. A typical transmitter system block diagram is given in Fig. I-4.

- (3) SCANIVALVE: Evaporator and Condenser pressures are being measured as described in paragraph 5.6.4 (3). Ammonia and liquid nitrogen storage tank pressures, as delineated in Dwg. No. 5531926, Appendix C, will use the same type of pressure transducer. The use of a Scanivalve as shown in the referenced drawing, effectively eliminated the multiple pressure transducers required for every pressure measurement and simplified the preliminary design. The selected Scanivalve sequentially monitors control and/or test pressures and interfaces with a single transducer, i.e., the Druck Ltd, Model PDCR22. Two reference level pressures are provided which enable automatic calibration of the system on every complete scan. The Scanivalve introduces no error into the system greater than that of the transducer. Figure I-5 depicts the basic Scanivalve principle.

Fig. I-4 Flow Transmitter System Block Diagram

Fig. I-5 Basic SCANIVALVE System

- (4) Fluid Analyzer. Ammonia Vapor Quality is being measured by a "Gam Rad" Model 150, Fluid Analyzer installed between the Demister and the Turbine inlet on the ammonia vapor pipes (Ref. Appendix C - Dwg No. 5531906). This is an optical type instrument that uses the back-scatter principle to obtain accurate measurements of suspended ammonia droplets in the vapor stream. As depicted in Fig. I-6, a condensed beam of light is directed through a window into the ammonia vapor stream. The light is scattered at effectively 180 degrees to the incident light by suspended particles. Although vapor phase ammonia is invisible, any droplets of ammonia scatter light making it visible. Light scattered or reflected backwards from the suspended droplets in the vapor phase passes through an adjacent window to a temperature stabilized light detector. The light source is electronically monitored and controlled to a constant candlepower. Sensitivity of this instrument is equal to or better than 10 parts per million. Additionally, this type of instrument offers no obstruction or pressure drop to the vapor flow, is explosion proof, and has no moving parts. This unit by monitoring the amount of backscatter of light off of the mist, measures mist density, which is proportional to the absolute concentration of liquid ammonia in the pipe. The output signal will be processed through the nearest RTU where, after sampling and conditioning, it will be transmitted to the control center. The control center CPU converts the signal to the percent relative liquid/gas concentration by comparison with the total ammonia throughout, and displays and/or activates controls as required.
- (5) Accelerometer: Tube vibration measurements will be made using an ENDEVCO Model 2221F hermetically sealed shear accelerometer. The Model 2221F is a self generating piezoelectric transducer that requires no electric power for operation and weighs 11 grams. The shear construction not only minimizes transverse and strain sensitivity but also provides flexibility of installation. Figure I-7 depicts the Model 2221F Accelerometer.

Fig. I-6 Ammonia Vapor Quality Measurement Light Scattering Optical System

Fig. I-7 ENDEVCO Model 2221F Shear Accelerometer

- (6) Ammonia Leakage Online Analyzer: The detection of ammonia out-leakage into the seawater system is being accomplished by use of an ORION, Series 1000, On-line Analyzer. The Series 1000 system selected is a single parameter, on-line analyzer that gives continuous real-time analyses of ammonia leakage into the seawater system. Referring to Fig. I-8, Basic Schematic, Series 1000 System, it can be seen that the design of this analyzer is simple and straightforward. The sample is first filtered and then mixed with a reagent which minimizes interferences and fouling. (Reagent consumption is kept low to keep operating costs low). This sample/ reagent mixture is pumped through the thermostatted electrode head for measurement. Sample color and turbidity do not affect system accuracy.

The electrode output is fed to the electronics unit and amplified. Voltage and current outputs are provided for remote reading and control. A panel meter gives continuous readings of concentration. Variable high and low set points on the meter can be positioned for alarming or control at specified concentration levels. A strip chart recorder gives a permanent record of the sample stream concentration.

The series 1000 unit has a sensitivity of 0.1 ppm, an accuracy of better than ± 10 percent of reading and a repeatability of better than ± 5 percent of reading. Multiple sampled stream seawater inputs will be provided taken from seawater outlets of the Evaporator and the Condenser. This will enable early detection of ammonia leaks from either the Evaporator or Condenser. (See attached brochure, Fig. I-8).

- (7) Ammonia Gas Leakage Sensor: An ammonia vapor alarm system will be provided and installed that satisfies regulatory body practices. An International Sensor Technology, (IST) Model AG22000, Solid-State electrolytic cell gas sensor housed in an explosion proof housing has been chosen to satisfy this requirement. This unit is reliable, accurate, requires no maintenance, and is stable over a wide range of temperature and humidity. Sensitivity can be set for whatever

Series 1000 on-line analyzers performance characteristics

The Series 1000 systems are single parameter, on-line analyzers that give continuous, real-time analyses of a variety of inorganic ions and dissolved gases. Measurements are made reliably with laboratory accuracy in the rigorous environment of the industrial plant. These analyzers can be used to alarm, monitor the plant's effluent, or control a process. Applications range from quality control measurements, to sewage treatment, to verifying that discharge permit levels are met.

These analyzers offer important economic savings whenever samples from a batch or continuous process, or the plant's effluent must be sent to the laboratory for analysis at frequent intervals. With a Series 1000 monitor results are available continuously day and night, and "out of spec" conditions are immediately reported.

system operation

The design of these analyzers is simple and straightforward. The sample is first filtered and then mixed with a reagent which minimizes interferences and fouling. (Reagent consumption is kept low to keep operating costs low.) The sample/reagent mixture is pumped through the thermostatted electrode head for measurement. Sample color and turbidity do not affect system accuracy.

The electrode output is fed to the electronics unit and amplified. Voltage and current outputs are provided for remote reading and control. A panel meter gives continuous readings of concentration. Variable high and low set points on the meter can be positioned for alarming or control at specified concentration levels. A strip chart recorder gives a permanent record of the sample stream concentration.

filtration

High levels of suspended solids and algae in the sample stream can raise havoc with the reliability of on-line analyzers. ORION has overcome this difficulty with a unique by-pass filtration system that uses the sample stream itself to keep the filter surface clean. Difficult samples such as river waters and sewage are handled with a minimum of filter maintenance.

ORION INDUSTRIAL

Division of Orion Research Incorporated

Fig. I-8

Ammonia Leakage Online Analyzer

typical applications

Monitoring of ammonia in plant effluent.
Control of coke oven ammonia still.
Maximizing ammonia recovery in the Solvay process.
Continuous measurement of ammonia in potable water.
Monitoring of ammonia in sour-water stripper bottoms.
Ammonia control before nitrification of secondary wastewater.
Quality control measurements of chloride in the manufacture of ascorbic acid.
Control of chloride in copper refining process.
Monitoring of HCl effluent in textile manufacture.
Control of chloride during crude desalting.
Measurement of chloride in the ppb range for early detection of sea water leaks in condenser tubes and monitoring of steam/water circuit quality.
Monitoring of cyanide in effluent from electroplating operations.
Control of cyanide destruction.
Monitoring effluent from blast furnace scrubber for cyanide.
Effluent control of fluoride.
Control of fluoride in aluminum etching process.
Fluoride removal from semiconductor manufacture wastewater.

Ensuring that chlorine effluent limitations are met.
Monitoring HF in stack gas scrubber.
Monitoring of sulfide in steam stripper effluent during heavy water separation.
Monitoring of nuclear fuel processing effluent for fluoride.
Control of water fluoridation.
Monitoring nitrate for continuous control of methanol addition during denitrification.

users:

Air Products, Alcoa, Allied Chemical, American Cyanamid, Amoco, Atlantic Richfield, Bethlehem Steel, Citgo, Detroit Diesel, Dow-Badische, Dow Canada, Dow Chemical, Du Pont, Eastalco Aluminum, Easterly Advanced Wastewater Treatment Plant, GTE Sylvania, Hoffman-LaRoche, Honeywell, Inland Steel, IBM, Kaiser Aluminum, Maine Yankee Atomic Power, Merck, Mobil, Monsanto, Motorola, NASA, Ontario Hydro, Ontario Research Foundation, Parker, Republic Steel, Reynolds Metals, Rohm & Haas, Shell, Sohio, Teledyne, Tenneco, U.S. Air Force, U.S. Army Corps of Engineers, U.S. EPA, Western Electric, Westinghouse.

ORION is the world's leading manufacturer of chemical-sensing electrodes. These devices are in use in literally thousands of quality control and industrial laboratories. On-line analyzers for a variety of other applications are easily designed around ORION electrodes for ammonia, bromide, cadmium, calcium, chloride, cupric, cyanide, fluoride, fluoroborate, iodide, lead, nitrate, nitrogen oxide, perchlorate, pH, potassium, silver/sulfide, sodium, thiocyanate, and water hardness.

Every Series 1000 on-line analyzer installation is tailored to the specific application. A choice of filtration systems, concentration range, reagent composition, standardization point, and dual set points allows great flexibility in monitor design. Streams with high solids content are fitted with a special by-pass strainer. Very concentrated samples are brought to measurable levels with an optional predilutor.

general specifications

accuracy	better than $\pm 10\%$ of reading
reproducibility	better than $\pm 5\%$ of reading
response time from filter inlet	1 to 2 minutes for initial response 6 to 8 minutes for 90% response
required sample conditions	flow: 4 liters/min. (1 gal/min.) pressure: 1.5 to 1.75 atm (20 to 25 psig) temperature at filter inlet: 0° to 70°C (32° to 158°F)
filtration system	by-pass filtration system standard equipment (sample temperatures to 70°C [158°F], high resistance to corrosives) by-pass strainer assembly available where sample particulate size greater than 0.8 mm (1/32 inch)
required environmental conditions	protected from weather and corrosive gases maximum ambient temperature: 45°C (113°F)
reagent consumption	20 liter (5 gal) carboy in 60 days (for most systems)
standard solution consumption	3 to 6 liters (0.7 to 1.5 gal) in 60 days
automatic restandardization	automatically introduces standard solution into monitor at 24-hour intervals; corrects base-line drift; cumulative drift recorded on meter; standardization point varied according to the application for maximum accuracy
controls — front panel	power (on/off), manual standardization, dual set-point adjust (high/low limits)
— amplifier panel	calibration control, slope control, electrode thermostat control, auto/manual standardization switch, auto cal bias switch
outputs — meter	14 cm meter, 2 or 4 decades of concentration
— recorder	10 cm logarithmic strip chart
— alarm control	high and low adjustable set-point control, SPDT contacts, 10 A rated at 125V (1/4-horsepower)
— analog control signal	linear or logarithmic with concentration 0 to 5V DC into 10K Ω minimum load and one of following current outputs: 1 to 5 mA (2K Ω max load), 4 to 20 mA (500 Ω max load), 10 to 50 mA (200 Ω max load)
power requirements	100/115/220/240V AC, 50/60 Hz, 220 watts
size: height	120 cm (52"), 167 cm (66") with thermoelectric cooler power supply
width	67 cm (24"); 92 cm (36") with by-pass filter
depth	36 cm (15")
weight	145 kg (320 lb)
shipping weight	160 kg (350 lb)

specifications subject to change without notice

Series 1000 on-line analyzers prices and options

model	parameter measured	standard concentration range	maximum concentration with predilutor
110200	carbonate	2.5 - 1000 ppm	25,000 ppm
110700	nitrate/nitrite	0.1 - 10 ppm (as N)	250 ppm
110900	fluoride	0.02 - 19,000 ppm	475,000 ppm
111000	ammonia	0.1 - 10,000 ppm (as N)	250,000 ppm
111100	sodium	1.0 - 10,000 ppm	250,000 ppm
111600	sulfide	0.1 - 1,000 ppm	100,000 ppm
111700	chloride	1.0 - 5,000 ppm	100,000 ppm
112500	total residual chlorine	0.05 - 100 ppm	2,500 ppm
113200	water hardness	1.0 - 1,000 ppm (as CaCO_3)	25,000 ppm
119100	hydroxide (with predilutor)	0.4 - 40% (as NaOH)	---
120600	cyanide (amenable to chlorination)	0.05 - 100 ppm	2,500 ppm
122900	copper (with predilutor)	1.0 - 10,000 ppm	---

Analyzer includes 4-inch strip-chart recorder, dual set-point control, logarithmic milliamp output, filter assembly, automatic restandardization, reagent for 60 days of operation, operating and maintenance instructions, and on-site commissioning. Only Orion reagents are to be used in the analyzer.

options

strip-chart recorder
dual set-point control
filter assembly
automatic restandardization
by-pass strainer assembly
linear milliamp output
predilutor type 1 (NH_3 , NO_3 , CN , Cl_2)
predilutor type 2

supplies contract

Supplies are shipped to the customer from ORION on a prearranged schedule and include replacement filters, all reagents, electrodes, and tubing replacements necessary for one year's *continuous* operation, twenty-four hours a day. Prices for supplies contracts depend on the composition of the reagent for each application. Available in U.S.A. and Canada only; elsewhere individual supplies available upon request.

For more information call:

In Massachusetts: (617) 864-5400
Outside Mass.: (800) 225-1480
In Canada: (800) 363-9270
In Europe: (01) 910-7858 (Zurich)

Fig. I-3

ORION INDUSTRIAL

Division of Orion Research Incorporated
380 Putnam Ave. Cambridge MA 02139

I-12

Form Series 1000/777
Printed in U.S.A.

range is desired, e.g., 0 to 10 ppm or 0 to 100 ppm, and since the unit does not operate on the combustion principle, the sensor will not burn out in high gas concentrations should they exist. Units will be installed in each Machinery Room, the Access Tunnels, the Main Deck and the 01 Deck with cabling being routed to the nearest RTU. Surveillance of each sensor, via periodic scanning will be handled automatically with alarms coming into the Control Center and triggering a flashing CRT color alarm with audio alert that will require operator intervention to silence. Additionally, alarms will be provided in the Machinery Rooms and the main deck alerting personnel of an ammonia leak. During detail design, the possibility of (1) interlocking this signal with valves to flood the area where the leak is located with nitrogen and (2) locking the door leading to the Machinery Rooms Access Trunks will be explored.

Figure I-9 shows the basic Model AG2200 housed in an explosion proof housing.

Fig. I-9 IST, Model AG2200 Gas Sensor

- (8) Near-Infrared Photometric Analyzer: Because of the importance of maintaining an ammonia system of ≥ 98 percent purity, a seawater detector is being designed into the system between the Evaporator sump outlet and the distribution pumps as shown in Dwg. No. 5531906, Appendix C. Continuously monitoring the percent water in the ammonia system will determine when to activate the ammonia cleanup system. The selected sensor for this measurement is an all

solid-state near-infrared (NIR) photometric analyzer which has both liquid and gas phase capability (Teledyne Analytical Instruments Model 514). This instrument is ideal for monitoring parts-per-million (ppm) seawater concentration in liquid ammonia with a sensitivity of zero to 10^4 ppm full scale and an accuracy of ± 2 percent. The output signal from this sensor, as determined by appropriate limits, will be used to activate the ammonia cleanup system and indicate unwanted seawater intrusion into the overall system. Figure I-10 depicts the Model 514.

Fig. I-10 Teledyne Analytical Instruments Model 514
NIR Photometric Analyzer

- (9) Oxygen Deficiency Detector: A "safe atmosphere" or oxygen deficiency detector which satisfies regulatory body requirements has been designed into each Machinery Room. The unit selected for this application is a Gas Tech, 1220 series oxygen alarm system. A catalytic detection element sensor responds to an oxidation reaction and alarm levels are triggered depending on sensor control electronics settings. Each unit will be connected, as shown in Dwg. No. 5531926, Appendix C, to the local machinery room RTU for signal conditioning and transmission to the Control Room. In the Control Room a continuous reading of oxygen levels in the Machinery Rooms will be available. Deficient oxygen levels in either of the Machinery Rooms will trigger a flashing CRT color alarm with audio alert that will require operator intervention to silence. During detail design, the possibility of interlocking this signal with the door lock leading to the Machinery Room Access Trunk will be explored. Such an interlock would preclude the possibility of personnel entering the Machinery Room Access Trunk during periods of oxygen deficiency. Figure I-11 depicts the series 1220 Oxygen Deficiency Detector.

Fig. I-11 Gas Tech Model 1220 Oxygen Deficiency Detector

- (10) **Flooding Sensors:** Flooding sensors will be installed in each of the Machinery Rooms to satisfy commercial marine practice. Individual magnetic float operated level switches, (Compac, Model 660N), will be mounted a few inches above the Machinery Room bilge and also approximately 13 ft above the low point of the bilge. In this manner, surveillance of each Machinery Room bilge space, via periodic scanning, will be handled automatically with alarms coming into the Control Center alerting operating personnel of flooding conditions. The selected sensor uses magnetic floats to detect liquid level changes. When the float moves, the attendant change in level is transmitted through a non-magnetic barrier to a magnetic reed switch. The advantages of this detection method are:

Simplicity - No Bearing, Linkages or Power Consuming Circuits

Reliability - Long Life Reed Switches Are Sealed in Glass (a Minimum of 1000,000 Cycles are Guaranteed)

A cutaway view of a typical single point magnetic level switch is given in Fig. I-12.

- (11) **10-MW(e) MAPS VALVE STATUS:** It can be seen (Ref. Dwg. No. 5531906, Appendix C), that there are 60 valves in the 10-MW(e) MAPS. Therefore, it was decided during the preliminary design phase to monitor valve status to ensure that appropriate operational procedures are followed; i.e., prior to startup the position of each

Fig. I-12 Compac Model 600N Single Point Magnetic Level Switch

valve in the system must be verified to ensure a proper startup sequence. A standard contact closure or switch with transient voltage and dv/dt suppression as required is being provided to sense valve position, i.e., open or closed. In the case of proportional control valves, flow control regulation, and indication of valve position will be sensed via a linear pot or equivalent sensor. The valve position signal outputs are being made continuously available to the nearest RTU for transmission to the Control Center for display, alarm and or control purposes as required. A simplified valve position indicating circuit is shown in Fig. I-13.

Fig. I-13 Simplified Valve Position Indicating Circuit

I.3 DACS HARDWARE DESCRIPTION

- (1) Central Processing Unit (CPU). A MODCOMP II Computer (Fig. I-14) has been selected which will satisfy the requirement for real-time multiprogrammed data acquisition and control.

Some of the outstanding features of this computer are as follows:

- 64K of non-volatile core memory
- 800 ns cycle time
- All memory directly addressable
- 15 general purpose registers
- 16 bit parallel processing
- A large instruction set
- Memory protect
- Memory parity
- Capability to add user instructions and processing extensions
- Four memory ports for simultaneous I/O and computation and for multi-processor configurations
- Front and back maintenance access to all computer and memory planes
- Plug-in integrated circuits for easy repairability

Data transfers and processing are controlled by the execution of 40-bit microinstructions stored in the Read Only Control Memory. A new microinstruction is accessed and executed each 267 nanoseconds. Therefore, three microinstructions are executed per 800 nanosecond main memory cycle. This rate enables many instructions, such as register-to-register operations, to be accessed from core memory, and executed in a single memory cycle.

Figure I-15 is a block diagram delineating the basic organization of the MODCOMP II computer. All major system elements are connected to the modular bus structure, which is the 16-bit parallel path used for all data transfers within the computer.

Fig. I-14 MODCOMP II Computer

(2) Plotter. Real time plotting of time history for selected test parameters is required. The unit selected to satisfy this requirement is the VERSATEC 3000 Series Printer/Plotter (Fig. I-16). This Plotter has the following features:

- Electrostatic plotting (no mechanical arms or pens)
- Standard ASCII character set
- 100 dots per inch minimum resolution
- Built-in diagnostic testing
- RS-232C interface
- Hard copy production from CRT display

Fig. I-15 MODCOMP II Block Diagram
I-20

LOCKHEED MISSILES & SPACE COMPANY, INC.

Fig. I-16 Versatec 3000 Plotter

- (3) Printer. For hardcopy printout of data, the MODCOMP Model 4213 matrix printer has been selected (Fig. I-17). This printer provides the computer with a buffered line printing capability. The printing rate is 60 lines per minute on full, 132 character lines, and up to 150 lines per minute on short lines.

Fig. I-17 MODCOMP Model 4213 Printer

- (4) Card Reader. For computer system loading a standard Card Reader is required. A MODCOMP Model 4411 Card Reader has been selected for this purpose (Fig. I-18). The Model 4411 Card Reader is a compact, reliable unit which reads standard 80 column punched cards photoelectrically at speeds up to 300 cards per minute. Its vacuum picker mechanism handles cards gently and smoothly to reduce card wear and facilitate the reading of worn and well used cards.

The card reader can read either binary or Hollerith (IBM 029) card codes. The Hollerith code is translated to an eight-bit code in the controller before being transferred to the computer.

The card reader incorporates extensive self checking and error-checking features for reliable, error-free reading over a wide range of environmental conditions.

Fig. I-18 MODCOMP Model 4411 Card Reader

- (5) Teletypewriter. A programmer's entry device is required for computer systems start-up, diagnostic routine execution and maintenance, and software development activity support. A Texas Instrument Model S743 Teletypewriter (Fig. I-19) has been selected for this activity which meets the following requirements:

- 30 characters per second
- 72 characters per line
- Standard typewriter keyboard
- RE-232C interface

- (6) Display/Keyboard Terminals. The man/machine interface will be via color CRT display/keyboard terminals. The CRT terminals selected for this system will be console mounted units manufactured by Intelligent Systems Corp. (ISC). The Intecolor 8001 CRT provides all features specified for the terminals and is depicted in Fig. I-20. Major features of the CRT display/keyboard terminals are as follows:

- 19 inches diagonal with rectangular display area of approximately 120 square inches
- Character format of 80 characters per line, 48 lines per page
- 64 ASCII characters displayed undistorted and of equal size
- Graphics operational modes with plotting on a 160 by 192 screen grid and automatic plotting of X and Y bar graphs by defining end points; also individual point addressing and plotting, and automatic incremental point movements
- Eight colors — red, green, blue, magenta, cyan, yellow, white and black
- Two color levels — foreground and background with eight colors each
- Full-Duplex/Half-Duplex/Local communication modes keyboard selectable
- Switch selectable data rates from 110 to 9600 baud with RS-232C interface

Fig. I-19 Texas Instrument Model S743 Teletypewriter

Fig. I-20 Intercolor 8001 CRT Display/Keyboard Terminal

- Separate standard ASCII 3-level code plus 16 function keys with keyboard cursor and color select cluster
- Double cursor XY positioning, page mode (with roll-up) operation, blink, color selection and transmit
- Programmable intelligent terminal with 8080 microprocessor
- Protected format for fill-in-the blanks operation

The alphabetic keyboard format will be the same as a standard office typewriter. All other keys will be engraved to indicate the function provided. All CRTs and keyboards will be identical to enhance maintenance and minimize spare parts provisioning.

- (7) Disc Storage. A disc storage capability is required for program storage and for interim experimental data buffering. This requirement is satisfied by the use of the MODCOMP Model 4128 Disc Storage unit (Fig. I-21). Features of the disc units are as follows:

- Dual platter discs (1 removable, 1 nonremovable platter)
- Total Storage — 2,598,400 16-bit words per disc unit
- 70 milliseconds average head positioning time
- 20 milliseconds average latency
- 97,800 words/sec transfer rate
- Hardware write protect switches to protect stored programs

- (8) Magnetic Tape Data Storage Units. A magnetic tape storage capability is required for long term storage of operational and diagnostic data enabling review at later dates and other locations. This requirement is satisfied by the use of MODCOMP

Model 4148-1 Magnetic Tape Drive and Controller (Fig. I-22). The MODCOMP Model 4148-1 Magnetic Tape Drive and Controller provides data and program storage at 45 IPS, 800 BPI on 10, 5-in. standard, 1/2-in. magnetic tape reels. Data recording format is 9 track with parity, standard computer industry compatible.

Fig. I-21 MODCOMP Model 4128 Moving Head Disc Storage Unit

Fig. I-22 MODCOMP Model 4148-1 Magnetic Tape Drive and Controller

Appendix J
MODULE ASSEMBLY

CONTENTS:

- J1 OTEC POWER MODULE STUDY
- J2 LSCC PRELIMINARY OTEC NOTES

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OTEC POWER MODULE STUDY

1.0 MODULE ASSEMBLY

The power system module assembly study delineates various methods that could be applied to produce the completed end article at a major shipyard. It was determined that a shipyard is best suited for the structural fabrication, component assembly and installation, and final outfitting requirements inherent with each power system configuration that was considered, particularly in view of the logistics problems and the implications of potentially conflicting labor jurisdictions. Waterfront location, shops essential to support the production requirements, and every principle craft with clearly defined labor jurisdiction agreements are all found in major U.S. shipyards. And it was further determined that a major shipyard would not face any requirements for compliance with OSHA or other government regulatory agencies in the production of this article other than those associated with ship construction.

1.1 Basis and Conditions

1.1.1 Configurations Reviewed. The following five power modules were reviewed from the standpoint of construction, installation, facilities, and costs:

- 50MW_(e) Immersed Unitized
- 50MW_(e) Immersed Segmented
- 50MW_(e) Submerged, Unitized, Cantilevered heat exchangers
- 50MW_(e) Submerged, Unitized, Cantilevered seawater pumps
- 10MW_(e) Immersed, Unitized

1.1.2 Basis of Study. This study evaluated the above configurations for assembly and cost comparisons, establishment of construction approaches, the identification of potential problems inherent with the installation of equipments, and to make recommendations of methods and facilities to support the installation and construction. This study did not include OTEC equipment costs.

1.2 Facility Requirements for Installation

1.2.1 Handling Requirements. Studies of the various power system configurations indicated that the first consideration for their installation and assembly must be the handling of heavy lifts.

Approximate weights of the various equipment are indicated in Table 1-1.

Table 1-1

MAJOR EQUIPMENT WEIGHTS

Approximate Weight (tons)

Equipment	50MW (e) Immersed	50MW (e) Submerged	10MW (e) Immersed
Condenser	2802	1872	928
Evaporator	2541	1872	880
Seawater Pump	175	175	65
Generator	153	153	67
Turbine	70	70	31
Condensate Pump	16	16	7
Distribution Pump	14	14	6

NOTE: ALL TONS AT 2000#.

1.2.2 Equipment Loading. Various alternatives for installing the heavy components into power modules are as follows:

- Graving dock with overhead gantries or whirley-type cranes where capacities permit.
- Gantry loading facility where components could be lifted from seagoing barges and positioned in power module.
- Stiff-leg or shear-leg at a pier where loads could be lifted from seagoing barges and positioned in power module.
- Barge cranes with a spreader beam between the cranes lifting from each side of seagoing barge then moving out the seagoing barge while bringing in the power module.

1.2.3 Pier-Side Installation. Foundations for the components determined by their weight would be installed at pier side or by the foregoing heavy lift means. Piping, valves, and other light equipment would be installed pier side. The major concern, however, is the extreme depth required pier side for the submerged configuration.

1.2.4 Heat Exchanger Handling. The extreme weight and bulk of the heat exchangers presents a special handling problem requiring a study of state-of-the-art handling facilities.

1.2.5 Existing Facilities

United States Shipyards. An investigation of U.S. shipyards disclosed that the maximum handling capacity was that of General Dynamics Corporation, Quincy Shipbuilding Division. A 1,200-ton Goliath Crane - the largest in the western hemisphere - has been installed for transferring spherical LNG tanks from the barge on which they are delivered to LNG ships. Their largest dock (936 ft by 143 ft) is not wide enough for the 50MW_(e) Power Modules.

The second largest handling capacity is located at Newport News Shipbuilding and Dry Dock Company. A 900-metric-ton (992-ton) Gantry Crane services their number 12 building dock. This dock is 1,600 ft long and 240 ft breadth at entrance, which is large enough for the power modules under consideration; however, the handling capability falls short of the lightest 50MW_(e) size heat exchangers. (Refer to Table 1-1.)

U.S. major dry docks and handling is given in Table 1-2.

Table 1-2

MAJOR SHIPBUILDING AND REPAIR DOCKS - UNITED STATES, 300,000 DWT TONS OR OVER

Length (ft)	Breadth (ft)	Draft (ft)	Weight (DWT) (TONS)	Service	Owner	Location
1,600	250	33	500,000	One 990-ton crane	Newport News Shipbuilding and Dry Dock Company	Newport News, Va.
1,200	200	28	400,000	Two 100-ton cranes	Bethlehem Steel Company	Sparrows Pt., Md.
1,200	120	42	500,000	Not Known	U. S. Navy	Boston, Mass.
1,152	157	53	500,000	Five 50-ton cranes	U. S. Navy	Bremerton, Wash.

Other U.S. shipyards with single lift handling in excess of 200-tons are:

- Sun Shipbuilding and Dry Dock Company, one 800-ton barge crane and three 250-ton gantry cranes
- Avondale Shipyard, Inc., one 600-ton barge crane
- Alabama Dry Dock and Shipbuilding Company, one 275-ton Goliath Bridge Crane
- Marathon LeTourneau Company, Gulf Marine Division, one 250-ton gantry crane

Figure 1-1 is a layout of the Newport News Shipbuilding and Dry Dock Company's dock and crane facility. It was determined that this facility is the most favorable for heat exchanger installation. Note that the 900-metric-ton gantry crane spans the final assembly area, a barge unloading area, and the large graving dock.

Commercial Barge Cranes. Due to the limited crane capacities of shipyards, an investigation was made into commercial barge cranes available for subcontract. Although barge cranes capable of handling about 3,000 tons have been built, they are for special application on northern oil exploration and production platforms and unless some unique agreement could be reached with the owners they would not be available for normal commercial use. Barge cranes that were available showed an absence of ample capacity for the 50MW_(e) size heat exchangers.

Various barge cranes, capacities, owners, and location are indicated in Table 1-3.

Fig. 1-1 Dock and Crane Facility at Newport News Shipbuilding and Dry Dock Company

Table 1-3

AVAILABLE BARGE CRANES

Location	Owner	Cap. Over Stern (tons)	Distance From Stern to Hook (ft)	Cap. Revolving (tons)
Seattle	Manson Construction	400	55	300
S. F. Bay Area	Smith-Rice	410	65	325
Los Angeles	Crowley Maritime	385	60	275
Los Angeles	U. S. Navy	385	54	250
Houston	Brown and Root	550	72	390
Houston	Brown and Root	350	67	230

Heavy Lift Specialists. Further search for heavy lift capabilities lead to consideration of heavy lift specialists, such as the firms that handle nuclear reactors and oil platform modules for the Alaska North Slope. Rigging International with headquarters in Oakland, California, was contacted. They currently have a 1,550-ton twin luffing derrick at Pinto Island, Mobile, Alabama. This facility was designed and constructed to install LNG tanks in large LNG ships under a contract with Kaiser Aluminum and Chemical Sales Corporation.

Another facility, owned by Rigging International, is a 660-ton stiff-leg at Longview, Washington. This facility can lift 600 tons 90 ft from pier side.

Shipyard Facilities in Japan. For information purposes a tabulation of building docks and repair docks in Japan along with crane capacities is presented in Tables 1-4 and 1-5. Although handling facilities in Japanese shipyards in general are much better than in the United States, they still fall short of the heavy lift requirements. The best handling in Japan's docks would indicate 800 tons and several at 600 tons.

800	55
600	60
400	65
300	70
200	75
100	80

TABLE 1-4

MAJOR SHIPBUILDING DOCKS-JAPAN, 300,000 DWT TONS OR OVER

Length (ft)	Breadth (ft)	Draft (ft)	Weight (DWT) (Tons)	Service	Owner	Location
3,248	328	38	Not Listed	Two 300-ton cranes	Mitsubishi Heavy Industrial, Ltd.	Koyagi
2,657	301	46	500,000	Two 400-ton cranes One 100-ton crane	Ishikawajima - Harima Heavy Industrial Company, Ltd.	Chita
1,667	262	27	500,000	Two 200-ton cranes Two 50-ton cranes	Ishikawajima - Harima Heavy Industrial Company, Ltd.	Kure
1,230	183	38	500,000	Two 300-ton cranes	Mitsubishi Heavy Industrial, Ltd.	Nagasaki
1,131	213	20	300,000	Two 150-ton cranes	Ishikawajima - Harima Heavy Industrial Company, Ltd.	Kure
1,837	262	41	500,000	Two 300-ton cranes Three 30- ton cranes	Sumitomo Shipbuilding and Machinery Company, Ltd.	Oppama
1,640	246	39	600,000	Two 300-ton cranes Two 100-ton cranes	Nippon Kokan	Tsu
1,362	246	30	500,000	Two 300-ton cranes Three 150- ton cranes	Kawasaki Heavy Industrial, Ltd.	Sakaide
1,312	236	28	500,000	Two 300-ton cranes One 40-ton crane	Mitsui Shipbuilding and Engineering Company, Ltd.	Chiba
1,312	180	25	300,000	Three 200- ton cranes	Hitachi Shipbuilding and Engineering Company, Ltd.	Osaka
1,181	197	25	300,000	Two 250- ton cranes	Hakodate Dock Company, Ltd.	Hakodate

Costs for Facility Handling Concepts

Acquisition costs of crane handling facilities are shown in Fig. 1-2.

This graph is based on a stiff-leg capable of reaching the load capacity at 120 ft from a pier, and on a gantry crane that would span a 220-ft-wide dock and lifting a capacity load on center. Cost figures to develop these curves were received from Rigging International for the stiff-leg, and Paceco for the gantry over dock.

Fig. 1-2 Acquisition Cost of Crane Handling Facilities

1.2.6 Movements by Other Than Cranes. Since cranes of sufficient capacity to handle 50MW_(e) heat exchangers are unavailable and extremely expensive, other means must be considered. Methods for the movement of heavy components by other than cranes that could be considered are:

- Floating
- Rolling track dollies
- Wheel carriages on tracks
- Pneumatic lift pallets (air cushion)
- Hydro lift pallets (water cushion)
- Gripper jacks
- Combination of the above

All these methods are widely used in the industry, but are generally best suited to rigid structures. In the case of heat exchangers for OTEC, care must be taken to avoid the transfer of concentrated loads into the vessel shell. Although the load to be lifted would be increased, the mounting foundations could be assembled to the heat exchangers and used to guard against load concentration. Transfers of loads without cranes is normally accomplished by hydraulic jacking. However, especially for long reach applications, chain jacks, gripping air jacks and rack and pinion jacks should be considered. Methods for the actual movements must be determined and developed for the specific item being moved and the facilities available at a definite location.

1.2.7 Graving Dock or Building Ways for Power Modules. Figure 1-3 depicts a plan of either a graving dock or building ways for construction of a 50MW_(e) power module. The graving dock facility has a gantry crane over the dock. Wing walls extend the gantry coverage beyond the miter gates allowing the gantry to transfer loads from a

seagoing barge to the power module. The graving dock would be more effective for installation than the building ways. The graving dock (or floating dry dock) also has the capability to unload a power module for repair or refurbishment. Another concept having the unload capability is a flat or near flat building way with track and wheel launch onto a sloping ramp. This, however, would be somewhat more cumbersome and costly in receiving barge loads of heavy components, requiring an extremely long gantry extension seaside to unload the barge.

Fig. 1-3 Graving Dock Facility (Power Module)

1.2.8 Conceptual Facility for Power Modules. A very effective facility for the power modules would be similar to the concept illustrated in Fig. 1-4. This concept has the advantage of working undercover with the exception of the heavy lift transfers by the stiff-leg. Production could be made more efficient by adding slips and shop barges. Two slips could be built side by side using a common center column line for overhead support of bridge cranes. Water in the slip could be relatively shallow and the barge allowed to bottom out during low tide. Movements would be scheduled during high tide. The barge would be made floodable for the launching or receiving of a power module. The stiff-leg must be built to handle the largest lift proposed. Fabrications from shops or slabs would be moved to the loading pad at the rear of the slip where the shop bridge crane could move outside, pick up the load, and move it into the shop assembly area. The shop crane capacity must be designed capable of handling all lifts received by railroad cars or trucks, as well as yard capacity.

Fig. 1-4 50MW_(e) Assembly and Refurbish Facility

1.2.9 Recommended Facility. A graving dock facility similar to that of Fig. 1-3 with crane capacity dictated by optimum module size and sea water pump weight is considered to be the most cost effective facility. Heat exchangers and power module configurations are ideally suited to float the heat exchangers into final position on the graving dock and construct the power module around the heat exchangers, utilizing modular construction techniques with a maximum of pre-outfitting.

1.3 Construction Plans and Assembly Sequences

Construction planning must integrate the structural analysis, design, loading plan and schedule of prefabrications to permit the effective construction of these power modules.

Special attention must be provided to interface connections to assure interchangeability between modules and platforms. Construction planning must closely monitor and control distortion. Emphasis must be placed on weld joint design and welding sequence.

Modular construction planning appears the best approach. Structure, along with component foundations, constructed to maximum size or weight (within the limits of lifting capabilities) would be fabricated. Interior piping and equipment would also be incorporated in the assemblies, with make-up piping installed after assemblies are fitted and welded together, as indicated in the following assembly sequences.

1.3.1 50MW(e) Immersed, Unitized

refs: a) SK-PSD-1-78-01

b) SK-PSD-1-78-02

Construction Plan. This power module requires a 180' x 320 graving dock (or dry dock) serviced by a crane or group of cranes having a minimum combined capacity of 175 tons (governed by sea water pump handling requirements). Actual crane capacity should be selected based on the optimization of structural assembly weights. No special equipment, tooling or handling techniques are required other than normal distortion control measures.

Assembly Sequence

- a. Structurally analyze and design equipment supports and temporary added structure
- b. Plan construction and preplan manufacturing.
- c. Fabricate modular foundations, structure, and supports.
- d. Float heat exchangers into position in graving dock (or dry dock) and de-water dock.
- e. Build up "power module support structure", deck-by-deck, of preoutfitted structural assemblies.
- f. Build-up heat exchanger support structure.
- g. Load preoutfitted "equipment area" assemblies on top of "power module support structure" and heat exchanger support structure. Schedule heavy equipment loading to minimize necessity for shipping holes.
- h. Sequentially install access openings as required for direct load of major components. Due to structure removal for the direct loading of major components, specific areas of the power module may require major system and component installation completion to permit replacement of structure required to carry loads generated by the placement of other major components in other areas.

- i. Sequentially install additional structure and foundations and secure.
- j. Prefabricate piping systems.
- k. Install piping components or equipment that will be restricted due to power module's structure or major components and secure.

1.3.2 50MW(e) Immersed, Segmented

refs: (not available)

Construction Plan. The segmented power module is assumed to be similar to the unitized except for its heat exchanger quick attach/detach feature.

The segmented power module generally requires the same building facilities as the unitized except building ways may be utilized to build this module without heat exchangers. The heat exchangers could be towed to location and connected, similar to routine three year interval replacement operation.

Assembly Sequence

- a. Structurally analyze and design equipment supports and temporary added structure.
- b. Plan construction and preplan manufacturing.
- c. Fabricate modular foundations, structure, and supports.
- d. Build-up "power module support structure".
- e. Build-up heat exchanger support structure.
- f. Load pre-outfitted "equipment area" modules to tops of "power module support structure", heat exchanger support structure and temporary cribbing in way of missing heat exchangers.

- g. Schedule heavy equipment loading to minimize shipping holes.
- h. Sequentially install access openings as required for direct load of major components. Due to structure removal for the direct loading of major components, specific areas of the power module may require major system and component installation completion to permit replacement of structure required to carry loads generated by the placement of other major components in other areas.
- i. Sequentially install additional structure and foundations and secure.
- j. Prefabricate piping systems.
- k. Install piping components or equipment that will be restricted due to power module's structure or major components and secure.
- l. Complete outfitting dockside.
- m. Attach heat exchanger on location at platform.

1.3.3 50MW(e), Submerged

- refs: a) SK-PSD-1-78-03
 b) SK-PSD-1-78-04
 c) SK-PSD-1-78-05
 d) SK-PSD-1-78-06

Construction Plan. The submerged configuration is designed to operate in a vertical position attached to a spar; however heat exchanger handling problems preclude building in this vertical position.

The module requires a 180' x 320' (minimum) graving dock (or floating dry dock) for horizontal assembly. This may require that equipment be mounted on its side if it cannot be mounted in subassemblies prior to loading.

A minimum crane capacity of 175 tons is dictated by sea water pumps, however due to the thickness of shell plating, a much larger crane would be desirable for handling larger structural subassemblies and thus reducing fitting, welding and outfitting time within the dock area.

Welding procedures must be developed and equipment acquired to efficiently form, fit and weld the relatively thick plating required.

Assembly Sequence

- a. Structurally analyze and design equipment supports and temporary added structure.
- b. Plan construction and preplan manufacturing.
- c. Fabricate modular foundations, structure, and supports.
- d. Float heat exchangers into final position in graving dock (or drydock) and dewater dock.
- e. Fabricate bottom-half subassemblies.
- f. Laydown, fit, and weldout bottom-half subassemblies until bottom-half structure is complete.
- g. Fit and assemble make-up piping, valves, etc., in bottom assembly.
- h. Set major components with interface tooling and secure.
- i. Install top-half modules in sequence that best suits distortion control and provides maximum access to interior.
- j. Remove from dock, ballast into upright position and complete outfitting pier side.

1.3.4 10MW(e) Immersed, Unitized

- refs: a) SK-PSD-1-78-07
b) SK-PSD-1-78-08
c) SK-PSD-1-78-09
d) SK-PSD-1-78-11

Construction Plan. This configuration requires a 100' x 140' graving dock or floating dry dock serviced by at least a 75-ton crane (goverened by sea water pumps). It is recommended, however, that a minimum crane capacity of 150-tons be obtained to provide for more efficient structural assembly sizes. No other special equipment is required.

Assembly Sequence

- a. Structurally analyze and design equipment supports and added structure.
- b. Plan construction and preplan manufacturing.
- c. Fabricate modular foundations; structure, and supports.
- d. Erect pump enclosure and heat exchanger support structure in graving dock.
- e. Flood dock and float heat exchangers into position.
- f. Dewater dock
- g. Attach heat exchangers to their support structures.
- h. Build-up equipment compartment

- i. Sequentially install access openings as required for direct load of major components. Due to structure removal for the direct loading of major components, specific areas of the power module may require major system and component installation completion to permit replacement of structure required to carry loads generated by the placement of other major components in other areas.
- j. Sequentially install additional structure and foundations and secure.
- k. Prefabricate piping systems.
- l. Install piping components or equipment that will be restricted due to power module's structure or major components and secure.
- m. Flood dock and complete outfitting pier side.

1.4 Installation Schedule

50MW_(e) Power Module Submerged. A conceptual schedule indicating 3 years to complete four power modules is illustrated in Fig. 4-55.

Basis of Schedule. Schedules are based on one-time installations at one facility. Schedules also require support in advance ordering of long lead items.

Although fig. 1-5 is specifically for the 50MW_(e), submerged, Power Module, it is representative of all configurations studied.

Fig. 1-5 Schedule for 50MW(e) Modules for Spar Platform

1.5 Power Module Attachment Hardware. The power module major components require refurbishment at three year intervals. It is assumed that these modules will be detached from the platform and replaced with a refurbished module. This replacement process is to be accomplished within two days, in calm seas. (Sea State 1)

A number of locking devices have been investigated (See Appendix A) and it is felt that a system of fixed mating wedges is the simplest, most effective means of quickly attaching/detaching power modules. These wedges can either be positioned to engage as the module is jacked (or ballasted) down along a guide rail and into position. In the case of ballasting or where jacks are to be removed, supplemental pins are required to hold the module against positive buoyancy, except where jack chains are allowed to remain, chain stoppers may be used in lieu of pins.

The wedges could also be positioned to engage after the module has been lowered beyond its final position and while being raised by buoyancy forces into the wedges. Wedges would be double faced, that is, will also act to locate module on athwartship center as well as pull into platform. The advantage of this configuration is that buoyancy forces hold the module into the wedges and jacks may be removed and used elsewhere. Supplemental pins need only be designed to carry loads due to loss of buoyancy, resulting from a casualty.

See fig. 1.6

Fig. 1.6 "Reverse Wedge" type module attachments utilizing buoyancy force to engage wedges. J1-22

This procedure applies to all studied module configurations and also heat exchanger handling in the case of segmented modules.

In the case of segmented power modules where heat exchangers can not be lowered vertically into position pivot arms may have to be substituted for the vertical guide rail. See fig. 1.8.

FIG. 1.7

POWER MODULE ATTACHMENT PROCEDURE

FIG. 1.8

HEAT EXCHANGER
ATTACHMENT PROCEDURE

This scheme of wedges is applicable to all module configurations studied as well as heat exchangers/module interfaces on segmented modules.

1.6 Power Module Attachment Procedure. Several methods of lowering power modules (heat exchangers - in segmented modules) into position for attachment have been investigated. Some of these are illustrated in appendix A.

The simplest method, affording a maximum of control consists of the following steps as illustrated in fig. 1-7:

Maneuver power module into position against fenders with tugs.

Attach power module to vertical guide rails on platform.

Jack into position using chain jacks (similar to "Hydranautics") between module and platform.

Install supplemental pins.

Replace jacks with chain stoppers.

Inflate sea water duct seals.

1.7 Construction Support Equipment. There is no special construction support equipment required which is not currently being used in major U.S. shipyards.

Existing crane capacities are not adequate to handle heat exchangers, even on the 10MW_(e) modules, therefore it is necessary to float heat exchangers into position onto a graving dock (or floating drydock) or transfer from a barge to a building ways by a transfer system such as a "Hydranautics" skidding system. The crane capacities are therefor dictated by Sea Water pump handling requirements, the heaviest being 175 tons which is well within the lift capacity of most shipyards.

1.7.1 Graving Docks and Cranes. A 180' x 320' graving dock serviced by a 175-ton crane or group of cranes is necessary for the 50MW_(e) modules whereas a 100 x 140 graving dock (or floating drydock) serviced by a 75-ton crane is sufficient for the 10MW_(e) power modules.

1.7.2 Barges - The heat exchangers will be loaded onto barges for transport to the shipyard. Upon arrival the barges will be flooded allowing the heat exchangers to float free for loading into the graving dock.

1.7.3 Skidding System- It is not a building yard requirement however it is conceivable that a skidding system, similar to "Hydranautics" would be very useful in the handling of the heat exchangers either at the manufacture's facilities and in the graving dock.

1.7.4 Thick Plate Facilities. Special equipment is required for the burning, handling, forming and welding of the thick plate associated with the submerged configuration. This equipment is not at all exotic. It is common to all major submarine facilities.

1.8 Risk Areas

1.8.1 Power Module Interchangeability. It is critical that interface tolerances be maintained to assure power module interchangeability.

Attachments are to be simple and sturdy, yet flexible enough to provide for normal structural tolerances associated with large, thick-plate fabrications.

This is accomplished through a judicious balance of design and distortion control. The design utilizes a simple, sturdy wedge attachment which combined with resilient pads and inflatable sea water duct seals is relatively unaffected by large tolerances.

See figures 1.6 and 1.7. The use of jigs, proper weld design, methods and sequence reduces distortion to an acceptable minimum.

1.8.2 . Power Module Attachment/Detachment. There is always danger of collision damage when maneuvering two large vessels such as a power module and platform in a docking operation.

This danger is minimized through the application of a sufficient number of tugs, a tendering system, guide rails (or pivot arms) and a synchronized, positive jacking system.

1.8.3 Handling of Heat Exchangers. The heat exchangers are heavier than conventional lift facility capabilities. They will therefore have to be capped, floated, ballasted and positioned in the graving dock without the aid of dockside cranes or other crane facilities.

These large, heavy structures are very fragile with respect to concentrated loads and therefore their handling constitutes a risk. Since their weight is far in excess of available conventional lifting facilities they must be handled by floating and ballasting into final position in the graving dock.

Very even load distribution is accomplished during this floating operation and the heat exchangers are lowered onto extensive grids of deck blocks fitted with a layer soft wood packing adjacent to the shell to prevent load concentrations.

1.8.4 Building Submerged Power Modules In A Horizontal Orientation.

The loading of heavy machinery is complicated by the fact that it must be mounted on a vertical plane (equivalent to bulkhead mounted).

It will be possible to install most of the equipment in a conventional manner in an assembly before loading the assembly to the power module. Other equipment which can not be loaded to the assemblies prior to assembly loading and which is difficult to mount on a vertical foundation can be loaded and temporarily mounted (without fitted chocks, fitted bolts and final alignment) and perform final alignment after power module has been launched and ballasted into upright position.

1.8.5 Corrosion, Encrustation and Fouling

The mild steel power module structure in close proximity to various other metals and exposed to tropical sea water and sea water spray is vulnerable to corrosion, encrustation and fouling.

Corrosion could cause severe structural damage, especially to segmented power modules which can not be detached for maintenance. Encrustation and fouling must be considered in the design of power module attachment hardware to assure proper functioning during replacement operations at three year intervals.

The corrosion problem can be effectively controlled by either a system of impressed current anodes or sacrificial anodes. Encrustation and fouling will be considered in developing attachment details. The proposed system of chain jacks and wedge attachments are virtually unaffected by encrustation and fouling.

1.9 Scantlings and Cost Estimates

Scantlings are based upon the following assumptions:

- . All structure is medium steel.
- . Pressures are equivalent to hydrostatic head plus twenty feet.
- . ASME pressure vessel code is used for shells under external pressure.

These scantlings provide the basis for the weight take-offs and ultimately cost estimates. Material costs are determined directly from the weight take-offs however labor costs contain factors derived from scantling plans relating to structural complexity and fabrication processes. Cost estimates are based on the following assumptions:

- . Mature industry
- . 1978 prices
- . Prototype, first and eighth of a class
- . OTEC equipment is government furnished including sea water pump housing.
- . All equipment including government furnished must be installed by the contractor.
- . All miscellaneous outfitting items necessary for habitability are included.
- . Engineering is complete

See appendix B for calculations.

1.9.1 Pump Enclosures - Pump enclosures for the various power module configurations are designed to ASME Pressure Vessel Code requirements as cylindrical pressure vessels under external pressure. Pressure heads have been increased by 20 feet to account for wave action. Pump enclosure cost estimates include installation costs for all components including government furnished equipment and complete outfitting necessary for habitability. Access trunks will be considered separately.

50 MW_(e) Immersed

The 50 MW_(e) Immersed pump enclosure is composed of a 2" thick, 35' diameter cylindrical section 35' deep with a 2½" thick, 8'-9" deep ellipsoidal head. A stiffener reinforced, 1½" thick flat end-closure bulkhead combines with the head to form the boundaries of the ballast tank. The remainder of the structure is composed of three, ½" thick decks at 8'-9" spacing. The structural weight is approximately 600,000 pounds and the total pump enclosure cost including outfitting is \$2,500,000.00 each (2 required). See Figure 1.9 for scantlings summary.

50 MW_(e) Submerged

The 50 MW_(e) Submerged pump enclosure, operating at 2½ times the hydrostatic head of the Immersed configuration, is substantially heavier. Its overall dimensions are the same, however its cylindrical section is 4½" thick with a 5" thick head. The flat end-closure bulkhead is 2" thick with comparably heavier stiffening. The decks however, being independent of head are ½" thick, stiffened plating. The structural weight is 1,260,000 pounds and the total cost is \$5,500,000.00 each (2 required). See Figure 1.10 for scantlings summary.

10 MW_(e) Immersed

The 10 MW_(e) Immersed pump enclosure has the same overall dimensions as the 50 MW_(e) Immersed configuration with the exception of diameter which is 20'. The cylindrical section thickness is 1½" with a 1½" thick 60" deep ellipsoidal head. The flat end-closure bulkhead is ¾" and the three decks are ½" plate. The structural weight is 175,000 pounds and the total cost is \$1,000,000.00 each (2 required).

See Figure 1.11 for summary.

50 MW_e) IMMERSED :

STRUCTURAL STEEL WEIGHT = 600,000 LBS.
TOTAL PRICE = \$2,500,000

Fig. 1.9

to 95%

50 MW (c) SUBMERGED

ELEV. - CYLINDER

PLAN - BOTTOM

PLAN - DECK (TYP.)

STRUCTURAL STEEL WEIGHT = 1,260,000 LBS
TOTAL PRICE = \$ 5,500,000

10' MW_(e) IMMERSED ;

ELEV - CYLINDER

PLAN - BOTTOM

PLAN - DECK (TYP.)

STRUCTURAL STEEL WEIGHT = 175,000 LBS.
TOTAL PRICE = \$1,000,000

Fig. 1.11

1.9.2 Pump Enclosure Access Trunks. Pump Enclosure Access Trunks were designed for both the 10 MW_(e) immersed, unitized and the 50 MW_(e) immersed, segmented power module configurations. These trunks were designed to provide personnel access from the surface to the pump enclosures. Trunks must be of sufficient size to accommodate the largest piece of equipment in the pump enclosure and be fitted with handling gear necessary for pump removal and replacement.

10 MW_(e) Immersed, Unitized

The 10 MW_(e) pump enclosure vertical access trunk has a 10' diameter and varies in thickness between 1" at the bottom to $\frac{1}{2}$ " at the top. The vertical trunk is fitted with ring stiffeners at 6' spacing. This trunk tees into a 12' diameter horizontal passageway between pump enclosures. The horizontal cylinder is 1" thick and has 12" x 9" x 34[#]T ring stiffeners at 48" spacing. The vertical trunk is outfitted with a vertical ladder and rails for an 8 ton hoist which is located on a machinery platform above the trunk. The horizontal trunk is fitted with a flat deck, and an 8 ton monorail system for handling pumps between the pump enclosure and the vertical trunk. The structural weight of these trunks is 130,000 pounds and the outfitted cost including ladders, hoists, monorails, lights, etc. is \$400,000.00. See Figure 1.12 for sketch and summary.

50 MW_(e) Immersed, Segmented

The 50 MW_(e) pump enclosure vertical access trunk is similar to that of the 10 MW_(e) module. The major difference is the necessity for two vertical trunks in the segmented configuration to allow heat exchangers to be attached/detached independently. Therefore instead of the tee configuration there are two ells, having 1" thick ellipsoidal heads. These ell shaped trunks are outfitted similar to the 10 MW_(e) trunks and

10MW(e) IMMERSED, UNITIZED PUMP ENCLOSURE ACCESS TRUNK

Fig. 1.12

J1-35

95%

have a structural weight of 235,000 pounds and a total outfitted cost of \$720,000.00 each (2 required). See Figure 1.13 for sketch and summary.

1.9.3 Equipment Enclosures. Bulkhead and deck quantities and locations were rather arbitrarily selected on the basis of structural considerations. It is felt that they are, however, representative of actual requirements based on arrangement and subdivision considerations and will have little affect on the cost estimate. Submerged configuration pressure vessel thicknesses are excessive. Consideration should be given submarine methods of analysis, spherical equipment enclosures and concrete construction.

50 MW_(e) Immersed

The 50 MW_(e) immersed configuration chosen is representative of either the unitized or segmented modules. The proposed scantlings result in a structural weight of 12,300,000 pounds and a structural cost of \$8,500,000.00. See Figure 1.14 for summary sketch.

50 MW_(e) Submerged, Cantilevered Heat Exchangers

The 50 MW_(e) submerged power modules having cantilevered heat exchangers are constructed of heavy plate as pressure vessels under external pressure. The sea water pump enclosures are located approximately 142 feet between centers and are connected by a 7" thick, 76' diameter cylindrical section, 88' long. This cylindrical portion is attached at both ends to the sea water pump enclosures by 7" thick conical transition sections. There are four decks constructed of tee stiffened $\frac{1}{2}$ " plate. The structural weight is 8,260,000 pounds and the total structural cost is \$12,000,000.00. See Figure 1.15 for summary sketch.

50 MW_(e) Submerged, Cantilevered Sea Water Pumps

This module is imilar to that with cantilevered heat exchangers except the machinery enclosure is located between heat exchangers rather than sea water pump enclosures. This configuration consists of a 7" thick,

50 MW(e) IMMERSED, SEGMENTED PUMP ENCLOSURE ACCESS TRUNKS

STRUCTURAL STEEL WEIGHT = 235,000 LBS.*
 TOTAL PRICE = \$720,000.*
 * UNIT VALUE (2 REQ'D)

Fig. 1.13

952

50 MW(e) IMMERSED EQUIPMENT ENCLOSURE

STRUCTURAL STEEL WEIGHT = 12,300,000 LBS.
 TOTAL PRICE = \$ 8,500,000.

Fig. 1.14

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50 MW(e) SUBMERGED, CANTILEVERED HEAT EXCHANGERS
EQUIPMENT ENCLOSURE

SCANTLINGS -

CYLINDRICAL SHELL, 7" ϕ
CONICAL HEADS, 7" ϕ
(4) DECKS, $\frac{1}{4}$ " ϕ w/10"x8"x45" I/T₃ @ 30"

STRUCTURAL STEEL WEIGHT = 8,260,000 LBS.
TOTAL PRICE = \$12,000,000.

FIG. 1.15

50 MW(e) SUBMERGED, CANTILEVERED SEA WATER PUMPS
EQUIPMENT ENCLOSURE

SCANTLINGS -

CYLINDRICAL SHELL, 7" ϕ
HEMISPHERICAL HEADS, 4 $\frac{1}{2}$ " ϕ
(2) DECKS, $\frac{1}{4}$ " ϕ w/10"x8"x45" I/T₃ @ 30"

STRUCTURAL STEEL WEIGHT = 4,520,000 LBS.
TOTAL PRICE = \$18,000,000.

Fig. 1.16

15%

76' diameter cylindrical section, 20' long with 7" hemispherical transition sections attaching to heat exchangers. There are two decks, fabricated of tee stiffened $\frac{1}{2}$ " plate. The structural weight is 4,520,000 pounds and the total structural cost is \$18,000,000.00. See Figure 1.16 for summary sketch.

10 MW_(e) Immersed

The machinery enclosure is a 100' x 60' x 18' deep structure. It has a 4' deep double bottom. There is only one deck, the inner bottom, which serves as the machinery deck. $\frac{1}{2}$ " plating is used throughout except for bottom plating which is 9/32". The structural weight is 454,000 pounds and the total structural cost is \$ 1,200,000.00. See Figure 1.17 for summary sketch.

1.9.4 Complete Power Modules. The complete power modules are built up of the following structural assemblies:

- . Equipment enclosure
- . Pump enclosure
- . Pump enclosure access trunk

These assemblies have been considered separately and must be combined to reflect the complete power module. OTEC equipment and piping is not included in material costs, just installation. Foundation weights are not included in scantlings take-offs however are considered in cost estimates. See Figure 1.18 for a structural weight and construction cost summary.

50 MW_(e) Immersed (Unitized or Segmented)

The total structural weight of the 50 MW_(e) immersed configuration is 104,000,000 pounds and the total construction cost, exclusive of OTEC equipment material costs, is \$37,500,000.00.

Fig. 1-17

10 MW(e) IMMERSED EQUIPMENT ENCLOSURE

STRUCTURAL STEEL WEIGHT = 454,000 LBS.
 TOTAL PRICE = \$1,200,000.

Fig. 1.17

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50 MW(e) Submerged, Cantilevered Heat Exchangers

The total structural weight is 11,250,000 pounds with a module cost of \$ 36,000,000.00.

50 MM(e) Submerged, Cantilevered Sea Water Pumps

The total structural weight is 7,500,000 pounds with a module cost of \$ 30,000,000.00.

10 MW(e) Immersed, Unitized

The total structural weight is 1,300,000 pounds with a module cost of \$ 5,500,000.00.

FIG. 1.18 - STRUCTURAL WEIGHT & CONSTRUCTION COST SUMMARY

	PUMP (1) ENCLOSURE		ACCESS TRUNK		EQUIPMENT (3) ENCLOSURE		POWER MODULE	
	WT. (#)	COST (\$)	WT. (#)	COST (\$)	WT. (#)	COST (\$)	WT. (#)	COST (\$)
50 MW _(e) IMMERSED UNITIZED	(1) 598,282	(1) 2,473,189 <i>\$4.8/10</i>	(2) —	(2) —	12,294,119	8,574,620	13,961,279	37,219,163
50 MW _(e) IMMERSED SEGMENTED	(1) 598,282	(1) 2,473,189	(1) 235,298	(1) 717,665 <i>3.05</i>	12,294,119	8,574,620	13,961,279	37,219,163
50 MW _(e) SUBMERGED CANT. H.E.	(1) 1,261,948	(1) 5,301,729 <i>4.20</i>	(2) —	(2) —	8,261,730	18,038,119	11,256,222	36,166,448
50 MW _(e) SUBMERGED CANT. S.W. PUMP	(1) 1,261,948	(1) 5,301,729	(2) —	(2) —	4,518,483	11,823,357	7,512,975	29,951,686
10 MW _(e) IMMERSED UNITIZED	(1) 173,309	(1) 977,865 <i>5.61</i>	132,253	403,374 <i>3.05</i>	453,616	1,186,947	1,279,105	5,479,271

- NOTES: (1) UNIT VALUE (2 REQ'D)
 (2) ASSUME VALUES FOR 50 MW_(e) IMMERSED SEGMENTED
 (3) STRUCTURE ONLY, NO OUTFITTING.

J1-43

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LOLL PRELIMINARY OTEC NOTES

APPENDIX J-2

TASKS : (REFERENCE IDC D. YOUNG TO DISTE. DATED 4/19/78)

CONFIG #1 - 50MW(e), Immersed

- a. Alternate power module attachments to platform. Attachment/detachment of 55' dia. ring must be completed at sea. Include dimensional tolerances. Four or five alts, i.e. V-groove, clamps, breech block, etc. Water tight seal not required.

1. Ballast or jack down into wedge slots - structural connections remote from water pipes, inflatable seals around water pipes.

2. Pump section will seal against gasket if alignment maintained by collar nose & held into vertical position by jacks.

3. Wedged, partial turn muff type couplings on water lines plus structural connections between power module & platform. Flexibility must be provided between power module and water pipes when both are rigidly attached to platform.

Config #1, task (a) (cont.)

4. Bolt ring at sliding flood gate at surface - slide down into position and make power module structural attachments.

5. Quarter turn dogs that extend from platform and engage flanges of power module. (recessed when not engaged)

6. Snap in dogs : manual release mechanism at water pipe connection

Config #1, task (a) (cont.)

7. Pull down into notch with chain jacks & tie off with chain stoppers. (see attached copy of "Hydranautics" brochure)

8. Pull down into position w/ chain jacks & pull horizontally into position w/ chain jacks (use notches for alignment)

Config. # 1, task (a). (cont.)

9. De Long type jacks from jacking platform over - pulled into position by wedging action of guide rails - Tightness provided by inflatable seals.

NOTE: Adequate flexibility must be maintained between rigidly connected portions of the power module to reduce structural tolerance requirements.

Config. #1 (cont.)

- b. Develop system or method for attachment/detachment of entire power module at sea without interrupting operation of other modules on platform. Include any platform interface requirments and motion constraints. Three year cycle is planned.
1. Design power module such that it can be saltwater ballasted to the proper depth. Float into position, attach to guide rails, ballast down into final position and attach by one of methods discussed in task a. Reverse procedure for detachment.
 2. If module cannot be ballasted down, float into position attach guide rails and chain jacks (10 (120T) DOUBLE RIEFVED JACKS USING $2\frac{1}{2}$ " MOORING CHAIN), jack into final position and attach.

Config #1, task (b) (cont.)

3. Float into position, attach 4 - 6' dia. jacking columns to power module through jacking platform on platform (Delona type jacks), jack down into final position and attach.

4. Float into position, attach to guide rails, apply solid ballast to top until reaches final position and attach.

5. Deballast entire platform to align with floating power module, attach power module and ballast platform to normal operating depth. This assumes power can be interrupted during module replacement or that limited operation is possible with heat exchangers partially above water.

Config #1, task (b) (cont.)

6. Attach power module to vertical sliding flood gate at surface, jack or ballast down to operating position

attach position

operating position

7. Attach power module to vertical guide rail and jack down into final position using rack and pinion jacks
8. Attach power module to vertical guide rail and ballast barges. Ballast the barges to lower power module into final position, attach module to platform, deballast barges to neutral buoyancy, disconnect barges and continue deballasting.

NOTE: Flood gates must be provided in cold water lines to prevent warm water contamination while module is removed. Consideration should be given to net thrust on platform due to water pump discharge. Outlet orientation could be controllable to provide propulsive power and steering.

Config #1 (cont.)

c. Develop a construction plan and assembly sequence for power module similar to that done in Task 1.

1. The immersed power module of SK-PSD-1-78-01 should be modified to facilitate the attachment/detachment of the heat exchangers at sea. The support structure could be built in most shipyards by standard methods. It appears that this structure should be massive, (possibly concrete) with negative buoyancy ballast capabilities. The major construction problem associated with this power module is the handling of the 1872 ton heat exchangers if they can not be attached water born. There are, however, "Translift" systems for heavy lifts such as the one designed by Hydranautics for San Shipbuilding which moves 26000 ton modules from land onto floating drydocks. It would appear that a box type concrete structure w/ cantilevered heat exchangers should be considered: w/ integral water ducts.

Config #1 (cont.)

- d. Develop an assembly schedule for power module similar to that done in task 1.
1. That of task 1. should be used until module definition refined.

Config #1 (Cont.)

- e. Examine alternatives for individual heat exchanger to water box attachment including ammonia lines. Attachment/detachment must be completed at sea. Include any required dimensional tolerances.

1. heat exchanger flange could be wedged into slots by jacking down

2. partial turn, breech block type coupling, both flanges slotted and wedged. (heat exchanger must turn) These can be bullet nosed for ease of alignment during required horizontal movement.

Config #1, task(e) (cont.)

3. partial turn breech block type coupling, one flange & mating muff flange slotted (muff turns)

NOTE: heat exchanger requires only movement (no horizontal or rotation)

4. bolt flange to sliding flood gate at surface - jack or ballast into position & bolt.

5. quarter turn dogs that extend from power module recess to engage flange of heat exchanger

Config #1, fast (€) (cont.)

6. various spring loaded snap-in type connections w/ mechanical locks and release mechanisms.

a.

b.

7. pull into position with chain jacks & tie off w/ chain stoppers - heat exchanger guided into position by rails or guide pads. Seal with inflatable seal.

Config. #1, tack 1

1. The proposed power module arrangement of 5K-PSD-1-78-01 would prove awkward in heat exchanger attachment/detachment, especially with heat exchanger 2000 T positive buoyancy in ballasted condition. If compatible liquid can not be found to ballast heat exchangers they will have to be jacked into position. This would be a very difficult operation to position heat exchangers under the saddle type support structure proposed by 5K-PSD-1-78-01. It is recommended that the power module be a box type structure with heat exchangers cantilevered from side. A jacking platform may be req'd beneath heat exchangers.

The above configuration is very versatile from a heat exchanger handling standpoint:

- ammonia disconnect accessible
- guide rails can be installed on vert. surface of power module
- heat exchanger need only be moved in

- one direction (directly opposite buoyancy forces - $\therefore$ easy control)
- detachment could be made between platform and power module, power module deballasted to attach heat exchanger at surface then power module & heat exchanger ballasted into final position and power module attachment made underwater. This would eliminate jacking except for control.

Config. #1, task f

Develop system or method for attachment/detachment of individual heat exchanger at sea without interrupting operation of other modules on platform. Include any platform or water box interface requirements and motion constraints. Examine problem of obtaining neutral buoyancy of heat exchanger if required for lowering beneath sea.

I Box type power module w/cantilevered heat exchanger.

1. Float heat exchanger into position, attach to vertical guide rails on power module, rig chain jacks between jacking platform on power module, jack heat exchanger into position (against zero buoyancy), make underwater attachment by one of methods described in task e above. Make standard bolted connections in ammonia lines at top of power module.
2. Float heat exchanger into position, attach to vertically sliding floodgate, jack floodgate into final heat exchanger position. Lock floodgate (this could be done above water).

3. Float heat exchanger into position, detach and deballast power module, attach heat exchanger to power module above water, ballast power module back into final position and attach as in task 9.

II SK-PSD-1-78-01 power module

1. Positioning linkage to position heat exchanger under saddle shaped power module.

Lifting Systems

For shiplifting, for heavy construction or wherever heavy loads must be lifted with precision and safety, a Chain Jack lifting system from Hydranautics may be the best answer.

The shiplifting system at right is composed of twenty-two Chain Jack units with a total capacity of 2,000 tons. Eleven units on each side of the elevator platform lower it into the water to launch or receive a ship. After the system lifts a ship to pier level, a separate Hydranautics skidding system is used to transfer the ship into an adjacent yard for repairs.

Another Hydranautics Chain Jack lifting system is used, bottom left, to build a modular pier. Sections of the pier are floated into position and pilings are sunk at their corners. Chain Jack units on top of each piling, bottom right, lift the section so it can be welded to the previous section. These modular sections are added one at a time until the pier extends the desired distance from shore.

Custom-designed lifting systems similar to these are in use now in Korea and Brazil as well as in the United States.

HYDRANAUTICS

CHAIN JACK APPLICATIONS

200-TON JACK UP BARGE
SYSTEM

400-TON CONTAINER CRANE
ERECTION SYSTEM

800-TON MARINE RAILWAY
INSTALLATION

2000-TON SHIPLIFT
PLATFORM

J2-18

18/11

HYDRANAUTICS

Double Chain Jack

Description

The Double-Chain Jack is a unique combination of hydraulic and hydro-mechanical linkage interconnected to produce a versatile mechanism for lifting or moving heavy loads. Consisting of a hydraulic cylinder with chain engagement latches on the outer cylinder base and on the rod end, the Chain Jack can pull or climb chain, depending on the operation desired. The Chain Jack can be used singly or in groups consisting of any number, all controlled from a central power/control unit.

Operation

The Double-Chain Jack is operated by alternately transferring the loaded chain from the cylinder latch mechanism to the ram latch mechanism and stroking the ram to haul in or pay out chain. The latch mechanism on each end of the Chain Jack alternately engages or releases chain. Models are available with either manual latch positioning or hydraulic latch positioning. Stroke length of the jack is slightly greater than the chain pitch. By alternately extending and retracting the rams with hydraulic pressure, while synchronizing the latches, the mechanism moves the loaded chain. Alternatively the Chain Jack may be used to advance the load along a stationary chain. The load is sequentially supported by one latch and then the other. One latch cannot be disengaged unless the other latch is supporting the load.

Advantages

Economy, simplicity and safety in any system are the major design goals to achieve. The Hydranautics Chain Jack fulfills all of these advantages. The mechanism is designed with an ultimate safety factor of four times the rated capacity. The system can replace expensive rotating machinery for many applications. Operation requires minimum operator skill, equivalent to that required for operation of any heavy duty type hydraulic jack. Chain jacks may be furnished to operate from the user's hydraulic power supply by addition of a control panel.

Chain Jack Systems

Hydranautics furnishes complete pulling or lifting systems employing the standard chain jack as the basic load-moving component. A simple system consists of a single chain jack and an operator station which combines the hydraulic power source, control console and hose assemblies for interconnecting the operator station with the chain jack. More complex systems employ multiple chain jacks, powered and controlled from one or more operator stations. There are many variations to the systems such as unidirectional travel, bidirectional travel, and synchronized travel of multiple units.

Applications

Chain jacks are in use throughout the world in marine, shipbuilding, and heavy construction applications. Chain jacks are used to replace any device using chain or cable to lift heavy loads more precisely and economically.

A basic Chain Jack unit consists of two sets of locking pins separated by a vertical hydraulic jack.

When engaged, locking pins do not go through the chain, but rather under the shoulders of the chain on both sides.

In this sequence, the weight of the load switches from the upper locking pins during jack extension to the lower locking pins during jack retraction.

Lifting System Operation At the heart of every Hydranautics lifting system is a series of units called Chain Jacks. As in other heavy load moving systems, the size and design of the component units vary with customer load requirements, however, basic operation remains the same:

Chain Jack units consist of a vertical hydraulic jack which lifts its load by pulling one or more chains

upward through two sets of locking pins.

With the weight of the load entirely on the upper locking pins, the jacks are extended, lifting the load. When the jack reaches the end of its stroke, the lower locking pins are engaged, locking the load. The upper locking pins then disengage, allowing the jack to be retracted in preparation for the next stroke. This cycle is repeated until the load is lifted in steps to its desired height.

Load let-down is performed in a similar way, with the sequence of engagement and retraction of upper and lower locking pins changed as required to accomplish this operational mode.

Chain Jacks may be used individually, but are normally employed in sets of two or more, and can be completely controlled by one operator from a single console station.

HYDRANAUTICS

DOUBLE CHAIN-JACK SYSTEM

J2-21

709

21/12

LIFT SEQUENCE

Sizes Available For Most Standard Stud Link Chain

Stud Link Chain

Hydranautics Chain Jacks are designed for use with high-tensile, alloy-steel, stud-link chain which insures the dimensional tolerances and safety factor necessary for the safe, precise operation of the chain jack systems.

HYDRANAUTICS

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P. O. Box 1068
Goleta, Calif. 93017

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Telex: 658445

Skidding Systems

On an offshore platform, inside a building hall, or wherever prepared surfaces are available, a Gripper Jack skidding system from Hydranautics is often the most efficient and economical means to move heavy loads.

In a typical offshore application, a Hydranautics skidding system is used on a platform in the Santa Barbara Channel, near right, to move a 340-ton derrick, allowing it to drill and maintain 43 separate wells.

The massive ship section, top right, weighs in excess of 4,000 tons. Moving it onto a floating drydock while contending with changing tide levels required the high reliability of a Hydranautics skidding system.

Another skidding system was used by a Western U.S. fabricator to move a prefabricated structural section, right center, onto a barge for transportation to its use site.

A Hydranautics system was used, bottom, to move a 15,000-ton rig jacket from shore onto a floating pontoon barge for transportation to the North Sea, where the same system was used in the offloading process.

Other Hydranautics skidding systems are in use offshore at Cook Inlet, Alaska, the North Sea, the Arabian Gulf, the Gulf of Mexico and off the coast of Borneo. Onshore applications include installations in Singapore, Sweden, Brazil, England and Venezuela.

A hydraulic jack and a friction lock gripper are combined here in one unit called a Gripper Jack.

This sequence shows one complete cycle for a basic system as the jack pushes the load, then retracts its gripper to anchor the next stroke.

Skidding System Operation The principal part of every Hydranautics skidding system is a unit called a Gripper Jack. While the size and design of the units vary with customer load requirements, operation remains basically similar:

Each Gripper Jack unit consists of a hydraulic jack for moving the load and a friction lock gripper for anchoring the jack.

The gripper can be hydraulically locked in any position along the load

supporting track to become the anchor point from which the jack can push or pull the load.

After each jack stroke, the gripper is de-pressurized, retracted by the jack to its new position, re-pressurized and locked again to become the anchor for the next stroke. This cycle is repeated, moving the load any required distance.

One important variation of the basic concept consists of the addition of a second gripper, located on the load side of the jack. This

Above, when hydraulic pressure is forced into pliable hoses, they expand, locking the gripper onto the track. In more powerful systems, as below, hydraulic pistons provide the gripping force.

All units in a system can be controlled by one man from a single console station.

feature requires hydraulic circuitry to lock the load side gripper during cylinder retraction and repositioning of the anchor gripper, thus preventing load runaway that might result from track declivity or wind forces.

Gripper Jack units are normally employed in sets of two or more and can be completely controlled by one operator from a single console station.

Appendix K
COST REPORTING TABLES

K-2

Back-up
Blank

Appendix K
COST REPORTING TABLES

This appendix provides individual cost estimates for each of the cost components, using the cost reporting format specified by DOE. The first set of Tables, K.1.1 through K.1.19, present cost estimates for components of 50-MW(e) power systems of the immersed segmented configuration. The second set of Tables, K.2.1 through K.2.19, do the same for the 10-MW(e) power system. As these tables are designed to be self-sufficient, no explanatory discussion appears to be necessary.

TABLE K.1.1
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant			Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes	
			Mat	Labor	Total		Mat	Labor	Total		8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
TURBINE	SEE SECTION 4.4.2 -RADIAL INFLOW -TURBINE WHEEL -CASING -INSTRUMENTATION AND CONTROLS -VARIABLE INLET VANES	INC INC INC INC			52	VENDOR QUOTE (ROTOFLOW)			52	SAME	0	43	8		N.A.	ROTO- FLOW ESTI- MATED COST REDUC- TION	17.3%	
SUBTOTAL					52				52			43						
Contingency				(20%)	10			(10%)	5		(10%)	4						
Home Office and Engineering				(15%)	8			(10%)	5		(10%)	4						
Fees				(10%)	5			(10%)	5		(10%)	4						
TOTAL					75				67			55						

K-2

95%

TABLE K.1.2
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not inc in cost	Prototype Plant			Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes	
			Prototype Unit Cost				First Production Unit Cost				8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total		Mat	Labor	Total									
GENERATOR	SEE SECTION 4.4.2 -TOTALLY ENCLOSED WATER AND AIR-COOLED (TENAC) -CASING -COOLING AND LUBRICATION SYSTEM -EXCITER -WINDINGS AND STATOR	INC INC INC INC INC			35	VENDOR QUOTE (ROTOFLOW)			35	SAME	0	32	15/16		N.A.	ROTO- FLOW ESTI- MATED COST REDUC- TION	8.5%	
SUBTOTAL					35			35				32						
Contingency				(20%)	7			(10%)	4		(10%)	3						
Home Office and Engineering				(15%)	5			(10%)	4		(10%)	3						
Fees				(10%)	4			(10%)	4		(10%)	3						
TOTAL					51			47				41						

95/96

TABLE K.1.4
50 MWe POWER SYSTEM COSTS (\$/KWe)

TABLE K.1.4 50 MWe POWER SYSTEM COSTS (\$/KWe)																		
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant			First Production Plant				Eighth Production Plant							Notes	
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis		% Reduct From 1st Prod
Mat	Labor	Total	Mat	Labor	Total													
COLD SEAWATER PUMP	4 PUMPS -IMPELLER -CASING -SUCTION BELL, DIFFUSER AND EXTENSION -SHAFT AND COUPLING -MOTOR -GEAR -SEE SECTION 4.4.1	INC INC INC INC INC INC INC			83	WORTHINGTON PARAMETRIC STUDY; SEE SECTION 4.4.1. RANGE: 400-2800 CFS 65-15 FT HEAD			83	SAME	0	69	57/64		N.A.	WORTH- INGTON ESTIMA- TED COST REDUC- TION	17.2%	
	PUMP SET SHROUD				13	425,00 LBS @1.50 \$/LB			13	SAME	0	11	15/16	20%	.95	NONE	15.4%	
SUBTOTAL					96			96				80						
Contingency				(20%)	19			(10%)	10		(10%)	8						
Home Office and Engineering				(15%)	15			(10%)	10		(10%)	8						
Fees				(10%)	10			(10%)	10		(10%)	8						
TOTAL					140			126				104						

TABLE K.1.5
50 MWe POWER SYSTEM COSTS (\$/kWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant		First Production Plant				Eighth Production Plant							Notes		
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor		Other Cost Reduct Basis	% Reduct From 1st Prod
			Mat	Labor	Total		Mat	Labor	Total									
AMMONIA CONDENSATE PUMPS	SEE APPENDIX F -3 PUMPS: -IMPELLER -CASING -MOTOR -GEARS -SHAFT AND COUPLING	INC INC INC INC INC INC			10	VENDOR QUOTES (BYRON JACKSON)			10	SAME	0	10		22/24	N.A.	NONE	0	
SUBTOTAL					10			10				10						
Contingency				(20%)	2			(10%)	1		(10%)	1						
Home Office and Engineering				(15%)	2			(10%)	1		(10%)	1						
Fees				(10%)	1			(10%)	1		(10%)	1						
TOTAL					15				13			13						

TABLE K.1.8
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant			Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes	
			Mat	Labor	Total		Mat	Labor	Total		8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expen't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
AMMONIA SYSTEM VALVING	SEE APPENDIX F				19	VENDOR QUOTES (CLOW)			19	SAME	0	19	8		N.A.	NONE	0	
SUBTOTAL					19				19			19						
Contingency				(20%)	4			(10%)	2		(10%)	2						
Home Office and Engineering				(15%)	3			(10%)	2		(10%)	2						
Fees				(10%)	2			(10%)	2		(10%)	2						
TOTAL					28				25			25						

TABLE K.1.10
50 MWe POWER SYSTEM COSTS (\$/KWe)

			Prototype Plant				First Production Plant				Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
CHLORINATION SYSTEM	-TEN 85 LB/HR CHLOROPAC GENERATORS	INC			23	VENDOR QUOTE (ENGELHARD)			23	SAME	0	23	15/16		N.A.	NONE	0	
	-SKID MOUNT	INC																
	-MANIFOLDING	INC																
	-POWER SUPPLIES IN NEMA 2 ENCLOSURES																	
SUBTOTAL					23			23			23							
Contingency				(20%)	5			(10%)	2		(10%)	2						
Home Office and Engineering				(15%)	3			(10%)	2		(10%)	2						
Fees				(10%)	2			(10%)	2		(10%)	2						
TOTAL					33			29			29							

TABLE K.1.11
50 MWe POWER SYSTEM COSTS (\$/KWe)

			Prototype Plant				First Production Plant				Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
MECHANICAL CLEADING SYSTEM	-MAN BRUSHES	INC			13	VENDOR QUOTE (MAN)			13	SAME	0	13	15/16		N.A.	NONE	0	
	-2 CATCHERS/BRUSH	INC																
SUBTOTAL					13				13			13						
Contingency			(20%)	3			(10%)	1		(10%)		1						
Home Office and Engineering			(15%)	2			(10%)	1		(10%)		1						
Fees			(10%)	1			(10%)	1		(10%)		1						
TOTAL					19				16			16						

TABLE K.1.12
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant			First Production Plant				Eighth Production Plant							Notes	
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis		% Reduct From 1st Prod
			Mat	Labor	Total		Mat	Labor	Total									
AMMONIA SUPPORT SYSTEMS	-FILL	INC			4	BECHTEL ESTIMATE BASED ON STANDARD PRICE LISTS			4	SAME	0	4	8		N.A.	NONE	0	
	-DRAIN	INC			4				4		0	4	8		N.A.	NONE	0	
	-VAPOR RECOVERY	INC			2				2		0	2	8		N.A.	NONE	0	
	-NON CONDENSIBLE REMOVAL	INC			1				1		0	1	8		N.A.	NONE	0	
	-PURGE	INC			11				11		0	11	8		N.A.	NONE	0	1
	-CLEANUP	INC			12				12		0	12	8		N.A.	NONE	0	1
SUBTOTAL					34			34			34							
Contingency				(20%)	7			(10%)	3		(10%)	3						1) SCOPE OF ESTIMATE EXCLUDES PLATFORM-BASED PURGE AND CLEANUP EQUIPMENT SERVING MORE THAN ONE POWER SYSTEM
Home Office and Engineering				(15%)	5			(10%)	3		(10%)	3						
Fees				(10%)	3			(10%)	3		(10%)	3						
TOTAL					49			43			43							

TABLE K.1.13
50 MWe POWER SYSTEM COSTS (\$/KWe)

50 MWe POWER SYSTEM COSTS (\$/KWe)			Prototype Plant				First Production Plant				Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
			Mat	Labor	Total		Mat	Labor	Total									
ELECTRICAL EQUIPMENT	-POWER DISTRIBUTION	INC			112	BECHTEL ESTIMATE BASED ON STANDARD PRICE LISTS			112	SAME		112	8		N.A.	NONE	0	
	-SWITCHGEAR	INC																
	-VARIABLE FREQUENCY INVERTERS AND RECTIFIERS	INC																
	-TRANSFORMERS o 115 KV/13.8 KV o 13.8 KV/4.16 KV o 4.16 KV/480 V	INC																
	-PUMP POWER SUPPLY o NH ₃ DISTRIBUTION PUMPS o NH ₃ CONDENSATE PUMPS o SEAWATER PUMPS	INC																
	-NH ₃ SUPPORT SYSTEMS POWER SUPPLY	INC																
SUBTOTAL					112			112			112							
Contingency				(20%)	22			(10%)	11		(10%)	11						
Home Office and Engineering				(15%)	17			(10%)	11		(10%)	11						
Fees				(10%)	11			(10%)	11		(10%)	11						
TOTAL					162			145			145							

TABLE K.1.14
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant			Description of Costing Basis	First Production Plant			Description of Costing Basis	% Reduct From Prototype	Eighth Production Plant						Notes
			Mat	Labor	Total		Mat	Labor	Total			8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
AUXILIARY SYSTEMS						BECHTEL ESTIMATE BASED ON STANDARD PRICE LISTS				SAME								
	-COMPRESSED AIR & HYDRAULIC SYSTEMS	INC			2				2		0	2	8		N.A.	NONE	0	
	-VENTILATION	INC			2				2		0	2	8		N.A.	NONE	0	
	-FIRE CONTROL	INC			2				2		0	2	8		N.A.	NONE	0	
	-SENSORS AND ALARMS	INC			2				2		0	2	8		N.A.	NONE	0	
	-COMMUNICATIONS	INC			1				1		0	1	8		N.A.	NONE	0	
	-LIGHTING	INC			4				4		0	4	8		N.A.	NONE	0	
SUBTOTAL					13				13			13						
Contingency				(20%)	3			(10%)	1		(10%)	1						
Home Office and Engineering				(15%)	2			(10%)	1		(10%)	1						
Fees				(10%)	1			(10%)	1		(10%)	1						
TOTAL					19				16			16						

TABLE K.1.15
50 Mw POWER SYSTEM COSTS (\$/KWe)

			Prototype Plant				First Production Plant					Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes	
			Mat	Labor	Total		Mat	Labor	Total										
EVAPORATOR	TUBE AND SHELL ALL ALUMINUM -TUBES -TUBESHEETS -TRANSITION RINGS -AMMONIA DIST SYSTEM -TUBE SUPPORT PLATES & SUPPORTS -FINAL ASSEMBLY -WATERBOXES	 INC INC INC INC INC INC INC	190	74	264	SEE SECTION 4.10.1	190	70	260	SEE SECTION 4.10.1	1.5%	240	8	27%	.97	SEE SECTION 4.10.1	7.7%		
SUBTOTAL					264				260			240							
Contingency				(20%)	53			(10%)	26		(10%)	24							
Home Office and Engineering				(15%)	40			(10%)	26		(10%)	24							
Fees				(10%)	26			(10%)	26		(10%)	24							
TOTAL					383				338			312							

TABLE K.1.6
50 MWe POWER SYSTEM COSTS (\$/kWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes	
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total		Mat	Labor	Total										
AMMONIA DISTRIBUTION PUMPS	SEE APPENDIX F -4 PUMPS -IMPELLER -CASING -MOTOR -GEARS -SHAFT AND COUPLING	INC IFC IFC IFC INC INC			12	VENDOR QUOTES (BYRON JACKSON)			12	SAME	0	12			29/32	N.A.	NONE	0	
SUBTOTAL					12			12				12							
Contingency				(20%)	2			(10%)	1		(10%)	1							
Home Office and Engineering				(15%)	2			(10%)	1		(10%)	1							
Fees				(10%)	1			(10%)	1		(10%)	1							
TOTAL					17				15			15							

TABLE K.1.7
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant		Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes
			Mat	Labor	Total	Mat	Labor	Total		8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
AMMONIA SYSTEM PIPING	SEE APPENDIX F				17			17	SAME	0	17	8	N. A.	NONE	0	
SUBTOTAL					17			17			17					
Contingency				(20%)	3			(10%)	2	(10%)	2					
Home Office and Engineering				(15%)	3			(10%)	2	(10%)	2					
Fees				(10%)	2			(10%)	2	(10%)	2					
TOTAL					25			23			23					

TABLE K.1.9
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant		Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes
			Mat	Labor	Total	Mat	Labor	Total		8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
CONTROL SYSTEMS	-COMPUTER SYSTEM -PLOTTER -3 DISPLAY TERMINALS -2 REMOTE TERMINALS -PROGRAM AND CONTROL CONSOLES -3 MODEMS -RTU TEST SET -RTU & CPU SPARE KITS				6			5	0	5	8		N.A.	NONE	0	
SUBTOTAL					6			5		5						
Contingency				(20%)	1			(10%)	(10%)	1						
Home Office and Engineering				(15%)	1			(10%)	(10%)	1						
Fees				(10%)	1			(10%)	(10%)	1						
TOTAL					9			8		8						

TABLE K.1.16
50 MWe POWER SYSTEM COSTS (\$/kWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
CONDENSER	TUBE AND SHELL ALUMINUM -TUBES -TUBESHEETS -TRANSITION RINGS -NON CONDENSIBLE REMOVAL SYSTEM -TUBE SUPPORT PLATES & SUPPORTS -FINAL ASSEMBLY -WATERBOXES	 INC INC INC INC INC INC INC	200	78	278	SEE SECTION 4.10.1	200	73	273	SEE SECTION 4.10.1	1.7%	252	8	27%	.97	SEE SECTION 4.10.1	7.7%	
SUBTOTAL					278				273			252						
Contingency				(20%)	56			(10%)	27		(10%)	25						
Home Office and Engineering				(15%)	40			(10%)	27		(10%)	25						
Fees				(10%)	28			(10%)	27		(10%)	25						
TOTAL					402				354			327						

TABLE K.1.17
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
MIST EXTRACTOR	HOOK AND VANE DEMISTER		4		4	VENDOR QUOTE (PEERLESS)	4		4	SAME	0	4	15/16	N.A.	N.A.	NONE	0	
SUBTOTAL					4				4			4						
Contingency			(20%)	1				(10%)			(10%)							
Home Office and Engineering			(15%)	1				(10%)			(10%)							
Fees			(10%)					(10%)			(10%)							
TOTAL					6				4			4						

TABLE K.1.18
50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant					Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total		Mat	Labor	Total										
STRUCTURES	-CONDENSER PUMP AND MACHINERY ROOM	INC	4	17	21	580,000 LBS	4	17	21	SAME	0	19	8	20%	.95	NONE	9.5%		
	-EVAPORATOR PUMP AND MACHINERY ROOM	INC	5	19	24	660,000 LBS	5	19	24	SAME	0	21	8	20%	.95	NONE	12.5%		
	-2 ACCESS PASSAGES	INC	3	14	17	475,000 LBS @1.80 \$/LB	3	14	17	SAME	0	14	15/16	20%	.95	NONE	17.6%		
SUBTOTAL					62			62				54							
Contingency				(20%)	12			(10%)	6		(10%)	5							
Home Office and Engineering				(15%)	9			(10%)	6		(10%)	5							
Fees				(10%)	6			(10%)	6		(10%)	5							
TOTAL					89			80				69							

TABLE K.1.19
50 MWe POWER SYSTEM COSTS (\$/kWe)

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50 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
COMPONENT INSTALLATION	SEE APPENDIX I AND SECTION 4.9.4			55	55	LSCC QUOTE (1-78) ADJUSTED FOR REFERENCE PLATFORM		55	55	SAME	0	55	8	N.A.	N.A.	NONE	0	
SUBTOTAL					55			55				55						
Contingency				(20%)	11			(10%)	6		(10%)	6						
Home Office and Engineering				(15%)	8			(10%)	6		(10%)	6						
Fees				(10%)	6			(10%)	6		(10%)	6						
TOTAL					80			73				73						

TABLE K.2.1
10 MWe POWER SYSTEM COSTS (\$/KWe)

			Prcototype Plant				First Production Plant				Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
TURBINE	SEE SECTION 5.4.2 -RADIAL INFLOW -TURBINE WHEEL -CASING -INSTRUMENTATION AND CONTROLS -VARIABLE INLET VANES	INC INC INC INC			71	VENDOR QUOTE (ROTOFLOW)			71	SAME	0	58	8		N.A.	ROTO- FLOW ESTIMA- TED COST REDUC- TION	19.5%	
SUBTOTAL					71				71			58						
Contingency				(20%)	14			(10%)	7		(10%)	6						
Home Office and Engineering				(15%)	11			(10%)	7		(10%)	6						
Fees				(10%)	7			(10%)	7		(10%)	6						
TOTAL					103				92			76						

TABLE K.2.2
10 MWe POWER SYSTEM COSTS (\$/KWe)

			Prototype Plant			First Production Plant				Eighth Production Plant								
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
GENERATOR	SEE SECTION 5.4.2 -TOTALLY ENCLOSED WATER AND AIR COOLED (TEWAC) -CASING -COOLING AND LUBRICATION SYSTEM -EXCITER -WINDINGS AND STATOR	INC INC INC INC			47	VENDOR QUOTE (ROTOFLOW)			47	SAME	0	44	8		N.A.	ROTO- FLOW	6.4%	
SUBTOTAL					47				47			44						
Contingency			(20%)	9			(10%)	5			(10%)	4						
Home Office and Engineering			(15%)	7			(10%)	5			(10%)	4						
Fees			(10%)	5			(10%)	5			(10%)	4						
TOTAL				68				62				57						

TABLE K.2.3
10 MWe POWER SYSTEM COSTS (\$/KWe)

TABLE K.2.3 10 MWe POWER SYSTEM COSTS (\$/kWe)																		
Component/ Subsystem	Description	Inc/not inc in cost	Prototype Plant				First Production Plant				* Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
WARM SEAWATER PUMPS	4 PUMPS -IMPELLER -CASING -SUCTION BELL, DIFFUSER AND EXTENSION -SHAFT AND COUPLING -MOTOR -GEAR -SEE SECTION 5.4.1	INC INC INC INC INC INC INC INC			70	WORTHINGTON PARAMETRIC STUDY; SEE SECTION 5.4.1 RANGE: 400-2800 CFS 6.5-15 FT HEAD			70	SAME	0	58	57/64		N.A.	WORTH- INGTON ESTIMA- TED COST REDUC- TION	17%	
	PUMP SET SHROUD	INC	3	12	15	100,000 LBS @1.50 \$/LB	3	12	15	SAME	0	12	15/16	20%	.95	NONE	20%	
SUBTOTAL					85			85				70						
Contingency				(20%)	17			(10%)	8		(10%)	7						
Home Office and Engineering				(15%)	13			(10%)	8		(10%)	7						
Fees				(10%)	8			(10%)	8		(10%)	7						
TOTAL					123			109				91						

TABLE K.2.4
10 MWe POWER SYSTEM COSTS (\$/KWe)

TABLE K.2.4 10 MWe POWER SYSTEM COSTS (\$/KWe)																		
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No., 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
Mat	Labor	Total	Mat	Labor	Total													
COLD SEAWATER PUMPS	4 PUMPS -IMPELLER -CASING -SUCTION BELL, DIFFUSER AND EXTENSION -SHAFT AND COUPLING -MOTOR -GEAR -SEE SECTION 5.4.1	INC INC INC INC INC INC INC			70	WORTHINGTON PARAMETRIC STUDY; SEE SECTION 5.4.1 RANGE: 400-2800 CFS 6.5-15 FT HEAD			70	SAME	0	58	57/64		N.A.	WORTH- INGTON ESTIMA- TED COST RE DUCTION	17%	
	PUMP SET SHROUD		3	12	15	100,000 LBS @1.50 \$/LB	3	12	15	SAME	0	12	15/16	20%	.95	NONE	20%	
SUBTOTAL					85				85			70						
Contingency				(20%)	17			(10%)	8		(10%)	7						
Home Office and Engineering				(15%)	13			(10%)	8		(10%)	7						
Fees				(10%)	8			(10%)	8		(10%)	7						
TOTAL					123				109			91						

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			Frototype Plant				First Production Plant				Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
AMMONIA CONDENSATE PUMPS	SEE APPENDIX F -3 PUMPS -IMPELLER -CASING -MOTOR -GEARS -SHAFT AND COUPLING	INC INC INC INC INC INC			15	SCALED DOWN FROM 50 MWe COSTS.10% OF COST ASSUMED FIXED, 90% DIRECT FUNCTION OF FLOW RATE. APPROXIMATE VALVE ONLY			15	SAME	0	15		22/24	N.A.	NONE	0	
SUBTOTAL					15				15			15						
Contingency			(20%)	3			(10%)	2		(10%)		2						
Home Office and Engineering			(15%)	2			(10%)	2		(10%)		2						
Fees			(10%)	2			(10%)	2		(10%)		2						
TOTAL				21				21				21						

TABLE K.2.6
10 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
AMMONIA DISTRIBUTION PUMPS	SEE APPENDIX F -4 PUMPS -IMPELLER -CASING -MOTOR -GEARS -SHAFT AND COUPLING	INC INC INC INC INC INC			17	SCALED DOWN FROM 50 MWe COSTS.10% OF COST ASSUMED FIXED, 90% DIRECT FUNCTION OF FLOW RATE. APPROXIMATE VALVE ONLY			17	SAME	0	17		29/32	N.A.	NONE	0	
SUBTOTAL					17			17				17						
Contingency				(20%)	3			(10%)	2		(10%)	2						
Home Office and Engineering				(15%)	3			(10%)	2		(10%)	2						
Fees				(10%)	2			(10%)	2		(10%)	2						
TOTAL					25			23				23						

TABLE K.2.7
10 MWe POWER SYSTEM COSTS (\$/kWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant		Description of Costing Basis	First Production Plant			Description of Costing Basis	% Reduct From Prototype	Eighth Production Plant						Notes
			Mat	Labor	Total	Mat	Labor	Total			8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
AMMONIA SYSTEM PIPING	SEE APPENDIX F				23			23	SAME	0	23	8		N.A.	NONE	0	
SUPTOTAL					23			23			23						
Contingency				(20%)	5			(10%)	2	(10%)	2						
Home Office and Engineering				(15%)	3			(10%)	2	(10%)	2						
Fees				(10%)	2			(10%)	2	(10%)	2						
TOTAL					33			29			29						

TABLE K.2.8
10 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
AMMONIA SYSTEM VALVING	SEE APPENDIX F				26	SCALED DOWN FROM 50 MWe COSTS 50% OF COST ASSUMED FUNCTION OF FLOW RATES, 50% OF PIPE DIAMETERS APPROXIMATE VALVE ONLY			26	SAME	0	26	8		N.A.	NONE	0	
SUBTOTAL					26			26				26						
Contingency				(20%)	5			(10%)	3		(10%)	3						
Home Office and Engineering				(15%)	4			(10%)	3		(10%)	3						
Fees				(10%)	3			(10%)	3		(10%)	3						
TOTAL					38			35				35						

TABLE K.2.9
10 MWe POWER SYSTEM COSTS (\$/KWe)

TABLE K.2.9
10 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant					Eighth Production Plant						Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No., 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
CONTROL SYSTEMS	-COMPUTER SYSTEM -PLOTTER -3 DISPLAY TERMINALS -2 REMOTE TERMINALS -PROGRAM AND CONTROL CONSOLES -3 MODEMS -RTU TEST SET -RTU & CPU SPARE KITS				30	VENDOR QUOTE (LEC)			30	SAME	0	30	8		N.A.	NONE	0	1
SUBTOTAL					30			30				30						
Contingency				(20%)	6			(10%)	3		(10%)	3						
Home Office and Engineering				(15%)	4			(10%)	3		(10%)	3						
Fees				(10%)	3			(10%)	3		(10%)	3						
TOTAL					43			39				39						

1. 10 MWe POWER MODULE IS SELF-SUFFICIENT

TABLE K.2.10
10 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc./not Inc in cost	Prototype Plant			Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes	
			Prototype Unit Cost				First Production Unit Cost				8th Plant Unit Cost	First/Last Unit No., 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total	Mat	Labor	Total										
CHLORINATION SYSTEM	-TWO 85 LB/HR CHLOROPAC GENERATORS	INC			23	VENDOR QUOTE (ENGELHARD)			23	SAME	0	23	15/16		N.A.	NONE	0	
	-SKID MOUNT	INC																
	-MANIFOLDING	INC																
	-POWER SUPPLIES IN NEMA 2 ENCLOSURES																	
SUBTOTAL					23			23				23						
Contingency				(20%)	5			(10%)	2		(10%)	2						
Home Office and Engineering				(15%)	3			(10%)	2		(10%)	2						
Fees				(10%)	2			(10%)	2		(10%)	2						
TOTAL					33				29			29						

TABLE K.2.11
10 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
Mat	Labor	Total	Mat	Labor	Total													
MECHANICAL CLEANING SYSTEM	-MAN BRUSHES	INC			28	VENDOR QUOTE (MAN)			28	SAME	0	28	15/16		N.A.	NONE	0	
	-2 CATCHERS/BRUSH	INC																
SUBTOTAL					28			28				28						
Contingency				(20%)	6			(10%)	3		(10%)	3						
Home Office and Engineering				(15%)	4			(10%)	3		(10%)	3						
Fees				(10%)	3			(10%)	3		(10%)	3						
TOTAL					41			37				37						

TABLE K.2.12
10 MWe POWER SYSTEM COSTS (\$/KWe)

10 MWe POWER SYSTEM COSTS (\$/KWe)																		
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
AMMONIA SUPPORT SYSTEMS	-FILL	INC			43	BECHTEL ESTI- MATE BASED ON STANDARD PRICE LISTS			43	SAME	0	43		N.A.	NONE	0		1
	-DRAIN	INC			7				7									
	-VAPOR RECOVERY	INC			18				18									
	-NON-CONDESIBLE REMOVAL	INC			18				18									
	-PURGE	INC			114				114									
	-CLEANUP	INC			65				65									
SUBTOTAL					265			265			265							
Contingency				(20%)	53			(10%)	26		(10%)	26						
Home Office and Engineering				(15%)	40			(10%)	26		(10%)	26						
Fees				(10%)	26			(10%)	26		(10%)	26						
TOTAL					384			343			343							

1. 10MWe POWER MODULE IS SELF-SUFFICIENT

TABLE K.2.13
10 MW POWER SYSTEM COSTS (\$/KWe)

			Prototype Plant			First Production Plant					Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes
			Mat	Labor	Total		Mat	Labor	Total									
ELECTRICAL EQUIPMENT	-POWER DISTRIBUTION	INC			140	SCALED DOWN FROM 50 MWe COST, 25% AS DIRECT FUNC- TION OF AMPER- AGE, 75% AS DIRECT FUNC- TION OF POWER. APPROXIMATE VALUE ONLY			140	SAME	0	140	8		N.A.	NONE	0	
	-SWITCHGEAR	INC																
	-VARIABLE FREQUENCY INVERTERS AND RECTIFIERS	INC																
	-TRANSFORMERS o 13.8 KV/4.16 KV o 4.16 KV/480 V o 4.16 KV/277 V	INC																
	-PUMP POWER SUPPLY o NH ₃ DISTRIBUTION PUMPS o NH ₃ CONDENSATE PUMP SEAWATER PUMPS	INC																
	-NH ₃ SUPPORT SYSTEMS POWER SUPPLY	INC																
SUBTOTAL					140			140			140							
Contingency				(20%)	28			(10%)	14		(10%)	14						
Home Office and Engineering				(15%)	21			(10%)	14		(10%)	14						
Fees				(10%)	14			(10%)	14		(10%)	14						
TOTAL					203			182			182							

TABLE K.2.14
10 MWe POWER SYSTEM COSTS (\$/kW_e)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant			Description of Costing Basis	First Production Plant			% Reduct From Prototype	Eighth Production Plant						Notes
			Mat	Labor	Total		Mat	Labor	Total		8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct. Basis	% Reduct From 1st Prod	
AUXILIARY SYSTEMS	-COMPRESSED AIR & HYDRAULIC SYSTEM	INC			10	BECHTEL ESTIMATE BASED ON STANDARD PRICE LISTS			10	0	10	8		N.A.	NONE	0	1
	-VENTILATION	INC			5				5	0	5	8		N.A.	NONE	0	
	-FIRE CONTROL	INC			5				5	0	5	8		N.A.	NONE	0	
	-SENSORS AND ALARMS	INC			6				6	0	6	8		N.A.	NONE	0	
	-COMMUNICATIONS	INC			1				1	0	1	8		N.A.	NONE	0	
	-LIGHTING	INC			7				7	0	7	8		N.A.	NONE	0	
SUBTOTAL					34				34		34						
Contingency				(20%)	7				3		3						
Home Office and Engineering				(15%)	5				3		3						
Fees				(10%)	3				3		3						
TOTAL					49				43		43						

1. 10MWe POWER MODULE IS SELF-SUFFICIENT

TABLE K.2.15
10 MWe POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant					Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total		Mat	Labor	Total										
EVAPORATOR	TUBE AND SHELL TITANIUM TUBING CARBON STEEL STRUCTURE TI-CLAD TUBESHEETS -TUBES -TUBESHEETS -TRANSITION RINGS -AMMONIA DIST SYSTEM -TUBE SUPPORT PLATES & SUPPORTS -FINAL ASSEMBLY -WATERBOXES		470	122	592	SEE SECTION 5.10.1	470	114	584	SEE SECTION 5.10.1	1.4%	551	8	20%	.97	SEE SECTION 5.10.1	6.9%		
SUBTOTAL					592				584			551							
Contingency				(20%)	108			(10%)	58		(10%)	55							
Home Office and Engineering				(15%)	89			(10%)	58		(10%)	55							
Fees				(10%)	59			(10%)	58		(10%)	55							
TOTAL					848				758			656							

TABLE K.2.16
10 MW(e) POWER SYSTEM COSTS (\$/kWe)

Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant					Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total		Mat	Labor	Total										
CONDENSER	TUBE AND SHELL TITANIUM TUBING CARBON STEEL STRUCTURE TI-CLAD TUBESHEETS -TUBES -TUBESHEETS -TRANSITION RINGS -NON CONDENSIBLE REMOVAL SYSTEM -TUBE SUPPORT PLATES AND SUPPORTS -FINAL ASSEMBLY -WATERBOXES	 INC INC INC INC INC INC INC	564	125	689	SEE SECTION 5.10.1	564	116	680	SEE SECTION 5.10.1	1.3%	645	8	17%	.97	SEE SECTION 5.10.1	6.4%		
SUBTOTAL					689				680			645							
Contingency				(20%)	138			(10%)	68		(10%)	64							
Home Office and Engineering				(15%)	103			(10%)	68		(10%)	64							
Fees				(10%)	69			(10%)	68		(10%)	64							
TOTAL					999				884			837							

TABLE K.2.17
10 MW(e) POWER SYSTEM COSTS (\$KWe)

			Prototype Plant				First Production Plant					Eighth Production Plant							
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	Notes	
MIST EXTRACTOR	HOOK AND VANE DEMISTER		7	--	7	VENDOR QUOTE (PEERLESS)	7	--	7	SAME	0	7	15/16	N.A.	N.A.	NONE	0		
SUBTOTAL					7				7			7							
Contingency				(20%)	1			(10%)	1		(10%)	1							
Home Office and Engineering				(15%)	1			(10%)	1		(10%)	1							
Fees				(10%)	1			(10%)	1		(10%)	1							
TOTAL					10				10			10							

TABLE K.2.18
10 MW(e) POWER SYSTEM COSTS (\$/KWe)

Component/ Subsystem	Description	inc/not inc in cost	Prototype Plant				First Production Plant					Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod		
			Mat	Labor	Total		Mat	Labor	Total										
STRUCTURES	-CONDENSER PUMP AND MACHINERY ROOM	INC	4	14	18	100,000 lbs	4	14	18	SAME	0	16	8	20%	.95	NONE	11.2%		
	-EVAPORATOR PUMP AND MACHINERY ROOM	INC	4	14	18	100,000 lbs	4	14	18	SAME	0	16	8	20%	.95	NONE	11.2%		
	-2 ACCESS PASSAGES	INC	7	28	35	195,000 lbs	7	28	35	SAME	0	28	15/16	20%	.95	NONE	20%		
SUBTOTAL					71			71			60								
Contingency				(20%) 14				(10%) 7		(10%)	6								
Home Office and Engineering				(15%) 11				(10%) 7		(10%)	6								
Fees				(10%) 7				(10%) 7		(10%)	6								
TOTAL					103			92			78								

TABLE K.2.19
10 MWe POWER SYSTEM COSTS (\$/KWe)

TABLE K.2.19 10 MWe POWER SYSTEM COSTS (\$/KWe)																		
Component/ Subsystem	Description	Inc/not Inc in cost	Prototype Plant				First Production Plant				Eighth Production Plant							Notes
			Prototype Unit Cost			Description of Costing Basis	First Production Unit Cost			Description of Costing Basis	% Reduct From Prototype	8th Plant Unit Cost	First/Last Unit No. 8th Plant	Lab Cost (% of 1st Prod Cost)	Learning Curve Expon't Factor	Other Cost Reduct Basis	% Reduct From 1st Prod	
			Mat	Labor	Total		Mat	Labor	Total									
COMPONENT INSTALLATION	SEE APPENDIX I			65	65	LSCL QUOTE (1-78) ADJUSTED FOR REFERENCE PLATFORM		65	65	SAME	0	65	8	N.A.	N.A.	NONE	0	
SUBTOTAL					65			65				65						
Contingency				(20%)	13			(10%)	6		(10%)	6						
Home Office and Engineering				(15%)	10			(10%)	6		(10%)	6						
Fees				(10%)	6			(10%)	6		(10%)	6						
TOTAL					94			83				83						