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OCEAN THERMAL ENERGY CONVERSION (OTEC)
TEST FACILITIES STUDY PROGRAM

Final Report. Volume II. Part C

January 17, 1977

Work Performed Under Contract No. E(04-3)-1156

Lockheed Missiles and Space Company, Incorporated
Sunnyvale, California

ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
Division of Solar Energy

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**OCEAN THERMAL ENERGY CONVERSION
(OTEC)
TEST FACILITIES STUDY PROGRAM**

VOLUME II PART C

FINAL REPORT

Prepared by
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17 JANUARY 1977

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PREPARED FOR
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
DIVISION OF SOLAR ENERGY

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FOREWORD

Lockheed Missiles & Space Company, Inc. and its team members have completed an 8-month study to develop alternative non-site-specific OTEC facilities/platform requirements for an integrated OTEC Test Program which may include land and floating test facilities. The study was performed for the Energy Research and Development Administration (ERDA) under Contract E(04-3)-1156 initiated with a kick-off meeting on 8 January 1976.

This document, Volume II - Appendixes, is bound in three parts (A, B, and C). Together they comprise a compendium of the most significant detailed data developed during the study.

Volume I provides updated copies of the visual aids and a summary of the oral presentation given to ERDA representatives on 26-27 August at Sunnyvale, California. For the convenience of the reader, the principal section headings for Volume I are listed below:

A. Program Overview	K. Testing II Seabased Cycle Plant
B. Baseline Configuration	L. Testing II Seabased Test Facility
C. Test Plans	M. Data Acquisition and Control System
D. Energy Utilization	N. Cost Summary
E. Scaling	O. Schedule Summary
F. Testing I Requirements	P. Conclusions
G. Testing I Test Beds	
H. Testing II Requirements	
I. Testing II Landbased Cycle Plant	
J. Testing II Landbased Test Facility	

CONTENTS

Appendix

- 8 Test Facility Support
- 9 Data Acquisition and Control System
- 10 Cost Data
- 11 Energy Self Sufficiency
- 12 Test Facility Applications

Appendix 8

TEST FACILITY SUPPORT

This Appendix defines, describes, and quantifies the cost of the necessary support for the test beds and cycle plants in terms of buildings, shops, equipments, platform characteristics, and personnel for both both land-based and sea-based test facilities. The approach used in defining and costing the support was to establish the land-based test facility support areas and then select or modify the land-based test facility and costs for sea-based test facility application.

This Appendix provides the details for Report Sections J and L and contains the following sections:

- 8.1 Buildings and Support Equipment
- 8.2 Site Facility Summary (Land Based)
- 8.3 Sea-Based Platform
- 8.4 Personnel

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8.1 BUILDINGS AND SUPPORT EQUIPMENT

The land-based test facility and sea-based test facility equipment are summarized by type in the first two figures. These figures were not presented on 26-27 August 1976 because of time limitation. The figures provide the description of the types of equipment contained in the miscellaneous equipment costs given in Report Sections J and L.

The miscellaneous equipment costs were established by listing the building, shop, or laboratory, and defining or describing the type of equipment contained therein. Vendors were contacted to obtain quotes for higher cost equipment. In cases where many items are contained in single entry, a lot cost quote was obtained.

The land-based test facility support equipment and estimated cost is contained in Table 8-1. The sea-based test facility with the land facility at the shore facility is in Tables 8-2 and 8-3 with the land portion in Table 8-2 and the at-sea portion in Table 8-3. The sea-based test facility with the land facility separated from the shore facility is in Tables 8-4 and 8-5 for the land facility and shore facility, respectively. The test platform for this latter case is the same as given in Table 8-3.

LAND BASED TEST FACILITY EQUIPMENT

- ADMINISTRATIVE

OFFICE FURNISHINGS, CAFETERIA
FIRE AND SAFETY

- TECHNICAL

INSTRUMENTATION/CALIBRATION LABORATORY
PHOTOGRAPHY LABORATORY
ANALYSIS LABORATORY
CENTRAL CONTROL (CYCLE PLANT)

- SHOPS

MACHINE TOOLS, HAND TOOLS, PORTABLE EQUIPMENTS
WELDING MACHINES, CRIBS/CABINETS
GAGES, BUILDING CRANES, PAINT SPRAYERS, SAND BLASTERS

- EQUIPMENT

HANDLING - MOBILE CRANES, FORK LIFTS, TRUCKS
STANDBY/MOBILE - DIESEL GENERATORS, AIR COMPRESSORS, WELDING MACHINES

- UNDEFINED/CONTINGENCY

SPECIALIZED TOOLS, RAW STOCK

LAND BASED TEST FACILITY EQUIPMENT

THE EQUIPMENTS TO FURNISH AND OUTFIT THE BUILDINGS, SHOPS AND LABORATORIES AND TO PROVIDE EQUIPMENT HANDLING AND MAINTENANCE CAPABILITY HAS BEEN SUMMARIZED IN THIS LISTING UNDER THE FIVE HEADINGS.

THE ADMINISTRATIVE EQUIPMENT FURNISHES THE OFFICES, CAFETERIA, GUARDHOUSE, EMPLOYEE WELFARE AND THE FIRE AND FIRE PUMP HOUSE. THE TECHNICAL EQUIPMENT OUTFITS ALL LABORATORIES AND THE CYCLE PLANT CENTRAL CONTROL BUILDING EXCEPT FOR THE DATA ACQUISITION AND CONTROL SYSTEM.

THE SHOP OUTFITTING AND FURNISHINGS INCLUDE ALL NECESSARY MACHINERY, TOOLS, INCLUDING INSIDE CRANES, HOWEVER ONLY A FEW TYPICAL ITEMS ARE LISTED.

IN ADDITION TWO SPECIAL CATEGORIES OF EQUIPMENT ARE LISTED. THE FIRST IS HANDLING EQUIPMENT SUCH AS MOBILE CRANES, FORK LIFTS, MAN LIFTS AND TRUCKS THAT ARE USED THROUGHOUT THE TEST FACILITY. THE SECOND IS THE STANDBY EQUIPMENT THAT IS USED TO ASSIST THE OPERATION WHEREVER NEEDED AND CONSISTS OF DIESEL GENERATORS, AIR COMPRESSORS, WELDING MACHINES, ELECTRIC BLOWERS, ETC. THESE EQUIPMENTS MAY BE MOBILE.

FINALLY AN UNDEFINED/CONTINGENCY GROUP OF EQUIPMENT CONSISTING OF SPECIALIZED TOOLS, MISCELLANEOUS HARDWARE AND RAW STOCK HAS BEEN INCLUDED.

SEA-BASED TEST FACILITY EQUIPMENT

- ADMINISTRATIVE

OFFICE FURNISHINGS, CAFETERIA, EMPLOYEE RECREATION (A. S.)*
FIRE AND SAFETY (A. S./L. F.)

- TECHNICAL

INSTRUMENTATION/CALIBRATION LABORATORIES (A. S./L. F.)
PHOTOGRAPHY LABORATORIES (A. S./L. F.)
ANALYSIS LABORATORIES (A. S./L. F.)
CENTRAL CONTROL (A. S.)

- SHOPS (A. S./L. F.)

MACHINE TOOLS, HAND TOOLS, PORTABLE EQUIPMENTS
WELDING MACHINES, CRIBS/CABINETS
GAGES, BUILDING CRANES, PAINT SPRAYERS, SAND BLASTERS

- EQUIPMENT (A. S./L. F.)

HANDLING – MOBILE CRANES, FORKLIFTS, TRUCKS, MANLIFTS
STANDBY/MOBILE – DIESEL GENERATORS, AIR COMPRESSORS,
WELDING MACHINES

- UNDEFINED/CONTINGENCY

SPECIALIZED TOOLS, RAW STOCK

* (A. S.) AT-SEA
(L. F.) LAND FACILITY

SEA-BASED TEST FACILITY EQUIPMENT

The equipments to furnish and outfit the buildings, shops, and laboratories and to provide equipment handling and maintenance capability has been summarized in the listing under the five headings. In addition the location of where the equipment is to be used is noted by the parenthetically enclosed initials.

The administrative equipment furnishes the offices, cafeterias, guardhouses, employee welfare on land and employee recreation at-sea, and the fire and fire pump house. The technical equipment outfits laboratories on-land and at-sea and the cycle plant central control except for the data acquisition and control system.

The shop outfitting and furnishings include all necessary machinery, tools including inside cranes; however, only a few typical items are listed. In addition, two special categories of equipment are listed. The first is handling equipment such as mobile cranes, forklifts, man lifts, trucks, and straddle lifts, that are used through the land or shore facility. The second is standby equipment that is used to assist the operation wherever needed and consists of diesel generators, air compressors, welding machines, electric blowers, etc. These equipments may be mobile. Finally, an undefined/contingency group of equipment consisting of specialized tools, miscellaneous hardware, and raw stock has been included.

Table 8-1
LAND-BASED TEST FACILITY

<u>Building/Shop/Laboratory</u>	<u>Estimated Cost</u> (\$1000)
A. <u>Inside Equipment</u>	
1. Gate House (Guard) (20 ft x 30 ft) Est. I.D. equipment (lot)	5
2. Administration Bldg. (160 ft x 80 ft) Est. office equipment (50 people)	15
3. Fabrication Bldg. (180 ft x 110 ft) Est. assembly equipment (lot)	25
4. Control Bldg. (80 ft x 50 ft) Est. Control Consoles - 2 ea. at \$250,000.00 ea.	500
5. Employee Welfare Bldg. (90 ft x 50 ft) Consists of kitchen equipment, messing facilities and first aid for 190 people.	80
6. Maintenance Shop Area (80 ft x 50 ft) Consists of vises at \$1,500 lot Roll-a-way tool kits at \$4,000 lot Portable electric blowers at \$2,500 lot Burning sets at \$10,000 lot Stores (Maint.) at \$5,000 lot	23
7. Heavy Machinery Shop (180 ft x 100 ft) Consisting of: Drill presses 2 ea. at \$5,000 ea. Lathes 3 ea. at \$12,000 ea. Welding Machines 2 ea. at \$4,000 ea. Shaper 1 ea. at \$4,000 ea. Planer 1 ea. at \$5,000 ea. Plate Shearer 2 ea. at \$20,000 ea. Brake Press 1 ea. at \$22,000 ea. Stores (Shop) \$10,000 lot Tool Crib \$10,000 lot Travelling Crane - 5 Ton 1 ea. at \$15,000 Travelling Crane - 2 Ton 1 ea. at \$12,000 Heat Treat Oven 2 ea. at \$8,000 ea. Misc. Tools (lot) \$5,000	193

Table 8-1 (Cont.)

8.	Pipe Shop (100 ft × 100 ft) Consisting of: Tube Benders 4 ea. at \$150,000 ea. Welding Machines 2 ea. at \$10,000 ea. Travelling Crane 2-Ton 1 ea. at \$20,000 ea. Misc. Tools (lot) \$17,000	657
9.	Electrical Shop (50 ft × 40 ft) Consisting of: Misc. Tools \$5,000 lot Tool Crib \$5,000 lot	10
10.	Carpenter Shop (50 ft × 40 ft) Consisting of: Band Saw 1 ea. at \$2,500 ea Circular Saw 1 ea. at \$1,500 ea. Planer 1 ea. at \$2,000 ea. Misc. Tools (lot) \$5,000 Tool Crib (lot) \$6,000	17
11.	Paint Shop (50 ft × 40 ft) Consisting of: Paint Sprayers 2 ea. at \$2,000 ea. Portable Electric Blowers (lot) \$2,500 100 psi Air Supply (lot) \$3,500 Tool Crib (lot) \$5,000	15
12.	Receiving Shop Area (100 ft × 100 ft) Consisting of: Work Benches (lot) \$1,200 Fork Lifts 2 ea at \$15,000 ea. Scales 2 ea. at \$1,800 ea. Banding Machinery (lot) \$1,200 Pallets (lot) \$2,000	38
13.	Sand Blasting Shed (40 ft × 40 ft) Consisting of sand blast equipment (lot)	50
14.	Instrumentation and Calibration Laboratory (50 ft × 40 ft) Consisting of storage cabinets, gages, calibration equipment and tool crib (lot)	30
15.	Photo Processing Lab (20 ft × 20 ft) Consisting of darkroom equipment (lot)	10
16.	Analysis Laboratory (30 ft × 30 ft) Consisting of laboratory equipment (lot)	50

Table 8-1 (Cont.)

B. Outside Equipment

<u>Item</u>	<u>Estimated Cost</u> <u>(\$1000)</u>
1. Fork lift trucks (total 3)	49
1 ea. 4-Ton Cap. at \$19,000 ea.	
2 ea. 2-Ton Cap. at \$15,000 ea.	
2. Mobile cranes (total 3)	550
2 ea. 50-Ton Cap. at \$150,000	
1 ea. 100-Ton Cap. at \$250,000	
3. Trucks (total 9)	79
Flat bed 5-Ton Cap. 2 ea. at \$8,000 ea.	
Pick-up 3/4-Ton Cap. 4 ea. at \$4,000 ea.	
Vans 3/4-Ton Cap. 2 ea. at \$3,500 ea.	
Straddle truck 10-Ton Cap. 1 ea. at \$40,000	
4. Man lifts	
60 ft. reach 2 ea. at \$50,000 ea.	100
5. Diesel Generators	135
for standby/start-up power	
1 ea. at 500 KW Cap. at \$45,000	
1 ea. at 1000 KW Cap. at \$90,000	
6. 100 psi Air Compressor/Filter/Controls	8
7. Welding Machines	30
8. Air Arc Welders	40
2 ea. at \$20,000 ea.	

C. Summary

Inside Total	1,718
Outside Total	991
Undefined*	<u>291</u>
Total	3,000

*Includes initial raw stock, miscellaneous small items, and contingency.

Table 8-2

**SEA-BASED TEST FACILITY
LAND FACILITY AT SHORE FACILITY**

ON LAND

<u>Building/Shop/Laboratory</u>	<u>Estimated Cost (\$1000)</u>
A. <u>Inside Equipment</u>	
1. Gate House (Guard) (20 ft x 30 ft) Est. I.D. equipment (lot)	5
2. Administration Bldg. (160 ft x 80 ft) Est. office equipment (50 people)	15
3. Fabrication Bldg. (180 ft x 110 ft) Est. assembly equipment (lot)	25
4. Control Bldg. (40 ft x 50 ft) Est. Simulated Control Consoles - 1 ea. at \$150,000 ea.	150
5. Employee Welfare Bldg. (90 ft x 50 ft) Consists of kitchen equipment, messing facilities, and first aid for 190 people.	80
6. Maintenance Shop Area (80 ft x 50 ft) Consists of vises at \$1,500 lot Roll-a-way tool kits at \$4,000 lot Portable electric blowers at \$2,500 lot Burning sets at \$10,000 lot Stores (Maint.) at \$5,000 lot	23
7. Heavy Machinery Shop (180 ft x 100 ft) Consisting of: Drill presses 2 ea. at \$5,000 ea. Lathes 3 ea. at \$12,000 ea. Welding Machines 2 ea. at \$4,000 ea. Shaper 1 ea. at \$4,000 ea. Planer 1 ea. at \$5,000 ea. Plate Shearer 2 ea. at \$20,000 ea. Brake Press 1 ea. at \$22,000 ea. Stores (Shop) \$10,000 lot Tool Crib \$10,000 lot Travelling Crane - 5 Ton 1 ea. at \$15,000 Travelling Crane - 2 Ton 1 ea. at \$12,000 Heat Treat Oven 2 ea. at \$8,000 ea. Misc. Tools (lot) \$5,000	193

Table 8-2 (Cont.)

8.	Pipe Shop (100 ft × 100 ft)	657
	Consisting of:	
	Tube Benders 4 ea. at \$150,000 ea.	
	Welding Machines 2 ea. at \$10,000 ea.	
	Travelling Crane 2-Ton 1 ea. at \$20,000 ea.	
	Misc. Tools (lot) \$17,000	
9.	Electrical Shop (50 ft × 40 ft)	10
	Consisting of:	
	Misc. Tools \$5,000 lot	
	Tool Crib \$5,000 lot	
10.	Carpenter Shop (50 ft × 40 ft)	17
	Consisting of:	
	Band Saw 1 ea. at \$2,500 ea.	
	Circular Saw 1 ea. at \$1,500 ea.	
	Planer 1 ea. at \$2,000 ea.	
	Misc. Tools (lot) \$5,000	
	Tool Crib (lot) \$6,000	
11.	Paint Shop (50 ft × 40 ft)	15
	Consisting of:	
	Paint Sprayers 2 ea. at \$2,000 ea.	
	Portable Electric Blowers (lot) \$2,500	
	100 psi Air Supply (lot) \$3,500	
	Tool Crib (lot) \$5,000	
12.	Receiving Shop Area (100 ft × 100 ft)	38
	Consisting of:	
	Work Benches (lot) \$1,200	
	Fork Lifts 2 ea at \$15,000 ea.	
	Scales 2 ea. at \$1,800 ea.	
	Banding Machinery (lot) \$1,200	
	Pallets (lot) \$2,000	
13.	Sand Blasting Shed (40 ft × 40 ft)	50
	Consisting of sand blast equipment (lot)	
14.	Instrumentation and Calibration Laboratory (50 ft × 40 ft)	30
	Consisting of storage cabinets, gages, calibration equipment and tool crib (lot)	
15.	Photo Processing Lab (20 ft × 20 ft)	10
	Consisting of darkroom equipment (lot)	
16.	Analysis Laboratory (30 ft × 30 ft)	50
	Consisting of laboratory equipment (lot)	

Table 8-2 (Cont.)

B. Outside Equipment

<u>Item</u>	<u>Estimated Cost</u> <u>(\$1000)</u>
1. Fork lift trucks (total 3)	49
1 ea. 4-Ton Cap. at \$19,000 ea.	
2 ea. 2-Ton Cap. at \$15,000 ea.	
2. Mobile cranes (total 3)	550
2 ea. 50-Ton Cap. at \$150,000	
1 ea. 100-Ton Cap. at \$250,000	
3. Trucks (total 9)	79
Flat bed 5-Ton Cap. 2 ea. at \$8,000 ea.	
Pick-up 3/4-Ton Cap. 4 ea. at \$4,000 ea.	
Vans 3/4-Ton Cap. 2 ea. at \$3,500 ea.	
Straddle truck 10-Ton Cap. 1 ea. at \$40,000	
4. Man lifts	100
60 ft. reach 2 ea. at \$50,000 ea.	
5. Diesel Generators	135
for standby/start-up power	
1 ea. at 500 KW Cap. at \$45,000	
1 ea. at 1000 KW Cap. at \$90,000	
6. 100 psi Air Compressor/Filter/Controls	8
7. Welding Machines	30
8. Air Arc Welders	40
2 ea. at \$20,000 ea.	

C. Summary - Land

Inside Total	1,368
Outside Total	991
Undefined*	<u>226</u>
Total	2,585

*Includes initial raw stock, miscellaneous small items, and contingency.

Table 8-3

SEA-BASED TEST FACILITY
LAND FACILITY AT SHORE FACILITY

AT SEA

A. <u>Inside Equipment</u>	<u>Estimated Cost</u> (\$1000)
1. Control Consoles (30 ft x 30 ft) 1 cycle plant inside, 2 test bed consoles	350
2. Analysis Laboratory (20 ft x 40 ft) 1 lot equipment	25
3. Photo Laboratory (10 ft x 20 ft) 1 lot photography and darkroom equipment	5
4. Instrumentation and Calibration Laboratory (20 ft x 20 ft) 1 lot cabinets, gages, tools, and work benches	15
5. Machine Shop	73
Drill Press 1 at \$5,000	
Lathe 1 at \$12,000	
Welding Machine 1 at \$4,000	
Plate Shearer 1 at \$20,000	
Brake Press 1 at \$22,000	
Misc. Tools (lot) \$5,000	
Stores (lot) \$5,000	
6. Welding Shop	35
Welding Machines, arc and gas (1 lot)	
7. Electrical Shop	10
Misc. tools and stock (1 lot)	
8. Carpenter Shop	17
1 lot similar to the land shop	
9. Paint Shop	15
1 lot similar to the land shop	
10. Maintenance Shop	23
1 lot similar to the land shop	

Table 8-3 (Cont.)

B. Outside Equipment

<u>Item</u>	<u>Estimated Cost</u> <u>(\$000)</u>
1. Diesel Generators	135
1 at 500 KW \$45,000	
1 at 1 MW \$90,000	
2. Forklift Truck	15
3. Pedestal Crane	110

C. Summary

Inside Total	568
Outside Total	260
Undefined*	<u>87</u>
Total	915

*Includes raw stock, miscellaneous small items, and contingency.

Table 8-4

SEA-BASED TEST FACILITY
LAND FACILITY SEPARATED FROM SHORE FACILITY
LAND FACILITY

<u>Building/Shop/Laboratory</u>	<u>Estimated Cost</u> (\$000)
A. <u>Inside Equipment</u>	
1. Gate House (Guard) (30 ft × 30 ft) Est. I.D. equipment (lot)	10
2. Administration Bldg. (180 ft × 80 ft) Est. office equipment (60 people)	20
3. Fabrication Bldg. (180 ft × 110 ft) Est. assembly equipment (lot)	25
4. Control Bldg. (40 ft × 50 ft) Est. Simulated Control Consoles - 1 at \$150,000	150
5. Employee Welfare Bldg. (90 ft × 50 ft) Consists of kitchen equipment, messing facilities, and first aid for 130 people.	70
6. Maintenance Shop Area (80 ft × 50 ft) Consists of vises at \$1,500 lot Roll-a-way tool kits at \$4,000 lot Portable electric blowers at \$2,500 lot Burning sets at \$10,000 lot Stores (Maint.) at \$5,000 lot	23
7. Heavy Machinery Shop (140 ft × 100 ft) Consisting of: Drill presses 2 ea. at \$5,000 ea. Lathes 2 ea. at \$12,000 ea. Welding Machines 2 ea. at \$4,000 ea. Shaper 1 ea. at \$4,000 ea. Planer 1 ea. at \$5,000 ea. Plate Shearer 1 ea. at \$20,000 ea. Brake Press 1 ea. at \$22,000 ea. Stores (Shop) \$10,000 lot Tool Crib \$10,000 lot Travelling Crane - 5 Ton 1 ea. at \$15,000 Travelling Crane - 2 Ton 1 ea. at \$12,000 Heat Treat Oven 2 ea. at \$8,000 ea. Misc. Tools (lot) \$4,000	160

Table 8-4 (Cont.)

8.	Pipe Shop (100 ft × 100 ft)	590
	Consisting of:	
	Tube Benders 3 ea. at \$150,000 ea.	
	Tube Bender 1 ea. at \$90,000	
	Welding Machines 2 ea. at \$10,000 ea.	
	Travelling Crane 2-Ton 1 ea. at \$20,000 ea.	
	Misc. Tools (lot) \$10,000	
9.	Electrical Shop (50 ft × 40 ft)	10
	Consisting of:	
	Misc. Tools \$5,000 lot	
	Tool Crib \$5,000 lot	
10.	Carpenter Shop (50 ft × 40 ft)	17
	Consisting of:	
	Band Saw 1 ea. at \$2,500 ea.	
	Circular Saw 1 ea. at \$1,500 ea.	
	Planer 1 ea. at \$2,000 ea.	
	Misc. Tools (lot) \$5,000	
	Tool Crib (lot) \$6,000	
11.	Paint Shop (50 ft × 40 ft)	15
	Consisting of:	
	Paint Sprayers 2 ea. at \$2,000 ea.	
	Portable Electric Blowers (lot) \$2,500	
	100 psi Air Supply (lot) \$3,500	
	Tool Crib (lot) \$5,000	
12.	Receiving Shop Area (100 ft × 100 ft)	38
	Consisting of:	
	Work Benches (lot) \$1,200	
	Forklifts 2 ea at \$15,000 ea.	
	Scales 2 ea. at \$1,800 ea.	
	Banding Machinery (lot) \$1,200	
	Pallets (lot) \$2,000	
13.	Sand Blasting Shed (40 ft × 40 ft)	50
	Consisting of sand blast equipment (lot)	
14.	Instrumentation and Calibration Laboratory	30
	Consisting of storage cabinets, gages, calibration equipment, and tool crib (lot)	
15.	Photo Processing Lab (20 ft × 20 ft)	10
	Consisting of darkroom equipment (lot)	
16.	Analysis Laboratory (30 ft × 30 ft)	50
	Consisting of laboratory equipment (lot)	

Table 8-4 (Cont.)

B. Outside Equipment

<u>Item</u>	<u>Estimated Cost</u> (\$000)
1. Forklift trucks (total 3)	49
1 ea. 4-Ton Cap. at \$19,000 ea.	
2 ea. 2-Ton Cap. at \$15,000 ea.	
2. Mobile cranes (total 3)	550
2 ea. 50-Ton Cap. at \$150,000	
1 ea. 100-Ton Cap. at \$250,000	
3. Trucks (total 9)	79
Flat bed 5-Ton Cap. 2 ea. at \$8,000 ea.	
Pick-up 3/4-Ton Cap. 4 ea. at \$4,000 ea.	
Vans 3/4-Ton Cap. 2 ea. at \$3,500 ea.	
Straddle truck 10-Ton Cap. 1 ea. at \$40,000	
4. Man lifts	100
60 ft. reach 2 ea. at \$50,000 ea.	
5. Diesel Generators	135
for standby/start-up power	
1 ea. at 500 KW Cap. at \$45,000	
1 ea. at 1000 KW Cap. at \$90,000	
6. 100 psi Air Compressor/Filter/Controls	8
7. Welding Machines	30
8. Air Arc Welders	40
2 ea. at \$20,000 ea.	

C. Summary

Inside Total	1,268
Outside Total	991
Undefined *	<u>326</u>
Total	2,585

*Includes initial raw stock, miscellaneous small items, and contingency.

Table 8-5

SEA-BASED TEST FACILITY
LAND FACILITY SEPARATED FROM SHORE FACILITY
SHORE FACILITY

<u>Building/Shop/Laboratory</u>	<u>Estimated Cost</u> (\$000)
A. <u>Inside Equipment</u>	
1. Gate House (Guard) (15 ft × 15 ft)	1
2. Administration Bldg. (60 ft × 60 ft) Est. office equipment (20 people)	4
3. Fabrication Bldg. (100 ft × 100 ft) Est. assembly equipment (lot)	15
4. Employee Welfare Bldg. (40 ft × 40 ft) Consists of kitchen equipment, messing facilities, and first aid for 60 people.	20
5. Maintenance Shop Area (80 ft × 50 ft) Consists of vises at \$1,500 lot Roll-a-way tool kits at \$4,000 lot Portable electric blowers at \$2,500 lot Burning sets at \$10,000 lot Stores (Maint.) at \$5,000 lot	23
6. Heavy Machinery Shop (120 ft × 100 ft) Consisting of: Drill presses 2 ea. at \$5,000 ea. Lathes 1 at \$12,000 Welding Machines 2 ea. at \$4,000 ea. Shaper 1 ea. at \$4,000 ea. Planer 1 ea. at \$5,000 ea. Plate Shearer 1 ea. at \$20,000 Brake Press 1 ea. at \$22,000 ea. Stores (Shop) \$10,000 lot Tool Crib \$10,000 lot Travelling Crane - 5 Ton 1 ea. at \$15,000 Travelling Crane - 2 Ton 1 ea. at \$12,000 Heat Treat Oven 1 at \$8,000 ea. Misc. Tools (lot) \$5,000	141

Table 8-5 (Cont.)

7.	Pipe Shop	590
	Consisting of:	
	Tube Benders 3 ea. at \$150,000 ea.	
	Tube Bender 1 ea. at \$90,000	
	Welding Machines 2 ea. at \$10,000 ea.	
	Travelling Crane 2-Ton 1 at \$20,000	
	Misc. Tools (lot) \$10,000	
8.	Electrical Shop	7
	Consisting of:	
	Misc. Tools \$4,000 lot	
	Tool Crib \$3,000	
9.	Carpenter Shop	12
	Consisting of:	
	Band Saw 1 ea. at \$2,500 ea.	
	Circular Saw 1 ea. at \$1,500 ea.	
	Planer 1 ea. at \$2,000 ea.	
	Misc. Tools (lot) \$3,000	
	Tool Crib (lot) \$3,000	
10.	Paint Shop	13
	Consisting of:	
	Paint Sprayers 2 ea. at \$2,000 ea.	
	Portable Electric Blowers (lot) \$2,000	
	100 psi Air Supply (lot) \$3,000	
	Tool Crib (lot) \$4,000	
11.	Receiving Shop Area	23
	Consisting of:	
	Work Benches (lot) \$1,200	
	Forklift 1 at \$1,800 ea.	
	Scales 2 ea. at \$1,800 ea.	
	Banding Machinery (lot) \$1,200	
	Pallets (lot) \$2,000	
12.	Sand Blasting Shed	23
	Consisting of sand blast equipment (lot)	

Table 8-5 (Cont.)

B. Outside Equipment

<u>Item</u>	<u>Estimated Cost</u> <u>(\$000)</u>
1. Forklift trucks (total 2)	46
1 ea. 4-Ton Cap. at \$19,000 ea.	
1 ea. 2-Ton Cap. at \$15,000 ea.	
1 ea. 1-Ton Cap. at \$12,000 ea.	
2. Mobile cranes (total 3)	510
2 ea. 40-Ton Cap. at \$130,000	
1 ea. 100-Ton Cap. at \$250,000	
3. Trucks (total 9)	56
Flat bed 5-Ton Cap. 1 ea. at \$8,000	
Pick-up 3/4-Ton Cap. 2 ea. at \$4,000	
Straddle truck 10-Ton Cap. 1 ea. at \$40,000	
4. Man lifts	100
60 ft. reach 2 ea. at \$50,000 ea.	
5. Diesel Generators	45
for standby power	
1 at 500 KW Cap. \$45,000	
6. 100 psi Air Compressor/Filter/Controls	3
7. Welding Machines	10
8. Air Arc Welders	20
1 at \$20,000	

C. Summary

Inside Total	872
Outside Total	790
Undefined*	<u>238</u>
Total	1,900

*Includes initial raw stock, miscellaneous small items, and contingency.

8.2 SITE FACILITY SUMMARY (LAND BASED)

The Site Facility Summary is a detailed summary for the land-based test facility. It contains the site assumptions, site plan development, building types, and details on utilities.

SITE FACILITIES SUMMARY

Since a site has not been selected for the Test Facility the following general assumptions were made:

- a) The site, approximately 21 acres, is slightly sloped and suitable for surface drainage, no catch basin underground collection system is included.
- b) Climate is temperate; no snow, excessive heat or rainfall conditions.
- c) Minimum soil bearing capacity (for preliminary building foundation design) is 2000 lbs. per square foot.
- d) A railroad line is available from which a spur may be routed into the plant site.
- e) Sources of warm and cold water exist to the north of the site. A pump structure will be constructed providing the circulating water requirements for the cycle plant and cooling water for the test facility. A free body of water is located to the south of the test facility and can accept the water discharge.
- f) A sewer main terminating in a sewage treatment plant is available to the north and within reasonable distance of the site. A lift station is required on site and the force main will be routed to the existing main.
- g) A source of potable water exists to the north of the site.
- h) Access to the site is from the west.

SITE PLAN DEVELOPMENT

The building layout defined on the Site Plan (Dwg. No. C-01) is developed with the facilities anticipated to handle the largest equipment loads located to the east and west of the railroad spur.

The Administration, Photo Processing and Analysis Laboratory Building, the Employee Welfare Building, and main parking lot are located adjacent to the site access road, to the west of and removed from the railroad and heavy shop complex.

The Instrument Calibration Laboratory - Electric Shop Building and Control Building are grouped in accordance with their functional relationship.

The two-story Control Building is centrally located to overlook the Cycle Plant Test Bed and possible future Test Bed.

The railroad spur will be designed in conformance with AREA^{*} standards and the carrier's specific requirements. The spur will terminate with a bumping post either on the north or south end of the site depending on the location of the main line relative to the site.

Paved roadways provide access to the various buildings and test facilities. Roads are asphalt surfacing on crushed rock base, to be designed in accordance with AASHTO^{**} HS-20-44 loading. Drainage ditches or swales for collection of surface runoff will parallel roads and follow the natural or graded down slope of the site.

Road widths vary from 12 to 50 feet. The wider roadways are designed to serve exceptionally wide load equipment such as crawler cranes.

The site is protected by a 7'0" chain link perimeter fence.

BUILDINGS - Refer to Dwg. No. C-03 (17 pages) and Dwg. No. S-01.

*AREA - American Railroad Engineers Association

**AASHTO- American Association of State Highway and Transportation Officials

The sixteen support buildings are categorized as Types I, II & III with respect to function as follows:

Type I are reinforced concrete structures and include: 1) the two-story Control Building and 2) the Central Data System Building, both structures requiring the maximum interior environmental controls. Interior partitions are steel studs with gypsum wall board on both sides. The grade level or first floor of the Control Building is designed for computer type flooring. The computer flooring may be used for the entire or partial first floor area as required.

Type II are prefabricated metal buildings with concrete foundations and floor slabs and include: 1) the Administration, Photolab, and Analysis Lab Building and 2) the Employee Welfare Building.

Exterior walls are of the "sandwich" panel type and the interior partitions are steel stud with gypsum wallboard on both sides.

Exteriors and interiors of these two buildings are to be given architectural consideration compatible with the building function.

These considerations may include office windows as required, a reception lobby for visitors in the Administration Building, architectural treatment of the exteriors of both buildings and local landscaping providing a pleasant environment for employees and visitors.

Type III are functional prefabricated metal buildings with concrete foundations and floor slabs. Exteriors are galvanized metal panels with baked enamel finish.

Interior finishes are minimum.

This category includes:

- 1) Heavy Machinery Shop
- 2) Fabrication Building

- 3) Pipe Shop
- 4) Paint Shop and Sand Blast Shop
- 5) Receiving Shop
- 6) Carpentry, Model & Maintenance Shops
- 7) Instrument Calibration Lab and Electric Shop
- 8) Gate House
- 9) Pump House
- 10) Fire Pump House
- 11) Change House
- 12) Cycle Plant Auxiliary Equipment Building

UTILITIES

The following utility systems are indicated on Dwg. No. C-02:

1. Sanitary Sewer System
2. Fire and Potable Water System
3. Plant Cooling Water System
4. Ammonia Supply and Return System
5. Nitrogen Supply System
6. Diesel Supply System
7. Electrical System

Sanitary Sewer System

The sewer system design is based on 90 persons per day and the fixtures are located in various buildings throughout the site. The fixture-unit method for estimating peak flows was used. The size of pipe was based on peak flows and pipe flowing half full at minimum slope.

It was assumed that the sewage would be collected in the north west corner of the site and would require pumping from the collection point to an existing main terminating at a treatment plant.

Fire and Potable Water System

According to N.F.P.A.* the plant will come under Group 3 fire protection which requires a supply of 1000 gpm and a looped pipe system allowing one to fight a fire anywhere within the site with a minimum hydrant pressure

* N.F.P.A. -National Fire Protection Association

of 75 psi. An emergency standby pump is also required with the above discharge rate and hydrant pressure and a reservoir allowing for 1½ hours of pumping. It is assumed that the water supply is from a domestic source that is potable allowing a one pipe system and can be delivered to the site at a rate of 1000 gpm and at 90 psi. A 6" pipe looped system with an emergency standby 1000 gpm/75 HP/120 psi diesel pump and a 90,000 gal. storage tank will give adequate fire coverage. Consideration of special fire protection within the various test bed areas is discussed in the test bed descriptions.

Plant Cooling Water System supply is from 3-350 HP pumps which are located in a structure adjacent to the cycle plant intake structure north of the plant site. It is brought to the site in a 60" ø pre-stressed concrete cylinder pipe and distributed to the Hydraulic Test Bed, Turbine Test Bed, Heat Exchanger Test Bed and the Cycle Plant Test Bed in smaller size pipes. After being used in the various test beds it is discharged from the site in a 60" ø prestressed concrete cylinder pipe to a discharge structure to the south of the site.

Ammonia Supply & Return System

Ammonia will be shipped to the site in either high pressure truck-trailers or rail cars and unloaded at the unloading station into a 70,000 pound storage tank located north of the cycle plant test bed. It is then piped in a 4" carbon steel pipe to the cycle plant area. Ammonia can be returned to the storage cylinder in a separate 4" carbon steel reject line.

Nitrogen Supply System

Nitrogen will be shipped to the site in high pressure truck trailers and unload into storage cylinders just south of the ammonia storage tank. It can then be piped to the cycle plant area in 2" carbon steel tubing.

Diesel Supply System

Diesel fuel will be shipped to the site in either truck trailers or rail cars and unloaded at an unloading station into a diesel storage tank just

north of the fire pump house. From the tank the diesel fuel is piped to the emergency stand-by diesel fire pump located in the Fire Pumphouse.

Electrical System

The test facility electrical demand is supplied from a utility substation at 13.8 KV. A 13.8 KV switch gear located in the utility substation houses the incoming breaker and four feeder breakers as shown on Dwg. No. E-01, the single line diagram. A smaller 13.8 KV switchgear located at the intake structure houses the breakers for the intake structure pump motors. Secondary substations or load centers are located close to the large load areas.

Motor loads larger than 900 hp are connected to the 13.8 KV bus. 4160 volt load centers supply motors of 250 hp to 900 hp. Motors from 1 to 200 hp are served by 480 volt motor control centers. Fractional horsepower motors, lighting and other miscellaneous loads are fed from 240/120V distribution panels.

The 13.8 KV switchgear of the utility substation will be housed in a metal clad enclosure. Load centers and 4160-480 volt step-down transformers will be of the outdoor type. Motor control centers will be indoor type and located inside the buildings.

The utility company will provide all necessary step-down transformers and auxiliaries to tie in to the 13.8 KV bus at the switchgear. Substation capacity should be at least 60 MW.

At the cycle plant, the 3 MW turbine generator is connected to the 13.8 KV bus. When in operation, it will be parallel to the utility supply to share the plant's auxiliary load.

The underground electrical distribution layout and the plant cathodic protection delineated on Dwg. No's. E-02 and E-03.

The underground electrical distribution layout and the plant cathodic protection are delineated on Dwg. No's. E-02 and E-03.

LIST OF ATTACHMENTS
(In Order of Reference)

<u>Dwg. No.</u>	<u>Size</u>	<u>Rev.</u>	<u>Title</u>
C-01	D	B	Site Plan
C-03			Seventeen pages (8½ x 11) of building descriptions as follows:
			<ol style="list-style-type: none"> 1. Heavy Machinery Shop 2. Fabrication Building 3. Pipe Shop 4. Employee Welfare Building 5. Paint Shop/Sand Blast Shed 6. Receiving Shop 7. Carpentry, Model & Maintenance Shops 8. Instrument Calibration Lab and Electrical Shop 9. Central Data System 10. Gate House 11. Pump House 12. Fire Pump House 13. Administration Building, Photo Lab and Analysis Lab 14. Locker Rooms (Change House) 15. Page 1 of 2 - Control Building 15. Page 2 of 2 - Control Building 16. Cycle Plant Auxiliary Equipment Building
S-01	D	A	Buildings - Types I, II & III
C-02	D	A	Paving, Fencing and Underground Lines
E-01	D	A	Electrical Single Line Distribution Diagram
E-02	D	A	Underground Electrical Distribution Layout
E-03	8½ x 11	A	Cathodic Protection Detail

16 JUNE 76/PN

① OTEC: HEAVY MACHINERY SHOP

FOUNDATION: Combined footing at each pair of columns (building frame and crane column). Tie-Rods in slab, extending transversely between footings - 8" concrete slab w/#3 @ 14" oc E.W., on a 6" granular pad or crushed rock.

SUPERSTRUCTURE: Structural steel rigid frames, separate structural steel columns to support 50 ton crane. Cold-form light-gauge wall girts and roof purlins.

EXTERIOR WALLS AND ROOF: 26 ga. galvanized cold-form sculptured panels, with a baked enamel finish. Insulation shall be 34 pound density fiberglass blankets with film face on the interior side; attached to purlins and girts.

INTERIOR PARTITIONS: Steel studs with 1/2" gypsum wallboard each side.

BRACING: Diagonal cable or rod bracing in the roof, wall, end wall, and longitudinally between crane columns.

② OTEC: FABRICATION BLDG

#11726
16 JUNE 76 /PN

PLAN 1"=40'

ELEV. 1"=40'

NOTE: 50 T CRANE

For description of construction see building #1, heavy machinery shop.

③ OTEC : PIPE SHOP

#11726
16 JUNE 76/PN

NOTE: 10T CRANE

FOUNDATION: Individual column footings; tie-rod in slab extending transversely between footings 8" concrete slab w/#3 @ 14" o.c. E.W., on a 6" granular pad or crushed rock.

SUPERSTRUCTURE: Structural steel rigid frames, with brackets to support 10 ton crane. End roof and wall bays are supported by a load-bearing column and beam frame. Cold-formed light-gauge wall girts and roof purlins.

BRACING: Diagonal cable or rod bracing in the roof, wall, and endwall.

EXTERIOR WALLS AND ROOF, INTERIOR PARTITIONS: See Building #1 Heavy Machinery Shop.

④ OTEC: EMPLOYEE WELFARE BLDG.

#11726
16 JUNE 76/PN

FOUNDATION: Individual footings, with hairpins in slab, at rigid frame columns.

4" concrete slab w/6 x 6 - w1.4 x w1.4 WWF, on a 6" granular pad or crushed rock.

SUPERSTRUCTURE: Structural steel rigid frame at interior bays; end roof and wall bays are supported by a load-bearing column and beam frame. Cold-formed light-gage wall girts and roof purlins.

BRACING: Diagonal cable or rod bracing in the roof, wall, and endwall.

EXTERIOR, WALLS AND ROOF: "Sandwich-type" panels (Integral foam core with a metal skin each side.)

INTERIOR PARTITIONS: Steel studs with 1/2" gypsum wallboard each side.

⑤ OTEC: PAINT/SAND BLAST SHOPS

#11726
17 JUNE 76/P.N.

EXTERIOR WALLS AND ROOF: 26 ga. galvanized cold-formed sculptured panels, with a baked enamel finish. Insulation shall be 34 pound density fiberglass blankets with film face on the interior side; attached to the purlins and girts.

For description of other elements of construction: See Building #4, Employee Welfare Building.

⑥ DTEC: RECEIVING SHOP

#11726
17 JUNE 76/P.N.

FTG 3'-6" SQ x 12"
w/4-#4EW (10 REQ'D)

* ADD. HGT. FOR PALLET
STORAGE

ELEV. 1" = 40'

PLAN 1" = 40'

For Description of Construction, see Building #5, Paint/
Sandblast Shops.

Exception: 6" concrete slab w/#3 @ 18" o.c. ea. way

⑦ OTEC: MODEL/MAINTENANCE SHOPS

#11726
17 JUNE 76 / P.N.

For description of construction, see Building #5, Paint/Sand-blast Shops

⑧ OTEC: INSTRUMENT CALIBRATION LAB
AND ELECTRICAL SHOP

#11726
 17 JUNE 76/P.N.

For description of construction, see Building #5, Paint/Sand-blast Shops

9. OTEC : CENTRAL DATA SYSTEM

#11726
22 JUNE 76/PN

FOUNDATION: Individual reinforced concrete footings at all columns.

Continuous reinforced concrete footing at exterior walls.

4" concrete slab w/6x6 - W1.4 x W1/4 WWF on 6" thick granular pad or crushed rock base.

SUPERSTRUCTURE: Reinforced concrete columns, girders, beams, slab, and load bearing shear walls.

ROOF: 3-Ply composition with gravel.

INTERIOR PARTITIONS: Steel studs with 5/8" gypsum wallboard on each side.

CEILINGS: Suspended Accoustical Tile.

⑩ OTEC: GATE HOUSE

#11726
17 JUNE 76/P.N.

ELEV. 1"=10'

PLAN 1"=10'

FOUNDATION: Individual footings at load bearing columns.

4" slab w/6x6 - W1.4 x W1.4 WWF, on a 6" granular pad or crushed rock.

SUPERSTRUCTURE: End wall framing is a load bearing column and beam frame. Cold-formed light-gauge wall girts and roof purlins.

For description of other elements of construction: See Building #4, Employee Welfare Building.

⑪ OTEC: PUMP HOUSE

#11726
17 JUNE 76/P.N.

FOUNDATION: 4" concrete slab w/W1.4 x W1.4 WWF, on a 6" granular pad or crushed rock. Separate pump foundation.

WALLS: 24 ga. "Self-framing" panels.

ROOF: 24 ga. Standing Seam Panels.

⑫ OTEC : FIRE PUMP HOUSE

#11726
17 JUNE 76 / P.N.

PLAN 1"=10'

* CLEAR. FOR FIRE TRUCK

ELEV. 1"=10'

Description of construction same as for Building #10,
gate house.

⑬ OTEC: ADMINISTRATION BLDG.
+ PHOTO LAB + ANALYSIS LAB

11726
 17 JUNE 76/PN

FOUNDATION: Individual column footings; tie-rod in slab extending transversely between footings.

4" concrete slab w/6x6 - W1.4 x W1.4 WWF, on 6" granular pad or crushed rock.

For description of other elements of construction see building #4 Employee Welfare Building.

⑭ OTEC : LOCKER RMS

#11.726
17 JUNE 76 /PN

For description of construction, See Building #5, Paint/Sand Blast Shops.

OTEC: CONTROL BLDG.

FRAMING

ROOF PLAN

2ND FL. PLAN

FDN PLAN

	SQUARE FTG DIM.	THK IN	#4 BARS EA WAY
1	8'-0"	18	23
2	6'-0"	14	12
3	6'-6"	15	15
4	4'-6"	12	6

FOUNDATION: Individual reinforced concrete footings at all columns (See footing schedule on detail sheet).

4" concrete slab w/6x6 - W1.4 x W1.4 WWF on 6" thick granular pad or crushed rock base.

Continuous footings at exterior concrete walls, reinforced concrete.

NOTE: Slab depressed 12" at "Computer Floor" or access floor.

SUPERSTRUCTURE: Reinforced concrete columns, girders, beams, slabs, and load bearing shear walls.

ROOF: 3-ply composition with gravel.

INTERIOR PARTITIONS: Steel Studs with 5/8" gypsum wallboard each side.

CEILINGS: Suspended accoustical tile.

SPECIAL CONSTRUCTION: "Computer" or access floor as required in areas housing computer installations. 2x2 panels, rigid grid supports, approximately 10½" underfloor clearance (12" face to face). Panel capacity: Uniform load = 250 psf; concentrated load = 1000 lb.

(16) DTEC: CYCLE PLANT AUXILIARY
EQUIPMENT BLDG

11726
 24 JUNE 76/PN

EXTERIOR DOORS: 2 Roll-up Doors, 10⁰ x 15⁰ and 12⁰ x 15⁰.

For description of other elements of construction see Building #5,
 Paint/Sand Blast Shops.

LEGEND

PAVING

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OTEC TEST FACILITY														
BUILDINGS - TYPES I, II & III
JOB No.				DRAWING No.				SHEET					
	1172G				S-01				A					

8-46D

NOTES:

1. UNDERGROUND FEEDERS SHALL BE THREE CONDUCTOR SHIELDED ARMOR CABLE HAVING AN OVERALL EXTRUDED COVERING OF PVC.

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8.3 SEA-BASED PLATFORM

This section of Appendix 8 provides the sea-based platform requirements in support of Report Section L. The sea-based platform requirements are based primarily on the sea-based cycle plant described in Appendix 7.

In addition to the platform requirements, a brief investigation was made into using one platform to mount several test beds and to conduct at-sea tests simultaneously. This investigation used a T-2 tanker as the test bed. The conceptual results presented at the end of this section show a 6-MW_e "net" cycle plant with a full-scale sea water pump test bed and a cold water pipe deployment demonstration capability with a maximum permissible diameter of 34 ft.

8.3.1 Platform Characteristics

A variety of existing floating platforms may be used for the sea-based cycle plant, such as barges, tankers, cargo ships, drydocks, and semi-submersible types. These vessels, in general, are sufficiently large to accommodate power plant capacities of six megawatts or more, depending upon which of the above vessels is being considered. The space (volume and deck area) and internal arrangement are important considerations in selecting a vessel because of the relatively large size of the plant equipment. Vessels, such as the tanker and cargo ship, will require extensive cutting-in and modifications to the primary hull structure in order to install the plant equipment below deck. Barges, drydocks and the like lend themselves readily to simply installing the plant equipment directly on the weather deck. Modification and expansion of the existing crew accommodations aboard the tanker and cargo ship will be necessary because of the larger number of on-board personnel. Since, in general, there are no provisions for crew accommodations aboard barges and drydocks, space will have to be provided.

Barges and drydocks for the most part are non-self propelled and will require the services of a tug for their movement. A mooring system is required to maintain these platforms on station. Several propulsion thruster types are available on the market which can be readily installed on the barge or drydock to either replace the mooring system or supplement it. Cargo ships and tankers are equipped with a propulsion system which can be used to maintain the vessel on station. It is recommended, however, that a mooring system be used and that the propulsion system be used in emergencies. Auxiliary electrical power for cycle plant start up, test recording equipment, hotel load, and ship auxiliary equipment will need to be installed on the barge or drydock. Supplemental auxiliary power, in all likelihood, will be required to backup the existing power generating equipment on board the tanker and cargo ship. Provision for communication and navigational equipment will be required for any of the above vessels.

In selecting a sea-based cycle plant platform, it is important that sufficient hull volume and deck space is available to put it in a fully operating condition. The volume should include the space required for ballast which is needed to place the platform at a draft and/or freeboard compatible with operational and seakeeping conditions. The list of the primary spaces on the platform with their respective deck areas and volumes is given in Section L. Both the areas and volumes are gross in that they include passageways and working areas. The space for the test and test support equipment is based on a six megawatt cycle power plant. All volumes are based on a seven foot overhead height for the space except for the auxiliary power and machinery space which is 12 feet, and test equipment space which is 40 feet. The deck areas for crew and test personnel sleeping accommodations, washroom and toilets, and hospital are in accordance with the U. S. Coast Guard manning regulations. The size of the crew, while set at 26, will be determined by a joint conference between owners, union, and U. S. Coast Guard representatives. Test personnel for conducting the tests and maintaining the equipment was set at 28. Additional space was provided for the accommodation of four visitors and six vendor representatives. The officers messroom was sized to accommodate all senior people on board as well as the visitors. Crew and test personnel messroom was sized to serve one-half of the members resulting in two mess servings.

A thirty day supply of potable water and a ninety day supply of diesel fuel has been provided. These amounts may be increased depending upon the platform selected. Dry and refrigerated stores are also based on thirty days. Crew and test personnel will be rotated every thirty days. The thirty day cycle for both crew rotation and supply replenishment reduces the logistics support required.

The makeup ammonia storage tank which has a capacity of 3500 cubic feet was sized to provide one and a half re-fills of the ammonia loop. It is desirable but not necessary that the tank be located in the vicinity of the ammonia condensate pump space in order to take advantage of the condensate pumps for pumping the ammonia from the tank.

The amount of liquid and/or solid ballast required on board the cycle plant platform will depend largely on what type of vessel is being considered and the test site environmental conditions. However, regardless of what vessel is selected for the test platform, proper ballasting is important to achieve adequate stability and satisfactory seakeeping qualities.

The safety of the platform and its operating personnel is subject to the rules of a number of regulatory bodies. The most important of these is the U. S. Coast Guard whose rules can be found in the Code of Federal Regulations (CFR) Title 46 – Shipping. In accordance with these rules, vessels which fall within a certain classification must satisfy certain stability standards. These standards are promulgated by the Coast Guard which must be met before the Coast Guard will approve the vessel for the intended service. A stability test or stability calculation or both may be required before approval is given by the Coast Guard. In Part 74 of the CFR Title 46, the Coast Guard has specified that the minimum metacentric height (GM) in feet at any particular draft is to be obtained from the following expression:

$$GM = \frac{PAh}{\Delta \tan \theta}$$

This expression is fundamentally a weather criteria in that the value (P) is the wind pressure acting on the projected lateral area (A) of the portion of vessel above the waterline and which has a moment arm of (h) taken as the vertical distance from the center of (A) to the center of the underwater lateral area; Δ is the displacement and θ is the roll angle. The expression applies to the ship in the intact condition.

Damaged stability standards have also been set down by the Coast Guard in which the stability of the vessel is determined for various flooding conditions. In the damaged condition, as well as in the intact condition, the range (large heel angles) of positive stability is important in assessing the safety of the vessel stability wise. Typical metacentric heights (GM) for several different vessel types in the intact condition are shown in Section L. The calculated Coast Guard minimum required (GM) is based on the vessel in the loaded condition and operating in partially protected water (relatively low wind velocities). Design static metacentric heights are shown for each of the vessels for comparison.

It is customary in the design of a new vessel to calculate and plot a set of cross-curves of stability over a range of heel angles (0 to 90°) for several displacements. The data enables the ship's master to evaluate the ship's stability in the event of damage and perform counterflooding measures.

Certain vessels, such as the deck barge and semi-submersible, are subject to a special criteria by the Coast Guard in which the area under the righting arm curve must be equal to or greater than the area under the wind heeling moment curve.

In addition to the Coast Guard regulations to which the vessel must conform are those laid down by the International Convention For The Safety Of Life At Sea (SOLAS) and the International Load Line Conventions (ILLC). Regarding damaged stability, SOLAS requires that the vessel have sufficient stability to withstand flooding after damage and to limit the amount of heel in order to provide reasonable assurance of survival of the ship and the ability to launch lifeboats. It also requires, in the case of fire protection, that provisions be made for alarm systems, fire extinguishing apparatus and fire retarding materials for internal divisional bulkheading.

The primary roll of the ILLC is the assignment of a load line or freeboard to the vessel. In all likelihood, the assignment of a load line to the cycle plant platform will not be necessary in view of its mission. However, it is important that there is sufficient freeboard to ensure an adequate stability range.

Several ship Classification Societies such as the American Bureau of Shipping, Lloyds Register, and Det Norske Veritas operate throughout the world, all of which publish rules and regulations relating primarily to the structural efficiency of the vessel and the reliability of the machinery. It is not mandatory that a ship be designed and built in accordance with these rules, however, in doing so the ship owner is in a more favorable position to find a marine underwriter for his ship and at a lower premium.

The behavior of the cycle plant platform in an ocean environment is dependent to a large degree on the platform's configuration, condition of loading, heading (moored

or unmoored) and the prevailing wind and sea state condition at the test site. For guidance in analytically assessing the behavior of the various candidate platforms, a set of requirements have been established. The requirements are divided into three categories. The first two categories – Safety Of Vessel and Personnel and Mission Performance – list the requirements for the platform on station; the third category lists the requirements for the platform underway to or from the station site. The platform on station may or may not be moored. In the unmoored condition the behavior of the platform will be a function of its seakeeping qualities and seamanship of the ship's captain.

Category 1 – Safety of Vessel and Personnel

- **Metacentric stability in calm water (magnitude and range) – Adequate metacentric stability in calm water, in terms of both magnitude (GM) and range of heel for which the righting remains positive. Adequate margin of stability in the event of flooding due to damage and for wave disturbances.**
- **Dynamic metacentric stability in calm water (magnitude and range) – Adequate dynamic metacentric stability in calm water, in terms of both magnitude and range of heel for which restoring energy remains. A large area under the calm water righting moment curve is required.**
- **Watertight integrity – Covers and closures and other features of watertight integrity which will be subject to hydrostatic heads and hydrodynamic impact shall be adequate in strength to prevent them from being torn loose or ruptured.**
- **Reserve buoyancy and freeboard – In general where reserve buoyancy and freeboard are provided to meet damage-control specifications, they are sufficient to ensure the safety of the platform. The amount of reserve buoyancy and freeboard necessary is a function of the degree of security with which the watertight integrity of the hull proper can be maintained.**
- **Minimal amount of water on decks – Water on weather decks reduces the metacentric stability (GM). Well decks surrounded by high bulwarks should have adequate freeing ports. The total weight of water on deck with the freeing ports considered temporarily closed, should not exceed 10 percent of the calm-water reserve buoyancy, nor should it change the trim by more than 10 percent of the minimum freeboard.**
- **Precaution against major slamming – Slamming may be expected in a vessel of any given design when underway in rough weather. Changing the vessel's heading can reduce or entirely eliminate this problem. Vessels which are moored may also be susceptible to slamming depending upon the hull shape and its orientation to the oncoming waves. Reorienting the vessel by rearranging the mooring systems may help in reducing the slamming. Where slamming cannot be eliminated, it is important that the structure in these areas be adequately strengthened.**

Category 2 – Performance of Mission

- Dryness of decks – Freeboard shall be adequate to prevent the least practical amount of green water, or no water taken on board in those areas where personnel must work at sea.
- Freedom from impacts, shock, jerks, slams, lurches – To ascertain whether a platform in a given sea is likely to experience impacts, shock, etc. is very difficult if not impossible. The existence of these forces may only be established at the time the platform is on station and under the influence of a sea state condition. For a moored platform, some reduction in these dynamic forces may be realized by varying the loading of the platform through the use of ballast water and/or by varying the scope and weight of the mooring line. In the case of an unmoored platform, varying the displacement of the platform and heading may be of some help.
- Steadiness and ease in roll, pitch, and heave – Steadiness and ease in roll are achieved by reducing or limiting the maximum angles and by increasing the rolling period. Maximum tangential acceleration in roll should be limited to approximately 0.10 g's.

Steadiness and ease in pitch and heave are also achieved by limiting the angular and up-and-down motion respectively, and by increasing the natural periods of both. Up or down pitch angles should preferably not exceed 8 degrees while the combined vertical acceleration in pitch and heave should not exceed 0.4 g's.

- Minimal interference by waves with shipboard functions – Minimizing or eliminating interference by waves with primary shipboard functions may require drastic measures. These measures may require major changes in the platform configuration and structure. Specific recommendations are difficult to establish because of the various platform types that might be considered for the mission and the sea states in which the platform will find itself.

- **Minimal tank face-surface** – Tank free-surface has the effect of reducing the metacentric stability of the platform. Tanks having large horizontal plane areas should either be completely pressed up (full) or empty. Where this is not possible, such as would be the case with fuel tanks, the tanks should be subdivided into several smaller tanks.
- **Freedom from spray in working areas of ship** – Freedom from sea spray in working areas of the platform can generally be taken care of by protective shields.
- **Freedom from objectionable internal elastic motion and vibration** – The presence of vibration, shudder, and whipping due primarily to ship and propulsion-device action in waves can have an adverse affect on the crew and their performance. These motions may also adversely affect the performance of the test equipment. Reduction of these motions can be achieved by controlled ballasting of the platform, platform orientation to waves, and by minimizing the propulsion-device, emergence and racing, drawing air to the propeller.

Category 3 – Vessel Under Way

- **Directionally stable** – Non-self-propelled platforms which require the services of a tug for mobility must be directionally stable while being towed. Excessive yawing of the platform is not only hazardous but places a heavy demand on the tug propulsion system. Directional stability can be achieved by proper platform ballasting, stern skegs, and controllable rudders.
- **Dry decks** – Large amounts of water on decks should be avoided for reasons of ship and crew safety. Changing the platform's heading and/or freeboard through ballasting will, in general, achieve the desired results.
- **Easy and good steering** – For a self-propelled platform, easy and good course-keeping requires a steering control adequate to keep the platform on or close to its course to within approximately ± 5 degrees.

- Minimal motion to prevent slamming or high acceleration -- During transit to the site, the platform motions (heave, roll, pitch, slamming) should be minimal to prevent excessive strains in the platform and on-board equipment. A reduction of these motions can be achieved by proper heading, reduced speed, and ballasting.

The foregoing is summarized in the following four figures not used at the ERDA presentation because of time limitation.

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SEAKEEPING QUALITY

- SAFETY OF VESSEL AND PERSONNEL
- PERFORMANCE OF MISSION
- VESSEL UNDER-WAY

SEAKEEPING QUALITY

THE REQUIREMENTS FOR GUIDANCE IN ANALYTICALLY ASSESSING THE PERFORMANCE OF VARIOUS CANDIDATE OFFSHORE TEST PLATFORMS IN AN ENVIRONMENT OF WIND, WAVES AND CURRENT FOR ANY CONDITION OF LOADING AND ORIENTATION ARE DIVIDED INTO THREE CATEGORIES. THE FIRST TWO CATEGORIES; SAFETY OF VESSEL AND PERSONNEL, AND MISSION PERFORMANCE LIST THE REQUIREMENTS FOR THE PLATFORM ON STATION WHILE THE THIRD CATEGORY LISTS THE REQUIREMENTS FOR THE PLATFORM UNDER-WAY TO OR FROM THE STATION SITE. THE PLATFORM ON STATION MAY OR MAY NOT BE MOORED. IN THE UN-MOORED CONDITION THE BEHAVIOR OF THE PLATFORM WILL BE A FUNCTION OF ITS QUALITIES AND THE SEAMANSHIP OF THE SKIPPER.

IN VIEW OF THE NUMBER OF POSSIBLE PLATFORM CANDIDATES AND THE ENORMOUS AMOUNT OF WORK ASSOCIATED WITH ESTABLISHING A NUMBER FOR EACH OF THE REQUIREMENTS A BRIEF TECHNICAL DISCUSSION OF EACH REQUIREMENT IS PRESENTED.

SEAKEEPING QUALITY (CONTINUED)

- SAFETY OF VESSEL AND PERSONNEL

1. METACENTRIC STABILITY IN CALM WATER (MAGNITUDE AND RANGE)
2. DYNAMIC METACENTRIC STABILITY IN CALM WATER (MAGNITUDE AND RANGE)
3. WATERTIGHT INTEGRITY
4. RESERVE BUOYANCY AND FREEBOARD
5. MINIMAL AMOUNT OF WATER ON DECKS
6. PRECAUTIONS AGAINST MAJOR SLAMMING

SEAKEEPING QUALITY (Cont.)

1. ADEQUATE METACENTRIC STABILITY IN CALM WATER, IN TERMS OF BOTH MAGNITUDE (GM) AND RANGE OF HEEL FOR WHICH THE RIGHTING MOMENT REMAINS POSITIVE. ADEQUATE MARGIN OF STABILITY IN THE EVENT OF FLOODING DUE TO DAMAGE AND FOR WAVE DISTURBANCES.
2. ADEQUATE DYNAMIC METACENTRIC STABILITY IN CALM WATER, IN TERMS OF BOTH MAGNITUDE AND RANGE OF HEEL FOR WHICH RESTORING ENERGY REMAINS. A LARGE AREA UNDER THE CALM-WATER RIGHTING-MOMENT CURVE IS REQUIRED.
3. COVERS AND CLOSURES AND OTHER FEATURES OF WATERTIGHT INTEGRITY WHICH WILL BE SUBJECT TO HYDROSTATIC HEADS AND HYDRODYNAMIC IMPACT SHALL BE ADEQUATE IN STRENGTH TO PREVENT THEM FROM BEING TORN LOOSE OR RUPTURED.
4. IN GENERAL WHERE RESERVE BUOYANCY AND FREEBOARD ARE PROVIDED TO MEET DAMAGE-CONTROL SPECIFICATIONS THEY ARE SUFFICIENT TO INSURE THE SAFETY OF THE PLATFORM. THE AMOUNT OF RESERVE BUOYANCY AND FREEBOARD NECESSARY IS A FUNCTION OF THE DEGREE OF SECURITY WITH WHICH THE WATERTIGHT INTEGRITY OF THE HULL PROPER CAN BE MAINTAINED.
5. WATER ON WEATHER DECKS REDUCES THE METACENTRIC STABILITY (GM). WELL DECKS SURROUNDED BY HIGH BULWARKS SHALL HAVE ADEQUATE FREEING PORTS. THE TOTAL WEIGHT OF WATER ON DECK WITH THE FREEING PORTS CONSIDERED TEMPORARILY CLOSED, SHOULD NOT EXCEED 10 PERCENT OF THE CALM-WATER RESERVE BUOYANCY, NOR SHOULD IT CHANGE THE TRIM BY MORE THAN 10 PERCENT OF THE MINIMUM FREEBOARD.
6. SLAMMING MAY BE EXPECTED IN A SHIP OF ANY GIVEN DESIGN, WHEN UNDERWAY IN ROUGH WEATHER. CHANGING THE SHIPS' HEADING CAN REDUCE OR ENTIRELY ELIMINATE SLAMMING. VESSELS WHICH ARE MOORED MAY ALSO BE SUBJECT TO SLAMMING DEPENDING UPON THE HULL SHAPE AND POSITION OF BOTTOM, SIDE AND DECK SURFACES TO THE ON-COMING WAVES. STRENGTHENING OF THESE SURFACES MAY BE REQUIRED.

SEAKEEPING QUALITY (CONTINUED)

- PERFORMANCE OF MISSION

1. DRYNESS OF DECKS
2. FREEDOM FROM IMPACTS, SHOCKS, JERKS, SLAMS, LURCHES
3. STEADINESS AND EASE IN ROLL, PITCH, HEAVE
4. MINIMAL INTERFERENCE BY WAVES WITH SHIPBOARD FUNCTIONS
5. MINIMAL TANK FREE SURFACE
6. FREEDOM FROM SPRAY IN WORKING AREAS OF SHIP
7. FREEDOM FROM OBJECTIONABLE INTERNAL ELASTIC MOTION AND VIBRATION

SEAKEEPING QUALITY (CONT.)

1. FREEBOARD SHALL BE ADEQUATE TO PREVENT THE LEAST PRACTICAL AMOUNT OF GREEN WATER, OR NO GREEN WATER TAKEN ON BOARD IN THOSE AREAS WHERE PERSONNEL MUST WORK AT SEA.
2. TO ASCERTAIN WHETHER A PLATFORM IN A GIVEN SEA IS LIKELY TO EXPERIENCE IMPACTS, SHOCKS, JERKS, SLAMS AND LURCHES IS VERY DIFFICULT, IF NOT IMPOSSIBLE. IN ALL LIKELIHOOD THE INFORMATION CAN ONLY BE DETERMINED AT THE TIME THAT THE PLATFORM IS ON STATION AND UNDER THE INFLUENCE OF A SEA STATE CONDITION. FOR A MOORED PLATFORM SOME REDUCTION IN THESE DYNAMIC FORCES MAY BE REALIZED BY VARYING THE LOADING OF THE PLATFORM THROUGH THE USE OF BALLAST WATER AND OR BY VARYING THE SCOPE AND WEIGHT OF THE MOORING LINE. IN THE CASE OF AN UN-MOORED PLATFORM, VARYING THE DISPLACEMENT OF THE PLATFORM AND ITS HEADING MAY BE OF SOME HELP.
3. STEADINESS AND EASE IN ROLL ARE ACHIEVED BY REDUCING OR LIMITING THE MAXIMUM ANGLES AND BY INCREASING THE ROLLING PERIOD. MAXIMUM TANGENTIAL ACCELERATION IN ROLL SHOULD BE LIMITED TO APPROXIMATELY 0.10 G'S.

STEADINESS AND EASE IN PITCH AND HEAVE ARE ALSO ACHIEVED BY LIMITING THE ANGULAR AND UP-AND-DOWN MOTION RESPECTIVELY, AND BY INCREASING THE NATURAL PERIODS OF BOTH. UP OR DOWN PITCH ANGLES SHOULD PREFERABLY NOT EXCEED 8 DEGREES WHILE THE COMBINED VERTICAL ACCELERATION IN PITCH AND HEAVE SHOULD NOT EXCEED 0.4 G'S.

4. MINIMIZING OR ELIMINATING INTERFERENCE BY WAVES WITH PRIMARY SHIPBOARD FUNCTIONS MAY REQUIRE DRASTIC MEASURES. THESE MEASURES MAY REQUIRE MAJOR CHANGES IN THE PLATFORM CONFIGURATION AND STRUCTURE. SPECIFIC REQUIREMENTS ARE DIFFICULT TO ESTABLISH BECAUSE OF THE VARYING PLATFORM TYPES THAT MIGHT BE CONSIDERED FOR THE MISSION AND THE SEA-STATES IN WHICH THE PLATFORM WILL FIND ITSELF.
5. TANK FREE SURFACE HAS THE EFFECT OF REDUCING THE METACENTRIC STABILITY OF THE PLATFORM. TANKS HAVING LARGE HORIZONTAL PLANE AREAS SHOULD EITHER BE COMPLETELY PRESSED UP (FULL) OR EMPTY. WHERE THIS IS NOT POSSIBLE BECAUSE OF THE LIQUID IN THE TANK BEING USED, SUCH AS A FUEL TANK, THE TANK SHOULD BE SUBDIVIDED INTO SEVERAL SMALLER TANKS.
6. FREEDOM FROM SEA SPRAY IN WORKING AREAS OF THE PLATFORM CAN GENERALLY BE TAKEN CARE OF BY PROTECTIVE SHIELDS.
7. THE PRESENCE OF VIBRATION, SHUDDER AND WHIPPING, DUE PRIMARILY TO SHIP AND PROPULSION-DEVICE ACTION IN WAVES CAN HAVE AN ADVERSE EFFECT ON THE CREW AND THEIR PERFORMANCE. THESE MOTIONS MAY ALSO ADVERSELY EFFECT THE PERFORMANCE OF THE TEST EQUIPMENT. REDUCTION OF THESE MOTIONS CAN BE ACHIEVED BY CONTROLLED BALLASTING OF THE PLATFORM, PLATFORM ORIENTATION TO WAVES AND BY MINIMIZING THE PROPULSION-DEVICE EMERGENCE AND RACING, DRAWING AIR TO THE PROPELLERS.

SEAKEEPING QUALITY (CONTINUED)

- VESSEL UNDER-WAY

1. DIRECTIONALLY STABLE
2. DRY DECKS
3. EASY AND GOOD STEERING
4. MINIMAL MOTION TO PREVENT SLAMMING ON HIGH ACCELERATIONS

SEAKEEPING QUALITY (CONT.)

1. NON SELF-PROPELLED PLATFORMS WHICH REQUIRE THE SERVICES OF A TUG FOR MOBILITY MUST BE DIRECTIONALLY STABLE WHILE BEING TOWED. EXCESSIVE YAWING OF THE PLATFORM IS HAZARDOUS NOT ONLY TO THE TOW OPERATION ITSELF BUT TO SHIPPING IN THE IMMEDIATE VICINITY. DIRECTIONAL STABILITY CAN BE ACHIEVED BY PROPER PLATFORM BALLASTING, STERN SKEGS AND CONTROLLABLE RUDDERS.
2. LARGE AMOUNTS OF WATER ON DECKS SHOULD BE AVOIDED FOR THE SAFETY CREW AND SHIP. CHANGING THE PLATFORM'S HEADING AND FREEBOARD THROUGH BALLASTING WILL IN GENERAL ACHIEVE THE DESIRED RESULTS.
3. FOR A SELF-PROPELLED PLATFORM EASY AND GOOD COURSEKEEPING REQUIRES A STEERING CONTROL ADEQUATE TO KEEP THE PLATFORM ON OR CLOSE TO THIS COURSE TO WITHIN ± 5 DEGREES.
4. DURING TRANSIT TO THE SITE THE PLATFORM MOTIONS (HEAVE, ROLL, PITCH, SLAMMING) SHOULD BE MINIMAL TO PREVENT EXCESSIVE STRAINS IN THE PLATFORM AND ON-BOARD EQUIPMENT. A REDUCTION OF THESE MOTIONS CAN BE ACHIEVED BY PROPER HEADING, REDUCED SPEED AND BALLASTING.

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8.3.2 T-2 Tanker

The conceptual arrangement of the sea-based test platform shown in Fig. 8-1 has the capability of conducting concurrently the testing of a 6 MW_e "net" cycle plant, a full-scale sea-water pump (25 ft diameter impeller), and various cold water pipe designs with a maximum permissible diameter of 34 ft. The test platform is a World War II T-2 tanker which has the following characteristics:

● Length overall	523 ft
● Length between perpendiculars	503 ft
● Beam (moulded)	68 ft
● Depth at side (moulded)	39 ft-3 in.
● Operating draft	29 ft
● Deadweight capacity	16,460 LT
● Shaft horsepower (normal)	6,000 shp
● Speed	14.5 knots

Several of these tankers (six) are located on the Sacramento River in California and are available to ERDA without cost.

The modifications to the tanker are largely confined to the mid length of the hull. In the area of the cycle plant installation, a number of the transverse bulkheads as well as longitudinal bulkheads will have to be removed in order to provide space for the equipment. New bulkheads will be installed to re-establish the watertight integrity of the hull and to permit the removal of the heat exchangers and sea water pump units. In order to remove this equipment without flooding the ship with sea water, a gate upstream of each pump and one downstream of each heat exchanger was provided. Both the warm and cold water inlets are located in the bottom shell amidships. The pump location can be moved below the hull depending upon the NPSH requirement of the pump. Extensive reinforcement of the ship's hull in these areas will be necessary to restore the hull girder to its original strength. Similar steps will have to be taken in way of the sea-water discharge ports in the hull side shell. The upper deck plating structure in way of the pumps, heat exchangers, and cold water pipe are portable to

allow for the installation or removal of these components. The installation of the cold water pipe will require the services of a crane barge and a deck barge for transporting the pipe. Tug boats will be needed to tow the barges to the test site.

The cold water pipe test equipment, which is located just forward of the mid-ship house, consists of a derrick structure and a 35-ft diameter test well in the ship's hull. A 150-ton traveling bridge crane mounted at the top of the derrick and an 18-ft port outreach of the derrick structure permits off-loading of 100-ft-long cold water pipe sections from the barge transporter. Structural reinforcement of the hull in way of the well will be necessary to compensate for the hull material removed as well as additional hull stiffening at each of the derrick legs.

Provisions were made for testing a full-scale sea water pump (25-ft diameter impeller), as well as smaller sizes, with the impeller rotating axis in either a horizontal or vertical attitude. The latter provision was incorporated in the test module because both a horizontal and vertical pump shaft design has been proposed for the OTEC power plant. The arrangement of the pump test shown consists of a pump test module guide and the pump test module. The function of the module guide is to maintain a fixed relative position between the pump module and the ship and to absorb the forces produced by the pump while in operation. Vertical movement of the module guide is provided for by means of two guide rails attached to the derrick and a wire rope winching arrangement mounted on the traveling bridge crane. Attachment of the guide structure to the pump module consists of four pin connections to maintain the pump module in a horizontal attitude. With the removal of two of these pins, the pump module can be rotated into a vertical position.

The pump test module is a cylindrical steel structure - 31 feet in diameter and 238 feet long - and weighs approximately 830 long tons. An inner shell with a maximum diameter of 25 ft comprises the test section. The test section consists of a bell-mounted inlet duct, a removable simulated tube sheet, a removable pump section, an antiscirl flow straightener, a removable venturi tube section, and a double right angle bend thrust neutralizer section. The annular space between the inner and outer shells is

subdivided into buoyancy compartments and ballast tanks for flotation and for up-ending and submergence of the modules. As a floating body the module can be towed to the test site for testing or returned to a shipyard for the installation of a different pump, maintenance and repair. To remove and install a pump of different size at the test site would require a 1,000-ton capacity crane barge and a deck barge on which the pump module can be placed and serviced.

A total of 70 accommodations consisting of ship's crew, test personnel, and visitors has been established. This is in excess of the number of berths available on the tanker; consequently, additional berthing space will need to be provided. Refrigerated and dry store spaces should be adequate for a one months supply of food.

Additional space will be needed to accommodate the electrical power generating equipment for providing power to the pump motors. Such spaces as the existing auxiliary machinery space, pump room, and a portion of a cargo tank are spaces which are available for this purpose. Space for additional machine shop equipment can be made available in the existing auxiliary machinery space. Space for test recording equipment and computers is available in the mid-ship deck house.

Because of the relatively low test equipment weight, sea water ballasting will be required in order to place the ship at a 29-ft draft. The tankage available for ballast water appears to be adequate to achieve the desired draft. The importance of the 29-ft draft is that the cycle plant pumps and heat exchangers are completely submerged, thus preventing air from entering the system. Moreover, the deep draft improves the sea keeping qualities of the platform in that it is less responsive to sea state conditions.

The platform at the test site will be moored with a bow and stern anchor. A complete anchoring system will be required at the stern. The capacity of the bow anchoring system may have to be increased depending upon the prevailing sea state condition at the test site. In an emergency, the propulsion system may be used to supplement the mooring system.

Transverse stability of the platform in the test operating condition should be more than adequate. In view of the high derrick structure, a higher metacentric height will result as determined from the U. S. Coast Guard stability weather criteria expression. The available metacentric stability, however, should be well in excess of the Coast Guard minimum stability requirements.

Fig. 3-1 Conceptual Arrangement of Sea-Based Test Platform

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8.4 PERSONNEL

The estimated number of personnel required to administer and operate the test facility was presented by four or five categories in Report Sections J and L, respectively. This section presents the detailed estimates on personnel types and members for both land based and sea based.

Table 8-6

ESTIMATED PERSONNEL FOR LAND-BASED AND SEA-BASED TEST FACILITY

		LAND BASED TEST FACILITY				SEA BASED TEST FACILITY					
		FAC	TEST	LAND		AT-SEA	LAND	FAC	SHORE	FAC	AT-SEA
				FAC	TEST		FAC	TEST	FAC	TEST	
1. ADMINISTRATIVE											
1.1	Manager	1	1	1	1	-	1	1	1	1	-
1.2	Admin. Ass't.	1	2	1	2	1	1	1	-	-	1
1.3	Secretary	1	2	1	1	-	1	1	1	1	-
1.4	Clerk Typist	1	2	1	2	1	1	2	-	-	1
1.5	Program Admin.	1	1	1	2	-	1	1	-	-	-
1.6	Personnel/Finance	3	4	3	4	-	3	4	1	1	-
1.7	Security	3	9	3	9	2	3	9	3	9	2
1.8	Medical Aide/Fire Marshall	2	6	2	4	2	2	4	1	2	2
1.9	Cafeteria	4	12	3	9	-	3	6	2	5	-
SUBTOTAL		17	39	16	34	6	16	29	9	19	6
2. ENGINEERING/TECHNICAL											
2.1	Supervisor	1	3	1	2	1	1	2	-	-	1
2.2	Lead Engr's.	2	5	1	3	1	1	3	1	2	1
2.3	Secretary	1	2	1	2	-	1	2	1	1	-
2.4	Test Engineers	4	8	2	4	2	2	4	1	1	2
2.5	Facility Operators	2	8	2	6	4	2	6	-	-	4
2.6	E&E/Inst. Engr.	2	3	1	2	1	1	2	1	1	1
2.7	Instr./Calib. Tech.	2	3	1	2	1	1	2	1	2	1
2.8	Designers	2	3	2	3	1	2	3	1	2	1
2.9	Chemical Engr.	1	3	1	2	1	1	2	-	-	1
2.10	Lab Ass'ts.	4	9	4	8	1	3	8	-	-	1
2.11	Computer Programmer	1	3	2	2	1	1	2	-	-	1
2.12	Computer Operator	2	5	2	4	3	1	3	-	-	3
2.13	Junior Engrs.	2	4	2	3	-	2	3	-	-	-
2.14	Photographers	2	4	2	3	1	2	3	1	1	1
2.15	Tech Pubs & Info Center	3	4	4	4	-	4	4	-	-	-
SUBTOTAL		31	67	28	50	18	25	49	7	10	18

Table 8-6
ESTIMATED PERSONNEL FOR LAND-BASED AND SEA-BASED TEST FACILITY (Cont.)

		LAND BASED TEST FACILITY		SEA BASED TEST FACILITY							
		FAC	TEST	LAND		AT- SEA	LAND FAC	FAC TEST	SHORE FAC	FAC TEST	AT- SEA
		FAC	TEST	FAC	TEST		FAC	TEST	FAC	TEST	
3. SHOP/MAINTENANCE											
3.1	Foreman	1	2	1	2	1	1	2	1	1	1
3.2	Leadman	2	4	1	2	—	1	2	—	1	—
3.3	Clerk Typist	1	2	1	2	—	1	2	1	1	—
3.4	Test Section Mechanics	6	15	4	12	3	3	6	2	3	3
3.5	General Machinists	4	8	3	6	2	2	3	1	2	2
3.6	Welders	2	4	2	4	1	2	3	1	2	1
3.7	Crane Operators	2	4	1	2	1	1	2	1	1	1
3.8	Equipment Maintenance	1	2	1	2	—	1	2	1	1	—
3.9	Electrician	1	3	1	2	1	1	2	1	1	1
3.10	General Maintenance	2	3	1	2	—	1	1	—	—	—
3.11	Janitorial Service	2	3	2	3	—	2	3	1	1	—
3.12	Receiving/Shipping	2	4	2	4	—	2	3	1	1	—
3.13	Material/Stores		2	4	2	4	1	2	1	1	1
SUBTOTAL		28	58	22	47	10	20	34	12	16	10
4. MARINE CREW											
4.1	Master	—	—	—	—	1	—	—	—	—	1
4.2	Deck Officers	—	—	—	—	2	—	—	—	—	2
4.3	Engineers	—	—	—	—	1	—	—	—	—	1
4.4	Assistant Engineers	—	—	—	—	2	—	—	—	—	2
4.5	Oilers	—	—	—	—	4	—	—	—	—	4
4.6	Radio Operators	—	—	—	—	1	—	—	—	—	1
4.7	Assistant Radio Operators	—	—	—	—	1	—	—	—	—	1
4.8	Electricians	—	—	—	—	1	—	—	—	—	1
4.9	Assistant Electricians	—	—	—	—	1	—	—	—	—	1
4.10	Bosun	—	—	—	—	1	—	—	—	—	1
4.11	Seamen	—	—	—	—	6	—	—	—	—	6
4.12	Chief Stewart	—	—	—	—	1	—	—	—	—	1
4.13	Assistant Stewarts	—	—	—	—	2	—	—	—	—	2
4.14	Messmen	—	—	—	—	2	—	—	—	—	2
SUBTOTAL		—	—	—	—	26	—	—	—	—	26

Table 8-6

ESTIMATED PERSONNEL FOR LAND-BASED AND SEA-BASED TEST FACILITY (Cont.)

	LAND BASED TEST FACILITY		SEA BASED TEST FACILITY							
	FAC	TEST	LAND		AT- SEA	LAND	FAC	SHORE	FAC	AT- SEA
			FAC	TEST		FAC	TEST	FAC	TEST	
5. TEST OBSERVERS										
5.1 ERDA (USG)	6	14	6	14	3	4	10	2	4	3
5.2 Contractor/Vendors	8	16	8	16	3	6	10	2	6	3
SUBTOTAL	14	30	14	30	6	10	20	4	14	6
8-78 TOTALS										
Payroll	76	164	66	131	60	61	112	28	45	60
Payroll Plus Observers	90	194	80	161	66	71	132	32	59	66
W/Rotation - Payroll	76	164	66	131	120	61	112	28	45	120
W/Rotation - All	90	194	80	161	132	71	132	32	59	132

Appendix 9

DATA ACQUISITION AND CONTROL SYSTEM

The data acquisition and control system information contained in this appendix is in two parts. The first part contains three visual aids and their text summaries not presented on August 26/27 because of time limitations. The second part is the Lockheed Electronics Company report on "Data Acquisition and Control System Recommendations - Ocean Thermal Energy Conversion Test Facility", which is the basis for Section M of this report.

DACS TYPICAL CONTROL ROOM CONSOLE

9-2

COMPUTER CLOSED LOOP CONTROL CAPABILITY			
<u>PRINTER</u>	<u>DISPLAY</u>	<u>KEYBOARD</u>	<u>PLOTTER</u>
ALPHANUMERICS STD. SYMBOLS COARSE PLOTS	DEDICATED DISPLAYS CRT COLOR (OPTIONAL) ALPHANUMERICS STD. SYMBOLS LIMITED GRAPHICS	ALPHANUMERICS FUNCTIONS OPTIONAL SPECIAL FUNCTIONS	ALPHANUMERICS STD. SYMBOLS HIGH RESOLUTION PLOTS

MANUAL CONTROL CAPABILITY			
<u>PRINTER</u>	<u>DISPLAY</u>	<u>KEYBOARD</u>	<u>PLOTTER</u>
NONE	DEDICATED KEY PARAMETERS LOG ALL DATA	NOT USED	NOT USED

MANUAL CONTROLS FOR TEST AREA'S ONLY.

DACS CONTROL ROOM CONSOLE

THE TYPICAL CONSOLE WILL PROVIDE THE TEST OPERATOR THE CAPABILITY TO PERFORM AUTOMATIC CLOSED LOOP CONTROL OF TEST ARTICLES OR MANUAL CONTROL VIA DEDICATED SWITCHES AND SETTINGS. IN MANUAL MODE CONSOLE ELECTRONICS INTERFACE WITH THE REMOTE TERMINAL IN THE TEST AREA AND THE CENTRAL COMPUTING ROOM FOR DATA LOGGING AND PARAMETER VALUE PROCESSING FOR QUICK LOOK DISPLAY. IN AUTOMATIC OPERATION THE COMMAND OR PARAMETER SETTINGS CAN BE MODIFIED VIA KEYBOARD ENTRY WITH BASIC CONTROL MAINTAINED BY THE COMPUTER AS CONFIGURED FOR TEST. LIMITED GRAPHICS CAPABILITY ARE INCORPORATED.

DACS INFORMATION INTERFACES

DACS INFORMATION INTERFACES

THE INTERFACES OF THE DACS SYSTEM ARE USER INTERFACES WHICH INCLUDE INPUT/OUTPUT EQUIPMENT, TEST ARTICLE MEASUREMENT SIGNALS AND CONTROL SIGNALS, EACH OF WHICH MUST INTERFACE WITH A DATA BASE CONSISTING OF PARAMETER DATA INCLUDING LIMIT AND CALIBRATION, PROGRAMS FOR PROCESSING, TEST CONFIGURING, LOGGING DATA, DRIVING DISPLAYS AND PERFORMING CONTROL FUNCTIONS AS CONFIGURED.

USERS WILL INPUT VIA CARD DECK, TAPES OR KEYBOARD ENTRY TO SETUP TEST CONFIGURATION, PERFORM ANALYSIS AND OBTAIN PLOTS, PRINTOUTS OR DISPLAYED DATA. THE COMPUTING CENTER WILL PROCESS AND COMPUTE DESIRED PARAMETERS OR DATA BASED ON THE ENTERED DATA BASE, PARAMETER VARIATIONS AND CALIBRATION DATA. DURING TESTING OPERATIONS THE PARAMETERS SIGNALS WILL BE OBTAINED BY DACS TERMINALS IN THE TEST AREA(S) AND TRANSMITTED TO THE COMPUTING CENTER.

DACS REQUIREMENTS

- INDEPENDENT TEST AREAS AND CYCLE PLANT OPERATION
- PROVIDE FOR SIMULTANEOUS TESTS
- PROVIDE FOR FLEXIBLE TEST CONFIGURATION
- GIVE REAL TIME DATA DISPLAY
- SINGLE POINT FAILURE WILL NOT CAUSE LOSS OF DATA OR CONTROL
- PERFORM ENGINEERING CALCULATIONS
- LOG DATA
- 3000 "SLOW" ANALOG SENSORS- CONTINUOUS SAMPLING
AT 1/2 SECOND
- 40 "FAST" ANALOG SENSORS - 500 SAMPLE BURSTS AT 1.5 MS
- PROVISION FOR DIGITAL AND DISCRETE SIGNAL INTERFACING

DACS REQUIREMENTS

THE REQUIREMENTS ESTABLISHED FOR DACS ARE THAT THE SYSTEM MUST BE CAPABLE OF PROVIDING INDEPENDENT TEST AREA AND CYCLE PLANT OPERATION AS WELL AS SIMULTANEOUSLY CONTROLLING AND MONITORING TEST OPERATIONS IN DIFFERENT AREAS. THIS REQUIRES THE SYSTEM TO BE SIZED AND CONFIGURED TO PERMIT MORE THAN ONE TEST OPERATION AT A TIME. THE DACS SYSTEM MUST BE CAPABLE OF ACCOMMODATING DIFFERENT TEST CONFIGURATIONS OF THE SAME COMPONENTS AS WELL AS DIFFERENT TEST CONDITIONS FOR THE SAME COMPONENT CONFIGURATION.

TO ASSURE TESTS ARE BEING PERFORMED SATISFACTORILY AND RELIABLY THE DACS HAS BEEN CONFIGURED WITH DUAL COMPUTER ACCESS TO PROVIDE REAL TIME DATA DISPLAY TO TEST CONDUCTORS AND OPERATORS AND MUST HAVE FORMATS WHICH CAN BE READILY UTILIZED. IT MUST ALSO DRIVE DEDICATED DISPLAYS FOR KEY PARAMETERS. CONSEQUENTLY NO SINGLE POINT FAILURE IN THE DACS EQUIPMENT SHALL CAUSE TEST ARTICLE DAMAGE, FAILURE TO ACQUIRE AND DISPLAY DATA OR TEST ABORT.

THE SYSTEM SHALL BE CAPABLE OF BEING UTILIZED FOR PRETEST AND POST TEST ANALYSIS INCLUDING PLOTS AND REPORT PREPARATION.

IT IS ESTIMATED THAT A FEW HUNDRED DIGITAL AND DISCRETE INTERFACES WILL BE REQUIRED IN ADDITION TO APPROXIMATELY 3000 SLOW ANALOG SENSOR SIGNALS SAMPLED AT 1/2 SECOND INTERVALS AND AN ESTIMATED 40 FAST ANALOG SIGNALS FROM ACCELEROMETERS SAMPLED AT 500 SAMPLE BURSTS AT 1.5 MILLISECCNDS.

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DATA ACQUISITION AND CONTROL SYSTEM RECOMMENDATIONS

OCEAN THERMAL ENERGY CONVERSION TEST FACILITY

BY

R. J. FISHER

August 1976

LOCKHEED ELECTRONICS COMPANY, INC.

HOUSTON, TEXAS

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1. OBJECTIVES AND REQUIREMENTS

This document presents recommendations for a digital computer based data acquisition and control system (DACS) for the Ocean Thermal Energy Conversion (OTEC) test facility presently under study by Lockheed Missiles and Space Company (LMSC).

The OTEC-DACS recommendations presented here apply primarily to a single land based facility since this concept was more clearly defined at the time of this study. However, the basic DACS concepts for a sea based facility or for dual land/sea facilities would be similar. Specific recommendations for sea based or dual DACS installations are presented whenever appropriate throughout this report.

1.1 OTEC TEST FACILITY

The OTEC test facility is to provide capability to develop and demonstrate the OTEC concept. The facility is to be utilized for the next ten to twenty years to test components of the type required for OTEC. The facility will also support advanced research and technology development relative to OTEC. Finally, it shall support testing of a small cycle plant operating system. As presently conceived, the OTEC test facility includes eight test areas, a cycle plant, a remote pumping station to supply large volumes of water at temperatures required by the cycle plant, control rooms containing operator control consoles for each test area, and support and administrative areas. The estimated staff is ninety employees.

The consideration of alternatives could lead to the implementation of other than eight test areas, or the implementation of several of the test areas and/or the cycle plant at a sea based location.

1.2 REQUIREMENTS

The OTEC-DACS must acquire data and control simultaneous but independent tests in all test areas as well as the cycle plant. Operations at any test area must not affect those at any other test area. The system must be highly reliable particularly during data acquisition. A single component failure should not cause substantial data loss or force the termination of any test due to loss of control functions or loss of data acquisition capability.

The definition of test configuration for data acquisition as well as control must allow maximum flexibility since the equipment under test as well as the type of testing at any area may vary greatly. Flexibility in programming control algorithms must also be provided. Closed loop and open loop control as well as operator control and operator override of automatic control are required.

Monitoring of all analog sensors for maximum and minimum values, and validity as specified is required. Out of limit conditions should be annunciated by a flashing display or, for critical conditions, an audible tone as specified.

Displays available at the control console for a particular test should present to operators the status of selected sensors and controls, the status of alarmed sensors, summaries of significant test events, and such other displays as may be required by a particular test area. Color display capability should be provided to increase operator efficiency and data recognition and to reduce operator fatigue. The desired display is to be selected by the operator at the console.

A printed periodic log of selected sensor values and/or other test events should be available at any console where this feature is needed.

Consideration should be given to providing high resolution plotting capability at selected control consoles to present real time data plots, vibration signature plots, ammonia pressure-enthalpy diagrams, or other significant graphs during testing.

Following a test, the OTEC-DACS should provide a flexible, pre-analysis "quick-look" feature which allows display, logging, plots, or preliminary analysis of the acquired data at the control console prior to the undertaking of an extensive post-test analysis.

The OTEC-DACS should provide the test facility with an extensive capability for analysis of test data. Standard format magnetic tapes should be produced from the acquired data

for use by analysis programs at the OTEC-DACS facility as well as at other data processing facilities. The OTEC-DACS should provide significant support for user analysis programs executed in a batch mode.

In addition to test data acquisition, control, and processing, OTEC-DACS will monitor heating, air conditioning, electric power consumption, outside weather conditions, fire detection, and security sensors. Heating and air conditioning will be controlled by algorithms selected to minimize energy consumption. Utility, fire, and security sensors will produce visual or audible alarms under specified conditions.

A secondary requirement is the utilization of OTEC-DACS for payroll, material and inventory accounting, operations scheduling data, test reports, and procedures.

Flexibility and modularity as well as reliance on the latest state-of-the-art technology are primary goals for the OTEC-DACS to assure its continued effectiveness over the life of the test facility.

An associated personnel communications system is required to allow communications between each test area and its control room and between areas required for the DACS.

2. ALTERNATIVES AND RECOMMENDATIONS

The basic design configuration recommended to meet the primary system requirements is a dual computer facility having communications links to intelligent data acquisition and control terminals in the test areas and intelligent operator control consoles in the control rooms.

Sections 3 through 6 discuss a "baseline" system of this type based on the most likely user applications. Since many user applications must be defined later, system flexibility has been emphasized. However, the range of possible applications is so great that a rigid configuration is not possible at this time. The baseline system is used as a frame of reference to evaluate various system options with respect to system capability as well as cost. This section briefly reviews the considered alternatives to this configuration and the recommendations regarding secondary system requirements.

It is assumed that the component test areas will be implemented first and that the cycle plant test area will be implemented approximately one year later. Correspondingly the OTEC-DACS is to be built in two phases herein referred to as Phase "A" for the initial system and Phase "B" for the cycle plant increment.

2.1 ALTERNATIVES

As stated earlier, only digital computer based systems have been considered. An analog system for a facility having such a large number of slowly varying parameters would be unmanageable, having hundreds of wires leading to each console, hundreds of multichannel magnetic tape recorders, and an inflexible console display and control configuration.

Individual dual computers for each test area would require an additional hardware cost of almost five hundred thousand dollars over the recommended system and would not provide as much computational power for analysis since the computers would be smaller. The computational power could be increased by adding a larger, shared computer for analysis. However, this would further increase the additional cost to more than six hundred thousand dollars. A system utilizing single small computers for each test area and a single large central computer for redundancy as well as for analysis could provide adequate reliability. However, this would produce an additional hardware cost of approximately two hundred and fifty thousand dollars plus additional software complications due to the lack of symmetry between primary and backup operations.

Some of the advantages of the recommended configuration that are not common to the alternative approaches are as follows: A minimum number of central processing units and basic

peripherals (line printers, teletypes, card readers, etc.) are required. A single large computer operation team and application software development team can bring more knowledge and experience to bear on an application problem at lower overall cost than can several small teams. Uniformity of hardware and software minimizes design and maintenance costs. Interchangeability of components reduces maintenance and parts inventory costs. The potential is available when required to concentrate a large amount of computing power on selected test areas.

The major advantage of the alternate individual computer approach is the ability of the small individual software development teams to become more intimately familiar with the operations of their particular test areas. In addition, the individual user has greater control of his computer resources with the multicomputer approaches even though the resources available are less. It should be noted in passing that if two or fewer test areas were implemented in addition to the cycle plant and facility utilities, then the multicomputer alternatives become economically desirable.

2.2 SECONDARY REQUIREMENTS

The relatively small size of the facility utility and security operations (approximately 100 sensors) would not normally indicate a computer utility data acquisition and control system (μ -DACS) to be cost effective. However, the

similarity of utility data acquisition and control to test data acquisition and control will allow OTEC-DACS to effectively monitor facility utility and security functions. A single console and a single data acquisition terminal for this function are included in the baseline system. The special applications software to control heating, ventilating, and air conditioning systems for increased operating efficiency in response to weather conditions is also included.

The secondary requirement for payroll, material and inventory accounting, operations scheduling data, can best be met through a small dedicated business oriented computer system completely independent of the OTEC-DACS. Such a system may be leased or purchased for approximately forty thousand dollars. The system would include a console, floppy disc, and printer and package programs tailored to the needs of the OTEC test facility for payroll, inventory, maintenance, reports, and an RPG (Report Program Generator) compiler to facilitate application programming by the test facility staff. The staff to support this system would be one programmer and one operator. This system is not included in the baseline since it is not a part of the OTEC-DACS. This approach eliminates any conflict for computer resources between diverse groups and allows business oriented data processing to be done more efficiently using a system specifically designed for this application. Although the OTEC-DAC computer would be available for this

application, the cost of developing the required application software would far exceed the \$40,000 cost of the recommended system.

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3. OPERATION

OTEC-DACS operation is divided into five phases: pretest, test, posttest, preliminary analysis, and analysis. Each phase may be executing for any test area independent of activities for other test areas. The pretest phase prepares the OTEC-DACS for a prescribed test. This preparation consists of calibrating the data acquisition systems and entering data such as test documentation (including test configuration and test descriptions) and test parameters (including channel transducer associations, engineering unit identifications, raw data conversion specifications, alarm limit values, control specifications, etc.).

The test phase controls the testing process and acquires test data under operator control as prescribed during the pretest phase. The test phase includes test control, data acquisition, limit checking, alarm notification, output disc and tape file creation, real-time displays, and real-time plots.

The posttest phase activities include a second calibration of data acquisition systems, output disc and tape file verification, and demultiplexed output tape creation.

The preliminary analysis phase allows the user to obtain data tabulations, plots, standard statistical analyses of selected test data for preliminary evaluation prior to undertaking a more extensive test data analysis during the analysis Phase.

The DACS operations occur in three areas, the computer facility, the test control rooms, and the test areas. The computer facility contains equipment operated by trained computer operators in support of all test areas. The control rooms contain control consoles used by trained members of each test team to observe all test process variables, control all test parameters, observe real-time data plots and tabulations, and communicate with DACS on all aspects of the test. The test areas contain the actual test processes which are interfaced to the DACS through DACS terminals connected to transducers and actuators incorporated in the test process. Each control console is dedicated to a specific test area but any control console can be reassigned to another test area.

3.1 PRETEST PHASE

The pretest phase allows the user for any test area to fully prescribe the requirements of the DACS during the following test. For each analog sensor a specific channel must be allocated, a mnemonic label assigned, engineering units specified, and the following specifications assigned: type of conversion (direct, linear, polynomial, or square root are standard), the required coefficients for the equation or a calibration indication (system computes coefficients via an interactive calibration process), the alarm limits (maximum and

minimum), the alarm type (visual, audible), the validity criterion (maximum sample variation), and specifications of scan sequence and frequency. For each discrete sensor, a specific channel must be allocated, a mnemonic label assigned, discrete state identifiers specified, alarm state or status change alarm (i.e., alarm notification occurs if state changes) selected, and specifications of scan sequence and frequency established. For each discrete or analog control a channel must be allocated, a mnemonic label assigned, and the control type specified (manual, proportional/integral/differential for analog controls, on/off for discrete controls, or other standard or user defined automatic control algorithms), as well as the required coefficients and designated sensor input.

In addition, time programmed analog control set point changes or discrete control state changes; various sensor real-time display, tabulation, or plot groups; and any other specifications required by specific test area requirements must be defined for the DACS during this phase.

The specifications described above, known as the test static data base may be entered to the DACS or modified through the console in the control room or through a card reader in the central computer facility. Establishment and modification of static data base is accomplished by convenient fill-in-the-blanks entries. The static data base may be displayed on a

CRT at the control room console and logged on a line printer in the central computer facility. The data are recorded as part of the test output tape and are stored on disc for use in future tests.

An interactive sensor calibration procedure during pretest verifies operation of selected sensors and records calibration data for the output tape. An interactive control test verifies the operation of selected controls.

3.2 TEST PHASE

The DACS enables test operations personnel to conduct test phase operations with very little intervention or as much intervention as desired. Data acquisition and automatic control proceed completely automatically. Acquired data and control actions are recorded on disc and magnetic tape automatically. Alarm conditions are monitored including sensors out of limits, loss of control feedback, and computer software and hardware alarms. Special preprogrammed abort procedures will be implemented which either automatically or by command through the control console stop the test by shutting down the process in the safest manner.

The operator, through commands at the console, can call up various displays to observe current values of selected groups of sensors, alarm conditions, and control variables. The static

data base may be observed and modified as in the pretest phase with restrictions allowing modification of only those specifications which will not affect test operations. Real-time plots and tabulations of selected test sensor values may be obtained at the console. Additionally, displays, tabulations, and plots of sensor values at previous times during the test are available through operator commands at the console. Other special displays, tabulations, and plots to be available at the consoles will be defined when the specific test area requirements are established. These could include schematic diagram displays of equipment configurations for the cycle plant test area, pressure enthalpy diagrams for the heat exchanger test area, and vibration signature plots for the turbine test area.

3.3 POSTTEST PHASE

The posttest phase of OTEC-DACS operation includes an interactive calibration procedure similar to that in pretest, and a logging procedure.

At the completion of a test, the complete data from the test has been recorded on a magnetic disc and a magnetic tape. The disc is the primary input for the posttest logging. The tape serves two purposes. First, it is a backup in the event of damage to the disc or malfunction of the disc hardware during the test. Second, it serves as a convenient storage medium to allow posttest processing to be delayed to utilize

the facility to record another test before the data from a previous test has been processed.

The data written on disc during the test is arranged on the disc grouped according to time of acquisition. For efficient processing, it must be regrouped according to channels. The user must enter through his control console the information required to do this. This includes the starting and ending times and the channels of the test data of interest. During long tests with many channels, multiple time grouped tapes may be produced which will be processed posttest to produce multiple channel grouped tapes. This processing may be done on each test tape as it is filled.

3.4 PRELIMINARY ANALYSIS PHASE

The preliminary analysis phase allows a user to critically observe selected portions of his test data to make judgements regarding the nature of analysis to be made. Tabulations, plots, and displays of data and processed data are available at the control console under control of the console operation. The processing available will include averaging, cross-plots, filtering, statistics, regression, correlation, and other standard analytical tools.

3.5 ANALYSIS PHASE

The analysis phase is executed at the computer operations room according to specifications and programs defined by the

user of the test area. All standard tools available for pre-analysis are also available during analysis; however, processing is done batch mode with results in the form of tabulations and plots delivered to the user. No displays are possible.

3.6 OPTIONS

The preceding discussion of operations applies generally for all hardware and software options to be discussed in later sections. One operational option not described is a direct data link to another computer facility elsewhere. If processing power or a special program not available in OTEC-DACS is available at another facility, a posttest data tape may be sent to the other facility which would perform the analysis and send the results back; or, if the data link option is implemented, then the other facility may acquire the needed posttest data tape information directly and return the results of the analysis directly via the link.

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4. HARDWARE

The general layout of the OTEC-DACS hardware is shown in figure 4-1. The hardware is divided into three categories according to function and location. The DACS-terminals located in the test areas acquire sensor data from the test process and transmit control commands to the test process. The control consoles located in the control rooms process all test operator inputs and present all information from OTEC-DACS to the test operator in the form of displays, printed tabulations and reports, and plots. The computer system located in the computer facility includes the computer and peripheral devices operated by trained computer operators in support of all test areas.

4.1 DACS-TERMINALS

The DACS-terminal configuration as well as its relationship to the test process is shown in figure 4-2. At least one terminal is located in each test area depending on the number of channels of each type required in the test area, the physical size and geometry of the test area, and redundancy requirements.

All signals between the terminal and the test process are standardized. Analog inputs are single ended, 4-20 milliamperes, compatible with industry standard transducers which allow simple fault detection. Analog outputs are also

Figure 4-1. - System layout.

Figure 4-2. - DACS terminal.

industry standard 4-20 milliamperes. Digital outputs are contact closure type which are easily interfaced to standard discrete actuators. Digital inputs are optically isolated.

To connect the test process components to the terminal, racks of signal conditioners connected on inputs and outputs through patch panels are used for all channels subject to disconnecting and reconnecting between tests. The panels should be arranged to facilitate connections between the test process components and the terminal directly as well as through signal conditioners. Connections to channels which remain unchanged between tests may be made via barrier strip connectors. However, a similar patch panel arrangement would be desirable for convenience and uniformity.

The terminal must have the capacity to sample all sensors once and one sensor (for vibration analysis) at 640 Hz for 625 msec (400 samples) and transmit this data to the computer within 0.5 sec. Simultaneously, it must be capable of receiving and executing at least one control command for each control point.

The following specifications are recommended.

General:

Up to 512 analog inputs

Up to 256 discrete inputs

Up to 128 analog outputs

Up to 128 discrete outputs

Random and Sequential Addressing

Operating Temperature Range 0° to 55°C

Microprocessor Control

Analog inputs:

Single ended

4 to 20 mA

Channel Rate 10 kHz minimum

Data Format 12 bit two's complement binary

Analog outputs:

Single ended

4 to 20 mA

Accuracy $\pm 0.1\%$

Setting time 100 μ sec maximum

Data Format 12 bit two's complement binary

Digital inputs:

Input current 10 to 40 milliamperes

Input voltage 5 volts

Optical Isolation

Digital outputs:

Mercury wetted reed 25 VA, 1.0 amperes, 100 v

10^8 operations at rated load

The terminal communicates with the computer through a serial link capable of a word rate of 8 kHz at a distance up to one-half mile. Communication security should be assured

through a seven bit Bose-Chaudhuri-Hocguenghem error detection code. A standard (RS-232C) serial link connects the terminal to a portable calibration and test unit which allows a technician in the test area to monitor sensors and actuate controls as well as to verify terminal functions and troubleshoot the test process as well as the terminal. During the OTEC-DACS calibration and testing phases, this interface is connected directly to the control room where it is utilized to operate and monitor the test process directly from the control console without the intervention of the computer. This "direct mode" of operation serves as a test mode for the console and DACS terminal as well as a third backup in case of a double central processing unit failure in the dual computer system (in which case, however, data acquisition and most displays will be lost).

The heart of the terminal is the microprocessor and its associated memory. This allows the terminal to relieve the computer of part of the processing burden. The terminal is programmed to execute several different programs including communications error checking, sequential sensor scan, random sensor scan, unauthorized digital and analog sensor change detection, validity and limit checking, and digital and analog control output. It is capable of future programming to implement direct digital control algorithms without processing support from the computer.

The terminal is contained in an enclosure suited to the test area environment. For purposes of estimating software and hardware costs, manpower, and schedules, the test area requirements of table 4-1 were assumed for the baseline system.

4.2 CONTROL CONSOLES

The basic control console configuration is shown in figure 4-3.

Each control console includes at least one CRT display, one alphanumeric character printer, one standard alphanumeric keyboard, and one special function keyboard. In addition, a console may include a high resolution printer plotter, additional CRT displays, and additional keyboards. With the exception of the high resolution plotter, these devices interface to a microprocessor which is part of the console. The console microprocessor as well as the plotter interface directly to the computer. The console microprocessor also interfaces to the related DACS-terminal microprocessor as described in section 4.2. The console microprocessor relieves the computer of part of the processing burden by generating standard format displays and performing standard plotting functions. It also translates operator commands for the DACS-terminal and formats DACS-terminal data for display in the direct mode.

TABLE 4-1. -- TEST AREA REQUIREMENTS

Area	Sensors		Controls		Terminals
	Analog	Discrete	Analog	Discrete	
<u>PHASE "A"</u>					
Turbine	384	128	32	128	1
Heat Exchanger	384	128	32	128	1
Heat Transfer	384	128	32	128	1
Pump	384	16	8	16	1
Energy Utilization	384	128	32	128	1
Controls	128	128	16	128	1
High Voltage	128	128	16	128	1
Anti Fouling	128	128	16	128	1
Facility	128	128	16	128	1
<u>PHASE "B"</u>					
Remote Pumps	8	16	0	16	1
Cycle Plant	768	256	64	256	2

PHASE "A" Totals	2432	1040	200	1040	9
PHASE "B" Totals	776	272	64	272	3
GRAND Totals	3208	1312	264	1312	12

4-9
9-41

DISPLAY

CRT
COLOR
ALPHANUMERICS
STD SYMBOLS
LIMITED GRAPHICS

KEYBOARD

ALPHANUMERICS
FUNCTIONS
OPTIONAL SPECIAL
FUNCTIONS

PRINTER

ALPHANUMERICS
STD. SYMBOLS
COARSE PLOTS

PLOTTER

(OPTIONAL)
ALPHANUMERICS
STD SYMBOLS
HIGH RESOLUTION
PLOTS

Figure 4-3.— Console.

The following specifications are recommended for the micro-processor and other console devices.

ENVIRONMENT:

Temperature +10°C to +40°C

Humidity 10 to 95% non-condensing

CRT:

19" diagonal screen size

Eight color

80 characters per line

48 lines

Standard ASCII characters

Graphic Symbols & Plotting

Blinking Function

RS-232 interface

Selectable transfer rate to 9600 Baud

Audible Tone

PRINTER:

80 characters per line

Standard ASCII characters

30 characters per second minimum

RS-232 interface

KEYBOARDS:

Standard ASCII characters

Typewriter Format with adding machine format numerics

Up to 64 special characters

PLOTTER:

Width 10 inches minimum

Resolution 100 points per inch minimum

Speed 1/2 inch per second minimum

For purposes of estimating, the control room requirements of table 4-2 were assumed for the baseline system.

4.3 COMPUTER SYSTEM

The computer system is shown in figure 4-4. The dual real time computer system assures the high reliability required for test operations. The redundant system is achieved at a relatively low expense since batch mode, analysis phase programs and real-time support programs of low critically can execute on one system (the secondary system) while the other system (primary system) is executing critical real-time programs.

The central processing units (CPU) should be proven equipment designed for and having full software support for real-time multiprogrammed data acquisition and control applications. A smaller compatible computer should be available to allow utilization of software developed for the land based test facility to be utilized for similar but less demanding applications such as a single sea based cycle plant or an individual test area at another location. The equipment should be field proven in high shock and vibration environments such as mobile van or shipboard applications.

TABLE 4-2. - CONTROL ROOM REQUIREMENTS

Control Room	CRT	Keyboards		Printer	Plotter
		Std.	Special		
<u>PHASE "A"</u>					
Turbine	2	1	1	1	1
Heat Exchanger	2	1	1	1	0
Heat Transfer	2	1	1	1	0
Pump	1	1	1	1	0
Energy Utilization	1	1	1	1	0
Controls	1	1	1	1	0
High Voltage	1	1	1	1	0
Anti Fouling	1	1	1	1	0
Facility	1	1	1	1	0
<u>PHASE "B"</u>					
Cycle Plant	2	1	2	1	1
PHASE "A" Total	12	9	9	9	1
GRAND Total	14	10	11	10	2

Figure 4-4. - Computer system.

The teletype, CRT's, and paper tape readers are required for program development, computer operations, and maintenance. The following specifications are recommended.

CPU:

- Memory (8-bit bytes), Phase "A":384k, Phase "B":512k
- 16 bit memory cycle time 500 nsec, maximum
- 16 bit integer operations
- 32 and 48 bit floating point operations
- Simultaneous I/O and CPU processing
- Memory Protect
- 16 interrupt levels
- 2 MHz byte I/O rate, minimum
- Redundant Cooling System

TELETYPE:

- 10 characters per second
- 72 characters per line
- Paper Tape 8 level, 1 inch wide
- Standard Typewriter Keyboard

CRT:

- 24 lines X 80 characters
- Full/half duplex switchable
- 110 to 9600 Baud switchable
- 64 ASCII characters

PAPER TAPE READER:

625 characters per second continuous

EIA Standard 1 inch, 8 level and sprocket

The card readers are required for static data entry, program development, and limited program entry. The following specifications are recommended.

CARD READER:

300 cards per minute

80 column (RS-292)

The line printers are required for reports and data tabulations on the secondary system and for real-time event, periodic, and demand logs, on the primary system. The following specifications are recommended.

LINE PRINTER:

132 columns

600 lines/minute

6 lines/inch

The plotters are required on the secondary system for analysis plots and, on the primary system for real-time plots in support of control rooms which do not have console plotters. The following specifications are recommended.

PLOTTER:

10 inch width minimum

100 points/inch minimum

1/2 inch/second minimum

The fixed head discs are required for program storage, static data base storage, and limited temporary dynamic test data storage. The following specifications are recommended.

FIXED HEAD DISC:

- 1 Million Words (16 bit) nominal capacity
- 200 kHz nominal word transfer rate
- Switch selected write lockout address

The moving head discs are used primarily for dynamic test data storage to allow real-time displays, plots, and tabulations, to facilitate more efficient posttest data processing than tape and to provide a back-up for test data tapes. The following specifications are recommended.

MOVING HEAD DISC:

- 25 Million Words (16 bit) nominal capacity
- 150 kHz nominal word transfer rate
- 35 msec nominal average head positioning
- Switch selected write lockout address

DUAL ACCESS MOVING HEAD DISC:

- 42 Million Words (16 bit) nominal capacity
- 400 kHz nominal word transfer rate
- 30 msec nominal average head positioning
- Switch selected write lockout address

The magnetic tapes on the primary system serve as redundant dynamic test data storage. On the secondary system, the

magnetic tapes are required for output of posttest data processing. The following specifications are recommended.

MAGNETIC TAPE UNIT:

9 track

800 bits per inch

45 inches per second

NRZI IBM compatible

Switch selected write lockout address

1.5 mil x 0.5 inch tape

10-1/2 inch reel size

The time of day clock provides a reference for display of time of day to operators and tagging data on tapes and discs. The following specification is recommended.

TIME OF DAY CLOCK:

Days, hours, minutes, seconds

24-hour interval battery back-up

Front panel display

Manually settable

Crystal Clock

The CPU-CPU link transmits critical data between the primary and secondary computers to allow rapid switchover to redundant system operation. The following specifications are recommended.

CPU-CPU LINK:

100 kHz nominal word transfer rate

Distance up to 100 feet

During the operation of several simultaneous tests, certain computer resources are allocated for the exclusive use of each test. For example, if a test were in progress at the turbine test area, one moving head disc and one magnetic tape drive would be reserved for the test data from this test. No other tests would in any way utilize these devices. This allocation of resources is accomplished as follows. Five primary system discs are each dedicated to specific tests having large data acquisition requirements. One such disc is filled by 8 hours of data from a test sampling 400 sensors at 1/2 second intervals or 24 hours of data from a test having 125 sensors. When a disc is filled, it can be transferred to the secondary system for immediate posttest processing. The data is then no longer available for real-time displays, etc. During the switchover, test data is stored temporarily on the fixed head disc until a new disc pack is inserted, so no data is lost. The remaining primary system disc is dedicated to tests having smaller data storage needs. For example; a 4-hour 300-sensor test; a 1-hour, 300-sensor test; and two 1-hour, 100-sensor tests would require about one-half of this disc. The utility and remote pump data will also be saved on this disc, but only for the previous sample period. The storage capacity is allocated before a test can begin. The system will always support simultaneous testing unless more real-time data storage is required than is available. In this case, a test

start may be delayed until another test is completed. The two large dual access discs are dedicated to the cycle plant dynamic test data. Each has the capacity for seven hours of data from 800 sensors. The dual access feature allows the secondary system to begin posttest processing immediately when one disc is filled and the other begins to fill. One magnetic tape unit on the primary system serves as redundant dynamic test data storage for the data on each of the six moving head discs. The remaining magnetic tape unit serves as redundant dynamic test data storage for the two dual access discs. When a tape is filled, test data is stored temporarily on the fixed head disc until the operator loads a new tape. In this way, no data is lost.

4.4 OPTIONS

Several optional approaches with respect to the baseline system hardware may be considered. The baseline system assumes high resolution plotting capability at the computer facility, the cycle plant control room, and one other control room. If additional plotting capability is desired, additional plotters can be added at other consoles.

The baseline system includes a console similar to those at other test areas having dual color CRT's. In order to utilize the cycle plant control room more effectively for demonstrations to government, industry, and student groups, two additional larger CRT's (25" diagonal) should be added to the console.

Additional console components should be kept available for redundancy in case of a failure. However, if a few minutes delay for connecting the back-up component cannot be tolerated at any of the control rooms, then a redundant component or a complete redundant console could be included.

If other than eight test areas are implemented, the number of consoles can be decreased or increased up to approximately 50 percent without modifying the baseline concept and configuration. In addition to the console components computer communications hardware are required for each console. At least one DACS terminal is required per test area depending

on the data acquisition requirements for the test area. For each test area, data recording resources are included at the computer facility depending on the data acquisition requirements for the test area, up to one moving head disc and one magnetic tape unit is required.

The color graphic CRT display offers almost limitless flexibility for display including panel meter simulations with superimposed color indications and digital values, engineering units, and other items with an information content and recognizeability factor which are greater than actual panel meters. In addition, through paging and display selection, hundreds of sensors may be displayed on a single CRT rather than on a very large confusing meter panel. Multicolored flashing or steady annunciator or indicator lights may be displayed far more flexibly and efficiently on a CRT than by multiple, dedicated, permanently labeled lights on a light panel. Lighted push-button keyboards are an effective replacement for toggle switches and they have a greater state recognition factor than toggle switches. Finally, rotating potentiometer knob functions may be accomplished by calculator keyboard entry supplemented by a simulated position indication on the CRT where a visual position feedback is required. Position feel cannot be simulated; however, this is not a requirement for adjusting parameters in slowly varying systems such as this. If, however, there is a desire to implement traditional meter panel,

indicator light panels, toggle switches, or potentiometer control boards to supplement to the other elements of the control console, this may be added by implementing D/A, A/D, and digital I/O in each console and installing the desired meters, switches, lights, and potentiometers.

The DACS terminals are required to be highly reliable, however, higher reliability may be achieved by installing additional terminals so that each test area has at least two terminals. Then, critical sensors and controls may be connected to redundant terminals to assure continuous monitoring and control even when a terminal fails. This capacity is included in the baseline system only for the cycle plant. It is an add on option for other test areas.

The terminal analog input system is a single-ended, high level, high channel rate A/D converter. This system is recommended for speed and noise immunity; however, it does require signal conditioning equipment. Optionally, if the average sampling rate were slowed from one-half second to ten seconds, a differential wide-range system could be implemented which would convert sensor inputs whose full scale values range from 10 mv to 10 volts. In addition to being slower, this system would be more costly than the baseline recommendation.

The baseline system includes dynamic test data storage resources (moving head discs) to allow data retrieval for display during tests. The size and number of discs depends on the baseline system assumptions on the number of sensors, the required sampling rates, and the period for which test data must be saved for display during tests. If the sampling rate were ten seconds rather than one-half second, or if one hours previous data would be sufficient, then only four discs rather than 14 would be sufficient. The baseline system can be easily expanded to include one pair of discs per test area; but greater data requirements than this have not been considered.

The data link to another computer facility mentioned in section 3.6 would require only the addition of a low cost communications interface and some communications software.

As specific application requirements are developed, the demand for very rapid retrieval of stored programs for execution or for very rapid retrieval of data for display and analysis may increase to the point at which disc word transfer delays become intolerable. To avoid this problem, external core memory should be considered. This memory can be shared by the two CPU's and thus serve as a replacement for the CPU-CPU link. For this reason, even though it is not required during the early life of the OTEC-DACS system, its installation in the phase "A" system will likely be less costly in the long run. This will

also allow an increase in the speed of some of the displays and analysis programs.

One final option which is included in the cost options is a second OTEC-DACS installed on an ocean platform cycle plant test facility similar to the land based cycle plant test area. The system will utilize the same hardware as the land based facility except the CPU's and core memory will be smaller and only the two dual access discs and two of the magnetic tape units will be required. This option is estimated assuming that the land based cycle plant has been operational for approximately one year before the ocean based cycle plant is to be operational.

5. SOFTWARE

The OTEC-DACS software is divided into two groups, system software and application software. System software consists of a set of field proven standard programs developed usually by the computer manufacturer to support requirements common to most users. Application software consists of a set of programs developed to support the specific requirements of the OTEC-DACS users.

5.1 SYSTEM SOFTWARE

The system software is further divided into four groups, the operating system, system processors, library programs, and diagnostics.

The operating system is a configurable, job oriented, real-time multiprogramming executive. It allocates core and execution control for all active jobs on a priority basis. It executes jobs by operator request, by request of an active job, by elapsed time, by time of day, or by hardware interrupt. It allows batch mode processing of jobs in background core. It controls I/O including spooling of all low speed printing devices. It also supports the required network processing between the two CPU's and their associated peripheral devices.

The system processors include programs required for program development, including applications programs as well as OTEC-DACS user programs. These include:

- Fortran IV Compiler: ANSI standard with extensions to allow efficient real-time data acquisition and control operations and direct access disc file I/O.
- Assembler: Producing absolute and relocatable code.
- Link Editor: Must support multi-level root/overlay structures.
- Load Module Cataloger: Provides functions required to maintain object modules on any standard peripheral media.
- Direct Access File Processor: Provides functions required to maintain Fortran defined direct access data files on disc.
- Program Debug Executive: Provides functions required to efficiently debug programs under development. It includes memory snapshots, traces, memory and register display and modification, breakpoint halts and reexecution.

- Source File Processor: Provides functions required to perform complete textual manipulation of cataloged source files and directories.
- Job Control Processor: Executes as a single or a multiple batch processing program to execute in turn other programs according to commands entered by a user from a specified device.

Library Programs include standard mathematical subprograms (e.g., sine, cosine, exponential), FORTRAN I/O run time subprograms, and process I/O and FORTRAN real-time interface subprograms.

Library programs also include special purchased software required to efficiently support the scientific and engineering applications required of OTEC-DACS. These include standard statistics, linear algebra, bessel functions, legendre polynomial, Runge-Kutta integration, roots of functions by Mueller's iteration, and many other commonly encountered mathematical operations. Also included in the library are software supporting convenient plotting of data and computed values.

Diagnostic programs allow hardware checkout and troubleshooting of all peripheral devices.

5.2 APPLICATIONS SOFTWARE

The applications software may be grouped as general applications and special applications software. The general applications software includes operations utilized by all or most test areas such as data acquisition, validity checking, engineering unit conversion, limit checking, control set point, basic automatic control, trend logging, periodic logging, static data display and modification, sensor calibration, alarm display, alarm acknowledge, current sensor group display, current sensor group plot, previous value plot or display, X-Y display, three mode control, and dead band control.

Special applications software is designed specifically for a unique requirement of a particular test area. These include special control algorithms, controlled automatic shut down procedures, pictorial or schematic displays of test equipment configurations, special analyses, plots, or displays such as vibration signature plots for the turbine test area, or pressure enthalpy diagrams for the heat exchanger test area.

In addition to the special applications software supplied with OTEC-DACS, additional user developed programs will be used particularly in the analysis phase. To facilitate this user activity, the data tapes produced by OTEC-DACS during the posttest phase are in a standard format well suited to FORTRAN program processing.

5.3 FIRMWARE

The control consoles and DACS-terminals contain micro-processors which perform some of the processing required for display and logging in the former case and data acquisition and control in the latter. The programs executed by these devices are stored semi-permanently in programmable read only memory (PROM) and since they are not eraseable under normal conditions as are the computer facility programs, they are called "firmware". However, since they are developed by programmers, they are considered part of the software development effort.

5.4 OPTIONS

Most options relating strictly to software are in the special applications area which cannot be defined at this time. The software development estimates are based on experience with systems performing similar test data and utility system data acquisition and control.

Several specific software options are available in the general utilities area. An equipment operating time analysis could be included which would automatically record the total "on" time of specific equipment. The resulting data could then be used by a maintenance scheduling program run in batch mode on the secondary system or the background of the primary system or on the payroll/inventory system if one is available. Special

utility or security system displays (e.g., a site map showing security alarm annunciators), automatic control algorithms for heating and air conditioning, and electric power monitoring and load control should be considered after the test facility is better defined. If the security system is relatively simple and there is a low heating and cooling load and a relatively small controllable electrical load, these options would not be cost effective. Since this seems to be the most likely case, these items are considered as options not included in the baseline system. It should be noted that the option for an additional ocean based cycle plant system includes additional software development even though it could be implemented using the software already in operation at the land based facility. However, since a year's experience will have been gained with the land based facility, it is probable that some system enhancements will be desirable at this time to be included in both the land and ocean based facilities.

6. PERSONNEL COMMUNICATIONS

Personnel communications are required between each control room and its associated test area not only during checkout and calibration prior to a test but also if problems arise during a test requiring coordination of activities of personnel in these areas. For example, a technician in the test area may read a direct pressure gauge to verify the calibration of the OTEC-DACS display value or he may open a valve manually according to the test director's verbal instructions as the director observes responses at the CRT. This communication may be of long duration and may be of an urgent nature. Some of the test areas may be considered hazardous locations. For these reasons, commercial telephone receivers are not suitable.

The large area and potentially noisy environment of the test areas can best be served by personal two-way FM portable radios carried by personnel in the test areas, and base stations at each control console. The portable radios should be acceptable for use in class I, division 1, group 0 hazardous locations (National Electrical Code). In the ocean platform case, they must be rated suitable for a salt atmosphere. Batteries should provide full power for 8-hours without recharging. High noise headsets should be available for use with the portable radios. Belt loop carrying cases should also be available. The system should include 18 one watt portable units, 9 desk top base

stations and control units, 6 high noise headsets, 18 spare batteries, and a charger to simultaneously recharge 18 batteries within 8 hours. Each unit should have a unique frequency. Each base station receiver should be equipped to communicate on either or both of two channels. This system should cost approximately \$30,000 and consist of standard equipment deliverable within 30 days of order.

As an option, if it is considered important to audibly monitor the operation of equipment, additional two-way stations may be acquired for installation at the locations to be monitored. The additional cost is about \$1,000 per test area.

Finally, a closed circuit television monitoring system is an option which should be installed in any locations subject to possible hazardous ammonia leak. Such a system should cost \$3,800 for each monitor and camera including a special hazardous location housing and cable and conduit installation.

7. IMPLEMENTATION

This section describes the recommended management activities required to implement OTEC-DACS most effectively and efficiently. A schedule of the proposed activities as well as cost estimates for the baseline system and options follows this. Finally, the required staffing and other ancillary requirements for the OTEC-DACS are discussed.

7.1 MANAGEMENT

The most critical stage in the development of OTEC-DACS is the requirements and functional design period. The best available hardware and software systems analysts must work closely with the best available user personnel to define precisely the specific needs and operational requirements for each test area. A thorough review of the resulting document by the user to assure that the requirements are correct and unambiguously specified will prevent later disappointment.

A thorough internal review of the design by the contractor should be followed by a careful operational review by the user. Any discrepancies or requirements changes should be resolved as quickly as possible before hardware fabrication and software coding begins.

Each hardware and software module should be unit tested. A detailed test plan should be formulated and reviewed to

assure system compliance with the requirements. Acceptance testing should be performed in the contractor's plant as well as at the final test facility location.

The site preparation and installation plan requires careful coordination between contractor and user to avoid a costly delay at installation time.

The contractor training program must be complete and effective and should be timed to allow the user to begin operating the system immediately upon installation.

The final system documentation should be carefully reviewed to assure that it is complete and accurate. This documentation must include an operator's manual, a system manual, and software and hardware manuals. The last two are particularly important for future maintenance and system expansion.

7.2 SCHEDULES

The schedules for phase "A" and phase "B" implementation are shown in figures 7-1 and 7-2. The dates are all relative to the dates of first test facility testing and start of cycle plant testing. If these dates change, the OTEC-DACS schedules shift accordingly. The ocean based cycle plant option schedule would be identical to the phase "B" schedule moved forward to coincide with the date of first ocean based cycle plant testing.

Figure 7-1. - Phase A schedule.

Figure 7-2. - Phase B schedule.

7.3 COSTS

Table 7-1 shows an estimated cost breakdown for the baseline OTEC-DACS. Table 7-2 shows estimated cost breakdowns for the options discussed in previous sections.

7.4 STAFFING AND ANCILLARY REQUIREMENTS

The minimum staff required to operate OTEC-DACS on a 24-hour basis would consist of a manager, an assistant, and 7 computer operators (3 for the day shift and 2 for evening and morning shifts. An additional programming and operation support staff of 2 to 6 programmers would be beneficial to aid the various test area users in developing analysis programs. The actual test console operators are trained members of the test teams and do not require any computer operating or programming experience.

The computer facility should contain approximately 900 square feet of raised computer floor. In addition to the equipment discussed in preceding sections, the facility should contain 2 keypunch machines, 6 standard computer card files each containing 22 tray each holding 24 inches of computer cards, and 6-2' x 3' x 6' for storing discs; magnetic tapes; line printer, teletype, and plotter paper; paper tape diagnostic programs, printer ribbons, plotter fluid, blank cards, lubricants, tools, and system reference manuals.

TABLE 7-1.— ESTIMATED OTEC-DACS COSTS (\$ Thousand)

Item (System Costs)	Subtotals	Item Costs
Requirements Specification	59	59
Computer System (\$1,105)		
Hardware	832	832
Software	273	
System		8
General Applications		143
Special Applications		122
Consoles (\$200)		
Hardware	159	
Material		75
Development		84
Firmware	41	41
Terminals (\$442)		
Hardware	391	
Material		241
Development		150
Firmware	51	51
Install, Test, Train, Document	260	
Hardware		67
Software		193
Phase A Total		2,066

TABLE 7-1.— Continued

Item (System Costs	Subtotals	Item Costs
Requirements Specification	27	
Computer System (\$274)		
Hardware	163	163
Software	111	
General Applications		35
Special Applications		76
Consoles (\$85)		
Hardware	64	
Material		23
Development		41
Firmware	21	21
Terminals		
Hardware	132	
Material		76
Development		56
Install, Test, Train, Document	73	
Hardware		20
Software		53
Phase B Total		591
Grand Total (A and B)		2,657

TABLE 7-2. - ESTIMATED OPTIONS COSTS (\$ Thousand)

Item (Systems Cost)	Subtotals	Item Costs
1. Data Link	12	
Hardware		2
Software		10
2. Plotting Capability (per console)	13	13
3. Cycle Plant Demonstration Console	80	
Hardware		20
Software		60
4. Meter, Potentiometer, Light, Switch (16 of each per console)	26	
Hardware		
Materials		10
Development		16
5. Redundant Console Components:	19	
CRT, keyboard, Microprocessor		4
Printer		2
Plotter		13
6. Redundant Terminals (44 channels) (per test area)		
Hardware	27	
Materials		11
Development		16
7. Wide Range Analog Input System (per test area 384 channels)	9	9

TABLE 7-2. — Continued

Item (Systems Cost)	Subtotals	Item Costs
8. Additional Data Storage (per 25 million words)	23	23
9. External Core Memory (1 million words)	86	86
10. Additional Test Areas (Average) (\$133)		
Computer System (\$48)		
Hardware	33	33
Software		
Special Applications	15	15
Console		
Hardware	20	
Material		9
Development		11
Terminal		
Hardware	49	
Material		30
Development		19
Install, Train, Test, Document	16	16
11. Ocean Platform Cycle Plant (\$767)		
Requirements Specification	27	27
Computer System (\$471)		
Hardware	360	360

TABLE 7-2. - Concluded

Item (Systems Cost)	Subtotals	Item Costs
Software	111	
General Applications		35
Special Applications		76
Consoles		
Hardware	64	
Material		23
Development		41
Terminals		
Hardware	132	
Material		76
Development		56
Install, Train, Test, Document	73	
Hardware		20
Software		53
12. Equipment Run Time Analysis	20	20
13. Utility Package	60	60

Fifty kW of 120 v, 60 Hz single phase and 20 kW of 208/230 v, 60 Hz three-phase electric power should be available in the computer facility and 1 kW for each console and DACS terminal in the control rooms and test areas. A temperature of 10°C to 40°C (50°F to 104°F) with relative humidity of 10 percent to 90 percent is suitable for most computer equipment. However, magnetic tape systems and moving head disc systems should not be operated above 90°F or below 60°F or below 20 percent relative humidity. A moving head disc should not be operated above 80 percent relative humidity. A card reader should not be operated below 30 percent relative humidity. A 60°F to 90°F, 30 percent RH to 80 percent RH environment should be facility if possible. Otherwise, special precautions should be taken to assure a suitable environment particularly for magnetic tapes, moving head discs, and card readers.

If an ocean platform location is utilized, precautions should be taken to protect computer room equipment from salt. The disc drives should be gimbal mounted to avoid precession due to the angular momentum.

Estimating the cost of the computer communications cables and their required conduits, ducts, or trays and their installation depends on numerous factors which are difficult to define at this time. The distances between the test areas, the control rooms, and the central processing room; the availability of utility tunnels for cable trays; the location of

conduits (buried, slab, hanging, etc.); the presence of unusual working conditions, or hazardous environments (e.g., ammonia) all significantly affect labor and material costs. An estimate of \$14,400 for conduit and \$5,800 for cabling is made assuming straight conduit runs as tabulated in table 7-3 and no unusual conditions. Additional cabling for the remote pumping station terminal could be by overhead line, buried cable, or leased telephone line depending on the location and distance. Assuming that electrical power line poles and right of way are available, the cost of this cable and installation should not exceed \$800 per 1000 feet.

TABLE 7-3. — CONDUIT/CABLE ESTIMATE

FROM	TO	NUMBER*	LENGTH	TOTAL (1000')
T.T.	C.R.	9 + 3	100'	1.2
T.T.	P.R.	9 + 3	500'	6.0
C.R.	P.R.	9 + 2	500'	5.5
F.T.	F.C.	1 + 0	300'	0.3
F.T.	P.R.	1 + 0	300'	0.3
F.C.	P.R.	1 + 0	100'	0.1

TOTAL LENGTH 13.4

(Material + Labor)/1000 FT. (est.):

Conduit: \$304 + \$770 = 1074

Cable: \$320 + \$110 = 430

(Material + Labor) Totals

Conduit: \$14,400

Cable: 5,800

Total: \$20,200

T.T. Test Area Terminal**

C.R. Control Room Console Device***

P.R. Processing Room (Computer Room)

F.T. Facility Terminal (Utility - Security)

F.C. Facility Control Console (Utility - Security)

*Phase A + Phase B

**Two for some areas

***Two cables for consoles with plot capability

Appendix 10

COST DATA

This Appendix presents seven sets of data arranged in separate sections as follows:

- 10.1 Cycle Plant and Component Test Cost Tables**
- 10.2 Land-Based Test Facility Conceptual Estimate and Schedule**
- 10.3 Pilot Generating Plant Conceptual Estimate and Schedule**
- 10.4 Sea-Based Test Facility Conceptual Estimate and Schedule**
- 10.5 Sea-Based Cycle Plant Costs**
- 10.6 T-2 Tanker Test Platform Costs**

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10.1 CYCLE PLANT AND COMPONENT TEST TABLES

This section comprises eight separate charts presenting capital and operating cost data for land, shore, and sea-based Cycle Plants, and for Component Test facilities. These tables are intended to provide direct backup for the cost estimates presented in Section N of the first volume of this report, OTEC Test Facility Cost Estimates. More detailed cost breakdowns than those found in these tables are presented in the next three sections of this Appendix for various Cycle Plant configurations of 3-, 6-, and 9-MW outputs; these data were used in various parametric studies to generate the cost estimates presented here. Finally, all personnel costs shown in this Appendix reflect the personnel complements presented in sections J and L of the main body of this report in connection with discussions of Land- and Sea-Based Test Facilities.

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LAND BASED CYCLE PLANT

SELECTED CONFIGURATION – SITE ADJACENT TO WATER

CAPITAL COST – \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
1	2.2	16.1	4.3	2.7	25.3
3	5.1	21.4	6.1	4.0	36.6
6	9.8	32.1	9.7	6.3	57.9
9	14.4	41.1	12.8	8.3	76.6

YEARLY OPERATING COST – \$M

MW	PERS	OH	G&A	PWR	CONT	TOTAL
1	0.5	0.5	0.2	–	0.2	1.4
3	0.8	0.9	0.3	–	0.3	2.2
6	1.0	1.1	0.3	–	0.4	2.8
9	1.2	1.2	0.9	–	0.4	3.2

LAND BASED CYCLE PLANT

SELECTED CONFIGURATION - SITE DISTANT FROM WATER

CAPITAL COST - \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
1	2.2	18.7	4.8	3.2	28.9
3	5.1	28.6	7.7	5.1	46.5
6	9.8	45.8	12.8	8.3	76.7
9	14.4	58.1	16.7	10.9	100.1

YEARLY OPERATING COST - \$M

MW	PERS	OH	G&A	PWR	CONT	TOTAL
1	0.5	0.5	0.2	0.4	0.2	1.8
3	0.8	0.9	0.3	1.4	0.5	3.8
6	1.0	1.1	0.3	2.7	0.8	6.1
9	1.2	1.2	0.4	4.2	1.1	8.1

SHORE BASED CYCLE PLANT

SELECTED CONFIGURATION – EASY PIPE LAYING SITE

CAPITAL COST – \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
1	2.2	24.6	6.2	4.0	37.0
3	5.1	36.4	9.6	6.2	57.3
6	9.8	53.1	14.5	9.4	86.8
9	14.4	67.2	18.8	12.1	112.5

YEARLY OPERATING COST – \$M

MW	PERS	OH	G&A	PWR	CONT	TOTAL
1	0.5	0.5	0.2	–	0.2	1.4
3	0.8	0.9	0.3	–	0.3	2.2
6	1.0	1.1	0.3	–	0.4	2.8
9	1.2	1.2	0.4	–	0.4	3.2

SHORE BASED CYCLE PLANT

SELECTED CONFIGURATION – DIFFICULT PIPE LAYING SITE

CAPITAL COST – \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
1	2.2	33.3	8.2	5.3	49.0
3	5.1	51.4	13.0	8.5	78.0
6	9.8	74.6	19.4	12.7	116.5
9	14.4	92.6	24.6	16.1	147.7

YEARLY OPERATING COST – \$M

MW	PERS	OH	G&A	PWR	CONT	TOTAL
1	0.5	0.5	0.2	–	0.2	1.4
3	0.8	0.9	0.3	–	0.3	2.2
6	1.0	1.1	0.3	–	0.4	2.8
9	1.2	1.2	0.4	–	0.4	3.2

SEA BASED CYCLE PLANT

BARGE PLATFORM

CAPITAL COST - \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
3	6.3	5.9	2.8	1.8	16.8
6	11.5	8.5	4.6	3.0	27.6
9	16.5	11.0	6.3	4.1	37.8
15	25.2	15.3	9.3	6.1	55.9

YEARLY OPERATING COST - \$M

MW	PERS	OH	G&A	CREW	SUP	CONS	CONT	TOTAL
3	1.1	1.1	0.3	1.9	1.0	0.3	0.9	6.6
6	1.4	1.4	0.4	1.9	1.0	0.4	1.0	7.5
9	1.6	1.6	0.5	1.9	1.0	0.4	1.2	8.2
15	1.8	1.9	0.6	1.9	1.0	0.4	1.3	9.0

SEA BASED CYCLE PLANT

TANKER PLATFORM

CAPITAL COST - \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
3	6.3	10.9	4.0	2.6	23.8
6	11.5	13.2	5.7	3.7	34.1
9	16.5	15.5	7.4	4.8	44.2
15	25.2	19.5	10.3	6.7	61.7

YEARLY OPERATING COST - \$M

MW	PERS	OH	G&A	CREW	SUP	CONS	CONT	TOTAL
3	1.1	1.1	0.3	1.9	1.0	0.3	0.9	6.6
6	1.4	1.4	0.4	1.9	1.0	0.4	1.0	7.5
9	1.6	1.6	0.5	1.9	1.0	0.4	1.2	8.2
15	1.8	1.9	0.6	1.9	1.0	0.4	1.3	9.0

SEA BASED CYCLE PLANT

SEMISUBMERSIBLE PLATFORM

CAPITAL COST - \$M

MW	OTEC COMP	FAC COMP	CONT	ES	TOTAL
3	6.3	38.4	10.3	6.7	61.7
6	11.5	40.5	12.0	7.8	71.8
9	16.5	42.6	13.6	8.9	81.6
15	25.2	46.4	16.5	10.7	98.8

YEARLY OPERATING COST - \$M

MW	PERS	OH	G&A	CREW	SUP	CONS	CONT	TOTAL
3	1.1	1.1	0.3	1.9	1.0	0.3	0.9	6.6
6	1.4	1.4	0.4	1.9	1.0	0.4	1.0	7.5
9	1.6	1.6	0.5	1.9	1.0	0.4	1.2	8.2
15	1.8	1.9	0.6	1.9	1.0	0.4	1.3	9.0

COMPONENT TEST CAPITAL COST DETAIL - \$M

	HX OUTPJT		TURBINE SCALE (PNR)				SN HYD
	0.25 MW	2.5 MW*	1 / 16	1 / 4	1	COMBINED	
MECHANICAL	1.5	4.4	1.5	2.7	5.4	7.3	0.3
ELECTRICAL	0.3	0.7	0.1	0.1	0.3	0.3	0.0
C&S	4.6	8.9	2.2	3.8	5.6	6.4	1.3
PIPING	0.6	3.0	0.2	0.9	2.3	2.5	0.1
FIELD COST	7.0	17.0	4.0	7.5	14.6	16.5	1.7
CONT.	1.6	3.9	0.9	1.7	3.4	3.8	0.4
E&S	1.1	2.6	0.6	1.1	2.2	2.5	0.2
TOTAL	9.7	23.5	5.5	10.3	20.2	22.8	2.3

* DOES NOT INCLUDE \$1M COST OF ADDITIONAL
FACILITY SUPPORT INSTALLATIONS

10.2 LAND-BASED TEST FACILITY CONCEPTUAL ESTIMATE AND SCHEDULE

This section consists of a Bechtel Corporation report presenting capital cost estimates for heat exchanger, turbine, and sea water hydrodynamics Component Test installations, a 3-MW Cycle Plant situated adjacent to water supply sources, and Test Facilities Support installations and equipment (not including the cost of the Data Acquisition and Control System). These data formed the basis from which the estimates presented in the previous section were extrapolated for various alternative Cycle Plant and Component Test configurations.

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LOCKHEED MISSILES AND SPACE COMPANY
OCEAN THERMAL ENERGY CONVERSION (OTEC)
LAND BASED TEST FACILITY

PRESENTATION OF
CONCEPTUAL ESTIMATE & SCHEDULE

August 11, 1976

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OTEC LAND BASED TEST FACILITY

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LOCKHEED: OTEC LAND BASED TEST FACILITY

PROJECT DATA

Client: Lockheed Missiles and Space Company, Inc., Sunnyvale, California, under contract to the U.S. Energy Research and Development Administration

Location: A site has not been selected for the OTEC Land Based Test Facility. The availability of an adequate supply of warm and cold water of the necessary temperatures is a major factor in site selection. Several locations in the Pacific Coast area of the United States are prime possibilities. A West Coast ocean site is assumed for this estimate.

Project Scope: Conceptual design, cost estimate and schedule for the engineering and construction of a Land Based Test Facility for Ocean Thermal Energy Conversion (OTEC). The facility includes an operating OTEC fractional sized plant, three test arrangements for testing of critical components and the support facilities necessary for the facility's operation.

Purpose of Estimate: To identify the cost of a test facility needed for developing OTEC technology as required by the project work statement. The estimates include Task 2, Critical Component Test Arrangements, Task 5, Test Facility Support Requirements, together with the selected 3MW cycle plant based on Task 1.

Project Schedule: A major milestone construction schedule is included for the OTEC Land Based Test Facility.

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SECTION 1

CONCEPTUAL ESTIMATE

CAPITAL COSTS

1.1 GENERAL

The estimate is based on conceptual design and engineering information developed for the OTEC Land Based Test Facility (LBTF). The LBTF includes a 3 MW cycle plant, three critical component test arrangements and the required support facilities.

Conceptual design and engineering information was prepared for the study in the form of engineering drawings, outline specifications, and equipment lists. Estimating methods consistent with the conceptual nature of the design information were employed. These rely on informal vendor contact as well as extrapolation from Bechtel historical information.

The construction cost estimate is composed of field costs, engineering services and allowance for uncertainty. The largest category, field costs, comprises the direct cost of permanent plant equipment and the indirect cost of temporary construction materials, supervision, etc., that are to be distributed across the entire facility. The estimate anticipates an engineer-constructor direct-hire operation employing field construction labor forces.

The cost estimate presented for the LBTF is divided into the following major components.

1.1.1 Cycle Plant

The OTEC cycle plant is a land-based test plant incorporating all the major facilities of the OTEC power plant. It is scaled to a size which will allow an economical but valid simulation of the critical components and systems. The cycle plant is a 3 MW, "ducted, open water loop configuration" selected from earlier parametric studies. The estimate is based on the Selected Cycle Plant Description, dated July 2, 1976

1.1.2 Critical Component Test Arrangements

Three critical component test arrangements are included in the OTEC-LBTF as follows:

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- Heat Exchanger Critical Component Test Bed
- Turbine Critical Component Test Bed
- Hydraulic Circuitry Test Bed

The cost estimates are based on the engineering descriptions entitled as above and dated June 23, 1976, June 23, 1976, and August 10, 1976, respectively.

1.1.3 Test Facilities Support

The test facilities support required for the OTEC-LBTF includes support buildings (office, shops, warehouses, etc.) site utility distribution systems and site development. The cost estimate is based on the Test Facilities Support Description, dated June 25, 1976.

1.2 PRICING LEVELS

The estimate is at First Quarter, 1976, price and wage levels. No allowance has been made for future escalation.

1.3 FIELD CONSTRUCTION COSTS

The direct field construction costs of permanent plant equipment, materials, subcontracts and construction labor have been included in the estimate on the basis of the following.

1.3.1 Equipment

Budgetary suppliers' estimates based on conceptual designs and specifications were obtained verbally or in writing for the major equipment items. These include:

Cycle Plant

- Heat exchangers (evaporator and condenser)
- Ammonia turbine-generator
- Circulating water pumps
- Intake structure pumps
- Main equipment crane

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Turbine Critical Component Test Bed

- Compressors
- Compressor drive motor
- Demisters
- Equipment crane

Heat Exchanger Critical Component Test Bed

- Compressors
- Circulating water pump
- Demisters
- Equipment crane

Hydraulic Circuitry Test Bed

- Pumps
- Equipment crane

Other equipment was estimated using Bechtel data derived from recent purchase orders and vendor contacts.

1.3.2 Material

Quantity evaluations were made for those materials identifiable from drawings, including concrete, steel, piping, wire and cable, etc. These quantities were priced using current unit prices from Bechtel sources. Other materials that would be delineated on the final engineering drawings have been evaluated by experience as a percentage of the installed cost of the identified materials.

1.3.3 Subcontracts

Subcontracts for equipment and materials commonly installed by subcontractors were estimated and priced in accordance with Bechtel experience from current sources.

1.3.4 Construction Labor

The direct construction labor costs for the installation of the plant equipment and material were estimated using recent productivity experience and a wage rate based on labor contracts and fringe benefits for Santa Clara County, California. This wage rate of \$17.50 per hour includes an allowance of \$1.25 per hour for travel and subsistence and is based on a craft mix appropriate to the type of construction together with a 5% allowance for casual overtime and 1% for craft furnished supervision. Sufficient manual labor to complete the project within the construction schedule is assumed to be available in the project vicinity, or to be attracted to the area by the travel allowance.

1.3.5 Indirect Field Costs

The indirect field costs are those items of construction cost that cannot be ascribed to direct portions of the facility and thus are accounted separately. They were estimated by modifying the experience on fossil-fired plants, resulting in an assessment of 100% of direct labor costs. Indirect costs have been distributed over the installation of direct equipment and materials as a function of the installation costs.

The items covered by indirect field costs are as follows:

- Temporary Construction Facilities: Temporary buildings, working areas, roads and parking areas, utility system and general purpose scaffolding.
- Miscellaneous Construction Services: General job clean-up, maintenance of construction equipment and tools, material handling and surveying.
- Construction Equipment & Supplies: Construction equipment, small tools, consumable supplies, and purchased utilities.
- Field Office: Field labor of craft supervision, engineering, procurement, scheduling, personnel administration, warehousing, first aid, and the costs of operating the field office.
- Preliminary Check-Out & Acceptance Testing: Testing of materials and equipment to insure that components and systems are operable.
- Project Insurance: Public liability, property damage, and builder's risk insurance.
- Taxes and Permits: State and local taxes and permits.

1.4 ENGINEERING SERVICES

The engineering services include engineering costs, other home office costs and fee. Engineering includes preliminary engineering, optimization studies, specifications, detail engineering, vendor-drawing review, site investigation, and support to vendors. Other home office costs comprise procurement, estimating and scheduling services, quality assurance, construction and acceptance testing, and project management. Fee is included as a function of the total project cost.

The sum of these three categories falls into historically consistent percentages in the range of 10% - 20% depending on the complexity of the project. For this study a figure of 15 percent of field construction costs has been used as typical for a plant that, while new in concept, does not depart radically from basic engineering principles.

1.5 ALLOWANCE FOR UNCERTAINTY

Included in the estimate is a 20 percent allowance for the uncertainty that exists within the conceptual design in quantity, pricing or productivity and that is under the control of the constructor and within the scope of the project as defined. Implicitly the allowance will be expended during the design and construction of the project and it cannot be considered as a source of funds for overruns or additions to the project scope. However, experience shows that it is quite difficult to assess the degree to which future processes are understood in the hardware sense. Thus, if the conceptual arrangement of the plant components contains major uncertainties, or the design duty of plant components proves to be more severe than anticipated, or if additional major subsystems are ultimately found to be necessary, then the scope of the project is deemed to have been inadequately defined and this then would not be covered by the allowance.

1.6 DESIGN ASSUMPTIONS

The following are the major design assumptions in the estimate:

- Construction Site: Favorable site conditions are assumed. No allowance is included for drilling and blasting rock, for unusual dewatering during excavation, or extensive foundation treatment.
- Cycle Plant Heat Exchangers: Both the evaporator and condenser are titanium horizontal tube-and-shell type heat exchangers. The heat exchangers will be shop fabricated and field assembled under subcontract by a heat exchanger manufacturer.

- Circulating Water Piping: The cycle plant includes warm and cold circulating water systems of a nominal 1000 linear feet of pipe each.
- Intake and Discharge Structures: The intake and discharge structures assumed are for a favorable ocean site where quiet water conditions and a steeply-shelving, narrow private beach exists.
- Intake Structure Pumps: These pumps are typical power plant cooling water pumps producing 40 feet of head in the system.

1.7 EXCLUSIONS

The following items are excluded from the project scope and are not therefore included in the estimate.

- Any special construction such as widening and strengthening existing roads.
- Railroads
- Computer facilities
- Test heat exchangers for the heat exchanger critical component test bed
- Test turbines for the turbine critical component test bed
- Special test instrumentation beyond operating instrumentation
- Switchyard and power transmission lines beyond the plant 13.8 KV main bus
- Client engineering, financing and other client costs
- Process royalties and licenses
- Site investigation and land acquisition
- Allowance for funds during construction
- Training of plant operators
- Plant startup and operation

1.8

ESTIMATE TABLES

The above discussion of pricing levels, field construction costs, engineering services, allowance for uncertainty, and exclusions, form the basis of the estimates contained in the following tables:

- Table 1-1 Conceptual Estimate Summary - Land Based Test Facility
- Table 1-2 Conceptual Estimate Detail - Cycle Plant
- Table 1-3 Conceptual Estimate Detail - Heat Exchanger Critical Component Test Bed
- Table 1-4 Conceptual Estimate Detail - Turbine Critical Component Test Bed
- Table 1-5 Conceptual Estimate Detail - Hydraulic Circuitry Test Bed
- Table 1-6 Conceptual Estimate Detail - Test Facilities Support

TABLE 1-1
CONCEPTUAL ESTIMATE SUMMARY
LAND BASED TEST FACILITY

	<u>\$ 1000's</u>
FIELD COST	
CYCLE PLANT	26,500
HEAT EXCHANGER TEST BED	7,000
TURBINE TEST BED	16,500
HYDRAULIC CIRCUITRY TEST BED	1,700
TEST FACILITIES SUPPORT	9,700
TOTAL FIELD COST	<u>61,400</u>
ENGINEERING SERVICES (15%)	9,200
	<u>70,600</u>
ALLOWANCE FOR UNCERTAINTY (20%)	14,400
ESTIMATED TOTAL CONSTRUCTION COST	<u>85,000</u>
<u>First Quarter 1976 Price and Wage levels</u>	

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TABLE 1-2
CONCEPTUAL ESTIMATE DETAIL

CYCLE PLANT

	<u>\$ 1000's</u>
<u>FIELD COSTS</u>	
HEAT EXCHANGERS	4,190
TURBINE GENERATOR	890
MECHANICAL EQUIPMENT	4,680
ELECTRICAL	1,200
CIVIL & STRUCTURAL	7,310
SEAWATER INTAKE & DISCHARGE	5,570
SEAWATER PIPING	2,200
OTHER PIPING AND INSTRUMENTATION	<u>460</u>
<u>TOTAL FIELD COST</u>	<u>26,500</u>

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TABLE 1-3
CONCEPTUAL ESTIMATE DETAIL
HEAT EXCHANGER CRITICAL COMPONENT TEST BED

	<u>\$ 1000's</u>
<u>FIELD COSTS</u>	
MECHANICAL	1,550
ELECTRICAL	250
CIVIL & STRUCTURAL	4,600
PIPING & INSTRUMENTATION	<u>600</u>
<u>TOTAL FIELD COST</u>	<u>7,000</u>

TABLE 1-4
 CONCEPTUAL ESTIMATE DETAIL
 TURBINE CRITICAL COMPONENT TEST BED

	<u>\$ 1000's</u>
<u>FIELD COSTS</u>	
MECHANICAL	7,300
ELECTRICAL	280
CIVIL & STRUCTURAL	6,370
PIPING & INSTRUMENTATION	<u>2,550</u>
<u>TOTAL FIELD COST</u>	<u>16,500</u>

TABLE 1-5
CONCEPTUAL ESTIMATE DETAIL
HYDRAULIC CIRCUITRY TEST BED

	<u>\$ 1000's</u>
<u>FIELD COSTS</u>	
MECHANICAL	270
ELECTRICAL	40
CIVIL & STRUCTURAL	1,340
PIPING & INSTRUMENTATION	<u>50</u>
<u>TOTAL FIELD COST</u>	<u>1,700</u>

TABLE 1-6
CONCEPTUAL ESTIMATE DETAIL

TEST FACILITIES SUPPORT

	<u>\$ 1,000's</u>
<u>FIELD COSTS</u>	
SITE IMPROVEMENT	600
BUILDINGS	4,100
ELECTRICAL	1,000
PIPING	700
SUPPORT EQUIPMENT	<u>3,300</u>
<u>TOTAL FIELD COST</u>	<u>9,700</u>

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SECTION 2

CONCEPTUAL ENGINEERING & CONSTRUCTION SCHEDULE

2.1 GENERAL

The engineering and construction schedule is based on the conceptual design engineering and the conceptual estimate prepared for the OTEC Land Based Test Facility. It reflects Bechtel's experience in the design and construction of power plant's and other similar facilities.

2.2 CONSTRUCTION SEQUENCE

The construction sequence and methods generally follow an approach to the construction of commercial plants which permits procurement and construction to commence before engineering is complete, thus shortening the schedule. The schedule is predicated on the economic use of manpower, as included in the conceptual estimate rather than the earliest possible completion date, although considerable parallel activity is included.

2.3 SCHEDULE

Figure 2-1 shows the engineering and construction schedule for the plant and indicates that the project could be completed within a 40-month period. The governing factor is the ordering, manufacture, delivery and installation of the major mechanical equipment.

The following are the major items included in the schedule and the assumptions that form the bases for the time durations and sequence.

2.3.1 Engineering Services

- **Engineering:** Engineering begins when siting studies are complete and optimization studies leading to design engineering begin. Design starts with the development of sufficient detail to initiate the procurement of the major mechanical equipment. It is approximately 50 to 75% complete when construction begins, and continues for about 6 months thereafter. Engineering support is provided throughout the construction period.
- **Environmental Report:** Report to the appropriate government agency that must approve the project before the notice to proceed with construction is given to the client. It is an underlying assumption of the schedule that the report preparation and approval will not be a critical time constraint.

- Long Delivery Procurement: This item covers the major equipment that has delivery times critical to the schedule. These items comprise the cycle plant heat exchangers, turbine generator and circulating water pumps, which have lead times currently reported by suppliers to be approximately 24 months. It is assumed that the purchase orders for the long lead time equipment can be issued before the final project environmental approval is given.

2.3.2 Field Construction

Field construction includes the routine procurement and installation of those items of equipment and material that do not have long delivery times, as well as the installation of the long delivery time components. It is divided into the major facility components of cycle plant, critical component test beds and test facilities support as follows:

Cycle Plant

- Civil/Structural: The construction of the test basin begins following site preparation work. It is followed by construction of the circulating water system including the intake and discharge structures.
- Mechanical: Installation of mechanical equipment can begin near completion of the civil/structural work. Major equipment will begin to arrive and be installed in the later part of mechanical construction.
- Piping, Valves and Instrumentation: Piping installation will begin with the circulating water lines. The cycle plant piping will be placed as the required civil/structural work is completed.
- Electrical: The placement of the electrical wire and cable will begin with the installation of the buried utility service after site work is completed and continue through the installation of the major mechanical equipment.
- Acceptance Testing: This begins when most of the equipment and bulk materials have been placed and continues until all testing is complete.

Critical Component Test Plant

- Civil/Structural: The critical component test bed buildings will be constructed after site preparation is completed.

- Mechanical: Installation of mechanical equipment can begin as the building construction nears completion. Major equipment will arrive and be installed during the later part of mechanical construction.
- Piping, Valves And. Instrumentation: The piping can be placed during and after the building installation.
- Electrical: The electrical equipment and materials installation will begin during building construction and will be completed after installation of the mechanical equipment.
- Acceptance Testing: Acceptance testing of equipment and systems in the critical component test arrangements begins as the systems are completed. This work is completed prior to facility completion.

Test Facility Support

- Civil/Structural: Construction begins with site preparation after the approval of the environmental report and notice to proceed. Building construction follows immediately with the construction of permanent warehouse and shop buildings which will be used during the construction period. Final yardwork and paving is completed in the last stages of facility construction.
- Piping: Installation of the underground utility piping begins near completion of the site work. This is followed by interior piping as the support buildings are completed.
- Electrical: Temporary power is installed as construction is initiated. The facility underground electrical distribution system is placed after site preparation is complete. The building electrical is installed as the buildings are completed. The switchyard equipment is placed in the later stages of the electrical work.

2.3.3 Ready for Plant Startup

The plant is ready for startup when all functional testing has been completed by the constructor and the plant is accepted by the owner for his own operator startup.

2.4 QUALIFICATIONS

The following qualifications to the schedule apply:

- No overtime is considered beyond the usual 5% necessary for casual overtime.
- Equipment deliveries remain as currently established.
- No allowance for time uncertainty has been included in the schedule.
- No plant startup and operation have been included.

Addendum I

1/25 SCALE HEAT EXCHANGER TEST BED

The OTEC Land Based Test Facility as estimated in the main body of this report included a Heat Exchanger Test Bed sized to test 1/256 scale OTEC Heat Exchangers. This addendum presents costs for a larger 1/25 scale Heat Exchanger Test Bed, which might alternately be included in the Land Based Test Facility (LBTF). This larger test bed is defined in the OTEC Heat Exchanger Test Bed specifications dated July 30, 1976.

The construction cost estimate for the 1/25 scale unit is summarized in Table A-1. If the LBTF were to include the 1/25 scale (2.5 MW) Heat Exchanger Test Bed rather than the 1/256 scale (0.25 MW), then this cost estimate would replace that presently included for the 1/256 scale unit in the cost estimate. A construction cost increment for adding to the present Test Facilities Support cost estimate is included to account for the increased utility requirement of the large Heat Exchanger Test Bed. The basis of the estimate is as defined in the body of this report for the smaller test bed.

The construction schedule for the LBTF as presented in Section 2 of the report will not be affected by increasing the Heat Exchanger Test Bed size as the construction can be accomplished by increased parallel activity within the same time period.

Table A-1

CONCEPTUAL ESTIMATE SUMMARY

1/25 SCALE HEAT EXCHANGER TEST FACILITY

	<u>\$1000's</u>
<u>FIELD COST</u>	
MECHANICAL	4,450
ELECTRICAL	700
CIVIL AND STRUCTURAL	8,900
PIPING AND INSTRUMENTATION	2,950
TOTAL FIELD COST	<u>17,000</u>
ENGINEERING SERVICES (15%)	2,500
	<u>19,500</u>
ALLOWANCE FOR UNCERTAINTY (20%)	<u>4,000</u>
<u>ESTIMATED HEAT EXCHANGER TEST BED</u>	23,500
<u>TOTAL CONSTRUCTION COST</u>	
First Quarter, 1976 Price and Wage Levels	
INCREMENTAL TEST FACILITIES SUPPORT	1,000
CONSTRUCTION COST	<u>1,000</u>
<u>TOTAL INCREMENTAL LBTF CONSTRUCTION COST</u>	<u>24,500</u>

Figure 2-1
OTEC LANDBASED TEST FACILITY
ENGINEERING AND CONSTRUCTION SCHEDULE

———— Critical Path

ENGINEERING SERVICES

ENGINEERING

ENVIRONMENTAL REPORT

LONG DELIVERY PROCUREMENT

FIELD CONSTRUCTION

CYCLE PLANT

Civil/Structural
 Mechanical
 Piping
 Electrical
 Acceptance Testing

CRITICAL COMPONENT TEST BEDS

Civil/Structural
 Mechanical
 Piping
 Electrical
 Acceptance Testing

TEST FACILITIES SUPPORT

Civil/Structural
 Piping
 Electrical
 Shop and Office Equipment

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10.3 PILOT GENERATING PLANT CONCEPTUAL COST AND SCHEDULE

The Bechtel Corporation report reprinted in this section presents detailed cost estimates for 3-, 6-, and 9-MW output Cycle Plants of Grade and Bathtub configurations. Although both configurations were eventually abandoned in favor of an intermediate design, the parametric information included in this report was used to generate some of the Cycle Plant cost estimates presented in the first section of this Appendix. Two aspects of the data presented here bear commenting upon: First, the cost estimates for both configurations were based on gravity dam construction (see Addendum); second, OTEC equipment costs are higher in this report than in that presented in the previous section, as the latter is based on an improved heat exchanger design.

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LOCKHEED MISSILES AND SPACE COMPANY

OCEAN THERMAL ENERGY CONVERSION (OTEC)

PILOT PLANT & TEST FACILITY

TASK 1 : PILOT GENERATING PLANT

CLIENT

PRESENTATION OF

CONCEPTUAL ESTIMATE & SCHEDULE

S.D. Cost Engineering
April 23, 1976

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LOCKHEED : OTEC PILOT GENERATING PLANT

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SECTION 2 : CONCEPTUAL ENGINEERING & CONSTRUCTION
SCHEDULE

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LOCKHEED : OTEC PILOT GENERATING PLANT

PROJECT DATA

Client: Lockheed Missiles And Space Company, Inc., Sunnyvale, California, under contract to the U.S. Energy Research And Development Administration.

Location: A site has not been selected for the land-based OTEC Pilot Plant. The availability of an adequate supply of warm and cold water of the necessary temperatures is a major factor in site selection. Several locations in the Pacific Coast area of the United States are prime possibilities. A West Coast ocean site is assumed for this estimate.

Project Scope: Conceptual design, estimate and schedule for the engineering and construction of an operating OTEC fractional-sized test plant together with a test facility. The project includes the following tasks:

Task 1: Conceptual designs, estimates and construction schedules for two configurations in each of three capacities (3, 6, and 9MWe net output) of the pilot generating plant.

Task 2: Critical components test arrangements.

Task 3: Deleted.

Task 4: Conceptual designs, estimates and construction schedules of two candidate energy utilization processes.

Task 5: Conceptual design and estimate of the facilities required to support the on-going test facility.

Task 6: Conceptual design, estimate and construction schedule of an integrated land-based test facility.

Task 7: Site selection.

Only Task 1 estimates and schedules are presented in this document.

Purpose of Estimate: To present a range of alternative OTEC Pilot Plants costs for the client to evaluate design tradeoffs in selection of a final configuration.

Project Schedule: A major milestone construction schedule is included for the 6 Mw closed loop Pilot Generating Plant. This will be integrated into the construction schedule for the total OTEC test facility in a later phase of the project.

SECTION 1

CONCEPTUAL ESTIMATE

1.1 GENERAL

The estimates are based on conceptual design and engineering information for the alternative OTEC Pilot Generating Plants. The facility is a land-based test plant incorporating all the major systems of the baseline OTEC facility. It is scaled down to a size which will allow an economical but valid simulation of the critical components and systems. The Pilot Plant will be only a part of the total OTEC land-based test facility, thus the costs presented at this stage are only partial costs.

The engineering drawings, outline specifications, and equipment lists for the cost estimate were provided as the basis. Estimating methods consistent with the conceptual nature of the design information were employed. These techniques, which rely on informal vendor quotes and extrapolation from Bechtel historical information, are outlined in detail below.

The estimate anticipates an engineer-constructor direct-hire operation employing field construction, union labor forces. The construction cost estimate is composed of field costs, engineering and home office costs and a contingency allowance. The largest category, field costs, comprises the direct cost of permanent field equipment and the indirect cost of temporary construction materials, supervision, etc. that are to be distributed across the entire facility.

1.2 PRICING LEVELS

The estimate is in first quarter, 1976, dollars. No allowance has been made for future escalation.

1.3 FIELD CONSTRUCTION COSTS

The direct field construction costs of permanent plant equipment, materials and subcontracts have been included in the estimate on the basis of the following discussion:

1.3.1 Equipment

Budgetary suppliers' estimates based on conceptual designs and specifications were obtained verbally or in writing for the major equipment items. These include:

- Heat exchangers (evaporator and condenser)
- Ammonia turbine-generator

- Circulating water pumps
- Intake structure pumps
- Main equipment crane

Other equipment was estimated using Bechtel data derived from recent purchase orders and vendor contacts and from data developed during the preceding OTEC baseline project.

1.3.2 Bulk Material

Quantity evaluations were made for the identifiable bulk materials of concrete, steel piping, wire and cable, etc., from the drawing and these quantities were priced using current unit prices from Bechtel sources. Other materials that would be delineated on the final engineering drawings have been evaluated by experience as a percentage of the identifiable bulk materials cost and installation.

The general level of pricing includes the following:

Civil and Structural

● Structural Steel:	\$800 per ton
● Concrete Delivered:	\$33 per cubic yard
● Reinforcing Steel:	\$450 per ton
● Fabricated Embedded Metal:	\$2 per pound

1.3.3 Subcontracts

Subcontracts were estimated for equipment and materials commonly installed by subcontractors and priced in accordance with Bechtel experience from current sources.

1.3.4 Construction Labor

The direct construction labor costs for the installation of the plant equipment and material were estimated using recent productivity experience and a wage rate based on labor contracts and fringe benefits for Santa Clara County. The wage rate is \$17.50 per hour, which includes an allowance of \$1.25 per hour for travel and subsistence, and it is based on a craft mix appropriate to the type of construction together with a 5% allowance for casual overtime and 1% for craft furnished supervision. Sufficient manual labor is assumed to be available in the project vicinity, or to be attracted to the area by the travel allowance, to complete the project within the construction schedule.

1.3.5 Indirect Field Costs

The indirect field costs are those items of construction cost that cannot be ascribed to direct portions of the facility and thus are held separately. They were estimated by modifying the experience on fossil-fired plants to the Pilot Generating Plant, resulting in an assessment of 100% of direct labor costs which has been distributed over the installation of direct equipment and materials as a function of the installation costs.

The items contained in distributables are as follows:

- Temporary Construction Facilities: Temporary buildings, working areas, roads and parking areas, utility system and general purpose scaffolding.
- Miscellaneous Construction Services: General job clean-up, maintenance of construction equipment and tools, material handling and surveying.
- Construction Equipment & Supplies: Construction equipment, small tools, consumable supplies, and purchased utilities.
- Field Office: Labor of craft supervision, field engineering, procurement, scheduling, personnel administration, warehousing, first aid, and the costs of operating the field office.
- Preliminary Check-Out & Acceptance Testing: Testing of materials, and equipment to insure that components and systems are operable.
- Project Insurance: Public liability, property damage, and builder's risk insurances.
- Taxes and Permits: State and local taxes and building permits.

1.4 ENGINEERING SERVICES

The engineering services include engineering costs, other home office costs and fee. Engineering includes preliminary engineering, optimization studies, specifications, detail engineering, vendor-drawing review, site investigation, safety analysis report and support to vendors. Other home office costs comprise procurement, estimating and scheduling services, quality assurance, checkout and acceptance testing, and project management. Fee is included as a function of the total project cost.

The sum of these three categories falls into historically consistent percentages in the range of 10%-20%, depending on the complexity of the project. For this study a figure of 15 percent of field construction costs has been used as typical for a plant that, while new in concept, does not depart radically from basic engineering principles.

1.5 ALLOWANCE FOR UNCERTAINTY

Included in the estimate is an allowance for the uncertainty that exists within the conceptual design in quantity, pricing or productivity and that is under the control of the constructor and within the scope of the project as defined. Experience shows that it is quite difficult to assess the degree to which future processes are understood in the hardware sense. Thus, if the conceptual arrangement of the plant components contains major uncertainties, or the design duty proves to be more severe than anticipated, or if additional major subsystems are ultimately found to be necessary, then the scope of the project is deemed to have been inadequately defined and this then would not be covered by the allowance. Implicitly the allowance will be expended during the design and construction of the project and it cannot be considered as a source of funds for overruns or additions to the project scope.

1.6 DESIGN ASSUMPTIONS

Two plant configurations, defined as the open water loop or "bathtub" configuration, and the closed water loop or "grade" configuration, were assessed. Each was considered for sizes of 3, 6 and 9 MWe. The estimates are predicated on a number of design assumptions that were necessary where specific data were not available. The effect on the estimate of alternate assumptions is discussed later in the text.

- Construction Site: Favorable site conditions are assumed. No allowance is included for drilling and blasting rock, for unusual dewatering during excavation, or extensive foundation treatment.
- Heat Exchangers: Both the evaporator and condenser are titanium tube-and-shell type heat exchangers. Both configurations assume the use of the horizontal tube arrangement. The heat exchangers will be shop fabricated and field assembled under subcontract by a heat exchanger manufacturer.
- Circulating Water Piping: Both plants include warm and cold water ducting systems using a nominal 1000 linear feet of pipe. Multiple steel pipes are used to keep individual pipe diameters to a maximum of 12 feet, thus eliminating field fabrication of the tube.
- Circulating Water Pumps: The two large axial flow pumps are fabricated of carbon steel with neoprene coating of the exposed surfaces to prevent corrosion.
- Intake Service Pumps: These pumps are typical power plant cooling water pumps producing 40 feet of head in the system.
- Intake and Discharge Structures: The intake and discharge structures assumed are for a favorable ocean site where quiet water conditions and a steeply-shelving narrow private beach exists.

1.7 QUALIFICATIONS

The following are the major qualifications in the estimates:

1.7.1 Civil Costs

A major portion of the construction costs of the Pilot Generating Plant is for earthwork and concrete. This is particularly true for the open water loop configuration. These civil costs can vary considerably due to site conditions. Civil costs are increased by the presence of sediment, sandy soil, clay or by a high water table. Alternately, dry sandstone or similar favorable conditions reduce the civil costs.

The costs presented are for a conservative, gravity dam type construction. Favorable site conditions not requiring extensive foundation work or dewatering are assumed.

1.7.2 Circulating Water Pumps

The pumps are of steel construction with a neoprene coating to prevent corrosion. The pump manufacturers have some reservations concerning the use of neoprene in this application and recommend more conventional bronze, aluminum or stainless steel. Use of these materials would increase the pump costs by 50-75%.

1.8 EXCLUSIONS

The following items are excluded from the project scope of Task 1 and are not therefore included in the estimate:

- General site improvements
- Any special construction such as widening and strengthening existing roads
- Buildings and support facilities
- Special test instrumentation beyond operating instrumentation
- Switchyard and power transmission lines, beyond the plant 13.8 Kv. main bus
- Client engineering, financing and other client costs
- Site investigation and land acquisition
- Allowance for funds during construction
- Training of plant operators
- Plant start-up costs

1.9 ESTIMATE SUMMARY

The estimated construction costs for the six pilot plants are summarized in Table 1.1

TABLE 1-1

PILOT GENERATING PLANT CONSTRUCTION CCSTS

<u>FIELD CONSTRUCTION</u>	ALL COSTS IN THOUSANDS OF DOLLARS					
	<u>OPEN WATER LOOP</u>			<u>CLOSED WATER LOOP</u>		
	<u>3MWe</u>	<u>6MWe</u>	<u>9MWe</u>	<u>3MWe</u>	<u>6MWe</u>	<u>9MWe</u>
Heat Exchangers	4,350	10,100	15,250	4,850	10,100	15,250
Turbine Generator	930	1,210	1,490	930	1,210	1,490
Circulating Water Pumps	1,720	2,820	4,300	1,720	2,820	4,300
Intake Structure Pumps	1,490	2,740	3,730	1,490	2,740	3,730
Equipment Handling Crane	1,530	2,200	3,480	1,530	2,200	3,480
Other Mechanical	420	650	840	420	650	840
Electrical	1200	1,720	2,260	1,200	1,720	2,260
Earthwork	1,430	2,000	2,520	760	1,000	1,330
Concrete Structures	38,800	49,000	57,130	16,770	18,600	23,420
Structural Steel	100	220	330	100	220	330
Seawater Intake & Discharge	5,570	8,730	12,260	5,570	8,730	12,260
Seawater Piping	2,200	4,640	7,020	2,200	4,640	7,020
Other Piping	460	570	690	460	570	690
TOTAL FIELD COST	60,700	86,600	111,300	33,000	55,200	76,400
ENGINEERING SERVICES	9,100	13,000	17,000	5,700	8,300	11,500
ALLOWANCE FOR UNCERTAINTY	14,200	20,400	25,700	8,300	12,500	17,100
TOTAL ESTIMATED CONSTRUCTION COSTS	84,000	120,000	154,000	52,000	76,000	105,000
First Quarter 1976 Dollars						

SECTION 2

CONCEPTUAL ENGINEERING & CONSTRUCTION SCHEDULE

2.1 GENERAL

The scope of the engineering and construction schedule is based on the conceptual design engineering and estimate for the 6 Mw closed water loop Pilot Generating Plant. The schedule is based on experience gained in design and construction of fossil-fired plants, adjusting for facility differences.

2.2 CONSTRUCTION SEQUENCE

The construction sequence and methods generally follow the Bechtel approach to the construction of commercial power plants, which permits procurement and construction to commence before engineering is complete, thus shortening the schedule. The schedule is predicated on an approach which emphasizes the most economic use of manpower rather than the earliest possible completion date.

2.3 SCHEDULE

Figure 2-1 shows the engineering and construction schedule for the 6 MWe closed water loop configuration and indicates that the project can be completed within a forty-eight-month period. The governing factor is the ordering, manufacture, delivery and installation of the major mechanical equipment.

2.3.1 Engineering Services

- Engineering: Contract Award is the point at which all optimization studies leading to design engineering begin. Design starts with the development of sufficient detail to initiate the procurement of the major mechanical equipment. It is about 60% complete when construction begins, and continues for about 6 months thereafter. Engineering support is provided throughout the construction period.
- Environmental Report: Report to the appropriate Government agency which must approve the project before the notice to proceed with construction is given. It is an underlying assumption that the report preparation and approval will not pose major problems and will not be a critical time constraint.
- Long Delivery Procurement: This item covers the major equipment that has delivery times critical to the schedule. These items currently

include the heat exchangers, turbine-generator and circulating water pump units. They have lead times currently reported by suppliers to be about 24 to 30 months. It is assumed that the heat exchanger purchase orders can be issued before the final project approval is given by the Government agency.

2.3.2 Field Construction

Field construction includes the routine procurement of those items that are not critical to the schedule as well as the installation of the long delivery time components.

- Civil/Structural: The site work can begin as soon as the notice to proceed is given. The excavation and concrete will not be the governing factor in scheduling.
- Mechanical: Installation of mechanical equipment can begin near completion of the civil/structural work. Major equipment will begin to arrive and be installed in the later part of mechanical construction.
- Piping and Instrumentation: Piping can begin near completion of the civil/structural work.
- Electrical: The electrical equipment placement can begin near completion of the civil/structural work.
- Acceptance Testing: This occurs at a time when most of the equipment and bulk materials have been placed and continues until all testing is complete at turbine roll.

2.3.3 Ready for Plant Start-up:

This occurs when all functional testing has been completed by the constructor and the plant is accepted by the owner for his own operation start-up.

2.4 QUALIFICATIONS

The following qualifications to the schedule as presented apply:

- No overtime is considered beyond the usual 5% necessary for casual overtime.
- Equipment deliveries remain as currently established.
- No allowance for time uncertainty has been included in the schedule.

FIGURE 2-1

PILOT GENERATING PLANT
ENGINEERING & CONSTRUCTION SCHEDULE
FOR THE 6MW_e CLOSED WATER LOOP CONFIGURATION

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APPENDIX A

SUPPLEMENTAL COST DATA

The following supplemental cost information is included to allow more flexibility in trade-off studies:

CIRCULATING WATER PIPING

All estimates include warm and cold seawater piping systems of 1000 linear feet each. Requirements for additional seawater piping will result in the following incremental field construction costs:

<u>Plant Size (MWe)</u>	<u>Piping Cost (\$/Linear foot)</u>
3	650
6	1250
9	1500

INTAKE STRUCTURE PUMPS

All estimates include pumps in the intake structures which have 40 feet of pumping head and the costs of the pumps on this basis are shown in the Estimate Summary. Variation of field construction cost (labor and material) due to different head requirements is as indicated:

SUPPLEMENTAL COST BREAKDOWN (Cont'd)

OPEN WATER LOOP CONFIGURATION DOWNSTREAM RESERVOIR

The total field construction costs of the downstream reservoirs included in the open water loop configuration estimates are as follows:

<u>Plant Size (MWe)</u>	<u>Reservoir Cost \$ Thousands</u>
3	5,900
6	6,500
9	8,500

HEAT EXCHANGER SUPPORT STRUCTURE

The estimates assume horizontally mounted heat exchanger configurations. Incremental field construction cost of structure required for vertical heat exchangers is as follows for the 6MWe plants:

Open water loop configuration	\$430,000
Closed water loop configuration	\$325,000

ALUMINUM HEAT EXCHANGERS

No costs are included for aluminum heat exchangers. Vendors contacted indicated that a simple ratioing by the material costs would not be appropriate. The alternative would therefore require additional study beyond the scope of this task.

APPENDIX B

VENDOR BUDGETARY ESTIMATES

The number of vendor budgetary estimates for major equipment and the variation in those estimates is as follows:

<u>Item</u>	<u>Number of Estimates</u>	<u>Cost Variation</u>
Heat Exchangers	3	- 10% + 15%
Circulating Water Pumps	2	- 15% + 15%
Turbine-Generator	3	- 30% + 30%
Equipment Crane	3	- 25% + 30%

Bechtel Corporation

Interoffice Memorandum

To	G. L. Smith	Date	April 23, 1976
Subject	Job No. 11726: OTEC Conceptual Estimate	From	M. R. Smith
		Of	S. D. Cost Engineering
Copies to	T. R. Fick B. J. Hunt	At	301/3

The field construction costs for earthwork and concrete structures for the alternative civil, structural designs utilizing a concrete cantilevered wall concept are given below for the 6MWe open water loop and closed water loop configurations. The estimate basis is as described in the previously submitted Pilot Generating Plant Conceptual Cost Estimate, Client Presentation, dated April 23, 1976.

All other field construction costs for the pilot generating plants will remain unchanged.

The revised earthwork and concrete structure costs are as follows:

	WATER LOOP CONFIGURATION	
	OPEN 6 MWe	CLOSED 6 MWe
Earthwork	\$ 1,000,000	\$ 700,000
Concrete Structure	15,600,000	10,200,000

This results in an estimate
at the total construction cost
level of

	\$72,000,000	\$64,000,000
--	--------------	--------------

This represents a substantial
saving in cost over the base design
of

	\$48,000,000	\$12,000,000
--	--------------	--------------

The costs for the 3 MW and 9 MW capacities have not been estimated, but it would appear that they would be in similar proportion to the 6MW plant.

Please call me if you require any further information on this revision.

M. R. Smith

MRS/hby

10-60

OTEC PILOT PLANT 6MWe

ANALYSIS OF ALTERNATE CIVIL/STRUCTURAL APPROACHES

The original OTEC pilot plant designs were based on gravity dam concrete construction for the framework. The costs of that approach appearing out of line with regard to the overall plant estimate, the civil-structural design was subjected to re-analysis and an alternate design approach. This discussion outlines the alternate approach methods used and presents the results of the re-analysis efforts.

It should be emphasized that civil costs for any project are extremely site-dependent, and costs can vary by a factor of 1 to 5 depending on conditions of the soil, water table, and other elements affecting civil design. For the re-analysis the soil was assumed to have the following parameters:

Allowable bearing stress, $Q_a = 4 \text{ ksf}$
Density, $\gamma = 95 \text{ pcf}$
Poisson's ratio, $u = .45$

Equivalent fluid pressure = 35 pcf

The concrete was assumed to have the following design conditions:

Allowable compressive stress $f' = 5000 \text{ psi}$
Density, $\gamma^c = 150 \text{ psf}$
Reinforcing steel allowable stress, $f_s = 24,000 \text{ psi}$

By shifting from gravity dam analysis to concrete cantilever wall analysis, including full hydrostatic pressure in addition to the equivalent fluid pressure of the soil, significant amounts of concrete were saved, although reinforcing would increase within the concrete. The rough analysis of forces and movements resulted in normal factors of safety in construction of this type being maintained.

Uplift forces on the base were assumed at one-half of absolute hydrostatic uplift with a water table at grade. The analysis resulted in a reasonable thickness of concrete, although a cost trade-off remains to be made based on raising the plant base to grade level, or some intermediate level, thus eliminating most of the structural concrete except for normal foundation design, and replacing the inlet and discharge basins with surface mounted tanks. Such an analysis is beyond the scope of this re-analytical effort.

In addition to reducing the concrete requirements, the re-design also shortens some piping lengths, resulting in further cost reduction.

Replacing the withdrawal pipes with gravity flow in open channels further reduces concrete and piping requirements.

The above comments apply to the "bathtub" 6MWe configuration. For the "grade" configuration, the use of cantilever retaining walls and channel withdrawal will result in reduced concrete costs also. Additionally, design may be arranged to mount the circulating water pump system and heat exchanger assembly on surface supported cradle assemblies, eliminating the need for the reinforced concrete shell altogether. A cradle supported arrangement could be designed for flexibility in the cradle system, enabling interchange of components, but replacing the costly concrete work with less expensive earthwork and fill operations. A study of this re-design arrangement is beyond the scope of this study also.

Attached drawings 11726-SK-P-004 and -005 illustrate the potential reductions in concrete using the revised cantilever wall analysis.

Other approaches that may be used, depending upon the specific site, could involve the use of soldier piles and/or sheet piles with tie-backs. Dewatering civil works and mechanical equipment may also be employed to reduce groundwater pressure. However, the addition cost must be justified by substantial savings in concrete. All these approaches cannot be meaningfully investigated until a specific site is selected. Obviously, in view of the considerable civil costs as a percentage of the total pilot plant cost, site selection should consider soil and groundwater conditions.

10.4 SEA-BASED TEST FACILITY CONCEPTUAL ESTIMATE AND SCHEDULE

The fourth, fifth, and sixth sections of this Appendix present backup cost data for sea-based Cycle Plant and Component Test activities. This section comprises related cost estimates prepared by Bechtel Corporation. Parts of these estimates were incorporated into the final cost estimates included in the main body of this report, which are presented in detail in Section 10.5 (Sea-Based Cycle Plant) and Section 10.6 (T-2 Tanker Test Platform).

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JOB 11726

LOCKHEED MISSILES AND SPACE COMPANY

OCEAN THERMAL ENERGY CONVERSION (OTEC)

SEA BASED TEST FACILITIES

PRESENTATION OF

CONCEPTUAL ESTIMATE & SCHEDULE

August 25, 1976

10-65

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LOCKHEED : OTEC SEA BASED TEST FACILITIES

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August 25, 1976

i

PROJECT DATA

Client: Lockheed Missiles and Space Company, Inc. Sunnyvale, California, under contract to the U.S. Energy Research and Development Administration.

Location: It is assumed that the Sea Based Cycle Plant and the Seawater Pump Test Bed will be constructed at a Seattle, Washington, dock facility.

Project Scope: Conceptual design, estimate and schedule for the engineering and construction of a sea based Test Facility for Ocean Thermal Energy Conversion (OTEC). The components include a sea based cycle plant in three candidate sizes (3, 6, and 9MWe), and a seawater pump test bed.

Purpose of Estimate: To identify the cost of sea based test facilities needed for developing OTEC technology as required by the extended scope of Task 1 Trade off Studies, and Task 2 Critical Component Test Arrangements.

Project Schedule: A major milestone construction schedule is included for the 6 MWe Sea Based Cycle Plant and for the Seawater Pump Test Bed.

SECTION 1

CONCEPTUAL ESTIMATE

1.1 GENERAL

The estimates are based on the conceptual design and engineering information for the alternative OTEC Sea Based Cycle Plants and for the Seawater Pump Test Bed.

The Sea Based Cycle Plant, which is being considered in three sizes (3, 6 and 9 MWe), includes all the mechanical equipment of the Land Based Cycle Plant, and incorporates all of the major systems of the baseline OTEC facility. The plant is scaled down to a size which will allow an economical but valid simulation, under ocean operating conditions, of the critical components and systems of the baseline facility. It includes the heat exchangers and ammonia turbine-generator support unit, which is submerged during testing operations, and the cycle plant auxiliary systems unit, which is contained on a surface vessel. The estimates are based on the Sea Based Cycle Plant description dated July 20, 1976.

The Seawater Pump Test Bed is a sea-based facility capable of testing full-scale OTEC seawater pumps. The facility includes the pump support structure which is submerged during testing operations and the power supply and support equipment which is contained on a surface vessel. The estimate is based on the Seawater Pump Test Bed description dated July 30, 1976.

Conceptual design and engineering information was prepared for the study in the form of engineering drawings, outline specifications, and equipment lists. Estimating methods consistent with the conceptual nature of the design information were employed. These rely on informal vendor contact as well as extrapolation from Bechtel current information.

The construction cost estimate is composed of field costs, engineering services and allowance for uncertainty. The largest category, field costs, comprises the direct cost of permanent plant equipment and the indirect cost of temporary construction materials, supervision, etc., that are to be distributed across the entire facility. The estimate anticipates an engineer-constructor direct-hire operation employing field construction labor forces.

1.2 PRICING LEVELS

The estimate is at first quarter, 1976, price and wage levels. No allowance has been made for future escalation.

1.3 FIELD CONSTRUCTION COSTS

The direct field construction costs of permanent plant equipment, materials, subcontracts and construction labor have been included in the estimate on the basis of the following discussion:

1.3.1 Equipment

Budgetary suppliers' estimates based on conceptual designs and specifications were obtained verbally or in writing for the major equipment items. These include:

Cycle Plant

- o Heat exchangers (evaporator and condenser)
- o Ammonia turbine-generator
- o Circulating water pumps
- o Diesel generators

Seawater Pump Test Bed

- o Diesel generators
- o Waring winches

Other equipment was estimated using Bechtel data derived from recent purchase orders and vendor contacts and from data developed during the preceding OTEC baseline and Land Based Cycle Plant projects.

1.3.2 Material

Quantity evaluations were made from the drawings for the identifiable materials of structural steel, piping, wire and cable, etc. These quantities were priced using current unit prices from Bechtel sources. Other materials that would be delineated on the final engineering drawings have been evaluated by experience as a percentage of the installed cost of the identified materials.

1.3.3 Subcontracts

Subcontracts for equipment and materials commonly installed by subcontractors were estimated and priced in accordance with Bechtel experience from current sources.

1.3.4 Construction Labor

The direct construction labor costs for the installation of the plant equipment and material were estimated using recent productivity experience and a wage rate based on construction labor contracts and fringe benefits for the Seattle, Washington, area.

This wage rate of \$14.20 per hour is based on a craft mix appropriate to the type of construction together with a 5% allowance for casual overtime and 1% for craft furnished supervision. Sufficient manual labor to complete the project within the construction schedule is assumed to be available in the project vicinity.

1.3.5 Indirect Field Costs

The indirect field costs are those items of construction cost that cannot be ascribed to direct portions of the facility and thus are accounted separately. They were estimated by modifying the experience on fossil-fired plants, resulting in an assessment of 90% of direct labor costs, which has been distributed over the installation of direct equipment and materials as a function of the installation costs.

The items covered by indirect field costs are as follows:

- o Temporary Construction Facilities: Temporary buildings, working areas, roads and parking areas, utility system and general purpose scaffolding.
- o Miscellaneous Construction Services: General job clean-up, maintenance of construction equipment and tools, material handling and surveying.
- o Construction Equipment & Supplies: Construction equipment, small tools, consumable supplies, and purchased utilities.
- o Field Office: Field labor of craft supervision, engineering, procurement, scheduling, personnel administration, warehousing, first aid, and the costs of operating the field office.
- o Preliminary Check-Out & Acceptance Testing: Testing of materials and equipment to insure that components and systems are operable.
- o Project Insurance: Public liability, property damage, and builder's risk insurances.
- o Taxes and Permits: State and local taxes and permits.

1.4 ENGINEERING SERVICES

The engineering services include engineering costs, other home office costs and fee. Engineering includes preliminary engineering, optimization studies, specifications, detail engineering, vendor-drawing review, and support to vendors. Other home office costs comprise procurement, estimating and scheduling services, quality assurance, acceptance testing and construction and project management. Fee is included as a function of the total project cost.

The sum of these three categories falls into historically consistent percentages in the range of 10% - 20% depending on the complexity of the project. For this study a figure of 15 percent of field construction costs has been used as typical for a plant that, while new in concept, does not depart radically from basic engineering principles.

1.5 ALLOWANCE FOR UNCERTAINTY

Included in the estimate is an allowance for the uncertainty that exists within the conceptual design in quantity, pricing or productivity and that is under the control of the constructor and within the scope of the project as defined. Implicitly the allowance will be expended during the design and construction of the project and it cannot be considered as a source of funds for overruns or additions to the project scope. However, experience shows that it is quite difficult to assess the degree to which future processes are understood in the hardware sense. Thus, if the conceptual arrangement of the plant components contains major uncertainties, or the design duty of plant components proves to be more severe than anticipated, or if additional major sub-systems are ultimately found to be necessary, then the scope of the project is deemed to have been inadequately defined and this then would not be covered by the allowance.

1.6 DESIGN ASSUMPTIONS

The following are the design assumptions for which design data was not available when the estimate was prepared:

1.6.1 Sea Based Cycle Plant

- o The cycle plant equipment and material will be assembled at a dock facility using field construction labor rather than a marine labor force.
- o The mechanical equipment and auxiliary systems of the Sea Based Cycle Plant are identical to the mechanical equipment and auxiliary systems of the Land Based Cycle Plant.

- o Material specifications for the Sea Based Cycle Plant are identical to those of the Land Based Cycle Plant; the additional corrosion protection required for the sea based facility will be provided by painting.
- o The ammonia turbine-generator, ammonia pumps, and turbine-generator auxiliary systems will be enclosed in water-tight, carbon steel containers to prevent saltwater from coming in contact with the mechanical and electrical systems.

1.6.2 Seawater Pump Test Bed

- o The seawater pump test bed equipment and material will be assembled at a dock facility using field construction labor.
- o The material quantities of the pump support structure are as follows:

Pump test ducting	250 tons
Ducting frame	250 tons
Strongback frame	180 tons

1.7 QUALIFICATIONS

The following are the major qualifications in the estimate:

1.7.1 Sea Based Cycle Plant Circulating Water Pumps

The pumps are of steel construction with a neoprene coating to prevent corrosion. The pump manufacturers have some reservations concerning the use of neoprene in this application and recommend more conventional bronze, aluminum or stainless steel. Use of these materials would increase the pump costs by 50-75%.

1.7.2 Seawater Pump Test Bed Power Supply

The 2500 kVA diesel engine generators as described in the Engineering Specification are included in the estimate. Switchgear for low voltage starting of the pump motors is also included. However, unless special provisions are made in the pump motor design to allow low power starting, the additional diesel generator required for starting the pump motors will increase the electrical cost by 80 to 100 percent.

1.8 EXCLUSIONS

The following items are excluded from the project scope and are not therefore included in the estimate:

1.8.1 Sea Based Cycle Plant

- o The equipment bases and ships or barges on which the Sea Based Cycle Plant and Auxiliaries are supported
- o The Cycle Plant - Auxiliaries Barge interconnecting umbilical cable, winches, and all other marine equipment to be supplied by Lockheed
- o Cold seawater piping below the Cycle Plant equipment base
- o Fuel oil tanks for the diesel generators

1.8.2 Seawater Pump Test Bed

- o Seawater pumps
- o Umbilical cable and reel
- o 100 ton capacity service crane
- o Computer facilities
- o Any modification of the existing surface vessel to accept installation of the electrical and mechanical equipment.

1.8.3 Common Items

- o Special test instrumentation beyond operating instrumentation
- o Client engineering, financing and other client costs
- o Allowance for funds during construction
- o Training of plant operators
- o Plant startup costs

1.9 ESTIMATE SUMMARY

The above discussion of pricing levels, field construction costs, engineering services, allowance for uncertainty, design assumptions, qualifications and exclusions form the basis of the estimates in the following tables:

- o Table 1-1 Estimated Construction Costs for Sea Based Cycle Plants
- o Table 1-2 Estimated Costs for Seawater Pump Test Bed

Table 1-1
CONCEPTUAL ESTIMATE SUMMARY
SEA BASED CYCLE PLANT

	Thousands of Dollars		
	<u>3MWe</u>	<u>6MWe</u>	<u>9MWe</u>
<u>FIELD COST</u>			
Heat Exchangers	4,920	10,300	15,440
Turbine-Generator	950	1,280	1,580
Circulating Water Pumps	1,720	2,830	4,280
Other Mechanical	730	910	880
Electrical	970	1,340	1,680
Structural Steel	180	330	500
Seawater Piping	320	440	540
Other Piping	410	570	700
	<hr/>	<hr/>	<hr/>
TOTAL FIELD COST	10,200	18,000	25,600
ENGINEERING SERVICES (15%)	1,500	2,700	3,800
	<hr/>	<hr/>	<hr/>
	11,700	20,700	29,400
ALLOWANCE FOR UNCERTAINTY (20%)	2,300	4,300	5,600
	<hr/>	<hr/>	<hr/>
<u>TOTAL ESTIMATED CONSTRUCTION COST:</u>	<u>14,000</u>	<u>25,000</u>	<u>35,000</u>
First Quarter 1976 price & wage levels			

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Table 1-2
CONCEPTUAL ESTIMATE SUMMARY
SEAWATER PUMP TEST BED

	<u>\$ 1000's</u>
<u>FIELD COST</u>	
Mechanical	470
Electrical	1,160
Structural	1,970
	<hr/>
TOTAL FIELD COST	3,600
ENGINEERING SERVICES (15%)	550
	<hr/>
	4,150
ALLOWANCE FOR UNCERTAINTY (20%)	850
	<hr/>
<u>TOTAL ESTIMATED CONSTRUCTION COST</u> <u>First Quarter 1976 price and wage levels</u>	<u>5,000</u>

SECTION 2

CONCEPTUAL ENGINEERING & CONSTRUCTION SCHEDULE

2.1 GENERAL

The engineering and construction schedules for the 6 MWe Sea Based Cycle Plant and for the Seawater Pump Test Bed are based on the conceptual design engineering and the conceptual estimates prepared for the study. They reflect Bechtel's experience in the design and construction of power plants and other similar facilities.

2.2 CONSTRUCTION SEQUENCE

The construction sequence and methods generally follow the Bechtel approach to the construction of commercial plants, which permits procurement and construction to commence before engineering is complete, thus shortening the schedule. The schedule is predicated on an approach which emphasizes the most economic use of manpower rather than the earliest possible completion date.

2.3 SEA BASED CYCLE PLANT SCHEDULE

Figure 2-1 shows the engineering and construction schedule for the 6 MWe Sea Based Cycle Plant and indicates that the project could be completed within a 48-month period. The governing factor is the ordering, manufacture, delivery and installation of the major mechanical equipment.

2.3.1 Engineering Services

- o Engineering : Contract Award is the point at which all optimization studies leading to design engineering begin. Design starts with the development of sufficient detail to initiate the procurement of the major mechanical equipment. It is about 60% complete when construction begins, and continues for about 6 months thereafter. Engineering support is provided throughout the construction period.
- o Environmental Report: Report to the appropriate government agency which must approve the project before the notice to proceed with construction is given. It is an underlying assumption of the schedule that the report preparation and approval will not be a critical time constraint.

- o Long Delivery Procurement: This item covers the major equipment that has delivery times critical to the schedule. These items comprise the cycle plant heat exchangers, turbine generator and circulating water pumps, which have lead times currently reported by suppliers to be approximately 30 months. It is assumed that the purchase orders for the long lead time equipment can be issued before the final project environmental approval is given.

2.3.2 Field Construction

Field construction includes the routine procurement and installation of those items of equipment and material that do not have long delivery times as well as the installation of the long delivery time components.

- o Structural: The structural work can begin as soon as the notice to proceed is given. The work will not be the governing factor in the construction schedule.
- o Mechanical: Installation of mechanical equipment can begin near completion of the structural work. Major equipment will arrive and be installed in the later part of the mechanical construction.
- o Piping, Valves and Instrumentation: Instrumentation of the process piping will begin on the Auxiliaries Barge. The large seawater ducts and process piping of the cycle plant will be installed on the submersible base as the required structural work is completed.
- o Electrical: The installation of the electrical equipment and bulk material will begin on the Auxiliaries Barge and will continue with the installation of the major mechanical equipment. The diesel generators will be installed in the last months of the electrical work.
- o Acceptance Testing: This begins when most of the equipment and bulk materials have been placed and continues until all testing is complete at turbine roll.

2.3.3 Ready for Plant Startup:

The plant is ready for startup when all functional testing has been completed by the constructor and the plant is accepted by the owner for his own operator startup.

2.4 SEAWATER PUMP TEST BED SCHEDULE

Figure 2-2 shows the engineering and construction schedule for the plant and indicates that the project could be completed within an 18-month period. The governing factor is the ordering, manufacture, delivery and installation of the major mechanical equipment.

The following are the major items included in the schedule and the assumptions that form the bases for the time durations and sequence.

2.4.1 Engineering Services

- o **Engineering:** Engineering begins with optimization studies leading to design engineering. Design starts with the development of sufficient detail to initiate the procurement of the major equipment. Engineering support is provided throughout the construction period.
- o **Environmental Report:** Report to the appropriate government agency that must approve the project before the notice to proceed with construction is given to the client. It is an underlying assumption of the schedule that the report preparation and approval will not be a critical time constraint.
- o **Long Delivery Procurement:** This item covers the major equipment that has delivery times critical to the schedule. These items comprise the warping winches and diesel generators. It is assumed that the purchase orders for the long lead time equipment can be issued before the final project environmental approval is given.

2.4.2 Field Construction

Field construction includes the routine procurement and installation of those items of equipment and material that do not have long delivery times, as well as the installation of the long delivery time components.

- o **Structural:** Field assembly of the pump support structures and ducting will begin after the shop fabricated components are delivered and be completed within a six month period.
- o **Mechanical:** The support system mechanical equipment will be installed on the service vessel after it is received and will not influence the construction period. The warping winches will be installed on the pump support structure after delivery and completion of the structure.

- o Electrical: The electrical equipment and materials installation will begin with the surface ship equipment. The large diesel generators will be installed after delivery in the last months of the electrical work.
- o Acceptance Testing: This begins when most of the equipment and bulk materials have been placed and continues until all testing is complete.

2.4.3 Ready for Seawater Pump Installation

The plant is ready for installation of the test seawater pump when all functional testing has been completed by the constructor and the plant is accepted by the owner.

2.5 QUALIFICATIONS

The following qualifications to each schedule apply:

- o No overtime is considered beyond the usual 5% necessary for casual overtime.
- o Equipment deliveries remain as currently established.
- o No allowance for time uncertainty has been included in the schedule.
- o Plant startup and operation have been excluded.

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Figure 2-1
ENGINEERING AND CONSTRUCTION SCHEDULE
OTEC SEA BASED CYCLE PLANT

Figure 2-2

ENGINEERING AND CONSTRUCTION SCHEDULE

SEAWATER PUMP TEST BED

10.5 SEA-BASED CYCLE PLANT COSTS

10.5.1 General

Alternatives

- A. Deck Barge
- B. Ship-Tanker
- C. Semisubmersible Platform

10.5.2 Capital Cost

10.5.2.1 Platform Cost. It is assumed that the platform would be purchased and modified for OTEC purposes. Representative purchase prices for the three types indicated above are as follows:

Deck barge - \$1.3M

Tanker - \$7.0M

Semisubmersible - \$35.0M

10.5.2.2 Modifications.

	\$K	
	<u>Barge</u>	<u>Tanker</u>
Drydock	30	30
Propulsion Systems	-	200
Auxiliary Systems	400	200
Hull Subdivisions and Reinforcements	120	50
Additional Space and Accommodations	290	100
Auxiliary Machinery	180	80
Workshop	150	100
Ducting and Foundations	190	140
Ammonia Tank	110	110
T-G Space and Ducting	100	100
Gates (4)	120	120
Crane	170	130
Mooring System	500	380
Electrical, Piping, Misc.	600	300
	2,960	2,040

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NOTE 1: Submersible modifications cost is expected to be approximately 2/3 of tanker modifications cost. Variety of semisubmersible platforms is too great for detailed estimation to be meaningful.

NOTE 2: Estimate is for 6-MW Cycle Plant. For different outputs, costs are expected to vary according to 0.5 power law. Assume basic platform (barge, tanker, or submersible) can carry up to 15-MW Cycle Plant.

10.5.2.3 Cycle Plant Equipment (6 MW).

	<u>\$K</u>
Heat Exchangers	8,240
Turbine Generators	1,750
Cold Water Pipe	1,500
Circulating Water Pumps	2,830
Electrical	<u>1,340</u>
	15,660

10.5.2.4 Other Charges:

15% for engineering services allowance
20% for contingency allowance

10.5.3 Operating Cost

10.5.3.1 Marine Crew.

	<u>\$K</u>
Straight Wages	960
Overtime	260
Fringe Benefits and Subsistence	<u>710</u>
	1,930

NOTE: All based on 26 man crew; two crews on rotation. Thirty-eight man test crew and related dockside support personnel costs to be estimated based on detailed skill breakdown, with appropriate OH and G&A rates applied.

10.5.3.2 Yearly Support Cost.

A. Dockside Support Equipment

250-ton crane, approx. \$15 k/day

Loading and transport of CWP and other equipment, approx. 10 days

Assume equipment change, approx. 3 times per year

Yearly cost: \$450,000 dollars

B. Support Vessels

165-ft crew/supply boat, approx. \$1.5 k/day

One vessel leased year-round

Yearly cost: \$550,000 dollars

10.5.3.3 Yearly Consumables Cost.

	<u>\$K</u>
Refrigerated and dry stores (70 man crew)	130
Fuel and lube oil - 2 month pump test	160
Fuel and lube oil - 12 month cycle plant test	<u>150</u>
	440

10.5.3.4 Other Charges.

15% for contingency allowance

10-6 T-2 TANKER TEST PLATFORM COSTS

10.6.1 General

10.6.1.1 Includes.

6 MW_e Cycle Plant
Full-Scale Sea Water Pump Test
Cold Water Pipe Test

10.6.1.2 Tanker Availability. Six T-2 tankers are in reserve fleet on Sacramento River. These ships are available to ERDA free of charge. Commercial price is approximately 7 million dollars.

10.6.2 Capital Cost

10.6.2.1 Modifications to Tanker.

	<u>\$K</u>
Dry Dock	100
Ripout	130
Propulsion System Conditioning	250
Auxiliary Systems Conditioning	300
Hull Subdivisions	420
Hull Reinforcements	100
Additional Accommodations and Space	160
Auxiliary Machinery	270
Workshop Equipment	230
Ducting and Foundations	370
Ammonia Tank	110
Turbine-Generator Space and Ducting	100
Gates (4)	120
Bridge Crane	450
Mooring System	380
Ballast System	170
Electrical, Ventilation, Fire Main, Misc.	<u>400</u>
	4,060

10.6.2.2 Cycle Plant Equipment.

	<u>\$K</u>
Heat Exchangers	8,240
Turbine Generators	1,750
Cold Water Pipe	1,500
Circulating Water Pumps	2,830
Electrical	<u>1,340</u>
	15,660

10.6.2.3 SW Pump Test Module.

	<u>\$K</u>
A-Frame	170
Steel Structure	2,010
Sensors and Leads	40
Delivery and Mooring Costs	<u>60</u>
	2,280

Note: Cost does not include test article.

10.6.2.4 CWP Test Module.

	<u>\$K</u>
Derrick	500
Ripout and Hull Reinforcement	<u>100</u>
	600

10.6.2.5 Other Charges.

15% for engineering services allowances
20% for contingency allowance

10.6.3 Operating Cost

10.6.3.1 Marine Crew

	<u>\$K</u>
Straight Wages	960
Overtime	260
Fringe Benefits and Subsistence	<u>710</u>
	1,930

Note: All based on 26-man crew; two crews on rotation.
Forty-four man test crew and related dockside support personnel costs to be estimated based on detailed skill breakdown, with appropriate OH and G&A rates applied.

10.6.3.2 Yearly Support Cost

A. Dockside Support Equipment

250-ton crane, approx. \$15 k/day

Loading and transport of CWP and other equipment, approx. 10 days

Assume equipment change, approx. three times per year

Yearly cost: \$450,000 dollars

B. Support Vessels

165-ft crew/supply boat, approx. \$1.5 k/day

One vessel leased year-round

Yearly cost: \$550,000 dollars

10.6.3.3 Yearly Consumables Cost

	<u>\$K</u>
Refrigerated and dry stores (70 man crew)	150
Fuel and lube oil - 2-month pump test.	160
Fuel and lube oil - 12-month cycle plant test	<u>150</u>
	460

10.6.3.4 Other Charges

15% for contingency allowance

Appendix 11

ENERGY SELF SUFFICIENCY

Table 11-1 presents power consumption estimates for heat exchanger, turbine, and hydrodynamics test beds, sea-based sea water pump test, and power production or consumption for land- and sea-based cycle plants. Since a number of test facility alternatives are acceptable and the final choice is to be made by ERDA upon consideration of a number of factors, the data are presented in matrix form to allow the average and peak power consumption (or output) to be calculated for any combination of test bed and cycle plant alternatives.

Only the sea-based cycle plant is energy self-sufficient. It requires an auxiliary power unit of about 3 MW_e for startup, but in operation generates in excess of 3 MW_e over its total power needs. The land-based cycle plant, if sited to require minimum warm and cold water pumping power, also produces net energy output, but that output is not sufficient to operate the remainder of the land-based test facility.

Table 11-1

TEST FACILITY POWER USAGE PER KILOWATT

ITEM	TEST BEDS								HYDRO-DYNAMICS	LAND-BASED CYCLE PLANT			SEA WATER PUMP	SEA-BASED CYCLE PLANT	
		HEAT EXCHANGER				TURBINE				Plant at Warm/Cold Water Supply Level	Plant 4 ft Above Warm/Cold Water Supply Level	Plant 120 ft Above Warm/Cold Water Supply Level			
		0.25 MW EVAP	0.25 MW COND	2.5 MW EVAP	2.5 MW COND	1/16	1/4	FULL							
AMMONIA EQUIPMENT															
Compressors		706	506	7,200	5,160	1,930	9,690	32,540							
Coolers		130	376	800	1,805										
Pumps - Condensate - Reflex		1	1	10	10	2	10	25		93	93	93		190	
Cleanup										18	18	18		40	
										1,200	1,200	1,200		2,500	
WATER															
Circulating		298	275	2,400	2,220				46.7	620	620	620	4,270	1,518	
Cooling		6		70		53	74	476		-	2,510	8,430			
Warm Intake										-	2,610	7,830			
Cold Intake															
BUILDING/SUPPORT ^(a)		45	45	170	170	50	65	65	48.7	50	50	50	112	200	
GENERATOR		-	-	-	-	-	-	-	-	-3,825 ^(e)	-3,825 ^(e)	-3,825 ^(e)		-7,650 ^(e)	
SUBTOTAL		1,186	1,203	10,650	9,365	2,035	9,839	33,105	95.4	-1,844 ^(e)	3,376	14,416	4,382	-3,202 ^(e)	
START-UP ^(b)		1,881	1,698	17,808	14,192	3,352	18,313	49,360	130	1,240	5,120	16,260	8,624	3,036	
NORMAL OPERATION ^(c)		390	902	7,958	7,024	1,526	6,329	24,830	72	-1,844 ^(e)	3,576	14,416	4,382	-3,502 ^(e)	
PRE/POST TEST ^(d)		45	45	170	170	50	65	65	49	50	50	50	112	200	

NOTES: SHOPS ESTIMATED AT 1 TO 2.5 MW; MAXIMUM AT 40% DUTY CYCLE.
 BUILDINGS OTHER THAN SHOPS AND TEST BEDS ESTIMATED AT 150 KW EACH.
 a. BUILDING/SUPPORT INCLUDES LIGHTS, HVAC, INSTRUMENT AIR COMPRESSION CRANES, ETC.
 b. ESTIMATED AT TWICE LARGEST COMPONENT PLUS ALL REMAINING EQUIPMENT PLUS 75% OF "BUILDING/SUPPORT".
 c. ESTIMATED AT 75% OF SUBTOTAL EXCEPT CYCLE PLANTS AT 100%.
 d. ESTIMATED TO BE THE SAME AS "BUILDING/SUPPORT".
 e. NEGATIVE NUMBERS MEAN "NET" OUTPUT.

Appendix 12

TEST FACILITY APPLICATION

12.1 INTRODUCTION

The Statement of Work requests a brief discussion of the relevance of the Test Facility requirements to the OTEC demonstration plant and to subsequent commercial plants. The Test Program Progression chart, shown in Section C, "Test Plans," presents flow paths for the major components as they progress through the various stages to the OTEC production plant. Section O, "Schedule Summary," presents a "Relative Risk Schedule" which shows several approaches to the development of the Demonstration Plant and the percentage of baseline performance anticipated with each approach. From these figures, it is seen that test facilities are required to achieve a demonstration plant which would provide at least 90% of the baseline performance.

12.2 TEST FACILITY TEST UTILIZATION

The term "Test Facility" should be understood as encompassing the individual facilities and test areas required to attain the integrated test program objective. The manner in which the individual facilities are utilized and the relationship of each to the final objective are as follows. As seen from the Test Program Progression, the OTEC Demonstration Plant incorporates first-generation hardware. This implies that AR&T testing is not required to attain this objective. However, improvements available from AR&T efforts will be incorporated into the Demonstration Plant hardware, as the schedule permits. AR&T test results will be utilized to improve the performance of future generation hardware with attendant energy cost reductions.

The Engineering Development effort is required for the Demonstration Plant since it encompasses such efforts as the determination of baseline heat transfer data and the hydrodynamic performance of the platform and cold water pipe. Continued Engineering

Development testing will be required if major modifications are made as a result of AR&T, component, or cycle plant testing.

Major component testing presents the first opportunity to evaluate the performance of components which represent an extension of the state-of-the-industry. These tests are, therefore, necessary to attain the objective of the Demonstration Plant having the baseline performance capability. These tests are also necessary to determine the performance improvements due to the application of AR&T test results to components of reasonable size before committing to full-scale hardware fabrication.

Cycle Plant testing presents the first opportunity to evaluate the power cycle thermodynamic performance and obtain operational data. These data are required to confirm the validity of the cycle assumptions used in the design of the baseline configuration. The use of the Cycle Plant in the production development phase will be dependent upon the extent of the modifications associated with the results of AR&T and component testing.

12.3 TEST FACILITY EQUIPMENT UTILIZATION

If the decision is made to provide full-scale turbine and pump test capability in the component test facility, these test beds can be used to conduct acceptance testing of production hardware for the commercial plants. This approach requires clarification and definition of the participation of ERDA, the turbine manufacturer, and the test facility operator.

The data acquisition and control system, depending upon its data reduction and storage capability incorporated into the test facility, could be used as the central data processing station for the pilot plant, demonstration plant and subsequent commercial plant test results. This approach provides a central independent service for evaluating individual plant performance and characteristics as well as developing a data base upon which to define system and component strengths and weaknesses for future actions.

The test facility will develop a unique instrumentation capability in terms of type, calibration ability, and quantity in order to support the component test beds and cycle plant tests. These sensors and instruments can be used in the pilot, demonstration, and commercial plants for test and checkout activities versus the operational controls installed in the plant, e.g., the test sensors and instruments could be employed as a means of verifying the functioning of the operational controls as well as plant performance verification.