DE/ET/4064 - (K001.1)

GIBBS & COX INC

NEW YORK, N. Y.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

18351-10 (W-10,000)

DOE/ET/4064--1 (Vol. 1)

DOE/10

OCEAN THERMAL ENERGY CONVERSION
(OTEC) PLATFORM CONFIGURATION AND INTEGRATION

FINAL REPORT

VOLUME I

MASTER

SYSTEMS REQUIREMENTS AND EVALUATION

NOTICE
This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

Prepared For:
U. S. Department of Energy
Contract Number EG-77-C-01-4064

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

GIBBS & COX, INC.
Washington, D. C.

GIBBS & COX, INC.
Washington, D. C.
June, 1978

R. P. Fulton
Division Head
Washington Division

R. J. SCOTT
Project Manager

TABLE OF CONTENTS

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
	REFERENCES	viii
1.	INTRODUCTION	1-1
1.1	The OTEC Concept	1-1
1.2	OTEC Program	1-1
1.3	Project Overview	1-2
1.4	Final Report Organization	1-4
1.5	Definitions	1-4
2.	TASK IIA SYSTEMS AND REQUIREMENTS ANALYSIS	2-1
2.1	Introduction	2-1
2.2	Payload Definition	2-2
2.3	Top Level Requirements (TLR)	2-4
2.4	Factors Affecting Size and Configuration	2-5
2.5	Producibility	2-58
2.6	OTEC Energy Park	2-64
3.	TASK IIB EVALUATION PLAN	3-1
3.1	Introduction	3-1
3.2	Methodology	3-3
4.	TASK III TECHNOLOGY REVIEW	4-1
4.1	Introduction	4-1
4.2	Identification of Technology Areas	4-1
4.3	Technology Limits and Requirements	4-2
4.4	Technology Advancement Program	4-81
5.	TASK IV SYSTEMS INTEGRATION AND EVALUATION	5-1
5.1	Introduction	5-1
5.2	Baseline Platform Alternatives	5-2
5.3	Cost and Schedule	5-9
5.4	Motions and Structural Loads Analysis	5-35
5.5	Cost Benefit Analysis	5-67
5.6	Influence of CWP Thickness Variation	5-99

TABLE OF CONTENTS
(Continued)

<u>SECTION</u>	<u>TITLE</u>	<u>PAGE</u>
6.	RECOMMENDATIONS	6-1
6.1	Configurations	6-1
6.2	Size	6-1
6.3	Site	6-2
6.4	Overall Ranking	6-2
	APPENDICES	
A	TOP LEVEL REQUIREMENTS (TLR)	A-1
B	DOE POWER SYSTEM DATA	B-1
C	COST AND SCHEDULE DATA	C-1
D	MOTIONS AND LOADS DATA	D-1
E	FIGURES OF MERIT	E-1
F	RISK EVALUATION - NEW ORLEANS SITE	F-1
G	ACQUISITION COSTS AND F.O.M. WITH VARIABLE CWP	G-1

LIST OF FIGURES

<u>FIGURE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
1.5-1	Proposed Third Level Ocean System Work Breakdown Structure	1-5
1.5-2	Power System/Seawater System Definition	1-6
2.4-1	Approach to Studies of Size and Configuration	2-7
2.4-2	Weight and Volume of Basic Power Module Using 5, 8, 12.5, and 25 MWe Components	2-11
2.4-3	25 MW Power Module Configurations (Typical)	2-12
2.4-4	Arrangement: Ship	2-22
2.4-5	Arrangement: Cylinder	2-23
2.4-6	Arrangement: Spar	2-24
2.4-7	Arrangement: Submersible	2-25
2.4-8	Arrangement: Semi-Sub	2-26
2.4-9	Arrangement: Sphere	2-27
2.4-10	Operating Displacement vs. Plant Size	2-28
2.4-11	Payload Wt. Operating Δ vs. Plant Size	2-29
2.4-12	Payload Wt. Hull Wt. vs. Plant Size	2-30
2.4-13	Commercial Plant Weight Breakdown for Ship Shape	2-31
2.4-14	Commercial Plant Weight Breakdown for Cylinder	2-32
2.4-15	Commercial Plant Weight Breakdown for Spar	2-33
2.4-16	Commercial Plant Weight Breakdown for Submersible	2-34
2.4-17	Commercial Plant Weight Breakdown for Semi-Submersible	2-35
2.4-18	Commercial Plant Weight Breakdown for Sphere	2-36
2.4-19	Commercial Plant Total Enclosed Volume vs. Plant Size	2-37
2.4-20	Commercial Plant Payload Vol./Total Vol. vs. Plant Size	2-38
2.4-21	Commercial Plant Volume Breakdown MW vs. $\text{Ft.}^3 \times 10^6$ Ship	2-39
2.4-22	Commercial Plant Volume Breakdown MW vs. $\text{Ft.}^3 \times 10^6$ Cylinder	2-40
2.4-23	Commercial Plant Volume Breakdown MW vs. $\text{Ft.}^3 \times 10^6$ Spar	2-41
2.4-24	Commercial Plant Volume Breakdown MW vs. $\text{Ft.}^3 \times 10^6$ Submer.	2-42
2.4-25	Commercial Plant Volume Breakdown MW vs. $\text{Ft.}^3 \times 10^6$ Semi-Sub.	2-43
2.4-26	Commercial Plant Volume Breakdown MW vs. $\text{Ft.}^3 \times 10^6$ Sphere	2-44
2.6-1	Effluent Plume Trajectories for Currents of 0, 2, and 4 Knots	2-70

LIST OF FIGURES

(Continued)

<u>FIGURE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
4.4-1	Cost, Schedule and Milestone OTEC Technology Advancement Program	4-83
5.2-1	500 MW Commercial Plant, Ship (Modified)	5-13
5.2-2	500 MW Commercial Plant, Cylinder (Modified)	5-14
5.2-3	500 MW Commercial Plant, Spar (Modified)	5-15
5.2-4	500 MW Commercial Plant, Submarine (Modified)	5-16
5.2-5	500 MW Commercial Plant, Semi-Submersible (Modified)	5-17
5.2-6	500 MW Commercial Plant, Sphere (Modified)	5-18
5.3-1	Operating Cost Summary	5-29
5.3-2	Construction Timeline for 100 MW Ship	5-31
5.3-3	Schedule Summary	5-34
5.4-1	Transmission Cable Motions Envelope	5-62
5.4-2	Sea Spectra Comparison	5-64
5.4-3	Response Spectrum Generation	5-65
5.5-1	Representative FOM's for Hawaii	5-76
5.5-2	FOM's, Aluminum Heat Exchangers ($i = 10\%$)	5-80
5.5-3	FOM's Aluminum Heat Exchangers ($i = 10\%$) Including Transmission System and Facilities Improvement Costs	5-81
5.5-4	FOM's, 3,000 MW Park Aluminum Heat Exchangers ($i = 10\%$) Including Transmission System and Facilities Improvement Costs	5-83
5.5-5	Risk Factor vs. Cost Overrun	5-89
5.5-6	Figure Of Merit w/o Transmission Line - Ship	5-93
5.5-7	Figure Of Merit w/o Transmission Line - Sphere	5-94
5.5-8	Figure Of Merit with Transmission Line - Ship	5-96
5.5-9	Figure Of Merit 3,000 MW Park with Transmission Line	5-97
5.6-1	Acquisition Cost Summary - Aluminum - Heat Exchanger Tubes - Variable CWP Thickness	5-106
5.6-2	Acquisition Cost Breakdown 350 MW Ship	5-107
5.6-3	Figure Of Merit - Hawaii	5-110
5.6-4	Figure Of Merit - New Orleans	5-111
5.6-5	Figure Of Merit - Key West	5-112

LIST OF TABLES

<u>TABLE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
2.4-1	Platform Volume Increase to Suite 5 - 25 MW Components	2-14
2.4-2	Power Module Matrix	2-16
2.4-3	Principal Characteristics - Ship	2-46
2.4-4	Principal Characteristics - Cylinder	2-46
2.4-5	Principal Characteristics - Spar	2-49
2.4-6	Principal Characteristics - Submersible	2-49
2.4-7	Principal Characteristics - Semi-Submersible	2-51
2.4-8	Principal Characteristics - Sphere	2-53
2.4-9	Baseline Plant Motion Summary - Sea State 9	2-54
2.5-1	OTEC Shipyard Survey - East Coast	2-60
4.3-1	Current State-Of-the-Art in Ocean Structures	4-4
4.3-2	Projected State-Of-the-Art in Ocean Structure	4-10
4.3-3	Industrial Capabilities for Large Capacity Low Head Pumps	4-39
4.3-4	Near Field Flow and Thermal Mixing Studies Relevant to OTEC Plant Design	4-44
4.3-5	Far Field or Regional Thermal Models and Studies Relevant to OTEC Plant Siting	4-48
4.3-6	Stability Mobile Offshore Drilling Units	4-74
4.3-7	Agencies and Their Areas of Jurisdiction in the Commercial Marine Transportation Industry	4-77
5.2-1	Assumed Weights and Dimensions	5-5
5.2-2	Principal Characteristics - Ship	5-10
5.2-3	Principal Characteristics - Cylinder	5-10
5.2-4	Principal Characteristics - Spar	5-11
5.2-5	Principal Characteristics - Submersible	5-11
5.2-6	Principal Characteristics - Semi-Submersible	5-12
5.2-7	Principal Characteristics - Sphere	5-12
5.3-1	Power System Component Costs (\$M)	5-20
5.3-2	Plant Manning	5-26
5.3-3	Estimated Daily Crew Costs	5-27
5.4-1	Matrix of Cases Considered	5-37
5.4-2	Factors to be Applied to the Hydronautics Values of Motions and Loads in Order to Account for Variations in CWP/Platform Connection Stiffness	5-43

LIST OF TABLES

(Continued)

<u>TABLE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
5.4-3	Factors to be Applied to the Hydronautics Baseline Platform Values of Motions and Loads to Account for Variation in CWP Length from 2,000 to 3,000 feet	5-44
5.4-4	Variation in Motions and Loads with Platform Displacement Based on Hydronautics Predictions: Sea State 7; 2,000 ft. Pipe, 110 ft. dia. K = Infinity	5-45
5.4-5	Correction Factors to be Applied to the Hydronautics Baseline Platform Values of Motions and Loads to Account for Variation in CWP Diameter from 110 ft. to 140 ft.	5-47
5.4-6	Correction Factors for CWP Flexibility Based on 150,000 L.T. Hydronautics Platform H $T/3 = 40$ ft.	5-48
5.4-7	Cases Simulated Using the Paulling ATEC Computer Program	5-52
5.4-8	Normalized Motions and Loads (1.0 = Minimum) 100 MW Plant	5-55
5.4-9	Normalized Motions and Loads (1.0 = Minimum) 200 MW Plant	5-56
5.4-10	Normalized Motions and Loads (1.0 = Minimum) 350 MW Plant	5-57
5.4-11	Normalized Motions and Loads (1.0 = Minimum) 500 MW Plant	5-58
5.4-12	Platform Ranking Based on Motions, Accelerations and CWP Bending Moments	5-59
5.5-1	Detailed Acquisition Costs (Ship)	5-69
5.5-2	Detailed Acquisition Cost Percentages (Ship)	5-69
5.5-3	Transmission Line Costs (\$M)	5-71
5.5-4	Shore Power Station Interface Costs (All Site) (\$M)	5-71
5.5-5	Total Transmission System Costs (\$M)	5-72
5.5-6	Total Transmission System Costs Per Megawatt (\$M)	5-72
5.5-7	Facilities Improvement Costs (\$M)	5-73
5.5-8	Facilities Improvement Costs Required to Construct a 3,000 MW Energy Park in 6 Years (\$M)	5-74
5.5-9	Aluminum and Titanium Heat Exchanger Comparisons (i=0%)	5-77
5.5-10	Aluminum and Titanium Heat Exchanger Comparison (i=0%)	5-78
5.5-11	OTEC Technical Risk Criteria	5-86
5.5-12	Risk Assessment - New Orleans Site	5-87
5.6-1	CWP Dynamic Bending Stresses*, KSI	5-100
5.6-2	CWP Wall Thicknesses (Ft.) For Modified F.O.M.	5-103

LIST OF TABLES

(Continued)

<u>TABLE NO.</u>	<u>TITLE</u>	<u>PAGE</u>
5.6-3	Modified Figure Of Merit Including Reduction for Utilization and Efficiency	5-108
5.6-4	Modified Figure Of Merit Excluding Reduction for Utilization and Efficiency	5-109
6-1	Overall Platform Ranking	6-3
6-2	Ranking By Size	6-4

REFERENCES

1. Gibbs & Cox, Inc. Report 18351-1/2 (W-8400) OTEC Platform Configuration and Integration Tasks I, IIA, and IIB - Final Report, Volumes I and II, dated October, 1977.
2. Gibbs & Cox, Inc. Report 18351-3 (W-8500) OTEC Platform Configuration and Integration - Task III - Technology Review - Final Report, dated October, 1977.
3. Gibbs & Cox, Inc. Report 18351-4 (W-8600) OTEC Platform Configuration and Integration - Task IV - System Integration and Evaluation - Final Report, dated January, 1978.
4. National Oceanographic Atmospheric Administration Letter to Gibbs & Cox, Inc., dated August 16, 1977.

National Oceanographic Atmospheric Administration Letter to Gibbs & Cox, Inc., dated August 29, 1977.
5. "Ocean Thermal Energy Conversion Research on an Engineering Evaluation and Test Program," Volumes 1 through 5, TRW Systems Group; 5 June 1975.
6. "Ocean Thermal Energy Conversion (OTEC) Power Plant Technical and Economic Feasibility," Volume 1 through 3, Lockheed Missile and Space Company, Inc., Report LMSC-0056566, dated April, 1975.
7. D'Arcangelo, A. M., "Ship Design and Construction", SNAME, 1969.
8. Energy Research and Development Administration (ERDA) "OTEC Demonstration Plant Environmental Package", Enclosure C to RFP EG-77-R-01-4011, dated July, 1977.
9. Barr, R. A., O'Dea, J. F., Ankudinov, V., "Theoretical Evaluations of the Seakeeping Performance and Resistance/Propulsion Characteristics of Five Candidate OTEC Platforms", Hydronautics, Inc., T. R. 7513-1, dated July, 1976.
10. Tuned Sphere International Handout for Presentation at Westinghouse Oceanic Division, Annapolis, Maryland, September 27, 1977.
11. Giannotti, Julio G. and Toomey-Gable, Laureen; Analysis of Motions and Loads for Gibbs & Cox, Inc. 100, 200, and 350 MW OTEC Commercial Plant Platforms; Giannotti & Buck Associates, Inc. Report No. 77-018-02, dated October, 1977.
12. Giannotti, Julio G., Jawish, William K., Toomey-Gable, Laureen; Analysis of Motions and Loads for Gibbs & Cox, Inc. 500 MW OTEC Commercial Plant, Giannotti & Buck Associates, Inc. Report dated September, 1977.

REFERENCES

(Continued)

13. Giannotti, Julio G., "Forecasting of Ocean Pollution and Practical Applications," paper presented at the 2nd Conference on Mediterranean Pollution Control, Malaga, Spain, September, 1974.
14. Davis, M. C., "Recent Progress in Surface Effect Ship Development", AII/SNAME Advanced Marine Vehicles Conference, February, 1974.
15. 125,000 M³ LNG Ship Abstract Specification with Reliability and Safety Highlights, General Dynamics, Quincy Shipbuilding Division, December, 1976.
16. Charleston LNG Sphere Manufacturing Facility, General Dynamics, Quincy Shipbuilding Division.
17. Dixon, R. H., et al, "Design and Building of the GRP Hull of HMS WILTON", Symposium on GRP Ship Construction, 1972.
18. Spaulding, K. B., and Della Rocca, R. J., "Fiberglass Reinforced Plastic Minesweepers", Society of Naval Architects and Marine Engineers, 1965.
19. Noton, B. R., "Composite Materials - Volume 3 - Engineering Applications of Composites", Academic Press, 1974.
20. "Proceedings of the Super Ocean Carrier Conference", San Pedro, California, 1974.
21. Altenberg, C. and Scott, R., "Design Considerations for Aluminum Hull Structures - Study of Aluminum Bulk Carrier", Ship Structures Committee Report SSC-218, 1971.
22. Scott, R. J. and Sommella, J. H., "Feasibility Study of Glass Reinforced Plastic Cargo Ship", Ship Structures Committee Report SSC-224, 1971.
23. Della Rocca, R. J. and Scott, R. J., "Materials Test Program for Application of Fiberglass Reinforced Plastics to U. S. Navy Minesweepers", Society of the Plastics Industry, 1967.
24. Gerwick, B. C., Editor; "Proceedings of the Conference on Concrete Ships and Floating Structures", University Extension, University of California, Berkeley, 1975.
25. Hove, D. T. and Shih, W. C. L., "Hydrodynamic Loads on the Cold Water Pipe", Science Applications, Inc., Fourth Annual Conference on OTEC, New Orleans, Louisiana, March, 1977.

REFERENCES
(Continued)

26. Barr, R. A., O'Dea, J. F., and Ankudinov, V., "Theoretical Evaluations of the Seakeeping Performance and Resistance/ Propulsion Characteristics of Five Candidate OTEC Platforms," Hydronautics, Inc., T. R. 7513-1, prepared for ERDA under Contract No. E(11-1)-2681, July, 1976.
27. Giannotti, Julio G., Band, E. G., and Lavis, D. R., "Prediction of Hydrodynamic Loads acting on SES and ACV Structures", AIAA Paper No. 76-868, Advanced Marine Vehicles Conference, Washington, D. C., September, 1976.
28. Giannotti, Julio G., and Jawish, W. K., "Development of Rational Seakeeping Design Criteria for Surface Ships", paper presented to the Chesapeake Section of SNAME, December, 1977.
29. Paulling, J. R., Jr., "A Linearized Dynamic Analysis of the Coupled OTEC Cold Water Pipe and HMB-1 Barge System", prepared for Morris Guralnick Associates, Inc., June 21, 1971.
30. Barr, R. A., O'Dea, J. F., "Preliminary Evaluation of HMB Motion and CWP Loads for OTEC One," Hydronautics Report No. 7513-3-1 ERDA Contract E(11-1)-2681.
31. "Definition of the Platform-CWP Problem and an Assessment of Currently Available Analytical Models," Gilbert Associates, Inc., Report under Contract No. EY-76-C-02-2847, July 16, 1977.
32. "Stress Analysis of the Cold-Water Pipe: Data Comparisons of Four Existing Computer Programs," Gilbert Associates, Inc. Report under Contract No. EY-76-C-02-2847, September 30, 1977.
33. Garrison, C. J., "Hydrodynamic Interaction of Waves with a Large Displacement Floating Body," U. S. Naval Postgraduate School, Monterey, California, Report No. NPS-69Gm 77091 for ERDA, dated September, 1977.
34. Garrison, C. J., "Hydrodynamics of Large Objects in the Sea, Part I - Hydrodynamic Analysis," Journal of Hydronautics, Volume 8, January, 1974.
35. Garrison, C. J., "Hydrodynamics of Large Objects in the Sea, Part II - Motion of Free-Floating Bodies," Journal of Hydronautics, Volume 9, April, 1975.
36. Giannotti, Julio G., "A Dynamic Simulation of Wave Impact Loads on Offshore Floating Platforms," Transactions of ASME, pp. 550-557, May, 1976.

REFERENCES

(Continued)

37. Frederick R. Harris, Inc., "Computer Plots in Accord with Input Data from Meeting on June 24, 1974, ERDA-OTEC-1, Pipe Modeling Program," Job No. 02-748-01, July 8, 1977.
38. Frederick R. Harris, Inc., "Pipe Model Program - Comparison Runs," Job No. 02-748-01, July 25, 1977.
39. Chang, Pin Yu, "Structural Analysis for Cold Water Pipes for OTEC Power Plants," Hydronautics, Inc. Technical Report No. C00-2424-1 (in press).
40. Little, T. E., Marks, J. D., and Wellman, K. H., "Deep Water Pipe, Pump, and Mooring Study, Ocean Thermal Energy Conversion Program," Westinghouse Electric Corporation Oceanic Division - Final Report C00-2642-3, dated June, 1976.
41. Stein, R. H., "Ocean Thermal Energy Conversion - International Environmental Aspects," ERDA Workshop, January, 1976.
42. Steol, T. B., "Ocean Thermal Energy Conversion - Domestic Environmental Aspects," ERDA Workshop, January, 1976.
43. Valent, P. J., Taylor, R. J., Atturio, J. M., and Beard, R. M., "OTEC Single Anchor Holding Capacities in Typical Deep Sea Sediments," Civil Engineering Laboratory, Port Hueneme, California, December, 1976.
44. Avery, W. H., et al, "Maritime and Construction Aspects of Ocean Thermal Energy Conversion (OTEC) Plant Ships," Johns Hopkins University/Applied Physics Lab Report SR76-1B, dated April, 1976.
45. Peerless Design Catalog, Peerless Manufacturing Company, Dallas, Texas.
46. "Deep Water Pipe, Pump, and Mooring Study - Ocean Thermal Energy Conversion Program" by Thomas Little, J. D. Marks, and K. W. Wellman, Westinghouse Electric Corporation, Oceanic Division, June, 1976.
47. "Ocean Thermal Power Plants Cold Water Pipe, Seawater Pumps and Platform Station Keeping" by T. Little and H. Davidson, Westinghouse Electric Corporation, Oceanic Division, September 27, 1977.
48. Detailed Report, Maritime and Construction Aspects of Ocean Thermal Energy Conversion (OTEC) Plant Ships, MA-RD-940-T76074 Johns Hopkins University, dated April, 1976.

REFERENCES

(Continued)

49. "A Technical and Economic Evaluation of the Mini-Trailership Concept for the U. S. Merchant Marine" Booz-Allen & Hamilton, Inc., July, 1977.
50. "Concrete Gravity Structures for the North Sea" by Ivar Foss, Ocean Industry, August, 1974.
51. Barr, R. A., O'Dea, J. F., Ankudinov, V., "Theoretical Evaluations of the Seakeeping Performance and Resistance/Propulsion Characteristics of Five Candidate OTEC Platforms," Hydronautics, Inc. Technical Report 7513-1, July, 1977.
52. Fink, C. R., et al, "Theoretical Determinations of the Seakeeping Response of Tuned Sphere Stable Platforms for OTEC Power Plants" TSI Report No. TSI-4032-2, October 26, 1977.
53. Barr, R. A. and O'Dea, J. F., "Preliminary Evaluation of HMB Motions and CWP Loads for OTEC One," Hydronautics, Inc. Technical Report No. 7513.3-1.
54. Barr, R. A., "Preliminary Results for Five 150,000 LT OTEC Platforms with CWP," Preliminary Data 7513, prepared for ERDA under Contract EY-76-C-02-2681, October, 1977.
55. "Definition of the Platform-CWP Problem and an Assessment of Currently Available Analytical Models," Gilbert Associates, Inc., Report under Contract No. EY-76-C-02-2847, July 16, 1977.
56. Paulling, J. R., Jr., "A Linearized Dynamic Analysis of the Coupled OTEC Cold-Water Pipe and HMB-1 Barge System," prepared for Morris Guralnick Associates, Inc., August, 1977.
57. Garrison, C. J., "Hydrodynamic Interaction of Waves With A Large Displacement Floating Body," interim report prepared for ERDA under interagency agreement E(49-26)-1044, September, 1977.
58. Simplex Wire and Cable Company, Development Engineering Report 18 "OTEC Preliminary Analysis of Allowable Movement of Plant as it Affects Power Cables," dated October 11, 1977.
59. Twiss, Brian, "Managing Technology Innovation", Longman Group, Ltd., 1974.

1. INTRODUCTION

This report summarizes studies conducted by Gibbs & Cox, Inc. under Department Of Energy Contract No. EG-77-C-01-4064 relating to the OTEC Platform Configuration and Integration study.

1.1 The OTEC Concept

The Offshore Thermal Energy Conversion (OTEC) power system is based on the Rankine thermodynamic cycle, utilizing working fluids such as ammonia capable of boiling and condensing over small temperature ranges in a closed system. Solar energy, stored in warm ocean surface waters, is transferred to the working fluid in a large heat exchanger, thereby causing evaporation of the working fluid. The vapor phase fluid passes through a low pressure turbine and then to a condenser cooled by waters pumped from ocean depths up to 3,000 feet. The condensed working fluid is then returned to the warm water heat exchanger (evaporator), and the cycle is renewed. Energy extracted by the turbine is used to generate electric power either for transmission to shore or for direct usage in an associated, energy-intensive manufacturing, chemical processing use.

1.2 OTEC Program

The OTEC Program schedule calls for the deployment and at-sea test of the OTEC plant facilities. The first test is called OTEC-1, signifying a test of the 1 MWe power cycle module. OTEC-1 is planned for FY 1980-81. OTEC modular experiment plants are planned for FY 1982-83 to test a power module between 10 MWe and 20 MWe in size. There are contracts currently awarded that deal with three major subsystems of the OTEC plant. One set of contracts is involved with the design of various size power cycle modules. Another set of contracts is involved with the configuration of the electric cable subsystem of both the riser/umbilical and bottom transmission cable. A third set of three contracts is involved with the configuration analysis of the OTEC Commercial Plant platforms. This report describes the Gibbs & Cox, Inc. studies conducted under one of these three contracts.

1.2 OTEC Program (Continued):

A comprehensive study of the Cold Water Pipe (CWP) is planned for FY 78 involving preliminary design of the CWP for the OTEC Modular Experiment. Other programs planned for FY 1978 besides the proposed effort of this RFP are an analysis of the stationkeeping subsystems for the modular experiment OTEC plant and an analysis of large system construction techniques.

After the major subsystem configuration studies have been completed, a system integration design contract will be awarded. It will be the responsibility of the systems integration contractor to design all OTEC subsystems (except the Power System and Energy Transmission System) into one integrated Ocean System. A separate contractor will integrate all the OTEC components into the working OTEC plant, and then deploy the plant and operate it at sea.

1.3 Project Overview

The purpose of this project is to evaluate six candidate hullforms as candidates for the OTEC Commercial Plant. The six hullforms will be systematically evaluated to rank them in order of preference considering factors such as cost, schedule and risk. Conceptual designs of two of these plants will then be conducted, and a plan for development of a Demonstration Plant will be prepared.

The project is being conducted under the following nine (9) tasks:

- Task I Data Assembly and Synthesis: Development of a data bank of OTEC-related documentation.
- Task IIA Systems Evaluation and Requirements: Definition of Top Level Requirements and an assessment of factors critical to the selection of hull configuration and size; quantification of payload requirements and characteristics; sensitivity of system characteristics to site selection.
- Task IIB Evaluation Plan: Development of a methodology for systematically evaluating the candidate hullforms, based on interrelationships and priorities developed during Task IIA.

1.3 Project Overview (Continued):

- Task III Technology Review: Assessment of current technology and identification of deficiencies in relation to OTEC requirements; development of plans to correct such deficiencies.
- Task IV Systems Integration Evaluation: Formal evaluation of the six (6) candidate hullforms in relation to site and plant capacity (effective megawatts) to quantify cost/size/capability relationships; leading to selection of an optimum Commercial Plant.
- Task V Conceptual Design: Development of Conceptual Design documentation for two selected Plants to identify plant characteristics to the level of detail required to quantify cost and schedule.
- Task VI Facilities and Equipment: Identification of the facilities and equipment necessary to build and deploy the OTEC Commercial Plant.
- Task VII Development Plan: A plan for the development of an OTEC Demonstration Plant including funding, key milestones, fallbacks, etc.
- Task VIII Cost, Schedules: Detailed assessment of cost and scheduling requirements for the OTEC Commercial Plant.
- Task IX Site Sensitivity: Assessment of the sensitivity of Plant characteristics to the specific environmental characteristics of potential deployment sites.

Gibbs & Cox, Inc. was assisted in this study by four (4) subcontractors:

- Giannotti & Buck Associates, Inc. for evaluation of platform motions, cold water pipe dynamics and environmental analysis.
- Alan C. McClure Associates, Inc. for development of positionkeeping systems and general input related to offshore technology.
- Santa Fe Corporation for systems analysis, cost-benefit analysis, and the Development Plan.
- Worthington Corporation for the design of Seawater Pumps.

1.4 Final Report Organization

This Final Report is divided into three (3) volumes:

- Volume I, Systems Requirements and Evaluation, summarizing Tasks II, III, and IV.
- Volume II, Conceptual Designs, summarizing Tasks V, VI, VIII, and IX.
- Volume III, Development Plan, summarizing Task VII.

This volume, Volume I, is a compilation and condensation of three interim reports presented at the end of each task, References 1, 2, and 3.

1.5 Definitions

Throughout this and subsequent volumes, reference will be made to the OTEC Ocean System, Power System and Transmission System. For this study, the Ocean System consists of those functional elements necessary to support the payload which generates and transmits electrical power from the platform to shore. These elements are defined on the Work Breakdown Structure shown in Figure 1.5-1 to consist of the Hull, Seawater, Position Control and Support Systems and related systems engineering sub-elements. The WBS shown in this Figure was modified at the completion of Task IV. Therefore, Figure 1.5-1 only applies to this Volume.

The Power System consists of those elements necessary to convert the seawater system temperature differentials into electrical power, and consists of the following:

- Evaporator System
- Condenser System
- Turbogenerator System
- Ammonia and Nitrogen Transfer and Storage System

Figure 1.5-2 defines the interfaces between the Power System and the Seawater System as used throughout this study.

FIGURE 1.5-1.

PROPOSED THIRD LEVEL OCEAN SYSTEM WORK BREAKDOWN STRUCTURE

POWER SYSTEM/SEAWATER SYSTEM DEFINITION

THIS PAGE
WAS INTENTIONALLY
LEFT BLANK

2.2 Payload Definition

The payload which the OTEC platform must support is comprised of three major systems. These include the Power System, Transmission System, and Seawater System. For the purpose of defining platform requirements and developing conceptual baseline designs, the following system descriptions are provided.

2.2.1 Power System

The Power System to be installed as one or more modules on the OTEC platform generates electrical power utilizing an ammonia closed loop cycle and the inherent temperature difference between the ocean surface and ocean depths. Heat stored in the warm ocean surface water is used to vaporize ammonia, which in turn is used to drive a turbo-generator. Cold ocean water from depths in the 3,000 foot range provide the necessary heat sink for ammonia condensation. A portion of the power generated by the turbo-generator is utilized for module equipment such as seawater and feed pumps while the remaining power is combined with the output of other modules for transfer ashore via the transmission system.

Data for the development of a baseline power plant was provided by Reference (4). This data consisted of weight, volume and cost characteristics for four (4) sizes of heat exchangers (5, 8, 12.5, 25 MW) so that comparison studies could be performed. This data was also utilized in development of Top Level Requirements including preliminary sizing of the Seawater System and auxiliary systems. Based on the results of studies utilizing this data in Section 2.4, a Power System composed of 25 MW heat exchangers requires the least amount of volume and weighs the least.

This Power System is comprised of an evaporator, turbo-generator, condenser, two feed pumps and connecting piping. Two feed pumps are specified for redundancy with one considered to be in an operating mode and the other in a standby mode. Appendix A provides power system component description based on the data in Reference (4). It is emphasized that this data is currently based upon gross system output, with no reduction for parasitic electrical load from Seawater System pumps or platform electrical requirements. All reference to MW ratings throughout this volume refers to gross output. Net output could be as much as 30 percent less.

2.2.1 Power Systems (Continued):

Areas of interface include heat exchanger connections with the Seawater Systems, the interface between generator and Transmission System, as well as Auxiliary and Support System interfaces. These interfaces have the form of hard connections such as those between heat exchangers and piping which may be bolted or welded and the interface between generators and the Transmission System which would be an electrical connection.

2.2.2 Transmission System

The Transmission System includes conversion and switching equipment, the interface with the Power System, and the cable between the Commercial Plant and shore based facilities. Initial data provided by DOE on the Transmission System is included in Appendix A. This information indicates that total Transmission System weight and volume is less than 10 percent of the weight of the Power System which feeds it. Therefore, from the standpoint of equipment arrangement, volume and weight, the impact of the Transmission System is not critical. Data on motion limits associated with the transmission cable was not available during Task IIA. However, it was recognized that these limits, once defined, would have a major impact on the Position Control System.

2.2.3 Seawater System

Reference to the Seawater System on the OTEC platform includes both the cold and warm seawater systems. The purpose of these systems is to provide the necessary water for the evaporation and condensation of ammonia in the power cycle. Each system includes the necessary pumps, piping and filters to fulfill this task. Component descriptions for equipment in the Seawater Systems are included in Appendix A.

Major components of the cold water system include the cold water inlet pipe, cold water pump, filtration assembly and a distribution system. A minimum of one each of these components is required for the cold water system on each module, although the cold water inlet pipe may be sized to provide cold

2.2.3 Seawater System (Continued):

water for all condensers in the OTEC Plant. For the feasibility design phase of the 25 MW module, a single cold water pump of the vertical propeller type has been assumed for purposes of estimating volumes and weights. This may be modified by later design developments, but it does provide a baseline. Preliminary design of a filtration device for the cold water system is based on a strainer plate type device sized so that the hole diameter is equal to or less than an assumed condenser tube inside diameter of 1-1/2 inches. Suction and discharge pipe sizes and seawater flow requirements are based on data provided by Reference (4).

Warm water system components also include a distribution system, a pump and a filtration device. Here too, a vertical propeller type pump has been assumed for purposes of estimating volume and weight requirements for preliminary design. Pipe data and flow requirements provided by Reference (4) were utilized in estimating pump characteristics. Of concern during the next design phase, other than pump and piping component refinements, will be system inlet and outlet locations both in relation to each other and to the cold water system to avoid contamination of warm inlet water with cooler discharge water.

2.3 Top Level Requirements (TLR)

The conventional marine system design cycle consists of a well-defined series of design phases. This cycle usually begins with early-stage feasibility studies to identify, at a low technical level, the relationships between key program requirements and possible solutions. These alternative solutions are validated during Conceptual Design, and principal system parameters are established. Preliminary Design leads to a complete technical definition of the system including subsystem trade-offs. Finally, Contract Design produces a contractable package of drawings and design specifications.

A control document must be developed for each of these design phases in order to ensure that all program activity is coordinated and responsive to a single set of overriding criteria. Naturally, the format, content and level of detail of such control documents varies widely between various segments of the marine industry; however, these documents generally begin with a very broad set of mission requirements and constraints as input to feasibility studies, and increase

2.3 Top Level Requirements (TLR) (Continued):

in level of detail as each design phase is initiated. This increase in level of detail would match that necessary to support the design phase in question. For example, structural design loads and safety factors would not be necessary for early phase feasibility studies, but would be essential for preparation of Contract Design documentation.

The control document proposed for the early phase parametric studies being conducted during Tasks IIA through IV is summarized in Appendix A, and is referred to as a Top Level Requirement (TLR). The document is totally self-contained, and is intended primarily as a set of groundrules for the studies leading to Conceptual Design. As such, it contains both the baseline requirements established for the OTEC Commercial Plant by DOE, as well as a number of assumptions reflecting engineering judgement and a general knowledge of the offshore environment. Such assumptions are subject to further considerations as the program develops, and may well change; however, they serve as a point of departure for these studies.

The TLR used as a baseline for Tasks II - IV is expanded and updated for Conceptual Design, and is presented in Volume II of this report.

2.4 Factors Affecting Size and Configuration

2.4.1 General

This phase of Task IIA establishes the basic volume, weight, and configuration requirements for the OTEC Commercial Plant Ocean System and is the first step in developing the technical input to be used in the Evaluation Plan to arrive at the optimum plant output and configuration. The initial quantification of the ocean system dimensions, displacement and proportions needed to support the payload requirements set forth in the TLR will take place at this stage thus providing a foundation from which a more detailed and refined input can later be generated. In addition, the sensitivity of the ocean system size and configuration to various factors will be identified and quantified in a gross sense.

2.4.2 Approach

The basic approach to this portion of the Task IIA effort is outlined in flow chart form in Figure 2.4-1. The critical input is the power plant and transmission system information that is to be provided by DOE. This data will be used to construct the basic building blocks of the commercial plant, namely the power modules. Once the volume requirements of the basic power module is known, along with its demands on the Seawater System and Support Systems, it will be possible to develop the gross area/volume and weight requirements that these systems will impose on the total Ocean System. Using this information, baseline Commercial Plant arrangements will be developed for the six (6) hull configurations to obtain a feeling for their dimensions, proportions, and displaced volume.

The baseline arrangements will be done for a series of plant outputs (50, 100, 200, 350, and 500 MW) yielding the data needed by the Evaluation Plan to optimize plant output and configuration. The range of plant sizes was selected to insure coverage of the most probable optimum plant output band yet not push technology beyond the near term state-of-the-art. Based on cumulative engineering judgement, 1×10^6 Tons is about the displacement of the largest offshore structure that could reasonably be expected to be built, and extrapolation of present data from previous studies indicate that to be the approximate size of a 500 MW plant. The lower limit was chosen to insure an end point for the data well below the hypothetical optimum, and since it is 50 MWe less than the value used by TRW in Reference (5), and 110 MW less than Lockheed's in Reference (6), it was deemed a reasonable lower limit. It must be realized that this range is not rigid and may be modified as more data is received and engineering studies reach more refined levels.

Gross weight studies utilizing data provided by DOE (Power and Transmission systems, weights/volumes), information synthesized from the baseline Ocean System configuration (structural and seawater system weights), and available parametric data (support system weight/volumes) will yield a total weight for the Commercial Plant enabling a determination of weight or volume criticality to be made. This is a critical point since a weight-critical platform might necessitate a weight reduction program or an increase in displaced volume to maintain the platform at the desired draft, and conversely with a volume limited space consideration will have to be given to minimizing platform volume or adding ballast.

FIGURE 2.4-1

APPROACH TO STUDIES OF SIZE AND CONFIGURATION

(Continued Next Page)

FIGURE 2.4-1

APPROACH TO STUDIES OF SIZE AND CONFIGURATION

(Continued)

2.4.2 Approach (Continued):

After resolution of the preceding question, an assessment of the baseline Commercial Plants motions and positionkeeping requirements will be made. Its purpose will be to obtain a rough comparison between the characteristics of each configuration and will act as a stepping-off point for further studies. Existing information will be relied upon for this phase which will out of necessity be very qualitative.

The final area of analysis undertaken as part of this task will be an assessment of the technology and facilities required to design, fabricate, assemble, and deploy the Commercial Plant. The size and configuration of the baseline Plants will be a variable in this study in that these factors must be balanced against the capabilities of U. S. facilities.

The preceding effort comprises the first step of an iterative process that results in increasingly detailed and refined information, as it spirals down to the final design point. This "design spiral" which is defined in Reference (7), begins with the lowest level of detail and the assumptions made at this stage may be modified as time goes on and technical analyses generate firmer data and conclusions. The probability of this happening in this case is relatively high because of the scarcity of well defined, proven parametric data for OTEC Ocean and Power Systems. Normal design practice would have been to utilize such information to enter the design spiral, but in this case, the required information had to be synthesized using standard ocean engineering design and analysis methods coupled with inputs from previous studies, and other pertinent literature. This is a difficult and time consuming task, but nevertheless, necessary when breaking new ground in Ocean System design. The synthesis approach also included a heavy reliance on engineering judgement and cumulative experience, and many simplifying assumptions were made that should not be interpreted as a prejudgement of the solution or a hard and fast answer. By the time the data is required in the actual evaluation during Task IV, it will be at a level commensurate with the detail required for the technical and economic evaluation and will progress to an even higher level at the time of the conceptual design.

2.4.3 Baseline Commercial Plant Development

2.4.3.1 Power System Definition

Enclosure (1) to Reference (4) contains weight and principal dimensions for the major power system components and is included as Appendix B to this volume. The various components were combined to form a baseline power plant module of 25 MW that is to be used as the basic building block of the OTEC Commercial Plant. Appendix B indicates that heat exchangers (condensers and evaporators) of four sizes are to be considered - 5, 8, 12.5 and 25 MW - totalling 25 MW per module.

In developing the basic power module, minimum weight and volume was of primary concern since the ultimate goal is to reduce total Plant cost through the minimization of size. As a first iteration, 25 MW components were chosen as the best candidates from which to build the basic power module because this approach provided the advantages of economy of scale. Figure 2.4-2 demonstrates the weight and volume savings accrued by using the 25 MW components in a cubic module. Cycle efficiencies and other such considerations were not included in the evaluation of the best component size to utilize since at this stage these were considered secondary effects.

The question of Power System component size involves more than the evaluation of total size and weight for a 25 MW module as shown in Figure 2.4-2; there is also the question of packing density and efficiency of the modules in the Ocean System. For example, 5 MW heat exchangers and turbogenerators could be more efficiently packed into the otherwise unuseable corners of volume-inefficient platforms such as a sphere. In order to test the validity of this assumption, packing efficiencies were calculated for the four (4) 25 MW modules incorporating 5, 8, 12.5, and 25 MW components respectively. Figure 2.4-3 illustrates typical layouts for 25 MW components. This packing efficiency was defined as the ratio of the volume of major components (heat exchangers, turbogenerators, demisters, manifolds and risers) to the total cubic volume enclosing the module. These efficiencies are as follows, based on the component sizes in Appendix B:

25	MW components	=	28.1%
12.5	MW components	=	19.5%
8	MW components	=	17.3%
5	MW components	=	19.5%

WEIGHT AND VOLUME OF BASIC POWER MODULE
USING 5, 8, 12.5, AND 25 MWe COMPONENTS

25 MW POWER MODULE CONFIGURATIONS
(Typical)

CONDENSER

VERTICAL HEAT EXCHANGERS

HORIZONTAL HEAT EXCHANGERS

2.4.3.1 Power System Definition (Continued):

This shows a clear superiority for the 25 MW components. Although the 5 MW components would be better than either their 8 or 12.5 MW counterparts due to the possibility of utilizing otherwise unusable areas, the 25 MW efficiency is so much greater as to offset any such potential for the 5 MW components.

This conclusion is further enforced by consideration of the piping into and out of the heat exchangers, which is not reflected in the volumes considered previously. For example, a single 28 foot diameter suction pipe would suffice for a 25 MW heat exchanger. Five - 5 MW exchangers would require an equivalent cross-section area, resulting in five 12.5 foot diameter pipes. With minimum clearances between pipes, the gross cross section of such a system would be at least 25 percent greater than the single pipe. Adding to this the necessary manifolding, filter assemblies and other weight-and-volume consuming equipment, it is obvious that the 25 MW components are preferable from the point of view of payload size and weight.

It is likely that further study could result in greater packing efficiency than that reflected in the above comparison. However, it is felt that such efficiencies could be achieved across the board, so that the relative conclusions reached above would still be valid.

The next step is to relate the weight and volumetric efficiencies of the four heat exchanger options to total Commercial Plant weight and volume. Figure 2.4-2 indicates that the volume of a module utilizing 25 MW heat exchangers allows a 25 to 30 percent reduction in volume relative to the smaller components. The corresponding weight reduction is between 3 and 11 percent. As will be shown later, the majority of platforms are volume critical, so that the impact of the 20 to 30 percent volume savings is far more important in terms of overall platform characteristics. In fact, the results shown later in this Section would indicate that the Power System contributes less than 20 percent of the total plant displacement. Thus, a 3 to 11 percent growth in Power System weight would have a negligible effect on total plant characteristics, and could generally be compensated for by reductions in ballast or structural weight.

2.4.3.1 Power System Definition (Continued):

On the other hand, these studies indicate that the volume of the Power System varies from one quarter to over one-half of the total plant volume, so that a 25 to 30 percent increase in this volume would have a very significant effect on plant size. Table 2.4-1 indicates that the overall increase in platform volume would be between 6 and 20 percent, with a proportional increase in structural weight and cost, and a somewhat lower increase in other platform systems.

TABLE 2.4-1PLATFORM VOLUME INCREASE TO SUIT 5-25 MW COMPONENTS

COMPONENT SIZE, MW	100 MW Plant				500 MW Plant			
	5	8	12½	25	5	8	12½	25
Ship	1.16	1.18	1.13	1.00	1.10	1.10	1.08	1.00
Cylinder	1.13	1.14	1.10	1.00	1.16	1.17	1.13	1.00
Spar	1.18	1.20	1.15	1.00	1.14	1.15	1.11	1.00
Submersible	1.14	1.15	1.11	1.00	1.10	1.11	1.08	1.00
Semi-Submersible	1.14	1.15	1.10	1.00	1.07	1.10	1.08	1.00
Sphere	1.13	1.13	1.11	1.00	1.07	1.07	1.06	1.00

NOTE: This data was obtained by increasing that portion of total volume occupied by power plant (Figures 2.4-21 through 2.4-26) by the following factors derived from Figure 2.4-2:

25 MW: 0% (Baseline)

12.5 MW: 25%

8 MW: 32%

5 MW: 30%

Another area to consider is cost. Although the data now available does not include heat exchanger costs, Appendix B indicates the following costs for other components of a 25 MW power module (also excluding seawater circulation piping, which varies with platform size and configuration).

25 MW components = \$4.05 M

12.5 MW components = \$4.46 M

8 MW components = \$4.39 M

5 MW components = \$5.04 M

2.4.3.1 Power System Definition (Continued):

This indicates a slight economy of scale which presumably would apply to the heat exchangers as well. Adding to this the higher installation cost of more, smaller-size components, it is apparent that cost considerations favor 25 MW components, both for the Power System and the Ocean System. This results since platform costs are roughly proportional to weight and volume which, as shown later, are directly related to Power System weight and volume.

A final cost-related factor to consider is maintenance. It can be assumed that 5 - 5 MW heat exchangers will require more maintenance than one 25 MW unit, even if the tube area is identical, due to greater shell and inlet pipe area to be cleaned. For example, one 25 foot pipe has 88 square feet of wetted surface area per foot of length, while 5 - 12.5 foot pipes have 196 square feet per foot, over twice the surface exposed to biofouling.

Based on the foregoing analysis, it is clear that 25 MW components are preferable from the point of view of platform size, weight and cost, maintainability and system simplicity. Therefore, 25 MW components are used for the remainder of the Task IIA studies.

With the power system component size established, it was possible to block out rough configurations for the power modules to be used on each of the six candidate hull forms. In all cases, attempts were made to minimize cycle losses by keeping piping runs as short as possible commensurate with the arrangement constraints imposed by the projected Ocean System configurations, although minimum Ocean System size was the primary concern. Since the six different hull forms involved radically different proportions and volumetric requirements, a number of power plant module configurations were developed to minimize the size of each given Ocean System configuration. The various power plant modules developed, their volumes, weights, and the platforms in which they are located are presented in Table 2.4-2 (See Appendix C, Reference (1) for module configurations).

2.4.3.1 Power System Definition (Continued):

TABLE 2.4-2

POWER MODULE MATRIX

<u>MODULE TYPE</u>	<u>VOLUME (Ft.³)</u>	<u>WEIGHT (L.T.)</u>	<u>PLATFORM</u>
High Cubic	8.9×10^5	6,150	Ship, Cyl, Submersbl.
Low Cubic	7.0×10^5	6,050	Ship, Submersible
Vertical	10.7×10^5	6,250	Spar, Sphere
Angular	14.9×10^5	6,150	Cylinder, Spar
Split	8.6×10^5	6,430	Semi-Submersible

2.4.3.2 Seawater System Definition

The Seawater System characteristics are dictated by the requirements of the Power System, the most significant of which are the necessary flow rates and temperature differentials. These in turn drive the diameter and length of the cold water pipe, the size of the warm and cold water pumps, and the distribution system internal to the Ocean System. Using the cycle information provided by DOE in Reference (4), the requirements of the Seawater System were established, and these led to a Seawater System configuration for a range of plant outputs. These configurations do not represent a final design, but are meant to be used as a tool in defining the baseline Ocean Systems; therefore, a number of simplifying assumptions were made to permit the timely development of the initial hull systems. The most important ones include:

- A cold water pipe length of 3,000 ft. was assumed in all cases since this length falls within the range of depths that yields a ΔT equal to or near that required by the Power System at all three sites. Varying this length does not appreciably change the bending moment of the cold water pipe, thus keeping it within the level of accuracy desired at this stage of development.

2.4.3.2 Seawater System Definition (Continued):

- The "worst case" surface current (5 knots at Key West), modified by the current profile given in Reference (8), was chosen to determine the cold water pipe drag induced bending moment.
- Prestressed concrete is assumed to be the material of construction, with a density of 165 Lb./Ft.³.
- A flow rate of 5 Ft./Sec. was selected for the cold water pipe to minimize biofouling and head losses.
- A single CWP was used for all Plant options from 25 to 500 MW.
- A joint between the cold water pipe and hull allows relative motion between them to reduce the bending moment developed in the pipe as a result of hull motions in a seaway.

Further studies of the cold water pipe were conducted in parallel with these studies to assess in somewhat greater detail the interaction of CWP motions, drag, fixity, materials and other factors which must be considered in selecting its characteristics. These studies are summarized in Reference (1). Due to time constraints, it was not possible to integrate these CWP studies with the analysis of factors affecting size and configuration which follow. Such integration was accomplished during Task IV, however.

The connection between the cold water pipe was not investigated during Task IIA, but it was recognized that this is a significant problem. A flexible interface as hypothesized by TRW in Reference (5) was considered so that the hull motion induced loading of the cold water pipe was minimized as much as practicable.

The pumps were developed based on the requirements of a 25 MW module and their dimensions and weight may be found in Appendix A. It was assumed that the pumps would be integrated into the volume of the cold and warm water pipes or the internal distribution plenums, and would not have a major volume impact on the Ocean System. On the other hand, the internal distribution piping or plenums are expected to have the greatest effect on the Ocean System volume with respect to the Seawater System. For arrangement purposes, these distribution systems were assumed to be integrated into the Ocean System structure and were of a sufficient cross sectional area to equal the warm and cold water intake areas.

2.4.3.3 Support System Definition

This category may be divided into two basic areas - personnel support and overall platform support. Personnel support includes only those functions involved with habitability considerations such as berthing, messing, and recreation, while overall platform support implies the entire spectrum of mechanical, electrical, electronic, and maintenance systems dedicated to the support of the Commercial Plant; e.g., materials handling systems, heating, ventilation, air conditioning, navigation systems, etc.

The independent variable with respect to habitability is the Commercial Plant manning level. Based on an initial assessment of the requirements of the Plant, a permanent manning level of 30 personnel was arrived at. Given the assumption that the Ocean and Power System machinery will be heavily automated, this level will not change appreciably with platform size. Using present day merchant vessel standards, 2,100 ft.³/man was selected as a viable criteria. This figure includes living, recreational, and messing space, and resulted in a total volume of 6.3×10^4 ft.³. This is an order of magnitude less than the volume of one 25 MW power module, so for estimating purposes, 1×10^5 ft.³ was assumed for the habitability volume to insure adequate space has been allocated. Finally, a weight factor of 3.5 Tons/man resulted in a total weight of approximately 105 L.T., an insignificant amount comparatively.

Platform support requirements have been developed based on the anticipated needs of the Commercial Plant. The relatively constant level of manning versus Plant size, the concept of an automated power system with its minimum of permanently manned spaces and resultant low heating, ventilation, and air conditioning load, and the fact that an increase in power plant module number does not necessarily impact the support system size because of duplication of support functions, all combine to desensitize support system weight and volume requirements with respect to Commercial Plant size.

Initial estimates have indicated an approximate volume of about 1×10^5 ft.³ for all support sub-systems on a 500 MW platform. This includes space for all group "D" third level WBS elements with the exception of personnel support which has been dealt with separately. This estimate is based on a very conservative gross estimate of the requirements of the Ocean System. As with personnel support, this value is

2.4.3.3 Support System Definition (Continued):

a small percentage ($\approx 15\%$) of the volume of one powermodule. This gross estimate was modified slightly (reduced 33%) for the smallest platform and was assumed linear between. This level of accuracy should be more than adequate for the initial baseline designs. The total weight of the Support Systems for the 500 MW Plant was estimated to be 600 Long Tons, again an insignificant figure in relation to the 6,000 Tons of one power module, and the same linear decrease was assumed.

2.4.3.4 Transmission System Definition

Transmission System data was incomplete during Task II, but it was not anticipated to be a driving factor in the baseline Plant size and configuration determination. For arrangement purposes, a figure equal to 5% of the power system volume and 10% of its weight was allocated for the Transmission System.

Information received from DOE subsequent to the completion of the baseline designs presented herein indicated that a volume and weight allowance equal to 5% of that for the Power System should have been reserved. This implies that the values used by Gibbs & Cox, Inc. were well within the limits of accuracy at this stage of analysis, and in any case, the impact on the Commercial Plant size is insignificant.

2.4.3.5 Positionkeeping System Definition

Positionkeeping was not addressed in the first-cut arrangements because of the large number of variables involved and the minimal anticipated impact on the Ocean System. For example, the following options are possible:

- Static positionkeeping,
- Dynamic positionkeeping using vectored cold and warm water discharges,
- Dynamic positionkeeping using dedicated thrusters powered by the Power System output or separate prime movers,
- A combination of any of the preceding.

Based on the configuration, the optimum positionkeeping approach could be any of the above. This problem need not be addressed at this time except in the context of allowing for sufficient volume and weight in these initial arrangements. For example, preliminary estimates for a 500 MW cylinder indicate approximately

2.4.3.5 Positionkeeping System Definition (Continued):

4.5×10^4 horsepower to maintain position in a 5 knot current. Of the above approaches, static positionkeeping would have the least impact on the Ocean System size, while the use of vectored sea water discharges would most probably involve the realignment of the discharge ducts - an operation of minimal impact at this stage. The use of dedicated thrusters tends to perturb the internal arrangements somewhat, but only if the increase in the parasitic loads on the Power System is unacceptable and additional modules must be added or extra space must be allocated to prime movers.

If it is assumed that a dedicated ducted thruster dynamic positioning system is fitted to the 500 MWe cylinder and diesel generators are used as prime movers, as either normal or emergency power sources, then a total internal space demand of about 1.5×10^5 ft.³ would be generated. In addition, based on typical ducted thruster and diesel generator weights, a figure of about 0.06 tons/horsepower is reasonable, therefore the corresponding Positionkeeping System weight would be in the vicinity of 2,700 Tons. Both these figures are small compared to the total volume and displacement of the Corresponding Plant; therefore, the impact of the Positionkeeping System is minimal. This percentage could vary as the Plant size and hull configuration changes because of non-linearities and the different drag coefficients, but it should still remain small.

2.4.3.6 First Iteration Baseline Commercial Plant Configurations

With the establishment of the basic volumetric requirements of the systems comprising the Commercial Plant, it was possible to commence the blocking out of functional volumes for the six different hull forms and five selected plant outputs. In all cases, the highest priority was given to the arrangement of the Power System modules and the seawater distribution system to arrive at hull forms with reasonable proportions. Perhaps the greatest single influence the Power System had on the Ocean System layout, was the necessity of locating the evaporator and condenser within the watertight boundaries of the hull because of their inability to withstand any type of structural loading. Placing these units external to the hull could have reduced the volume of the Ocean System significantly, but would have subjected them to hydrostatic pressures or bending moments possibly beyond their limits. An external location would also complicate maintenance problems, but the

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

external arrangement was later demonstrated to be cost-effective during Task V (see Volume II).

As previously discussed, the connection between the cold water pipe and the hulls under consideration was not investigated in detail at this time, but in all cases a reasonable volume was allowed for an interfacing system.

As demonstrated in Section 2.4.3.3, the comparatively small volume demands of the Support System resulted in its component subsystems being located after the requirements of the Power and Seawater Systems were met. Extensive consideration was not given to the special relationships of these minor impact systems since the purpose of this phase of the study was to define gross volumetric envelopes, not develop final conceptual arrangements which is a portion of Task V. The general guidelines followed at this time with reference to these systems did locate habitability areas high in the various hulls and auxiliary machinery near the main machinery.

In developing the Commercial Plant baselines, an allowance was made for hull structure since the structural systems that will be used in each of the hull forms will require a finite amount of space and have a major impact on Ocean System displacement. Since all previous major OTEC studies proposed concrete construction, it was assumed to be the primary material of construction for this initial iteration, and based on this assumption, the ship-shapes were allowed an extra 10 feet on all dimensions and the other configurations 5 feet. This is solely a first-cut assumption and should not be construed to be the actual dimensions required. In the same vein, the use of steel and/or composites as portions of the structure should not be ruled out at this time; this will be investigated in more detail during the evaluation phase and in depth during conceptual design. Structural calculations accomplished at this time serve the sole purpose of estimating total Ocean System displacement and validating the assumed arrangements with respect to possible structural interference.

The factors behind the development of the baseline platforms for each configuration are discussed below, while the Commercial Plant layouts are presented in Appendix D to Reference (1). Figures 2.4-4 through 2.4-9 are typical examples, for the 500 MW size. The parametric weight and volume relationships derived from the layouts are illustrated in Figures 2.4-10 through 2.4-26.

500 MW

1" = 100'

220'

760'

150'

FIGURE 2.4-4

ARRANGEMENT: SHIP

FIGURE 2.4-5
ARRANGEMENT: CYLINDER

18351-10
(W-10,000)

FIGURE 2.4-6
ARRANGEMENT: SPAR

FIGURE 2.4-7
ARRANGEMENT: SUBMERSIBLE

500 MW

1" = 200'

FIGURE 2.4-8

ARRANGEMENT: SEMI-SUB

FIGURE 2.4-9
ARRANGEMENT: SPHERE

FIGURE 2.4-10

NOTE: PAYLOAD WEIGHT INCLUDES POWER SYSTEM
TRANSMISSION SYSTEM & S.W. SYSTEM (DEY)

FIGURE 2.4-11

NOTE: PAYLOAD WEIGHT INCLUDES POWER SYSTEM
TRANSMISSION SYSTEM & G.W. SYSTEM (DR)

FIGURE 2.4-12

FIGURE 2.4-13

FIGURE 2.4-14

FIGURE 2.4-15

FIGURE 2.4-16

FIGURE 2.4-17

FIGURE 2.4-18

FIGURE 2.4-19

FIGURE 2.4-20

FIGURE 2.4-21

FIGURE 2.4-22

FIGURE 2.4-23

FIGURE 2.4-24

FIGURE 2.4-25

FIGURE 2.4-25

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

- Ship - The proportions of this configuration were developed by arranging the high and low cubic Power System modules in a manner so as to keep the total Ocean System volume to a minimum. Since the larger systems involved power modules located some distance from the hypothesized locations of the seawater inlets, space was allocated for a seawater distribution system that would be integral with the hull structure.

The hull forms were not optimized with respect to hydrodynamic drag since the block coefficient of most of the smaller hulls approaches unity. In actuality, modified Power System modules could be utilized in the "bow" and stern" or fairings could be added fore and aft to decrease drag.

From a structural standpoint, the low length/draft ratio resulting from the arrangements of the Power System is advantageous since it results in lower longitudinal bending stresses. With concrete construction, minimizing these stresses is very desirable to reduce the tensile loading on the concrete and the problems of longitudinal structural continuity.

Table 2.4-3 presents the principal dimensions for the five ship shape Plants evaluated. All were volume limited with the exception of the 50 MW configuration, which required an additional 20 feet of depth to achieve a reasonable freeboard of 15 feet. The 500 MW version necessitated the addition of 1.3×10^5 Tons of ballast to maintain the evaporators and condensers in the second tier submerged.

- Cylinder - Although the cylinder is analogous to the ship shape with respect to its large waterplane area, it differs in its basic arrangement and proposed structural system. The "angular" Power System module was utilized to maximize the use of the circular platform area, thus minimizing overall Ocean System size while the circular configuration of the power modules allowed direct access by the Seawater System to each module.

TABLE 2.4-3

PRINCIPAL CHARACTERISTICS - SHIP

<u>SHIP SHAPE</u>					
Plant Size, MW	50	100	200	350	500
Length, Ft	260	280	430	820	760
Beam, Ft	120	180	260	280	300
Depth, Ft	120	140	140	140	220
Draft, Ft (excl. CWP)	105	105	95	100	150
Lightship, LT	90,200	143,800	263,200	432,600	692,000
S.W. in Systems, LT	2,800	7,300	39,300	115,000	156,800
Ballast, LT	0	0	0	0	128,300
Full Load, LT	93,000	151,100	302,500	547,600	977,100

TABLE 2.4-4

PRINCIPAL CHARACTERISTICS - CYLINDER

<u>CYLINDER</u>					
Plant Size, MW	50	100	200	350	500
Length, Ft.	200	320	420	400	480
Beam, Ft	<i>Diameter</i> -----				
Depth, Ft	160	120	100	220	200
Draft, Ft (excl. CWP)	130	85	85	170	170
Lightship, LT	104,000	185,800	304,800	561,100	783,600
S.W. in Systems, LT	8,400	6,700	31,400	54,000	87,000
Ballast, LT	0	0	0	0	8,300
Full Load, LT	112,400	192,500	336,200	615,100	878,900

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

- Cylinder (Continued):

The proposed structural system for the cylinder consists of a circular outer shell with radial bulkheads separating the various power modules and different portions of the seawater system. The problem of longitudinal bending moments is not of critical concern with the cylindrical configuration, but overall structural rigidity and hydrostatic pressure at the increased drafts remain a consideration.

As with the ship-shape configurations, the majority of the cylinders were volume limited. The exception in this case was the 50 MW size which required a 20 foot increase in diameter. Table 2.4-4 contains the particulars of the five (5) cylindrically shaped Commercial Plants.

- Spar - In most cases the spar configurations approximated nothing more than a submerged cylinder although the proportions of the spars tended more towards the vertical. The similarity of the two types descended from the fact that the volume of the Power System modules in both systems were equal because the "angular" module was used in all the spars except for the 50 and 100 MW versions, where a vertically oriented module of about the same volume efficiency was fitted. The arrangements maintained the similarity between the two configurations with the Power System modules surrounding a central Seawater System. Habitability and control spaces were located in the surface-piercing "tower" of the spars to maintain ready access to the surface for the Plant operating personnel.

The larger spars uncovered a problem unique to most submerged platforms, i.e., structural requirements driven by hydrostatic forces. The lower shells of all of the platforms became critical because of their large spans and relatively high pressures at the depths being considered. In the case of all platforms, hemispherical heads were hypothesized to reduce the thickness of the concrete required in these areas.

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

- Spar (Continued):

Again, the majority of the Plants were volume limited, with ballast being required to achieve a reasonable submergence of the main body of the spars. The 50 MW version was the exception; requiring additional volume in the form of increased depth. Particulars of each Plant may be found in Table 2.4-5.

- Submersible - The submersibles were essentially ships with water-tight shells as their upper decks. High and low cubic Power System modules were utilized along with a single cold water pipe discharging to a seawater distribution plenum. It was assumed that the submersibles would operate with their upper decks approximately 80 to 100 feet below the surface, the exact distance to be determined later after motions and structural schemes are examined in more detail. Access to the surface and above water portions of the Plants were omitted for simplicity since they do not impact the baseline platforms greatly at this point.

In all cases, but more particularly so in the 350 and 500 MW sizes, hydrostatic head became a critical problem with respect to loading on the bottom shell. This resulted from the extreme submergence of this portion of the submersibles (approximately 360 ft. in the 500 MW version), and is coupled with the large size of the shell panels in those areas which resulted in some difficulty in developing a satisfactory structural arrangement. It must be realized that the operational depth of a WW II fleet submarine was not significantly different than the depths being dealt with here.

In all cases, the submersibles were volume limited and required ballasting to submerge to their operating depth. In fact, based on these preliminary studies, upwards of 3.5×10^5 tons was estimated for the 500 MW Plant. Principal characteristics were summarized in Table 2.4-6.

TABLE 2.4-5

PRINCIPAL CHARACTERISTICS - SPAR

<u>SPAR</u>					
Plant Size, MW	50	100	200	350	500
Length } Ft	150	170	300	385	430
Beam }					
Depth, Ft	215	290	280	340	340
Draft, Ft (excl. CWP)	195	260	230	290	290
Lightship, LT	72,500	143,000	312,200	709,200	898,500
S.W. in Systems, LT	600	1,700	22,400	55,000	92,000
Ballast, LT	1,900	3,100	46,200	66,800	42,200
Full Load, LT	75,000	147,800	380,800	831,000	1,032,700

TABLE 2.4-6

PRINCIPAL CHARACTERISTICS - SUBMERSIBLE

<u>SUBMERSIBLE</u>					
Plant Size, MW	50	100	200	350	500
Length, Ft	300	320	510	860	720
Beam, Ft	140	200	300	300	340
Depth, Ft	120	160	160	160	280
Draft, Ft (excl. CWP)	170	210	210	210	330
Lightship, LT (Concrete)	102,000	203,900	416,900	608,400	1,038,300
S.W. in Systems, LT	7,560	15,120	61,000	130,800	199,400
Ballast, LT	62,300	23,800	156,100	270,300	358,000
Full Load, LT Δ (Concrete)	172,900	242,800	634,000	1,009,400	1,595,600

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

- Semi-Submersible - This configuration presented some difficulties in that a use for the above water cross structure had to be found. Ideally, all Power System equipment should be contained in the lower hulls for two reasons:

- The heat exchangers and condensers remain submerged,
- NH_3 piping runs are minimized thus reducing system losses.

The "split" Power System module configuration was developed to attempt to satisfy both these conditions as well as possible, and at the same time use some of the extensive space available in the cross-structure. Habitability and other Support System subsystems were also located cross structure with the vertical struts being used for the demisters, turbine exhaust piping, auxiliary services distribution, and access.

The cold water pipe on all the semi-submersible plants was attached to a plenum that joined the lower hulls, and in the case of the 350 and 500 MW Plants, it also tied into a third lower hull running between the outer ones and used as a cold water distribution pipe. This arrangement was advantageous from a structural standpoint because it formed the two outer lower hulls, the struts, and the cross-structure into a ring resulting in a closed structural system. This is quite significant since the critical structural loading in a semi-submersible is the bending stresses developed in the cross-structure as a result of beam seas. This could be potentially quite high in the configurations being considered here because of the large size of the lower hulls and the relatively low depth of the cross-structure.

In all cases, the semi-submersibles were extremely weight limited. It may be seen from Table 2.4-7 that the full load weight of the semi-submersibles exceed the full load displacement, assuming a realistic waterline, by a minimum of 3.5×10^4 tons for the 50 MW Plant to 1.3×10^5 tons for the 500 MW Plant. This problem is typical of semi-submersibles and in this case can be attributed to the following:

TABLE 2.4-7
PRINCIPAL CHARACTERISTICS - SEMI-SUBMERSIBLE

<u>SEMI-SUBMERSIBLE</u>					
Plant Size, MW	50	100	200	350	500
Length, Ft.	260	580	780	980	1,160
Beam, Ft	160	190	360	420	540
Depth, Ft	170	170	170	172	174
Draft, Ft (excl. CWP)	90	90	90	92	94
Lightship, LT (Concrete)	85,400	154,600	306,200	394,700	650,900
S.W. in Systems, LT	3,360	12,320	22,400	86,800	184,800
Ballast, LT	0	0	0	0	0
Full Load, LT Δ (Concrete)	88,720	166,900	328,600	481,500	835,700
Displacement @ Design Draft, LT	53,800	106,800	280,900	411,500	703,000
Full Load Δ (Steel Construc- tion), LT	59,800	108,700	280,900	411,500	703,000
Ballast* Required (Steel Construc- tion), LT	0	0	80,500	67,700	143,700

*"Ballast" may include permanent ballast in the form of reinforced concrete construction of underwater hull.

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

- A significant portion of the payload and hull structure are contained in the vertical struts and upper cross-structure which contribute little or nothing to buoyancy.
- The lower hulls are very volume efficient since they essentially are concentric with the heat exchangers contained within and thus provide a limited amount of net buoyancy.

Increasing Ocean System buoyancy by altering the dimensions of the lower hulls does not readily solve this problem because insufficient volume is obtained; e.g., increasing the hull diameter of the 50 MW Plant by 10 feet only gained one-third the necessary additional buoyancy. Also, as the hull diameters increase, the structural loading became more critical and hull weight rises because of the additional shell thickness required. A combination of inner hull length and diameter increases could yield sufficient buoyancy, but a large amount of wasted space would result.

The other solution involves steel construction, either in total or in combination with concrete to reduce the Commercial Plant weight to an acceptable value. Based on the fact that a steel ship would be approximately three to four times lighter than an equivalent concrete one, the 50 MW Commercial Plant, if constructed of steel, would float at a reasonable draft as presently configured solely as a result of the savings in hull structural weight. By utilizing a part steel and part concrete structure, the weight could be adjusted as necessary to achieve the necessary weight without ballasting, in a case where an all steel structure would be too light.

- Sphere - This configuration presented unique problems in effectively utilizing its internal volume. The majority of the hypothesized Power System modules were cubic in nature and highly volume efficient, given the nature of the components of which they were composed; therefore, utilizing these modules in a spherical envelope resulted in a relatively large amount of unused space. Both vertical and low cubic modules were used in an attempt to minimize the outer diameter of the spherical hulls, and the results in many cases formed compact arrangements to which the Seawater System could readily distribute warm and cold water.

2.4.3.6 First Iteration Baseline Commercial Plant Configurations (Continued):

In all cases the spheres were volume limited and ballasting was necessary to submerge them to an assumed operating draft of two thirds their diameters. Table 2.4-8 contains the principal characteristics of the spherical configurations, and it may be seen that 2.7×10^5 tons of ballast was required in the 500 MW Plant while the 50 to 100 MW Plants required neither ballast nor additional volume to float at or very near their assumed drafts.

TABLE 2.4-8
PRINCIPAL CHARACTERISTICS - SPHERE

<u>SPHERES</u>					
Plant Size, MW	50	100	200	350	500
Length, Ft.	180	260	360	440	500
Beam, Ft.	<i>Diameter</i> -----				
Depth, Ft.	<i>Diameter</i> -----				
Draft, Ft. (excl. CWP)	131	175	242	300	374
Lightship, L.T.	64,500	170,900	332,000	626,000	902,500
S. W. in Systems, L.T.	7,000	25,800	46,500	152,000	226,800
Ballast, L.T.	0	0	143,700	175,400	270,000
Full Load, L. T.	71,500	196,700	522,200	953,400	1,399,300

2.4.3.7 Motions

Appendix F of Reference (1) presents an assessment of baseline Commercial Plant motions based on the information of Reference (9), while Table 2.4-9 is a summary of the range of motions to be expected from the baseline Commercial Plant in Sea State 9. Motions and CWP/Platform connection bending moments have been derived by applying correction factors to the Hydronautics motions and loads predictions report in Reference (9). The correction factors account for:

18351-10 (W-10,000)

2.4.3.7 Motions (Continued):

- CWP/Platform connection stiffness
- CWP Length
- CWP Diameter
- Platform Displacement

In addition, a preliminary analysis of heave response for the sphere configuration has been conducted based on an interim report by Tuned Sphere International, Reference (10). A more detailed discussion of the methodology used to correct for the above four factors may be found in Reference (11) and Reference (12). These motions will not be evaluated in detail in this section, since these results are superseded by studies conducted during Task IV.

TABLE 2.4-9

BASELINE PLANT MOTION SUMMARY - SEA STATE 9

	<u>SHIP</u>	<u>SUBMERSIBLE</u>	<u>SEMI-SUBMERSIBLE</u>	<u>SPAR</u>	<u>CYLINDER</u>
Surge, Ampl., Ft. ⁽¹⁾	29-19	26-8	27-11	21-10	30-23
Sway, Ampl., Ft.	30-23	105-51	16-10	-	-
Heave, Ampl., Ft.	48-44	29-26	29-19	28-21	50-45
Roll Angle, Deg.	2.1-3.6	22-11	12.6-3.7	-	-
Pitch Angle, Deg.	10.5-3.5	8.8-3.6	11.2-3.6	7.8-6.9	14.5-6.8
Yaw Angle, Deg.	2.9-2.2	2.3-1.8	1.0-0.8	-	-
Heave Accel., "g" ⁽²⁾	.20-.16	.09-.06	.08-.04	.07-.05	.18-.09
CWP Bend. Moment x 10 ⁻¹⁰ , Ft.-Lbs.	0.3-1.13	.08-1.4	.02-0.9	.1-1.1	.7-2.7

NOTES:

- (1) All values represent the range of values for platforms of from 100 to 500 MW, CWP lengths of 3,000 feet, and a hull/CWP attachment stiffness of 0 for angular motions, except as noted below.
- (2) Heave accelerations are for platforms with outputs of 100 to 500 MW, a CWP length of 2,000 feet, and a hull/CWP attachment stiffness of infinity.

2.4.3.8 Summary and Discussion of Results

Section 2.4.3.6 presents the more significant data generated from the baseline Commercial Plant study in the form of parametric curves which reflect those factors having an influence on Ocean System size and configuration for each of the six basic hull forms. The two intrinsic parameters that define the Commercial Plant at this stage are weight and total enclosed volume; cost is not covered in this Section and will be considered in Task IV, Systems Integration and Evaluation.

It may be seen from Figures 2.4-21 through 2.4-26 that the installed power generation capacity in the form of Power System modules was the most important factor that determined Commercial Plant volume as expected. A variance in the magnitude of the total volume occupied by the Power System in the six different hull configurations may be noted since the various Power System module configurations vary in their volume efficiency, although each configuration is best suited for the hull into which it has been located.

The Seawater System had the next greatest effect on Plant volume, primarily because of its large demands on space required for the distribution of the seawater to each Power System module. This effect was more pronounced in the linearly configured platforms such as the ship and submarine than in the radially oriented ones such as the spar because of the more efficient arrangement of the modules around the seawater inlet plenums in the latter cases. A detailed analysis of the effect of hull structure on volume was not attempted because the level to which the structural systems were developed at this stage of the study was not sufficient to elicit any meaningful conclusions. Additionally, other system volume requirements may be integrated with many proposed structural arrangements, thus taking advantage of existing space; i.e., auxiliary machinery, habitability spaces, storerooms, etc., may be located within the spaces formed by deep web frames or structural support bulkheads.

In almost all other cases, "Unassigned and Ballast" comprised the last major volume category of the Commercial Plant. Basically, it included the so-called "empty space" between the outer shells of the Plants and the payload envelopes along with the spaces reserved for ballast. The sphere contained the greatest volume of such space as is evidenced by Figure 2.4-26 and the poor Payload/Total

2.4.3.8 Summary and Discussion of Results (Continued):

Volume ratio in Figure 2.4-20. This resulted primarily from the inefficient packing of the standard cubic Power System modules in a spherical envelope, and it resulted in the sphere having the largest total volume over most of the range of Plant sizes considered. To alleviate this situation, the use of modules specifically configured for the sphere should be considered. This approach should meet with some success, although at the possible expense of modularity, since the 50 and 100 MW Plants made relatively efficient use of their volume through the use of a vertical Power System module, and similar successes might result with the others. The submersible and semi-submersible configurations also exhibited poorer volume utilization characteristics; the former for reasons similar to the sphere and the latter because of the large unused volume contained in the upper cross-structure. In general, the submarine had this problem and the ship did not because the submarine utilized a number of arched shell panels to better resist the hydrostatic loads imposed at its operating depths. The semi-submersible could be made more attractive by leaving the majority of the upper cross-structure open so that it serves only as a structural tie between the two lower hulls.

Finally, from Figure 2.4-19, it may be noted that volume is in general linear with increasing Plant capacity; yet the ship and semi-submersible deviate slightly from this trend at the larger outputs. For the ship, this is a result of the decrease in volumetric efficiency in the 350 and 500 MW sizes because of the arrangement of the end power modules and the relatively larger pipe trunk. In subsequent design iterations these plants could be modified, possibly by staggering the Power System Modules so that the hull envelope tapers towards the ends. The semi-submersible experiences a similar phenomena in the two largest configurations because of the switch from a circular to elliptical lower hull cross section along with the addition of the third lower hull in the form of a distribution pipe.

From a weight standpoint, Figures 2.4-13 through 2.4-18 demonstrate that Hull System weight comprised the largest portion of total Commercial Plant weight (approximately 50%) followed by the Power System, water in the Sea Water System, and in some cases, ballast. Ballast became quite significant in the submersible and the sphere as a result of the requirement to submerge the Commercial Plant to its operating draft which in the case of the sphere was dictated by the necessity

2.4.3.8 Summary and Discussion of Results (Continued):

of submerging the heat exchangers in the upper tier of Power System modules and reducing the waterplane area of the hull.

The question of ballast enters into the baseline Commercial Plants because, as previously discussed, most were volume-limited. The primary exceptions were the semi-submersibles. In further design iterations, more efficient payload arrangements will be investigated for these Plants in an attempt to reduce the amount of ballast carried along with the overall Commercial Plant size; however, an alternative to this would be to integrate the ballast either in part or totally into the concrete structure of the Hull Systems thus allowing reduced stresses and consequent lower levels of quality control in the concrete. This latter approach will be the subject of further study in Task V, Conceptual Design, but it illustrates that in a volume limited design which has been optimized with respect to volumetric efficiency will have a given displacement irrespective of the manner in which its weights are apportioned.

Figure 2.4-11, a plot of payload weight/operating displacement versus Commercial Plant size may be used as an indicator of hull efficiency and can demonstrate certain salient points about the baseline designs including some of those discussed above. At first glance it appears that the sphere, submersible and spar are grouped together with relatively low values of payload weight/operating displacement while the ship and cylinder are tending to slightly higher values. This can be partially explained by the increased structural weight inherent with the three former Plants which must withstand higher hydrostatic loads because of their greater depths of submergence along with the larger weight required to immerse them to their operating depth.

Figure 2.4-10, Commercial Plant Operating Displacement Versus Plant Size, tends to verify the trends of Figure 2.4-11, and in addition, demonstrates the tendency of the Commercial Plants to show no economy of scale. In fact, the ship and spar appear to exhibit a reverse economy of scale which is even more curious. These tendencies most probably result from the "building block" approach taken in assembling the Power System modules into the different Commercial Plants; i.e., in most cases to make a Plant with a larger output the only action taken was to add additional modules of a similar configuration which meant that the Plant

2.4.3.8 Summary and Discussion of Results (Continued):

displacement was essentially linear. The ship and spar deviated slightly from this most likely because of inaccuracies resulting from fitting a continuous curve to the data points and the addition of a second level of Power System Modules to the ship and a third level of the spar at higher Plant output levels thus necessitating the need for additional structure in both configurations and ballast in the case of the ship.

The displacements of the TRW, Lockheed Missile and Space Company, and Johns Hopkins Applied Physics Laboratory's OTEC Plants were plotted on Figure 2.4-10 using gross megawatts as the dependent variable for comparison purposes. Relatively good correlation exists for this level of development between the Gibbs & Cox, Inc. trends and these configurations; the differences being as follows:

- TRW - 20% Lighter
- Lockheed - 28% Lighter
- Johns Hopkins - 5% Lighter

Level of detail in the weight analyses, basic design assumptions and parameters, and variations in configuration all combine to result in these differences, and one should not attempt to make any close comparisons between platform weights for these reasons. This is even more true when comparing the Gibbs & Cox, Inc. base-line Plant displacements with those postulated in Reference (8) since they were based on the extrapolation of a line fitted through data points based on a number of Plants of different configurations and was intended only to establish a base-line for motions studies.

2.5 Producibility

The studies summarized in Section 2.4 indicate that the construction of OTEC Commercial Plants will be impacted by two principal considerations:

- Shipyard capacity to handle hulls of the size being considered,
- Capabilities in concrete design and construction.

2.5.1 Size Limitations

Tables 2.4-3 through 2.4-7 provide an indication of the approximate physical dimensions of OTEC Commercial Plants of from 50 to 500 MWe size. In an effort to assess the impact of these dimensions on construction, a brief survey of U. S. shipyard capabilities was made, based on published data and telephone surveys. Written survey questionnaires were also submitted to all new-construction yards considered capable of handling OTEC-type platforms.

Table 2.5-1 indicates overall characteristics of East, Gulf and West Coast yards. For the configurations being considered, beam is generally a limiting factor, based on limits of graving docks or building ways. These limits are as follows, based upon data now in hand:

East Coast: 240 feet (Newport News)

Gulf Coast: 216 feet (Avondale)

West Coast: 170 feet (National Steel)

Considering the data in Tables 2.4-3 through 2.4-7, it appears feasible to build all of the 50 MW plants and four of the six 100 MW plants as a single unit at Newport News or Avondale, based on a width limit (the 100 MW cylinder and sphere require 320 and 260 feet of width respectively). The West Coast limit of 170 feet eliminates most of the 100 MW options. Beyond the sizes noted above, it would be necessary to build the platforms modularly.

An even more critical facilities limitation is the limiting draft of most U. S. shipyards of 30 - 40 feet. It appears that the draft of an empty structural concrete shell for even the 50 MW plants will be between 45 and 60 feet, depending on configuration, and that the addition of Power System modules, Seawater System and outfit will increase this to about 100 feet. This means that a concrete OTEC platform of the proportions envisioned cannot be built in any U. S. shipbuilding facility. Equivalent steel platforms would have significantly lighter structural weight (1/4 to 1/3) with proportionally lesser drafts. Therefore, it can be tentatively concluded that steel OTEC platforms could be fabricated in existing facilities, though modular construction with assembly afloat or in a new facility would be required for sizes above 50 or 100 MW, depending upon configuration.

TABLE 2.5-1
OTEC SHIPYARD SURVEY
EAST COAST

Name	Bath Iron Works	Bethlehem Steel Corp.	General Dynamics Corp.	Maryland Shipbldg & Drydock	Newport News Shipbldg & Drydock	Seatrain Shipbldg Corp.	Sun Shipbldg & Drydock
Location	Bath, Maine	Sparrows Pt., Md.	Quincy, Mass.	Baltimore, Md.	Newport News Va.	Brooklyn, N.Y.	Chester, Pa.
<u>Building Ways:</u>							
Number	3	2	0	1	2	0	4
Max Length, Ft	700	900	-	850	940	-	700
Max Width, Ft	130	108	-	110	125	-	195
<u>Graving Docks:</u>							
Number	0	1	0	3	5	3	0
Max Length, Ft	-	1200	936	900	1600	1094	-
Max Width, Ft	-	192	143	146	240	143	-
Max Draft, Ft	-	30	35	NA**	NA	NA	-
<u>Floating Drydocks:</u>							
Number	1	3*	0		0	0	1
Max Length, Ft	500	775	-	900	-	-	1100
Max Width, Ft	81	106	-	146	-	-	195
Capacity, LT	9000	40,000	-	36,000	-	-	70,000
<u>Cranes:</u>							
Max Lift, LT	200	100	1200	NA	900	NA	NA
<u>Channel:</u>							
Depth, Ft	30	20	35	42	45	35	35
Width Limits, Ft	None	None	175	None	NA	None	NA
Height Limits, Ft	None	185	None	185	NA	125	NA

*Key Highway Yard, Baltimore, Md

**NA = Not Available

TABLE 2.5-1 (Cont.)

OTEC SHIPYARD SURVEY
GULF COAST

Name	Alabama Drydock & Shipbldg	Avondale Shipyards	Bethlehem Steel Corp	Ingalls Shipbldg Division	Galveston Shipbldg	Marathon LeTourneau	Tampa Ship Repair
Location	Mobile, Ala.	New Orleans La.	Beaumont Texas	Pascagoula Miss	Galveston Texas	Brownsville Texas	Tampa Fla
<u>Building Ways:</u>							
Number	2	2	1	6	1	1	1
Max Length, Ft	620	1200	842	650	700	1100	600
Max Width, Ft	90	130	96	90	100	150	150
<u>Graving Docks:</u>							
Number	0	0	0	1	0	0	1
Max Length, Ft	-	-	-	480	-	-	550
Max Width, Ft	-	-	-	70	-	-	75
Max Draft, Ft	-	-	-	NA	-	-	NA
<u>Floating Drydocks:</u>							
Number	3	2	1	1	0	0	0
Max Length, Ft	750	1000	650	820	-	-	-
Max Width, Ft	100	216	83	176	-	-	-
Capacity, LT		NA	17,500	NA	-	-	-
<u>Cranes:</u>							
Max Lift, LT	NA	277	500	NA	NA	NA	NA
<u>Channel:</u>							
Depth, Ft	40	40	40	38	40	36	34
Width Limits, Ft	NA	150	NA	NA	NA	NA	NA
Height Limits, Ft	NA	NA	NA	NA	NA	NA	NA

TABLE 2.5-1 (Cont.)

OTEC SHIPYARD SURVEY
WEST COAST

Name	Bethlehem Steel Corp	FMC Corp	National Steel Corp	Triple A Machine Shop	Lockheed Shipbldg & Constr.	Todd Shipyards Corp	Todd Shipyards Corp
Location	San Francisco, Cal.	Portland Oregon	San Diego Cal.	San Francisco, Cal.	Seattle Wash.	San Pedro Cal.	Seattle Wash.
Building Ways:							
Number	1	1(side)	3		3	1	1
Max Length, Ft	550	700	900		700	800	550
Max Width, Ft	90	100	106		100	84	96
Graving Docks:							
Number	0	0	2	6	0	0	0
Max Length, Ft	-	-	996	1100	-	-	-
Max Width, Ft	-	-	170	144	-	-	-
Max Draft, Ft	-	-	NA		-	-	-
Floating Drydocks:							
Number	2	0	1	0	3	2	3
Max Length, Ft	950	-	350	-	530	665	550
Max Width, Ft	144	-	60	-	80	83	88
Capacity, LT	65,000	-	NA	-	NA	NA	NA
Cranes:							
Max Lift, LT	NA	200	NA	300	NA	NA	NA
Channel:							
Depth, Ft	45	30	40	45	35	35	35
Width Limits, Ft	NA	NA	NA	NA	NA	NA	NA
Height Limits, Ft	NA	NA	NA	NA	NA	NA	NA

2.5.1 Size Limitations (Continued):

The data in Table 2.5-1 also indicates that the East and Gulf Coasts offer a broader selection of yards with greater capability than the West Coast. In particular, there is no major facility on Hawaii, so that platforms deployed at that site would require new facilities or a long tow.

2.5.2 Materials

The studies conducted to date tend toward concrete as a hull material, since submersibles, spheres, spars and the larger ships and cylinders are volume limited, i.e., light hull weight would require ballasting to compensate. If high weight is not a problem, concrete is obviously attractive because of its low cost, non-corrosive nature, minimum maintenance, fireproofness and other features. Even the weight-critical platforms such as the semi-submersible will benefit from a composite steel-concrete construction since a total steel hull might be too light. Based on this, it appears that serious consideration must be given to development of a new facility geared specifically to construction of massive concrete structures, similar to those used for recent North Sea concrete offshore platforms and storage facilities. Due to draft considerations, such a facility may have to be located several miles offshore, and would incorporate a dedicated batch mixing plant for continuous pouring operations. A caisson of some type would be required to form a building basic. A special offshore platform or platforms (floating or fixed) could be used for the batch mixing plant, crane support, shops, material storage, etc.

The CWP presents special considerations in that concrete again appears to be a good initial choice, since it acts as inexpensive ballast for the platform. Due to its length to diameter ratio, it would be extremely difficult and risky to attempt to tow such a pipe in open waters due to the possibility of high wave-induced bending stresses. High stresses could also result during the transition of the pipe from horizontal to vertical. If concrete is used for the CWP, one interesting possibility is to install temporary batch mixing capability on the platform and to fabricate a neutrally-buoyant CWP on-site, letting it simply "grow down" into the water as the pipe is continually poured. This would be analogous to current offshore pipelaying techniques, though oriented vertically. This and other concepts for hull and CWP construction and deployment will be addressed in later tasks.

2.6 OTEC Energy Park

2.6.1 General

The OTEC Commercial Plants that are anticipated at the present time are relatively limited in output when compared to land-based central generating stations (50 to 500 MW versus 1,000 to 3,000 MW); therefore, the concept of an "energy park" where the output from a number of Plants could be combined to yield a greatly increased total power might prove to be necessary if OTEC is to become a meaningful contributor to the shoreside energy grid or extensive energy intensive manufacturing process are located at the OTEC site. The analysis of the necessity of an energy park is beyond the scope of this study, although the optimum spacing of the OTEC Plants within such a park will be considered here.

In arriving at an optimum distribution of individual OTEC Plants within a group, a number of factors need to be considered, the more significant of which are:

- Transmission Systems (Cables)
- Positionkeeping Capabilities
- Thermal Interference

2.6.2 Transmission System

Based on discussions with DOE, it has been determined that the designs of the riser cable that will connect the OTEC Plant with the bottom cable is still highly developmental and little information is available concerning cable characteristics or limitations. From the standpoint of economy, one could assume that minimizing cable length and consequent costs would be of paramount concern so that the optimum configuration of an energy park and its component Plants would be the one that placed them in a circle around a central collection point. Of course, this configuration does not take into account the other two areas of concern, nor does it allow for current and platform motions on the cable. There is a possibility that there exists a favorable orientation of the cable with respect to the OTEC platform and the predominant current such that cable flexure and twist, both major contributors to potential failure, are minimized. This implies that other arrangements such as those will allow the platform and cable to align themselves with the current might be more satisfactory, and this, in turn, implies

2.6.2 Transmission System (Continued):

another arrangement of Plants in the cluster. Until the transmission line is better defined, the unknowns involved prohibit the optimization of an energy park from this standpoint.

2.6.3 Positionkeeping System

Based on present technology in the offshore industry, both static and dynamic positionkeeping systems can maintain a platform within a circle with a radius equal to 5 % of the water's depth under normal conditions and 15 to 20% in survival conditions. These figures are based on the requirements imposed by the drill string connected to the sea floor, while in the case of the OTEC Plant, a transmission line has replaced the drill string. As indicated in Section 5.4 of this Volume, this is well within the limiting motions envelope for riser cable mechanical strength.

Based on the above assumptions and an average water depth of 4,000 feet for the OTEC sites under consideration, a "watch" circle 1,600 feet in diameter may be postulated. This implies that the Plants in the energy park could be placed as close as 1,600 feet apart which would allow no room for error. Practical considerations and good judgement preclude such an arrangement, and given the size of the Plants being considered, a separation of approximately 3,000 feet would be in order. It must be realized that this is solely an estimate derived from cumulative engineering experience and may well be modified either up or down depending upon the mode of positionkeeping chosen during the conceptual design studies. The critical problem will probably be the survival situation when the cyclic and steady state forces on the platform are the greatest, and the highest probability of the Positionkeeping System's capabilities being exceeded for a period of time exists. If this period extends long enough for one Plant, a collision between plants could result, so the question that must ultimately be answered is what is the minimum distance required to prevent this event.

2.6.4 Thermal Interference

2.6.4.1 Introduction

The concept of having several OTEC plants operating within short distances of each other, as is the case of an OTEC park, raises the question of thermal mixing and its possible impact on plant efficiency. The warm and cold water discharges of each plant will have temperatures which are lower than the ambient surface temperatures at the site. The cold water discharge for example, is expected to have a temperature of approximately 42°F which if compared to a nominal 76°F temperature at the water surface indicates that the combined discharge of, say, a ten-plant-park could have serious effects on the thermal gradient at the site and on the plant efficiencies.

The problem arises when, in the presence of the local currents, the cold water discharge of the OTEC plants overlap and the result is a reduction in the ambient water temperatures. It is clear, therefore, that in designing an OTEC park due consideration must be given to the thermal mixing caused by simultaneous discharges. A preliminary analysis of this phenomenon has been conducted in order to estimate the requirements for platform spacing, park arrangement and orientation with respect to predominant current direction. It should be noted that this analysis is independent of Transmission System and Positionkeeping System considerations.

2.6.4.2 Nature of the Problem

The problem of a jet or plume discharging into a receiving water environment has been studied by several investigators and the results applied to problems of coast zone power plant siting and ocean outfall design.

The interaction of several plumes discharging simultaneously in the presence of ocean currents and into a stratified medium has been analyzed by Giannotti (Reference (13)) for the purpose of siting ten sewage treatment plants and their outfalls along a 100 kilometer span of the Spanish Mediterranean. In the case of the OTEC park, the problem is similar in nature except that the plants will be operating closer to each other, and the plumes will tend to sink initially instead of staying at the discharge depth or rising to the surface of the ocean. The key consideration is how far apart should the plants be located in order to minimize or avoid the mixing of individual effluents and the corresponding

2.6.4.2 Nature of the Problem (Continued):

detrimental effects of reduced ambient water temperatures. The criteria is to insure that the cold water plumes remain at depths which are well below the warm water intake of the other platforms such that disadvantageous thermal mixing is minimized. This can be accomplished by a combination of several factors. The heavier cold water plumes may sink naturally to the desired depth before stabilizing. The cold water discharge may be placed sufficiently below the warm water intake so that the plumes originate at the desired depths. Dilution and dispersion caused by currents and turbulence may also play an important role in minimizing the problem, especially if the platform spacing is large enough to reduce the possibility of the cold water plume of one plant reaching the vicinity of the warm water intake of another plant.

The optimum OTEC Park arrangement from the standpoint of thermal mixing is postulated to be a linear one with the park's axis oriented perpendicular to the predominant current. This would allow the discharge of each plant to be carried clear of the others except during those times when the current shifts so that it tends to sweep down the line. That is the critical case which will determine plant spacing, and will be developed further below.

2.6.4.3 Thermal Mixing, Plume Geometry and Trajectories for Discharges Into Waters of Constant Density and No Current

Reference (1), contains the detailed development of the sea-water effluent, plume geometries using parameters derived from the OTEC Commercial Plant baseline designs for the zero current and constant density seawater case. The results of this study are as follows:

<u>y, ft.</u>	<u>x, ft.</u>	<u>b, ft.</u> <u>(half width of plume)</u>
517	828	85
1,034	1,086	145
2,068	1,293	255
3,102	1,397	357
4,136	1,552	459
5,170	1,655	553

2.6.4.3 Thermal Mixing, Plume Geometry and Trajectories for Discharges Into Waters of Constant Density and No Current

Where x = Horizontal distance from the effluent discharge
 y = Vertical distance below the effluent discharge

The figures indicate that without the presence of a current and assuming a constant density of the water environment, the cold water plume of a plant will reach the bottom of the ocean half way between two adjacent plants positioned 3,000 ft. apart. By that time, the plume will be about 700 feet wide. The temperature variation along the centerline of the plume has also been estimated in Appendix (H) of Reference (1) and the results show that by the time the plume has sunk to a little over 500 feet, the temperature difference between the centerline of the plume and the ambient water is about 1°F .

The estimates given here appear to indicate that there is no serious danger of detrimental thermal mixing caused by the simultaneous discharging of cold water from the plants of an OTEC park. However, two important parameters have not been included in this analysis which may make these estimates somewhat optimistic. First, the presence of currents and turbulence may prevent the plumes from sinking as fast as in the case of a stagnant receiving water environment and the cold water discharge of one plant may be carried to the general area of the adjacent plant before significant dilution has taken place. A second limitation of this analysis is that the receiving water environment has been characterized as having uniform density and temperature. Clearly this is not the case and density stratification may well cause the plume to achieve neutral buoyancy at a certain depth and continue moving with the current. These two factors (currents and density stratification) will be included in the next section.

2.6.4.4 Thermal Mixing, Plume Geometry and Trajectories for Discharges Into Waters With Currents and Linearly Varying Density

This section presents the results of the studies of Appendix I of Reference (1) which addressed the effects of a local current profile and the density stratification of the ambient water. As in the previous analysis, the trajectory of the cold water plume discharged from one of several plants of an OTEC park has been estimated. The initial conditions are the same, but this time the density stratification and local current velocity has been taken into account. Since no specific data has been made available for density stratification at the sites under

2.6.4.4 Thermal Mixing, Plume Geometry and Trajectories for Discharges Into Waters With Currents and Linearly Varying Density (Continued):

consideration values typical for the general areas under consideration were chosen and the current velocity was taken at 0, 2, and 4 knots which is representative for each of these conditions. Based on these results, the plume centerline trajectories are as shown in Figure 2.6-1. The maximum plume width is about 1,100 ft. when the final depth is achieved.

The results of this analysis indicate that in the case of zero and two knot current, the cold water plume centerline will sink to final depths of about 1,000 and 850 feet below the discharge point respectively before reaching a neighboring plant 3,000 ft. away. This would result in little or no impact on the temperature structure around the area of the warm water intake of the neighboring plant. In the case of a four-knot current and above (e.g., Key West) the analysis shows that the cold water plume centerline of one plant will stabilize at about 380 ft. below the discharge point. Considering a plume half width of about 500 ft., then some thermal interference would be expected in the vicinity of the warm water intake. However, estimates of dilution over the distances under consideration show that the temperature difference between the centerline of the plume and the ambient water is about 1°F.

Based on the above calculations, it appears that a platform separation of 3,000 ft. for an OTEC Park is satisfactory for the purpose of minimizing detrimental thermal mixing.

FIGURE 2.6-1

EFFLUENT PLUME TRAJECTORIES
FOR CURRENTS OF 0, 2, AND 4 KNOTS

3. TASK IIB EVALUATION PLAN

3.1 Introduction

The OTEC evaluation methodology has been designed to systematically assess each of the candidate platforms in terms of the following basic issues:

1. What is the total system life cycle cost?
 - Acquisition, including research, development, design, construction, testing and deployment.
 - Operations, including manning, maintenance, repair, consumables, etc.
2. What schedules are associated with each phase of the program, and specifically how long will it take to deploy an operable OTEC platform of each size and configuration being considered?
3. What are the risks associated with the baseline "best engineering estimates" of cost and schedule, and how do these risks ultimately impact the final selection of the optimum platform?
4. How do the alternatives rank in terms of key technical parameters; and what are the associated risks:
 - Motions
 - Positionkeeping
 - Structural integrity, including CWP and CWP attachment
 - Safety and survivability
 - Producibility
 - Deployability
 - Operability/Maintainability

Considering each of the four areas delineated above, it is obvious that the evaluation could become extremely complex, especially when one considers the basic inputs to be considered, which result in 90 alternatives:

1. 6 Hull forms
2. 5 Plant capacities (50 to 500 MW assumed to bracket the range of interest)
3. 3 Sites

3.1 Introduction (Continued):

Added to these are alternatives for hull and CWP material, CWP/hull attachment characteristics (finite versus infinite stiffness), and other variables. It is also possible to postulate relatively simple cost analyses versus a more meaningful, though more complex analysis considering cash flow and its related financial assumptions.

In order to reduce the complexity of this evaluation, it is desirable that a common denominator be established. Ideally, a single parameter such as cost could be postulated. However, in the case of the OTEC plants, there is an urgency based on national energy priorities which must be considered. Thus, both cost and schedule are of interest. Naturally, these factors are inter-related. A tighter schedule can be achieved by the judicious application of more money - witness the NASA moonlanding program. Since DOE management will undoubtedly wish to trade-off cost versus schedule, it is desirable to develop baseline cost and schedule estimates for each alternative, such that a point of departure can be defined for later sensitivity studies of the impact of tightening schedules.

The question of risk must then be assessed. In its simplest sense, risk is the modifier which must be added to the "best engineering estimates" to reflect uncertainties. Considering the level of effort associated with the studies conducted during Task IIA, there is no question but that there are many uncertainties in both the technical parameters defined for the platforms and the associated costs and schedules to be developed in Task IV. The Task III efforts related to technology assessment illuminate these risks. Therefore, risk can be quantified as a modifier to the cost/schedule estimates insofar as the Task IV efforts are concerned.

The final technical issue to consider is the technological ranking. Again, many variables exist. Fortunately, all but one can be easily converted to cost/schedule factors, i.e., positionkeeping requirements can be related to hardware which in turn can be defined in terms of cost and development schedule. Assuming the availability of a valid Top Level Requirement developed in Task IIA, the same analogies can be made for the other technological areas defined.

3.1 Introduction (Continued):

The sole exception is motions. At present, there is no definitive limit on motions which can be established based on equipment or personnel considerations. Obviously, minimum motions are desirable. However, the cost/benefit relationships cannot be defined, nor can lower limits be promulgated and defended with any authority. Based on this, motions will initially be considered as an independent variable to be considered along with cost and schedule. Ultimately, it will be necessary for DOE program management to make a decision on the relative value in terms of time and money of reduced motions.

One of the dangers of relating technological areas to cost and schedule is the possible masking of major problems. For example, the Cold Water Pipe (CWP) is recognized as a major technological problem. It would be nice to take the cavalier approach that "if we can land a man on the moon, we can solve the CWP problem" and simply assign a cost, schedule and risk modifier to the CWP line item. This would be a gross oversimplification. Therefore, the evaluation methodology must provide visibility to such problem areas via reference to the Technology Assessment studies conducted during Task III. This is accomplished during Task IV where a sensitivity study is conducted to define the impact of CWP cost differences on the evaluation.

The basis for the evaluation methodology is directed toward the ultimate user - the electrical utility industry. Since the investment by such utilities in OTEC represents a major front-loaded investment, it is considered essential to provide an evaluation methodology which is financially oriented, and which reflects the ultimate return on investment. For this reason, discounted cash flow techniques will be used, which permit consideration of various financial options including cost of capital. The following section defines the basic methodology considered appropriate to this investigation.

3.2 Methodology

The evaluation methodology described below represents a number of iterations and refinements directed toward development of a consistent, cost-related procedure to compare alternatives.

3.2 Methodology (Continued):

The evaluation of the total set of ninety OTEC platform alternatives will be conducted using the baseline cost and schedule information developed in Task IV as inputs to an analytical methodology which examined the cost-benefit ratio of each alternative. The impact of technical risk as analyzed under the technology review conducted as part of Task III will be incorporated into the methodology to examine the sensitivity of the cost-benefit relationships to uncertainties in platform design, construction, deployment, and operations. The objective of applying this methodology is to obtain preference rankings for hull type (e.g., spar, ship, submersible, etc.) and plant size (i.e., MW) for each of three sites: Hawaii, Key West, and New Orleans. These preference rankings are then used as the primary basis for developing the set of recommendations for pursuing conceptual design of two platforms in the remaining tasks under the OTEC Platform Configuration and Integration Study.

Before describing the methodology, it is worthwhile to note several factors which place constraints on the analysis and limit the scope to a manageable size. First, the level of detail and precision of the analysis is purposefully intended to be appropriate for a conceptual design decision, not for a comprehensive and final assessment of the technical and economic feasibility of a particular OTEC platform concept. The primary objective, to select two platforms for conceptual design and analysis, can be accomplished without performing extremely detailed cost and design studies. The level of precision of the cost and schedule estimates, and therefore of the cost-benefit analyses, reflects this constraint and is consistent with the level of detail of other DOE-supplied data required for the analysis (e.g., data on Power System and Transmission System design, configuration, and cost).

Second, the results of the cost-benefit analysis are intended to identify clear and unmistakable advantages or disadvantages associated with alternative platform concepts in order to make a rational selection of candidates for further evaluation. Said another way, the analysis is intended to facilitate discrimination among alternative platforms, not prediction of the level of technical and economic performance associated with each platform.

3.2 Methodology (Continued):

The methodology basically constructs a Figure Of Merit (FOM) for each alternative based on the ratio of benefit to cost:

$$\text{FOM} = \frac{\text{Benefit}}{\text{Cost}} = \frac{\text{Energy Produced}}{\text{Cost to Produce}}$$

The benefit is expressed in terms of energy produced over the 40-year life of the power plant and the cost to produce includes all the identifiable costs from construction through operation. Energy is measured in gross megawatt-years and costs are in terms of dollars spent for acquisition, operations, overhaul, etc. Since different hull/plant size combinations require different times to design, build, and deploy, the present value of both the benefit and the individual cost terms must be considered. Thus, the Figure Of Merit is expressed as:

$$\text{FOM} = \frac{\text{PV (ENERGY PRODUCED)}}{\text{PV (ACQ) + PV (OPR) + PV (OVHL) + PV (TRANS) + PV (FAC)}}$$

Where,

PV = Present Value
 ACQ = Acquisition Costs
 OPR = Annual Operation Costs
 OVHL = Overhaul Costs
 TRANS = Transmission System Costs
 FAC = Construction Facilities Costs

Now let,
 T = Plant Construction Time (Years)
 i = Interest Rate
 d = Fraction of Year Down Time for Overhaul
 a, b, c = Years in which Overhaul is Performed
 E(t) = Energy Produced in Year t

Then in greater mathematical detail the following equation results:

$$\text{FOM} = \frac{\sum_{t=T}^{t=T+40} \frac{E(t)}{(1+i)^t} - \sum_{t=a,b,c} \frac{d \cdot E(t)}{(1+i)^t}}{\sum_{t=0}^{t=T} \frac{\text{ACQ}(t)}{(1+i)^t} + \sum_{t=T}^{t=T+40} \frac{\text{OPR}(t)}{(1+i)^t} + \sum_{t=a,b,c} \frac{\text{OVHL}(t)}{(1+i)^t} + \sum_{t=0}^{t=T} \frac{\text{TRANS}(t)}{(1+i)^t} + \sum_{t=0}^{t=T} \frac{\text{FAC}(t)}{(1+i)^t}}$$

4. TASK III TECHNOLOGY REVIEW

4.1 Introduction

This section consists of three major subsections. The first section includes an overview of the Task IIA efforts to qualitatively assess the level of risk associated with each technology area. This develops a shopping list for further evaluation of existing technology.

The second subsection addresses each area identified to determine the current State-Of-the-Art (SOA), and near-term developments. A program is identified to advance the SOA to the level required to reduce technical risk to an acceptable level.

The third section addresses an overall Technology Advancement Program considering inputs from the studies of each technology area. Priorities are established, and overall program scope, schedule and funding are presented and justified in terms of risk reduction.

4.2 Identification of Technology Areas

The Task IIA studies summarized in Section 2 provided early visibility of potential shortfalls in the State-Of-the-Art (SOA) in OTEC Ocean System Technology. Due to the lack of available parametric data, it was necessary to utilize a more pragmatic approach to the analysis of size and configuration of the OTEC platforms, and in evaluating related considerations such as motions, materials, cold water pipes, positionkeeping, producibility and site sensitivity. During these studies, it was necessary to conduct a thorough review of the available technical literature and to make maximum utilization of this data base in deriving first-cut conclusions relative to the factors influencing platform size and configuration.

An overall initial assessment of the areas of technical risk was first conducted based upon the Task IIA studies. This assessment used the Work Breakdown Structure (WBS) proposed in Reference (1) as a checklist, and assessed the relative technical risk of each WBS element. This assessment was very sensitive to platform size in many cases, since most of the larger platforms (up to 500 MW) are well beyond the current State-Of-the-Art in nearly all respects, while the smaller options are closer to today's technology. Risk was initially categorized as major,

4.2 Identification of Technology Areas (Continued):

moderate or minor, since the quantification of risk could not be accomplished until completion of the Task III studies. Therefore, this initial assessment was intended principally as a means of developing a shopping list of technology areas to be considered.

The foregoing assessment leads to the following list of technology areas to be investigated:

1. Platform Size and Configuration
2. Materials
3. Motion and Load Prediction
4. Cold Water Pipe and CWP/Hull Connection
5. Seawater Pumps
6. Seawater System Interference Effects and Environmental Protection
7. Position Control Systems
8. Cost Analysis
9. Construction and Deployment
10. Maintenance and Operation
11. Stability
12. Licenses and Regulations

Each of these areas is discussed in the following paragraphs.

4.3 Technology Limits and Requirements

4.3.1 Platform Size/Configuration

4.3.1.1 General

Perhaps the most intimidating aspect of the OTEC Commercial Plants as developed in Task II is their size. The baseline plants possess full load displacements ranging from 59,800 tons (all displacements and weights are given in long tons = 2,240 lbs.) for the 50 MW semi-submersible to 1,600,000 tons for the 500 MW submersible. In addition, the configurations being considered are themselves unique even in the case of the more conventional forms such as the ship. The combination of these two factors result in a significant amount of risk and in turn they can generate a high level of apprehension in any segment of the business world that would be involved with their design, construction, operation, or financing. As to

4.3.1.1 General (Continued):

whether or not this apprehension is justified remains to be seen, but the following discussion will attempt to give a quantitative and qualitative feel for the position of the OTEC Commercial Plants with respect to the current State-Of-the-Art in ocean structure design.

4.3.1.2 Current State-Of-the-Art

Table 4.3-1 presents some of the principal dimensions and displacements of what are believed to be the largest ocean structures of various types that are either in service or under construction while Table 2.4-3 through 2.4-8 contain the principal characteristics of the OTEC Commercial Plants being considered by Gibbs & Cox, Inc. When making comparisons between the OTEC Plants and the conventional structures in Table 4.3-1 it must be realized that the displacements will not be directly comparable, since all but the semi-submersible OTEC Plants were assumed to be concrete while most of the other platforms are steel. If an equivalent steel hull is assumed for the OTEC Plants, their light ship displacements could be reduced approximately 40 percent and the full load displacement approximately 30 percent and a more direct comparison may be made. However, it must be remembered that almost all of the OTEC Plants are volume limited so that their full load displacement and dimensions are driven by volumetric requirements. This indicates that any comparisons must be made in a circumspect manner and detailed conclusions should be avoided in the interest of developing gross relationships.

As mentioned earlier, the sizes of the OTEC Plants need to be evaluated in light of their configurations to gain a true appreciation of their position with respect to the present State-Of-the-Art.

- Ship - Of all the configurations being considered, the ship is the closest to anything produced or being considered on a near term basis today. The full load displacements and dimensions of all but the 500 MW platform are relatively in line with those of the largest tanker presently at sea. The lightship displacements are of course more widely separated because of the concrete construction of the OTEC Plants, but a comparison using equivalent steel construction results in numbers with a relatively small difference. The 500 MW Plant still

TABLE 4.3-1

CURRENT STATE-OF-THE-ART IN OCEAN STRUCTURES

<u>STRUCTURE TYPE</u>	<u>MATERIAL</u>	<u>DIMENSIONS, Feet</u> <u>l x b x d</u>	<u>DISPLACEMENT (L.T.)</u>		
			Full Load	Light Ship	Dead-weight
Ship: Tanker	Steel (Batillus)	1,360 x 261 x 145	630,000	78,000	552,000
Tanker	Concrete	434 x 54 x 36			7,500
Barge	Concrete (ARCO LPG Barge)	461 x 136 x 56	65,000	29,000	36,000
Drilling Rigs: Semi-Submersible	Steel (Penrod 71)	288 x 216 x 138	41,000	12,500	28,500
Oil Production Platforms: Bottom Sitters	Concrete (Brent "B")			348,000 (includes ballast)	
	Concrete (Statford "A")	883 feet high			
Moored Spar	Steel (Spar 1)	445 feet high x 100			70,000
Oil Storage Platform: Bottom Sitters	Concrete (Ninian Central)	776 feet high		600,000 (includes ballast)	
Submarines:	Steel (Delta II)	500 x 36	16,000		

4.3.1.2 Current State-Of-the-Art (Continued):

- Ship (Continued):

remains beyond the present State-Of-the-Art with respect to full load and lightship displacement and both steel and concrete construction. It should be noted that the largest concrete ship type platforms built to date (the ARCO LNG Barge) has overall dimensions similar to those of the smaller OTEC Plants, but the lightship weights are a factor of 2 to 3 less than the 50 MW configuration.

In summary, the 50, 100, 200, and 350 MW Plants do not significantly deviate from the State-Of-the-Art in ship design assuming steel construction. These four Plants, along with the 500 MW Plant, are far beyond any similar structure fabricated of concrete and, in addition, the 500 MW size exceeds the current state of development for steel construction.

- Cylinder - This configuration deviates from anything produced yet; unless one considers the parallel that can be drawn between it and the ship form. The cylinder could be looked at as a ship form with a length to beam ratio of one since it possesses many of the same structural characteristics. The size of the cylindrical Plants is again much greater than anything in existence in the larger outputs, but in a manner analagous to the ships is within the realm of reasonable comparison when dealing with steel construction in the smaller Plants (50, 100, and 200 MW). Reference may be made to the Ninian Central oil storage platform which weighs 600,000 tons when ballasted down and is made of concrete. While this does indicate that large ocean structures in the size range of the 350 MW cylinder may be fabricated, there is a difference between it and the OTEC Plants under study, i.e., the Ninian Central storage facility rests on the sea floor.
- Spar - The spars represent a unique entry into the field of ocean engineering. Although spar type oil production platforms have been placed in service (Spar 1), they are much simpler in configuration and mission and possess a lightweight displacement significantly smaller than all the OTEC Spar Plants. If these Plants could be treated merely

4.3.1.2 Current State-Of-the-Art (Continued):

- Spar (Continued):

as submerged cylinders, then the jump in the State-Of-the-Art would not seem as great because of the similarity between the cylinders and ships discussed previously, but the extreme operating drafts encountered with the spars place them in a separate class since the structure required to withstand the resultant hydrostatic loads encountered at these drafts is of necessity more complex. It appears at this time the spar configuration is quite far beyond anything built.

- Submersible - This case is analogous to the ship and spar configurations in that it is in essence a submerged ship yet at the same time it is operating at extreme keel depths. Assuming a 50 - 100 foot depth of submergence for the upper surface of the hulls the keels could range from 170 to 220 feet for the 50 MW Plant to 330 to 380 feet for the 500 MW one. By comparison, World War II American fleet submarines had normal diving depths of from 250 to 400 feet, depending upon the class and building year, although modern military types may exceed this by a considerable margin. Both types are relatively small when compared to the proposed OTEC Plants. The largest submarine in service today, the Soviet "Delta II" Class possesses considerably smaller dimensions and displacement than those projected for OTEC use as can be seen by a comparison of the figures in Tables 4.3-1 and 2.4-6. Size becomes an extremely significant factor when dealing with underwater craft because critical stresses are dependent upon hull diameter or shell panel size.

Another factor that complicates the issue is the choice of materials since no submarine has been built of concrete and the ones constructed of steel presently use high strength expensive alloys such as HY-80 and HY-100. A number of large offshore platforms that have portions sitting on the ocean floor have been constructed of concrete; however, their underwater volume is usually flooded with oil or ballast water and most of the submerged structure is made up of relatively small diameter sections with no real unobstructed internal space requirements.

4.3.1.2 Current State-Of-the-Art (Continued):

- Submersible (Continued):

It must be concluded that the ability to construct a submarine OTEC Plant of the sizes considered in Section 2 is quite far beyond the present State-Of-the-Art. Even the smallest Plant is about ten times the size of the "Delta II" submarines. It is also doubtful that the baseline submersible designs could be sufficiently optimized to result in a configuration much closer to what has been produced to date.

- Semi-Submersible - These Plants form an interesting offshoot of the semi-submersible oil drilling platforms and Small Waterplane Area Twin Hull Ships (SWATH's) being considered by the U. S. Navy. There are two major differences; however, the first being the extreme size of the ones being considered for the 100 MW and greater sizes, and second, the large size of the lower hulls when compared to the upper hull, or cross structure. With respect to size, the 50 MW Plant is not far beyond the Penrod 71 drilling platform when the full load displacements and overall dimensions are concerned, but it leaps ahead when lightship weights are compared. This indicates as in the case of the ship, that the basic structure and payload of the OTEC variant is more complex, but at the same time the difference is not that great; however, the higher output Plants move rapidly away from this approximate equivalency. It should be remembered that the semi-submersible plants were hypothesized to be of steel as a result of their characteristic to be weight limited, so a direct comparison of the baseline Plants and existing structures may be made.

The second point concerning the relative sizes of the lower and upper hulls needs to be considered in addition to the size of these plants. The problem here is that the arrangement of the payload (the Power and Seawater Systems) resulted in large lower hulls and a small enclosed volume in the upper cross structure. This was dictated by payload requirements but nevertheless it means that loads resulting from the action of the seaway on the submerged portion of the Plant (transverse

4.3.1.2 Current State-Of-the-Art (Continued):

- Semi-Submersible (Continued):

bending, torsion, longitudinal bending, etc.) encounter very little resistance in the upper hull unless additional open structure is added in this area. Of course, the CWP attachment and the seawater distribution plenum in 350 and 500 MW Plants may be assumed to act as load carrying members. However, such a configuration has yet to be constructed. Also, in keeping with this discussion, the larger the lower hulls are, the greater the imposed loads will be; therefore, the baseline semi-submersibles can expect relatively high loadings when compared to conventional semi-submersibles and SWATH's.

In Summary, all semi-submersibles with the possible exception of the 50 MW case surpass any conventional structure of the type in size, but perhaps even more significant than this is the disparity in structural arrangements and proportions. Similarly, extensive development work will be necessary to develop the hull/CWP attachment mechanism because of the loadings developed from the interaction of the two lower hulls, in addition to the forces imposed solely by the platform and pipe motions.

- Sphere - The sphere has no real parallel in the realm of ocean structures and even the smallest Plant of this configuration differs from anything presently afloat by a wide margin. Aside from the obvious difference in size, these plants possess a unique structural arrangement and a hull form. Although they could be compared to the cylinder and ship in that they are large waterplane area surface platforms, albeit with extreme drafts in the three larger outputs, a rigorous interpretation would place them in a separate category. Even if configuration is not considered, the aforementioned operating drafts are far in excess of standard practice.

4.3.1.3 Projected Near Term Developments

Significant advances in floating ocean structure size especially with respect to the more unusual hull configurations are not anticipated in the future. In most cases the need for immense floating platforms of the size of the larger OTEC Plants does not exist; therefore, the State-Of-the-Art is not expected to be furthered.

Even though there are no near term advances anticipated, a number of design studies have been conducted and some of the resulting platforms are presented in Table 4.3-2. It can be seen that a significant size increase is encountered with the 1,000,000 ton deadweight tanker, and its anticipated lightship displacement exceeds those of all the OTEC Plants with the exception of the 500 MW one assuming steel construction. Even in this case, the disparity is not very great, and although no one has contracted for the ship, it is more a result of a surfeit of tankers in the world rather than any technical problem.

Concrete, on the other hand, has not yet advanced into the region being considered for OTEC use. DYTAM Marine of West Germany has developed a conceptual design for a 128000 M³ LNG tanker which has an estimated lightship displacement of approximately 60,000 tons - still only about 2/3 that of the 50 MW Plant.

The only other hull configuration that makes a significant leap forward in size, but only on paper, is the submersible. In a General Dynamics study, the conceptual design for a 170,000 ton dead-weight tanker was developed and solicitation to a number of oil companies was made. The dimensions given in Table 4.3-2 indicate that this proposed design would approach the size of the smaller two baseline OTEC Plants, but what these figures don't indicate is that the majority of the vessel is flooded cargo or ballast tankage that sees no hydrostatic loading, leaving only a comparatively small water tight volume for habitability, control, and machinery. This volume is more in line with that available on larger present-day submarines than on OTEC Commercial Plant; therefore, once again no counterpart in size to the baseline design is anticipated in the foreseeable future.

TABLE 4.3-2

PROJECTED STATE OF THE ART IN OCEAN STRUCTURE

Structure Type	Material	Dimensions, feet l x b x d	Displacement (L.T.)		
			Full Load	Light Ship	Dead- weight
Ship: Tanker	Steel		1,142,000	142,000	1,000,000
LNG Tanker	Concrete (DYTEN Marine)	950 X 144 X 77	115,000	60,000	55,000
Offshore Power Plant	Steel (Offshore Power Systems)	400 X 378 X 40	140,000		
Drilling Rigs: Semi-Submers- ible			50,000		
Submarines: Military	Steel (Trident)	560 X 52	16,000		
Tanker	Steel (General Dynamics)	900 X 140 X 85			170,000

4-10

18351-10 (M-10,000)

4.3.1.3 Projected Near Term Developments (Continued):

The other configurations (cylinder, spar, semi-submersible, and sphere) are not expected to be approached in size by any known near-term programs. As discussed in Section 4.3.1.2, the cylinder and sphere could possibly be construed to be variations on the ship; thus the 1,000,000 ton tanker design study could be extrapolated to these forms, but in reality this does not have any great significance since the tanker has yet to be built.

4.3.1.4 Proposed Technology Development Program

The large size and unusual configurations being considered for the OTEC Commercial Plant make it obvious that a number of elements of Plant design, construction and operation will be well beyond the State-Of-the-Art. In this context, it is not considered appropriate to address a Technology Development Program for size and configuration per se. Rather, such programs will be required for those specific elements which are impacted by size and configuration such as motions, structural loads, materials, construction and the other elements identified in Section 4.2. Each of these elements is addressed in later sections. In a sense, the comprehensive Technology Advancement Program discussed in Section 4.4 can be thought of as a program directed to addressing all aspects of size and configuration..

The current DOE concept of developing a Demonstration Plant prior to the Commercial Plant can also be thought of in these terms, since it affords the opportunity to solve many of the problems related to size and configuration in a prototype/test and evaluation environment rather than under the pressures of commercial operation. The Technology Advancement Program leading to the Demonstration Plant is expected to reduce technical risk to an acceptable level.

4.3.2 Materials

4.3.2.1 Current State-Of-The-Art

This study is concerned with materials for both the hull and cold water pipe (CWP) of the OTEC Commercial Plant. As currently envisioned, these include the following:

1. Steel - mild steel (1020 series) in low stress areas, with higher strength (HTS, HY80, HY100) in high stress areas.

4.3.2.1 Current State-Of-the-Art (Continued):

2. Aluminum - 5083 or 5086 series of weldable salt water corrosion-resistant alloys.
3. Glass Reinforced Plastic (GRP) - composite filament wound and unidirectional "E" glass reinforcing polyester resin, possibly with Kevlar organic fiber locally reinforcing high-stress areas. Either stiffened single skin or sandwich construction could be used.
4. Reinforced marine-grade concrete, similar to those now used in offshore platforms, prestressed by either pretensioning or post-tensioning to about 20% of the compressive strength.

4.3.2.1.1 Steel

The SOA in steel construction is the 550,000 deadweight ton tanker BATTILLUS, which is equivalent to a 350 MW ship-type OTEC Plant. The technology of steel design and construction has historically kept pace with the corresponding growth in ship size. Within the last 15 years, this growth has accelerated rapidly from an SOA of about 100,000 tons in the 1950's and early 1960's to today's Ultra Large Tankers. As this growth has occurred, the shipbuilding and materials community has had to keep pace, particularly in such areas as welding technology and non-destructive testing. Specialized problems such as those created by the introduction of cryogenic cargoes have also been met. Based upon these considerations, it can be postulated that the SOA in steel materials, technology is now adequate for OTEC platforms of up to 350 MW. Currently available steel alloys and welding techniques are considered suitable for OTEC applications without further development.

4.3.2.1.2 Aluminum

Aluminum has, until recently, been used primarily for specialized applications where light weight and reduced maintenance offered sufficient economic benefit to offset higher construction costs. The following lists the largest aluminum ship applications to date:

- U.S. Navy 154 foot, 300 ton high speed patrol craft
- 244 foot, 2000 ton oceanographic vessel SEA PROBE
- 306 foot, 2500 ton trailership SACAL BORINCANO
- 3000 ton Surface Effect Ship for U.S. Navy (3KSES) now in the design stages

4.3.2.1.2 Aluminum (Continued);

- 165 foot gas turbine ferry SAN FRANCISCO
- Hydrofoils up to 300 tons displacement

Of those designs listed above, the 3KSES represents the largest quantity of aluminum structure, requiring about 700 tons of plate and shapes (Reference (14)). This craft will be of conventional lightweight construction with relatively thin plates supported by a system of transverse and longitudinal frames. All of the applications noted above use 5000 series weldable seawater resistant alloys, predominantly 5456 for Navy applications and 5083 or 5086 alloys for commercial applications.

Another recent application of aluminum to the marine industry is the spherical tanks utilized by General Dynamics Corporation, Quincy, Massachusetts for the containment of liquified natural gas (LNG), References (15) and (16). These spheres are 120 feet in diameter, weighing 800 tons. They are fabricated at a special facility in Charleston, South Carolina using unstiffened 5083 alloy plate varying from 1-1/2 to 2-3/4 inches thick. These tanks are now in series production, and represent the current SOA both in terms of the size of the fabricated unit, and in advanced welding technology. In the development of the LNG tank program, General Dynamics worked closely with the American Bureau of Shipping, Det Norske Veritas, and the Alcoa Research Laboratory to establish design criteria and analytical procedures, material properties, fabrication procedures and other critical elements. These efforts, plus parallel efforts by other LNG system designers, are considered to represent the aluminum technology most closely applicable to the OTEC concept. However, as noted in Section 2, the smallest spherical OTEC platform (50 MW) is 180 feet in diameter, an increase of 3.38 in volume (and thus weight) relative to the SOA. The largest spherical platform (500 MW) is over 70 times larger than the SOA.

4.3.2.1.3 GRP

The SOA in GRP in terms of ship size is well behind that of aluminum. The largest GRP hull currently in existence is the 153 foot Royal Navy minesweeper WILTON, Reference (17). This craft weighs 450 tons, of which 130 tons is GRP. Studies of a similar minesweeper for the U.S. Navy were conducted by Gibbs & Cox, Inc. Reference (18). The corresponding SOA for commercial GRP craft is about 120 feet.

Virtually all of the State-Of-the-Art GRP hulls have been

4.3.2.1.3 GRP (Continued):

fabricated using the relatively unsophisticated hand layup techniques developed over the years for small pleasure craft. The only significant effort to automate the layup process was in connection with the WILTON construction and in laying up a full scale test midship section for a U.S. Navy minesweeper. Both of these efforts involved relatively simple procedures and must be considered as first-generation layup automation. No significant improvements have taken place in the intervening years, even in high-volume small boat plants where improved automation would seem to be a natural development.

In the area of high performance reinforced plastics, there have been a number of significant recent developments in aerospace and related industries (Reference (19)) with boron, graphite and carbon fibers reinforcing epoxy resins. However, these are highly specialized applications using materials which cost an order of magnitude more than the more conventional GRP composites, and are limited to relatively small applications where weight savings are extremely critical. Therefore the use of such advanced composites for the OTEC application will not be considered further.

4.3.2.1.4 Reinforced Concrete

By land-based standards, the OTEC platforms do not present insurmountable problems. Recent hydroelectric dams involve pouring as much as 6 million cubic yards of concrete, whereas the largest OTEC platform investigated during Task II required less than 300,000 yards of concrete. Obviously, this comparison must be tempered with an appreciation of the marine environment, which involves relatively high cyclic loading, extreme hydrostatic pressures (for the CWP), and highly corrosive conditions. Thus a direct correlation is by no means possible, though it is obvious that the State-Of-the-Art in terms of the massiveness of the pour is certainly adequate for OTEC.

The application of reinforced concrete to ocean vessels has been limited until recently. The largest use of reinforced concrete came during World War I and World War II, influenced by the shortage of steel. Ships in the range of 6000 tons were common at that time. The world wide energy crisis has brought about renewed interest in the use of reinforced concrete for ocean vessels and structures. A 65000 ton LPG floating processing platform has been built for Atlantic Richfield Company. Perhaps the largest advancement

4.3.2.1.4 Reinforced Concrete (Continued):

in the SOA of reinforced concrete for ocean applications has been the construction of large gravity structures. Oil production platforms such as those discussed in Section 4.3.1 have been built for depths of as much as 300 feet. Construction techniques have been much advanced by these structures, though most of this technology resides in Europe.

Durability of the concrete material in marine environment is of concern in the design of ocean platforms. Historically concrete vessels have shown high durability and required relatively little maintenance. Investigations have shown that some concrete hulls submerged for up to 60 years have sustained little degradation. Due to higher pressures and stress levels of OTEC platforms, corrosion control will remain a major problem. Concrete remains relatively watertight when proper mix and efficient composition have been provided, thus preventing corrosion. Various other State-Of-the-Art practices, such use of high strength concrete, will help to control permeability and corrosion.

Based on the above discussion, it can be concluded that the current SOA in reinforced concrete for marine applications will require some extension to suit the OTEC requirements. However, the basic technology does exist.

4.3.2.2 Near Term Developments

4.3.2.2.1 Steel

In recent years, there has been a continuing interest in the concept of the million ton tanker. Designs have been completed by several groups including Mitsubishi in Japan and a number of tanker operators (Reference (20)). The concept of a million ton tanker does not represent a major increase in the SOA, considering the rapid growth in tanker size during the last 10 - 15 years. It would appear that the primary drawbacks to the concept are economic and environmental rather than technical. Therefore it can be postulated that a million ton tanker, or steel OTEC platform of up to 500 MW, is within the near-term capabilities of the marine materials industry. Naturally there are a number of problems related to load prediction and fabrication which are addressed elsewhere. However, the basic array of State-Of-the-Art steel alloys and the related welding technology is adequate.

18351-10 (W-10,000)

4.3.2.2.2 Aluminum

Discussions with representatives of the aluminum and shipping industry indicate that there will continue to be a growth in the use of aluminum for LNG containment, which indicates that a gradual growth and refinement in the current SOA can be expected. However, no radical developments are foreseen, suggesting a near-term SOA of about 1,000 tons for heavy aluminum weldments.

Studies were conducted by Gibbs & Cox, Inc. for the Ship Structures Committee of an all-aluminum 45,000 ton bulk carrier in 1971. These studies, summarized in Reference (21), indicated that the concept is technically feasible, though of questionable economic benefit. The hull girder proposed in the study utilized plates up to 1-1/2 inches thick which, based upon the General Dynamics efforts, can be considered to be within the SOA. None the less, this design study only corresponds to a 50 MW platform in terms of total size, so that the concept of an aluminum OTEC platform must be considered to be well beyond both the current SOA and that projected for the near term.

Relative to the CWP, earlier studies indicate maximum wall thicknesses of nearly 8 inches for a fixed CWP/hull connection. The General Dynamics LNG spheres incorporate an equatorial ring which is 7.68 inches thick and 120 feet in diameter. However, the vertical dimension of this ring is only about 3 feet, whereas many hundreds of linear feet of such material would be required for a CWP. This is considered to be well beyond the SOA in aluminum weldments, suggesting that a non-rigid CWP/hull connection would be required if aluminum were to be a serious contender.

4.3.2.2.3 GRP

The growth in the SOA for GRP is expected to remain relatively gradual, since rising costs for resins and flammability problems continue to inhibit many new applications which might otherwise lead to significant developments. There are a number of new materials now in various stages of development, such as Kevlar; a high-performance organic fiber being marketed by Dupont, and magnesium oxychloride inorganic, non-burning resins. However, there is no major program in the near term which will accelerate the development of these materials beyond the current gradual rate.

4.3.2.2.3 GRP (Continued):

Up to the present time, the most ambitious program to evaluate major applications of the GRP to the marine industry was a study conducted by Gibbs & Cox, Inc. for the Ship Structure Committee in 1971. This study investigated the technical and economic feasibility of a GRP cargo of 16,000 tons displacement, and included extensive studies of materials and fabrication. This study, summarized in Reference (22), concluded that the fabrication of such a hull was technically feasible, but that the long-term durability was questionable. Also, the fire characteristics of GRP made the concept unacceptable under current Coast Guard rules. The economics of the concept were also unfavorable, with a higher required freight rate for all levels of procurement and technical options investigated. The developments in the intervening 6 years have not altered the situation appreciably, leading to the conclusion that GRP is not a serious contender for the hull of the OTEC Commercial Plant.

Relative to the CWP, GRP remains a contender due to its light weight and resistance to the marine environment. As with aluminum, GRP wall thicknesses of about 8 inches would be required for a rigid CWP/hull connection. This is well beyond the current or near term projected SOA, but can be achieved more easily than with metals. The reason for this is that the problems associated with extra thickness of GRP are more easily solved than with metals, where welding technology would have to be advanced. The major problems associated with GRP in this thickness range would be exotherm (heat release due to resin curing), secondary bonding and producibility. Since the normal near term technology developments will not answer these questions, they would have to be solved as part of the OTEC CWP development program.

4.3.2.2.4 Concrete

There is a continuing, though gradual increase in the SOA of reinforced concrete in the marine environment. The success of current-generation concrete offshore storage tanks will no doubt lead to continual growth in this application. Large offshore floating concrete platforms will most likely continue to be developed, following the lead of the ARCO LNG barges. It is likely that the SOA in the mid 1980's will be more than adequate for the OTEC program, in terms of material technology.

4.3.2.2.4 Concrete (Continued):

Current studies of improved cement and materials are expected to result in a significant increase in the design stresses for concrete. Reference (24) projects a potential ultimate compressive strength of 15 KSI versus today's upper limits of 5 to 10 KSI. Such advances will require continuing investigations of aggregate types, mix compositions, admixtures, air entrapment, curing techniques, and other factors. It can be assumed that OTEC can take full advantage of these developments without an extensive independent research and development effort. In other words, it presently appears advantageous to adapt available current and near-term reinforced concrete technology to the OTEC application rather than assuming that an entirely new approach will be required. This is based upon the fact that the OTEC platforms are generally not weight critical, so that a costly program to develop lighter weight high performance matrices is unwarranted.

The only areas in which near-term technology may not be adequate are fatigue, notch sensitivity, permeability/corrosion under high pressures (i.e., CWP applications) and other parameters unique to floating platforms.

4.3.2.3 Proposed Development Program

The following program is proposed in order to advance the State-Of-the-Art in the area of materials technology to reflect OTEC requirements. The program is based upon the assumption that only steel and concrete will be considered for the primary platform structure, whereas the CWP material selection process will consider aluminum and GRP as well.

4.3.2.3.1 Hull Materials Development Program

It is assumed that all of the OTEC Commercial Plant platform developers will conduct initial hull materials trade-off studies as part of Task V - Conceptual Design. If this is not now included in the scope of the Contractors' efforts, such studies are definitely in order and should be negotiated as required. Such studies will lead to the selection of either steel or concrete as the most cost-effective material for the OTEC platforms.

4.3.2.3.1 Hull Materials Development Program (Continued):

Because of the relatively limited scope of the current platform evaluation contracts, it is likely that the hull material trade-off studies to be conducted during the next six months will, of necessity, be limited. Many variables will not have been evaluated and the confidence in the conclusions and recommendations will not be sufficiently strong to embark on the multi-million dollar Demonstration Plant and Commercial Plant programs to follow. Therefore, it is recommended that a separate program be undertaken to fully assess the use of reinforced concrete for this application versus conventional steel construction.

Scope: Such a program should be patterned after References (21) and (22), including the following scope, based upon a platform selected by DOE:

	•	State-Of-the-Art Summary (expansion of this section)
	•	Materials Characteristics (cement, aggregate, reinforcement, etc.)
I	•	Design Load Assessment
TASK I	•	Allowable Design Stresses and Deflections
	•	Fatigue, Notch, Sensitivity and Creep
TASK II	•	Comparative Structural Analysis
	•	Weight Comparisons
TASK II	•	Producibility, Including Facilities, Quality Control, etc.
TASK III	•	Deployment
	•	Maintenance and Repair
TASK III	•	Life Cycle Cost Comparisons with Equivalent Steel Platforms
	•	Conclusions and Recommendations

Such studies should be conducted by a qualified naval architectural firm with off-shore technology background, and with subcontractor assistance in the areas of concrete materials, design and production. Close liaison should be maintained throughout with the two Regulatory Agencies which will ultimately approve the OTEC hull structure, the American Bureau of Shipping and U. S. Coast Guard.

4.3.2.3.1 Hull Materials Development Program (Continued):

Cost and Schedule: The program described above is expected to cost approximately \$200,000. and will require a minimum of 9 months to complete. It is recommended that the RFP effort be timed for contract award immediately after completion of the OTEC Commercial Plant Configuration and Integration plant studies now in progress, with completion near the end of CY 1978. In this way, the results of the three ongoing Conceptual Design studies will be available as a baseline, and this study can be directed toward the Demonstration Plant.

4.3.2.3.2 CWP Materials Development Program

A program similar to that described in the previous section is recommended for the CWP, though expanded in scope to include all potential materials. This program would have essentially the same scope as that for the hull materials, with the added studies in the area of CWP/hull attachment and should be integrated into the overall CWP technology program defined in Section 4.4.

4.3.2.3.3 OTEC Materials Test Program

If either the hull or CWP materials development programs defined previously result in the selection of reinforced concrete or GRP, it will be necessary to conduct a test program to define material properties. This program will provide sufficient confidence in the design properties to support the later development of hull criteria, inspection and quality control requirements. Properties to be determined will include, but not be limited to the following, as a function of resin or concrete to reinforcement ratios:

- Static Strength (tensile, compressive, flexural, shear)
- Impact Strength/Notch Sensitivity
- Flexural Modules
- Fatigue Strength
- Creep
- Specific Gravity, Water Absorption, Void Content
- Long-Term Durability

Reference (23) describes a program similar to that proposed, undertaken with industry participating for GRP laminates in 1966.

18351-10 (W-10,000)

4.3.2.3.3 OTEC Materials Test Program (Continued):

Schedule and Cost: A materials test program of the type described above is expected to cost about \$150,000. and would require about 6 to 9 months, depending on how long it takes to prepare and cure samples. The cost could be reduced by soliciting industry participation. This program should be conducted after both the hull and CWP material studies described in Sections 4.3.2.3.1 and 4.3.2.3.2 are completed.

4.3.3 Motions and Structural Loads Prediction

4.3.3.1 General

Estimation of structural loads and rigid body motions for new ocean platform concepts is a critical part of the design cycle. Because of their advanced nature there is usually very little previous experience to draw on so that the design loads and motions have to be developed largely from analyses and model test programs. For example, as discussed in Section 4.3.4, the cold water pipe bending moments may require pipe wall thicknesses which could produce significant fabrication and installation problems, so that considerable importance must be attached to achieving an adequate structure that is sufficiently strong, but not over-designed. Likewise, should cost factors and ease of construction and operation result in a platform selection where motions are problematic, the need arises for accurately and rationally predicting the long-term motion response of the platform to ensure mission success. The methodology required to accomplish this objective must be probabilistic in nature as it entails forecasting events which will take place over a long period of time; i.e., essentially the lifetime of the platform. Specifically, one must analyze the probable mode of operation of the platform and its environment and then make use of this information to define a number of deterministic load and motion conditions for analysis or eventual test. Each specific condition can be represented by an rms (root-mean-square) value and a short term distribution about that rms value. Also, each of the load and motion conditions is assigned a probability of occurrence, which can be used to compound all of the data generated into single long-term probability distributions for each type of load and motion. By accepting reasonable levels of structural failure probability and motion exceedance probability, the design values can be selected from the long-term distribution of loads and motions.

4.3.3.1 General (Continued):

In the case of the OTEC Commercial Plant platform, the question of large accelerations and roll or pitch angles and the problem of the cold water pipe bending moments are extremely critical. Large accelerations are a possible source of failure in the large power system components (heat exchangers, turbines, pumps, etc.), and torsional moments at the transmission line connection points must be known for proper design. Bending moments acting on the cold water pipe with quasi-infinite attachment stiffness may require very large pipewall thicknesses. If the loads or motions are underestimated, the platform may either suffer failure or will have to operate only in restricted conditions, yet if the loads are overestimated, then unnecessary fabrication and construction problems and costs will arise. Either one of these possibilities could doom the program, so that extreme care must be exercised to take the middle, rational road. The traditional methods of the naval architect, however, are not entirely available in this case since these methods rely heavily on past experience. Departures from previously used sizes, speeds, or hull forms are, usually, never very large; the ten-fold growth of tankers from 50,000 tons to 500,000 tons over a period of thirty years in almost as many steps is considered to be a revolutionary process. Yet, in the OTEC Program in which no full size platforms have been built and where the ocean platforms of the types to be considered in this study rarely exceed 100,000 tons, the steps from concept design to operating units are to be accomplished in relatively few steps and in less than ten years.

4.3.3.2 Current State-Of-the-Art

Until the last year or two, loads for ships and ocean platforms have been generated almost entirely by using analytical models. Frequency-domain and time-domain analyses have been used by all the institutions involved in this field - industrial, governmental, and academic. The frequency-domain analysis assume linear relationships between the wave-induced, forcing functions and the structural response. This assumption of linearity in a system which could be highly non-linear is a considerable limitation but can be "lived with" if no better information is available. The time-domain simulation alternative, to be effective, must be an extremely complex analytical representation and, when computerized, is too expensive to use in a routine fashion. Again, the analyst has had to make what he has considered to be an appropriate and economic use of these two approaches.

4.3.3.2 Current State-Of-the-Art (Continued):

During the last years attention has finally begun to be paid to the structural loads and motions question and a wide range of experimental programs have begun to yield usable experimental data. This combined test data represents a formidable body of information that requires careful analysis and interpretation before usable design data can be extracted.

Available tools for predicting motions and loads for ocean platforms can perhaps be divided into three main groups:

- Analytical Prediction Procedures
- Model Test Results
- Full-Scale Test Results

Of these three, only the first one will be employed in the present project; however, it would be highly desirable to conduct model tests on those platform configurations which are selected as a result of the current evaluation. The results of these model tests would greatly add to the confidence in the predictions and would permit the designers to sort out platform deficiencies which may not be evident based on the analytical predictions.

4.3.3.2.1 Analytical Predictions Techniques

- Empirical Formulae - The simplest form of analytical procedure is the empirical formula. It should not be forgotten that until less than twenty years ago, many successful ships were designed to formulae since before the advent of modern computational techniques this was often the only procedure available to most designers. Except for current induced loads (Reference (25)), no such formulae are available for the platform geometries and sizes under consideration.

- Frequency Domain Simulation - Provided that the response of the platform to a seaway can be assumed to be linear, then frequency-domain analysis can provide load and motion information in a reasonably economical fashion. The response amplitude operators for the quantity in question (longitudinal bending moment, pitch, motion, etc.), can be computed by treating the hydrodynamic and hydrostatic forces acting on the vehicle as linear systems. The root mean square (rms) response of each quantity can then be determined for any specific condition of operation.

4.3.3.2.1 Analytical Predictions Techniques (Continued):

● Frequency Domain Simulation (Continued):

In spite of the fact that ocean platform responses are nonlinear, it has been found experimentally, that the agreement between rms responses measured in the model tank and those predicted by frequency-domain simulation is surprisingly good, even for operation in severe sea states. It should be emphasized, however, that it is only the rms values that correspond to the predicted values. As the responses are nonlinear, especially in high sea states, the distribution of peak responses usually do not follow the Rayleigh distribution and therefore the statistical values predicted by assuming this distribution do not, in general, match experimental values. The OTEC platform seakeeping predictions conducted up to the present time, Reference (26), yield values of motions and loads which are the average of the one third highest amplitudes computed on the assumption that the Rayleigh distribution is a valid one. This may be so, in particular in high sea states such as 6, 7, and 9 which are the ones of interest for design; therefore, other more flexible distributions such as the Weibull distribution should be considered for long term predictions.

The great advantage of the frequency-domain situation is that it is simple and flexible and inexpensive, and as it has now been proven, many times, to yield usable values of rms response, it provides a very valuable design tool. The key lies in how the rms values of motions and loads are combined with the appropriate statistical distribution. A detailed description of the technique is given in References (27) and (28).

In the present OTEC Commercial Plant effort two types of frequency domain motions and loads computer simulations are available for use:

- (a) Modified Strip Theory Simulation
- (b) Arbitrary Shape or "Fat Body" Motions Simulation

Both types of computer programs have limitations which must be kept in mind when using them as an evaluation or design tool.

4.3.3.2.1 Analytical Predictions Techniques (Continued):

- Frequency Domain Simulation (Continued):

Strip theory programs are based on the assumption of a long slender body experiencing modest motions at moderate speeds. Under these conditions each section of the body can be treated as moving independently in the medium with negligible interactions between adjacent sections. Viscous effects are for the most part not considered. Motions in the vertical plane (pitch and heave) at relatively low speeds have been well validated by experiment with the above limitations of the theory. At higher speeds the agreement varies from fair to poor, and incidence of deck wetness is also poorly predicted. Furthermore, the prediction of large amplitude roll motions is erratic showing fair agreement with experiment in some cases and poor in others.

In general, the use of strip theory simulations for "fat body" predictions is outside the realm of applicability.

For the specific case of OTEC platforms, two computer simulations are based on a strip theory approach. Paulling Reference (28) formulated a 6-Degree of Freedom linear dynamic model and solved it in the frequency domain. It is based on the concept of coupled motions between a rigid body (the platform) and an elastic body (CWP). Three dimensional CWP motions are included in the analysis and the responses of the CWP are calculated by means of linear beam theory. Barr, et. al of Hydronautics, Inc., developed a 6-Degree-of-Freedom linear dynamic model in the frequency domain, References (26) and (3), which included coupled rigid-body motions of the platform and the CWP. The CWP was originally treated as a rigid body, but more recently pipe flexibility has been included in the simulation. Detailed descriptions, comments and comparisons relevant to these two models are given in References (31) and (32).

Fat body, large object or arbitrary shape body simulations such as the one developed for DOE by Professor C. J. Garrison of the Naval Postgraduate School, Monterey, do offer a more promising approach to the problem of predicting motions and loads for non-slender arbitrary shaped bodies such as the various OTEC platform configurations. The geometry of the body is represented by the selection of an appropriate number of nodal points much like the finite-difference and finite-element techniques used in modern structural analysis and heat transfer problems. The method, which is described in detail in References (33), (34), and (35) has

4.3.3.2.1 Analytical Predictions Techniques (Continued):

- Frequency Domain Simulation (Continued):

been validated using shapes which include floating hemispheres, disk buoys, caissons, etc. In spite of these validations, there are three limitations pertaining to the use of this program of which the user must be aware. First, there are specific frequencies at which the numerical results break down and it becomes impossible to obtain a valid solution. This, however, does not occur for completely submerged bodies and in Reference (34) Garrison gives a method of checking the validity of the results showing when the break down occurs so that invalid results will not be mistaken for good results. A second limitation of the method is the complexity of the geometry of the surface of the body since the number of nodal points must be increased as the shape becomes more complex. If the shape becomes too complex, the number of nodal points will become so large that the computer time and storage requirements for calculating the hydrodynamic coefficients will become impractical. The third limitation of the Garrison program at this point is that apparently it does not incorporate a simulation of the CWP/platform interaction. This is a key factor in the prediction of loads and motions as it is necessary to know what the effects of the CWP/platform connection rigidity and CWP flexibility will be on the structural design of the system.

In an effort to bridge the gap between the R&D and design communities, DOE organized a workshop aimed at familiarizing all contractors with the use of the Paulling and Garrison models. This workshop took place on October 18 and 19, 1977 at the Control Data Corporation in Oakland, California. The benefits of this briefing became evident in Task IV and V when detailed motions and loads predictions were made for all six candidate platform configurations at several displacements and for three different sites.

- Time Domain Simulation - A great deal of effort has been devoted to developing very comprehensive time-domain simulations of ships and other ocean platforms. These may be used to generate 6-Degree-of-Freedom response to wave action, impulsive loads due to wave impact, maneuverability characteristics and simulated emergency conditions, Reference (36).

As time goes on, and the power of computation techniques increase, it is very probable that the time-domain approach will be used more and more in design

4.3.3.2.1 Analytical Predictions Techniques (Continued):

• Time Domain Simulation (Continued):

work, but at the present State-Of-the-Art, it does have some disadvantages. First, it is a very elaborate procedure to use, so that when engineering time and computer hours are taken into account, it is very expensive to operate. Second, due to the expense involved, it is not usually possible to run the program long enough to obtain a reasonable statistical sample. By its nature, the time-domain model is deterministic whereas the real world of wave-induced loads (even in the model tank) is probabilistic. The current tendency seems to be to use time-domain models for specific, time-constrained, transient events, such as maneuvering and emergency conditions, etc., rather than for steady state operation. A possible application would be to predict the response of the platform in the event of loss of the cold water pipe (emergency condition).

There are two existing simulations developed in the time-domain for predicting platform motions and loads specifically for OTEC platforms. One is the model formulated by Frederic R. Harris, Inc., References (37) and (38), where the motions of the platform and the CWP are uncoupled. Two separate programs are actually used. The first program calculates the 6-Degree-of-Freedom motions of the platform. The load on the platform was assumed to be generated by a train of regular waves. A second program calculates the responses of the CWP subjected to current and wave loadings. The boundary at the top of the pipe at a specified time is given by the platform motions at that time. In this manner the output of the first program is used as an upper boundary input for the second program. The spatial integration of the CWP equation is accomplished by means of an implicit finite difference technique.

In addition to the F. R. Harris model, the Southwest Research Institute (SWRI) has developed a time domain model where the motions of the platform and CWP are uncoupled. SWRI assumes that the motions of the platform are known and uses these motions as a boundary condition at the top of the pipe. The model then solves the partial differential equation which describes the CWP motions as an initial-boundary value problem. The deflections of the CWP are calculated along the length of the pipe and shown as a function of time. The spatial integration of the CWP equation is accomplished by means of an implicit finite

4.3.3.2.1 Analytical Predictions Techniques (Continued):

- Time Domain Simulation (Continued):

difference technique. References (31) and (32) give detailed descriptions of these models along with assessments of their validity and examples of numerical results obtained with each.

4.3.3.2.2 Limitations of Existing Motions and Loads Prediction Methods

For OTEC platform motion and loads predictions, the only available tools are computer programs such as those described above. The extremes to which these analytical simulations will be pushed and their limitations must be recognized. It cannot be established whether the computer predictions will be high or low. In fact, one cannot even have great confidence in the comparisons made between configurations unless the demonstrated differences are large. The ranking of candidate platform configurations based on computer predictions could very well be altered based on the results of full scale trials conducted on the OTEC-1 platform, or model tests conducted in a towing-tank with scaling effects properly accounted for. The models discussed above do not account for several key parameters including loading, structural characteristics and coupling effects. Most of the models do not consider the effect of the mooring lines on the motions of the platform and in all cases wave drift forces are not considered. One of the most important effects which needs to be addressed is the simulation of the loads induced on the CWP/Platform connection due to wave and current action. Although the models described here account for this effect by varying the connection stiffness, the predictions presented so far show unexplainable discrepancies such as the large axial bending moments predicted by Hydronautics, Reference (26), for the case of zero CWP/Platform connection stiffness. Clearly the bending moment should be zero for this case. As important as the prediction of the CWP/Platform connection loads are:

- The assessment of CWP flexibility and its effect on platform and pipe motions and loads,
- The effect of cold water motion inside the pipe on platform motions.

Operational OTEC plants and their CWP's will have required lifetimes of 30 to 40 years. This will result, for a realistic ocean environment, in about 10^8 stress cycles and hence, CWP fatigue failure could be a distinct

4.3.3.2.2 Limitations of Existing Motions and Loads Prediction Methods (Continued):

possibility. The probability of fatigue failure is increased by the significant reduction of material fatigue strength in a corrosive water environment. The fatigue strength of metals in seawater can be less than 50 percent of that in air after 10^8 cycles and fatigue strength in seawater, unlike that in air, continues to decrease with increasing number of cycles. Since fatigue failure is induced by cycle loading, it is essential that the frequency of occurrence, the duration of the sea states in each site under consideration and the spectral shapes be well defined. Likewise, temporal variations in current magnitude and direction can give rise to serious cyclic loading. Some of the problems associated with cyclic loading of the CWP and its impact on structural design are covered in Reference (39).

4.3.3.3 Projected Near Term Developments - None Anticipated.

4.3.3.4 Proposed Technology Development Program

Based on the above discussion, it is clear that the problem of predicting structural loads and motions for OTEC platforms represent a major technological risk area which needs to be addressed in depth in future efforts.

A report recently prepared by Gilbert Associates, Inc., Reference (31), suggests that the "ideal model" of OTEC platform loads and motions should account for the following parameters:

I. Loading Parameters

1. Platform

- a. Surface Waves
- b. Surface Current
- c. Wind
- d. Warm Water Intake
- e. Warm Water Discharge
- f. Cold Water Discharge

2. Cold Water Pipe

- a. Surface Waves
- b. Surface Current
- c. Variable Drag Coefficient Along CWP
- d. Internal Waves

4.3.3.4 Proposed Technology Development Program (Continued):

- e. Internal Flow and Cold Water Column Motions
- f. Cold Water Intake
- g. Stationary Mass of Fluid in CWP
- h. Weighted End Conditions

II. Structural Parameters

1. Platform

- a. Rigid Body Motion
- b. Elastic Deformation

2. Cold Water Pipe

- a. Bending (Beam Theory)
- b. Shear Deformation
- c. Axial Motion
- d. Torsional Motion
- e. Bending (Shell Theory)
- f. Discrete Flexible Joints on CWP
- g. Conditions on Pipe Joint Attachment:
 - Finite Attachment Stiffness
 - Fixed Clamped Joint
 - Hinged Pinned Joint
- h. Internal Damping of CWP Material
- i. Different Wall Thickness of Pipe Sections

III. Coupling Effects

- 1. Coupling Effects Between Lateral, Torsional, and Axial Motions of the CWP
- 2. Coupled Motions Between Platform and CWP
- 3. Wave-Current Interaction

The Gilbert Associates, Inc. report also establishes which of these requirements are satisfied by the available models described earlier (except Garrison's). Based on this comparison, Gilbert made two recommendations pertaining to the prediction of motions and loads for OTEC-1 and all other OTEC Platforms:

- Paulling's model could be used in OTEC-1 to obtain qualitative frequency domain solutions. It is considered that the model is generally good for describing small amplitude motions.

4.3.3.4 Proposed Technology Development Program (Continued):

- A complete model should be developed to simulate the real forces and the real deflections to which the platform - CWP system will be subjected. This model will be used not only in OTEC-1, but in all the succeeding tests deemed necessary to bring the OTEC project to a successful conclusion.

The first recommendation is currently being implemented by means of the Oakland workshop mentioned earlier. In fact, the Paulling program which is based on a two-dimensional strip theory approach is to be supplemented with Garrison's "fat body" program. The second recommendation for an "ideal model" will require a high level of effort and large sums of money, possibly two man years and one to two hundred thousand dollars. The amounts of manhours and dollars to be spent in implementing such a program will necessarily be dictated by the level of technological risk assigned to the motions and loads problem.

The real key to the direction in which to proceed is the degree of validity of the Garrison/Paulling model which is scheduled to become the definitive work for OTEC. As addressed in Reference (31) and Section 4.3.3.2.1 of this Volume, frequency domain models have a number of drawbacks, most notably the inability to account for non-linearities, but the effect of these shortcomings on the predicted motions needs to be evaluated by model test programs and/or full scale results on OTEC-1 before the model is discounted. The non-linear and higher order effects may not have a significant enough effect to invalidate the model as a prediction tool given the level of accuracy required for design.

The model test programs would be quite extensive because of the variables involved and as a minimum should evaluate:

- The hull forms under consideration for OTEC (this may not involve all six being presently studied)
- Different pipe attachment stiffnesses (zero, finite, infinite)
- Different pipe stiffnesses to represent various materials of construction
- A range of sea states.

Problems with scaling effects and the unusual configuration of the OTEC Plant with its long cold water pipe would necessitate the establishment of a special facility similar to the one constructed by Hydronautics, Inc. for its OTEC-1 tests.

4.3.3.4 . Proposed Technology Development Program (Continued):

As an adjunct to, or in lieu of, a model test program which in itself could prove to be quite expensive (the above program could run up to five hundred thousand dollars, not including the cost of a special test facility) experimental measurements on OTEC-1 could be conducted. These would involve measurements of sea state, platform motions, and CWP loads. The latter effort would require extensive instrumentation of the CWP and would be limited to one material unless a number of pipes could be fitted over the Plant's period of operation.

There are certain difficulties involved with such a test program, perhaps the most important being the inability to establish the desired experimental conditions. The full range of sea states required the existence of well developed long-crested waves, and the measurements of these sea states are all subject to the vagaries of the weather, and they all could combine to reduce the effectiveness of the program. Again, the cost of the full-scale experimentation, which could be as high as half a million dollars, and run for a year or more, assuming only one CWP, must be evaluated against the value of achieving a highly accurate motions and loads prediction procedure.

All of the above considerations are further addressed in the next section relating to the CWP, since the question of hull motions and CWP motions are closely interrelated.

4.3.4 Cold Water Pipe and CWP/Hull Connection

4.3.4.1 Current State-Of-the-Art

The cold water pipe and its connection to the hull require some extension of current State-Of-the-Art in several areas. First, the configuration of a floating moored platform supporting a long slender pipe represents a marine structure unique to the OTEC concept. The excitation forces acting on the pipe-hull system and the corresponding response of that system cannot be easily modeled or predicted by currently available computer programs or experimental data. Simplified models used to date have all neglected to accurately address the flexibility of the pipe and the possibility of resonant response to the large high energy waves present in storm conditions at sea. Such an analysis is a prerequisite to the efficient structural design of the CWP. Second, even when using the optimistic

4.3.4.1 Current State-Of-the-Art (Continued):

results of the simplified loading models derived thus far, the thicknesses required indicate that material forming and fabrication procedures may be near or beyond current limits of the State-Of-the-Art. Obviously, in this area the relationship between current and required technologies is extremely dependent on the material selected, as well as the details of the design solution. For example, fabrication from mild steel may be entirely within current technology of the CWP if to be built up as a single or double thin walled tube with a supporting grillage of circumferential and axial stiffeners, but fabrication of a single shell with a wall thickness on the order of 6 inches will require development in the area of plate preparation and forming. Third, the deployment and erection of the CWP at the site will involve considerable forethought and development primarily because of the unique nature of this procedure. Finally, the connection to the platform, whether rigid or flexible, must efficiently transmit the reactions and moments developed by the various loadings described above from the CWP to primary structure within the platform. Here again, any evaluation of the adequacy of current technology is very dependent on the selected design solution.

The first two of these areas are the subjects of more detailed discussions found in Sections 4.3.2 and 4.3.3 of this Volume respectively. The latter two areas are discussed below.

The deployment and erection of the CWP can best be accomplished by one of two methods: prefabrication of several sections of the pipe ashore with final assembly and connection accomplished on-site, or continuous production of the pipe on-site with simultaneous lowering as the pipe "grows" in length. The prefabrication of the entire length of pipe in a single assembly ashore currently appears to be infeasible due to the inherent problems in constructing, transporting, and erecting a single 3,000 foot long flexible structure. The size of the assemblies to be prefabricated ashore will be dependent on the material selected. Size limitation of a GRP CWP subassembly will probably be dictated by the State-Of-the-Art of GRP fabricating procedures as discussed in Section 4.3.2 of this report. Steel subassemblies will probably be limited in length by the loads which will be experienced during transit to and erection at the platform site. Concrete subassemblies may present either technological problems in production of the desired cross section (incorporating voids, reinforcing bars, and method of

4.3.4.1 Current State-of-the-Art (Continued):

connection of assemblies) or by weight limitations dictated by the capacity of available cranes. By producing the pipe on-site some, but not all, of the above problems are eliminated. Technological problems related to production of concrete or GRP exist regardless of site of fabrication. Quality control may in fact be harder to ensure if production is to be accomplished on-site. Additional problems encountered in continuous fabrication include the development of a method to hold the pipe in intermediate positions during its production. This may be accomplished by either providing slight positive buoyancy (either through the use of temporary buoyancy chambers or the incorporation of voids within the wall structure) or some type of mechanical grip. A grip of this type has been developed for use on small diameter pipes on drillings and ocean exploration ships (i.e., GLOMAR EXPLORER), but would require considerable development for use on a pipe with a diameter of over 100 feet.

Similarly, the method of attachment to the platform is tied to the material selection and arrangement configuration. It may be possible to design a rigid connection using steel or concrete without reliance on advanced technology, but the resultant impact of the required back-up structure on the remainder of the platform arrangement may be undesirable. A universal or ball joint connection eliminates the bending moments at the joint, but the bearing surfaces must be capable of supporting the net weight together with the CWP vertical dynamic loads. Bearings, using materials currently available, could be designed, but because of the unique nature of the magnitude and variation of the loads to be supported and the configurations of back-up structure and cold water distribution systems, the engineering effort to develop the design is expected to be considerable.

As indicated in the preceeding discussions, several alternatives remain to be evaluated to ensure feasible producibility and operation of the design solution.

4.3.4.2 Projected Near Term Developments

Prior to the investigation of the details to be used in the fabrication of the CWP, the Garrison program will be available to facilitate the accurate prediction of the OTEC Ocean System motion characteristics and loadings. As discussed in Section 4.3.3, it is anticipated that this program will be the most

4.3.4.2 Projected Near Term Developments (Continued):

comprehensive seakeeping program devised to date. The verification of this program with appropriate modification and model definition for the specific platforms under consideration will equip design engineers with a valuable tool for the subsequent design.

Following the determination of the design loading conditions, the trade-off studies involving material selection and details of the arrangement will be developed under Task IV. During the course of these studies, development of new techniques and procedures may evolve as the unique requirements of the OTEC platform become more clearly defined. To predict the development of these techniques and procedures would require presupposition of design decisions which cannot be accurately anticipated at this time.

4.3.4.3 Proposed Technology Development Programs

Because of the uncertainties involved in several of the areas of technology related to design and construction of the CWP, an effort should be made to verify, through a series of model and full scale tests, as many of the techniques, procedures and analytically determined design parameters as is practically feasible.

A six phase program of CWP development is proposed, which should ultimately be based upon the platform/CWP configuration selected by DOE for the Preliminary Design of the OTEC Demonstration Plant. It is further proposed that these studies begin as soon as possible, in order to gain sufficient confidence in the available design tools to support cost, schedule and risk assessments.

Phase 1 - Idealization of Garrison/Paulling Program

This phase was addressed in Section 4.3.3 relative to motions, but is discussed further in this section since the hull/CWP interaction is an area of primary concern. This initial phase would involve the reassessment of the Garrison/Paulling program in light of its performance during Task IV to accomplish the following:

4.3.4.3 Proposed Technology Development Programs (Continued):

Phase 1 - Idealization of Garrison/Paulling Program (Continued):

- (1) Eliminate any obvious problems in the software
- (2) Develop a single program rather than two separate programs where the output of one must be manually fed to the other
- (3) Consider incorporation of additional capabilities in the programs to eliminate the shortcomings highlighted in Reference (31) and incorporate those capabilities considered to be worthwhile.

It is suggested that this phase begin with DOE solicitation of user comments near the end of Task IV, when all contractors will have had a chance to study and work with the programs. Suggestions for specific changes can be circulated throughout the OTEC community, leading to the specific steps suggested above. Without Task IV input, it is difficult to arrive at a valid estimate of cost or schedule. However, for planning purposes, a 9 month, \$80,000 program appears reasonable, starting about January, 1978.

Phase 2 - Verification of Garrison/Paulling Program with Model Tests

This phase would involve a series of scale model tests of the six (6) OTEC platforms selected for Conceptual Design in December, 1977 to verify the Garrison/Paulling analytical predictions of platform motions and CWP response in varying sea conditions. The scope would include, as a minimum, determination of platform motions in the six degrees of freedom, heave accelerations and CWP bending moments in Sea State 3, 6, and 9. Current-induced moments could be mathematically superimposed on the model test results. Such tests would identify any discrepancies between the results of the computer program and model tests, and would lead to the identification of data to be determined from full scale tests.

This program could begin as soon as possible after the selection of OTEC Conceptual Design Candidates. Allowing six (6) months for the RFP/proposal/evaluation phase, it is unlikely that such a program could begin before June, 1978, and would require twelve (12) months to complete, at a cost of \$150,000.

18351-10 (W-10,000)

4.3.4.3 Proposed Technology Development Programs (Continued):

Phase 3 - CWP Analytical Studies

These studies were partially described in Section 4.3.2.3.2, and would be conducted in parallel with the Phase 2 studies. The baseline study would involve a scope of work as proposed in Section 4.3.2.3.1, covering CWP materials, loads, structural design, attachment, weight, cost, construction, deployment and operations. The baseline phase would require about 12 months to complete, similar to Phase 2, and would cost about \$120,000.

The second part of this study would involve the reassessment of the baseline results to reflect the outcome of Phase 2. If the Garrison/Paulling programs were shown to be in error, the baseline results would be reassessed. A margin of 2 months and \$15,000. is recommended for this effort.

Phase 4 - Full Scale Verification - OTEC-1

This phase would initially involve the use of the Garrison/Paulling program to predict the response of the CWP installed on OTEC-1 to the anticipated sea spectrum. The full scale CWP would then be instrumented with a series of strain gages at critical locations along its length (these should be installed during construction), and CWP strain and hull motion data would be taken throughout the OTEC-1 at-sea test cycle. Such readings would initially be taken in calm seas to establish a baseline, and would then be taken whenever sea conditions deteriorate. In order to correlate data, it would also be necessary to monitor wind and wave conditions while strain gage and motion readings are taken.

The program described above would involve extensive instrumentation. This, in conjunction with formidable data reduction and interpretation requirements, could involve a cost of as much as \$250,000. and a minimum of one year in order to gather a sufficient range of data. This phase would begin with the deployment of OTEC-1.

18351-10 (W-10,000)

4.3.4.3 Proposed Technology Development Programs (Continued):

Phase 5 - Refinement of Analytical Techniques

This phase would involve a thorough reassessment of the Phase 1 and 2 results to refine analytical CWP response prediction techniques based on the Phase 4 full scale tests. Due to the unknown nature of the problems which may arise, a program cannot be defined; however, for budgetary purposes, \$50,000. and nine (9) months are allocated, beginning three (3) months after completion of the Phase 2 tests.

Phase 6 - Further Verification on 10/20 MW Pilot Plant (OTEC 10/20)

This phase would be essentially identical to Phases 4 and 5, involving a minimum of one year and \$250,000.

It should be assumed that the CWP verification program will continue beyond Phase 6 of CWP responses on the Demonstration and prototype Commercial Plants, at an average cost per year of \$150 - \$200,000 (1977 dollars).

4.3.5 Seawater Pumps

4.3.5.1 Current State-Of-the-Art

The design requirements of the warm and cold seawater pumps on first inspection would apparently meet or exceed the current State-Of-the-Art for pump design. As noted in Appendix A, the Top Level Requirements for the baseline cold water pump are 8.45×10^8 lbm/hr. at 39.5 RPM and a head of 9.5 feet while the warm water pump requirements are 7.52×10^8 lbm/hr. at 40.84 RPM and a 9.8 foot head. These rates correspond to approximately 1.7×10^6 GPM and 1.5×10^6 GPM respectively and were based on vertical pit propeller type pumps. A motor drive rated at 5,200 HP was estimated for the cold water pump and 4,775 HP for the warm water pump. To determine the position of these pump requirements with respect to existing technological limits, previous pump investigations were reviewed and the question discussed with industry representatives to best define the current State-Of-the-Art.

4.3.5.1 Current State-Of-the-Art (Continued):

An industry survey revealed that although no pumps have been built that would meet the total requirements of the proposed OTEC Plants, the requirements of the 25 MW module could be met. Table 4.3-3 provides a summary of industrial capabilities for large capacity low head pumps. This data was derived from Reference (40) and industry sources. Pump types other than the vertical pit or bulb type, such as centrifugal or mixed flow, did not meet or approach the baseline requirements so they are not included. As noted in Table 4.3-3, the bulb type pumps do meet the baseline requirements while the vertical pit type (axial flow/propeller) fall somewhat short. It should be noted that although the one bulb type pump will provide 3,600,000 GPM of water at a 15 foot head, the high specific speed indicates a low efficiency and corresponding high power requirement.

TABLE 4.3-3

INDUSTRIAL CAPABILITIES FOR LARGE CAPACITY LOW HEAD PUMPS

<u>PUMP TYPE</u>	<u>FLOW (GPM x 10³)</u>	<u>HEAD (Feet)</u>	<u>SPEED (RPM)</u>	<u>SPECIFIC SPEED</u>	<u>MANUFACTURER</u>
Vertical Pit	500	20	-	-	Allis-Chambers
Vertical Pit	630	20	-	-	Worthington
Vertical Pit	350	6	90	13,900	Byron Jackson
Vertical Pit	230	25	235	10,000	Ingersoll-Rand
Bulb	1,800	9	54	14,000	Mitsubishi
Bulb	3,600	15	94	23,400	Ateliers de Charmille

4.3.5.2 Projected Near Term Developments

Near term development for large capacity low head pumps appears to tie into the development of OTEC plants. Several industry representatives noted that they were familiar with OTEC and the proposed requirements. The most recent developments in comparable size pumps were for flood control and were in the area of 630,000 GPM.

4.3.5.3 Proposed Technology Development Program

The initiation and intensity of a technology development program is dependent on the design direction of the baseline OTEC power module and in particular, the Seawater System. For example, the specification of a single pump for the cold Seawater System and a single pump for the warm Seawater System would require a pump with a capacity approaching 2,000,000 GPM and a 10 foot head. This would require an extension, or at least a refinement, of the State-Of-the-Art. A multiple pump design, on the other hand, would result in individual pump requirements within the current State-Of-the-Art.

- Scope - For a single pump design, a technology development program would have to encompass an entire design sequence from preliminary to final design, a testing program, development of manufacturing procedures and considerations of transportation and installation problems. A multiple pump technology development program design sequence would not be as extensive. Existing designs and guidelines could be utilized along with existing model data if it could be extrapolated for OTEC requirements. Other considerations that are important with the single pump design, such as manufacturing, transportation, and installation, would not be a significant problem with a multiple pump design.

The magnitude of risk involved in the design of the seawater pumps is directly related to the degree with which the pumps stay within or exceed the current State-Of-the-Art. A design arrangement centered around single seawater pumps would have a high risk factor due to the pump requirements, whereas multiple pumps would have a relatively low risk factor since they could be in the range of existing pumps. In either case, the risk factor becomes less as each milestone is completed. This would include the completion of model tests and the successful operation of Seawater Systems on OTEC-1 and OTEC-10/20. In addition, the benefits gained through operation experience on OTEC-1 and OTEC-10/20 would be incorporated into the design process leading to the development of the seawater pumps for the 50 MW test module and the OTEC Plant.

Based on the above, and assuming a multiple pump design, it does not appear necessary to embark on a formal seawater pump technology program. Rather, the sequential design process for the Seawater System from Conceptual through Detail Design should be sufficient. The following paragraphs provide some guidance relative to key milestones.

4.3.5.3 Proposed Technology Development Program (Continued):

- Milestones and Schedule - Important milestones for the seawater pump design sequence would be completion of preliminary design, selection of a contractor, completion of contract design, model test analysis and incorporation of test results. The manufacturing portion of the pump development would have milestones of process development, pattern completion, manufacture of parts, assembly, transportation to module construction site and installation. Considering the fact that a major portion of preliminary design will be accomplished during Task V and Task VI with respect to the pumps and manufacturing requirements, and not considering any lag time for selection of pump manufacturer, a preliminary schedule of events can be postulated. The contract design phase can be assumed to extend over a six (6) month period, including model design and construction, with one month each allocated for analysis of test results and design refinement. This results in a total of eight months for the design phase. Manufacturing of the pumps would evolve from a facilities preparation including tooling, fitting and pattern development of nine (9) months duration, a manufacturing period of four (4) months and one (1) month for delivery and installation. Assuming that a period of the manufacturing process development phase may overlap with the design phase and not allowing for any lag between milestones results in a minimum elapsed time of one (1) year. If no overlap of manufacturing process and design are considered, the time becomes twenty-two (22) months from initiation of contract design to installation in a waiting module. This of course, applies in most part to the development and construction of prototype pumps for a test platform. Subsequent "production" model pumps could be produced in a shorter period of time which could be determined by factoring out development time. This also considers the fact that data and experience gained on the design, construction, and operation of OTEC-1 and OTEC-10/20.

- Funding - The funding of seawater pump development, design and manufacturing would be covered as a subproject on the overall Seawater Systems project funding.

4.3.6 Seawater System Interference Effects and Environmental Protection

4.3.6.1 General

In addition to the problems of thermal recirculation with a single platform and thermal interference of a number of Plants in an energy park, the deployment of OTEC Plants raises a number of domestic and international environmental problems which must be addressed during the planning and design phases of the OTEC Commercial Plant study.

In 1975, the American Society of International Law, pursuant to an NSF-ERDA grant, commissioned studies on legal, political, and environmental aspects of ocean thermal energy conversion. The results of these studies were disseminated at a workshop held in Washington, D. C. on January 15 - 16, 1976. One of the most important issues analyzed was that of protection of the ocean environment and its international and domestic implications.

The paper presented by Robert E. Stein, Reference (41), indicated that OTEC plants may cause changes in ocean temperature and perhaps in the atmosphere which could have impacts far from the site; water intake and exhaust could affect the biosphere in broad areas. Likewise, the use of fluids and chemicals of a potentially hazardous nature could produce adverse effects if spilled. Although some legal precedents exist to deal with international pollution, new initiatives stemming from the Stockholm Conference on the Human Environment and the United Nations Environment Program (UNEP) are more likely to have significant effects on OTEC deployment. There are also a number of international agreements which may impact on OTEC, such as the 1972 Ocean Dumping Convention and the 1973 IMCO Convention for the Prevention of Pollution from Ships. Stein concluded that there will inevitably be environmental effects from OTEC deployment and that as a result there will be a growth in multilateral regulation of OTEC devices. A second paper presented at the same workshop, Reference (42), addresses the effect of the National Environmental Protection Act (NEPA), subsequent litigation, and environmental impact statements. This paper differentiates between the research and development stage, the demonstration stage, and commercial development in discussing the likely applicable domestic environmental laws and regulations.

4.3.6.1 General (Continued):

At this time it may be impossible to anticipate all requirements of the regulatory and environmental agencies. The filing of an actual application for operation may be needed for this information. It could well be that compliance with requirements may not be a serious technical problem, but it will require time, substantial attention to detail and documentation for the processing of the needed permits.

4.3.6.2 Current State-Of-the-Art

In order to deal with the problems discussed above, pertaining to the environmental impact of OTEC plants, DOE in cooperation with several academic and industrial organizations has been sponsoring extensive investigations aimed at answering some of the more critical questions. The purpose of this section is to present a synthesis of the efforts which have either been completed or are currently underway so that ready reference may be made to the State-Of-the-Art as it presently exists.

4.3.6.2.1 Thermal Mixing in the Vicinity of OTEC Plants: Local Effects and Near Field Flow

Near field flow computations are of fundamental importance to the OTEC program for two main reasons. First, they determine the inflow temperatures to the evaporators as a function of design operating parameters, and the ambient conditions. Second, they are a basic input to far-field environmental impact computations since they determine the redistribution of heat, salt, horizontal momentum, biological species, and nutrients between different ocean layers and the possible addition of biocides and pollutants to certain layers. Table 4.3-4 describes the studies which are applicable to near field flow and thermal mixing analysis.

4.3.6.2.2 Impact of OTEC Plants on Regional Thermal Structure: Far Field Flow

The impact of one or more OTEC plants operating in a specific region of the ocean requires looking at oceanographic processes in a much larger scale

TABLE 4.3-4

Near Field Flow and Thermal Mixing Studies Relevant
to OTEC Plant Design

18351-10 (M-10,000)

AUTHOR(S)	ORGANIZATION(S)	PROBLEM	FINDINGS/RESULTS
Roberts, G. D.	Science Applications, Inc., McLean, Va.	Stratified Turbulence Modeling for the Near Field External Flow	A simplified two dimensional model was used to calculate the turbulent flow near the two outflows and the warm inflow associated with one power module of the Lockheed OTEC design. It was found that the OTEC-generated turbulence is negligible at distances greater than 350 ft from the inflow and outflows.
Jirka, G. H. Fry, D. J. Johnson, P. R. Harleman, D. R.	R. N. Parsons Laboratory for Hydrodynamics and Water Resources Dept. of Civil Engineering, M.I.T. Cambridge, Mass.	Investigations of Mixing and Recirculation in the Vicinity of an Ocean Thermal Energy Conversion Plant	Experimental and analytical studies on the external fluid mechanics in the vicinity of an OTEC plant were conducted. Schematic OTEC conditions defined by a mixed discharge mode and a discretely stratified ocean were assumed. The interaction of several fluid mechanical regions, a jet entrainment zone, an intermediate buoyant layer and an intake flow zone was simulated in a shallow laboratory basin representing the upper layer of the stratified ocean. A concurrent analytical model development gives satisfactory agreement with the experiments and allows definition of an approximate criterion for the existence of recirculation of discharge water back into the plant intake.

TABLE 4.3-4 (Continued):

Near Field Flow and Thermal Mixing Studies Relevant
to OTEC Plant Design

18351-10 (M-10,000)

AUTHOR(S)	ORGANIZATION(S)	PROBLEM	FINDINGS/RESULTS
Kirchhoff, R.H. Mangarella, P. A. McGowan, J. G.	University of Massachusetts Amherst, Mass.	Hydrodynamics of OTEC plants sited in the Gulf Stream	This study included the deter- mination of the characteristics of the inlet and exit of the hot water system for both nat- ural pumped evaporators (using kinetic energy of the Gulf Stream) and forced pumping sys- tems. The hydraulic investiga- tion of the cold water included a determination of the with- drawal layer and the effects on the site water stratification. Also the characteristics of the condenser exhaust plume were examined to determine salinity concentration and flow pattern in the wake of the plant.
Giannotti, J.G.	Giannotti & Buck Associates, Inc. Annapolis, Maryland	Thermal Mixing Considerations for OTEC Park Concept Design (Part of the Task IIA studies summarized in Refer- ence 1	This study presents the results of an analysis aimed at predict- ing the temperature profiles and cold water plume trajectories for the case of several OTEC plants operating as an energy park. The analysis treats the problem of a cold water dis- charge into a stratified enviro- nment and in the presence of a current. The model allows one to estimate the required plant spacing and location of the warm water intake and cold water dis- charge in order to minimize detrimental thermal mixing.

TABLE 4.3-4 (Continued):

Near Field Flow and Thermal Mixing Studies Relevant
to OTEC Plant Design

AUTHOR(S)	ORGANIZATION	PROBLEM	FINDINGS/RESULTS
Sunderam, T. R. Sambuco, E. Sinnarwalla, A. M. Kapur, S. K.	Hydronautics, Inc. Laurel, Maryland	External Flow Induced by an OTEC Power Plant	Study assesses the recirculation potential for OTEC outflow and inflow. Experiments were conducted on two classes of problems; the first is one in which an ambient current is present without ambient stratification; the second is one for which the opposite is true. Recirculation was measured directly by introducing dye into the discharges and by measuring the dye concentration in the intake flow. Maps of the distributions in the jet flow of the mean and turbulent quantities were obtained. These measurements are useful for the tuning of mathematical models of the flow field.

18351-10 (W-10,000)

4.3.6.2.2 Impact of OTEC Plants on Regional Thermal Structure: Far Field Flow
(Continued):

than in the case of the near field problem discussed previously. It is the regional model which will allow the policy maker or program manager to arrive at decisions with long term implications regarding the possible impact of OTEC plants on a geographical area. These decisions go beyond the details of the individual plant design as they affect the economic, social, political, and environmental structure of the area of concern.

As was done in the previous section for the near field problem, Table 4.3-5 has been prepared to summarize the work which has been carried out or is currently underway in the area of regional environmental modeling relevant to OTEC plant siting.

4.3.6.3 Near Term Developments

There are no programs known to be currently underway to further define the environmental impact of the OTEC concept, though impact assessments of OTEC-1 and OTEC-10/20 are planned.

4.3.6.4 Proposed Technology Development Program

4.3.6.4.1 Near Field Flow

On the overall, the near field flow problem has been investigated in sufficient depth by several investigators. What is needed now is an effort to merge the different analyses and experimental results into a consistent methodology or model which can then be used uniformly across the board in the design of OTEC plants. Such a task should not prove inordinately difficult, and the analytical model could be verified during the operation of OTEC-1 and OTEC-10/20. Although the full scale experiments would probably not be absolutely necessary given the experimentation that has been used to back up present models, full scale results are a valuable aid to the credibility of any prediction tool used for a previously untried system. The OTEC-1 and OTEC-10/20 program could consist of the following:

- Temperature, salinity, and effluent velocity profile measurements in the vicinity of the platform in the presence of various winds, currents, and sea states. The measurements would be taken at varying depths to the limits of the effluent plume.

TABLE 4.3-5

Far Field or Regional Thermal Models and Studies Relevant
to OTEC Plant Siting

AUTHOR(S)	ORGANIZATION(S)	PROBLEMS	FINDINGS/RESULTS
Placzek, S. A. Warn-Varnas, A. C.	Naval Ocean Research and Development Activity, Bay St. Louis, Miss.	Air-Sea Interaction Perturbations by Plant Operations	The readjustment in the air- sea heat flow and the air-sea temperature contrast following a possible sea surface temper- ature lowering by OTEC opera- tions was calculated for the areas of Puerto Rico, Gulf of Mexico, and Hawaii. The net heat flow in these areas was found to be +76, -27 and +50 $\text{cal/cm}^2\text{-day-}^\circ\text{C}$ respectively, and the perturbations due to OTEC operations were found to be +96, +81 and +67 $\text{cal/cm}^2\text{-}$ $\text{day-}^\circ\text{C}$.
Martin, P. J. Roberts, G. O.	Science Applications, Inc., McLean, Va.	Estimate of the Impact of OTEC Operations on the Vertical Distribu- tion of Heat in the Gulf of Mexico	Recirculation between the intake and discharge flows of an OTEC plant is a potential problem for OTEC operations in that recirculation can bring about a decrease in the avail- able thermal resource of the general area of the site. This study considered the effects caused by far field recircula- tion due to the operation of 100 and 1,000 OTEC plants in a semi-confined basin such as the Gulf of Mexico.

18351-10 (W-10,000)

TABLE 4.3-5 (Continued):

Far Field or Regional Thermal Models and Studies Relevant
to OTEC Plant Siting

AUTHOR(S)	ORGANIZATION(S)	PROBLEM	FINDINGS/RESULTS
Thompson, J. D. Hurlburt, H. E. Lin, L. B.	JAYCOR, Alexandria, Va.	Development of a Numerical Ocean Model of the Gulf of Mexico for OTEC Environmental Impact and Resource Availability Studies	This effort included the development of a hierarchy of numerical models of the Gulf of Mexico for predicting the interactions of OTEC operations and the environment. The development of these models was based on the concept that the best strategy for OTEC far-field modelling of the ocean is the selection of a single, well-observed ocean basin with well defined boundary and surface input data with conditions in the basin representative of those to be encountered in the tropical and subtropical oceans. The basin should be large enough to represent open ocean conditions but small enough for economical computer modelling. The Gulf of Mexico was therefore appropriate for initial model studies.

18351-10 (M-10,000)

TABLE 4.3-5 (Continued):
Far Field or Regional Thermal Models and Studies Relevant
to OTEC Plant Siting

AUTHOR(S)	ORGANIZATION(S)	PROBLEM	FINDINGS/RESULTS
<p>Atwood, D. K.</p> <p>Duncan, P. G.</p> <p>Stalcup, M. G.</p> <p>Barcelona, M. J.</p>	<p>NOAA/AOML/OCL, Miami, Florida</p> <p>Marine Sciences Dept., University of Puerto Rico, Mayaguez, Puerto Rico</p> <p>Woods Hole Oceanographic Institution, Woods Hole, Mass.</p> <p>California Institute of Technology, Pasadena, California</p>	<p>Resource Assessment of a High Potential OTEC Site near Puerto Rico</p>	<p>An Assessment of potential OTEC sites near Puerto Rico indicated that a high-potential site exists off the southeast coast. The AT is ideally suited. Geotrophic conditions guarantee a warm, thick mixed layer with surface currents in the order of 1/3 of a knot. The supply of cold water can be considered limitless. The salinity, temperature and nutrient distributions of the site are typical of tropical seas making the site ideal for a prototype OTEC plant.</p>
<p>Bathen, K. H.</p>	<p>Department of Ocean Engineering, Univ. of Hawaii, Honolulu, Hawaii</p>	<p>Evaluation of the Oceanographic Conditions Found off Keahole Point, Hawaii, and the Environmental Impact of Nearshore OTEC Plants on Sub-tropical Hawaiian Waters</p>	<p>Based on the temperature and cold water discharge rate of 100 MW and 240 MW OTEC plants, and the local meteorological and oceanographic data, estimates were made of changes in surface heat exchange, alteration in heat content of the mixed layer, and rates of spreading of the discharged cold water. Given then an estimate of the plume outfall characteristics and local biological data, the degree of nutrient addition and the extent of possible biostimulation were estimated.</p>

18351-10 (W-10,000)

4.3.6.4.1 Near Field Flow (Continued):

- Effluent discharge geometry variations to evaluate the effects on the plume
- Power System performance checks to evaluate the effects of reingestion.

The development of the model could be accomplished at any time, but it would be most advantageous to have it completed prior to the end of Task V, Conceptual Designs, and no later than the time when OTEC-1 is placed in operation. This schedule would allow the timely analysis of the designs generated as part of this project and a dovetailing of these analytical predictions with data resulting from full scale tests during the period of operation of the OTEC Plants.

It is estimated that the cost of developing the analytical model given the earlier of the two times would be \$50,000. and require about nine (9) months. The test program on the OTEC-1 is more difficult to estimate, but a figure of \$100,000. would seem reasonable at this time.

4.3.6.4.2 Far Field Flow

As with the near field flow, there appears to be a need to synthesize the various analyses into a single regional decision making model for predicting the overall environmental impact of OTEC Plants on the geographic areas of concern and the world wide ecosystem as a whole. As discussed in Section 4.3.6.1, it is difficult to bound the problem without knowing the demands that will be placed by various regulatory bodies and the international groups; however, it is generally conceded that the full impact of the OTEC concept on the environment must be fully understood. To fully complete this task, the time frame involved would span the entire development, construction and operational period of the first OTEC Plants both singly and in energy parks since the models would need to be verified by operational experience. The Far Field flow problem will be a continuing one until sufficient operational experience is obtained.

4.3.7 Position Control Systems

4.3.7.1 Current State-Of-the-Art - Static Systems

The combined environmental and vessel factors involved in the OTEC mooring systems are beyond the current State-Of-the-Art. However, in most respects the extrapolation is not drastic. The basic conditions for OTEC mooring systems are water depth of 3500 to 5000 feet, current velocities to 6 knots, waves and winds up to and including hurricane conditions, size to 1.5 million tons displacement.

Drilling platforms have operated successfully in 6 to 8 knot current in sheltered waters, and have withstood 90 to 100 foot waves accompanied by hurricane velocity winds in the North Sea, North Atlantic, Gulf of Mexico, and in the Pacific Ocean.

Offshore petroleum technology represents the State-Of-the-Art for large size deep water moorings. Although most rigs are designed for 600 foot water depths, several are in the 2000 to 3000 foot range. One vessel using combined dynamic positioning and mooring systems drilled and completed a well in 3400 feet of water, establishing the present depth record for moored vessels. In terms of size, however, this vessel of only about 10,000 tons is only a small fraction of the size of OTEC plants.

The largest drilling and construction vessels in current use are about 50,000 displacement tons. Vessels of this size have not been moored in the deepest water depths, although the capability exists for doing so.

Mooring system components exist in sizes close to those required for OTEC mooring systems. Wire rope is available in 4 inch diameter extra improved plow steel having a breaking strength of about 720 short tons. Winches in common use on drilling and construction vessels can handle wire as large as 3-1/2 inches in diameter having a breaking strength of about 564 short tons. Fairleaders and other auxiliary equipment are readily available in the 3-1/2 inch size. The extension of design and production capability to 4 inch wire rope would not be a major step.

Wire rope manufacturing capacity is limited to batches of about 90 tons. This works out to about one nautical mile of 4 inch wire. Since mooring lines in the deepest water projected for OTEC platforms may require a length 1-1/2 to 2-1/2 times that number, it will be necessary to develop means of

4.3.7.1 Current State-Of-the-Art - Static Systems (Continued):

handling and joining these large diameter wires. This is not expected to pose a problem since mooring lines are often made up of more than one line segment.

anchors in common use for drilling and construction vessels range up to 40,000 pounds. High holding power lightweight anchors are commonly used for drilling rigs. These anchors have a holding capacity of about 8 to 15 times their weight in reasonably good holding ground. A modest increase in size of anchors will, therefore, meet OTEC platform requirements. Special high holding anchors such as the Bruce anchor or the Delta type have a much higher holding power to weight ratio and are available in sizes which closely approach the requirements for OTEC plants. Deadweight anchors may prove to be desirable for use in mooring OTEC platforms. These can be manufactured in the sizes required with the existing technology. Reference (43) addresses the SOA of anchor development in detail.

The principal factor in which the OTEC mooring system drastically exceeds the State-Of-the-Art is in the expected life or duration of the mooring. Drill ships, which stretch the State-Of-the-Art in terms of water depth and holding capacity to the present limits, remain on station on the order of one to three months in the drilling of an oil or gas well. Floating storage vessels remain on station more or less permanently, interrupted for overhaul and drydock inspection at intervals of four to six years. The OTEC power plants and their mooring systems will probably operate on a similar cycle, except that in lieu of drydocking any inspection required will be done in place. The mooring system, however, will be as vulnerable, as is the case with storage vessels. The parallel with storage vessels breaks down when one considers the extreme water depths in which the OTEC platforms will be sited compared with the depths of no more than a few hundred feet for storage vessels. Means must be developed to determine the long-life effects of the environment and the imposed loads on the life of deep water mooring system components. Storage vessel moorings, being in relatively shallow water, employ chain, which is not suitable for OTEC plant moorings. Long-term effects of exposure of wire can, therefore, not be inferred from storage vessel moorings. Combination moorings may be suitable, however, using lengths of chain slightly greater than the water depth and wire lines connecting the chains to the OTEC platform. The demonstrated long life of a chain would, therefore, be used in that part of the mooring system which would be most difficult to replace.

4.3.7.1 Current State-Of-the-Art - Static Systems (Continued):

Cathodic protection is used widely in the offshore petroleum industry to protect fixed platforms, pipelines, and floating vessels. Some experience has been obtained in the use of cathodic protection for mooring systems. This technology must be extended greatly in order to insure the required long life of OTEC plant components.

4.3.7.2 Current State-Of-the-Art - Dynamic Systems

The dynamic positioning system consists of a position sensing system, a computer to determine the required magnitude and direction of thrust, a control system to actuate the thrust units, and finally thruster units to develop the required stationkeeping forces. All of these components exist in a highly developed state with the required accuracy and dependability for OTEC plant positioning. Subsystems have not, however, been applied to vessels even remotely similar in size to the larger OTEC plants. The largest dynamically positioned vessels in operation today are the drilling semi-submersible SEDCO 709 of about 25,000 tons displacement and the pipelaying semi-submersible VIKING PIPER of about 35,000 tons displacement. These vessels and other dynamically positioned vessels utilize right angle drive propulsion units for part or all of the thrust requirements. At the present time, right angle drive units are limited in capacity to 3000 horsepower. This limitation is imposed by available gear cutting machinery and is not likely to be increased significantly in the near future. Large power requirements can, therefore, be met only by increasing the number of units. Main propellers are in common use in much larger sizes, however, with 50,000 horsepower per shaft being considered the present day upper limit. In-line or parallel-shaft reduction gears for this power level are well within the present State-Of-the-Art.

Position sensing is accomplished by primarily acoustic or mechanical means. Acoustic positioning involves a bottom-mounted transponder interrogated by an array of sonar heads mounted on the vessel. Redundancy can be built in readily by using multiple transponders and sonar heads. Reliability is high. These systems have been used in depths of a few hundred to several thousand feet for oil well drilling and as deep as 20,000 feet for shorter term scientific drilling.

Mechanical position sensing utilizes either a taut wire from an anchor on the bottom up to the vessel (used in shallow water only) or the drilling riser. In either case, the angle of the wire or riser at the surface and/or

4.3.7.2 Current State-Of-the-Art - Dynamic Systems (Continued):

the bottom is measured and used as an indication of relative location. This method would probably not be adaptable to the OTEC plants.

Satellite systems are in current use for accurate position determination for ships which are underway remote from land areas. Position determination within a few meters is possible with repeated satellite passes. Those OTEC sites which are within about 50 miles of land could utilize line-of-sight high frequency radio wave navigation systems such as the Cubic Autotape system. By using a variety of such position sensing methods, it is believed that the current State-Of-the-Art will provide the required accuracy and reliability for OTEC platform position sensing.

The heart of the dynamic positioning system is the computer, which calculates the platform position from the various input data and directs the propulsion control system. The high level of reliability achieved with solid state electronic computers will be satisfactory for OTEC plant positioning systems. A system of three computers continuously on line and comparing results would immediately show when a computer is malfunctioning. With such a system, reliability ought to be 100%.

4.3.7.3 Projected Near Term Developments

If past trends continue, advancements in positionkeeping systems technology will result from the need to drill for oil in progressively more hostile environments as the "easy oil" is depleted. This implies that, as oil must be sought in deeper waters, the State-Of-the-Art in static mooring systems will be advanced to suit increased depths and platform sizes until economic and/or technical considerations favor dynamic systems. At the present time, it appears that such considerations favor dynamic systems or a combination of static and dynamic systems beyond about 3,000 feet. If current trends continue, it can be projected that the SOA in positionkeeping systems will not be suitable for OTEC within the timeframe now being considered.

4.3.7.3 Projected Near Term Developments (Continued):

Based on the above, it can be assumed that OTEC-1, OTEC-10/20, and the OTEC Demonstration Plant will drive the SOA as each program is developed and that extensive technology development will be required. It is noted that the Offshore Power Systems floating nuclear power plant is relatively close in size to a number the OTEC platform alternatives. However, this plant will be moored in relatively shallow water, and will be surrounded by a breakwater. Thus, the positionkeeping characteristics of this plant are not expected to advance the SOA appreciably.

A number of studies of OTEC positionkeeping requirements have been conducted to date, including References (5), (6), (40), and (44). These studies define some of the problems which must be addressed in the near future.

4.3.7.4 Proposed Technology Program

The technology program for OTEC positionkeeping will take two essentially parallel directions. First, the impending OTEC-1 program will require a near-term solution to the positionkeeping problem for that combination of platform and environment. Simultaneously, the Ocean System contractors will be conducting positionkeeping trade-off studies in conjunction with the Conceptual Designs of the six (6) Commercial Plant options to be selected in December, 1977. Thus, during early 1978, in-depth studies of various positionkeeping options will be made for a variety of Plant sizes, locations and configurations.

Because of the large number of positionkeeping options now available, as well as the number of sites and plant options being considered, it is not possible to formulate a specific Technology Program for the period following Ocean System Conceptual Design. It can be readily seen that the risk, and thus R&D effort required for a 500 MW Plant off Key West would be far greater than for a 100 MW Plant off Hawaii. However, once the six (6) Conceptual Designs have been finalized, it would be possible to formulate such a program geared specifically to the option or options selected for further development as the Demonstration Plant and ultimately the Commercial Plant. This program should begin as soon as possible after completion of the Conceptual Design effort, and should address the following:

18351-10 (W-10,000)

4.3.7.4 Proposed Technology Program (Continued):

- (1) Environment - Fill in missing data on current profiles, current/wind sectional relationships, bottom characteristics, wind/sea spectra and other oceanographic considerations as required.
- (2) Plant/CWP Drag - Theoretical calculations should be verified by model tests of the selected hull and CWP, particularly if the hull is of unusual configuration. Such tests should include both steady state drag and drag in waves up to the most critical environment anticipated. In order to avoid adverse scale effects, it is likely that only a short section of CWP could be included, with the added drag of the lower portion added mathematically. These tests should reflect the environmental data gathered in Task 1.
- (3) Full Scale Analysis - The OTEC-1 and OTEC-10/20 platforms should be fully instrumented to determine actual positionkeeping system requirements (line tensions, thruster HP, etc.) as a function of sea state and current conditions.
- (4) Equipment Development - Specific studies of high risk components of the selected positionkeeping system or systems should be conducted as required. Such studies might include prototype development and testing on OTEC-1 and OTEC-10/20. However, as indicated previously, it is impossible to become specific on such a program until the system is further defined.

Cost and Schedule - Because of the variables and unknowns described above, it is premature to estimate the cost and schedule for a positionkeeping technology program. It is recommended that each Ocean System Contractor be required to do so for the specific system(s) reflected in their Conceptual Designs as a decision making tool for DOE management. However, for current planning purposes, the following budgetary estimates are proposed:

	<u>Phase</u>	<u>Cost, \$</u>	<u>Schedule</u>
(1)	Environment	250 k	12 months
(2)	Plant/CWP Drag	60 k	6 months
(3)	Full Scale Tests-EOTP	150 k	6 months each
(4)	Equipment Development	500 k	15 months

4.3.7.4 Proposed Technology Program (Continued):

The estimate for Phase 1 includes instruments, personnel and data reduction, but not chartering of an oceanographic vessel. Phase 2 includes model preparation, tests, data reduction and analysis. Phase 3 includes deployment of velocity and temperature sensors around the platform at various distances and depths, automatic data recording equipment, data reduction and analysis. Phase 4 is purely a guess.

4.3.8 Cost Analysis

4.3.8.1 Current State-Of-the-Art

The prediction of acquisition cost is not truly an area of technical risk. Nonetheless, the ability to accurately estimate the cost of any project is obviously vital. Such estimates are an essential element, perhaps the key element in obtaining top management approval for project authorization. Confidence in the accuracy of such estimates is a primary concern to managers, because most of them have been burned many times by overly optimistic or inaccurate estimates. In short, the credibility of the cost estimates directly impacts the credibility of the entire program.

For OTEC, as with most Government-sponsored projects, there are a series of decision gates which must be passed wherein the need for the project and its cost must be continually justified. In general, each gate is preceded by an R&D effort of increasing scope and level of detail such that the confidence in the data presented is continually enhanced. For an OTEC platform, each design phase (Conceptual, Preliminary, Contract) will result in cost estimates of increasing accuracy, reflecting the greater level of engineering data upon which to base estimates.

The level of accuracy of a cost estimate is a direct function of the historical data base upon which the project is estimated. For ships and other marine platforms, such estimates are normally made by applying historic unit cost factors (\$/pound, \$/horsepower, \$/KW) against technical parameters. The accuracy of the estimate is directly dependent both on the unit cost factors and the parameters against which they are applied.

4.3.8.1 Current State-Of-the-Art (Continued):

At the Conceptual Design phase, acquisition cost estimates are generally based upon \$/ton figures applied against the major weight groups, plus major installed equipment costs. For the OTEC platforms, it is felt that all of the inputs to the cost estimating process are of questionable validity at this time due to:

- Sizes exceeding the SOA
- Hull shapes which exceed the SOA
- Materials which exceed the SOA for floating platforms
- Producibility/deployability requirements which exceed the SOA

This raises the basic question - how much confidence can we have in the cost estimates reflected in this study? Are these estimates a valid baseline for the major decisions to be made at the end of Task IV relative to optimum size and configuration? We feel that the answer is a qualified "yes". Current indications are that the cost estimates will provide a good indication of relative cost trends though the absolute costs may be questionable. Nonetheless, the SOA in cost estimating OTEC platforms remains an area of risk.

4.3.8.2 Near Term Developments

The continuing engineering efforts applied to the various OTEC concepts during Conceptual Design are expected to greatly enhance the absolute accuracy of the early-phase cost estimates. However, the near term improvement in the confidence of these estimates will be a direct function of the level of technical development and the qualifications of those individuals making the estimates.

4.3.8.3 Proposed Technology Program

There is no formal technology program proposed to improve the SOA in cost estimating. However, based upon the above comments, it is recommended that DOE carefully screen the qualifications of those individuals who will be making the cost estimates during follow-on Tasks of the Platform Configuration and Integration contracts. In addition, it is considered appropriate under the circumstances to have DOE contract an independent authority to review the estimates from the three Contractors and to negotiate a mutually agreeable and consistent set of cost estimates for all platforms considered. This will not impact overall schedules

18351-10 (W-10,000)

4.3.8.3 Proposed Technology Program (Continued):

appreciably, but might cost as much as \$30,000. - \$50,000. for the services of the consultant.

4.3.9 Construction and Deployment

4.3.9.1 Current State-Of-the-Art

As indicated in Section 4.3.1, the overall dimensions of many of the OTEC options are very large compared to the SOA, which has been established by tanker proportions.

4.3.9.1.1 Existing Facilities

Studies in Task II, summarized in Section 2, indicated the following limits of current U. S. shipbuilding capacity:

	<u>East Coast</u>	<u>Gulf Coast</u>	<u>West Coast</u>
Building Ways			
Length, Feet	700- 940	600-1,200	550- 900
Width, Feet	108- 195	90- 150	84- 106
Graving Docks			
Length, Feet	900-1,600	480- 550	996-1,100
Width, Feet	143- 240	70- 75	144- 170
Draft, Feet	30- 35	NA	NA
Channel Limits			
Depth, Feet	20- 42	34- 40	34- 45
Width, Feet	175-None	NA	NA
Height, Feet	124-None	NA	NA

NA = Not Available

In addition to this, Offshore Power Systems, Inc. is completing its Jacksonville, Florida facility which includes a building basin 2,700 x 450 feet in dimensions, with two cranes each having a 900 ton capacity. This facility is intended for the offshore nuclear plants in the near future.

4.3.9.1.2 Steel Construction Overview

Studies conducted in Task II indicated that most of the 50 MW and several of the 100 MW candidates are within the limits of graving dock or building way length and width. Larger platforms would have to be built using modular techniques, involving the welding of major subassemblies afloat. Though this capability currently exists, much of the welding technology was perfected in Japan, implying a learning curve for the U. S. yards.

A major problem which would have to be dealt with is inadequate shipyard and harbor drafts, even with steel platforms. The problem with concrete platforms is far more critical.

A number of shipyards are available on both the East and West Coasts which can accommodate 40 to 45 feet of draft at dockside. Since all of the OTEC plants exceed this by a factor of two or more, a production system must be devised to enable shallow draft components to be built in the yard. These are then assembled and loaded down to deeper draft in a remote but sheltered location. A few such locations exist on the East Coast such as Cape Cod Bay and outer New York Harbor which afford only a small degree of protection. Gulf Coast fabrication would require the final fabrication stages to be conducted in the open Gulf. Assembly of large components is a familiar task to the offshore oil industry. This can be done by selecting the most favorable season of the year and waiting for favorable weather. Protected deep water sites are available on the West Coast at San Francisco Bay, Puget Sound, and, for the deeper draft systems, Santa Barbara Channel. Here again, proven oil field technologies can be used to carry out offshore assembly operations; however, the problem in connection with the OTEC plants is greatly accentuated by the more extensive and more complex assembly procedures required at the offshore sites. It will be necessary for the design to utilize modular concepts to the greatest extent possible to enable the offshore construction to be essentially a plug-in operation.

4.3.9.1.3 Concrete Construction Overview

Concrete construction for floating or marine structures has not been developed to a high degree in the United States. A number of 200 foot barges have been built on the Gulf Coast by a combination of pre-cast and cast-in-place reinforced concrete techniques. Very little work has been done regarding post-tensioned

4.3.9.1.3 Concrete Construction Overview (Continued):

concrete marine structures. Stationary structures having dimensions of 400 to 800 feet have been constructed in Europe. Their size has ranged up to about 600,000 tons. The technology for large post-tensioned structures exists and certainly can be made available to the OTEC program.

Since large concrete structures are not under construction in this country, new facilities will be required to build the concrete OTEC plants. Owing to the specialized nature of the construction, it is deemed infeasible to consider using existing shipyards except for the smaller sizes; therefore, in scheduling construction of OTEC plants, it would be necessary to consider the lead time necessary to design and build the construction facility.

Fabrication methods will depend upon the hull form being built. Ship or barge type hulls can be built using extensions of existing methods. The cylinder and spar type hulls can be built using the techniques developed for the CONDEEP and similar platforms built in Norway for the North Sea. The sphere, semi-submersible, and submersible would require new developments in fabrication and assembly techniques, since no large scale concrete structures of these types have been built.

The same limitations regarding draft apply to the concrete structures. Owing to their greater weight, however, the concrete structures will encounter draft limits in smaller sizes than their steel counterparts. Since we do not have any well sheltered deep water fabrication areas resembling the Norwegian fjords, we will be obliged to work out construction methods which are suitable for less protected waters.

An OTEC platform contractor will have to acquire concrete mixing facilities and a labor force capable of reinforced concrete construction. However, such labor capability is available in the shore-based concrete construction industry.

The acquisition of reinforced concrete construction capability by U. S. shipyards would be in the area of low risk. Costs, however, would be increased by concrete plant construction and movement of the very large quantities of required materials.

4.3.9.1.4 Selection of Building Site

As noted above, the capability of the U. S. shipyards to partially complete plants in existing building berths or graving docks is very limited for capacities of 100 MWe and under and non-existent for capacities over 100 MWe. In addition, a sheltered, deep water facility is required for completion of any of the baseline Plants. This site should be reasonably close to the materials, equipment, outfit, labor and facilities required for completion.

The drafts for the various OTEC platform configurations as listed in Section 4.3.1 indicate that site selection could be in the high risk area. The water surrounding the shipyards listed in Table 2.5-1 in general will not permit completion of a platform with a draft of 100 feet at a location close to the shipyard.

Selection of a building site will also be influenced by the operating location of the platform. It would be desirable to build platforms for the Hawaiian site either in Hawaii on the West Coast and for the Gulf of Mexico and Key West sites on either the lower East or Gulf Coasts so that a tow of a massive floating structure over long distances could be avoided.

Further analysis of completion sites convenient to shipyards could lead to the conclusion that a completely new facility would be the most economical.

4.3.9.1.5 Procurement-Materials, Equipment and Outfit

The potentially large size of an OTEC plant could lead to procurement problems due to the large quantities of material, equipment and outfit. The risk of slippage in construction schedule is proportional to adherence to the procurement schedule; i.e., on-time receipts can be expected to result in on-time milestones. Delivery of the following to the shipyard are considered critical due to the large quantities required:

- Concrete, sand, aggregate and reinforcing bars
- Heat exchangers
- Warm and cold water pumps
- Turbine-generator sets
- Working fluid pumps and demisters

Heat exchanger production is probably the most critical procurement item.

18351-10 (W-10,000)

4.3.9.1.5 Procurement-Materials, Equipment and Outfit (Continued):

Long-lead schedules can be shortened by investing in additional facilities, e.g., additional tube fabricating plants, concrete batch plants, etc., providing the increased funds are allocated early enough to permit construction of the expanded facilities.

Procurement will be a low risk area for construction providing advance investigation of sources of supply are conducted to identify items which could result in late delivery in the absence of remedial action. Alternately, construction of the platform can be scheduled to suit procurement schedules attainable without the expansion of facilities.

4.3.9.1.6 Pre-Launch Construction

Pre-launch construction should be in a low risk area, assuming that a suitable construction site is available.

The following pre-requisites must be met prior to launching:

- Draft at launching must permit movement to completion site
- Hull must be watertight and have sufficient internal support to withstand launching loads, buoyancy loads and environmental conditions at the completion site.

Pre-launch objectives can be attained by proper planning and scheduling by the Contractor.

4.3.9.1.7 Launching and Move to Completion Site

The launching and move to the completion site are both in the low risk area, since they are within the current State-Of-the-Art.

As noted in 4.3.9.1.6, shipyard planning must provide for adequate strength of the platform for launching and post-launch operations.

18351-10 (W-10,000)

4.3.9.1.8 Deployment

Deployment consists of moving the OTEC hull from the completion site to the intended operating site, erecting and installing the cold water pipe, and mooring. Towing will not be a problem with the ship type units since these are designed for reasonably low drag in the fore and aft direction. The moderate draft cylinder can also be towed readily. When the platform arrives on site, a fleet of anchor handling/supply boats and construction barges will be required to bring the anchors and lines into position and emplace and connect the mooring system.

Existing mooring winches can accommodate only 1/2 to 1/3 of the total amount of wire which will be required in the OTEC water depths; therefore, mooring lines will have to be joined with the aid of the auxiliary craft. Specifically equipped craft will be required for this purpose with larger winches than are customarily used, although the largest winches available now should be satisfactory. Existing derrick barges will be capable of handling the anchors and mooring lines to assist the anchor handling boat. Mooring of the construction barges at the site would be an extremely troublesome prospect. It will be virtually a necessity for the construction barges as well as the anchor handling boats to be equipped with dynamic positioning systems. As noted above, these systems are in common use with the required accuracy and reliability, but very few boats and almost no construction craft are equipped with these systems at the present time.

Large units must have a two-stage deployment. Sub-units will first be moved to a deep water staging area, hopefully with some protection from the environment, for assembly. After this, the assembled vessel will be moved to the OTEC site for final outfitting and deployment of the CWP.

Movement of some of the OTEC configurations will require a large number of high powered tugs. For example, to tow the 500 megawatt cylindrical hull at about 3 knots, which is about the minimum velocity which can be considered safe, about six 10,000 horsepower tugs will be required in the ahead direction with two similar trailing tugs for control. This capacity is available at the present time but represents a major problem in mobilization, particularly for West Coast sites.

4.3.9.1.8 Deployment (Continued):

Installation of the cold water pipe will require development of completely novel procedures. Nothing even remotely resembling the cold water pipe exists in offshore operations today. In the smaller sizes, the cold water pipe may be brought to the offshore site in sections, either on barges or in self-floating sections. These could be erected by means of a derrick barge, connected to the section below and progressively lowered. In the larger sizes, it may be necessary to fabricate the entire cold water pipe in protected water and tow it as a complete unit to the offshore site. Mating of a 3,000 foot long, 150 foot diameter pipe to the OTEC hull is a project which transcends present offshore operations. This operation will require exhaustive computer and model studies to analyze the dynamics and stress distribution during the erecting process. Once erect, the cold water pipe will be difficult to move horizontally. It is somewhat analogous to fixed offshore platforms which have been assembled and tilted to the upright position in lengths up to approximately 1,000 feet. It is expected that similar techniques can be used. At some point, however, the cold water pipe must be brought underneath the OTEC platform and moved up into place. This operation has no direct parallel and is considered formidable.

The question of cold water pipe technical risk and associated technology requirements is addressed in further detail in Section 4.3.4.

4.3.9.2 Near Term Developments

The projected near term developments related to potential OTEC construction and deployment include completion of the Offshore Power Systems facility in Jacksonville and facility developments as required to suit planned platforms as described in Section 4.3.1. However, there are no known developments in the U. S. related to massive offshore concrete structures. In this area, OTEC will have to take the lead.

4.3.9.3 Proposed Technology Program

If steel construction is selected for the OTEC platform, it can be assumed that no formal technology program will be required, and that sufficient studies can be conducted during subsequent design phases to resolve technical questions. In addition, the Contractor's proposal for lead platform construction should include a detailed approach to construction and deployment.

For concrete platform construction, the problem is more complex, since DOE management will require assurance that concrete construction is feasible and that cost and schedule estimates are realistic. This problem has been addressed in Section 4.3.2, where a concrete materials development program was addressed. As presented, this near term program would consider producibility and deployment as applicable to the Demonstration Plant. Section 4.3.2.3.1 describes the proposed program, which is expected to define whether existing facilities are adequate or whether a new facility is required.

The studies described above will bridge the gap between Conceptual Design and Preliminary Design. During this period leading to the Demonstration Plant Preliminary Design Baseline, DOE will have had to come to grips with the following key issues relating to the OTEC Ocean System:

- Size (100 MW, 300 MW, etc.)
- Configuration (ship, spar, cylinder, etc.)
- Deployment site
- Platform materials
- Number of Commercial Plants to be built
- Number of power modules to be installed (may be less than potential platform capacity)
- Commonality of Demonstration Plant and Commercial Plant
- Overlap in Demonstration Plant and Commercial Plant program, based upon risk assessment.

If it is decided to utilize concrete for the Commercial Plant, based upon cost/risk/benefit trade-offs, DOE might opt to build the Demonstration Plant of steel, to accelerate the program by developing the Demonstration Plant and new facilities for the Commercial Plant in parallel.

4.3.9.3 Proposed Technology Program (Continued):

Alternatively, DOE may prefer to accelerate the concrete development aspect of the program by using concrete for the Demonstration Plant, thereby requiring a decision on building site, number of units over which to amortize the investment and other key issues within the next year. The problem is further complicated by considerations of whether the facilities development and platform construction contracts will go to the same Contractor or Contractor Team, or whether separate contracts will be issued.

All of the above issues make it very difficult to define the type of concrete development program required during the Demonstration Plant design process. In order to be meaningful, such studies should be directed toward a specific platform, deployment site and Contractor; therefore, until the design process is turned over to the potential platform Contractors and their teams, construction studies beyond those proposed in Section 4.4 are not expected to be particularly meaningful. However, once this transition in design responsibility occurs, it will be essential to continue with studies of construction and deployment to maintain confidence in cost and schedule estimates.

If DOE elects to not turn over control of the Ocean System Contract Design to the potential Contractors, one acquisition strategy which warrants consideration is the "Technical Characterization" concept used by the U. S. Navy for the DDG-47 program. Because of the complexity of the combat system of that ship, a competitive RFP was issued to the total shipbuilding community soliciting interest in the program and requesting proposals to support the Navy's Contract Design effort in the areas of producibility, commonality, scheduling, technical product development, contractual language, etc. Three yards were awarded Technical Characterization contracts and embarked on a one year \$1M effort which made them eligible to bid on the lead ship. The lead ship RFP were issued to these three yards in late 1977. The advantages of this concept include:

1. Potential lead yard familiarity with the design, which will hopefully reduce later claims.

4.3.9.3 Proposed Technology Program (Continued):

2. A better technical bid package due to shipyard input, particularly in the areas of producibility, simplification of specifications, reduction of ambiguity in specifications and contractual language, etc.

The applicability of this technique to the OTEC program is particularly appropriate due to the unique construction and deployment programs anticipated with both the Demonstration and Commercial Plants. If the potential lead shipbuilders were an integral part of the OTEC team during Contract Design, it would be possible to obtain valuable input in these areas which would more than pay for the program in terms of reduced risk and lead item costs. In a sense, this methodology can be thought of as "buying" bids, i.e., paying the prime candidates for the lead item for at least part of their bid preparation effort. This is particularly appropriate and cost effective where program complexity or unknowns may scare off potential bidders, or where the cost of preparing a sound proposal is not commensurate with the potential reward. Naturally, the program would have to be structured in a manner that retained competitiveness and protected the proprietary nature of Contractor input. On the DDG-47, this was accomplished by having all three yards respond to identical statements of work, very much like what DOE is doing with the OTEC Power System Contractors.

As noted above, the Technical Characterization program for DDG-47 involved three Contractors and cost \$3 million, roughly 5 percent of lead ship bid price exclusive of Government Furnished Equipment. The cost of the program, considering GFE and multiple-ship procurement, is insignificant. For OTEC, a program involving three contractors and perhaps a total cost of \$1.5 million during the Contract Design period of the Demonstration Plant would appear reasonable for concrete construction, and about \$0.8 million for steel construction.

4.3.10 Maintenance and Operation

4.3.10.1 Current State-Of-the-Art

In many regards, the maintenance and operation of the OTEC Ocean Systems is similar to other fixed and floating offshore platforms. Most of the unique or difficult areas are related to the Power and Transmission System which are beyond the scope of this study. Relative to the Ocean Systems, the principal

18351-10 (W-10,000)

4.3.10.1 Current State-Of-the-Art (Continued):

areas of concern include a 40 year life, which is beyond today's 25 to 30 year limits, and the inability to return to shoreside facilities for maintenance and repair.

Fortunately, many of the problems associated with the above areas can be solved by proper application of conventional engineering design practices, giving adequate consideration to the longer life of the individual components. Likewise, special consideration can be given to shipping routes to facilitate equipment removal and replacement. In addition, the capability exists to remove marine growth in place, down to a depth of about 80 feet using diver-operated scrubbers. It would appear feasible to extend this depth using manned or remotely controlled mini-submersibles without extensive technical risk or effort.

Seawater pumps are considered to be close enough to the current SOA that maintenance and repair requirements can be addressed as a normal part of product development. Many of the related problems can be resolved on the Demonstration Plant.

The CWP may present some unique maintenance problems, particularly related to fouling. However, the scrubbers mentioned above in conjunction with flow rates high enough to preclude fouling should minimize the problem.

The positionkeeping system will also present some operational and maintenance problems, but none appreciably beyond the current State-Of-the-Art.

4.3.10.2 Near Term Developments

There are no known developments which will significantly improve the near term SOA in the areas of operation and maintenance. Rather, there will be a continued program based on the gradual development of protective coatings, material technology and other related areas in response to the new frontiers being opened by the marine and offshore industries.

4.3.10.3 Proposed Technology Program

There is no formal technology program proposed in the areas of operations and maintenance. Rather, it is proposed that the Preliminary Design scopes of work issued by DOE for the Demonstration Plant require that each Contractor develop a

4.3.10.3 Proposed Technology Program (Continued):

maintenance and operations program which fully demonstrates how such issues will be addressed. Specifically, such a program should address the following issues:

A. Maintenance

1. Hull Maintenance
 - Schedules
 - Procedures
 - Special Equipment
 - Manpower
 - Interference with Plant Operations
2. Seawater System Maintenance
 - Schedules
 - Procedures
 - Special Equipment
 - Manpower
 - Interference with Plant Operations
3. Positionkeeping System Maintenance
 - Schedules
 - Procedures
 - Special Equipment
 - Manpower
 - Interference with Plant Operations
4. Support Systems Maintenance
 - Schedules
 - Procedures
 - Special Equipment
 - Manpower
 - Interference with Plant Operations
5. Equipment Shipping/Access Study
 - Shipping Routes
 - Handling Equipment
 - Service Areas
 - Trade-Offs of removal versus service-in-place for major components.

4.3.10.3 Proposed Technology Program (Continued):

A. Maintenance (Continued):

6. Logistics Support

- Spare Parts Requirements
- Shoreside Parts Pools
- On-Board Spares
- Inventory Control
- Commonality

7. Repair Procedures

(Address specific procedures for repair of each WBS element not covered by Vendor technical manuals - may require development of on-site concrete repair manual).

B. Operations

1. Manning Requirements

- Normal
- Plant Start-Up or Shut-Down
- Emergency

2. Duty Cycles (by Department)

3. Consumables Replenishment

- Schedules
- Procedures
- Transfer Routes
- Inventory Control

4.3.11 Stability

4.3.11.1 Current State-Of-the-Art

Stability of floating platforms involves three primary considerations: The type and extent of the threat, the response of the platform to this threat, and finally the inherent margin of reserve stability required in the presence of a specific threat. Two conditions which must be considered for the OTEC platforms include:

4.3.11.1 Current State-Of-the-Art (Continued):

1. Intact (no loss of buoyancy)
 - High seas and winds
 - Loss of CWP
 - Failure of positionkeeping/mooring system
 - Free surface effects on slack tanks
2. Damaged (loss of buoyancy)
 - Collision
 - Grounding
 - Structural Failure
 - Rupture of pipe in Seawater System

Stability criteria for Commercial (non-military) seagoing platforms are normally established by the U. S. Coast Guard, the American Bureau of Shipping and one international organization to which the United States conforms:

- IMCO (Inter-Governmental Maritime Consultative Organization) -
Promulgates SOLAS (Safety of Life at Sea) Regulations

In all cases, U. S. Coast Guard and American Bureau of Shipping rules conform to IMCO and SOLAS, and are often more stringent. These rules are generally developmental in nature, and reflect intensive analysis of historical damage and survival data.

The developmental nature of stability criteria will create a problem with many of the potential OTEC platforms, since such criteria are currently limited to conventional ship shapes and offshore drilling rigs. The latter are considered most appropriate to the OTEC platforms and are summarized in Table 4.3-6; however, a review of current stability criteria indicates that the more unusual hull shapes will require additional consideration. Also, the OTEC platforms present an additional constraint not reflected in current regulations, namely the sudden change in stability characteristics due to loss of the CWP.

The problems of establishing adequate stability criteria for the OTEC platforms are intensified by the international and political implications of such criteria. As an example, the first mobile offshore drilling platform was deployed nearly a generation ago, yet the ABS criteria, Table 4.3-6, have not yet been ratified

TABLE 4.3-6

STABILITY
MOBILE OFFSHORE DRILLING UNITS

(Summary of ABS Rules and proposed USCG and IMCO Codes pertaining to Mobile Offshore Drilling Units)

I. Intact Stability - All Types

Wind velocities depend upon region of service and mode of operation:

- (a) 70 knot wind for off-shore service at normal operating conditions
- (b) 100 knot wind for off-shore service at severe storm conditions
- (c) 50 knot wind for sheltered locations at normal operating conditions

II. Damaged Stability

A. Subdivision and Damaged Stability

- (1) Sufficient freeboard and subdivision to withstand one compartment damage
- (2) Sufficient reserve stability in a damaged condition to withstand wind heeling moment based on 50 knot wind
- (3) Unit assumed in worst anticipated service condition

B. Stability Criteria

- (1) Surface Type and Self-Elevating Units - Area under righting moment curve to second intercept or angle of downflooding should be not less than 140% of the area under the wind heeling moment curve to the same limiting angle.
- (2) For column stabilized units - Area under righting moment curve to second intercept or angle of downflooding should be not less than 130% of the area under the wind heeling moment curve.
- (3) Righting moment curve should be positive over entire range of angles from upright to the second intercept.

4.3.11.1 Current State-Of-the-Art (Continued):

by the U. S. Coast Guard or IMCO. Though the U. S. Coast Guard will undoubtedly take an early and active part in developing stability rules for OTEC and similar platforms, the participation and interest of IMCO will depend to a great extent upon foreign interest in such platforms.

Summarizing, it is relatively easy to define the response of a given platform to a specific set of environmental and/or damage conditions based upon conventional naval architectural principles, even for the larger and more unique OTEC platforms. However, definition of that environment and/or extent of damage and the required reserve stability after exposure to such events is beyond the current rules.

4.3.11.2 Near Term Developments

Near term developments in offshore floating nuclear stations, LNG storage barges, etc., may require a careful reassessment of current stability requirements; however, the former case is mitigated by the presence of a protective breakwater, while the latter represents a fairly straightforward extension of current LNG ship stability requirements. Due to the reactive nature of such criteria (i.e., create a new concept and the stability criteria will follow) it is apparent that OTEC will have to generate its own stability criteria. Initially, these will be straightforward extensions of current policies promulgated by the designers, but it is obvious that the Regulatory Agencies must be brought onboard very soon so that their input can be obtained and reflected in the proposed criteria.

4.3.11.3 Proposed Technology Program

A formal program to develop stability criteria for OTEC platforms is not considered necessary. Rather, it is recommended that both the American Bureau of Shipping and the U. S. Coast Guard be consulted during the upcoming Conceptual Design phase (Task V), so that their preliminary input can be reflected in all of the designs to be developed. At this stage, their input will probably be of a consultative nature since neither organization will be in a position to mount a major technical effort.

18351-10 (W-10,000)

4.3.11.3 Proposed Technology Program (Continued):

Once a decision is made to proceed with a specific concept for the Demonstration Plant, both the U. S. Coast Guard and the American Bureau of Shipping should be brought onboard by DOE as "full partners" in the development of stability criteria. Consultative input from IMCO should also be sought via the United States Delegation to IMCO. This should include the promulgation of a set of proposed criteria by the delegation, though formal ratification would be a long-term goal and should not impede OTEC progress.

There would be no specific cost and schedule for such a program. Rather, such consultation and development of acceptable stability criteria should be included as part of the Work Statement for the Commercial Plant Conceptual Design. In addition, similar requirements should be inherent in both the OTEC-1 and OTEC-10/20 design programs, which will have a direct bearing on the Demonstration and Commercial Plants.

4.3.12 Licenses/Regulations

4.3.12.1 Current State-Of-the-Art

It can be anticipated that the OTEC Commercial Plant will be subject to the requirements of a vast array of Government and Commercial regulatory agencies to oversee and control virtually every aspect of design, construction, and operation. Table 4.3-7 summarizes the agencies which apply to a conventional ship design. In addition, it can be assumed that OTEC will be governed by the requirements of the following agencies:

- Federal Power Commission
- Operational Safety and Health Administration
- Environmental Protection Agency
- Unions appropriate to powerplant operators

Also, DOE might very well establish regulations directly impacting the Plant.

TABLE 4.3-7

Agencies and Their Areas of Jurisdiction in the Commercial Marine Transportation Industry

JURISDICTION AREA

	PROPULSION MACHINERY	HULL	HABITABILITY	ENVIRONMENTAL AND SAFETY	MANNING & LICENSING	FINANCIAL ASSISTANCE	ITINERY	ENTRY RESTRICTIONS	TARIFF REVIEW AND FILING	MONOPOLY CONTROL	FINANCIAL ASSISTANCE	CARGO ALLOCATION	FUEL PRICE AND AVAILABILITY	TRAFFIC CONTROL	MAINTENANCE & REPAIR STANDARDS	ENVIRONMENTAL AND SAFETY
1. UNITED STATES COAST GUARD	•	•	•	•	•									•	•	•
2. FEDERAL ENERGY ADMINISTRATION																
3. MARITIME ADMINISTRATION	•	•	•	•		•	•				•	•			•	
4. FEDERAL MARITIME COMMISSION							•	•	•							
5. CLASSIFICATION SOCIETIES	•	•	•	•	•										•	
6. ENVIRONMENTAL PROTECTION AGENCY				•												•
7. INTERGOVERNMENTAL MARITIME CONSULTATIVE ORGANIZATION	•	•	•	•	•											•
8. FOREIGN GOVERNMENTS				•			•	•	•			•	•		•	•
9. ST. LAWRENCE SEAWAY DEVELOPMENT CORP.											•	•		•		
10. PANAMA CANAL COMPANY		•		•										•		
11. STATE GOVERNMENTS	•	•												•		•
12. ARMY CORPS OF ENGINEERS													•			
13. UNIONS			•	•	•						•					

4.3.12.1 Current State-Of-the-Art (Continued):

The regulations imposed by these agencies are obviously necessary for the safety of the platform and its personnel, but can be extremely disruptive and costly if not considered early in the design process. This is particularly critical in the case of OTEC, where the SOA is virtually non-existent. Previous sections have highlighted shortfalls in the SOA for structural design, materials, stability, and other areas falling under the jurisdiction of Regulatory Agencies. Such shortfalls are particularly acute for the larger platforms and those of unusual configurations.

In so far as the Ocean System is concerned, the two agencies of primary importance are the American Bureau of Shipping and the U. S. Coast Guard. The requirements of these agencies, or lack thereof, will most significantly impact OTEC.

- American Bureau of Shipping Requirements

There are no ABS rules for construction of OTEC platforms such as are contained in the ABS publication: "Rules for Building and Classing of Steel Vessels", published annually. In addition to rules for conventional steel cargo and passenger vessels, ABS also publishes rules for special purpose vessels such as chemical carriers and liquified gas carriers.

The rules for steel vessels do recognize that not all configurations desired by owners will be covered by published rules, as exemplified by Section 1.5 of the rules for steel vessels, which reads as follows:

"1.5 Novel Features

Vessels which contain novel features of design in respect to the hull, machinery or equipment to which the provision of the Rules are not directly applicable may be classed, when approved by the Committee, on the basis that the Rules, insofar as applicable, have been complied with and that special consideration has been given to the novel features based on the best information available at the time."

4.3.12.1 Current State-Of-the-Art (Continued):

Significant wordings in the above are "may be classed" and "that special consideration has been given to the novel features".

Usually, at the outset of a design which contains "novel" features, the designer prepares calculations and drawings to an extent which will define the "novel" features so that ABS surveyors can satisfy themselves that the design is structurally adequate and safe.

For an OTEC platform, agreement with ABS on acceptable design practices for the platform and the attachment of the cold water pipe are considered to be very high risk areas with respect to timely development of an OTEC platform design, especially if the platform material is reinforced concrete.

- United States Coast Guard Requirements

The USCG is responsible for establishing criteria which will ensure the structural integrity and stability of an OTEC platform in either the damaged or undamaged condition and the safety of the crew under all conditions.

Risk assessment of the problem of establishing suitable damaged and undamaged stability criteria is discussed under Section 4.3.11.

There are no current USCG criteria specifically applicable to OTEC platforms such as are available for passenger ships, cargo ships, tankers, LNG carriers and other special purpose vessels.

Except for structural design of an OTEC platform, USCG requirements for lifesaving, fire prevention, fire fighting, system safety, etc., can be met by application of existing USCG criteria.

For structural design, the USCG has in recent years been moving in the direction of accepting structural designs which meet ABS criteria. For the novel construction and configuration of OTEC platforms, the USCG will undoubtedly wish to participate with ABS in establishing design criteria. Accordingly, USCG structural design criteria are a risk area and the discussion under ABS requirements also apply to USCG.

4.3.12.2 Near Term Development

As implied in previous sections, Regulatory Agencies react to a demonstrated need rather than generating requirements of purely academic interest. This means that any near term developments in the area of regulations will result directly from a strong OTEC program development. Some benefit will be gained from current programs for offshore nuclear plants, LNG storage barges and other platforms; however, OTEC will be sufficiently unique as to require special regulatory consideration.

4.3.12.3 Proposed Technology Program

Again, a formal technology program is not considered appropriate to the area of regulatory requirements. Rather, a concerted, early effort by DOE to involve these agencies in the OTEC concept is recommended, similar to that proposed in Section 4.3.11.3 relative to stability. In particular, ABS and USCG should be brought onboard immediately after the completion of Task IV in December 1977. They should be briefed on the results of the studies to date, and advised that the three Ocean System Contractors will be proceeding with Conceptual Designs of selected platforms, and that their input is urgently needed. The DOE Support Services Contractor should coordinate such liaison.

It is further recommended that these agencies be requested to define specific technical input which will be required in order to develop new rules applicable to OTEC platforms. The assumption here is that their resources may not permit them to develop the necessary technical baseline to undertake approval action without specific DOE input. As an example, if reinforced concrete construction is proposed, material properties data as proposed in Section 4.3.2 may be required. Similarly, they may require DOE input on environmental data, payload characteristics, etc.

The cost to DOE of such consultative efforts by their Support Services Contractor might be as high as \$60,000, including subcontractor support. No schedule impact is anticipated.

4.4 Technology Advancement Program

4.4.1 Introduction

This section combines the individual technology advancement programs proposed in Section 4.3 into an overall Technology Advancement Program. Initially, an idealized program is proposed encompassing all of the sub-programs in Task III. Schedules, milestones and funding profiles for such a program are developed. The next step is to assess the priorities of this program in the event that funding is not available to support the idealized effort. At each incremental reduction in available funding, it will be possible to identify cutbacks or elimination of specific portions of the program and to identify fallbacks possible to alleviate risk by a less costly but less effective method. It is noted that the far term schedule (i.e., beyond CY 1979) is referenced to key program events rather than specific dates since the former are subject to further refinement as the overall program develops.

It is noted that this section is only concerned with studies considered essential to program completion which are over and above the scope of the normal design process. In addition, Section 4.3 noted a number of areas where risk exists, but where the normal design process should satisfactorily resolve the unknowns. These areas are addressed at the end of this section.

4.4.2 Scope

The scope of the proposed program includes five (5) major phases, listed in the order that they are presented in Section 4.3:

- (1) Materials Development
 - 1A Hull and CWP Materials Development
 - 1B OTEC Materials Test Program
- (2) Motions and CWP/Hull Interaction
 - 2A Computer Program Idealization
 - 2B Model Test Verification
 - 2C CWP Analytical Studies
 - 2D Full Scale Tests - OTEC-1
 - 2E Analytical Technique Refinement
 - 2F Full Scale Tests - OTEC-10/20

4.4.2 Scope (Continued):

- (3) Seawater System Interference
 - 3A Mathematical Simulation
 - 3B Full Scale Tests - OTEC-1
- (4) Positionkeeping
 - 4A Environmental Data
 - 4B Model Tests - Drag
 - 4C Full Scale Tests - OTEC-1
 - 4D Full Scale Tests - OTEC-10/20
 - 4E Equipment Development
- (5) Construction and Deployment Utilizing the Technical Characterization Concept.

The scope of each of these five phases is described in Section 4.4.3, and priorities are discussed in Section 4.4.4.

4.4.3 Schedule and Milestones

Figure 4.4-1 is a schedule for the five major phases of the Technology Advancement Program, and indicates key milestones, reflecting the discussion of schedules in Section 4.3. The following are major milestones indicated on the figures:

- 1. Materials Development (Section 4.3.2.3)
 - (1) = Report on Task I, Section 4.3.2.3.1
 - (2) = Report on Task II, Section 4.3.2.3.1
 - (3) = Specify Test Scope
 - (4) = Complete Test Samples
 - (5) = Complete Tests
- 2. Motions, CWP/Hull Interface (Section 4.3.4.3)
 - (6) = Define Scope of Changes
 - (7) = Complete Software Modifications
 - (8) = Complete Debugging
 - (9) = Complete Models
 - (10) = Complete Tests

COST, SCHEDULE AND MILESTONE OTEC TECHNOLOGY ADVANCEMENT PROGRAM

* For Concrete Only

** For definition of milestones, see Section 4.4.3

18351-10 (W-10,000)

4.4.3 Schedule and Milestones (Continued):

2. Motions, CWP/Hull Interface (Section 4.3.4.3) (Continued):

- (11) = Complete Data Analysis
- (12) = Report on Task I (similar scope to 4.3.2.3.1)
- (13) = Report on Task II (similar scope to 4.3.2.3.1)
- (14) = Report on CWP/Hull Attachment

3. Seawater System Interference

- (15) = Technology Review
- (16) = Complete Model
- (17) = Complete Software
- (18) = Complete Debugging

4. Positionkeeping

- (19) = Complete Instrumentation
- (20) = Complete Data Gathering
- (21) = Complete Data Reduction
- (22) = Complete Model
- (23) = Complete Testing

4.4.4 Funding

The total cost of the Technology Advancement Program shown on Figure 4.4-1 is estimated to be between \$3.15 M for steel construction and \$4.01 M for concrete construction, including Technical Characterization as proposed in Section 4.3.9.3. The breakdown by calendar years and phase is as follows (all costs thousands of dollars):

<u>Phase</u>	<u>CY 78</u>	<u>CY 79</u>	<u>Beyond CY 79</u>	<u>TOTAL</u>
1 (Steel)	200	-	-	200
(Concrete)	200	150	-	350
2	200	150	500	900
3	20	30	100	150
4	120	440	550	1,110
5 (Steel)			800	800
(Concrete)			1,500	1,500
TOTAL (Steel)	540	620	2,000	3,150
(Concrete)	540	770	2,700	4,010

4.4.5 Priorities

If it is infeasible to fund the Technology Advancement Program as indicated in Figure 4.4-1, the following priorities should be considered:

1. High Priorities

- 1A Hull Materials Development
- 2 (All Tasks) Motions, CWP/Hull Interface
- 4B Model Tests - Drag
- 4C Full Scale Tests - OTEC-1
- 4D Full Scale Tests - OTEC-10/20

2. Medium Priorities

- 1B OTEC Materials Test Program (for concrete only)
Fallback: Use available data on concrete materials properties based on landbased practices/compositions
- 3A Mathematical Simulation
Fallback: Use simplified, non-computerized analytical procedures for predicting interference effects, similar to those used in Task IIA of the current studies
- 4A Environmental Data
Fallback: Use currently existing data for the site selected and use analytical techniques to estimate missing data
- 4E Positionkeeping Equipment Development
Fallback: It might be possible to reduce the scope of this effort by various means, but some development efforts will undoubtedly be required
- 5 Technical Characterization
Fallback: Conventional procurement strategies could be retained, with Contractors required to include detailed construction techniques and facilities descriptions in their proposals.

3. Low Priorities

- 3B Seawater Interference Tests - Full Scale Tests
Fallback: Rely on analytical prediction techniques

These generalized priorities may very well shift depending upon the size and configuration of the plant, deployment site and other factors. Assuming

18351-10 (W-10,000)

4.4.5 Priorities (Continued):

for the moment that high priority items are retained, low priority items dropped and medium priority items cut by 50 percent, the total cost of the program is as follows:

<u>Item</u>	<u>Basic Scope</u>	<u>Reduced Scope</u>
Total Program (Steel)	\$3.15 M	\$2.25 M
Total Program (Concrete)	\$4.01 M	\$2.67 M

It can be seen that the reduced scope cuts about 30 percent off the cost of the program, which is relatively insignificant in terms of the lost benefit. Therefore, such reductions are not recommended.

4.4.6 Related Studies

As noted in Section 4.4.1, the technology risks identified earlier require a number of studies as part of the basic Ocean System design process. It is important that the necessity for these studies not be overlooked, or overshadowed by the separate Technology Advancement Program described above. These areas include:

- Seawater Pumps
- Maintenance and Operations
- Stability
- Cost Estimating
- Licenses, Regulations

It is recommended that the concepts and considerations related to these areas be given consideration in the development of work statements for all subsequent design phases.

5. TASK IV SYSTEMS INTEGRATION AND EVALUATION

5.1 Introduction

This section summarizes the studies conducted during Task IV leading to the evaluation of the ninety candidate OTEC platforms and ranking them in terms of cost-benefit to optimize size, configuration and deployment site.

The evaluation of the candidate OTEC platforms is a highly complex task due to the number of variables involved, and the difficulty of defining a universally acceptable and all-inclusive evaluation criterion. It is also an extremely critical milestone, perhaps the single most critical milestone in the entire OTEC program. The decisions reached as a result of this evaluation will have far reaching implications in terms of the economic viability of OTEC as a means for energy independence for the United States.

Based upon this complexity and criticality, it is imperative that the evaluation methodology and implementation be responsive to the DOE management decision-making processes, and provide clear visibility of all of the variables which will influence their ultimate decision.

The approach taken by the Gibbs & Cox, Inc. team involves five basic phases which are described in this section. The first phase involves refinement of the first-cut feasibility baseline designs developed in Task IIA, Section 2 of this Volume, to suit further analysis and later information on the heat exchangers, Seawater System, Transmission System, power cable and other technical parameters.

The second phase involves the development of acquisition costs, life cycle costs and construction/deployment schedules for the platform alternatives. Although these cost and schedule estimates are necessarily very approximate at this stage of design, they are considered adequate for the qualitative or relative types of comparisons required.

Phase three involves a careful reassessment of platform motions. First, the motions of each of the alternatives must be quantified based on the best available analytical tools which can be economically utilized. Next, the relative criticality of motions must be defined in terms of personnel, installed equipment and the transmission cable.

5.1 Introduction (Continued):

Phase four is the major effort of this Task, and involves five subtasks:

1. Refinement of the evaluation methodology developed during Task IIB and as described in Section 3 of this Volume.
2. Application of the selected methodology utilizing the "best engineering estimates" of cost and schedule derived in Phase 2, to evaluate platform size and configuration as a function of deployment site.
3. Application of risk-uncertainty factors to the baseline cost estimates to assess the sensitivity of the Figure Of Merit (FOM) to varying levels of risk.
4. Preparation of additional cost-benefit sensitivity studies including variations in utilization, risk, efficiency and specific cost factors.
5. Development of conclusions re: size, configuration, and site based upon economic considerations.

The final phase combines the results of the cost-benefit analysis, motion analysis and other technical considerations into an overall series of recommendations relative to the optimum platform size and configuration for the selected sites.

5.2 Baseline Platform Alternatives

5.2.1 Feasibility Baselines

Any evaluation of a concept involving the selection of an optimum size and configuration must be preceded by a determination of the relationships between size and various parameters, including cost, for the configurations being considered. Conventional ship design relies heavily on past experience in predicting these relationships. The unique nature of the OTEC concept, with regard to both size and subsystem characteristics, precludes the extrapolation of any existing data for use in the determination of these parametric relationships. For this reason, a family of baseline designs was generated in order to provide the technical inputs

5.2.1 Feasibility Baselines (Continued):

to the evaluation plan. The first iteration arrangements and associated weights and volumes are presented in Section 2 of this Volume and in Reference (1). These arrangements were developed with a minimum amount of background information regarding subsystem configuration and interfacing requirements. The hulls were "optimized" by arrangement of the individually optimized Power Systems modules. Although this method did permit the development of reasonable values for overall ocean system dimensions and weights, the feasibility arrangements discussed in Section 2 were not intended as prejudgements of the actual conceptual design solutions. As presented, these arrangements were intended to be baseline designs to which modifications would be made as requirements and preferences became more clearly defined or new firmer data became available.

5.2.2 Design Refinements

This section presents the refinements made to the first iteration baseline arrangements which are described in Section 2. These refinements reflect updated information and more detailed investigations into the component characteristics, module configurations and overall platform integration of the hull, power and seawater systems.

The configurations re-evaluated include the ship, cylinder, spar, submersible and sphere. The inflexibility of the semi-submersible configuration limits the power system arrangement by dictating the use of horizontally oriented heat exchangers. Regardless of the specific details of the various subsystems, its general arrangement cannot be significantly modified. For this reason, this section concentrates on the other five schemes.

This section is divided into three subsections: (1) Updated characteristics of major components, (2) refinements to module arrangements, and (3) refinements to platform integration.

5.2.2.1 Updated Characteristics of Major Components

Power System - The guidelines which are presented in Appendix B regarding heat exchangers, demisters, and turbine-generator dimensions and weights represent the best estimates currently available. Data presented in

18351-10 (W-10,000)

5.2.2.1 Updated Characteristics of Major Components (Continued):

Power System (Continued):

Reference (45) indicates virtually unlimited flexibility in the configuration of demisters; however, vertical demisters with various manifold arrangements have been assumed throughout.

Seawater System - Several desirable features of the Seawater System were identified subsequent to the completion of Task IIA. References (46) and (47) present the results of a seawater pump study which investigated the means of minimizing the parasitic losses resulting from seawater pumping. The results of this study indicate that the maximum pumping efficiency of 76 percent can be achieved with a specially designed, self-contained bulb-type pump diffuser assembly. The length of such an assembly assuming one pump per module varies from 75 to 120 feet depending on details of the pump and diffuser designs. By use of external drive pumps, it appears that this dimension may be reduced by approximately 30 percent. For the arrangements presented here, an attempt was made to incorporate a minimum length of 40 feet for the diffuser section in addition to the length of the pump.

Additional reduction of parasitic losses can be achieved by minimizing the fluid velocity through the sea water intake filters. A maximum velocity of 1.5 feet per second is assumed which corresponds to a filter area of approximately 2,500 square feet per 25 MW module.

The required flow rates of 1.7 million gallons per minute per 25 MW module cannot be achieved with current State-Of-the-Art propeller type pumps. Use of three or four pumps of the 500,000 gpm capacity range represents a more realistic solution and provides a certain amount of redundancy to allow for pump maintenance. The dimensions of the multiple pump-diffuser assemblies are less critical than the dimensions for the single pump configurations discussed above, therefore, pending the detailed analysis of this subsystem during Task V, a single pump per module is assumed. A summary of the weights, volumes and dimensions assumed for each major subsystem is presented in Table 5.2-1.

18351-10 (W-10,000)

TABLE 5.2-1
ASSUMED WEIGHTS AND DIMENSIONS

	No. Req'd per 25MW	Dimensions	Volume	Weight
TOTAL HULL SYSTEM		As Req'd	13.6 ft ³ /LT	0.074 LT/ft ³
Power System				
Heat Exchangers				
Vertical	1	35D X 73L	As req'd	2100 (wet)
Horizontal	1	35D X 93L		4900 (wet)
T.G.	1	85L X 12W X 12H		170
Demisters	5	14D X 43H		180
Miscellaneous				830
Total Power System				
Vertical				3280
Horizontal				6080
TOTAL TRANSMISSION SYSTEM		To Suit Arrangement	1400 ft ³ /MW	12.2 LT/MW
Seawater System				
CWP	1	3000L X D to suit Flow reqm'ts	As req'd	10,000
SW Piping	1	25D X L to suit arrg't bend radius of 38 ft (1.5 X D)		1.4 LT/ft pipe 14.0 LT/ft fluid in pipe
WW Equipment	1	To suit arrg't		280 LT (wet)
CW Equipment	1	To suit arrg't		330 LT (wet)
POSITION KEEPING SYSTEM		To Suit Arrangement	4.69 ft ³ /HP	0.06 LT/HP
SUPPORT SYSTEM		To Suit Arrg't	73.3 LT/MW + 163300	0.44 LT/MW + 485
MARGIN			None	10% of Light- ship

NOTE: Dimensions in feet, Weights in long tons (2240 lbs.)

5.2.2.2 Refinement of Module Arrangements

As mentioned previously, during the development of the first iteration baselines, the module arrangements were optimized strictly on a volume basis. Little effort was made to fit the modules to the volume available in a specific configuration. After the completion of Task II, an attempt was made to utilize smaller heat exchangers of a lower rating (i.e., 5, 8, 12.5 MW) and thereby utilize some of the small, irregularly shaped, apparently unused, volumes which exist in the first iteration baseline arrangements. It was found that the smaller heat exchangers required between 60 and 70 percent more plan area per MW than the 25 MW heat exchangers. Together with the significantly increased complexity of the seawater distribution system, this more than offset the arrangement flexibility potentially available through the use of a larger number of smaller units.

During the development of the first iteration arrangements, insufficient allowance within each module was made for major structure or clearance between structure and major power system components. The modules of this iteration are tailored to the specific configuration with allowance included for structural clearance.

Discussions with power system designers indicate that maintenance of the heat exchangers may require the withdrawal of tubes. Several means of accommodating this requirement are possible. The small plants (i.e., all of the 50 MW and some of the 100 MW plants) do not incorporate sufficient room for tube withdrawal. The overall size of these plants restricts the flexibility of the individual module arrangements. Incorporation of allowance for tube withdrawal in some cases would double the enclosed volume. For this reason, major maintenance of these small plants, as presented, can only be accomplished by shutting down the plant and deballasting in such a manner as to allow access through a patch in the hull. It is probable that these plants would have to be part of an energy park concept; therefore, the disruption of operation of any one plant for maintenance would not be as unattractive as it would be for the larger plants. Alternatively, it is conceivable that a temporary local

5.2.2.2 Refinement of Module Arrangements (Continued):

drydock structure similar to the "bow dock" concept currently under development by the U. S. Navy, could be designed to satisfy the requirement for maintenance without the addition of excessive volume, or the total disruption of plant operation. For the remainder of the ship and cylinder arrangements, a hatch in the upper boundary of the module and use of vertical heat exchangers provide for extensive maintenance with minimal impact on overall plant operation. For the submersibles or small water plane area configurations such as the spar and sphere, provision for withdrawal of tubes through a hatch in the water tight envelope would require complete plant shut down and deballasting of the platform. Most of the large spheres and spars incorporate sufficient internal clearance to accommodate tube withdrawal within the module boundaries.

It is further assumed that the performance of any major maintenance of the heat exchangers or seawater system on any platform will require a means of isolating and dewatering the heat exchangers and internal seawater piping.

5.2.2.3 Refinement of Platform Integration

By reviewing each of the baseline arrangements and developing a typical layout of major components suited to the individual configuration, several specific areas of the arrangement may be addressed in greater detail than was possible previously. The first iteration baselines, while allowing volume and access for seawater distribution, did not investigate any details of the actual distribution system. By investigating some of these details, it is possible to identify features which simplify the seawater distribution system. Similarly, features may be identified which facilitate the incorporation of maintenance considerations or minimize the probability of thermal pollution of the surface water. Two significant features which conveniently accommodate, to varying degrees, all of these desirable characteristics are: (1) The use of vertical heat exchangers, and, (2) the use of a single level of modules. The following paragraphs present a discussion of the applicability of these concepts to the various configurations.

Ship and Cylinder - The use of vertical heat exchangers and a single level arrangement simplifies maintenance procedures, allows the incorporation of diffuser sections, and provides for downward discharge of the effluent seawater. None of these features can be conveniently accommodated in the first iteration

5.2.2.3 Refinement of Platform Integration (Continued):

baseline arrangements. The arrangements as presented do however present certain difficulties not encountered in the other configurations. The use of vertical heat exchangers requires that the seawater has to be lifted above the operating waterline in order to enter the heat exchangers. This may require the development of a method to prime the system. A combination of temporary addition of ballast and a vacuum priming system resolves this problem with minimal impact on plant operations. Additionally, the direction of fluid must be reversed 180° in each system. Although this results in a higher pumping power than an arrangement with in line flow, none of the ship or cylinder configurations can be arranged to improve the piping runs.

The small sizes (50 and 100 MW for the ship, and 50 MW for the cylinder) utilize horizontal heat exchangers. An attempt to utilize vertical heat exchangers results in platform proportions which indicate potential stability problems. The requirement for maintenance on these smaller plants is less important, as discussed in Section 5.2.2.2.

Spar, Submersible and Sphere - These configurations each utilize essentially the same arrangements. The seawater system is greatly simplified by the use of a single level of vertical heat exchangers. Warm water is drawn in at the top of each module, passed through the pump, diffuser, and heat exchanger and discharged directly downward out the bottom of the module. Similar to the ship and cylinder arrangements, the smaller sizes do not incorporate sufficient room for convenient tube withdrawal, because of the restricted flexibility of these arrangements.

No details of the CWP-hull connection are specified at this time; therefore, no method of attachment is shown in the arrangement drawings. Although the method of construction and material for use in the CWP have not been selected, a net weight (i.e., weight in air-weight of displaced volume of water) of 10,000 L.T. is budgeted to the CWP. It is assumed that by incorporation of an appropriate volume of voids or the use of lightweight materials, this is the maximum weight of a CWP, regardless of size, to be supported by the platform.

5.2.3 Selected Characteristics

Principal characteristics of all six of the revised platforms are presented in Tables 5.2-2 through 5.2-7. The general arrangements of the revised 500 MW platforms are presented in Figures 5.2-1 through 5.2-6 as typical examples. Appendix C of Reference (3) provides arrangements of other size platforms. These characteristics and arrangements form the baseline for the acquisition cost estimates in the following section.

5.3 Cost and Schedule

5.3.1 Acquisition Costs

Cost estimates were prepared for the six platform configurations and five power plant sizes presented in Section 5.2 taking into account differences resulting from the three sites under consideration. Since the initial cost is largely influenced by the material for heat exchanger tubes, separate estimates were prepared for heat exchangers with titanium tubes and with aluminum tubes. Summaries and individual estimates for platform costs are given in Appendix C.

Ideally, estimates of acquisition costs for floating structures should be based on historical cost data from previously constructed, similar structures. In the case of OTEC platforms, there is no historical data available from similar platforms for the Power System (heat exchangers, generators, etc.), Transmission System (cabling, transformers, etc.), Seawater System (cold water pipe, cold and warm water circulating systems), and even the Hull System. Since these systems represent almost all of the acquisition cost for any platform size and configuration, the estimates presented herein should be viewed as a first approximation which must be refined as more design data becomes available; however, because the estimates of Appendix C were all prepared on the same basis, the relative costs among the configurations are sufficient to provide a quantitative ranking. A meaningful and absolute cost estimate requires a higher level of information than is available at present, since a certain amount of engineering is required before such estimates can be made, and the scarcity of acceptable historical data precludes any type of parametric cost study. As with a standard ship design that involves previously untried concepts, cost estimating relationships can be synthesized only after the design has been developed to a reasonable degree.

TABLE 5.2-2

PRINCIPAL CHARACTERISTICS - SHIP

	SHIP				
Size (MW Gross)	50	100	200	350	500
Length (Ft)	250	300	470	815	985
Beam (Ft)	120	180	260	340	360
Depth (Ft)	120	140	180	180	180
Draft (Ft)	80	95	90	90	90
Lightship Disp. (L.T.)	65,400	113,400	208,500	419,500	633,400
S.W. in Systems (L.T.)	5,700	21,900	54,400	101,900	161,900
Ballast (L.T.)	0	0	0	92,800	0
Operating Disp. (L.T.)	71,100	138,300	262,900	614,200	795,300

1 L.T. = 2240 lbs.

TABLE 5.2-3

PRINCIPAL CHARACTERISTICS - CYLINDER

	CYLINDER				
Size (MW Gross)	50	100	200	350	500
Length (Ft)	200	320	380	480	590
Beam (Ft)	200	320	380	480	590
Depth (Ft)	160	130	180	170	220
Draft (Ft)	85	85	100	115	160
Lightship Disp. (L.T.)	67,300	146,300	223,500	421,300	625,000
S.W. in System (L.T.)	4,700	44,300	93,100	168,900	387,300
Ballast (L.T.)	0	0	0	0	0
Operating Disp. (L.T.)	72,000	190,600	316,600	588,200	1,012,300

1 L.T. = 2240 lbs.

TABLE 5.2-4
PRINCIPAL CHARACTERISTICS - SPAR

	SPAR				
Size (MW Gross)	50	100	200	350	500
Length (Ft)	150	230	345	360	440
Beam (Ft)	150	230	345	360	440
Depth (Ft)	145	270	210	320	310
Draft (Ft)	185	320	270	380	370
Lightship Disp. (L.T.)	50,000	163,800	225,700	447,900	564,000
S.W. In Systems (L.T.)	12,300	54,300	105,600	185,200	236,500
Ballast (L.T.)	14,200	110,500	271,600	267,400	515,200
Operating Disp. (L.T.)	17,000	328,600	603,900	900,500	1,315,700

1 L.T. = 2240 lbs.

TABLE 5.2-5
PRINCIPAL CHARACTERISTICS - SUBMERSIBLE

	SUBMERSIBLE				
Size (MW Gross)	50	100	200	350	500
Length (Ft)	300	340	560	770	860
Beam (Ft)	125	170	230	330	390
Depth (Ft)	165	180	180	180	130
Draft (Ft)	210	230	230	230	230
Lightship Disp (L.T.)	82,500	169,600	357,600	516,500	919,300
S.W. In System (L.T.)	12,100	38,900	80,200	131,700	168,100
Ballast (L.T.)	12,800	39,200	146,500	449,100	331,200
Operating Disp. (L.T.)	107,400	247,700	584,300	1,097,300	1,419,100

1 L.T. = 2240 lbs.

TABLE 5.2-6

PRINCIPAL CHARACTERISTICS - SEMI-SUBMERSIBLE

	SEMI-SUBMERSIBLE				
Size (MW Gross)	50	100	200	350	500
Length (Ft)	250	380	780	980	1160
Beam (Ft)	160	190	360	420	540
Depth (Ft)	170	170	170	172	174
Draft (Ft)	90	90	90	92	94
Lightship Disp. (L.T.)	56,400	96,400	258,500	324,700	518,200
S.W. In Systems (L.T.)	3,400	12,300	22,400	86,800	184,300
Ballast (L.T.)	0	0	0	0	0
Operating Disp. (L.T.)	59,800	108,700	280,900	411,500	703,000

1 L.T. = 2240 lbs.

TABLE 5.2-7

PRINCIPAL CHARACTERISTICS - SPHERE

	SPHERE				
Size (MW Gross)	50	100	200	350	500
Length (Ft)	230	250	370	440	500
Beam (Ft)	230	250	370	440	500
Depth (Ft)	210	205	275	290	340
Draft (Ft)	185	170	240	245	300
Lightship Disp. (L.T.)	85,800	106,100	294,100	418,700	519,100
S.W. In System (L.T.)	15,800	24,800	67,300	135,500	225,200
Ballast (L.T.)	43,800	47,400	181,500	274,400	581,800
Operating Disp. (L.T.)	145,400	178,300	542,900	827,600	1,326,100

1 L.T. = 2240 lbs.

FIGURE 5.2-1

500 MM COMMERCIAL PLANT, SHIP

(Modified)

FIGURE 5.2-2
500 MW COMMERCIAL PLANT, CYLINDER
(Modified)

18351-10 (W-10,000)

FIGURE 5.2-3
500 MW COMMERCIAL PLANT, SPAR
(Modified)

FIGURE 5.2-4
500 MW COMMERCIAL PLANT, SUBMARINE
(Modified)

FIGURE 5.2-5
500 MW COMMERCIAL PLANT, SEMI-SUBMERSIBLE
 (Modified)

FIGURE 5.2-6
500 MW COMMERCIAL PLANT, SPHERE
 (Modified)

5.3.1 Acquisition Costs (Continued):

These estimates are based principally on cost data from previous OTEC studies. These studies were performed by Lockheed Missiles and Space Company, Reference (6), TRW Corporation, Reference (5), and Johns Hopkins University, Reference (48). The Lockheed and TRW reports also include reviews of OTEC studies by Carnegie Mellon Institute and the University of Massachusetts, and the TRW report also contains a review of work by SSPI (John Anderson & Son). The cost data in these studies represents 1974 dollars. This data has been adjusted so that the Appendix C estimates represent 1977 dollars.

The data noted above was grouped so that it was logical to prepare the Appendix C estimates under the following cost categories:

- Hull System - Reinforced concrete and steel
- Power System - Heat exchangers, turbine, generator, ammonia system, etc., (for both titanium and aluminum tubes)
- Transmission System - Cabling from generators, transformers, converters, etc., (Cable from platform to shore was not included)
- Seawater System - Cold water pipe, cold and warm water pumps and piping, trash screens, etc.
- Support System - Habitability provisions for crew and other systems
- Positionkeeping System - Static and Dynamic
- Systems Engineering - Engineering and Miscellaneous

All cost estimates were based on the assumption that the Power System of all platform configurations and sizes would be comprised of multiple 25 (gross) megawatt units.

Hull System - The cost estimates for the Hull System were based on the following assumptions:

1. Reinforced concrete construction was used for all hulls except the semi-submersible which was considered to have a composite steel and concrete structure.
2. A figure of \$500/yd.³ for reinforced concrete was applied to the ship, cylinder, and spar; \$525/yd.³ to the sphere and semi-submersible; and \$540/yd.³ to the submarine. The different figures reflect the varying degrees of complexity among the hulls.

5.3.1 Acquisition Costs (Continued):

3. Steel work for the semi-submersible was estimated at \$2,500/ton based on available shipyard cost data for conventional steel ship construction.
4. Forms for concrete work were assumed to be of steel since the higher initial cost was considered to be offset by re-use on follow-on platforms. The use of wood forms was not considered on the basis that form labor and material costs would largely be repetitive for each succeeding platform.

Power System - The Power System was estimated on the basis of 25 MW modules and includes items such as the heat exchangers, (titanium or aluminum tubes), turbine generators, and ammonia system. Cost data for the Power System were selected from data in the six available studies, with 15% added for inflation from 1973 to 1977 as a basis for 25 megawatt modules. The values assigned for various components are summarized in Table 5.3-1.

TABLE 5.3-1

POWER SYSTEM COMPONENT COSTS (\$M)

<u>TUBE MATERIAL</u>	<u>TITANIUM</u>	<u>ALUMINUM</u>
Heat Exchangers	20.0	8.1
Turbine/Generator	1.8	1.8
Ammonia System	<u>1.75</u>	<u>1.75</u>
	23.55	11.65
+ 15%	<u>3.53</u>	<u>1.75</u>
Cost per 25 megawatt unit	27.08	13.40

An allowance for ammonia system, vacuum pumps and contingencies of 0.3 million dollars was added to the power system costs for each plant size. The heat exchanger costs are initial costs and do not include subsequent overhauls. These have been considered as a special operational cost. It should be noted that titanium can be expected to have the same life as the platform, but that aluminum heat exchangers may require renewal at 10-year intervals.

Transmission System - The Transmission System includes the cabling from the generators, the transformers, AC/DC converters, etc. The Lockheed study provided a cost of 3.7 million dollars for the transmission system, while all other studies gave a cost in the order of 1.0 million dollars per 25 megawatt module. A figure of 4.0 million dollars was selected as the 1977 cost per module as a conservative estimate.

5.3.1 Acquisition Costs (Continued):

Seawater System - Costs for the Seawater System include warm and cold water piping, pumps and filtration screens as well as the cold water pipe. Estimates for warm and cold water pumps from the six available studies ranged from 2.9 million to 5.2 million dollars per 25 megawatt module. In view of the large size of these pumps, a 1977 cost of 5.2 million dollars was selected. To this, 0.42 million dollars per module was added for 600 feet of warm and cold water suction and discharge piping at \$700 per foot, plus an allowance of 0.1 million dollars for trash screens and filters, for a total of 5.72 million dollars per module.

The estimated cost of the Cold Water Pipe (CWP) reflected in the Commercial Plant cost estimates was based on the following assumptions:

1. Reinforced concrete construction with an average wall thickness of two feet. Early studies during Task IIA based only on steady state current loading and fabricability considerations resulted in a one foot pipe wall. Subsequent bending moment studies, which are discussed in Section 5.4 of this volume, indicated that this value was totally unrealistic and that a two foot thickness would be more appropriate for estimating purposes. The assumption of constant wall thickness is investigated in Section 5.6.
2. A compliant or hinged connection at or near the top of the CWP to eliminate or at least minimize the bending moment introduced by platform motions. This means that the CWP scantlings will be determined primarily by dynamic loading, hydrodynamic effects, buckling instability, construction requirements, and axial stresses because of deadweight. The latter are assumed to be minimized by the introduction of buoyancy material. Based on this assumption of end condition and the complexity of analyzing all loading modes at this time, the CWP scantlings were assumed to be relatively independent of platform configuration and site. This is discussed further below.
3. A length equal to 3,000 feet minus the draft of the platform.

5.3.1 Acquisition Costs (Continued):

Seawater System (Continued):

4. A fabricated and installed cost of \$1,250/yd.³ based on an allowance of \$500/yd.³ for basic forming, \$250/yd.³ for the attachment to the hull and/or joining of sections, and \$500/yd.³ for deployment.

Obviously, these assumptions are quite gross, but they were necessitated for the initial cost-benefit analysis by a number of factors as enumerated below and as further discussed in Section 5.4.

1. The number of variables being considered is too extensive for a thorough technical evaluation. These variables include 6 configurations, 5 sizes (50 - 500 MW), 3 sites, perhaps 4 or 5 materials and varying degrees of end fixity. In addition, dynamic response can be varied by varying the stiffness, inertia, and damping characteristics along the length of the pipe.
2. The previous studies by Hydronautics involved certain simplifying assumptions in analyzing dynamic response, such as a 4 foot uniform wall thickness for concrete in all platforms (except for the semi-submersible in which a thickness of 0.4 feet was assumed). The platform sizes, shapes and CWP diameters do not correlate with the current Gibbs & Cox, Inc. baselines (Section 5.2), and CWP wall thicknesses were not optimized to suit moment distribution and allowable stresses. Likewise, such effects as buckling instability were not investigated, and the effects of thickness variations and damping on dynamic response were not investigated.
3. The tools available to properly analyze the CWP dynamic response problem have just recently become available, but are too expensive to utilize in a parametric evaluation of CWP thicknesses and materials under the current effort.

Based on the above and the premise that the relativity of costs is more meaningful than the application of absolute values at this stage of design, the accuracy of the costs presented herein for the CWP are considered to be adequate. It is understood that these values may prove to be too high or too low after firmer cost estimates are produced in Task V, but so long as consistency is demonstrated now, the relative

5.3.1 Acquisition Costs (Continued):

Seawater System (Continued):

rankings of the configurations will remain the same.

Support Systems - The habitability costs were based on a 27-man crew for a 50 megawatt platform with personnel increasing slightly with the plant size. These estimates were taken from the Lockheed, Johns Hopkins, and TRW estimates for crew requirements, with consideration given to plant management and personnel requirements of land and ship type power plants.

Other Support Systems such as heat, ventilation, air conditioning, deck outfit (lifeboats, rigging, etc.), firemain, ballast systems, etc., were assumed to be \$20,000. per ton, using typical shipyard costs for such systems.

Positionkeeping Systems - Positionkeeping systems which include anchoring and dynamic positionkeeping were not only based on plant size and configuration, but were also keyed to the site location. For example, Key West has a much larger current profile than either the New Orleans or Hawaiian site and therefore drag forces on the platform will require more equipment to keep an OTEC platform on station; therefore, there are large cost differences for the Key West site over the other two.

The following assumptions were made in developing costs in this area:

1. The total mooring force required for ahead and beam force conditions was obtained by adding current, wind, and wave forces for each of the three sites.
2. A unit mooring line was selected in order to express all configurations in a common reference. A four-inch wire rope, 15,500 feet long with a 100,000 pound gravity anchor was used, and the cost of one mooring line was obtained. The horizontal holding power of one such line was calculated for the water depth at each site location using a constant line tension equal to half the breaking strength of the wire rope.
3. To simplify comparison of the ninety size/type/site configurations, a four point mooring was assumed with mooring lines at ninety degree intervals. At present, a single point mooring was considered to have a number of difficulties that precluded its use. The final mooring design for the selected size/type/site configuration would, of course, not be this simple.

5.3.1 Acquisition Costs (Continued):

Positionkeeping Systems (Continued):

3. (Continued):

The number of unit mooring lines was calculated for each direction, and the total mooring costs were figured from the cost of the unit mooring line.

4. The use of dynamic positioning system would allow orienting the platform in the most favorable direction. The ahead current/wind/wave loadings were used to establish cost. An installed cost was obtained in dollars per pound of thrust for the smaller power systems. This figure was weighted to reflect the savings that would be realized when using the higher thrust producing systems.

5. Dynamic positionkeeping systems were assumed for Hawaii and New Orleans while a combination mooring/dynamic positionkeeping system was selected for Key West for comparison purposes.

The positionkeeping cost estimates are based on the use of a sufficient number of lines to provide the maximum required holding power at half the line breaking strength. The cost per pound of horizontal force varies from about \$1.12 at Hawaii to \$1.21 at Key West. The Westinghouse cost estimate for the hollow cylindrical links amounts to about \$1.18 per pound of horizontal force at the same design conditions.

Systems Engineering - The engineering and miscellaneous costs were intended to cover such items as engineering preliminary and contract design, home office costs, contractor's fee, permits, ocean checkout, insurance, taxes, and towing costs. Research and development costs have not been included in the acquisition cost estimates.

5.3.2 Operating Costs

Annual operating costs were estimated based on the concept of a 3,000 megawatt park in which a number of OTEC plants would supply the requisite power. This resulted in the following plant size/number relationship:

5.3.2 Operating Costs (Continued):

<u>Plant Size</u> <u>(Megawatts)</u>	<u>Number of</u> <u>Plants</u>
50	60
100	30
200	15
350	9
500	6

A slight irregularity for comparing data occurs in this approach for the 350 megawatt platform, since 9 platforms will exceed the 3,000 megawatt power output by 5 percent.

As for acquisition costs, described in Section 5.3.1, operating costs were estimated for six platform configurations, five sizes, three operating sites where applicable and for both titanium and aluminum heat exchanger tubes. Summaries and details for these cost estimates are given in Appendix C, which also includes a per platform cost for each power plant size.

Estimates were broken down by the following categories:

- Crew (by site) - Wages and fringe benefits
 - Subsistence
- Insurance (by site)
- Maintenance - Inspection and Repair
 - Mini-submarine
 - Marine growth
 - Repair team
- Service Ship - Ship/supplies and crew transport
 - Helicopter/aircraft
- Spare Parts (by site)
- Fuel and Lube Oil
- Miscellaneous Expenses

Costs for crew and insurance comprise a major share of the operating costs. Estimates for crew have a high degree of accuracy, but estimates for insurance could be quite inaccurate due to lack of experience by insurance companies with OTEC platforms, however, insurance estimates are based on rates which apply to conventional marine structures.

18351-10 (W-10,000)

5.3.2 Operating Costs (Continued):

Crew - The power plant personnel were assumed to work 12-hour shifts similar to offshore drill rig practice with 14 days on duty and 14 off. Based on this, the following manning was estimated for the various plant sizes with no additions or deletions made for configuration or site:

TABLE 5.3-2

<u>PLANT MANNING</u>					
SIZE, MW	50	100	200	350	500
Deck	8	8	8	8	8
Steward	6	6	8	10	12
Plant	6	6	10	16	26
Maintenance	<u>7</u>	<u>10</u>	<u>18</u>	<u>24</u>	<u>30</u>
TOTAL	27	30	44	58	76

These estimates of personnel were made using typical ship or offshore rig manning and then cross checked using previously published data in References (5), (6), and (48). Costs associated with the manning were based upon data in Reference (49).

Daily crew costs were estimated on current wage scales and fringe benefits for crews operating smaller U. S. flag vessels as provided by MarAd's Office of Manpower, for each salary grade. These costs include an estimated overtime factor and a daily charge for subsistence and supplies. Table 5.3-3 provides a summary of these factors.

18351-10 (W-10,000)

5.3.2 Operating Costs (Continued):

Crew (Continued):

TABLE 5.3-3

<u>ESTIMATED DAILY CREW COSTS</u>				
<u>Title</u>	<u>Wages & Fringe</u>	<u>Overtime</u>	<u>Subsistence etc.</u>	<u>Total</u>
Master	\$204	\$45	\$18	\$267
1st Mate	124	25	18	169
3rd Mate	107	20	18	145
A.B.	48	15	18	81
Chief Eng.	205	42	18	265
Asst. Eng.	130	25	18	173

Site sensitivity for wages and subsistence was taken into account for Hawaii where the cost of living is appreciably higher than either the Key West or New Orleans site.

Insurance - Insurance costs for all platforms except the spar and submarine were based on Reference (6) since 0.8 percent of the acquisition cost is approximately the same value used for merchant ships and nuclear plant evaluations. The figure was increased to 1.0% for Key West and New Orleans due to the higher probability of encountering severe storms and higher density of shipping traffic. The spar and submersible are considered especially liable to total loss due to flooding, since the survival of either depends on rapid counter-measures started within seconds after damage to prevent the platform from sinking to depths which would collapse the hull. Accordingly, insurance rates were assumed to be double for the spar and submersible configurations. This was discussed with representatives of The American Hull Insurance Syndicate and U.S. Salvage Corporation who consider this to be a realistic set of assumptions at this stage of the program.

Maintenance - Since the OTEC platform is ocean based at some distance from the shore and represents a considerable capital investment, it was assumed that down time because of equipment failures would be minimized by a preventive maintenance program. Certain scheduled maintenance can be done during low demand periods, while others such as tube replacement will be scheduled on a definite time basis.

18351-10 (W-10,000)

5.3.2 Operating Costs (Continued):

Maintenance (Continued):

The estimate of maintenance included the following:

- Inspection - Routine inspection of major plant components such as pumps, turbines, condensers.
- Mini-submarine - This will be used for periodic underwater inspection of the platform, cold water pipe, and mooring system.
- Marine growth - Divers will be brought aboard to remove growth and for cleaning of intake and exhaust ducts for the cold and warm water systems.
- Repair teams - Replacement or refurbishment of machinery and equipment in accordance with a pre-established schedule.

The cost for transporting the crews, supplies, spare parts, etc., was made for service ships and helicopters, using available data from Gulf Coast drill rigs.

Costs of material, component parts, and spares for general maintenance and repair including overhaul were based upon References (5) and (6) with adjustments for site, configuration and power size.

Fuel and lube oil costs are very modest since the use of diesel oil is anticipated only for use in the emergency diesel generators. Lube oil requirements for pumps and the turbo-generators were based on ship operation.

Systems Engineering - The miscellaneous expenses and contingencies include items that are not directly attributable to plant operation costs. These would include such things as home office costs, warehousing, depots, special equipment rentals, etc. Emergency repairs, such as plugging of leaky heat exchanger tubes, were also considered to be covered by this item.

Summary - Figure 5.3-1 summarizes the annual operating cost for the OTEC plants under consideration.

5.3.3 Schedule

The construction of an OTEC platform will occur in discrete phases and in modular fashion. This can be integrated into a complete construction schedule which is summarized under "Procedure to Construct OTEC Platform" in Appendix C.

OPERATING COST SUMMARY

FIGURE 5.3-1

5.3.3 Schedule (Continued):

A typical construction schedule was made for the 100 megawatt ship shape configuration using Reference (6). No Research and Development (R&D) time was included in the time line, since it is assumed that R&D is being performed at the present time by current studies on the OTEC system for DOE. The proposed construction schedule was checked with a shipyard experienced in concrete/steel construction, and the proposed schedule and time spans were considered reasonable. Some significant parameters that were considered were regulatory approvals of the design, environmental impact statements, facility requirements, ease of construction test-out phase, and support requirements for operation.

The heat exchangers were assumed to be a production item when the first OTEC platform is ordered; thus, the critical items in the construction of the plant will be the engineering and production of the pumps, the development of the ammonia turbo-generator and the construction of the concrete platform.

Construction and attachment of the cold water pipe to the platform could be in the area of high risk, but for the purpose of this study it was assumed that R&D efforts would resolve cold water pipe problems prior to the need for the pipe. The time line in Figure 5.3-2 indicates about 18 months after contract before work begins on the CWP, which would be only slightly longer than the corresponding time line for a 50 megawatt platform and is considered adequate.

The following major construction phases were considered and are reflected in the time line Figure 5.3-2. Although this time line is for a 100 MW ship, similar reasoning was used in developing the schedules for all plants.

● Heat Exchangers

- 1A Engineering and Drawing Preparation - 15 months
- 1B Fabricate and Deliver steel sections for one complete module - 15 months after 1A
- 1C Assemble Module - 18 months - Commence 6 months after start of steel fabrication
- 1D Order and Deliver Tube - Commence after 1A - 12 months duration.

FIGURE 5.3-2
CONSTRUCTION TIMELINE FOR 100 MW SHIP

5.3.3 Schedule (Continued):

• Heat Exchangers (Continued):

- 1E Fabricate tubes for one set of heat exchangers
18 months - commence after 1D
- 1F Install tubes in semi-complete hull and leak test once a
completed bank of tubes is in place
9 months - start after 1E

• Cold and Warm Water Pumps

- 2A Final Vendor Design
12 months
- 2B Impeller pattern making, casting, machining, and delivery
6 months - commence at end of 2A
- 2C Fabrication and delivery of pod steel
9 months - start after 2A
- 2D Pump Machinery Procurement
21 months after 2A
- 2E Pump assembly and installation
6 months after 2D

• Turbine Generators

- 3A Preliminary Vendor Studies
12 month duration
- 3B Vendor Engineering, Fabrication and Delivery
21 months after 3A - subsequent units on one month intervals
- 3C Install and test units
9 months after 3B

• Auxiliary Systems (ammonia pumps, controls,
cooling water, heat exchangers, diesel generators, compressors)

- 4A Purchase of materials and equipment
24 months
- 4B Installation of Equipment
12 months - start 21 months after procurement of lead items
- 4C Pipe tightness tests and wiring checkout
3 months - start at conclusion of 4B

• Demisters and Manifolds

- 5A Procurement
12 months
- 5B Installation
6 months at end of 5A
- 5C Tightness tests
3 months after 5B

5.3.3 Schedule (Continued):

- Warm and Cold Water Screens
 - 6A Procurement
12 months
 - 6B Construction
6 months - at end of 6A
- Outfitting
(This includes plant control, crew living and support systems, helicopter platforms, internal associated wiring and piping)
 - 7A Procurement
24 months
 - 7B Installation (Modular)
18 months - 9 months after start of 7A
May have to be increased if crew living space modules are assembled offshore.
 - 7C Tests
3 months - after 7B
- Cold Water Pipe
 - 8A Construction and Fabrication
Modular units and delivery to site 18 months
 - 8B Assembly of cold water pipe
3 months

Platforms were assumed to be reinforced concrete. In order to decrease the building schedule with increasing plant capacity, the number of cement batch plants was correspondingly increased. This resulted in the following:

<u>MW</u>	<u>Number and Capacity of Cement Batch Plants</u>
50-100	2 at 1500 cubic/yr month
200	3 at 1500 cubic/yr month
350	4 at 1500 cubic/yr month
500	5 at 1500 cubic/yr month

The number of batch plants required was based on a survey of concrete structures delivered to North Sea production areas. This was taken from Reference (50) which indicated for a structure of some 140,000 tons, light ship, that two batch plants would be required. Construction time was approximated to be a maximum of two years; however, these platforms are less complicated than that of OTEC.

The construction schedule for the various configurations is dependent on the volume of concrete required and the complexity of the configuration. The submersible and semi-submersible will require special forms over and above those for the other configurations. Figure 5.3-3 summarizes the schedule estimates.

FIGURE 5.3-3

SCHEDULE SUMMARY

5.4 Motions and Structural Loads Analysis

5.4.1 Background

One of the main objectives of this study is to evaluate the seakeeping characteristics of the six candidate platform configurations under consideration and to rank them according to the levels of motions and structural loads induced by the ocean environment.

OTEC platforms and their cold water pipes are expected to operate for periods of up to 40 years in the ocean while subjected to extreme winds, waves and currents. The cold water pipes must be designed to withstand the largest single load occurring during its lifetime. At the same time, the design must have adequate fatigue strength to survive the 40 years of cyclic loading in moderate seas. It is estimated that for an average wave period of 10 seconds, a typical CWP will be subjected to about 10^8 load cycles in 40 years. When one considers the effect of seawater on the fatigue strength of potential CWP materials, it is clear that the structural design of the CWP will require a solid understanding of its loading and response spectra.

Platform motions, on the other hand, are important for four main reasons. First, excessive angular motions under severe wind conditions could lead to capsizing. Therefore, the platforms must have the ability to withstand a given wind velocity with a residual margin of righting moment in both the intact and damaged conditions. Second, excessive platform motions can transmit large bending moments to the CWP's. This will give rise to dynamic bending stress distributions acting along the length of the CWP with high peaks at various locations depending on the pipe geometry and structural characteristics. Third, the accelerations experienced by the platform under different sea states and wave headings can lead to cessation of plant operations, reduced crew effectiveness, and inefficient operation of or damage to heat exchangers and rotating machinery. Fourth, translational and rotational motions envelopes must also be specified for the design of transmission lines since static, hydrodynamic and inertial loads can have detrimental effects on the cables.

A number of studies have been conducted recently in the area of OTEC platform motions and structural loads. Hydronautics, Inc. (Reference (51)), developed a six degree of freedom platform/CWP motions and loads computer

5.4.1 Background (Continued):

simulation in the frequency domain. The program was used to generate motions (heave, surge, sway, roll, pitch, yaw) and CWP bending moments and shear forces as a function of sea state and heading relative to the waves. In addition three platform displacements were considered for each of five candidate configurations (ship, submarine, semi-submersible, cylinder and spar). The cold water pipe was assumed to be rigid and the CWP/platform attachment was assumed to have varying degrees of heave and roll/pitch stiffnesses (quasi-infinite, finite and zero). CWP length, diameter and attachment point (vertical and longitudinal) were also varied. A key element in this simulation was the establishment of platform displacement-vs-plant-output correspondence based on studies conducted for DOE up to that time. This correspondence was as follows:

<u>PLANT OUTPUT</u>	<u>PLATFORM DISPLACEMENT</u>
100 MW _e	150,000 long/tons
500 MW _e	500,000 long/tons
1000 MW _e	900,000 long/tons

The baseline case was considered to be the 500 MW_e plant with a CWP 2000 feet in length and 110 feet in diameter. Other studies by Hydronautics have included the prediction of motions and CWP loads for a sixth candidate configuration, the tuned sphere. These results are reported in Reference (52). Reference (53) presents the results of a preliminary evaluation of the Hughes Mining Barge motions and CWP loads for EOTP One. The methods used in this study are similar to those described in Reference (51) with two significant differences. The first difference is the inclusion of the pipe flexibility or structural stiffness, EI. The second difference is the treatment of loads due to currents as well as waves. More recently Hydronautics has presented some preliminary results for five OTEC platforms including the effect of CWP flexibility (Reference (54)). These studies were designed to duplicate the earlier studies of Reference (51) with two main differences. First, CWP flexibility is accounted for in the prediction of motions and loads and second, 150,000 L.T. platforms rather than 500,000 L.T. platforms and a CWP length of 3,000 feet rather than 2,000 are used as baseline cases. Computer simulations were made for the matrix of cases shown in Table 5.4-1. Allowable stresses were established for various CWP materials considered corresponding to the significant load in 40 foot significant wave heights only. Maximum allowable

TABLE 5.4-1MATRIX OF CASES CONSIDERED

by Hydronautics, Inc. (Reference (44))

<u>PLATFORM SIZE</u>	<u>CWP MATERIAL</u>	<u>CWP LENGTH</u>	<u>ATTACH. STIFF.</u>	<u>SHIP</u>	<u>DISC</u>	<u>SEMI</u>	<u>SPAR</u>	<u>SUB</u>
150,000 L.T.	Al	3,000	0 Finite ∞	x x x	x x x	x x x	x x x	x x x
		2,000 4,000	Finite	x x		x x	x x	
	GRP	3,000	0 Finite ∞	x x x	x x x	x x x	x x x	x x x
		2,000 4,000	Finite	x x		x x	x x	
	Concrete	3,000	0 Finite ∞	x x x	x	x x x	x x x	x
	Al	3,000	Finite	x x		x x	x x	
	Al	3,000	Finite	x x		x x	x x	

5.4.1 Background (Continued):

CWP wall thicknesses of one foot for aluminum and GRP and four feet for concrete were specified. CWP attachment stiffnesses considered for heave, pitch and roll were the same as those used in the earlier studies with a rigid CWP (Reference (51)).

The tuned sphere platform was not covered in the study of Reference (54); however, the seakeeping report of Reference (52) was prepared by Hydronautics, Inc. using the same model and conditions so that the effect of CWP flexibility on motions and loads was also included in the case of the sphere.

In addition to the simulations developed by Hydronautics, there are at least four other efforts which have either been completed or are in progress in the area of platform/CWP motions and loads analysis. A very detailed description and comparison of these studies is given in References (55) and (32) which include comparisons with the Hydronautics work. The most relevant of these additional studies are the models developed by Paulling (Reference (56)) and Garrison (Reference (57)). Paulling's model is a six-degree-of-freedom simulation of the platform/CWP coupled dynamic response. The model is divided into two parts. The first part is a preprocessor which generates the hydrodynamic coefficients and excitation forces for the platform alone. Paulling has developed preprocessors for the ship and semi-submersible configurations (named SHIPF and PLFOR, respectively). The ship preprocessor may also handle the submarine configuration. The second part of the model predicts the coupled response of the platform/CWP using as inputs the forces and coefficients generated by the preprocessor. This portion of the model, referred to as ATEC, gives the motion response of the platform in 6 degrees of freedom as a function of sea state (Bretschneider or any other spectrum) and heading relative to the waves. In addition, it gives a very detailed mapping of the CWP modal displacements, velocities, and dynamic stress distributions. The pipe is modelled in its original static condition with or without the presence of a current profile. The program can simulate variations in thickness, diameter and structural material throughout the entire length of the CWP. It also allows for varying the connection stiffness at the platform junction and at any point along the length of the pipe. The static stress distribution due to the weight of the CWP is also given.

Garrison's program, OTECPR, does not yet include the presence of the CWP, but it has the advantage of being applicable to arbitrarily shaped bodies

5.4.1 Background (Continued):

(slender and fat). The program is written in the frequency domain and yields hydrodynamic coefficients, exciting forces and platform response to the waves. At the present time this program is being used as a preprocessor for Paulling's ATEC program in order to generate the coefficients and forces for those configurations not covered by SHIPF and PLFOR (i.e., cylinder, sphere, spar). At the time of the writing of this report the interfacing between OTECPR and ATEC was being done manually pending the delivery by Dr. Garrison of the appropriate job control cards and additional program for inputting the OTECPR data into ATEC.

The discussion presented above summarizes the key efforts which have or are being conducted in the area of OTEC platform seakeeping evaluation outside of this study. This section will therefore concern itself with the prediction of motions and structural loads for the specific OTEC platform/CWP designs discussed in Section 5.2 of this report. The methodologies used to accomplish this objective are described, followed by a presentation of results and the evaluation and ranking of the various platform designs from a seakeeping standpoint.

5.4.2 Procedures, Analytical Tools and Results

The procedure followed in the evaluation of the seakeeping characteristics of the OTEC/CWP configurations developed during the course of the study is based on the combined use of the Hydronautics and Paulling/Garrison simulations. A concise description of this methodology follows.

In general the methodology was outlined based on the fact that the only seakeeping data in existence prior to the availability of the Paulling/Garrison models was that developed by Hydronautics. The Paulling/Garrison models were made available in late October of 1977 but, as an integral package, they are only applicable to three configurations (ship, semi-submersible and submarine). In view of this situation the following course of action was adopted:

1. Motions and loads were predicted by applying correction factors to the Hydronautics values in order to account for differences between the Gibbs & Cox, Inc. and Hydronautics designs.

5.4.2 Procedures, Analytical Tools and Results (Continued):

2. The ATEC program along with the preprocessors SHIPF and PFLOR were exercised for the ship and the semi-submersible configurations. Coincidentally, the ship and the semi-submersible are near the high and low ends of the motions and loads spectra respectively.
3. A comparison was then made between the results of (1) and (2) above for the ship and semi-submersible for the entire range of plant sizes, platform displacements, sea states, and heading relative to the waves. This was done in order to determine whether or not the technique of correcting the Hydronautics predictions was a valid one. As it turned out, the results of this comparison demonstrated that for ranking purposes the correction factor technique was reasonable and acceptable. The corrected Hydronautics values were consistently higher than the ATEC predictions, but the relative differences between the ship and the semi-submersible were of the same order of magnitude and in the same direction. The ship has one of the worst seakeeping characteristics (the cylinder being the worst), while the semi-submersible is one of the best. At the same time, ATEC made it possible to assess in more detail the CWP dynamic response including lateral and dynamic bending stress distributions, shears, torsional moments and model shapes.

Depending on the outcome of step (3), the Garrison OTECPR program would or would not have been used to generate hydrodynamic coefficients and forces for the remaining configurations; however, based on these observations, it was assumed that similar agreement between the two procedures would exist for the other candidate configurations. Consequently, it was decided to use the results of step (1) to evaluate and rank the various shapes from a sea-keeping standpoint. It is emphasized, however, that such an approach can only be reasonable for ranking purposes. In the conceptual design (Task V) and future phases of the OTEC program, a detailed platform/CWP dynamic analysis using ATEC must be carried out in order to insure a safe, structural design.

5.4.2.1 Motions and Loads Predictions Based on Corrected Hydronautics Results

CWP/platform motions and bending moments for the various configurations described in Section 5.2 were derived by applying correction factors to the Hydronautics predictions reported in References (51), (52), and (54). The correction factors account for differences between the Hydronautics and Gibbs & Cox, Inc. designs in the following areas:

- (a) CWP/Platform Attachment Stiffness
- (b) CWP length
- (c) Platform displacement for given MW
- (d) CWP diameter
- (e) CWP flexibility (material and structural design)

In addition there are some differences in the overall proportions such as length-to-beam, length-to-draft and beam-to-draft ratios as well as relative positions of the c.g and CWP attachment point; however, it was decided that the most important factors were (a) through (e) above, and that any errors in the correction technique could be attributed to these other factors.

(a) Effect of CWP Attachment Stiffness on OTEC Platform Motions and Loads Predictions - Hydronautics' computer predictions of OTEC platform motions assume three conditions at the CWP/Platform connection (Reference (51)).

1. Zero attachment stiffness: $k_{\text{pipe}} = 0$
2. Finite pipe attachment stiffness:
 $(k_{\text{pipe}})_{\text{heave}} = 10^4 \text{ pounds/ft}$
 $(k_{\text{pipe}})_{\text{pitch/roll}} = 10^{10} \text{ pound-feet/radian}$
3. Infinite pipe attachment stiffness (very large finite stiffness):
 $(k_{\text{pipe}})_{\text{heave}} = 10^9 \text{ pounds/ft}$
 $(k_{\text{pipe}})_{\text{pitch roll}} = 10^{14} \text{ pound-feet/radian}$

These numbers (infinite stiffness case) are large enough to eliminate the three degrees of freedom of the CWP (pipe heave, pipe pitch, pipe roll) and insure identical motions of platform and pipe.

5.4.2.1 Motions and Loads Predictions Based on Corrected Hydronautics Results
(Continued):

(a) (Continued):

In order to estimate the effects of CWP/Platform attachment rigidity on the motions and loads, a first approximation can be made based on the Hydronautics predictions. In general, the critical parameters are platform pitch, roll, and maximum axial bending moment at the attachment. Intuitively, the pitch and roll will increase as the stiffness decreases and the bending moment will decrease as the stiffness decreases.

The data given in Reference (51) corresponds to the case of an infinitely stiff CWP/Platform attachment. These numbers can be multiplied by appropriate factors to obtain the values of motions and bending moment for finite and zero stiffness. Table 5.4-2 gives very preliminary factors for different platform configurations. In using these factors it is assumed that the relative effect of CWP/Platform connection stiffness does not vary with sea state (i.e., the factors in Table 5.4-2 are the same as for sea states 6, 7, 9, etc.). The factors are computed based on the Hydronautics, Inc. baseline platform of Reference (51), which is the 500 MW plant with a 2,000 ft. CWP, 110 ft. in diameter.

(b) Effect of CWP Length on Motions and Loads - The Hydronautics baseline design considers a CWP 2,000 ft. long, whereas the Gibbs & Cox, Inc. designs require lengths of 3,000 ft. and above in order to meet the ΔT requirements. With this in mind, Table 5.4-3 presents correction factors for extending the Hydronautics predictions to the case of a 3,000 ft. CWP. In general, an increase in CWP length results in smaller motions and larger bending moments.

(c) Effect on Platform Displacement on Motions and Loads - The Hydronautics baseline design considers a baseline design of a 500 MW plant on a 500,000 L.T. platform of any shape. The Gibbs & Cox, Inc. designs for the same plant output are significantly different and Table 5.4-4 gives the correction factors to be applied to the Hydronautics baseline design in order to obtain the motions and bending moments for the 500 MW Gibbs & Cox, Inc. design.

TABLE 5.4-2

Factors to be Applied to the Hydronautics Values of Motions and Loads in Order to Account for
Variations in CWP/Platform Connection Stiffness

CONFIGURATION RESPONSE	SHIP		SUBM.		SEMI-SUBM.		CYLINDR.		SPAR		(*) SPHERE	
	K= FINITE	K=0	K= FINITE	K=0	K= FINITE	K=0	K= FINITE	K=0	K= FINITE	K=0	K= FINITE	K=0
SURGE	.9	.9	.6	.6	.7	.7	1.0	1.0	1.0	.8		
SWAY	1.0	1.0	4.2	3.3	.6	.6	1.0	1.0	1.0	.8		
HEAVE	1.0	1.0	1.0	1.0	1.1	1.1	1.0	1.0	1.0	1.0		
ROLL	4.3	2.6	40.0	35.0	17.9	17.3	14.1	17.1	14.5	12.6		
PITCH	10.0	10.0	20.0	19.5	18.1	17.2	14.1	17.1	14.5	12.6		
YAW	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0		
MAX ATTACHMENT BENDING MOMENT	.3	0	.08	0	.3	0	.9	0	.4	0		
MAX. BENDING MOMENT ALONG CWP	.29	.28	.08	.10	.24	.26	.88	.86	.36	.31		

(*) No results given in Reference 41

TABLE 5.4-3

Factors to be Applied to the Hydronautics Baseline Platform Values of Motions and Loads to Account for Variation in CWP Length from 2,000 to 3,000 feet

CONFIGURATION RESPONSE	SHIP	SUBM.	SEMI- SUBM.	CYLINDER	SPAR	(*) SPHERE
SURGE	.8	1.0	.9	.9	.9	
SWAY	.9	.9	.9	.9	.9	
HEAVE	1.0	1.0	1.0	1.0	1.0	
ROLL	.6	.6	.8	.6	.6	
PITCH	.5	.8	.8	.6	.6	
YAW	1.0	1.0	1.0	1.0	1.0	
MAXIMUM BENDING MOMENT ALONG THE CWP	1.3	1.0	1.0	2.5	1.1	

(*) No results given in Reference (51).

TABLE 5.4-4

Variation in Motions and Loads with Platform Displacement Based on Hydronautics
 Predictions: Sea State 7; 2,000 ft Pipe, 110 ft dia. $K = \infty$

CONFIGURATION RESPONSE	SHIP	SUBM.	SEMI- SUBM.	CYLINDER	SPAR	(*) SPHERE
SURGE	.81	.46	.85	.87	.78	
SWAY	.86	.69	.84	.86	.78	
HEAVE	.91	.81	.88	.88	.78	
ROLL	.87	.70	.83	.83	.73	
PITCH	.82	.45	.83	.86	.73	
YAW	.80	.66	.89	-	-	
MAXIMUM BENDING MOMENT ALONG CWP	1.71	3.04	1.40	1.52	2.15	

Plant Output.Hydronautics Platform Displacement (full load)

100 MWe	→	150,000 L.T
500 MWe	→	500,000 L.T
1000 MWe	→	900,000 L.T

(*) No results given in Reference (51).

5.4.2.1 Motions and Loads Predictions Based on Corrected Hydronautics Results
(Continued):

- (d) Effect of CWP Diameter on Motions and Loads - The CWP diameters vary between 60 feet for the 100 MW plants; up to 140 feet for the 500 MW plants. Hydronautics has considered variations in diameter for the ship and submersible cases from 76 to 128 feet in diameter. In general, the results of Reference (51) indicate that an increase in pipe diameter leads to a reduction in motions and little or no increase in CWP/Platform connection bending moments. Table 5.4-5 gives the correction factor for pipe diameter for the ships and submarine configurations. Since no information is available for the effect of CWP diameter on the remaining configurations, no correction for CWP diameter was made in those cases.

Appendix F of Reference (1) contains detailed predictions of motions and loads including correction factors (a) through (d) prior to including CWP flexibility.

- (e) Effect of CWP Flexibility on Motions and Loads - Based on the preliminary results presented recently by Hydronautics in Reference (54), the effect of CWP flexibility was assessed in a similar manner. However, a few significant differences between the efforts reported in References (51) and (54) must be pointed out. First, the Hydronautics baseline platform is no longer the 500 MWe (500,000 L.T.) plant. It has been replaced with the 100 MWe (150,000 L.T.) plant. Second, the CWP baseline length has been changed from 2,000 feet to 3,000 feet. Third, the CWP thicknesses vary depending on material (concrete, GRP, aluminum), platform size, platform configuration and CWP/platform connection stiffness. Maximum allowable CWP wall thicknesses of one foot for aluminum and GRP and four feet for concrete were specified. Larger wall thicknesses were considered impractical due to excessive weight and/or problems in fabrication.

Table 5.4-6 gives the CWP flexibility correction factors to be applied to the Hydronautics 500,000 L.T. baseline design as derived from comparing the 150,000 L.T. platforms with and without flexible CWP's. In general, the effect of CWP flexibility is to increase the platform motions with a few exceptions as in the case of the semi-submersible roll which decreases with CWP flexibility. The effect on

TABLE 5.4-5

Correction Factors to be Applied to the Hydronautics Baseline Platform Values
of Motions and Loads to Account for Variation in CWP Diameter from 110 ft to 140 ft

CONFIGURATION RESPONSE	SHIP	SUBM.	SEMI- SUBM. (*)	CYLINDER (*)	SPAR (*)	SPHERE (*)
SURGE	.92	.97				
SWAY	.94	.93				
HEAVE	.97	1.0				
ROLL	.97	.97				
PITCH	1.0	1.0				
YAW	1.0	1.0				
MAX. BENDING MOMENT	1.0	1.1				

(*) No data given in Reference (51).

TABLE 5.4-6

Correction Factors for CWP Flexibility Based on 150,000 L.T. Hydronautics

Platform $H_{1/3} = 40$ ft

RESPONSE	SHIP	SUBM.	SEMI-SUB.	CYLINDER	SPAR	SPHERE (*)
SURGE	1.46	2.14	1.54	1.12	1.58	
SWAY	1.11	0.33	1.20	1.17	1.58	
HEAVE	1.0	1.02	1.03	1.0	0.87	
ROLL	4.69	.19	1.20	1.94	2.44	
PITCH	2.11	1.19	1.28	1.94	2.44	
YAW	1.01	1.0	1.44	-	-	
VERT. ACC.	0.97	1.6	1.29	1.03	1.93	

(*) No results given in Reference (51).

5.4.2.1 Motions and Loads Predictions Based on Corrected Hydronautics Results
(Continued):

(e) (Continued):

the maximum axial bending moment along the CWP is an increase for all configurations except for the semi-submersible where the opposite is true. Based on the significant differences in the Hydronautics CWP conditions as discussed above, it was decided that it would be unrealistic to attempt to correct the Gibbs & Cox, Inc. baseline Plants for the effect of CWP flexibility based on Hydronautics' results. Instead, since the relative standing of the various configurations was not affected by the comparison with the rigid CWP conditions, absolute values of maximum bending moment along the pipes were derived by comparing the values generated for the ship and semi-submersible using the Paulling program (see Section 5.4.2.2) with the rigid pipe values extrapolated from the Hydronautics rigid pipe results. Furthermore, it was felt that since the importance of CWP flexibility would become more critical only in the conceptual design phase, these results would be sufficient to perform a valid comparison study.

5.4.2.1.1 Platform Accelerations

Previous studies in this effort had not presented predictions of platform accelerations obtained by means of the technique used with the motions and loads. A similar approach has been used although in the case of the accelerations, the most important parameter for correcting the Hydronautics predictions is platform displacement. Figures D-1 through D-5 in Appendix D show the variation of platform heave acceleration as a function of sea state and displacement for all configurations except the sphere.

5.4.2.1.2 Prediction of Motions and Loads for the Sphere Platform

The recent seakeeping study completed by Tuned Sphere International (TSI) (Reference (52)) made it possible to derive motions and loads for the Gibbs & Cox, Inc. sphere platform designs. The procedure used was the same as that used with the other platforms. The only difference is that the TSI data was not corrected for CWP flexibility as it was already included in the simulation. Furthermore, the surge data was

5.4.2.1.2 Prediction of Motions and Loads for the Sphere Platform (Continued):

taken to be the largest value predicted, as opposed to the surge measured at the c.g. of the platform. The rationale here was to consider the worst case condition. In the case of the sphere, the draft-to-diameter ratio (T/D) is a critical parameter from a seakeeping point of view. The results given in Reference (52) indicate that a T/D = 0.8 gives the best performance. Most of the Gibbs & Cox, Inc. designs approach a value of 0.7 as shown by the dark points in Figures D-6 through D-10. As one would expect, the effect of T/D is more significant in the case of heave and pitch response, in particular, at the smaller platform displacements.

In the case of the CWP bending moment data shown in Figure D-10, it seemed meaningless to use these values as being representative of the loads experienced by the Gibbs & Cox, Inc. sphere/CWP configurations. This is because of the differences in material, CWP wall thickness and structural design as discussed previously. Consequently, it was decided to derive CWP bending moments for the sphere from the results of the dynamic analysis using the Garrison/Paulling model.

Figures D-6 through D-10 show the sphere motions and loads versus platform displacement for 40 foot significant wave heights. Figures D-11 through D-15 show the same data for 20 foot and 80 foot significant wave heights. For ranking purposes, a T/D of 0.8 was assumed instead of 0.7. This would require adding ballast to the designs described in Section 5.2.

5.4.2.1.3 Platform/CWP Motions and Loads as a Function of Sea State and OTEC Plant Output

The results obtained using the corrected Hydronautics and TSI predictions are contained in Figures D-16 through D-17. The following significant responses are presented as a function of significant wave height, plant output and platform configuration (see Section 5.2):

- Surge, feet
- Sway, feet
- Heave, feet
- Roll, degrees
- Pitch, degrees
- Yaw, degrees
- Vertical acceleration at the c.g., ft./sec.²
- Maximum CWP axial bending moment, ft.-lbs.

5.4.2.1.3 Platform/CWP Motions and Loads as a Function of Sea State and OTEC Plant Output (Continued):

All values are significant (average of highest one third) single amplitudes corresponding to twice the rms response if a Rayleigh distribution is assumed. The following is a summary of figures showing all results:

<u>Figure Numbers</u>	<u>Plant Output (Six Configurations)</u>
D-16 to D-23	100 MW
D-24 to D-31	200 MW
D-32 to D-39	350 MW
D-40 to D-47	500 MW

5.4.2.2 Motions and Loads Predictions Based on the Paulling Model (ATEC)

The purpose of using the Garrison/Paulling computer program was twofold. First, it was necessary to assess the validity of the methodology described in Section 5.4.2.1. Second, it was felt that the CWP dynamic response had to be addressed in order to emphasize the significant importance of its role in future design efforts.

The ATEC program and its preprocessors SHIPF and PLFOR were used to predict platform/CWP responses as a function of displacement, heading and sea state. Table 5.4-7 is a matrix of the cases considered. The CWP was considered to be 3,000 feet long with a constant thickness of 1.0 ft. The structural material was reinforced concrete with a Young's modulus of 3.5×10^6 psi. It is emphasized that the selection of CWP wall thickness is arbitrary as one would expect to conduct several simulations iteratively in order to arrive at an acceptable thickness as well as thickness distribution along the CWP. Furthermore, the CWP structural design would perhaps be varied based on initial simulations in order to account for the presence of excessive dynamic stresses at specific points along the length of the pipe.

As an example of the output of these simulations, Figures D-48 through D-53 show results for the 50 MW plants. Figures D-54 through D-59 give results for the 500 MW cases.

Static and dynamic stress distributions are given in Figures D-60 through D-95 covering the hurricane conditions in each of three sites (New Orleans, Hawaii, Key West), as follows:

TABLE 5.4-7

CASES SIMULATED USING THE PAULLING ATEC COMPUTER PROGRAM

<u>PLATFORM CONFIGURATION</u>	<u>OUTPUT MW</u>	<u>HEADING (DEGREES)</u>	<u>SIGNIFICANT (*) WAVE HEIGHTS, Ft.</u>
Ship	50	0, 45, 90	6, 8, 12, 16, 20, 35.9, 48.8, 58.1
	100		
	200		
	350		
	500		
Semi-Submersible	50	0, 45, 90	6, 8, 12, 16, 20, 35.9, 45.8, 58.1
	100		
	200		
	350		
	500		

(*) Significant wave heights for hurricane conditions at New Orleans, Hawaii and Key West sites were considered.

5.4.2.2 Motions and Loads Predictions Based on the Paulling Model (ATEC) (Continued):

<u>Figure</u>	<u>Configuration</u>	<u>Plant Output (MW)(Gross)</u>
D-60 through D-63	Ship	50
D-64 through D-67	Ship	200
D-68 through D-71	Ship	350
D-72 through D-75	Ship	500
D-76 through D-79	Semi-Submersible	50
D-80 through D-82	Semi-Submersible	100
D-84 through D-87	Semi-Submersible	200
D-88 through D-91	Semi-Submersible	350
D-92 through D-95	Semi-Submersible	500

5.4.2.3 Comparison Between Motions and Loads Prediction Methodologies

Motions predicted using the ATEC program were compared to the values derived from the Hydronautics simulations presented in Section 5.4.2.1. Figures D-54 through D-59 show this comparison for the 500 MW ship and semi-submersible platforms. In all cases the ATEC predictions are lower but the relative differences and trends do not change.

A comparison of maximum CWP bending moments between the corrected Hydronautics values and those predicted using the ATEC program was conducted. This was done for the case of the ship and semi-submersible platforms at different plant outputs. In the case of the ATEC values the bending moments were derived from the maximum dynamic bending stresses in each case. A comparison with the bending moments derived from the Hydronautics predictions reveals that the ATEC values are larger in all cases, but the order of magnitude is the same. The differences can be reconciled on the basis that the bending moments presented by Hydronautics in Reference (54) correspond to a CWP made of different structural material (aluminum and GRP), different wall thicknesses and different platform dimensions. To attempt to correct for the effect of CWP flexibility from such predictions would be highly unrealistic.

In summary, based on the comparisons of motions and loads between the two methods for the ship and semi-submersible, it was concluded that the results were consistent. Therefore, the ranking of the six candidate platform configurations can be carried out using the values given in Section 5.4.2.1. It is emphasized that the ship and the semi-submersible are at the high and low

5.4.2.3 Comparison Between Motions and Loads Prediction Methodologies (Continued): ends of the spectrum. This strengthens the argument for proceeding as indicated above for the remaining configurations.

5.4.3 Evaluation and Ranking

5.4.3.1 Methodology and Results

The quantitative evaluation of the six candidate platforms was conducted by normalizing the motions and loads results presented in Figures D-16 through D-47 of Appendix D. The normalization was conducted with respect to the minimum response predicted for given plant size, configuration, significant wave height and mode of motion (e.g., heave, surge, etc.). This implies that a value of 1.0 for a normalized response corresponds to the minimum, and as the value gets larger so does the response. This type of presentation allows for a straight-forward ranking of the candidates from a seakeeping standpoint and the results can be readily used as inputs to the overall evaluation discussed in Section 6.0 of this report.

Tables 5.4-8 through 5.4-11 give the normalized motions and loads for plants between 100 MW and 500 MW. Using these results the various candidate platforms were ranked for each plant output on the basis of specific overall normalized motions and CWP loads. The ranking is given in Table 5.4-12 based on minimum motions, minimum accelerations, and minimum peak CWP bending moments as a function of plant output. An estimated overall rank is also given assuming equal weight for all motions and loads.

From the point of view of motions (surge, heave, sway, pitch, roll, yaw) the semi-submersible is the best in the 100 MW and 200 MW cases while the sphere is the best in the 350 and 500 MW cases. The ship and the cylinder are at the bottom of the scale with the ship being better than the cylinder.

From the point of view of vertical accelerations, the spar, the sphere and the semi-submersible are in the upper three positions with very small differences between each. Again, the ship and cylinder are at the bottom. However, in all cases the levels of acceleration are not serious from human comfort and equipment loading standpoints.

A comparison of peak CWP bending moments places the semi-submersible at the top of the list in all cases. The submarine follows in the 200 to 350 MW

TABLE 5.4-8

NORMALIZED MOTIONS AND LOADS (1.0 = Minimum) 100 MW PLANT

RESPONSE	$\frac{H}{L/3}$	SHIP	SUBMER.	SEMI-SUBMER.	CYLINDER	SPAR	SPWEEZE
SURGE	20	2.7	1.2	1.0	3.0	1.9	4.4
	40	2.0	1.3	1.0	1.3	1.3	4.3
	80	1.7	1.4	1.0	1.4	1.4	3.2
SWAY	20	4.5	2.6	1.0	3.5	2.3	5.2
	40	2.7	2.0	1.0	2.4	2.0	5.5
	80	1.9	1.6	1.0	1.8	1.3	4.1
HEAVE	20	8.2	2.5	1.6	6.0	1.6	1.0
	40	4.8	2.1	1.9	4.8	1.6	1.0
	80	1.9	1.2	1.2	2.0	1.0	1.5
ROLL	20	3.3	1.0	1.8	6.4	3.0	2.8
	40	2.5	1.0	2.4	5.6	3.7	9.3
	80	2.1	1.0	3.0	5.2	3.9	7.6
PITCH	20	5.9	1.0	1.5	10.3	4.3	4.3
	40	2.9	1.0	1.6	3.7	2.4	5.9
	80	2.3	1.0	1.5	2.8	2.0	3.9
YAW	20	1.8	1.0	1.2	NOT APPLICABLE		
	40	1.8	1.2	1.0	NOT APPLICABLE		
	80	2.0	1.6	1.0	NOT APPLICABLE		
VERTICAL ACCEL.	20	2.5	1.2	1.4	1.8	1.0	1.2
	40	1.9	1.0	1.1	1.6	1.1	1.1
	80	1.6	1.1	1.0	1.5	1.1	1.1
MAX CWP	20	13.0	7.0	1.0	13.2	6.0	20.0
AXIAL	40	16.9	8.6	1.0	129.4	6.9	15.8
B.M. (X=0)	80	19.9	8.3	1.0	43.6	6.8	15.0

TABLE 5.4-9

NORMALIZED MOTIONS AND LOADS (1.0 = Minimum) 200 MW PLANT

RESPONSE	$\frac{E}{L^3}$	SHIP	SUMMER.	SEMI-SUMMER.	CYLINDER	SPAR	SPHERE
SURGE	20	3.5	1.0	1.2	5.7	2.3	4.3
	40	2.5	1.0	1.1	3.3	1.7	2.4
	80	2.0	1.0	1.1	2.5	1.5	1.9
SWAY	20	5.3	2.6	1.0	4.2	2.4	4.7
	40	3.2	2.0	1.0	2.9	2.2	3.2
	80	2.2	1.6	1.0	2.2	1.9	2.5
HEAVE	20	8.2	2.5	1.6	6.0	1.6	1.0
	40	12.3	4.4	4.1	12.3	3.3	1.0
	80	3.4	1.7	1.8	3.6	1.5	1.0
ROLL	20	4.1	1.0	2.1	8.7	3.5	2.2
	40	3.3	1.0	2.9	8.0	4.5	1.0
	80	2.7	1.0	3.5	6.5	4.6	1.1
PITCH	20	8.0	1.0	2.2	17.1	7.0	4.2
	40	5.2	1.4	3.2	8.2	4.6	1.0
	80	4.5	1.5	3.14	8.5	4.2	1.0
YAW	20	2.3	1.0	1.5	NOT APPLICABLE		
	40	1.8	1.0	1.0	NOT APPLICABLE		
	80	2.0	1.3	1.0	NOT APPLICABLE		
VERTICAL ACCEL.	20	3.0	1.2	1.1	2.0	1.1	1.0
	40	2.6	1.2	1.1	2.3	1.1	1.0
	80	1.9	1.2	1.0	1.9	1.2	1.0
MAX C/P AXIAL B.M. (K*O)	20	1.8	1.1	1.0	6.7	1.6	2.0
	40	2.1	1.3	1.0	5.9	1.7	1.8
	80	2.7	1.3	1.0	5.1	1.8	2.7

TABLE 5.4-10

NORMALIZED MOTIONS AND LOADS (1.0 = Minimum) 350 MW PLANT

RESPONSE	$\frac{Z}{L/3}$	SHIP	SUBMER.	SEMI-SUBMER.	CYLINDER	SPAR	SPHERE
SURGE	20	3.7	1.0	1.4	4.4	2.4	10.0
	40	2.6	1.0	1.3	2.5	1.3	2.4
	80	2.1	1.0	1.2	1.9	1.5	2.1
SWAY	20	5.3	2.5	1.0	4.2	2.3	9.4
	40	3.2	2.0	1.0	2.9	2.0	2.8
	80	2.2	1.6	1.0	2.2	1.8	2.4
HEAVE	20	12.6	3.7	2.3	8.7	1.9	1.0
	40	19.3	6.7	5.9	13.5	4.1	1.0
	80	5.2	2.6	2.5	5.2	1.8	1.0
ROLL	20	4.4	1.0	2.2	9.3	3.2	1.1
	40	6.8	2.0	5.8	16.9	7.9	1.0
	80	4.6	1.6	5.3	12.7	6.7	1.0
PITCH	20	8.8	1.0	2.8	21.3	7.4	2.5
	40	9.5	2.3	6.0	17.0	8.1	1.0
	80	7.7	2.3	5.6	12.9	6.9	1.0
YAW	20	2.3	1.0	1.6	NOT APPLICABLE		
	40	1.8	1.0	1.1	NOT APPLICABLE		
	80	1.9	1.2	1.0	NOT APPLICABLE		
VERTICAL ACCEL.	20	3.5	1.8	1.1	1.9	1.1	1.0
	40	3.6	1.8	1.2	3.1	1.0	1.3
	80	2.3	1.4	1.0	2.2	1.3	1.1
MAX CWP	20	2.2	1.3	1.0	8.0	2.8	2.1
AXIAL	40	2.6	1.5	1.0	7.0	3.0	1.8
B.M. (X=0)	80	3.3	1.6	1.0	6.0	3.2	3.1

TABLE 5.4-11

NORMALIZED MOTIONS AND LOADS (1.0 = Minimum) 500 MW PLANT

RESPONSE	$\frac{L}{L/3}$	SHIP	SUMMER.	SEMI-SUMMER.	CYLINDER	SPAR	SPHERE
SURGE	20	4.0	1.0	1.3	4.0	3.2	4.3
	40	2.3	1.0	1.4	3.4	2.3	3.2
	80	2.3	1.0	1.3	2.6	2.0	2.3
SWAY	20	3.4	2.4	1.0	3.0	2.7	3.7
	40	3.4	2.1	1.0	3.6	2.5	3.3
	80	2.4	1.7	1.0	2.7	2.1	3.0
HEAVE	20	36.0	17.8	9.5	39.9	9.0	1.0
	40	18.9	7.1	5.4	18.6	4.3	1.0
	80	5.3	2.8	2.4	5.4	1.9	1.0
ROLL	20	6.8	1.6	2.8	1.49	5.4	1.0
	40	7.8	2.4	5.5	19.8	9.9	1.0
	80	5.0	1.3	5.2	14.0	7.9	1.0
PITCH	20	6.1	1.8	1.5	15.4	5.4	1.0
	40	11.0	3.1	5.8	20.5	9.9	1.0
	80	8.4	2.9	5.1	14.6	7.9	1.0
YAW	20	2.2	1.0	1.5	NOT APPLICABLE		
	40	1.7	1.0	1.1	NOT APPLICABLE		
	80	1.8	1.2	1.0	NOT APPLICABLE		
VERTICAL ACCEL.	20	2.8	2.5	1.0	1.5	1.5	1.2
	40	1.6	2.1	1.0	3.3	1.0	1.5
	80	2.8	1.9	1.0	2.9	1.7	1.5
MAX CWP	20	2.3	1.7	1.0	7.4	1.8	1.8
AXIAL	40	2.7	2.0	1.0	6.5	1.9	1.5
B.M. (K-O)	80	3.5	2.1	1.0	5.6	2.0	2.5

TABLE 5.4-12

PLATFORM RANKING BASED ON MOTIONS, ACCELERATIONS AND CWP BENDING MOMENTS (*)

(*) The numbers in parenthesis are the average normalized motions in each case)

PLANT OUTPUT (MW)	PLATFORM TYPE	MOTIONS	ACCELERATIONS	CWP BENDING MOMENTS	OVERALL RANK
100	Ship	4 (3.10)	6 (2.00)	4 (15.6)	4 (4.52)
	Submarine	2 (1.54)	2 (1.10)	3 (7.97)	2 (2.29)
	Semi-Submersible	1 (1.43)	4 (1.17)	1 (1.0)	1 (1.34)
	Cylinder	5 (4.05)	5 (1.63)	6 (64.4)	6 (12.32)
	Spar	3 (2.46)	1 (1.07)	2 (6.57)	3 (2.35)
	Sphere	6 (4.37)	3 (1.13)	5 (16.93)	5 (5.7)
200	Ship	5 (4.25)	6 (2.5)	5 (2.20)	5 (3.78)
	Submarine	1 (1.56)	4 (1.2)	2 (1.23)	1 (1.47)
	Semi-Submersible	2 (1.91)	2 (1.07)	1 (1.0)	2 (1.69)
	Cylinder	6 (6.52)	5 (2.07)	6 (5.9)	6 (5.80)
	Spar	4 (3.13)	3 (1.13)	3 (1.7)	4 (2.64)
	Sphere	3 (2.17)	1 (1.0)	4 (2.17)	3 (2.0)
350	Ship	4 (5.61)	6 (3.10)	4 (2.70)	5 (4.94)
	Submarine	6 (19.70)	4 (1.67)	2 (1.47)	1 (1.87)
	Semi-Submersible	2 (2.75)	1 (1.10)	1 (1.0)	2 (2.33)
	Cylinder	5 (9.37)	5 (2.4)	6 (7.0)	6 (8.04)
	Spar	3 (3.99)	2 (1.13)	5 (3.0)	4 (3.44)
	Sphere	1 (2.64)	2 (1.13)	3 (2.33)	3 (2.39)
500	Ship	5 (8.40)	6 (3.07)	5 (2.83)	5 (7.05)
	Submarine	2 (1.99)	4 (2.50)	3 (1.93)	3 (2.30)
	Semi-Submersible	3 (2.95)	1 (1.0)	1 (1.0)	2 (2.46)
	Cylinder	6 (11.60)	5 (2.60)	6 (6.5)	6 (9.59)
	Spar	4 (5.09)	2 (1.40)	2 (1.90)	4 (4.11)
	Sphere	1 (1.95)	2 (1.40)	3 (1.93)	1 (1.39)

5.4.3.1 Methodology and Results (Continued):

range with the sphere being a close third in the 350 MW case and equal to the submarine in the 500 MW case. The spar is second in the 100 MW and 500 MW cases but drops to fifth place at 350 MW. The ship and cylinder are generally last, the ship being better than the cylinder. It is difficult to establish a ranking on the basis of CWP bending moment in view of the problems associated with CWP flexibility and the need to optimize the CWP design for each configuration. In general, it appears that the semi-submersible has the least CWP bending moment followed by the submarine, the sphere, the spar, the ship and the cylinder in that order.

An overall rank was computed based on all normalized motions and loads. The semi-submersible was the best for 100 MW; the submarine was the best for 200 MW and 350 MW while the sphere takes first place at 500 MW. In fact, with the exception of the 100 MW case, these three configurations placed consistently in the top three. For the 100 MW case the spar is better than the sphere. In fact, it was pointed out in Reference (52) that the smaller sizes are not advantageous for the sphere.

5.4.3.2 Observations on CWP Dynamic Response

The dynamic analysis of the CWP conducted during this phase of the study and reported in Section 5.4.2.2 was limited to the specific case of concrete pipes of constant diameter and thickness throughout their lengths and with no stiffening. The diameter increased as the plant output increased and the wall thickness was maintained constant at one foot regardless of platform size.

The dynamic response and structural design of the CWP is one of the most important technological problems to be solved by the OTEC program. The results presented in this report indicate that to assume a CWP of constant thickness, diameter, or even uniform material, throughout its length may not be realistic. For example, the dynamic bending stress distributions presented earlier for the case of the 1 foot thick concrete pipe indicate that a few more design iterations would have to be made in order to bring the stresses down to an acceptable level for concrete. This would probably require increasing the pipe thickness and stiffening in sections of the CWP where the peak dynamic stresses show up. Still the new design would have to be run through the computer to find out if the new configuration experiences other serious dynamic responses not seen in the first go-around.

5.4.3.2 Observations on CWP Dynamic Response (Continued):

The design of the CWP will have to account for stresses of various sources including buckling, fatigue and creep which will vary depending on platform displacement, configuration and CWP structural material. For example, Figures D-96 through D-98 give comparisons of dynamic vertical stresses as well as dynamic lateral and axial bending stresses for the 50 and 500 MW ships. It is clear that the location and magnitude of the peak stresses vary from one design to the next. Figures D-99 and D-100 compare the dynamic axial bending stresses for the 50 and 500 MW ship and semi-submersible. The semi-submersible experiences smaller stresses as one would expect based on seakeeping performance. Similar effects can only be studied and predicted by means of a systematic and careful dynamic analysis of the OTEC platform/CWP system. The end result would be an optimized CWP structural design for the platform under consideration.

5.4.3.3 Observations on Platform Motions

The other area of major concern is the power transmission cable which is subjected to loads resulting from platform displacements, velocities, and accelerations in addition to direct excitation from a seaway. At present, very little data concerning cable motion limits has been made available, but Reference (58) contains the results of some initial studies done by Simplex Wire and Cable Company. These studies only considered the effects of platform displacements (surge, sway, heave, yaw, and drift) and did not include the added loads resulting from hydrodynamic drag of the cable and inertial loads caused by platform accelerations.

At present, Simplex envisions the transmission cable will rise from the sea bottom to a buoy moored deeply enough to avoid the more significant wave effects, and from the buoy it will be led to a point on the hull of the OTEC Plant. The allowable motions envelope of the Plant is defined in terms of the depth of water beneath the buoy. Figure 5.4-1 depicts this arrangement and the motions envelope in the vertical and horizontal planes. Assuming a water

FIGURE 5.4-1

TRANSMISSION CABLE MOTIONS ENVELOPE

Motions Profile - Vertical Plane

Position	Max Heave
1.00 D	$\pm 0.01 D$
1.04 D	$\pm 0.10 D$
1.10 D	$\pm 0.15 D$
1.30 D	$\pm 0.12 D$
1.50 D	$\pm 0.06 D$
1.60 D	0

Motions Profile - Horizontal Plane

- Notes:
1. Drawings are not to scale
 2. Permissible yaw = $\pm 5^\circ$
 3. Assume $D = 3500$ ft

5.4.3.3 Observations on Platform Motions (Continued):

depth of approximately 4,000 feet, a reasonable figure for the sites under consideration, and also assuming that the buoy would be moored 500 feet below the surface, the permissible range of platform motions is well in excess of the values presented in Appendix D for the baseline Plants. In addition, the capabilities of the Positionkeeping Systems under consideration are within the bounds indicated by the above restrictions.

This does not mean that the cable motion restrictions disappear as an issue since, as mentioned above, the dynamic forces have not been dealt with. Given the probable low vertical accelerations of these large structures and the possible use of such techniques as cable fairings, these factors may not become critical, but it is essential that they be formally evaluated once the information becomes available.

5.4.3.4 Observations on Sea State Representation

The seakeeping characteristics of the various platforms considered for the OTEC commercial plant have been conducted using either Pierson-Moskowitz or Bretschneider spectra to represent the wave excitation. The work conducted by Hydronautics and reported in References (51), (52), (53), and (54) make use of the Pierson-Moskowitz spectrum while the results given in Section 5.4.2.2 using Paulling's ATEC program correspond to a Bretschneider spectrum.

The choice of a spectrum can have a considerable impact on the prediction of platform motions and loads. For example, Figure 5.4-2 shows a superposition of Bretschneider and Pierson-Moskowitz spectra for the same wind speed. Although the peak energies are almost the same, the shift in the frequency or period at which the peak occurs can be significant. This becomes more evident by inspecting Figure 5.4-3. The hurricane spectra was derived using the Bretschneider representation and it acts on the sphere heave Response Amplitude Operator (RAO) to give the total heave response shown at the bottom of the page. Had the Pierson-Moskowitz representation been used, the peak of the sea spectrum would have excited the RAO at a lower frequency. The end result would have been an increase in total heave response

Frequency $f = (\text{sec}^{-1})$	Spectral Density $S(f) = (\text{ft}^2 \text{ sec})$	Frequency $f = (\text{sec}^{-1})$	Spectral Density $S(f) = (\text{ft}^2 \text{ sec})$
0.058	1.07186	0.205	22.32007
0.060	12.70023	0.210	25.49676
0.065	13.95708	0.215	22.96211
0.070	54.62093	0.220	20.56244
0.075	139.72730	0.225	18.25215
0.080	224.98440	0.230	14.96224
0.085	297.99950	0.235	14.94928
0.090	343.97330	0.240	13.49546
0.095	367.01580	0.245	12.20575
0.100	375.74750	0.250	11.05944
0.105	368.95830	0.255	10.03864
0.110	323.00880	0.260	9.12772
0.115	292.67130	0.265	8.31331
0.120	261.30950	0.270	7.58385
0.125	230.97880	0.275	6.92928
0.130	202.81790	0.280	6.34083
0.135	177.34920	0.285	5.81100
0.140	154.71370	0.290	5.33306
0.145	134.82780	0.295	4.90125
0.150	117.49160	0.300	4.51051
0.155	102.45250	0.305	4.15434
0.160	89.44426	0.310	3.83491
0.165	78.20984	0.315	3.54271
0.170	68.51167	0.320	3.27670
0.175	60.13734	0.325	3.03422
0.180	52.90063	0.330	2.81257
0.185	46.63707	0.335	2.61056
0.190	41.20591	0.340	2.42540
0.195	36.49556	0.345	2.25573
0.200	32.49500	0.350	2.10007

FIGURE 5.4-2
 SEA SPECTRA COMPARISON

FIGURE 5.4-3

RESPONSE SPECTRUM GENERATION

5.4.3.4 Observations on Sea State Representation (Continued):

for the sphere. Reference (52) describes the marked effect of the choice of spectrum when representing the hurricane condition at different OTEC sites.

In view of these observations it appears when the prediction of motion and loads will be sensitive to the spectrum used to represent the seaway and careful attention should be given to its choice depending on the site under consideration.

5.4.3.5 Conclusions

An evaluation of the seakeeping characteristics of the six candidate platform configurations has been performed using two different methodologies. The following conclusions can be drawn:

- (1) The prediction of motions and CWP bending moments derived from the Hydronautics simulations reported in References (51) through (54) appears to be reasonable based on comparisons with results obtained using the ATEC program.
- (2) The ATEC program motion predictions yield smaller values of motion response for the ship and the semi-submersible. The relative differences between platforms, however, are consistent with the Hydronautics data in all six degrees of freedom.
- (3) The evaluation of platforms on the basis of overall motions and loads show the semi-submersible, the submarine and the sphere as being the most desirable followed by the spar, the ship and the cylinder.
- (4) The platform maximum vertical accelerations fall below 0.2g in all cases. When compared to human comfort criteria this would result in a very low percentage of crew motion sickness incidence. As the platform displacement increases the accelerations get smaller thus minimizing the problem.
- (5) CWP static and dynamic bending stresses vary significantly along the length of the pipe and are a function of platform displacement, configuration, sea state, CWP diameter, wall thickness, material and structural configuration. Preliminary simulations using the ATEC program indicate that a

5.4.3.5 Conclusions (Continued):

(5) (Continued):

realistic design could include variable wall thickness, pipe stiffening and even different materials throughout the length of the CWP.

(6) The choice of sea spectrum representation must be carefully done for each site as different spectra may lead to significant differences in the predicted response for the same wind speed.

(7) The most important seakeeping characteristics of OTEC platforms is not platform motion per se, but rather the bending moments and stresses induced on the CWP as a result of platform/CWP coupling and pipe structural characteristics.

A more complete evaluation of the six candidate platforms should include an optimization of the CWP design for each configuration leading to minimum stresses and costs of construction, with due consideration given to buckling, creep and fatigue loading. Having achieved this objective, one can then proceed to compare the seakeeping characteristics of the various platform candidates with their optimized CWP designs. Such optimization should include not only the effects of dynamic bending stresses induced by extreme sea states or hurricanes, but also the more frequently occurring lower stresses resulting from moderate seas. The latter could give rise to serious fatigue loading conditions.

5.5 Cost Benefit Analysis

This section applies the cost-benefit criteria developed in Task IIB (Section 3) to the baseline platform alternatives of Section 2 to assess trends in return on investment versus size, configuration, site, plant efficiency, utilization and risk.

5.5.1 Baseline Economic Evaluation

This section contains a brief discussion of the acquisition, operating, overhaul, facilities and salvage costs considered in the analysis. This discussion will be followed by presentation of the results which led to the choice of heat exchanger (titanium versus aluminum), hull type and plant size for each site. These results are presented for each of three cases: (1) A plant without an external transmission system connecting it to a land terminal, (2) a single hull/plant size/site combination with external transmission system, and (3) a 3,000 MW energy park concept. In all cases, a constant CWP wall thickness of 2 feet of reinforced concrete is used as a baseline.

The analysis used ten percent cost of capital as the baseline interest rate criterion. Section 5.5.3 discusses sensitivity of the results to the choice of interest rate.

5.5.1.1 Acquisition Costs

A preliminary analysis of the detailed breakdown of platform acquisition costs for various plant sizes reveals an important point for this analysis. The data extracted from Section 2 can be re-structured as shown in Tables 5.5-1 and 5.5-2 (using the ship hull as an example).

Notice that the hull is nominally less than 10 percent of the cost of the hull/power plant system, and the only component which exhibits significant economy of scale is the cold water pipe.

Notice also, that the cost of the power plant itself is approximately linear with the power plant size, based on numbers generated by Gibbs & Cox, Inc. and data provided by DOE. The cost of the cold water pipe varies with the square root of the power plant size given the assumptions made concerning the cold water pipe thickness. The support costs are small and nearly constant. The costs for the hull itself are nearly linear with plant size.

TABLE 5.5-1
DETAILED ACQUISITION COSTS (SHIP)

Cost Component	Variation with Plant Size (MW)	50MW	100MW	200MW	350MW	500MW
Power system, transmission system, pipes and pumps	Approximately linear	73.90	146.68	294.60	515.50	736.30
Cold Water Pipe	Proportional to $\sqrt{\text{MW}}$	36.79	49.61	70.61	92.61	108.54
Support Subsystems	Constant	3.5	3.5	3.5	3.5	3.5
Hull	Approximately linear	8.55	15.69	35.32	76.25	119.64
TOTAL		122.74	215.48	404.03	687.76	967.98

TABLE 5.5-2
DETAILED ACQUISITION COST PERCENTAGES (SHIP)

	50MW	100MW	200MW	350MW	500MW
POWER PLANT	60	68	73	75	76
COLD-WATER PIPE	30	23	17	13	11
SUPPORT	3	2	1	1	1
HULL	7	7	9	11	12
TOTAL	100	100	100	100	100

18351-10 (W-10,000)

5.5.1.2 Operating Costs

Differences in operating costs have an impact on hull selection where differences in support complexity or distance to shore vary. They are especially significant where the acquisition costs for different candidates are approximately the same.

5.5.1.3 Overhaul Costs

Overhaul costs and schedule are different depending on whether aluminum or titanium heat exchangers are used in the plant. Based on the assumptions of Section 4, the titanium heat exchanger plant overhaul would require \$80 million for a 3000 MW park. There is one overhaul at the 20th year for the titanium heat exchanger option. An entire plant would not necessarily be down, but each heat exchanger would be down only one month during the overhaul process. The analysis assumed the plant is down 1/12 of a year during the 20th year and that the overhaul cost is allocated on a per-megawatt basis. Therefore,

$$\frac{\text{Overhaul Costs}}{\text{MW}} = \frac{\$80 \times 10^6}{3000 \text{ MW}} = \$2.667 \times 10^4 / \text{MW}$$

and overhaul costs for each plant are:

	<u>SINGLE HULLS</u>					<u>ENERGY PARK</u>
	50 MW	100 MW	200 MW	350 MW	500 MW	
\$x10 ⁶	1.33	2.67	5.33	9.33	13.3	80.0

The aluminum heat exchanger plant overhaul requires \$400 million for a 3000 MW park. Three overhauls are required at the 10th, 20th, and 30th years in the 40-year life cycle. Each component plant in overhaul would be down one year. For simplified analysis the entire plant is considered down for a one year overhaul period. On a per-megawatt basis the cost is calculated as:

$$\frac{\text{Overhaul Cost}}{\text{MW}} = \frac{\$400 \times 10^6}{3000 \text{ MW}} = \$1.33 \times 10^5 / \text{MW}$$

and overhaul costs for each plant are as follows:

	<u>SINGLE HULLS</u>					<u>ENERGY PARK</u>
	50 MW	100 MW	200 MW	350 MW	500 MW	
\$x10 ⁶	6.67	13.3	26.7	46.7	66.7	400 MW

The above costs and assumptions are included in the FOM calculations.

5.5.1.4. Transmission System Costs

The cost of the transmission line from the ocean-based thermal power plant to a useable shore facility should be included as a factor in the choice of the best location. It is particularly important because its cost can be up to ten percent of the cost of the program, based on DOE initial unit cost estimates which were as high as \$250 per foot for power outputs of from 50 to 500 MW.

Table 5.5-3 shows the gross estimates for the three sites considered.

TABLE 5.5-3TRANSMISSION LINE COSTS (\$M)

<u>SITE</u>	<u>DISTANCE</u>	<u>COST @\$250/FT</u>
Hawaii	4 nautical miles	6.0
New Orleans	75 nautical miles	112.5
Key West	40 nautical miles + 130 statute miles land line or shallow water cable	231.6

In addition, a shore site interface is required which is estimated by DOE to be \$87M for a 3000 MW energy park, and it is proportional to plant size. Table 5.5-4 shows the power station interface costs for each plant size:

TABLE 5.5-4SHORE POWER STATION INTERFACE COSTS (ALL SITES) (\$M)

<u>SINGLE HULLS</u>					<u>ENERGY PARK</u>
50 MW	100 MW	200 MW	300 MW	500 MW	3000 MW
1.45	2.90	5.80	10.15	14.5	87.0

The next two tables, Table 5.5-5 and Table 5.5-6 combine the transmission line cost and the shore power station interface costs for the three sites for all five plant sizes and the 3,000 MW energy park. Table 5.5-5 displays total costs and Table 5.5-6 display costs per megawatt.

TABLE 5.5-5TOTAL TRANSMISSION SYSTEM COSTS (\$M)

	SINGLE HULLS					ENERGY PARK
	50MW	100MW	200MW	350MW	500MW	3000MW
HAWAII	7.45	8.90	11.80	16.15	20.5	93.0
NEW ORLEANS	113.95	115.40	118.3	122.65	127.0	199.5
KEY WEST	233.05	234.5	237.4	241.75	246.1	318.6

TABLE 5.5-6TOTAL TRANSMISSION SYSTEM COSTS PER MEGAWATT (\$M)

	SINGLE HULLS					ENERGY PARK
	50MW	100MW	200MW	350MW	500MW	3000MW
HAWAII	.149	.089	.059	.046	.041	.031
NEW ORLEANS	2.279	1.154	.592	.350	.254	.067
KEY WEST	4.661	2.345	1.187	.691	.492	.106

5.5.1.4 Transmission System Costs (Continued):

The above tables show the extreme penalties on single small power plants when the cost of linking up with shore facilities is included. At New Orleans, in the 50 MW case, the transmission system cost approximates the cost of the entire power plant itself. At Key West, at the same plant size, the transmission system is approximately twice the cost of the power plant. On the other hand, the economies of scale are significant as power plant size increases. Transmission system costs approximate ten to twenty percent of the single power plant cost at the 500 MW level at New Orleans and Key West. Economies of scale accrue for all candidates when the 3000 MW energy park is considered. When used in the FOM calculations, the transmission system costs are assumed evenly spent over the overall plant construction time.

5.5.1.5 Facility Costs

The costs for the improvement of existing shipyard facilities or construction of new facilities to build the large hulls have been estimated based on the average cost per unit area of the Offshore Power Systems facilities in Jacksonville, Florida and the area required to construct the most critical platform of a given size. These costs are tabulated in Table 5.5-7 on a total cost and cost per megawatt basis. The data for each plant size are applicable to all hull types.

TABLE 5.5-7

FACILITIES IMPROVEMENT COSTS (\$M)

	50 MW	100 MW	200 MW	350 MW	500 MW
Total Cost for one facility	60	110	200	300	400
Cost per MW	1.2	1.1	1.0	.857	.800
Number of years to build plants for 3000 MW park with one facility	80	45	15	15.7	12

It is apparent that the facilities improvement costs are significant as they approximate one-half the cost of the hull and power plant combined. Further,

5.5.1.5 Facility Costs (Continued):

it is apparent that multiple facilities will be required to produce energy parks on a timely basis. Additional facilities might be considered in sufficient quantity to produce a 3,000 MW park in six years. Estimates of these costs are indicated in Table 5.5-8.

TABLE 5.5-8

FACILITIES IMPROVEMENT COSTS REQUIRED TO CONSTRUCT
A 3,000 MW ENERGY PARK IN 6 YEARS (\$M)

	<u>50 MW</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
Total Cost	660 M	925 M	840 M	840 M	800 M
Cost per MW	.222	.275	.280	.280	.267

If a single plant were to be built, the facilities improvement costs should be charged against that plant along with the transmission system costs in order to evaluate the project as a whole. This assignment may make the single plant, even at the 500 MW size, not cost-effective. If a 3,000 MW energy park is built, the costs can be distributed among several component plants and may make the difference between an acceptable or unacceptable program.

From the FOM calculations, the facilities costs are assumed to be incurred evenly over the construction time of the first plant.

5.5.1.6 Salvage Costs

Little data is available on salvage costs. The probable least cost salvage action is to scuttle the plant after scavenging all useful material, though this could result in environmental problems. Salvage considerations include the possibility that the hull itself may last more than 40 years. In this case, the entire plant may be replaced within the hull itself, although this is unlikely. On the other hand, if titanium heat exchangers are used, the titanium might be recovered for use in other plants.

Using a discounted cost analysis means that the present value of the salvage cost incurred at year 40 will be very small compared to the present value of the investment expended in the first portion of the 40-year period. Therefore, omission of salvage costs has a negligible effect on individual FOM calculations and no impact on the relative preference ranking among alternatives.

5.5.1.7 Hull-Plant Size Selection

This section includes a set of graphical illustrations of the figures of merit plotted versus plant size for each hull type and site. The first set of figures corresponds to the case where transmission system and facilities improvement costs are not included. The second set is for the choice of hull, plant size, and location with the transmission system and facilities construction costs included. The third set is for the 3000 MW energy park concept with the transmission system and facilities cost included.

Each graph plots data from the corresponding data in Appendix E. Each graph includes plots of the figures of merit versus plant size for the six hull candidates for one of the three sites. Analogous figures are provided for interest rates other than 10 percent. The choices of hull type, plant sizes, and site location are made on the basis of the highest figures of merit and their trends with size. The graphs have been reduced in size and placed side by side on one page to facilitate comparison. The analysis will start with the issue of type of heat exchangers - aluminum versus titanium.

5.5.1.7.1 Choice of Heat Exchangers

Figures E-1 through E-6 are a set of FOM graphs for the aluminum heat exchanger case. Figures E-7 through E-12 are another set for the titanium heat exchanger case. One figure from each of these two sets representing the site at Hawaii is shown in Figure 5.5-1. This initial study was performed to select one heat exchanger tube material, thereby reducing the number of options by one half.

It is clear that the aluminum heat exchanger results in a higher FOM at both zero and ten percent cost of capital. Therefore, the aluminum heat exchanger will be more cost effective whether or not present value analysis is used because of the substantially lower initial costs. Tables 5.5-9 and 5.5-10 provide corresponding tabular data for three plant sizes for the three top hull shapes/ship, cylinder, sphere for both zero and ten percent discount rates. Note that the relative differences (on a percentage basis) in the FOMs increase as the interest rate increases, reflecting the reduced significance of higher aluminum overhaul costs in the out years.

FIGURE 5.5-1
REPRESENTATIVE FOM'S FOR HAWAII

FIGURE E-1

FIGURE E-7

FIGURE E-4

FIGURE E-10

TABLE 5.5-9

ALUMINUM AND TITANIUM HEAT EXCHANGER COMPARISONS (i=0%)

FOM - Aluminum Heat Exchangers

HULL	SITE*	200MW	350MW	500MW
SHIP	H	11.50	12.40	12.89
	N	11.01	11.86	12.16
	K	10.83	11.52	11.94
CYLINDER	H	11.45	12.38	13.32
	N	10.97	11.83	12.38
	K	11.20	11.46	11.97
SPHERE	H	10.44	11.62	12.86
	N	9.847	10.91	12.26
	K	9.757	10.82	12.00

FOM - Titanium Heat Exchangers

HULL	SITE	200MW	350MW	500MW
SHIP	H	10.96	11.69	11.96
	N	10.25	10.99	11.38
	K	10.17	10.84	11.07
CYLINDER	H	10.91	11.69	12.00
	N	10.40	10.98	11.41
	K	10.16	10.79	11.09
SPHERE	H	10.03	10.92	11.32
	N	9.437	10.24	10.63
	K	9.273	10.17	10.56

*Note: In all subsequent figures the following site designation apply - H = Hawaii, N = New Orleans, K = Key West.

TABLE 5.5-10ALUMINUM AND TITANIUM HEAT EXCHANGER COMPARISON (i=10%)

FOM - Aluminum Heat Exchangers

HULL	SITE	200MW	350MW	500MW
SHIP	H	3.839	3.955	3.957
	N	3.744	3.870	3.865
	K	3.640	3.753	3.751
CYLINDER	H	3.809	3.943	4.046
	N	3.724	3.959	3.934
	K	3.674	3.720	3.791
SPHERE	H	3.285	3.612	3.677
	N	3.167	3.479	3.579
	K	3.120	3.432	3.523

FOM - Titanium Heat Exchangers

HULL	SITE	200MW	350MW	500MW
SHIP	H	3.149	3.195	3.168
	N	3.001	3.116	3.112
	K	3.003	3.039	3.033
CYLINDER	H	3.130	3.195	3.201
	N	3.067	3.116	3.144
	K	2.998	3.039	3.057
SPHERE	H	2.762	2.996	3.003
	N	2.675	2.878	2.924
	K	2.636	2.848	2.898

5.5.1.7.2 Choice of Hulls/Plant Size Without Transmission System and Facilities Improvement Costs

With the choice of the aluminum heat exchangers, the number of graphs of concern is reduced to six to illuminate the choice of hull type and plant size for each site. The choice is a matter of choosing the maximum Figure Of Merit and its corresponding size. Figures E-4, E-5, and E-6 are reproduced in Figure 5.5-2 on one page for comparison. The figures show that for each site, the six alternative hulls have Figures Of Merit that are fairly constant in the range of from 200 to 500 MW. Three groups appear: The ship and cylinder comprising the top set, the sphere next, and the spar, semi-submersible, and submersible at the bottom of the ranking.

At the three locations, the ship and cylinder FOM curves are fairly flat for sizes greater than 200 MW. This suggests that the choice of size could range from about 200 MW to 500 MW with nearly the same benefit-cost relationship. Therefore, within this size range, the choice could be made based on other factors such as risk associated with very large platforms and/or inferior CWP load characteristics of certain platforms. For the case of the sphere, diminishing marginal returns for the Figure Of Merit begin to appear at about 350 MW.

The best locations are Hawaii and New Orleans. Key West alternatives exhibit lower FOM's because of the higher anchoring and positionkeeping costs required in that high current environment.

5.5.1.7.3 Choice of Hulls/Plant Size with Transmission System and Facilities Costs Included

Again, the choice is a matter of choosing the highest Figure Of Merit from among the candidates. Figures E-13 through E-18 present data for the three sites and for zero and 10 percent interest rates. Figures E-16, E-17, and E-18 are reproduced in Figure 5.5-3 for direct comparison of the ten percent discount rate. The curves show a slightly increasing FOM in the 200 - 500 MW range. The locations are ranked as Hawaii, New Orleans, and Key West again reflecting the higher transmission line and system costs at New Orleans and Key West.

FOM's, ALUMINUM HEAT EXCHANGERS. ($i = 10\%$)

FIGURE E-4

FIGURE E-5

FIGURE E-6

FOM's ALUMINUM HEAT EXCHANGERS (i = 10%) INCLUDING
TRANSMISSION SYSTEM AND FACILITIES IMPROVEMENT COSTS

FIGURE E-16

FIGURE E-17

FIGURE E-18

5.5.1.7.4 Choice of Hulls for a 3,000 MW Energy Park

The 3,000 MW park concept will reduce average unit costs through the allocation of developmental costs, external transmission system costs, and facilities improvement costs over all the component plants. The analysis assumes additional plants cost the same to build; have the same construction time and are constructed at the same time as the first plant. This assumption simplifies the calculations without significantly distorting the overall FOM and has the effect of equalizing the individual FOM for each component hull/power plant unit of the park. Figures E-19 through E-24 illustrate the results of the analysis for 10 percent and 0 percent discount rates. Figures E-22, E-23, and E-24 are reproduced in Figure 5.5-4 for comparative purposes for the ten percent discount rate.

From these figures, it is concluded that the ship and cylinder are the leading candidates at a ten percent cost of capital. The sphere is generally the next best candidate. The FOM is relatively independent of plant size above 200 MW, implying choices may be made totally on the basis of other factors such as the complexity in interconnecting a large number of small plants, the rate of production of plants, motions/cold water pipe interface, electrical requirements at the particular location, etc.

At zero cost of capital, by looking at Figures E-13 through E-15, it is concluded that the best of two candidates are the ship and the cylinder. At this unrealistic discount rate, the semi-submersible is better than the sphere because of the relationship between construction schedule and the interest rate.

For the 3,000 MW energy park, all sites exhibit approximately the same FOM. The sensitivity to site is less than the individual plant case, because the transmission system and facilities construction costs are allocated among a number (from 6 to 60) of component plants; however, the ranking order remains the same - Hawaii, followed by New Orleans, and Key West.

FOM's, 3000 MW PARK ALUMINUM HEAT EXCHANGERS ($i = 10\%$)

INCLUDING TRANSMISSION SYSTEM AND FACILITIES IMPROVEMENT COSTS

FIGURE E-22

FIGURE E-23

FIGURE E-24

5.5.2 Risk Assessment

The cost and schedule estimates used in the evaluation reflect the "best engineering estimates" of acquisition cost, operating cost, and construction schedule commensurate with the level of technical detail developed to date. It must be concluded that these cost and schedule estimates are, at best, first order approximates of ultimate program costs. Unfortunately, such rough estimates must often support major program decisions. In the case of the OTEC Commercial Plant studies, these first-order estimates will form the basis of the decision on optimum Plant size and configuration.

Based on historical precedent, it can be assumed that the first order estimates evaluated previously will necessarily increase due to a number of factors related to uncertainty and risk. Despite the best efforts of the estimator, there are invariably a number of factors which perturb initial estimates, such as:

- Inflation
- Greater R&D cost than anticipated in order to achieve an acceptable level of risk
- Inability to accurately anticipate all start-up costs
- Overly optimistic cost estimates
- Program delay and disruption to incorporate cost changes and to suit available funding
- Labor disputes, material shortages, late delivery of Government or vendor furnished equipment
- Unanticipated operational requirements and complexities resulting in increased maintenance and operational costs
- Unanticipated hazards, causing higher insurance costs
- Acts of God

The list of factors which can invalidate initial cost estimates is virtually endless, and any attempt to quantify them at this stage is not only difficult, but nearly meaningless. Nonetheless, risk must be considered, if only as a means of justifying the elimination of obvious high-risk candidates which would appear equal in cost-benefit to lower risk candidates.

5.5.2 Risk Assessment (Continued):

In order to accomplish this task, a qualitative risk weighting system was evolved based on the Work Breakdown Structure proposed in Section 1. In order to reduce the scope of this effort, only two Plant sizes were considered, 100 and 500 MW, on the assumption that a nearly linear relationship in risk existed between (and beyond) these limits, since both plant physical characteristics and costs exhibited linear characteristics. Thus, the assessment of risk reduced to 36 candidates: 6 hull shapes, 2 sizes, and 3 sites.

A risk weighting criteria was next developed which rated risk between one (very high risk) and ten (essentially no risk) as shown on Table 5.5-11. In this table, the categories of "major", "moderate" and "minor" correspond to the initial risk assessment reflected in the evaluation of technical risk in Task III of this study, Section 4. However, for the current studies, these three categories are further subdivided.

The criteria of Table 5.5-11 were next applied to each third level element of the WBS. In order to minimize the potential introduction of personal prejudices or preconceived conclusions by the evaluators, key personnel from each of the four members of the Gibbs & Cox, Inc. team were asked to perform an independent risk assessment, reflecting their personal perspective of the relative criticality of risk in each case. These results were then normalized, as indicated in Appendix F. It is interesting to note that, in all but a few cases, the agreement among individual investigators was quite close.

The final step in assessing the risk of the OTEC candidates involved an overall weighting, whereby each element of the evaluation matrix was assigned a maximum weight, and the actual weight was derived by multiplying the maximum by the risk factor expressed as a percentage. The summation of such weighted element factors was the overall ranking of the candidate in terms of risk. Table 5.5-12 presents the summary risk assessment for the New Orleans site. The corresponding assessments for the other two sites (Key West and Hawaii) would not differ appreciably, since Appendix F indicates relatively little difference between site rankings. The reason for this is that, while the differences in motion and positionkeeping characteristics may vary significantly between sites, the ability to predict and account for such differences and the associated risks are not greatly different. Based on this, it is considered reasonable to consider the quantification

TABLE 5.5-11
OTEC TECHNICAL RISK CRITERIA

High Risk	1.	Technology is non-existent and cannot be satisfactorily developed within the time frame of the OTEC program.
	2.	Technology is very limited, and massive R&D efforts would be required, with high risk.
	3.	Technology is limited, and extensive R&D programs required to solve the problem represent a relatively high risk.
Moderate Risk	4.	Technology is marginally well developed but cannot be applied to offshore environment or to large OTEC platforms without extensive R&D, with moderate risk.
	5.	Technology is well developed and verified, but cannot be applied to offshore environment or to large OTEC platforms without nominal R&D programs of moderate risk.
	6.	Technology is well developed and verified by limited offshore experience, but not to large floating platforms.
	7.	Existing technology can be extended to OTEC platforms by application of nominal low-risk R&D.
Low Risk	8.	Existing technology can be extended to OTEC platforms with relatively little R&D, requiring no testing.
	9.	Existing technology requires little R&D and no testing to be extended to OTEC platforms.
	10.	Existing technology is fully adequate for use in OTEC platforms with no additional development.

TABLE 5.5-12

RISK ASSESSMENT - NEW ORLEANS SITE

		SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
	MAX WT	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
HULL SYSTEMS	20	10	9	13	12	8	7	8	7	11	10	12	11
Structures	10	6	5	6	5	4	3	4	3	4	3	6	5
Arrangements	2	2	2	2	2	1	1	1	1	2	2	2	2
Motions	8	2	2	5	5	3	3	3	3	5	5	4	4
SEAWATER SYSTEMS	35	10	10	10	10	14	14	12	12	12	12	10	10
Cold Water	27	6	6	6	6	10	10	8	8	8	8	5	6
Warm Water	6	3	3	3	3	3	3	3	3	3	3	3	3
Interference	2	1	1	1	1	1	1	1	1	1	1	1	1
POSITION CONTROL SYST	15	8	6	9	7	9	7	9	7	8	6	9	7
Static	10	6	5	6	5	6	5	6	5	6	5	6	5
Dynamic	5	2	1	3	2	3	2	3	2	2	1	3	2
SUPPORT SYSTEMS	5	5	5	5	5	5	5	5	5	5	5	5	5
Mech/Elect	1	1	1	1	1	1	1	1	1	1	1	1	1
Environ. Cont	1	1	1	1	1	1	1	1	1	1	1	1	1
Personnel Suppt	1	1	1	1	1	1	1	1	1	1	1	1	1
Life Saving	1	1	1	1	1	1	1	1	1	1	1	1	1
Platform Suppt	1	1	1	1	1	1	1	1	1	1	1	1	1
Mat'l Handling	0												
Nav, Comm	0												
SYSTEMS ENGINEERING	25	13	10	17	15	12	10	11	9	16	14	15	12
Cost Anal	10	5	4	7	6	5	5	5	4	7	6	6	5
Syst Reqmt	12	6	5	8	7	5	4	5	4	7	6	7	6
Admin Reqmt	3	2	1	2	2	1	1	1	1	2	2	2	1
TOTAL	100	46	40	54	49	48	43	45	40	52	47	51	45

Note: Assessment for Key West, Hawaii considered similar

5.5.2 Risk Assessment (Continued):

of risk to be relatively independent of site.

The overall risk assessment shown in Table 5.5-12 indicates that the difference in risk among candidates is not great, with the smaller platforms nearer the State-Of-the-Art exhibiting the lowest risk. The greatest difference in risk factor, between the 500 MW sphere or submarine and the 100 MW ship, is only about 35 percent. The reason for this is that the major element of risk, the CWP, represents an unknown in all cases, which can be normalized to a great degree by the use of a flexible connection. Other elements which exhibit variations in risk tend to be normalized by the overall weighting process such that, in the overall context, there is not as great a difference in risk between candidates as might be expected when each element is considered independently.

The final aspect of the risk assessment sensitivity studies is to convert the risk factors in Table 5.5-12 to equivalent cost growths. This is by far the most difficult and subjective part of the evaluation in that the relationship between risk and cost growth is virtually impossible to quantify with any degree of confidence. Projects which would initially appear to be highly risky have been completed within original budgets, while supposedly low-risk projects have overrun by factors of 3 or more. A further complication is introduced by inflation. Failure to properly predict inflationary trends or schedule slippage can both result in cost increases due to inflation alone. Since these studies are based on constant 1977 dollars, it is important to normalize all historical data on cost overruns by eliminating inflation, which is a very difficult, time-consuming task. For the purposes of this study, the following risk/cost overrun factors are proposed, assuming no inflationary influences:

- (1) For the very low risk end, corresponding to a risk criteria factor in Table 5.5-11 of 8 to 10, a cost overrun of 10 to 20 percent is appropriate, based on typical data on commercial tankers and cargo ships.
- (2) For the very high risk end, corresponding to a risk factor of 2 to 3 in Table 5.5-11, an overrun of between 200 and 250 percent is not uncommon, based upon limited return data on recent large offshore concrete storage structures (EKOFISK, etc.).
- (3) For the moderate risk range, corresponding to a risk of between 4 to 7, the overall trends of recent Government

5.5.2 Risk Assessment (Continued):

(3) (Continued):

projects are considered appropriate. Recent Government Accounting Office studies indicate an overall cost overrun of between 40 to 100 percent, with an average of about 70 percent.

Combining the foregoing, the risk/overrun curve of Figure 5.5-5 results, where risk criteria of one to 10 are multiplied by a factor of 10 to obtain weighting factors corresponding to Table 5.5-12.

FIGURE 5.5-5
RISK FACTOR VS. COST OVERRUN

The resultant projected cost overruns for the candidate OTEC Commercial Plant, relative to today's best engineering cost estimates, vary from about 70 percent at the low risk end to 120 percent at the high risk end.

The reciprocal of these potential cost increases can be considered to be the level of confidence which we have in the FOM's derived previously, reflecting both the probability of business and technical success. For potential cost overruns of between 70 and 120 percent (cost multipliers of 1.70 and 2.20) the resultant risk factors vary from 0.45 to 0.60.

5.5.2 Risk Assessment (Continued):

In order to incorporate this risk assessment into the cost-benefit analysis, it is possible to develop an alternative formulation for the Figure Of Merit. For a more detailed discussion of this type of approach to R&D project selection, see Reference (59).

Let,

$$FOM^1 = (P_{BS} \times P_{TS}) \times FOM$$

where,

$$FOM^1 = \text{Risk-Impacted FOM}$$

$$P_{BS} = \text{Probability of Business Success}$$

$$P_{TS} = \text{Probability of Technical Success}$$

This formulation facilitates transformation of the FOM in order to reflect risk via modifications to the cost estimates in accordance with the preceeding discussion. This transformation can be used to demonstrate the sensitivity of FOM to risk.

The technical factors considered indicate moderate technical risk in the OTEC program for all hulls and plant sizes, requiring extensive research and development to mitigate uncertainty in key technology areas. It is suggested that the combination of technical and business risk is in the range of .45 to .60 probability range. This risk probability would reduce the FOM to a level between 45 and 60 percent of the baseline values. The implications are that unplanned schedule delays and variances in cost estimates might reduce the benefit below acceptable levels.

The process of reducing the FOM by a risk probability factor can be applied to any of the candidate hulls. This analysis can be performed to demonstrate the sensitivity of the discount rate, FOM, and cost per MW relationships to risk. Specific risk factors and risk sensitivity are discussed in Section 5.5.3

5.5.3 Sensitivity Analysis

The figures in this section of the analysis show the relationships between cost of capital and FOM for various levels of risk for all hull type/plant size/site combinations. The analysis also shows the impact of lower plant utilization rates and plant efficiency, and various combinations of these three factors.

5.5.3.1 Plant Utilization

Plant utilization can be incorporated into the cost benefit analysis by again modifying the formulation of the Figure Of Merit.

Let,

$$FOM_2 = (P_{BS} \times P_{TS}) \times U \times FOM$$

when,

$$FOM_2 = \text{Risk and utilization impacted FOM}$$

$$U = \text{Utilization factor as a fraction of 1.}$$

This formulation facilitates modification of the FOM to demonstrate sensitivity to utilization. The Top Level Requirement, Reference (1), requires a utilization of .90. However, other factors might be assumed in subsequent sections of this analysis.

5.5.3.2 Plant Efficiency

It was noted earlier, that all of the baseline cost factors derived thus far have been based on gross output of the power modules, with no reduction for parasitic loads. Studies during Task II, Section 2, as well as other earlier studies by other investigators, indicate that such loads may amount to as much as 30 to 40 percent of gross plant output, resulting in net generating efficiencies of between 60 and 70 percent. This factor is considered in conjunction with risk and plant utilization factors in Section 5.5.3.3.

5.5.3.3 Interest Rate, Plant Utilization and Risk Sensitivity

The following sub-sections discuss the sensitivity of interest rate, plant utilization, plant efficiency and facilities for the single plant without transmission line, the single plant with transmission line and facilities improvements, and the 3,000 MW electric park with transmission line and facilities. It must be understood that all cost figures for the OTEC Plants presented herein are extremely "soft", therefore the figures in this section are for illustrative purposes only.

For the purpose of these sensitivity studies, a set of baseline (solid) curves of FOM versus percent interest are presented, Figures 5.5-6 through 5.5-9, for typical cases of interest. These represent FOM's for zero risk, 100 percent utilization, and 100 percent efficiency, which are obviously optimistic. Therefore, a series of dashed curves are presented which represent reductions in the optimistic curves of 40, 60 and 80 percent. This reduction could be made up of risk, plant underutilization, plant inefficiency or a combination of these factors.

5.5.3.4.1 The Single Plant Without Transmission and Facilities Improvement Costs

Figure 5.5-6 shows the FOM plotted versus interest rates for selected single plant sizes (without transmission line and facilities improvements) at the three sites. As an example, entering the graph at 10 percent interest leads to a maximum (optimistic) FOM of 4.0 for the Hawaii/350 MW case.

The figure can be used to demonstrate the impact of risk utilization and efficiency. Assuming a risk factor of 0.75, plant utilization of 0.95 and a plant efficiency of 0.70, the total reduction factor is 0.50. At 10 percent interest, the FOM is reduced to about 2.2. Application of a risk/utilization/efficiency factor less than 0.5 would further reduce the FOM, resulting in a higher cost to produce electricity. Figure 5.5-7 shows the same type of relationship for a 350 MW sphere. The results indicate that risk can have a crucial impact on the economic viability of the plant.

FIGURE 5.5-6

FIGURE 5.5-7

18351-10 (W-10,000)

5.5.3.4.2 The Single Plant with Transmission System and Facilities Improvement

From data displayed in Section 5.5.1 it might be deduced that the economic viability of a single plant was not extremely favorable. The costs of the transmission line and system, as well as the cost for facilities modification and construction are large compared to the cost of the hull plant at all sizes.

Figures E-25 and E-26 show the results of the inclusion of these large costs for the ship and sphere. Figure E-25 is shown below as Figure 5.5-8 for easy reference.

5.5.3.4.3 The 3,000 MW Electric Park with Transmission Lines and Facilities Costs Included

Figures E-29 and E-30 represent the results of the analysis for the 3,000 MW energy park. These results are similar to the single plant without transmission line and facilities because these add-ons are shared and their impact is reduced. Figure E-29 is reproduced below as Figure 5.5-9. The FOM for the 350 MW ship case varies from 3.7 down to 1.8 for the risk/utilization/efficiency factor of 0.5 at a 10 percent discount rate.

5.5.3.5 Learning Curve

The plant acquisition costs developed in Section 5.3 of this Volume were based on procurement of a sufficient number of identical units that such costs would have stabilized, i.e., there would be no further reductions based on production efficiency. This recognizes that the cost of the prototype unit would be far higher due to traditional start-up problems and construction inefficiencies. This effect is referred to as a "learning curve", and for most marine systems tends to stabilize after about 5 to 10 units, depending on their relative complexity.

For the OTEC platforms, learning curve effects have been neglected. The largest portion of the acquisition cost (60-70%) is the 25 MW power modules which, for the plants in the range of interest (200 - 500 MW), would have to be procured in quantities of 8 to 20 units for each plant. Thus, the learning

FIGURE 5.5-8

FIGURE 5.5-9

5.5.3.5 Learning Curve (Continued):

curve for this most expensive portion of the plant is not a factor. Applying a liberal learning curve factor of perhaps 20 percent to the remaining acquisition costs results in an overall increase of less than 10 percent for the prototype plant relative to production units.

5.5.4 Conclusions

The following conclusions are derived from the foregoing cost function and cost-benefit analysis. Costs of capital between zero and 15 percent were considered with 10 percent as the baseline for the results presented:

- OTEC plants with aluminum heat exchangers are more cost effective than those with titanium heat exchangers for cost of capital ranging from zero to 15 percent.
- The relative ranking of candidates does not change with variations in discount rate when schedules are the same. Higher discount rates favor candidates with shorter schedules.
- The ship and the cylinder are the preferred hull candidates at all sites. They are nearly the same on a benefit-cost basis over the 200 - 500 MW range based on a 10 percent discount rate.
- The sphere is the third ranking candidate at a 10 percent cost of capital. The semi-submersible is the third ranking candidate at zero percent cost of capital.
- Alternative uses for the single plant should be considered.
- The energy park concept appears more economically viable than a single plant due primarily to the transmission lines and shore interface system costs.
- The energy park concept appears more viable with a small number of large hulls because of the greater complexity of a large number of small hulls in the park.

5.6 Influence of CWP Thickness Variations

5.6.1 Introduction

The foregoing cost/benefit analysis reflects acquisition costs which are based on a uniform CWP wall thickness of two (2) feet of reinforced concrete for all options. This assumption was based on the discussion in Section 5.4, which indicated that much of the influence of platform motions on CWP bending moments could be mitigated by the proper tuning of CWP and platform in such areas as CWP materials, configuration, flexibility, and attachment point. However, it was impossible to properly address these variables during Task IV due to the large number of platform options being considered. In addition, it was necessary to consider motions in parallel with the cost/benefit analysis due to scheduling constraints, so that the results of the motion studies were not available in time to be properly integrated directly into the cost/benefit studies.

Nonetheless, it is considered essential to attempt to quantify the relationship between platform motions and CWP cost, and to develop an overall ranking of candidates by site, size, and configuration. The supplemental studies described in this Section were undertaken to accomplish this goal. The scope of this effort includes the following phases:

- (1) Assessment of CWP stress/cost relationships.
- (2) Modifying baseline FOM's to reflect these relationships as well as realistic values of risk, plant efficiency, and utilization:
- (3) Ranking of candidates in descending order of merit.

5.6.2 CWP Stress/Cost Relationships

In Section 5.4, data was presented on CWP stress profiles for both the ship and semi-submersible at three sites and sizes from 50 to 500 MW. These data, presented in Figures D-60 through D-100, are summarized in Table 5.6-1 for both zero and 90 degree headings. All of the stresses are based on a concrete CWP with an assumed wall thickness of one foot, versus the two feet reflected in the previous cost studies.

TABLE 5.6-1

CWP DYNAMIC BENDING STRESSES*, KSI

		SHIP		SEMI-SUBMERSIBLE		RATIO - $\frac{\text{Ship}}{\text{Semi-Sub.}} (0^\circ)$	
	MW	0°	90°	0°	90°	Paulling	Hydronautics**
NEW ORLEANS	50	5.1	4.7	1.8	0.7	2.83	-----
	100	---	---	12.2	6.2	-----	19.0
	200	6.6	9.5	2.9	3.2	2.28	2.74
	350	4.4	8.5	3.9	1.3	1.13	2.88
	500	6.5	6.6	3.3	---	1.97	3.01
KEY WEST	50	4.5	4.1	1.7	0.4	2.65	-----
	100	---	---	11.8	6.2	-----	18.0
	200	5.2	6.9	1.9	3.1	2.74	2.20
	350	3.6	6.8	3.4	1.3	1.05	2.66
	500	5.6	5.7	2.8	---	2.00	2.83
HAWAII	50	3.7	3.4	1.4	0.3	2.64	-----
	100	---	---	10.7	5.4	-----	17.0
	200	4.1	5.2	1.3	2.8	3.15	2.08
	350	2.7	5.1	2.6	1.2	1.04	2.56
	500	4.4	4.4	2.4	---	1.83	2.74

*For one foot wall thickness, derived from Figures D-60 through D-100.

**Figures D-23, D-31, D-39, D-47.

5.6.2 CWP Stress/Cost Relationships (Continued):

There are several significant conclusions to be drawn from Table 5.6-1:

- (1) There is no linearity in stress change with platform size. Rather, the stress patterns change randomly with size and heading to suit the interaction between sea spectra definition, platform geometry and CWP diameter.
- (2) The very high stresses for the 100 MW semi-submersible cannot be explained without further study, but are considered an anomaly and are ignored for the purposes of this study.
- (3) The ratio between stresses at Hawaii and New Orleans varies between 0.45 and 0.92, though most of the ratios are in the range of 0.60 to 0.66. Data for Key West is approximately midway between that for New Orleans and Hawaii.
- (4) The one-foot wall thickness results in excessive stresses in most cases. Assuming an allowable stress of 2.0 KSI, it is apparent that a wall thickness of about 2 feet is required for the larger semi-submersibles at New Orleans, with proportionately smaller thicknesses at other sites. Since changes in wall thickness will result in changes in CWP stiffness and resultant bending moments, it is not possible to predict the precise change in CWP stresses corresponding to a thickness of 2 feet. However, for the purposes of this study, it will be assumed that a 2 foot wall thickness will suffice for 350 and 500 MW semi-submersibles located at New Orleans, with a one foot thickness adequate for 50 MW and 1½ foot for 100 and 200 MW semi-submersibles respectively.

Relative to other plant configurations, Table 5.6-1 indicates that the ratio between ship and semi-submersible stresses resulting from the Paulling and Hydronautics programs are not consistent. In general, the Hydronautics data indicates higher ratios. Unfortunately, funding limitations precluded the use

5.6.2 CWP Stress/Cost Relationships (Continued):

of the Paulling program for other shapes, though there is complete data from the Hydronautics program. In order to get around this problem, it has been assumed that the ratios in bending moments resulting from the use of the Hydronautics program are valid, and can be applied to the baseline CWP thicknesses for the semi-submersible proposed in Item 4 above. This is considered to be a generally conservative approach, and results in the CWP wall thicknesses indicated in Table 5.6-2. This table indicates the relative bending moments for New Orleans based upon Table 5.4-12. Relative moments for other sites are proportioned based upon the following assumptions in all cases:

$$BM_{\text{Key West}} = BM_{\text{New Orleans}} \times 0.8$$

$$BM_{\text{Hawaii}} = BM_{\text{New Orleans}} \times 0.6$$

A minimum thickness of one foot has been assumed throughout to suit fabrication considerations. It is noted that this procedure assumes a "brute force" approach to the CWP problem by simply adding more material in proportion to relative bending moment. This is considered highly conservative since proper engineering can result in a significant improvement through the tuning of the platform and CWP, and in the introduction of flexibility into the CWP system.

Some of the thicknesses resulting from this methodology are obviously unrealistic, particularly for the 100 MW plants. For example, a wall thickness of about 64 feet would be required for the 100 MW cylinder, which implies that the methodology is invalid in this case. This results from a very sharp drop in the magnitude of the 100 MW semi-submersible moments in the Hydronautics data which would theoretically permit wall thicknesses of about 2 - 3 inches, which is totally inconsistent with the Paulling data. For the purposes of this analysis, thicknesses for 100 MW ship CWP has been averaged between those indicated for 50 MW ship and 200 MW ship in the Paulling data to establish a reference point. Other thicknesses were ratioed up or down on the basis of relative bending moment.

TABLE 5.6-2
CWP WALL THICKNESSES (FT) FOR
MODIFIED F.O.M.

	Site*	100 MW		200 MW		350 MW		500 MW	
		Rel BM	T	Rel BM	T	Rel BM	T	Rel BM	T
Ship	NO	16.60	2.5	2.20	3.3	2.70	5.4	2.83	5.7
	KW	13.28	2.0	1.76	2.6	2.16	4.3	2.26	4.5
	H	9.96	1.5	1.32	2.8	1.62	3.2	1.70	3.4
Cylinder	NO	64.4	10.0	5.90	8.9	7.00	14.0	6.50	11.0
	KW	51.52	8.0	4.72	7.1	5.60	11.2	5.20	10.4
	H ₂	38.64	6.0	3.54	5.3	4.20	8.4	3.90	7.8
Spar	NO	6.57	1.0	1.70	2.6	3.00	6.0	1.90	3.8
	KW	5.26	1.0	1.36	2.0	2.40	4.8	1.52	3.0
	H	3.94	1.0	1.02	1.5	1.80	3.6	1.14	2.3
Sub	NO	7.97	1.2	1.23	1.8	1.47	2.9	1.93	3.9
	KW	6.38	1.0	0.98	1.5	1.18	2.4	1.54	3.1
	H	4.78	1.0	0.74	1.1	0.88	1.8	1.16	2.3
Semi-Sub	NO	1.00	1.00	1.00	1.5	1.00	2.0	1.00	2.0
	KW	0.80	1.00	0.30	1.2	0.80	1.6	0.80	1.6
	H	0.60	1.00	0.60	1.0	0.60	1.2	0.60	1.2
Sphere	NO	16.93	2.5	2.17	3.3	2.33	4.6	1.93	3.9
	KW	13.54	2.0	1.74	2.6	1.86	3.7	1.54	3.1
	H	10.16	1.5	1.30	2.0	1.40	2.8	1.16	2.3

* NO = New Orleans KW = Key West H = Hawaii

5.6.3 Modified Figures Of Merit

The Figures Of Merit indicated in Appendix E were used as a basis for this reanalysis. These FOM's reflect aluminum heat exchangers, no transmission system costs and a 10 percent interest rate. The studies in Section 5.5 indicated that other assumptions would modify the absolute values of the FOM, but that the relative trends would remain unchanged. Therefore, the conclusions derived from this reanalysis are considered valid even if the interest rate is changed or transmission system costs are added.

These baseline FOM's were modified for this reanalysis by multiplying by the following factors:

- (1) 0.90 to reflect an assumed plant utilization of 90%
- (2) 0.65 to reflect an assumed plant efficiency of 65%
i.e., parasitic losses of 35 percent.
- (3) An acquisition cost modified to reflect changes in
CWP acquisition cost, as defined below.
- (4) A risk modifier as defined below.

The acquisition cost modifier was derived on the basis of all baseline cost estimates (Tables C-7 through C-12) reflecting a 2 foot thick CWP. This was accomplished by reducing or increasing the CWP construction costs by the ratio of thickness from Table 5.6-2 to 2 feet. Over half of the total CWP acquisition costs in Tables C-7 through C-12 reflected tooling, deployment and attachment, which would not change appreciably with thickness. Therefore, only half of the CWP acquisition cost was adjusted for thickness.

The risk modifiers were derived from Table 5.5-12 and Figure 5.5-5 by assuming that a risk factor of 40 corresponds to a cost overrun of 120 percent and a factor of 54 corresponds to a cost overrun of 70 percent. The risk modifiers were the reciprocals of these percentages, i.e., 0.45 for high risk platforms, and 0.60 for low risk platforms. However, such factors are not considered appropriate to the Power System or Transmission System which account for between 30 and 45 percent of acquisition costs, since the relative risk of such systems is beyond the scope of these studies and is essentially constant for all platform configurations.

5.6.3 Modified Figures Of Merit (Continued):

Therefore, the risk modifiers were adjusted accordingly so that the Power and Transmission Systems were not penalized. This was accomplished by applying the risk modifier only to the Hull, Seawater, Positionkeeping, Support and Engineering/Miscellaneous costs indicated in Table C-7 through C-12, and modifying the baseline CWP costs as follows:

$$\$CWP_{MOD} = \left[\frac{\$CWP_B}{2} + \frac{T^1}{2} \times \frac{\$CWP_B}{2} \right] R$$

where: $\$CWP_{MOD}$ = Modified CWP Cost, \$M

$\$CWP_B$ = Baseline CWP Cost, \$M

T^1 = Modified CWP Thickness, Table 5.6-2

R = Risk Modifier

The modified acquisition costs are indicated in Tables G-1 through G-6 in Appendix G. Figure 5.6-1 illustrates these costs graphically. Figure 5.6-2 illustrates typical trends in relative acquisition cost breakdown.

Table 5.6-3 indicates the modified FOM's for the specific conditions investigated, i.e., aluminum heat exchangers, 10% interest, 90% utilization, and 65% efficiency. It is noted that the 50 MW plants are not included since previous cost/benefit studies combined with relatively poor motion characteristics make these candidates obviously unattractive. These results are shown graphically in Figures 5.6-3 through 5.6-5, the significance of which is discussed in Section 7. Table 5.6-4 presents similar FOM's, but without the reductions for utilization and efficiency.

FIGURE 5.6-1

ACQUISITION COST SUMMARY - ALUMINUM -
HEAT EXCHANGER TUBES - VARIABLE CWP THICKNESS

ALUMINUM H/X TUBES
HAWAII

TITANIUM H/X TUBES
HAWAII

ACQUISITION COST BREAKDOWN 350 MW SHIP

FIGURE 5.6-2

MODIFIED FIGURE OF MERIT
INCLUDING REDUCTION FOR UTILIZATION
AND EFFICIENCY

CONFIGURATION	LOG.	100 MW	200 MW	350 MW	500 MW
SHIP	H	1.578	1.603	1.614	1.591
	N	1.417	1.523	1.430	1.421
	K	1.404	1.531	1.454	1.438
CYLINDER	H	1.031	1.312	1.202	1.254
	N	0.815	1.080	0.965	1.046
	K	0.880	1.153	1.027	1.077
SPAR	H	1.322	1.546	1.402	1.573
	N	1.281	1.396	1.228	1.433
	K	1.130	1.306	1.177	1.355
SUB.	H	1.247	1.381	1.328	1.197
	N	1.169	1.189	1.217	1.094
	K	1.088	1.139	1.169	1.059
SEMI-SUB.	H	1.138	1.413	1.455	1.321
	N	1.112	1.346	1.382	1.263
	K	1.005	1.217	1.293	1.169
SPHERE	H	1.394	1.379	1.486	1.595
	N	1.213	1.233	1.310	1.441
	K	1.237	1.254	1.340	1.457

Notes:

Heat Exchangers = Aluminum
Interest = 10%
Utilization = 90%
Efficiency = 65%
No Transmission System, etc.

MODIFIED FIGURE OF MERIT
EXCLUDING REDUCTION FOR UTILIZATION
AND EFFICIENCY

CONFIGURATION	LOC.	100 MW	200 MW	350 MW	500 MW
SHIP	H	2.675	2.717	2.735	2.696
	N	2.401	2.582	2.423	2.409
	K	2.380	2.595	2.464	2.437
CYLINDER	H	1.748	2.223	2.037	2.125
	N	1.382	1.830	1.635	1.773
	K	1.491	1.954	1.741	1.825
SPAR	H	2.241	2.621	2.376	2.666
	N	2.171	2.366	2.081	2.428
	K	1.915	2.213	1.995	2.296
SUB.	H	2.113	2.341	2.250	2.028
	N	1.982	2.015	2.063	1.854
	K	1.844	1.888	1.981	1.795
SEMI-SUB.	H	1.929	2.395	2.466	2.239
	N	1.885	2.281	2.342	2.140
	K	1.704	2.063	2.192	1.981
SPHERE	H	2.363	2.337	2.518	2.704
	N	2.056	2.089	2.221	2.443
	K	2.097	2.125	2.271	2.470

Notas:

Heat Exchangers = Aluminum
Interest = 10%
Utilization = 100%
Efficiency = 100%
No Transmission System, etc.

FIGURE 5.6-3

FIGURE OF MERIT, HAWAII

FIGURE 5.6-4

FIGURE OF MERIT, NEW ORLEANS

FIGURE 5.6-5

FIGURE OF MERIT, KEY WEST

6. RECOMMENDATIONS

This Section presents an overall ranking of the ninety (90) candidates considered for the OTEC Commercial Plants:

6 Configurations (Ship, Cylinder, Spar, Sub, Semi-Submersible, Sphere)

5 Sizes (50, 100, 200, 350, 500 MW)

3 Sites (Hawaii, New Orleans, Key West)

Conclusions are presented for each of the above three variables as well as an overall ranking.

6.1 Configurations

The ship is marginally superior or equal to all other candidates regardless of size or site. The spar is the second choice in the 100 - 200 MW range, while sphere is the second choice beyond the 300 - 400 MW size, depending on site. Between these two ranges the choice varies between the spar, semi-submersible and sphere, depending on site. Within the accuracy of the costs reflected in the FOM's, the choice within this range can be considered a virtual standoff between those three options. Finally, the submarine falls in fifth place, with the cylinder at the bottom of the ranking.

6.2 Size

The economy of scale present in the FOM curves of Section 5.5 is essentially lost when the variation in CWP wall thickness is introduced. Only the sphere indicates an economy of scale, while both the submarine and semi-submersible indicate an economy of scale up to the midrange, with a decided falloff at 500 MW. Finally, the cylinder, spar, and ship show a random or zig-zag pattern due to the nonlinearity in CWP thickness effects. The optimum size appears to be insensitive to site, as follows:

Ship:	200 MW
Cylinder:	200 MW
Spar:	500 MW

6.2 Size (Continued):

Submarine:	350 MW
Semi-Submersible:	350 MW
Sphere:	500 MW

As noted earlier, it is likely that some of the irregularities of the trends in Figures 5.6-3 through 5.6-5 can be eliminated by proper tuning of the CWP to the hull and the related critical sea state. Therefore, it does not appear prudent to put too much faith in the relationship between FOM and size indicated in the figures. In the final analysis, it is considered that an economy of scale would result, though consideration of risk with larger platforms suggests 200 to 350 MW as the range of primary interest.

6.3 Site

Hawaii is the preferred site, in virtually all cases, due to more benign sea conditions and currents. For the ship, sphere, and cylinder, Key West is marginally better than New Orleans, while for the other three configurations, the reverse holds true. However, the maximum difference in FOM between Key West and New Orleans is only about 8 percent.

6.4 Overall Ranking

Due to the nonlinearities exhibited in Figure 5.6-3 through 5.6-5, and the reasons for these nonlinearities discussed above, it is not considered appropriate to develop a highly structured ranking system for all 90 candidates. Rather, it is considered more realistic to draw a more generalized sequence of ranking which groups candidates with essentially identical FOM's, where such minor differences are beyond the accuracy of the cost estimates. The following ranking is therefore proposed, independent of site:

TABLE 6-1OVERALL PLATFORM RANKING

<u>RANKING</u>	<u>CONFIGURATION</u>	<u>SIZE, MW (Gross)</u>
1	Ship	200
2	Ship	100, 350 - 500
3	Sphere Spar Semi-Submersible	350-500 200, 500 200-350
4	Sphere Semi-Submersible Spar	100-200 500 100, 350
5	Semi-Submersible Submarine	100 A11
6	Cylinder	A11

18351-10 (W-10,000)

6.4 Overall Ranking (Continued):

It is interesting to note that the above ranking confirms the selection in Section 5.5 of the ship as the first choice, even when motions are considered. The cylinder, which was the second choice in the earlier evaluations, drops to last place, while the sphere moves up with the other sea-kindly platforms (spar and semi-submersible) to vie for the "middle ground" between second and fourth place. Finally, the submarine remains near the bottom of the list.

If one were to rank the platforms as a function of plant size, the following would result:

TABLE 6-2
RANKING BY SIZE

<u>RANKING</u>	<u>SIZE BAND, MW</u>		
	<u>100-200</u>	<u>200-350</u>	<u>350-500</u>
1	Ship	Ship	Ship
2	Spar	Spar or Sphere	Sphere
3	Sphere	Spar or Sphere	Spar
4	Submarine	Semi-Submersible	Semi-Submersible
5	Semi-Submersible	Submarine	Submarine
6	Cylinder	Cylinder	Cylinder

APPENDIX A

TOP LEVEL REQUIREMENTS (TLR)

NOTE: The following is a condensation of the TLR used for Task IIA, containing key technical assumptions. See Reference (1) for the complete document.

A.1 Power System

The System shall consist of from one to "N" modules of 25 gross megawatts (MW) each, where "N" is an undefined upper limit per Plant which shall be established based upon economic analysis and risk assessment. Each 25 MW module shall include the following options for condensers and evaporators:

- 1 - 25 MW
- 2 - 12.5 MW
- 3 - 8 MW
- 4 - 5 MW

Approximate physical parameters for the principal Power System components shall be assumed as shown in Table 1, based on data in Reference (A-1). Table 1 assumes one each of the following components per 25 MW module, in addition to the heat exchanger(s):

- Turbine
- Generator

Table 1 also identifies additional support requirements to be provided by the platform. It is noted that Table 1 defines the characteristics of components producing a gross output of up to 25 MW, with no allowance for parasitic electrical loads from Seawater System pumps or platform electrical loads. Deduction of such loads could result in net plant output as much as 30 percent less than the gross output.

TABLE 1POWER SYSTEM COMPONENT DESCRIPTION1. EVAPORATORS

SIZE	DIMENSIONS (Ft.)			WEIGHT (Lbs.)		MATERIALS	
	LENGTH	WIDTH	HEIGHT	WET	DRY	SHELL	TUBES
25 MW	93	35	35	5,472 K	3,283 K	Steel	Titanium
12.5 MW	73	28	28	2,790 K	1,674 K	Steel	Titanium
8 MW	66	23	23	1,956 K	1,174 K	Steel	Titanium
5 MW	55	20	20	1,245 K	747 K	Steel	Titanium

Fluid Characteristics (Nominal + Allowable Variation)

FLUID	INLET		OUTLET		TOTAL FLOW RATES LB./HOUR
	TEMP., °F.	PRESSURE, PSIG	TEMP., °F.	PRESSURE, PSIG	
Ammonia	48°	141.3	72°	118.7	7,677,030
Seawater	80°	= 48	76°	=45.5	7.52×10^8

Required Orientation: Limits, if any, to be determined.

Interfaces: See Figure 1 (Reference (1))

Limiting Motions, Accelerations: To Be Determined

Required Location: Limits, if any, to be determined.

2. CONDENSER

Dimensions (Ft.): Identical to Evaporator

Weight (Lbs.): Identical to Evaporator

Fluid Characteristics (Nominal + Allowable Variation)

FLUID	INLET		OUTLET		TOTAL FLOW RATES LBS./HOUR
	TEMP., °F.	PRESSURE, PSIG	TEMP., °F.	PRESSURE, PSIG	
Ammonia	48°	71.1	48°	71.1	6,397,030
Seawater	40°	=48	44°	45.5	8.45×10^8

TABLE 1
(Continued)

2. CONDENSER (Continued):

Required Orientation: *

Interfaces: See Figure 1 (Reference (1))

Limiting Motions, Accelerations: *

3. TURBO-GENERATOR

Turbine - * HP Rated Output @ * RPM

Generator - * MW Rated Output @ 4,160 Volts

Weight (Lb.): 170 Long Tons - Total for 25 MW Unit

Turbine Working Fluid: Vaporized Ammonia

Turbine Inlet Conditions: 72°F., 118.7 PSIG

Turbine Outlet Conditions: 48°F., 71.1 PSIG

Working Fluid Flow Rate: 6,397,030 Lbs./Hr.

Orientation: *

Interfaces: See Figure 1 (Reference (1))

Limiting Motions, Accelerations: *

Location: Internal to platform

4. SUPPORT

Ammonia (per module) = 648,000 Lbs. @ * PSIG

Nitrogen (one purge) = 24,170 Lbs. @ 1,800 PSIG

Spare Parts Stowage = * Lbs., * Cubic Feet

Manning * = * (Supervisory) (Non-Supervisory)

Other Support Requirements:

5. TEMPERATURE DIFFERENTIAL

The design difference in temperature between condenser and evaporator inlet is 40°F. Allowable tolerance is ± * °F.

* To Be Determined

A.2 Seawater System

The Seawater System shall consist of single or multiples of the following major components:

- Cold Water Inlet Pipe
- Cold Water Discharge Pipe
- Cold Water Pump(s) and interface pipes
- Warm Water Inlet Pipe
- Warm Water Discharge Pipe
- Warm Water Pump(s)
- Filtration Assemblies

A minimum of one each of the above components shall be provided for each 25 MW module. Table 2 defines tentative characteristics for those components suitable as a baseline for early-phase Conceptual Design studies, based on data in Reference (A-1). These characteristics shall be refined during later phases of Conceptual Design. All components may be external to the platform if they can still be properly inspected, monitored and maintained. All characteristics of the Seawater System are assumed to be identical for all operating locations being considered except for the Cold Water Pipe which will vary in length depending on the depth of water required to develop the required temperature differential for Power System operation.

A.3 Transmission System

The Transmission System shall be capable of receiving the power generated by the Power System, converting it to a voltage suitable for transmission, and transmitting the power to shore via hardwired cable or cables. For the purposes of this study, the following shall be assumed for the transmission system, based upon very preliminary input from DOE:

- Transformer Weight = 2,000 lb./MW @ 100 MW, 1,600 lb./MW @ 500 MW
- Transformer Space = 20 x 20 x 20 ft. @ 100 MW, 26 x 26 x 26 ft. @ 500 MW, plus 10 ft. clearance per side and top.
- Conversion Equipment Weight = Assumed less than transformers.
- Conversion Equipment Space = 19 sq. ft. area/terminal/MW, 20 to 40 ft. clearance height (400-800 cu. ft./MW).

TABLE 2SEAWATER SYSTEM COMPONENT DESCRIPTION1. COLD WATER INLET PIPE (Assume one per Plant)

SIZE PLANT (MW)	PIPE DIAMETER	FLOW RATE Ft. ³ /Sec.	WEIGHT (Dry) L.T./Ft.
50	40 Ft.	7,540	11
100	60 Ft.	15,080	16
200	90 Ft.	30,160	24
350	120 Ft.	52,780	31
500	140 Ft.	75,400	36

Limiting Motions: To Be Determined

Nominal Length of Pipe: 3,000 Feet

Actual Length: To Be Determined based on environmental conditions at each site and requirements on condenser and evaporator inlet temperatures.

2. COLD WATER PUMP SUCTION PIPE(From Deep Pipe (CWP) to Pump Inlet - One per 25 MW Module)

Length: To Accommodate Arrangement

Diameter: 28 Ft. Nominal

Weight (Dry): 0.14 Long Tons/Ft.

Material: Cu Ni (90-10) or concrete if part of structure

Flow Rate: 1.415×10^7 Lbs./Hour

Limiting Motions: To Be Determined

3. COLD WATER PUMP DISCHARGE PIPE (One per 25 MW Module)(CW Pump Discharge to Condenser and Overboard)

Length: to Accommodate Arrangement

Diameter: 26 Ft.

Weight (Dry): 0.14 Long Tons/Ft.

Material: Cu Ni (90-10) or concrete if part of structure

Flow Rate: 1.415×10^7 Lbs./Hour

Limiting Motions: To Be Determined

TABLE 2
(Continued)

4. COLD WATER PUMP(S)

Number per 25 MW Module (Assumed): One (1)

Pump Type: Vertical - Propeller

Pump Rating: 3.45×10^8 Lbs./Hour @ 39.5 RPM and 9.5 Foot Head

Drive Type: Motor

Drive Rating: 5,200 HP @ 1,800 RPM and 4,160 VAC

ITEM	DIMENSIONS			WEIGHT, POUNDS	
	LENGTH	WIDTH	HEIGHT	DRY	WET
Pump	40'	31'	66'	619,460	685,275
Drive	7.5'	7.5'	14'	66,200	-----

Limiting Motions: To Be Determined

5. WARM WATER INLET PIPE (One per 25 MW Module)

Length: To Accommodate Arrangement

Diameter: 27 Ft. Nominal

Weight (Dry): 0.14 Long Tons/Ft.

Material: Cu Ni (90-10) or concrete if part of structure

Flow Rate: 7.52×10^8 Lbs./Hour

Limiting Motions: To Be Determined

6. WARM WATER DISCHARGE PIPE (One per 25 Module)

Length: To Accommodate Arrangement

Diameter: 25 Ft.

Weight (Dry): 0.14 Long Tons/Ft.

Material: Cu Ni (90-10) or concrete if part of structure

Flow Rate: 7.52×10^8 Lbs./Hour

Limiting Motions: To Be Determined

TABLE 2
(Continued)

7. WARM WATER PUMP(S)

Number per 25 MW Module (Assumed): One (1)

Pump Type: Vertical - Propeller

Pump Rating: $(7.52) 10^8$ Lbs./Hour @ 40.84 RPM and 9.8 Foot Head

Drive Type: Motor

Drive Rating: 4,775 HP @ 1,800 RPM and 4,160 VAC

ITEM	DIMENSIONS			WEIGHT, POUNDS	
	LENGTH	WIDTH	HEIGHT	DRY	WET
Pump	44'	27'	66'	509,690	561,510
Drive	7.3'	7.3'	12'	61,500	-----

Limiting Motions: To Be Determined

8. WATER FILTRATION ASSEMBLY (One each per pump inlet)

Description: Plate Strainer

Dimensions (Ft.): Diameter: 27 Ft.

Weight (Lbs.): 11,400 Lbs.

Material: Cu Ni (90-10)

9. SUPPORT

Spare Parts Stowage: To Be Determined

Manning: 6 (Supervisory) 24 (Non-Supervisory) 10 (Temporary Personnel)

Support Requirements:

Starting Power: To Be Determined

Cooling: To Be Determined

Lubrication: To Be Determined

Other: To Be Determined

A.3 Transmission System (Continued):

- Switchgear, circuit breakers, potheads: Assume 20 x 20 x 20 ft. for 25 MW.
- Power Transmission:
 - AC for distances up to 30 miles offshore.
 - DC for distances beyond 50 miles offshore.
 - AC or DC between 30-50 miles offshore.
- Heat Dissipation: To Be Determined
- Manning: To Be Determined
- Equipment Motion Limitations: To Be Determined
- Cable Characteristics:
 - Type and Number: From 2 to 6, various options
 - Diameter: Up to 6 inches
 - Maximum Unsupported Length: To Be Determined
 - Motion Limitations: To Be Determined
 - Unit Weight (Submerged): Up to 200 lbs./ft. depending on type

A.4 Payload Maintenance

The payload maintenance concept to be reflected in the platform design shall be based upon the following assumptions:

1. Normal cleaning of heat exchanger and condenser tubes and filtration units without removing them from the shell.
2. Ability to remove tubes for repair or replacement with minimum disruption of fixed platform components.
3. Ability to remove rotating elements of pumps, turbines, motors and generators for repair onboard or shipment to shoreside facilities by sea.
4. Maintenance and marine growth removal from cold water and warm water pipes in place.
5. Ability to operate the Plant at design efficiency with selected elements of the Power and Seawater System inoperative during routine maintenance or emergency repairs. This shall be accomplished by a combination or redundancy, cross-connection and other features enhancing maintainability.

18351-10 (W-10,000)

A.5 Hull Systems

A.5.1 Configurations

The platform configurations to be considered for the OTEC Commercial Plant shall include the following six (6) candidates:

- Sphere
- Ship
- Spar
- Submersible
- Semi-Submersible
- Cylinder

Each of the candidate platforms shall fully satisfy the requirements of this TLR.

A.5.2 Structures

The platform structure shall be designed to withstand the overall and local loads imposed during construction, deployment and operation at the specified operating site for the platform life. Design loads and safety factors shall reflect the intent of American Bureau of Shipping and U. S. Coast Guard regulations applicable to offshore platforms. If concrete, glass reinforced plastics or composites are utilized which do not exhibit a well-defined yield point or for which properties vary, special consideration shall be given to these areas when developing safety factors.

A.6 Position Control System

A Position Control System consisting of anchors, dynamic positioners or a combination of these shall be provided which is capable of limiting the movement of the platform as follows:

A.6.1 Operational Mode

The platform shall not drift from its intended position in excess of the following limits:

18351-10 (W-10,000)

A.6.1 Operational Mode (Continued):

- That required to prevent grounding of the CWP
- That required to maintain a cold water inlet temperature no more than $\pm 1^{\circ}\text{F}$. from the nominal inlet temperature.
- That required to prevent failure of the power cable.
- That required to prevent drifting into shipping lanes or restricted areas.

These limits shall be met during the worst combination of wind, current, sea state and storm duration to be encountered during the life of the platform, except for the 100 year event defined in Section A.9.

* To Be Determined

A.7 Support Systems

The Ocean System shall incorporate all systems necessary to support the payload and operating personnel including those subsystems listed in the Work Breakdown Structure. In general, these subsystems shall conform to current offshore design and construction practices, and shall satisfy the requirements of the American Bureau of Shipping, U. S. Coast Guard and other regulatory agencies.

A.8 Systems Engineering Requirements

A.8.1 Construction

The Ocean System shall be fabricated at existing or modified U. S. facilities or in a new facility located on U. S. territory. The hull and major systems may be constructed as a unit or as a series of modules to be joined afloat, depending on the size and configuration of the platform, and economic considerations.

A.8.2 Deployment

The Plant shall be deployed to the operating site utilizing tugs, dynamic positioners or a combination of these. Additional self-propulsion capability is not required.

A.8.3 Maintenance

The maintenance concept for the Ocean System parallels that for the payload, Section A.4, and is based upon the assumption that the Ocean System will remain on site throughout its useful life and will not return to drydock for maintenance and repair except in the event of major damage. Based upon this, the maintenance concept for the Hull, Position Control and Support Systems shall include the following:

1. Use of materials which are not degraded by the marine environment.
2. Removal of marine growth from underwater surfaces by divers.
3. Repair and maintenance of equipment in place or by replacement.
4. Rotation of common equipment to shoreside maintenance facilities for periodic overhaul.

A.8.4 Operation

The OTEC Commercial Plant shall be operated by rotating crews similar to the concepts now in use with offshore platforms. The Plant shall function 24 hours a day, with crews rotating in 12 hour shifts. Maintenance and the operation of functions such as the laundry, administration, shops, etc., shall be during a single shift, with reduced crews operating the Power System, Seawater System and essential platform functions during the other shifts.

A.8.5 Safety

The design, construction and operation of the Plant shall reflect considerations of safety throughout. All applicable safety codes and standards shall be implemented, including OSHA and Coast Guard. Special attention shall be directed toward the potential safety hazards associated with ammonia vapor.

A.8.6 Stability

The subdivision and other stability features of the platform shall guarantee survival after the following events, where survival means retention of adequate reserve buoyancy to prevent sinking, and adequate stability to prevent capsizing:

A.8.6 Stability (Continued):

1. Flooding of any two adjacent compartments.
2. Being struck by a ship of displacement not greater than the Plant, with sufficient force to penetrate 20 percent of the beam.
3. Operating with or without the CWP in the worst 100-year event.

A.8.7 Logistics

The OTEC Commercial Plant shall utilize off-the-shelf components and identical components from the same manufacturer to the maximum extent practical. Stockpiles of platform-peculiar components shall be maintained to the extent necessary to insure availability of critical components throughout the life of the Plant. Stockpiles of small items shall be maintained aboard the platform, while those of larger items shall be maintained in a shoreside facility.

A.8.8 Noise and Vibration

Noise and vibration producing equipment shall be resiliently mounted or isolated to minimize degradation of working and living conditions in nearby manned compartments. Special attention shall be directed toward noise reduction in living, recreation, and control spaces.

A.8.9 Environmental Protection

Pollution control systems shall be provided to treat or collect pollutants such that overboard discharge of solid wastes, oily ballast, sewage wastes, and chemicals is eliminated. Onboard treatment and reuse of oily wastes, chemical wastes, sanitary water and similar pollutants shall be provided. Those pollutants which cannot be processed for economic or technical reasons shall be collected and transferred to shoreside facilities for treatment and disposal. Special attention shall be paid to minimizing the possible release of ammonia into the environment in the event of collision or other disastrous events.

18351-10 (W-10,000)

A.8.10 Manning

The operating personnel for the Ocean System shall be licensed or unlicensed civilian marine operating personnel with qualifications similar to those of current offshore platforms. The operating personnel for the Power and Transmission Systems shall have parallel qualifications to personnel now operating shoreside power plants of similar size. All personnel shall be rotated on assignment in accordance with current offshore platform practices. Work schedules shall be in accordance with Section A.8.4. The platform shall have a 10 percent reserve in accommodations to house transients including scientists, vendor representatives, inspectors, flight crews, shore based maintenance personnel and other visitors.

A.8.11 Licenses and Regulations

The OTEC Commercial Plant shall meet all regulations and satisfy all licensing requirements currently applicable to offshore platforms and power plants of similar size and capacity. Where the scope of such regulations does not reflect the specific characteristics of the Plant, the intent of these regulations shall be met pending modification to the regulations.

A.9 Environment

A.9.1 Location of Sites

Five locations have been identified as potential sites for an OTEC Plant: Keahole Point, Hawaii; Punta Tuna, Puerto Rico; New Orleans, Louisiana; Key West, Florida; and an area in the South Atlantic off the coast of Brazil. Figure 1 shows the location of these sites. Only the Hawaii, New Orleans and Florida sites are of concern in the studies being conducted by Gibbs & Cox, Inc. The Plant design shall be optimized individually for each of these sites, thus providing three options for each hull configuration and plant capacity.

A.9.2 Site Characteristics

Table 3 and Figure 2 summarize the principal characteristics of the above sites, based upon detailed data in Reference (A-2). For reference purposes, data is presented for all five sites.

TABLE 3

SUMMARY OF SITE ENVIRONMENTAL CHARACTERISTICS

<u>SITE:</u>	<u>HAWAII</u>	<u>PUERTO RICO</u>	<u>NEW ORLEANS</u>	<u>KEY WEST</u>	<u>BRAZIL (Questionable Data)</u>
Water Depth, ft.	3,150	4,000	3,950	4,850	(18,000)
Depth for 36° F ΔT:					
Maximum, ft.	3,280*	2,790	3,940	4,100	2,020
Minimum, ft.	1,560	2,050	1,340	1,850	950
Current Velocities:					
Extreme, Kts.	2.18	2.76	2.49	6.40	3.20
Normal, Kts.	1.13	1.21	1.17	4.73	0.50
<u>100 YR. RETURN PERIOD:</u>					
Maximum Wind, Kts.	65.7	92.8	100.3	113.8	61.0
Gusts, Kts.	95.2	134.6	145.4	165.0	----
Period Max. Energy, Sec.	12.72	13.8	15.91	13.67	18.0
Sign. Wave Ht. Ft.	35.9	44.2	58.1	45.8	32.0
<u>AVG. MONTHLY EXCEEDANCES:</u>					
20 kt. wind	1.09	3.37	26.42	21.92	6.52
32 kt. wind	0.01	0.17	2.20	1.72	0.23
44 kt. wind	0.01	----	0.26	0.21	----
12 ft. sign. wave ht.	1.71	0.15	2.02	0.62	1.32
16 ft. sign. wave ht.	0.51	0.05	0.46	0.17	0.31
19 ft. sign. wave ht.	0.31	0.02	0.24	0.07	0.06

* To achieve a 36° F. ΔT in the worst month (March) site must be relocated to deeper water.

GENERAL SITE LOCATION MAP

18351-10 (M-10,000)

GENERAL SITE LOCATIONS

FIGURE 1

X POTENTIAL SITE LOCATIONS

FIGURE 2

FIGURE 3

POWER SYSTEM/SEAWATER SYSTEM DEFINITION

18351-10 (W-10,000)

APPENDIX A
REFERENCES

- A-1 ERDA Letter to Gibbs & Cox, Inc. dated August 16th, 1977.
- A-2 OTEC Demonstration Plant Environmental Package dated July 14th, 1977.

APPENDIX B

DOE POWER SYSTEM DATA

NOTE: All data in this Appendix reflects
gross output from the generator.

memorandum

Gilbert/Comi

August 15, 1977

to: D. Price

from: R. D. Berg *RD*

subject: Power System Components - Sizes and Costs

Size and cost information for 5, 8, 12.5 and 25 MW power system components is given below. Size information for heat exchangers was sent to you by memo on July 27, 1977; heat exchanger cost information will be provided at a later date.

Also, enclosed are two (2) copies of the following drawings: D-398-031B, Composite Flow Diagram; and D-398-032A, Composite Flow Diagram Data Sheet. These drawings will be useful in defining power system layout and operating conditions.

I. Warm and Cold Water Circulating Piping

- a) Piping is from pump discharge to overboard discharge.
- b) Pipe sizes: 25 MW - 25 foot OD
12.5 MW - 18 foot OD
8 MW - 15 foot OD
5 MW - 12 foot OD
- c) Pipe length - 600 feet/module
- d) Pipe weight (operating) - 11.5 tons/module
- e) Pipe cost: \$2500/ft for 12.5 MW
\$3000/ft for 5, 8, 25 MW

II. Ammonia Piping

- a) Liquid (L) piping is from condenser to evaporator; vapor (V) piping is from evaporator to demister to condenser; weight and cost of miscellaneous piping (vents, drain, fills) is added into V and L data.
- b) 5 MW - 5' OD (V), 3' OD (L), 45' each, 30 tons
8 MW - 6' OD (V), 4' OD (L), 50' each, 50 tons
12.5 MW - 9' OD (V), 7' OD (L), 50' each, 70 tons
25 MW - 10' OD (V), 8' OD (L), 60' each, 130 tons
- c) Pipe cost: \$700/ft for 5, 8, 25 MW
\$850/ft for 12.5 MW

D. Price

Page 2

August 15, 1977

III. Ammonia Compressor

- a) 25 MW module: 5.5L x 18W x 4H
weight = 10 tons
motor = 160 HP
cost = \$40,000

IV. Ammonia Storage Tanks

- a) Sized for 30 day storage
b) 12 standard tanks, 10 ft. dia. x 35 ft. long each
operating weight - 756 tons
c) Cost = \$500,000

V. Ammonia Feed Pumps

- a) Use 2 pumps/module (1 spare)
b) 5 MW - 5' dia. x 11', 4.5 tons ea., 300 HP ea.
8 MW - 5.5' dia. x 11', 7.5 tons ea., 600 HP ea.
12.5 MW - 6.5' dia. x 13.5', 10.5 tons ea., 1000 HP ea.
25 MW - 7' dia. x 13', 13.5 tons ea., 2000 HP ea.
c) Cost: \$350,000 total for 5, 8, 25 MW
\$565,000 total for 12.5 MW

VI. Vacuum Pump

- a) Single pump used regardless of number of modules
b) 5L x 6W x 7H
Weight = 4 tons
c) Cost = \$30,000

VII. Turbo-Generator

- a) 5 MW - 35L x 8W x 8H, 48 tons
8 MW - 45L x 10W x 10H, 65 tons
12.5 MW - 55L x 12W x 12H, 110 tons
25 MW - 85L x 12W x 12H, 190 tons
b) Cost: 5 MW (5 ea) - \$3,500,000
8 MW (3 ea) - 2,850,000
12.5 MW (2 ea) - 2,700,000
25 MW (1 ea) - 2,500,000

18351-10 (W-10,000)

D. Price

Page 3

August 15, 1977

VIII. Demister

a) One size selected at 5 MW rating (use multiple units) -
14 ft. dia. x 43 ft. high, weight = 40 tons each

b) Cost = \$600,000 total

877-032

RDB/pw

cc: J. vanSumeren
W. Traskoma
S. Griffith
S. Gronich (2)

RECEIVED

memorandum

Gilbert/Commonwealth

AUG 24 1977

August 23, OFFICE OF OCEAN

to: D. Price

from: R. D. Berg

subject: Heat Exchanger Design Information

In response to your request, the heat exchanger information originally transmitted to you by memo of July 27, 1977 has been normalized, and is presented below.

1. Horizontal Shell and Tube

$V = 3500 \text{ ft}^3 / \text{MW}$ $L/D = 2.7$
 Dry weight = 140,000 lbs. /MW
 Operating weight = $1.66 \times$ dry weight

2. Vertical Shell and Tube

$V = 2770 \text{ ft}^3 / \text{MW}$ $L/D = 2.1$
 Dry weight = 58,000 lbs. /MW
 Operating weight = $1.66 \times$ dry weight

3. AFL Trombone - Type

$V = 26 \text{ L} \times 13 \text{ W} \times 3 \text{ ft high} / \text{MW}$
 Dry weight = 69,000 lbs. /MW
 Operating weight = $1.8 \times$ dry weight

4. Plate-Fin

$V = 250 \text{ ft}^3 / \text{MW}$ $L = 1.25 \text{ W}$ $H = \text{as required}$
 Dry weight = 39,000 lbs. /MW
 Operating weight = $1.9 \times$ dry weight

cc: J. vanSumeren
 W. Thompson
 S. Griffith
 J. Vedus
 W. Sherwood

877-053
 EDB/jh

18351-10 (W-10,000)

APPENDIX C
COST AND SCHEDULE DATA

The data in Appendix C is arranged as follows:

- Scheduling
- Acquisition Costs Summary
 - Titanium
 - Aluminum
- Operating Costs
 - Titanium
 - Aluminum
- Transmission Cable Costs
- Acquisition Cost Detailed Breakdown by Hull Configuration
 - Aluminum Only
- Operating Cost Detailed Breakdown by Hull Configuration
 - Aluminum Only

Detailed breakdowns for acquisition and operating costs for titanium tubed heat exchangers are identical to those for aluminum tubes except for the heat exchangers themselves, which add the following constant costs to the acquisition cost with aluminum tubes:

50 MW:	\$ 27 M
100 MW:	\$ 55 M
200 MW:	\$110 M
350 MW:	\$192 M
500 MW:	\$274 M

Appendix B of Reference (3) includes detailed breakdowns for titanium tubes reflecting the above increases.

PROCEDURE TO CONSTRUCT OTEC PLATFORM

50-100 MW Plants are assumed to be constructed in a shipyard.

200-500 MW Plants will be built at a specially constructed facility to build OTEC type platforms. This complex will feature a batch plant, large capacity cranes, rolling mills for condenser tubing, etc.

Method of Construction

50-100 MW

- Construct basic shell of platform to point where some Power System Components may be installed and the beam and draft which will permit a semi-complete platform to be floated from conventional shipyard.
- Launch Incomplete Platform
- Tow to deep water site (suitably sheltered against wind and wave) and complete installation of major components and construction of hull.
- Complete outfitting to point of cold water pipe installation
- Tow to predesignated OTEC site

200-500 MW

- Construct basic shell of platform at a specially designed OTEC platform construction site; install Power and Seawater System Components
- Launch Platform
- Tow to off-shore site for completion of outfitting

50-200 MW

- Cold water pipe constructed in sections, moved to the site, and joined in place on the platform.
- CWP and platform are joined together
- Complete platform
- Start up
- Checkout and testing
- Plant becomes operational

350-500 MW

- Because of their large diameters the CWP's will be built in sections or poured in place at the platform site

TABLE C-1
SCHEDULE TO BUILD OTEC
COMMERCIAL PLANTS

CONFIGURATION	TIME	50MW	100MW	200MW	350MW	500MW
SHIP	MO	57	60	62	68	74
	YR	4.75	5.00	5.17	5.67	6.17
CYLINDER	MO	57	60	62	68	73
	YR	4.75	5.00	5.17	5.67	6.08
SPAR	MO	55	62	62	70	72
	YR	4.58	5.17	5.17	5.83	6.00
SUBMERSIBLE	MO	59	65	76	85	95
	YR	4.92	5.42	6.33	7.08	7.92
SEMI-SUBMERSIBLE	MO	63	67	79	88	110
	YR	5.25	5.58	6.58	7.33	9.17
SPHERE	MO	55	61	69	69	72
	YR	4.58	5.08	5.75	5.75	6.00

Assumptions:

- Heat Exchanger Construction will keep pace with concrete erection. All other equipment delivered on time.
- 50 & 100 MWe Concrete Erection 3000 yd³/mo
200 MWe Concrete Erection 4500 yd³/mo
350 MWe Concrete Erection 6000 yd³/mo
500 MWe Concrete Erection 7500 yd³/mo
- Figures include Construction/Erection of Forms, Pouring of Concrete, Installation of Reinforcements, Curing, Removal of Forms, Post Treatment of Concrete
- No R&D Time

TABLE C-2
ACQUISITION COSTS
(\$M)
TITANIUM

CONFIGURATION	LOC.	50MW	100MW	200MW	350MW	500MW
SHIP	H	137.4	242.2	451.7	765.1	1076.9
	N	139.0	244.9	457.1	770.4	1084.6
	K	142.9	253.1	468.6	783.7	1112.2
CYLINDER	H	138.6	255.4	455.4	765.4	1070.6
	N	141.1	259.8	459.1	772.6	1077.2
	K	147.9	267.3	470.0	794.3	1105.9
SPAR	H	140.4	276.9	502.5	819.1	1134
	N	140.5	278.9	507.5	826.3	1140
	K	149.9	299.8	538.6	875.5	1198.6
SUBMERSIBLE	H	143.3	256.1	489.5	792.2	1152.3
	N	147.7	261.8	498.5	802.5	1164.0
	K	157.9	275.4	521.3	834.1	1207.7
SEMI-SUBMERSIBLE	H	165.5	295.9	494.8	812.6	1147.8
	N	168.0	298.8	500.0	818.6	1155.3
	K	180.5	319.1	530.5	855.6	1206.8
SPHERE	H	174.6	249.8	501.2	821.4	1148.0
	N	176.4	256.1	511.7	836.0	1162.8
	K	177.4	260.2	518.8	845.9	1177.2

LEGEND:

H - HAWAII
N - NEW ORLEANS
K - KEY WEST

TABLE C-3
ACQUISITION COSTS
(\$M)
ALUMINUM

CONFIGURATION	LOC.	50MW	100MW	200MW	350MW	500MW
SHIP	H	107.3	181.9	331.3	554.5	775.9
	N	108.9	184.7	336.7	559.7	783.6
	K	112.8	192.8	348.2	578.0	811.3
CYLINDER	H	108.5	195.2	335.0	554.8	769.6
	N	111.0	199.6	338.7	561.9	776.2
	K	117.8	207.1	349.6	583.6	805.0
SPAR	H	110.3	216.6	382.1	608.5	833.2
	N	110.4	218.6	387.1	615.6	839.8
	K	119.8	239.6	418.2	664.8	897.8
SUBMERSIBLE	H	113.2	195.9	369.1	581.5	851.4
	N	117.6	201.5	378.2	591.8	863.0
	K	127.9	215.1	400.9	623.5	906.7
SEMI-SUBMERSIBLE	H	135.4	235.6	374.5	601.9	846.8
	N	137.9	238.6	379.6	607.9	854.4
	K	150.4	258.9	410.1	645.0	905.8
SPHERE	H	144.5	189.6	380.8	610.7	847.0
	N	146.3	195.9	391.3	625.3	861.8
	K	147.3	200.0	398.4	635.2	876.2

LEGEND:

H - HAWAII
N - NEW ORLEANS
K - KEY WEST

TABLE C-4

ANNUAL OPERATIONAL COST
\$M
(TITANIUM HEAT EXCHANGERS)

CONFIGURATION	LOC.	50MW	100MW	200MW	350MW	500MW
SHIP	H	2.69	3.99	6.79	10.56	14.36
	N	2.95	4.42	7.67	12.10	16.56
	K	3.00	4.52	7.81	12.35	16.96
CYLINDER	H	2.75	4.07	6.81	10.59	14.33
	N	2.97	4.55	7.67	12.14	16.49
	K	3.07	4.68	7.83	14.41	16.89
SPAR	H	4.19	6.97	11.92	18.27	25.25
	N	4.68	7.97	14.04	22.13	30.10
	K	4.92	8.57	14.00	23.32	31.52
SUBMERSIBLE	H	4.24	6.56	11.68	18.10	25.58
	N	4.85	7.74	13.84	21.58	30.61
	K	5.10	8.01	14.41	22.37	31.71
SEMI-SUBMERSIBLE	H	3.08	4.54	7.31	11.18	15.19
	N	3.36	5.10	8.23	12.77	17.56
	K	3.53	5.38	8.68	13.28	18.23
SPHERE	H	3.06	4.02	7.23	11.09	15.03
	N	3.36	4.54	8.29	12.85	17.47
	K	3.37	4.59	8.38	13.00	17.65

LEGEND:

H - HAWAII
N - NEW ORLEANS
K - KEY WEST

TABLE C-5
ANNUAL OPERATIONAL COST
\$M
(ALUMINUM HEAT EXCHANGERS)

CONFIGURATION	LOC.	50MW	100MW	200MW	350MW	500MW
SHIP	H	2.468	3.425	5.732	8.730	11.722
	N	2.615	3.743	6.347	9.783	13.300
	K	2.665	3.851	6.493	10.023	13.627
CYLINDER	H	2.479	3.546	5.759	8.736	11.673
	N	2.642	3.913	6.354	9.817	13.187
	K	2.733	4.020	6.495	10.116	13.589
SPAR	H	3.665	5.867	9.806	14.884	19.972
	N	4.024	6.726	11.396	17.480	23.490
	K	4.257	7.240	12.148	18.679	24.907
SUBMERSIBLE	H	3.713	5.495	9.570	14.407	20.295
	N	4.193	6.353	11.198	16.963	24.009
	K	4.442	6.680	11.753	17.721	25.071
SEMI-SUBMERSIBLE	H	2.819	4.017	6.249	9.322	12.549
	N	3.031	4.438	6.945	10.473	14.219
	K	3.198	4.713	7.357	10.957	14.879
SPHERE	H	2.794	3.501	6.163	9.231	12.351
	N	3.027	3.880	6.952	10.526	14.168
	K	3.040	3.934	7.058	10.674	14.349

LEGEND:

H - HAWAII
N - NEW ORLEANS
K - KEY WEST

TABLE C-6TRANSMISSION SYSTEM (CABLE) COST
(\$M/MW)

LOCATION	50MW	100MW	200MW	350MW	500MW
HAWAII	.149	.089	.059	.046	.041
NEW ORLEANS	2.297	1.154	.592	.350	.254
KEY WEST	4.661	2.354	1.187	.691	.492

- Based on an installed cost of \$240/foot

TABLE C-7

ACQUISITION COSTSTYPE CONFIGURATION - SHIP SHAPE
ALUMINUM HEAT EXCHANGERS

		<u>Dollars in Millions</u>				
		<u>50 MW</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
		<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Hull System						
• Concrete \$500/yd ³		8.55	15.69	35.32	76.25	119.64
• Steel						
Power System (Al Tubing)		27.10	53.90	107.5	187.90	268.30
Transmission System		8.00	16.0	32.0	56.0	80.0
Seawater System						
• Cold Water Pipe		36.79	49.61	70.61	92.61	108.54
• Piping/Pumps, etc.		11.44	22.88	45.76	80.08	114.4
Support System						
• Habitability		3.10	3.10	3.40	3.7	4.0
• Other		0.01	0.01	0.01	0.01	0.01
Position Keeping	H	2.6	4.2	6.6	7.5	10.5
	N	4.0	6.7	11.5	12.3	17.5
	K	7.5	14.1	22.0	28.9	42.6
Engineering & Miscellaneous (10%)	H	9.8	16.5	30.1	50.4	70.5
	N	9.9	16.8	30.6	50.9	71.2
	K	10.3	17.5	31.7	52.5	73.8
Totals - Cost (\$M)	H	107.3	181.9	331.3	554.5	775.9
	N	108.9	184.7	336.7	559.7	783.6
	K	112.8	192.8	348.2	578.0	811.3

Key: H = Hawaii
 N = New Orleans
 K = Key West

TABLE C-8

ACQUISITION COSTSTYPE CONFIGURATION - CYLINDERALUMINUM HEAT EXCHANGERS

		<u>Dollars in Millions</u>				
		<u>50 MW</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
		<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Hull System						
• Concrete \$500/yd ³		8.77	25.87	38.67	76.68	115.62
• Steel						
Power System (Al Tubing)		27.10	53.90	107.50	187.90	268.30
Transmission System		8.00	16.00	32.00	56.00	80.0
Seawater System						
• Cold Water Pipe		36.45	50.22	71.55	90.38	107.08
• Piping/Pumps, etc.		11.44	22.88	45.76	80.08	114.4
Support System						
• Habitability		3.10	3.10	3.40	3.70	4.00
• Other		0.01	0.01	0.01	0.01	0.01
Position Keeping	H	3.8	5.4	5.6	9.5	10.2
	N	6.0	9.4	9.0	16.0	16.2
	K	12.3	16.2	18.9	35.7	42.3
Engineering &	H	9.9	17.7	30.5	50.4	70.0
Miscellaneous (10%)	N	10.1	18.1	30.8	51.1	70.6
	K	10.7	18.8	31.8	53.1	73.2
Totals - Cost (\$M)	H	108.5	195.2	335.0	554.8	769.6
	N	111.0	199.6	338.7	561.9	776.2
	K	117.8	207.1	349.6	583.6	805.0

Key H = Hawaii
 N = New Orleans
 K = Key West

TABLE C-9

ACQUISITION COSTSTYPE CONFIGURATION - SPARALUMINUM HEAT EXCHANGERS

		<u>Dollars in Millions</u>				
		<u>50 Mw</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
		<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Hull System						
• Concrete \$500/yd ³		6.33	29.54	38.97	81.55	100.06
• Steel						
Power System (Al Tubing)		27.10	53.90	107.50	187.90	268.30
Transmission System		8.0	16.0	32.0	56.0	80.0
Seawater System						
• Cold Water Pipe		35.57	44.48	67.10	86.60	103.41
• Piping/Pumps, etc.		11.44	22.88	45.76	80.08	114.4
Support System						
• Habitability		3.10	3.10	3.40	3.70	4.00
• Other		0.01	0.01	0.01	0.01	0.01
Position Keeping	H	3.8	5.4	5.6	9.5	10.2
	N	3.9	7.2	10.2	16.0	16.2
	K	12.5	26.3	38.5	60.7	68.9
Engineering & Miscellaneous (10%)	H	10.0	19.7	34.7	55.3	75.7
	N	10.0	19.9	35.2	56.0	76.3
	K	10.9	21.8	38.0	60.4	81.6
Totals - Cost (\$M)	H	110.3	216.6	382.1	608.5	833.2
	N	110.4	218.6	387.1	615.6	839.8
	K	119.8	239.6	418.2	664.8	897.8

Key H = Hawaii
 N = New Orleans
 K = Key West

TABLE C-10

ACQUISITION COSTSTYPE CONFIGURATION - SEMI-SUBMERSIBLEALUMINUM HEAT EXCHANGERSDollars in Millions

		<u>50 Mw</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
		<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Hull System						
• Concrete	\$525/yd ³			31.89	26.82	57.18
• Steel		32.75	66.25	45.00	97.24	134.50
Power System (Al Tubing)		27.10	53.90	107.5	187.4	268.30
Transmission System		8.00	16.00	32.00	56.00	80.00
Seawater System						
• Cold Water Pipe		36.45	47.25	66.76	86.33	100.32
• Piping/Pumps, etc.		11.44	22.88	45.76	80.08	114.40
Support System						
• Habitability		3.1	3.10	3.40	3.70	4.0
• Other		0.01	0.01	0.01	0.01	0.01
Position Keeping	H	4.2	4.8	8.1	9.1	11.1
	N	6.5	7.5	12.8	14.6	18.0
	K	17.9	27.0	47.3	54.6	75.5
Engineering & Miscellaneous (10%)	H	12.3	21.4	34.0	54.7	77.0
	N	12.5	21.7	34.5	55.3	77.7
	K	13.7	23.5	37.3	58.6	82.3
Totals - Cost (\$M)	H	135.4	235.6	374.5	601.9	846.8
	N	137.9	238.6	379.6	607.9	854.4
	K	150.4	258.9	410.1	645.0	905.8

Key H = Hawaii
 N = New Orleans
 K = Key West

TABLE C-11

ACQUISITION COSTSTYPE CONFIGURATION - SUBMERSIBLE

ALUMINUM HEAT EXCHANGERS

		<u>Dollars in Millions</u>				
		<u>50 MW</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
		<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Hull System						
• Concrete \$540/yd ³		14.88	33.69	74.61	106.57	197.93
• Steel						
Power System (Al Tubing)		27.10	53.90	107.50	187.90	268.30
Transmission System		8.0	16.0	32.0	56.0	80.0
Seawater System						
• Cold Water Pipe		35.91	46.10	67.70	89.17	101.93
• Piping/Pumps, etc.		11.44	22.88	45.76	80.08	114.40
Support System						
• Habitability		3.10	3.10	3.40	3.70	4.00
• Other		0.01	0.01	0.01	0.01	0.01
Position Keeping	H	2.5	2.4	4.6	5.2	7.4
	N	6.5	7.5	12.8	14.6	18.0
	K	15.8	19.9	33.5	43.4	57.7
Engineering & Miscellaneous (10%)	H	10.3	17.8	33.6	52.9	77.4
	N	10.7	18.3	34.4	53.8	78.5
	K	11.6	19.6	36.4	56.7	82.4
Totals - Cost (\$M)	H	113.2	195.9	369.1	581.5	851.4
	N	117.6	201.5	378.2	591.8	863.0
	K	127.9	215.1	400.9	623.5	906.7

Key H = Hawaii
 N = New Orleans
 K = Key West

TABLE C-12

ACQUISITION COST
TYPE CONFIGURATION - SPHERE
 ALUMINUM HEAT EXCHANGERS

		<u>Dollars in Millions</u>				
		<u>50 MW</u>	<u>100 MW</u>	<u>200 MW</u>	<u>350 MW</u>	<u>500 MW</u>
		<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>	<u>\$</u>
Hull System						
• Concrete	\$525/yd ³	15.36	17.90	57.62	79.88	96.72
• Steel						
• Fixed Ballast	\$400/yd	9.08	5.96	24.36	49.55	93.70
Power System (Al Tubing)		27.10	53.90	107.5	187.9	268.3
Transmission System		8.00	16.00	32.00	56.0	80.00
Seawater System						
• Cold Water Pipe		36.45	47.25	66.76	86.33	100.32
• Piping/Pumps, etc.		11.44	22.88	45.76	80.08	114.40
Support System						
• Habitability		3.10	3.10	3.40	3.70	4.00
• Other		0.01	0.01	0.01	0.01	
Position Keeping						
	H	2.6	5.3	8.7	11.7	12.5
	N	4.3	11.0	18.3	25.0	26.0
	K	5.2	14.8	24.8	34.0	39.1
Engineering & Miscellaneous (10%)						
	H	13.1	17.2	34.6	55.5	77.0
	N	13.3	17.8	35.6	56.8	78.3
	K	13.4	18.2	36.2	57.7	79.7
Total - Cost (\$M)						
	H	144.5	189.6	380.8	610.7	847.0
	N	146.3	195.9	391.3	625.3	861.8
	K	147.3	200.0	398.4	635.2	876.2

Key H = Hawaii
 N = New Orleans
 K = Key West

TABLE C-13

OPERATIONAL COSTS FOR 3000 MW PARK						
TYPE PLATFORM - SHIP SHAPE						
ALUMINUM HEAT EXCHANGERS						
Dollars in Millions						
		50 MW	100 MW	200 MW	350 MW	500 MW
		\$	\$	\$	\$	\$
Crew						
• Wages & Fringe Benefits	H	54.3	30.1	23.1	17.8	14.2
	N	49.4	27.4	21.0	16.2	12.9
	K	49.4	27.4	21.0	16.2	12.9
• Subsistence	H	11.7	6.5	4.8	3.7	3.0
	N	10.6	5.9	4.3	3.4	2.8
	K	10.6	5.9	4.3	3.4	2.8
Insurance						
• Hawaii (.8%) of Acquisition Cost	H	51.6	43.6	39.8	40.0	37.2
	N	65.4	55.4	50.6	50.4	47.0
• New Orleans & Key West (1%) of Acquisition Cost	K	67.6	57.8	52.2	52.0	48.6
Maintenance						
• Inspection		2.90	2.90	2.90	2.90	2.90
• Mini-submarine		0.66	0.33	0.33	0.20	0.13
• Marine Growth		0.70	0.35	0.20	0.15	0.10
• Repair Team		1.75	1.75	1.75	1.75	1.75
Service						
• Supplies, Crew Transport		6.0	4.0	2.0	1.7	1.7
• Helicopter/Plane		1.93	1.19	0.91	0.86	0.76
Spare Parts	H	2.11	2.03	1.96	1.97	1.87
	N	2.31	2.22	2.15	2.08	1.98
	K	2.85	2.77	2.34	2.45	2.36
Fuel and Lube Oil		0.99	0.66	0.41	0.40	0.33
Miscellaneous Expenses and Contingencies	H	13.5	9.4	7.8	7.1	6.4
	N	14.3	10.2	8.6	8.0	7.3
	K	14.6	10.5	8.8	8.2	7.4
Totals	H	148.14	102.81	85.96	78.53	70.34
	N	156.94	112.30	95.15	88.04	79.65
	K	159.98	115.55	97.34	90.21	81.73
No. Units		60	30	15	9	6
Cost Per Unit	H	2.49	3.43	5.73	8.73	11.72
	N	2.62	3.74	6.34	9.78	13.28
	K	2.67	3.85	6.49	10.02	13.62

TABLE C-14

OPERATIONAL COSTS FOR 3000 MW PARK

TYPE PLATFORM - CYLINDER

ALUMINUM HEAT EXCHANGERS

Dollars in Millions

		50 MW \$	100 MW \$	200 MW \$	350 MW \$	500 MW \$
Crew						
• Wages & Fringe Benefits	H	54.3	30.1	23.1	17.8	14.2
	N	49.4	27.4	21.0	16.2	12.9
	K	49.4	27.4	21.0	16.2	12.9
• Subsistence	H	11.7	6.5	4.8	3.7	3.0
	N	10.6	5.9	4.3	3.4	2.8
	K	10.6	5.9	4.3	3.4	2.8
Insurance						
• Hawaii (.8%) of Acquisition Cost	H	52.0	46.8	40.2	40.0	37.0
	N	66.6	59.8	50.8	50.6	46.6
• New Orleans & Key West (1%) of Acquisition Cost	K	70.6	62.2	52.4	52.6	48.4
Maintenance						
• Inspection		2.90	2.90	2.90	2.90	2.90
• Mini-submarine		0.66	0.33	0.33	0.20	0.13
• Marine Growth		0.70	0.35	0.20	0.15	0.10
• Repair Team		1.75	1.75	1.75	1.75	1.75
Service						
• Supplies, Crew Transport		6.0	4.0	2.0	1.7	1.7
• Helicopter/Plane		1.93	1.19	0.91	0.86	0.76
Spare Parts	H	2.29	2.12	1.93	2.02	1.87
	N	2.62	2.42	2.05	2.16	1.96
	K	3.56	2.93	2.42	2.61	2.35
Fuel and Lube Oil		0.99	0.66	0.41	0.40	0.33
Miscellaneous Expenses and Contingencies	H	13.5	10.6	7.8	7.1	6.3
	N	14.4	10.7	8.6	8.0	7.2
	K	14.9	11.0	8.8	8.2	7.4
Totals	H	148.72	106.30	86.33	78.58	70.04
	N	158.55	117.40	95.25	88.32	79.13
	K	163.99	120.61	97.42	90.97	81.52
No. Units		60	30	15	9	6
Cost Per Unit	H	2.48	3.54	5.76	8.73	11.67
	N	2.64	3.91	6.35	9.81	13.19
	K	2.73	4.02	6.49	10.11	13.59

TABLE C-15

OPERATIONAL COSTS FOR 3000 MW PARK

		TYPE PLATFORM - SPAR ALUMINUM HEAT EXCHANGERS				
		Dollars in Millions				
		50 MW	100 MW	200 MW	350 MW	500 MW
		\$	\$	\$	\$	\$
Crew						
• Wages & Fringe Benefits	H	65.2	36.2	26.7	20.5	16.4
	N	59.3	32.9	24.3	18.7	14.9
	K	59.3	32.9	24.3	18.7	14.9
• Subsistence	H	11.7	6.5	4.8	3.7	3.0
	N	10.6	5.9	4.3	3.4	2.8
	K	10.6	5.9	4.3	3.4	2.8
Insurance						
• Hawaii (1.6%) of Acquisition Cost	H	105.8	104.0	91.8	87.6	80.0
	N	132.4	131.2	116.2	110.8	100.8
	K	143.8	143.8	125.4	119.6	107.8
• New Orleans & Key West (2%) of Acquisition Cost						
Maintenance						
• Inspection		2.90	2.90	2.90	2.90	2.90
• Mini-submarine		0.66	0.33	0.33	0.20	0.13
• Marine Growth		0.70	0.35	0.20	0.15	0.10
• Repair Team		1.75	1.75	1.75	1.75	1.75
Service						
• Supplies, Crew Transport		6.0	4.0	2.0	1.7	1.7
• Helicopter/Plane		1.93	1.19	0.91	0.86	0.76
Spare Parts	H	2.29	2.12	1.93	2.02	1.87
	N	2.29	2.26	2.10	2.16	1.96
	K	3.59	3.69	3.16	3.17	2.75
Fuel and Lube Oil		0.99	0.66	0.41	0.40	0.33
Miscellaneous Expenses and Contingencies	H	20.0	16.0	13.4	12.2	10.9
	N	21.9	18.4	15.5	14.3	12.7
	K	23.2	19.8	16.6	15.3	13.6
Totals	H	219.92	176.00	147.13	133.98	119.34
	N	241.42	201.84	170.90	157.32	140.83
	K	255.42	217.27	182.26	168.13	149.46
No. Units		60	30	15	9	6
Cost Per Unit	H	3.67	5.87	9.81	14.89	19.97
	N	4.02	6.73	11.39	17.43	23.47
	K	4.26	7.24	12.15	18.68	24.92

TABLE C-16

OPERATIONAL COSTS FOR 3000 MW PARK

		TYPE PLATFORM - SUBMERSIBLE		Dollars in Millions				
		ALUMINUM HEAT EXCHANGERS		50 MW	100 MW	200 MW	350 MW	500 MW
				\$	\$	\$	\$	\$
Crew								
• Wages & Fringe Benefits	H		65.2	36.2	26.7	20.5	16.4	
	N		59.3	32.9	24.3	18.7	14.9	
	K		59.3	32.9	24.3	18.7	14.9	
• Subsistence	H		11.7	6.5	4.8	3.7	3.0	
	N		10.6	5.9	4.3	3.4	2.8	
	K		10.6	5.9	4.3	3.4	2.8	
Insurance								
• Hawaii (1.6%) of Acquisition Cost	H		108.6	94.0	88.6	83.8	81.8	
	N		141.2	121.0	113.4	106.6	103.6	
	K		153.4	129.0	120.2	112.2	108.8	
• New Orleans & Key West (2%) of Acquisition Cost								
Maintenance								
• Inspection			2.90	2.90	2.90	2.90	2.90	
• Mini-submarine			0.66	0.33	0.33	0.20	0.13	
• Marine Growth			0.70	0.35	0.20	0.15	0.10	
• Repair Team			1.75	1.75	1.75	1.75	1.75	
Service								
• Supplies, Crew Transport			6.0	4.0	2.0	1.7	1.7	
• Helicopter/Plane			1.93	1.19	0.91	0.86	0.76	
Spare Parts	H		2.09	1.90	1.89	1.92	1.83	
	N		2.69	2.28	2.20	2.13	1.99	
	K		4.08	3.21	2.97	2.78	2.58	
Fuel and Lube Oil			0.99	0.66	0.41	0.40	0.33	
Miscellaneous Expenses and Contingencies	H		20.2	15.0	13.0	11.8	11.1	
	N		22.9	17.3	15.3	13.8	13.1	
	K		24.3	18.2	16.0	14.5	13.6	
Totals	H		222.72	164.78	143.49	129.68	121.80	
	N		251.62	190.56	168.00	152.59	144.06	
	K		266.61	200.39	176.27	159.54	130.35	
No. Units			60	30	15	9	6	
Cost Per Unit	H		3.71	5.49	9.57	14.41	20.3	
	N		4.19	6.35	11.20	16.95	24.01	
	K		4.44	6.68	11.75	17.73	25.06	

TABLE C-17

OPERATIONAL COSTS FOR 3000 MW PARK						
TYPE PLATFORM - SEMI-SUBMERSIBLE						
ALUMINUM HEAT EXCHANGERS						
Dollars in Millions						
		50 MW	100 MW	200 MW	350 MW	500 MW
		\$	\$	\$	\$	\$
Crew						
• Wages & Fringe Benefits	H	59.8	33.2	24.9	19.2	15.3
	N	54.3	30.1	22.7	17.4	13.9
	K	54.3	30.1	22.7	17.4	13.9
• Subsistence	H	11.7	6.5	4.8	3.7	3.0
	N	10.6	5.9	4.3	3.4	2.8
	K	10.6	5.9	4.3	3.4	2.8
Insurance						
• Hawaii (.8%) of Acquisition Cost	H	65.0	56.6	45.0	43.4	40.6
	N	82.8	71.6	57.0	54.8	51.2
	K	90.2	77.6	61.6	58.0	54.2
Maintenance						
• Inspection		2.90	2.90	2.90	2.90	2.90
• Mini-submarine		0.66	0.33	0.33	0.20	0.13
• Marine Growth		0.70	0.35	0.20	0.15	0.10
• Repair Team		1.75	1.75	1.75	1.75	1.75
Service						
• Supplies, Crew Transport		6.0	4.0	2.0	1.7	1.7
• Helicopter/Plane		1.93	1.19	0.91	0.86	0.76
Spare Parts	H	2.34	2.08	2.02	2.01	1.88
	N	2.69	2.27	2.20	2.13	1.99
	K	4.40	3.66	3.23	2.89	2.59
Fuel and Lube Oil		0.99	0.66	0.41	0.40	0.33
Miscellaneous Expenses and Contingencies	H	15.3	10.9	8.5	7.8	6.8
	N	16.5	12.1	9.4	8.5	7.8
	K	17.4	12.9	10.1	9.0	8.1
Totals	H	169.07	120.46	93.72	84.07	75.25
	N	181.82	133.15	104.10	94.19	85.36
	K	191.83	141.34	110.43	98.65	89.26
No. Units		60	30	15	9	6
Cost Per Unit	H	2.82	4.02	6.25	9.34	12.54
	N	3.03	4.44	6.94	10.47	14.23
	K	3.20	4.71	7.36	10.96	14.88

OPERATIONAL COSTS FOR 3000 MW PARK

TYPE PLATFORM - SPHERE
ALUMINUM HEAT EXCHANGERS

		Dollars in Millions				
		50 MW	100 MW	200 MW	350 MW	500 MW
		\$	\$	\$	\$	\$
Crew						
• Wages & Fringe Benefits	H	54.3	30.1	23.1	17.8	14.2
	N	49.4	27.4	21.0	16.2	12.9
	K	49.4	27.4	21.0	16.2	12.9
• Subsistence	H	11.7	6.5	4.8	3.7	3.0
	N	10.6	5.9	4.3	3.4	2.8
	K	10.6	5.9	4.3	3.4	2.8
Insurance						
• Hawaii (.8%) of Acquisition Cost	H	69.4	45.6	45.6	44.0	40.6
	N	87.8	58.8	58.6	56.2	51.8
• New Orleans & Key West (1%) of Acquisition Cost	K	88.4	60.0	59.8	57.2	52.6
Maintenance						
• Inspection		2.90	2.90	2.90	2.90	2.90
• Mini-submarine		0.66	0.33	0.33	0.20	0.13
• Marine Growth		0.70	0.35	0.20	0.15	0.10
• Repair Team		1.75	1.75	1.75	1.75	1.75
Service						
• Supplies, Crew Transport		6.0	4.0	2.0	1.7	1.7
• Helicopter/Plane		1.93	1.19	0.91	0.86	0.76
Spare Parts	H	2.11	2.11	2.04	2.07	1.90
	N	2.36	2.54	2.40	2.36	2.11
	K	2.50	2.82	2.64	2.57	2.30
Fuel and Lube Oil		0.99	0.66	0.41	0.40	0.33
Miscellaneous Expenses and Contingencies	H	15.3	9.6	8.4	7.6	6.7
	N	16.5	10.5	9.5	8.6	7.7
	K	16.6	10.7	9.6	8.8	7.8
Totals	H	167.74	105.09	92.44	83.13	74.07
	N	181.59	116.32	104.30	94.72	84.98
	K	182.43	118.00	105.84	96.13	86.07
No. Units		60	30	15	9	6
Cost Per Unit	H	2.80	3.50	6.16	9.24	12.35
	N	3.03	3.88	6.95	10.52	14.16
	K	3.04	3.93	7.06	10.68	14.35

18351-10 (W-10,000)

APPENDIX D
MOTIONS AND LOADS DATA

The Figures contained in Appendix D are organized as follows:

<u>Figures</u>	<u>Content</u>
D-1 through D-5	Heave Acceleration vs. Plant Displacement for the ship, cylinder, spar, semi-submersible, and submarine.
D-6 through D-15	Platform motions and CWP Loads vs. Displacement for the sphere.
D-16 through D-47	Platform motions and CWP Loads vs. significant wave height for the ship, cylinder, spar, semi-submersible, submarine and sphere as extrapolated from Hydronautics data.
D-48 through D-59	Ship and semi-submersible motions data for the 50 and 500 MW Plants vs. significant wave height as derived from the Paulling program.
D-60 through D-95	Distributed CWP loads for the 50 through 500 MW ship and semi-submersible as derived from the Paulling program.
D-96 through D-100	Comparison of CWP distributed loads between the 50 and 500 MW ships.

FIGURE D-1

FIGURE D-2

FIGURE D-4

SIG. HEAVE ACCELERATION SPAR PLATFORM

FIGURE D-5

SIG. SURGE AMPLITUDE SPHERE PLATFORM

FIGURE D-6

SIG. PITCH DISPLACEMENT SPHERE PLATFORM

FIGURE Q-7

SIG. HEAVE DISPLACEMENT SPHERE PLATFORM

FIGURE Q-8

SIG. HEAVE ACCELERATION SPHERE PLATFORM

FIGURE D-9

MAX. SIG. AXIAL BENDING MOMENT SPHERE PLATFORM

FIGURE D-10

FIGURE D-13

FIGURE D-14

MAX. SIG. AXIAL BENDING MOMENT SPHERE PLATFORM

FIGURE D-15

SIG. SURGE AMPLITUDE - 100 MW PLATFORMS

FIGURE D-16

SIG. SWAY AMPLITUDE - 100 MW PLATFORMS

FIGURE D-17

SIG. HEAVE AMPLITUDE - 100 MW PLATFORMS

FIGURE D-18

SIG. ROLL AMPLITUDE - 100 MW PLATFORMS

FIGURE D-19

SIG. PITCH AMPLITUDE - 100 MW PLATFORMS

FIGURE D-20

SIG. YAW AMPLITUDE - 100 MW PLATFORMS

CHAPTER D-21

SIG. VERTICAL ACCELERATION - 100 MW PLATFORMS

D-12

FIGURE D-22

18351-10 (W-10,000)

FIGURE D-23

FIGURE D-24

SIG. SWAY, AMPLITUDE - 200 MW PLATFORMS

FIGURE D-25

SIG. HEAVE AMPLITUDE - 200 MW PLATFORMS

SIG. ROLL AMPLITUDE - 200 MW PLATFORMS

FIGURE D-27

SIG. PITCH AMPLITUDE - 200 MW PLATFORMS

FIGURE D-29

SIG. YAW AMPLITUDE - 200 MW PLATFORMS

FIGURE D-29

SIG. VERTICAL ACCELERATION AMPLITUDE - 200 MW PLATFORMS

FIGURE D-30

FIGURE D-31

FIGURE D-32

SIG. SWAY AMPLITUDE - 350 MW PLATFORMS
FIGURE D-33

SIG. HEAVE AMPLITUDE - 350 MW PLATFORMS
FIGURE D-34

FIGURE D-35

FIGURE D-36

SIG. YAW AMPLITUDE - 350 MW PLATFORMS

FIGURE D-37

SIG. VERTICAL ACCELERATION AMPLITUDE - 350 MW PLATFORMS

FIGURE D-38

MAX. CWP AXIAL BENDING MOMENT - 350 MW PLATFORMS

FIGURE D-39

SIG. SURGE AMPLITUDE - 500 MW PLATFORMS

FIGURE D-40

SIG. SWAY AMPLITUDE - 500 MW PLATFORMS

FIGURE D-41

SIG. HEAVE AMPLITUDE - 500 MW PLATFORMS

FIGURE D-42

FIGURE D-45

SIG. VERTICAL ACCELERATION - 500 MW PLATFORMS

FIGURE D-46

MAX. CWP AXIAL BENDING MOMENT - 500 MW PLATFORMS

FIGURE D-47

SIG. SURGE AMPLITUDE - 50 MW PLATFORMS

FIGURE D-48

SIG. SWAY AMPLITUDE - 50 MW PLATFORMS

FIGURE D-49

SIG. HEAVE AMPLITUDE - 50 MW PLATFORMS

FIGURE D-50

SIG. ROLL ANGLE - 50 MW PLATFORMS

FIGURE D-51

SIG. PITCH ANGLE - 50 MW PLATFORMS

FIGURE D-52

SIG. YAW ANGLE - 50 MW PLATFORMS

FIGURE D-53

SIG. SURGE AMPLITUDE - 500 MW PLATFORMS

FIGURE D-54

SIG. SWAY AMPLITUDE - 500 MW PLATFORMS

FIGURE D-55

SIG. HEAVE AMPLITUDE - 500 MW PLATFORMS

FIGURE D-56

FIGURE 0-57

SIG. PITCH ANGLE - 500 MW PLATFORMS

FIGURE 0-58

SIG. YAW ANGLE - 500 MW PLATFORMS

FIGURE D-59

AXIAL DISTRIBUTION OF VERTICAL DEADWEIGHT STRESS -
50 MW SHIP PLATFORM

FIGURE D-60

18351-10 (W-10,000)

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE O-61

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE O-62

18351-10 (W-10,000)

TOP OF CAP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-63

TOP OF CAP 0

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-64

18351-10 (W-10,000)

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-65

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-66

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-67

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-68

TOP OF CAP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-69

TOP OF CAP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-70

18351-10 (W-10,000)

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-71

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-72

TOP OF CAP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-73

TOP OF CAP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-74

D-38

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-75

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-76

18351-10 (W-10,000)
TOP OF CHP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-77

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-78

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-79

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-80

18351-10 (W-10,000)

TOP OF CWP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-31

TOP OF CWP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-32

18351-10 (W-10,000)

TOP OF CWP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-33

TOP OF CWP 0

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-34

TOP OF CWP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-85

TOP OF CWP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-86

18351-10 (W-10,000)

TOP OF CWP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-37

TOP OF CWP 0

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-38

18351-10 (W-10,000)

TOP OF CWP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-89

TOP OF CWP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-90

18351-10 (W-10,000)

TOP OF CAP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-91

TOP OF CAP 0

VERTICAL DEADWEIGHT STRESS DISTRIBUTION

FIGURE D-92

18351-10 (W-10,000)

TOP OF CWP 0

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-93

TOP OF CWP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-94

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEES)

FIGURE D-95

VERTICAL DYNAMIC STRESS DISTRIBUTION

FIGURE D-96

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (BEAM SEAS)

FIGURE D-97

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-98

TOP OF CAP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-99

TOP OF CAP 0

AXIAL DYNAMIC BENDING STRESS DISTRIBUTION (HEAD SEAS)

FIGURE D-100

18351-10 (W-10,000)

APPENDIX E
FIGURES OF MERIT

The information in Appendix E is arranged as follows:

<u>Figures</u>	<u>Subject</u>
E-1 through E-12	FOM's for aluminum and titanium heat exchangers without transmission line, facilities improvement and salvage costs at 0% and 10% interest rates, all hull configurations.
E-13 through E-18	FOM's for aluminum heat exchangers with transmission line and facilities improvement costs at 0% and 10% interest rates, all hull configurations.
E-19 through E-24	FOM's for aluminum heat exchangers with transmission line and facilities improvement costs in a 3,000 MW energy park at 0% and 10% interest rates, all hull configurations.
E-25 through E-30	FOM's for ship and sphere, aluminum heat exchangers plotted against interest rate.

Tables of data reflecting these Figures appear in Appendix D of Reference (3).

E-2

FIGURE E-1

FIGURE E-2

18351-10 (W-10,000)

E-3

E-4

FIGURE E-5

FIGURE E-6

18351-10 (W-10,000)

FIGURE E-7

FIGURE E-8

FIGURE OF MERIT

KEY WEST
TITANIUM H.E.'S
WITH OVERHAUL
W/O TRANSMISSION,
FACILITY, & SALVAGE
INTEREST 0%

F.O.M.

LEGEND

- SHIP
- CYLINDER
- SPAR
- SUBMERSIBLE
- ⊕ SEMI-SUBMERSIBLE
- SPHERE

MW SIZE

FIGURE E-9

E-6

FIGURE OF MERIT

HAWAII
TITANIUM H.E.'S
WITH OVERHAUL
W/O TRANSMISSION,
FACILITY, & SALVAGE
INTEREST 10%

F.O.M.

LEGEND

- SHIP
- CYLINDER
- SPAR
- SUBMERSIBLE
- ⊕ SEMI-SUBMERSIBLE
- SPHERE

MW SIZE

FIGURE E-10

E-7

18351-10 (W-10,000)

E-9

FIGURE OF MERIT KEY WEST

ALUMINUM HEAT EXCHANGERS
WITH TRANSMISSION LINE
& FACILITIES
INTEREST 0%

FIGURE E-15

FIGURE OF MERIT HAWAII

ALUMINUM HEAT EXCHANGERS
WITH TRANSMISSION LINE
& FACILITIES
INTEREST 10%

FIGURE E-16

18351-10 (W-10,000)

E-10

FIGURE OF MERIT NEW ORLEANS

ALUMINUM HEAT EXCHANGERS
WITH TRANSMISSION LINE
& FACILITIES
INTEREST 10%

FIGURE E-17

FIGURE OF MERIT KEY WEST

ALUMINUM HEAT EXCHANGERS
W:T-1 TRANSMISSION LINE
& FACILITIES
INTEREST 10%

FIGURE E-18

18351-10 (W-10,000)

E-11

FIGURE E-19

FIGURE E-20

E-12

FIGURE E-21

FIGURE E-22

18351-10 (W-10,000)

FIGURE E-23

FIGURE E-24

E-14

E-15

18351-10 (W-10,000)

APPENDIX F
RISK EVALUATION
NEW ORLEANS SITE

NOTE: Similar evaluations for New Orleans and
Key West sites are available in Appendix F,
Reference (3).

APPENDIX F

RISK EVALUATION

HULL CONFIG: ALLSIZE: 100, 500 MWSITE: HAWAII

1 of 6

A. HULL SYSTEMS		SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
		100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
1	CONFIGURATIONS												
	1. SPHERE	See overall evaluation in text of report											
	2. SHIP SHAPE												
	3. SPAR												
	4. SUBMERSIBLE												
	5. SEMI-SUBMERSIBLE												
	6. CYLINDRICAL												
2	STRUCTURES												
	1. MATERIALS	6	5	6	5	4	3	4	3	4	3	6	5
	2. CONFIGURATION	4	3	6	5	4	3	4	3	4	3	6	5
3	ARRANGEMENTS												
	1. MISSION SUPPORT	4	4	5	5	4	4	4	4	4	4	4	4
	2. PERSONNEL SUPPORT	8	8	9	9	5	5	4	4	9	9	9	9
	3. PLATFORM SUPPORT	8	8	9	9	7	7	7	7	9	9	9	9
4	MOTIONS												
	1. OPERATIONAL	4	4	7	7	5	5	5	5	7	7	6	6
	2. SURVIVAL	4	4	7	7	5	5	5	5	7	7	6	6
5	INTERFACE AREAS												
	1. OTHER OCEAN SYSTEMS	4	4	4	4	5	5	4	4	4	4	3	3
	2. POWER SYSTEM	4	4	4	4	4	4	4	4	4	4	4	4
	3. TRANSMISSION SYSTEM	3	3	2	2	4	4	3	3	3	3	2	2

APPENDIX F

RISK EVALUATION

HULL CONFIG: ALLSIZE: 100, 500 MWSITE: HAWAII

2 of 6

8. SEAWATER SYSTEMS		SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
		100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
1 COLD WATER SUB-SYSTEMS													
1. INLET PIPE		3	3	3	3	5	5	4	4	4	4	3	3
2. DISCHARGE PIPE		5	5	4	4	5	5	5	5	5	5	4	4
3. PUMPS		5	5	5	5	5	5	5	5	5	5	5	5
4. CWP/HULL CONN.		3	3	3	3	4	4	4	4	4	4	3	3
2 WARM WATER SUB-SYSTEMS													
1. INLET PIPE		5	5	4	4	5	5	5	5	5	5	4	4
2. DISCHARGE PIPE		5	5	5	5	5	5	5	5	5	5	5	5
3. PUMPS		5	5	5	5	5	5	5	5	5	5	5	5
4. WWP/HULL CONN.		5	5	4	4	5	5	5	5	5	5	4	4
3 INTERFERENCE EFFECTS													
1. COLD WATER DISCHARGE													
2. WARM WATER INLET		5	5	5	5	5	5	5	5	5	5	5	5
3. WARM WATER DISCHARGE													
4 INTERFACE AREAS													
1. OTHER OCEAN SYSTEMS		3	3	2	2	3	3	3	3	3	3	2	2
2. POWER SYSTEM		7	7	7	7	7	7	7	7	7	7	7	7
3. TRANSMISSION SYSTEM						NOT APPLICABLE							

APPENDIX F

RISK EVALUATION

HULL CONFIG: ALLSIZE: 100, 500 MWSITE: HAWAII

3 of 6

C. POSITION CONTROL SYSTEMS		SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
		100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
1	STATIC POSITION CONTROL SUBSYSTEM												
	1. ANCHOR	7	6	7	6	7	6	7	6	7	6	7	6
	2. LINE												
	3. CONTROLS												
2	DYNAMIC POSITION CONTROL SUB-SYSTEM												
	1. PRIME MOVER	5	4	6	5	6	5	6	5	5	4	6	5
	2. PROPULSOR												
	3. CONTROLS												
3	PLATFORM PROPULSION												
	1. PRIME MOVER												
	2. PROPULSOR	NOT APPLICABLE											
	3. CONTROLS												
4	INTERFACE AREAS												
	1. OTHER OCEAN SYSTEMS	7	7	7	7	7	7	7	7	7	7	7	7
	2. POWER SYSTEM	8	8	8	8	8	8	8	8	8	8	8	8
	3. TRANSMISSION SYSTEM												

APPENDIX F

HULL CONFIG: ALL

RISK EVALUATION

SIZE: 100, 500 MM

SITE: HAWAII

4 of 6

D. SUPPORT SYSTEMS

MECHANICAL/ELECTRICAL
SUB-SYSTEM

1. AUX. ELECTRICAL
2. COMPRESSED GAS
3. BILGE AND BALLAST
4. FUEL OIL TRANSF./STOR.
5. FIRE EXTINGUISHING
6. LUBR./HYDRAULIC
7. FRESH WATER
8. SANITARY
9. MISC. FLUID DISTRIB.
10. FLUID STORAGE

2	ENVIRONMENTAL CONTROL SUB-SYSTEM
---	-------------------------------------

1. HEATING
2. VENTILATION
3. AIR CONDITIONING

3	PERSONNEL SUPPORT
---	-------------------

1. HABITABILITY
2. MEDICAL
3. OFFICES
4. PERSONNEL STOWAGE
5. COMMISSARY, LAUNDRY

4	LIFE SAVING
---	-------------

1. BOATS AND RAFTS
2. DAMAGE CONTROL.

SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
9	9	9	9	9	9	9	9	9	9	9	9
10	10	10	10	8	8	8	8	10	10	10	10
10	10	10	10	9	9	9	9	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
8	8	8	8	7	7	7	7	8	8	8	8
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	9	9	9	9	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	8	8	8	8	10	10	10	10
10	10	10	10	8	8	8	8	10	10	10	10
10	10	10	10	8	8	7	7	10	10	10	10
10	10	10	10	7	7	6	6	10	10	10	10
9	9	10	10	8	8	8	8	9	9	10	10

APPENDIX F

HULL CONFIG: ALL

RISK EVALUATION

SIZE: 100, 500 MWSITE: HAWAII

5 of 6

D. SUPPORT SYSTEMS
(CONTINUED)

5 PLATFORM SUPPORT

1. SHOPS
2. SPARE PARTS/STOWAGE

6 MATERIAL HANDLING

1. AIR TO SEA
2. SEA TO SEA
3. INTRA PLATFORM

7 NAVIGATION AND
COMMUNICATION

1. RADIO
2. RADAR
3. INTERCOM
4. POSITION SENSING
5. LIGHTS
6. WEATHER MONITOR
7. EXPLORATION AIDS

8 INTERFACE AREAS

1. OTHER OCEAN SYSTEMS
2. POWER SYSTEM
3. TRANSMISSION SYSTEM

SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	9	9	8	8	10	10	10	10
10	10	10	10	9	9	8	8	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
9	9	9	9	9	9	9	9	9	9	9	9
9	9	10	10	8	8	7	7	10	10	9	9
10	10	10	10	9	9	8	8	10	10	10	10
10	10	10	10	10	10	10	10	10	10	10	10
10	10	10	10	9	9	9	9	10	10	10	10
9	9	9	9	9	9	9	9	9	9	9	9
8	8	8	8	8	8	8	8	8	8	8	8

APPENDIX F

RISK EVALUATION

HULL CONFIG: ALLSIZE: 100, 500 MWSITE: HAWAII

6 of 6

E. SYSTEMS ENGINEERING		SPHERE		SHIP		SPAR		SUB		SEMI		CYL	
		100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW	100 MW	500 MW
1	MISSION ANALYSIS												
	1. POWER GENERATION												
	TESTING												
	DEMONSTRATION												
	OPERATION												
	2. CHEMICAL PLANT												
	TESTING												
	DEMONSTRATION												
	OPERATION												
2	COST ANALYSIS												
	1. ACQUISITION	4	3	7	6	5	4	4	3	6	5	5	4
	2. OPERATION	7	6	7	6	6	5	6	5	7	6	7	6
3	SYSTEMS REQUIREMENTS												
	1. CONSTRUCTION	3	2	6	5	3	2	3	2	4	3	4	3
	2. DEPLOYMENT	3	2	6	5	3	2	3	2	4	3	4	3
	3. MAINTENANCE	7	6	7	6	6	5	6	5	7	6	7	6
	4. OPERATION	7	6	7	6	6	5	6	5	7	6	7	6
	5. SAFETY	8	8	8	8	7	7	7	7	8	8	8	8
	6. STABILITY	5	5	7	7	5	5	4	4	6	6	5	5
	7. LOGISTICS	9	9	9	9	9	9	9	9	9	9	9	9
	8. NOISE/VIBRATION	8	8	8	8	8	8	8	8	8	8	8	8
	9. ENVIRONMENTAL PROTEC	7	6	7	6	7	6	7	6	7	6	7	6
	10. MANNING	9	9	9	9	9	9	9	9	9	9	9	9
4	ADMINISTRATIVE REQ'MTS												
	1. CONFIGUR. MGMT.	9	9	9	9	9	9	9	9	9	9	9	9
	2. LICENSES/REG.	5	4	7	6	4	3	4	3	6	5	5	4

18351-10 (W-10,000)

APPENDIX G
ACQUISITION COSTS AND F.O.M. WITH
VARIABLE CWP

TABLE G-1
 OTEC - ACQUISITION COST WORKSHEET -
 VARIABLE CWP

SHIP

		100 MW	200 MW	350 MW	500 MW
Risk Modifier		1.70	1.74	1.82	1.87
Hull System		27	62	138	224
Power, Transmission System		70	140	244	348
CWP:	H	74	148	217	273
	N	95	164	310	389
	K	84	142	263	327
SW Pumps, Support System		44	85	152	220
Positionkeeping	H	7	12	14	20
	N	12	20	22	33
	K	24	39	52	80
Eng'r, Misc(10%)	H	22	45	77	109
	N	25	47	87	121
	K	25	47	85	120
Total, \$M	H	244	492	842	1194
	N	273	518	953	1335
	K	274	515	934	1319
Baseline FOM	H	3.49	3.84	3.96	3.96
	N	3.41	3.74	3.87	3.87
	K	3.27	3.64	3.75	3.75
Utilization - Efficiency Factor		0.59	0.59	0.59	0.59
Acquisition Cost Ratio	H	0.74	0.67	0.66	0.65
	N	0.67	0.65	0.59	0.59
	K	0.70	0.67	0.62	0.61
Modified FOM	H	1.52	1.52	1.54	1.52
	N	1.35	1.43	1.34	1.35
	K	1.35	1.44	1.37	1.35

TABLE G-2
 OTEC - ACQUISITION COST WORKSHEET
 VARIABLE CWP

CYLINDER

		100 MW	200 MW	350 MW	500 MW
Risk Modifier		1.80	1.90	2.05	2.20
HuIT System		47	74	157	255
Power, Transmission System		70	140	244	348
CWP:	H	180	249	481	579
	N	272	370	740	768
	K	225	309	610	732
SW Pumps, Support System		44	85	152	220
Positionkeeping	H	10	12	19	22
	N	17	18	33	36
	K	29	36	73	93
Eng'r, Misc(10%)	H	35	56	105	142
	N	45	69	133	163
	K	42	64	124	165
Total, \$M	H	386	616	1158	1566
	N	495	756	1459	1790
	K	457	708	1360	1813
Baseline FOM	H	3.28	3.81	3.94	4.05
	N	3.22	3.72	3.86	3.93
	K	3.11	3.67	3.72	3.79
Utilization - Efficiency Factor		0.59	0.59	0.59	0.59
Acquisition Cost Ratio	H	.51	.54	.48	.49
	N	.40	.45	.39	.43
	K	.45	.49	.43	.44
Modified FOM	H	0.99	1.21	1.12	1.17
	N	0.76	1.01	0.88	0.99
	K	0.83	1.06	0.94	0.98

OTEC - ACQUISITION COST WORKSHEET -
VARIABLE CWP

SPAR

		100 MW	200 MW	350 MW	500 MW
Risk Modifier		1.91	1.95	2.02	2.08
Hull System		56	76	165	208
Power, Transmission System		70	140	244	348
CWP:	H	64	115	244	231
	N	64	152	349	312
	K	64	131	297	270
SW Pumps, Support System		49	95	170	245
Positionkeeping	H	10	11	19	21
	N	14	20	32	34
	K	50	75	123	143
Eng'r, Misc(10%)	H	25	44	84	105
	N	25	48	96	115
	K	29	52	100	121
Total, \$M	H	274	481	926	1158
	N	278	531	1056	1262
	K	318	569	1099	1335
Baseline FOM	H	2.78	3.17	3.40	3.51
	N	2.69	3.06	3.27	3.40
	K	2.48	2.84	3.04	3.20
Utilization - Efficiency Factor		0.59	0.59	0.59	0.59
Acquisition Cost Ratio	H	0.79	0.79	0.66	0.72
	N	0.78	0.73	0.58	0.66
	K	0.75	0.73	0.61	0.67
Modified FOM	H	1.29	1.48	1.33	1.49
	N	1.23	1.32	1.12	1.32
	K	1.10	1.22	1.09	1.26

TABLE G-4
OTEC - ACQUISITION COST WORKSHEET -
VARIABLE CWP

SUBMARINE

		100 MW	200 MW	350 MW	500 MW
Risk Modifier		2.00	2.05	2.12	2.20
Hull System		67	153	226	436
Power, Transmission System		70	140	244	348
CWP:	H	70	109	182	242
	N	74	133	233	330
	K	70	123	210	286
SW Pumps, Support System		52	100	178	259
Positionkeeping	H	5	9	11	16
	N	15	26	31	40
	K	40	68	92	127
Eng'r, Misc(10%)	H	26	51	84	130
	N	28	55	91	141
	K	30	58	95	146
Total, \$M	H	290	562	925	1431
	N	306	607	1003	1554
	K	329	642	1045	1602
Baseline FOM	H	3.01	3.10	3.35	3.18
	N	2.86	2.96	3.22	3.06
	K	2.69	2.80	3.06	2.92
Utilization - Efficiency Factor		0.59	0.59	0.59	0.59
Acquisition Cost Ratio	H	0.68	0.66	0.63	0.59
	N	0.66	0.63	0.59	0.56
	K	0.65	0.62	0.60	0.57
Modified FOM	H	1.21	1.21	1.25	1.11
	N	1.11	1.10	1.12	1.01
	K	1.03	1.02	1.08	0.98

TABLE G-5
OTEC - ACQUISITION COST WORKSHEET -
VARIABLE CWP

SEMI-SUBMERSIBLE

		100 MW	200 MW	350 MW	500 MW
Risk Modifier		1.77	1.81	1.88	1.94
Hull System		117	139	233	370
Power, Transmission System		70	140	244	348
CWP:	H	63	91	130	155
	N	63	105	162	194
	K	63	96	145	175
SW Pumps, Support System		46	89	158	231
Positionkeeping	H	9	15	17	22
	N	13	23	27	35
	K	48	86	103	146
Eng'r, Misc(10%)	H	30	47	78	113
	N	31	50	82	118
	K	34	55	88	127
Total, \$M	H	335	521	860	1237
	N	340	546	906	1296
	K	378	605	971	1397
Baseline FOM	H	2.68	3.20	3.39	3.16
	N	2.61	3.13	3.33	3.11
	K	2.42	2.91	3.16	2.93
Utilization - Efficiency Factor		0.59	0.59	0.59	0.59
Acquisition Cost Ratio	H	0.70	0.72	0.70	0.68
	N	0.70	0.70	0.67	0.65
	K	0.68	0.68	0.66	0.64
Modified FOM	H	1.11	1.35	1.40	1.27
	N	1.08	1.29	1.30	1.19
	K	0.97	1.16	1.23	1.11

TABLE G-6
OTEC - ACQUISITION COST WORKSHEET -
VARIABLE CWP

SPHERE

		100 MW	200 MW	350 MW	500 MW
Risk Modifier		1.98	2.03	2.11	2.20
Hull System		35	117	169	213
Power, Transmission System		70	140	244	348
CWP:	H	83	134	217	238
	N	107	177	300	326
	K	95	154	259	281
SW Pumps, Support System		51	99	177	259
Positionkeeping:	H	10	18	25	28
	N	22	37	53	57
	K	29	50	72	86
Eng'r, Misc(10%)	H	25	51	83	109
	N	29	57	94	120
	K	28	56	92	119
Total, \$M	H	274	559	915	1195
	N	314	627	1037	1323
	K	308	616	1013	1306
Baseline FOM	H	3.35	3.29	3.61	3.68
	N	3.21	3.17	3.48	3.58
	K	3.15	3.12	3.43	3.51
Utilization - Efficiency Factor		0.59	0.59	0.59	0.59
Acquisition Cost Ratio	H	0.68	0.68	0.67	0.71
	N	0.62	0.62	0.60	0.65
	K	0.65	0.65	0.63	0.67
Modified FOM	H	1.34	1.32	1.43	1.54
	N	1.17	1.16	1.23	1.37
	K	1.21	1.20	1.27	1.39