DOE/ET/4065--1 (Exect Summ)

MR&S Report No. 5142-6

FINAL REPORT
OTEC PLATFORM CONFIGURATION & INTEGRATION

EXECUTIVE SUMMARY

Prepared For

U.S. Department of Energy
Division of Solar Energy
600 E. Street, N.W.
Washington, D.C. 20545

under

DoE Contract No. EG-77-C-01-4065

by

M. ROSENBLATT & SON, Inc.
350 Broadway
New York, New York 10013

MR&S Report No. 5142-6

FINAL REPORT

OTEC PLATFORM CONFIGURATION & INTEGRATION

EXECUTIVE SUMMARY

Prepared For

U.S. Department of Energy
Division of Solar Energy
600 E. Street, N.W.
Washington, D.C. 20545

under

DoE Contract No. EG-77-C-01-4065

by

M. ROSENBLATT & SON, Inc.
350 Broadway
New York, New York 10013

July 26, 1978

ABSTRACT

The commercialization of the OTEC platforms requires the following basic decisions to be reached prior to initiation of any final design and construction efforts:

- o Selection of the best platform hull shape
- o Selection of the best cold water pipe configuration
- o Selection of the best positioning system
- o Development of a conceptual design for platform ocean systems

The Department of Energy project "OTEC Platform Configuration and Integration" sought to arrive at these decisions in two phases. The first phase consisted of evaluation investigations to obtain the ranking of candidate ocean systems, and the second phase involved the performance of conceptual designs for two selected platform candidates.

This report provides a brief but comprehensive summary of the original four volume final report.

In the first phase studies, an evaluation methodology was developed for analyzing the ocean system requirements against site criteria and a final evaluation of integrated OTEC commercial platform candidates was performed. A ranking of candidate platforms was obtained as the end result.

For Phase-II studies, M. Rosenblatt & Son, Inc. project team was given the SPAR and the SPHERE platforms to perform not only the conceptual designs for, but also cost and time schedules and sensitivity analyses. The commercial plant size was specified to be 400 MWe (net).

All conceptual design work was performed for the baseline site of West Coast of Florida. The cost differentials and other considerations involved with deploying the platforms in the New Orleans and Puerto Rico sites were also determined.

A demonstration plant of 100 MWe (net) capacity, to fill the gap between test platforms and commercial plants, was also investigated, and a project plan was developed.

As an end product of the complete study, the costs for the SPAR and the SPHERE platforms are reported both in terms of acquisition costs in 1978 dollars and life cycle costs in dollars per kilowatt.

ACKNOWLEDGMENT

This Department of Energy study on "OTEC Platform Configuration and Integration" was conducted by M. Rosenblatt & Son, Inc. (MR&S) Basic Ship Design division, New York headquarters. The MR&S OTEC project team assigned to this study consisted of:

Nedret S. Basar	- Project Manager
John C. Daidola	- Head - Naval Architecture
Richard C. Sheffield	- Project Engineer for Sphere
H. David Kaysen	- Project Engineer for Spar

Also contributing to the study efforts on an as-needed basis were the following MR&S personnel:

Zachary Awer	- Head - Mechanical Engineering
Stuart H. Grossman	- Head - Electrical Engineering
Alfred D. Issacson	- Head - Marine Engineering
John Johnson	- Senior Naval Architect
Sam Tsui	- Structural Engineer, Naval Architect
Walter Lu	- Naval Architect
Doug Graham	- Naval Architect
Jim Bister	- Design Engineer

A technical management team consisting of Mr. Naresh M. Maniar (Vice President), Captain Perry W. Nelson (Vice President, Operations), and Mr. Lester Rosenblatt, President) periodically reviewed the work for the present project.

MR&S as prime contractor had the backing of the personnel from its subcontractors and consultants:

- Messrs. Robert J. Vondrasek (Project Manager), John Klein and Dr. Han Liu (Project Engineer) of Burns & Roe, Inc.

- Dr. C. H. Kim and Dr. Hires of Davidson Laboratory of the Stevens Institute of Technology.

- Dr. John McDermott of U.S. Steel Research Laboratory.

- Mr. Eivind Hjellum of Shipping Research Services, Inc.

- Professor Willard J. Pierson of the City College of New York.

- Mr. Charles Fink of Tuned Sphere International, Inc.

- Mr. David Waller of Waller Associates, Inc.

- Mr. Walter Farmer of Oceanic Development Company, Inc.

- Mr. James Childers of Childers Engineering Company

- Dr. Roderick Barr of Hydronautics, Inc.

The MR&S project team would like to thank and acknowledge the guidance provided by the following individuals in various government departments and monitoring agencies:

- Messrs. Sigmund Gronich, Wilbur Sherwood, William Smith, and Drs. Lloyd Lewis and Abrahim Lavi of the Department of Energy, Solar Energy Division.

- Mr. David Price and Dr. Terence McGuinness of the National Oceanic and Atmospheric Administration, Ocean Engineering.

- Messrs. Walter Trzaskoma and Herbert Woods of Gilbert Associates, Inc.

For their guidance and assistance in reviewing the platform configurations, acknowledgment and appreciation must be extended to Radm. R. Burk, USN (ret), Captain W. Howerton, and Mr. Fred Agdern of the Hull Recommendations Board.

Also, acknowledged, with gratitude, is the help furnished by the following organizations:

- Engelhardt Systems Corporation
- Owens Corning Fiberglas Corporation
- Parsons Brinkerhoff Quade & Douglas
- Price Brothers, Co.
- Simplex Corporation
- Sperry Systems, Inc.
- Symons Corporation
- American M.A.N. Corporation
- Amertap Corporation
- B.F. Goodrich Corporation
- Florida Power Corporation of St. Petersburg, Florida
- Puerto Rico Water Resources Authority
- Worthington Corporation

TABLE OF CONTENTS

Page No.

LIST OF FIGURES

LIST OF TABLES

LIST OF TABLES, continued

SECTION 1.0

INTRODUCTION AND SUMMARY

1.1 Introduction

Commercialization of the Ocean Thermal Energy Conversion (OTEC) concept is the main objective of the current Department of Energy (DoE) OTEC programs. To arrive at this objective, the DoE, and prior to that the National Science Foundation (NSF) and the Energy Research and Development Administration (ERDA), had sponsored a number of research and development projects to arrive at feasible methods of applying the ocean thermal energy conversion process. These individual studies covered the following various areas of OTEC plant development:

- The hull/platform: the design of a marine vessel to house the OTEC power cycle as well as all other installations making up the complete ocean systems.
- The power cycle: development of an OTEC cycle, consisting of the evaporators, condensers, working fluid loops, turbines, generators, demisters, and power conditioning equipment up to the riser power cable.
- Site environment: a study of site conditions, including parameters such as the wind, waves, current, depth, bottom conditions, seasonal weather and temperature differentials at the specified OTEC sites.
- Electric power cable: the methods and details of transmitting the electrical power generated on the platform to the shore, including a riser segment, a bottom segment, and their connections.
- Biofouling/Corrosion: effects of biofouling and corrosion on any of the OTEC components leading to degraded performance and the prevention and control of biofouling and corrosion for each ocean engineering element.

In addition to these, the institutional/regulatory constraints applicable to projected operation of OTEC commercial platforms and the legal problems that may have to be faced have also been subjected to studies [1].*

Developing electrical energy from the thermal energy contained in the tropical oceans requires the use of a marine platform on which all systems needed for the operation of the OTEC plant can be installed. The determination of the most feasible shape for this platform and the development of a conceptual design as well as cost estimates and time schedules are the subjects of this project.

As defined by the DoE, the OTEC commercial platform would contain all seawater handling, biofouling control, and power cycle components and facilities, and "if appropriate, energy intensive product production and support facilities". It would also provide for interface with the cold water pipe, the power delivery cable, and station keeping systems. It would contain hotel and support accommodations for the OTEC plant operating and maintenance personnel, including OTEC plant auxiliaries, storage, and all floating facilities for energy intensive products.

* The numbers in brackets denote similarly numbered references at end of report.

Preceding page blank

The above definition of the hull/platform is applicable to all versions of OTEC power generation and its use. The present study, however, concerns itself with only one version of the OTEC power generation and use: it is specifically for the transmission of OTEC generated electricity to a shore-based electrical utilization network for further distribution.

M. Rosenblatt & Son, Inc. was one of three contractors who were assigned 5 manyear effort contracts to perform this study. The project was performed under Department of Energy Contract #EG-77-C-01-4065, it was initiated in July 1977, and completed in July 1978.

The study consisted of the following main Tasks:

Task 1 - Data assembly and synthesis

Task 2A - Systems and Requirements Analysis

Task 2B - Evaluation Plan

Task 3 - Technology Review

Task 4 - Systems Integration and Evaluation

Task 5 - Conceptual Design

Task 6 - Facilities and Equipment

Task 7 - Development Plan for Demonstration Unit

Task 8 - Cost and Time Schedule

Task 9 - Site Sensitivity

The final report for the complete project is presented in three separate volumes. Volume I reports the results of Tasks 1 through 4, and Volume II addresses the results of Tasks 5, 6, 8 and 9.

The first two volumes therefore report the results for the commercial OTEC plants. The commercial OTEC plant is different from a demonstration unit. It is of larger capacity; the actual output capacity was established by the DoE at the end of the first phase of the project.

Detailed information and the conceptual design drawings are presented in a separate volume "Appendixes to Volume II".

Volume III addresses the results of Task 7 and reports the studies performed on a development plan for the "Demonstration Plant".

1.2 Summary

The study was conducted in two phases. The first phase covered tasks 1 through 4 and consisted of a detailed evaluation of numerous candidate platform hull shapes. The Department of Energy had specified six generic hull shapes:

- o Surface Ship
- o Submersible
- o Semi-submersible
- o Spar
- o Disc (Cylindrical Surface Barge)
- o Sphere

The MR&S team opted to study a tubular truss type platform as a seventh generic hull shape.

The second phase covered Tasks 5 through 9 and consisted of conceptual designs, analyses of facilities and equipment requirements, cost and time estimates, and site sensitivity analyses, for two platforms selected by the DoE for candidate commercial plants, as well as the development of a project plan for a demonstration plant.

On the basis of results obtained from the detailed evaluation studies and analyses performed in Phase I, the following platforms were recommended to the DoE, by the MR&S team, as the most feasible candidates for commercial OTEC platforms, in order of priority:

1. Tubular Truss
2. Submersible
3. Spar
4. Semi-submersible
5. Sphere

It was concluded, based on preliminary cold water pipe stress analyses, that the surface ship type platforms with integral cold water pipes would be subjected to much larger wave-induced bending moments than those for platforms with submerged main bodies.

The DoE, after reviewing the conclusions and recommendations of all three platform contractors, assigned to MR&S the SPAR and SPHERE platforms for Phase II studies; and established the commercial platform output capacity to be 400 MW_e (net).

MR&S team generated two complete conceptual designs, one for a "Spar" type platform hull shape with inboard heat exchangers and one for a "Sphere" type platform also with inboard heat exchangers.

The "Spar" platform is a vertical axisymmetric body with a high length-to-diameter ratio. The main hull is completely submerged, and a slender access trunk leads to the surface. This design minimizes motions. All OTEC power and seawater systems are located in the main hull. Control and test facilities, offices, and the platform's hotel facilities are located in the deckhouse, (Figure 8).

The "Tuned Sphere" platform has substantially evolved from its original concept [2]. The lower half of the platform is hemispherical with the exception of the fairing into the cold water pipe well. The upper platform has been extensively modified, (Figure A).

Cost economics and fabrication problems eliminated steel hulls for both platforms. Reinforced concrete became the material of choice. Hulls and seawater piping were designed to take the static water pressure head (a function of depth) and a wave overpressure. Decks were designed to take a 400 psi live load when not otherwise loaded. An ANSYS analysis was performed on each hull to confirm the structural design calculations.

The cold water pipe selection was made for each platform with the aid of computer analysis techniques. Hull motions for each platform were predicted using a computer program. These responses were then used in both cold water pipe stress analysis computer programs available to optimize cold water pipe designs for each platform. These analyses yielded two optimized pipes for each platform, coincidentally of similar characteristics. The first was a double-walled steel pipe with buoyancy chambers. The second, which was eventually selected, was a single walled pipe formed of glass-reinforced plastic with 8" (.203m) wall thickness, and a rigid hull attachment for both platforms. Scenarios for manufacturing, assembling, deploying, and attaching these pipes were developed.

The arrangements of the seawater systems were the primary factors in the evolution of both OTEC platform hulls. To achieve maximum plant efficiency, the systems were optimized, considering limitations on equipment, resource availability, and platform geometry. Arrangements of the other power, support, and auxiliary systems followed.

Drag calculations showed that the forces on the platforms at the primary site were tremendous. At all sites the size of the platforms and the resultant drag forces ruled out the use of dynamic positioning systems because of size, cost, and power consumption. While a multipoint mooring system could be developed for the other sites, the prime site was found to require the use of a 3 leg "hollow cylindrical link" (HCL) mooring system. Analysis of watch circle data showed no need for a tensioning winch system.

Extensive investigations were performed for the construction and deployment of both platforms. Analyses showed that construction of both platforms had to be accomplished in phases, due to their immense size. The optimum land-based construction site, was found to be on the Florida panhandle. An intermediate construction site at the head of the DeSoto canyon in the Gulf of Mexico would be used, followed by final construction at the selected commercial OTEC deployment site.

The development of these construction/deployment scenarios interfaced continuously with the parallel efforts to determine the critical facilities and equipment, and cost and time schedules.

No existing facilities can currently handle the Phase I construction. However, following European practice for large concrete construction projects, few problems are foreseen in developing a site, or perhaps even an artificial island if cost economics should prove to be promising.

The total acquisition, operation, and life cycle costs for the two platforms, in terms of $/KW, are estimated to be, per platform:

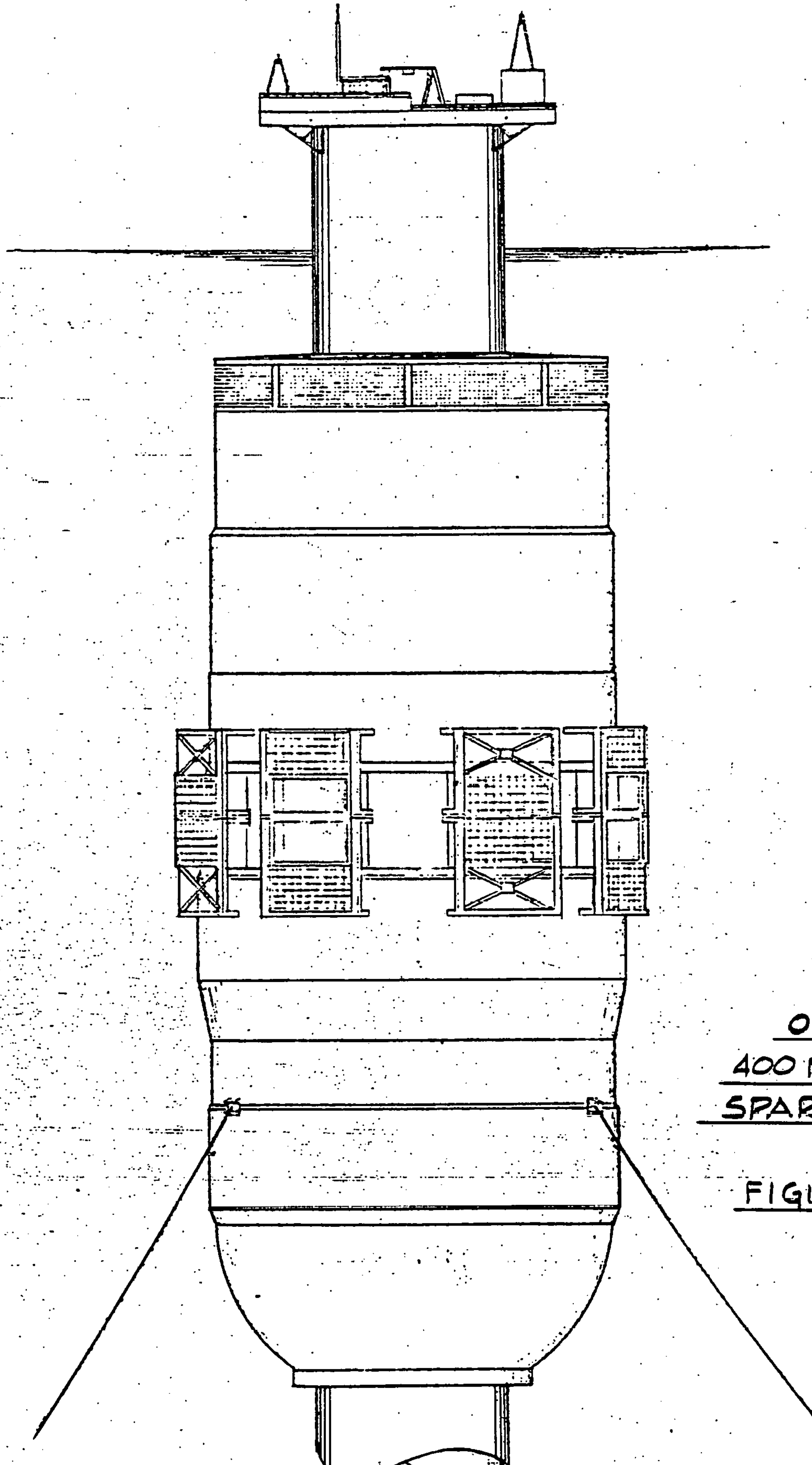
	Sphere	Spar
Acquisition	2690	2357
Operation	1755	1596
Life Cycle	4445	3953

The sensitivity of the OTEC plants to the environmental conditions at alternate sites and its impact on platform designs were also studied. These studies revealed that:

- o Current drag at both alternate sites (New Orleans and Puerto Rico) was considerably less than the baseline (West Coast of Florida) site, allowing a reduction in the mooring system costs.
- o More total thermal resource would be available at the Puerto Rico site than at the other two sites.
- o The baseline site is farthest from its nearest landfall, causing it to be the extreme in costs for power transmission and personnel/supply transfer.

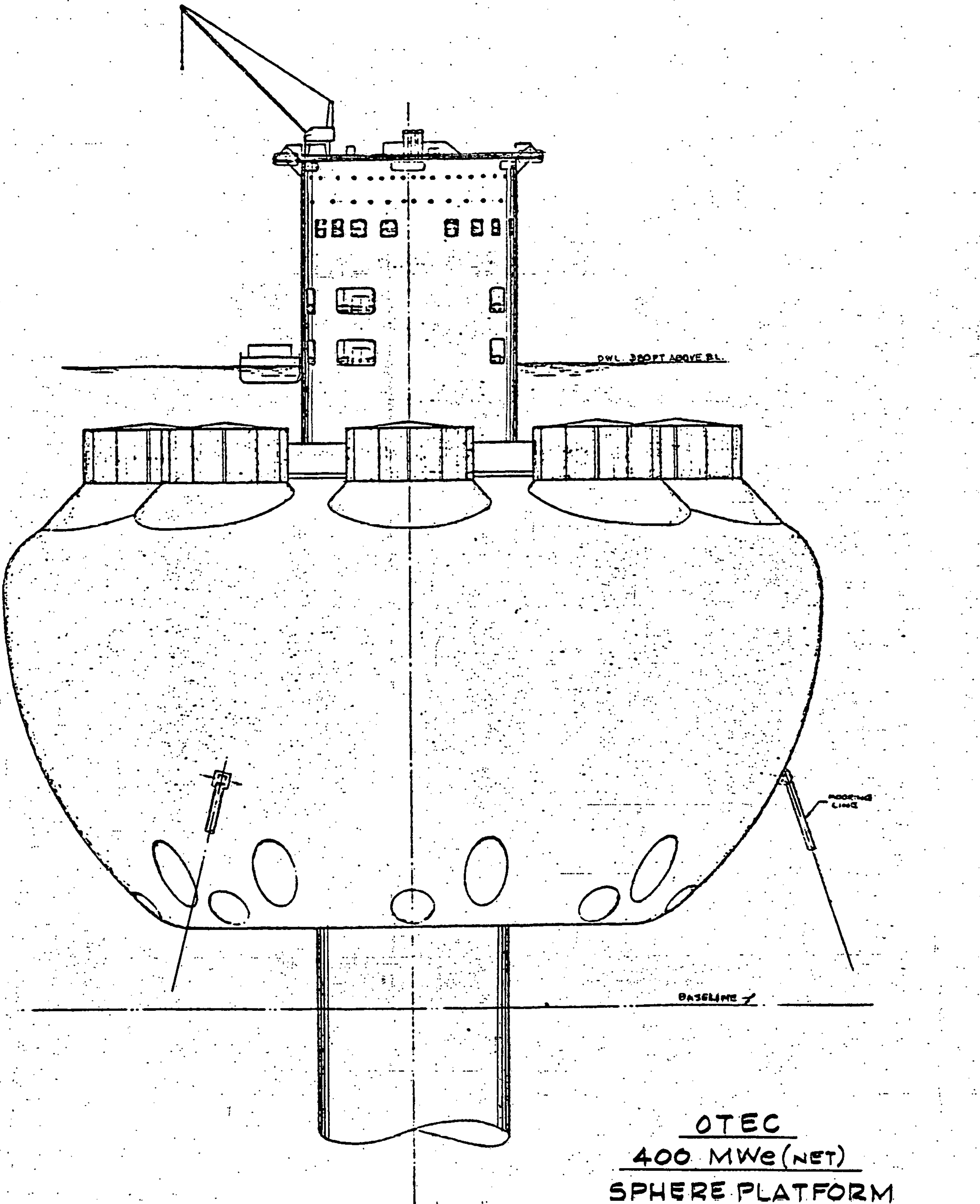
It was concluded on the basis of all items discussed above that:

- o The Spar platform, with inboard heat exchangers as assigned to MR&S, appears to be preferable to the Sphere configuration.
- o A conservative estimate for one Spar platform construction would be three years (as opposed to nearly four years for the Sphere).
- o The most logical choice for the "Demonstration Plant" size would be 100 MW_e.



OTEC
400 MWe (NET)
SPAR PLATFORM

FIGURE B



OTEC
400 MWe (NET)
SPHERE PLATFORM

FIGURE A

SECTION 2.0

SYSTEMS ENGINEERING AND INTEGRATION

2.1 Platform Ocean Systems - General

The objective of the ocean systems, when integrated with the electrical transmission system and the OTEC power cycle, is to generate sufficient power at reasonable cost to be attractive for commercial applications. The attractiveness will be based on the minimum installation and operating costs in terms of $/KW for the platforms which best meet the system requirements. The ocean systems must perform within requirements dictated by the characteristics of the power cycle, the electrical transmission system, the site characteristics, and the energy park configuration.

The commercial application of ocean thermal energy conversion can be summarized as shown in Table 1. As seen there, the end output of the OTEC plants could be either electrical power or energy intensive products. The present project considers the case of the electrical power generation only. The production of energy intensive products by the use of OTEC generated electricity on board the platform plants themselves is being performed by others [3].

The basic scenario as specified by the DoE for a commercial OTEC application comprises an energy park consisting of a number of individual platforms, each producing a certain level of electrical energy output. The individual platform would interface with the macroscopic support facilities and with the interplant and shore power transmission lines. The platforms would be spaced on the basis of not perturbing the thermal resource availability at the specified ocean site. Each platform, as seen in Table 1, would consist of the OTEC power equipment installations, the electrical transmission system interface (the power conditioning equipment), and the ocean systems themselves that comprise the platform.

The first task undertaken to arrive at this objective was the development of a work breakdown structure to enable a thorough analysis and evaluation of the ocean systems.

2.1.1 Work Breakdown Structure

The ocean systems making up the complete commercial OTEC platform are best explained in the third level work breakdown structure shown in Table 2.

It must be noted that this work breakdown structure (WBS) was developed by MR&S on the basis of an original WBS supplied by the DoE. It was modified to suit the needs of development specifically for the purpose of evaluating the multitude of possible shapes and configurations of the platform hulls and various systems. As such, it includes hardware as well as software. A more thorough WBS was later developed in the course of this project prior to the initiation of Phase II work as a result of a joint effort by the three platform contractors, the DoE, and the NOAA.

2.1.2 Ocean Systems Requirements and Constraints

In general, the ocean system is expected to satisfy the following requirements:

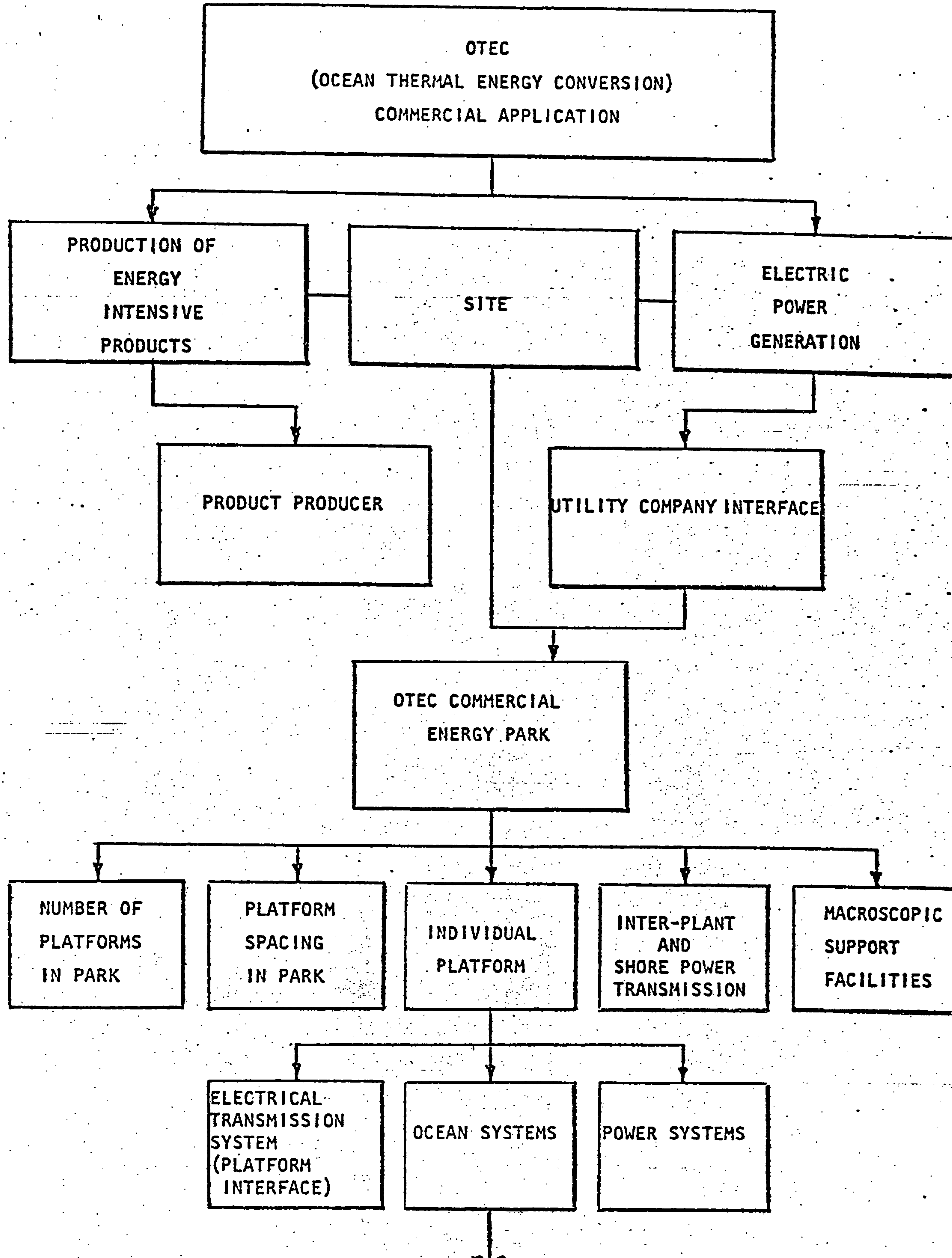

OTEC
(OCEAN THERMAL ENERGY CONVERSION)
COMMERCIAL APPLICATION
PRODUCTION OF ENERGY INTENSIVE PRODUCTS
SITE
ELECTRIC POWER GENERATION
PRODUCT PRODUCER
UTILITY COMPANY INTERFACE
OTEC COMMERCIAL ENERGY PARK
NUMBER OF PLATFORMS IN PARK
PLATFORM SPACING IN PARK
INDIVIDUAL PLATFORM
INTER-PLANT AND SHORE POWER TRANSMISSION
MACROSCOPIC SUPPORT FACILITIES
ELECTRICAL TRANSMISSION SYSTEM (PLATFORM INTERFACE)
OCEAN SYSTEMS
POWER SYSTEMS

TABLE: 1

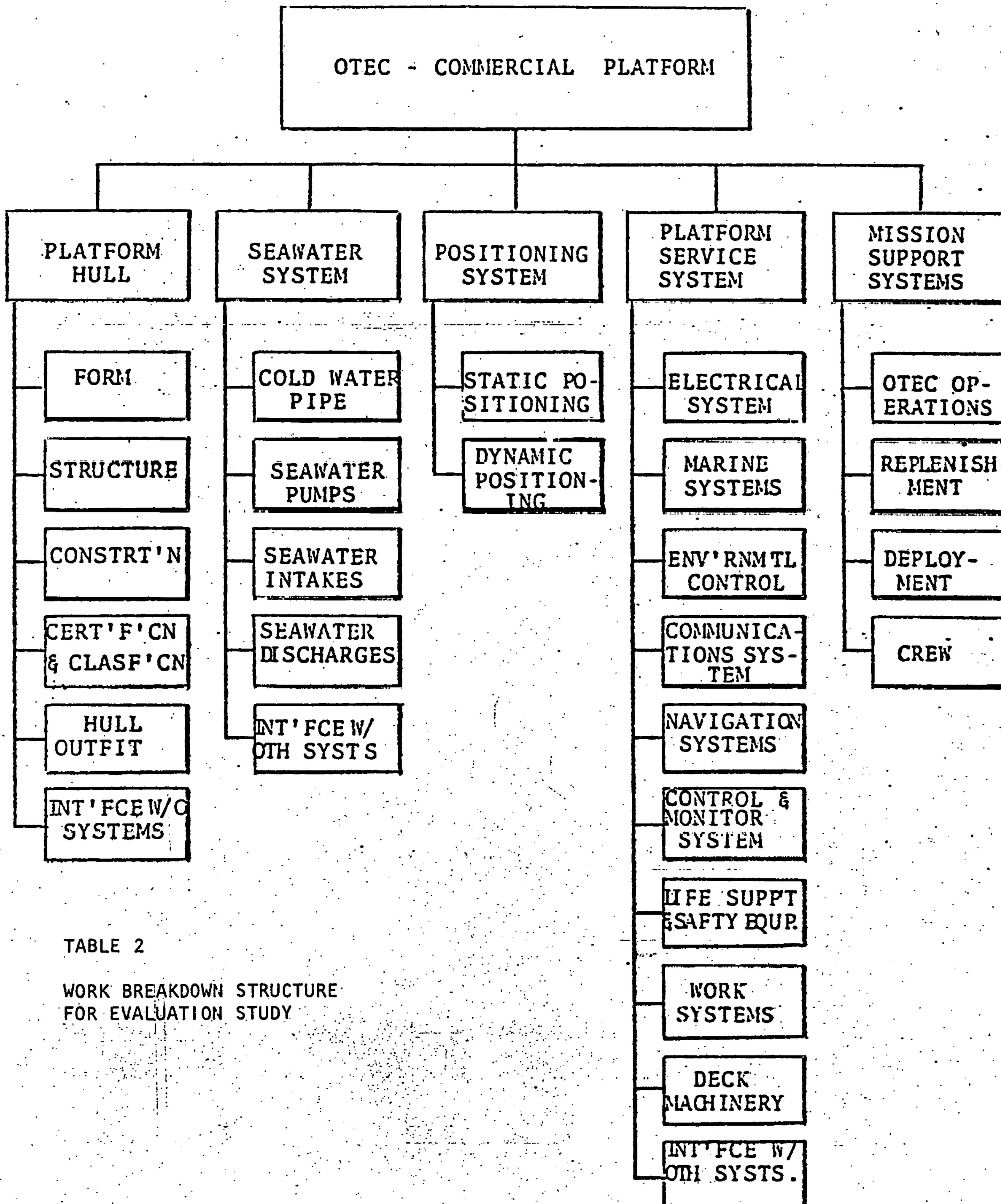


TABLE 2

WORK BREAKDOWN STRUCTURE FOR EVALUATION STUDY

- Provide a satisfactory platform to contain and support the power system and other ancillary equipment.
- Provide sufficient continuity of operation to ensure commercial viability.
- Enable construction of major platform components in the United States.
- Survive the expected extreme environmental events at all the sites considered.
- Exhibit 40 year service life.
- Provide for maintenance or replacement of internal equipment.
- Deliver required quantity of cold and warm seawater to the power system.
- Maintain commercially competitive costs of the final output power.

In order to meet the above mentioned requirements, various systems of the OTEC platform must exhibit certain characteristics and comply with certain conditions. Given below is a summary of the requirements and constraints for each major ocean system.

a. Platform Hull

The platform hull shall support the power system, the seawater system and service systems, and shall provide living quarters for the crew. The platform shall be sufficiently stable and structurally sound to permit electrical production during even the most severe storm conditions anticipated except hurricane conditions. For each of the seven generic hull shapes the forms, capacities, arrangements, the stability, drag characteristics, motions and loads, structural scantlings, construction considerations, costs, certification requirements, and outfitting requirements were investigated.

b. Seawater System

The seawater system must transport sufficient quantities of cold and warm water to the power system for the production of a specified output power per platform. The amount of seawater required based on the power system design data is about 70 GPM per kilowatt warm water, and 71.8 GPM per kilowatt cold water (assuming a power plant efficiency of 2.5% and a cold and warm water temperature range of 4°F).

c. Positioning System

The basic objective of the positioning system is to maintain the OTEC plant on station within a specified tolerance, to offer low acquisition, operation, and maintenance costs, and to require low parasitic power consumption. The requirements must be determined by the effects of site conditions, platform drag forces, economic considerations, and the reliability of new applied technology. Two positioning systems, namely dynamic thrusters and anchor mooring systems, must be considered and a selection must be made of one or the other, or a combination of both.

d. Platform Service Systems

The platform service systems, as indicated in Table 2, consist basically of the electrical and mechanical installations, interior communications systems, environmental control and monitoring systems, navigation and life support systems, deck machinery, and other work systems.

e. Mission Support Systems

Mission support system considerations shall include, but not be limited to, the following equipment and systems:

1. OTEC control and monitoring systems
2. Equipment and spare parts storage and handling installation
3. Replenishing services, including supply vessel landing and helicopter landing
4. Deployment facilities including transportation and towing, and requirements for the complete OTEC platform

All of the above requirements and constraints for the five major ocean systems and their subsystems were investigated in detail. However, the systems requirements considered herein were used specifically for the development of an evaluation and ranking of the platforms for Phase I work. Some of the requirements were changed in some specific areas including OTEC power module size, cold water pipe diameters, characteristics of OTEC sites, etc. for the Phase II work.

2.2 Platform Hull Studies

2.2.1 Variations of Generic Shapes and Candidate Configurations

The configurations of OTEC commercial platforms from previous studies were reviewed and new configurations were developed and analyzed as possible candidates for consideration in the evaluation. It was seen that essentially they belong to one of the following generic types:

- Spar Buoy - main hull below water surface, smaller "spar" pierces surface for access.
- Tubular Truss Structure - network of truss members connected to a submerged main hull.
- Surface Floating Vertically Axisymmetric - cylindrical main hulls.
- Surface Shipshape
- Surface Sphere
- Semi-Submersible
- Submersible

2.2.2 First Screening

All possible variants of each platform shape were subjected to a preliminary screening and the most obviously impractical variants were eliminated from further consideration. With the addition of some further variants of the spar and disc type platforms, a total of 84 hull shapes were entered into the preliminary screening evaluation process and they were graded in accordance with the evaluation methodology developed for this purpose.

The variants that received the highest grades for each generic hull shape were the following:

- o <u>Shipshape</u>
  - . Surface Hull with Integral Cold Water Pipe (CWP)
  - . Surface Hull with Detached CWP
- o <u>Submersible-Integral CWP</u>
  - . Elliptical with Access Trunk, Inboard Heat Exchangers (HX)
  - . Elliptical/Access Trunk/Outboard HX
- o <u>Semi-Submersible-Integral CWP</u>
  - . Inboard HX
  - . Outboard HX
- o <u>Spar-Integral CWP</u>
  - . Mono-hull
  - . Multi-hull
- o <u>Sphere-Integral CWP</u>
  - . Inboard HX
  - . Outboard HX
- o <u>Disc-Integral CWP</u>
  - . Inboard HX
  - . Outboard HX
- o <u>Tubular Truss</u>
  - . Submerged Main Hull

The above 13 hull configurations were selected as candidates for integration with other ocean systems to form the OTEC platform.

A schematic representation of these integration candidates can be seen in Figure 1.

2.2.3 Arrangements for Candidate Hull Systems

For each of the 7 generic hull shapes, an advanced concept design was started. As the feasibility studies for the platform hull, seawater, and positioning systems progressed, the designs were modified and arrangement sketches were developed for each hull. Based on the thermal resource studies and constructability considerations, it was found necessary to develop arrangements for platform output sizes ranging from 100 MW to 400 MW.

CANDIDATE HULLS FOR FEASIBILITY STUDIES

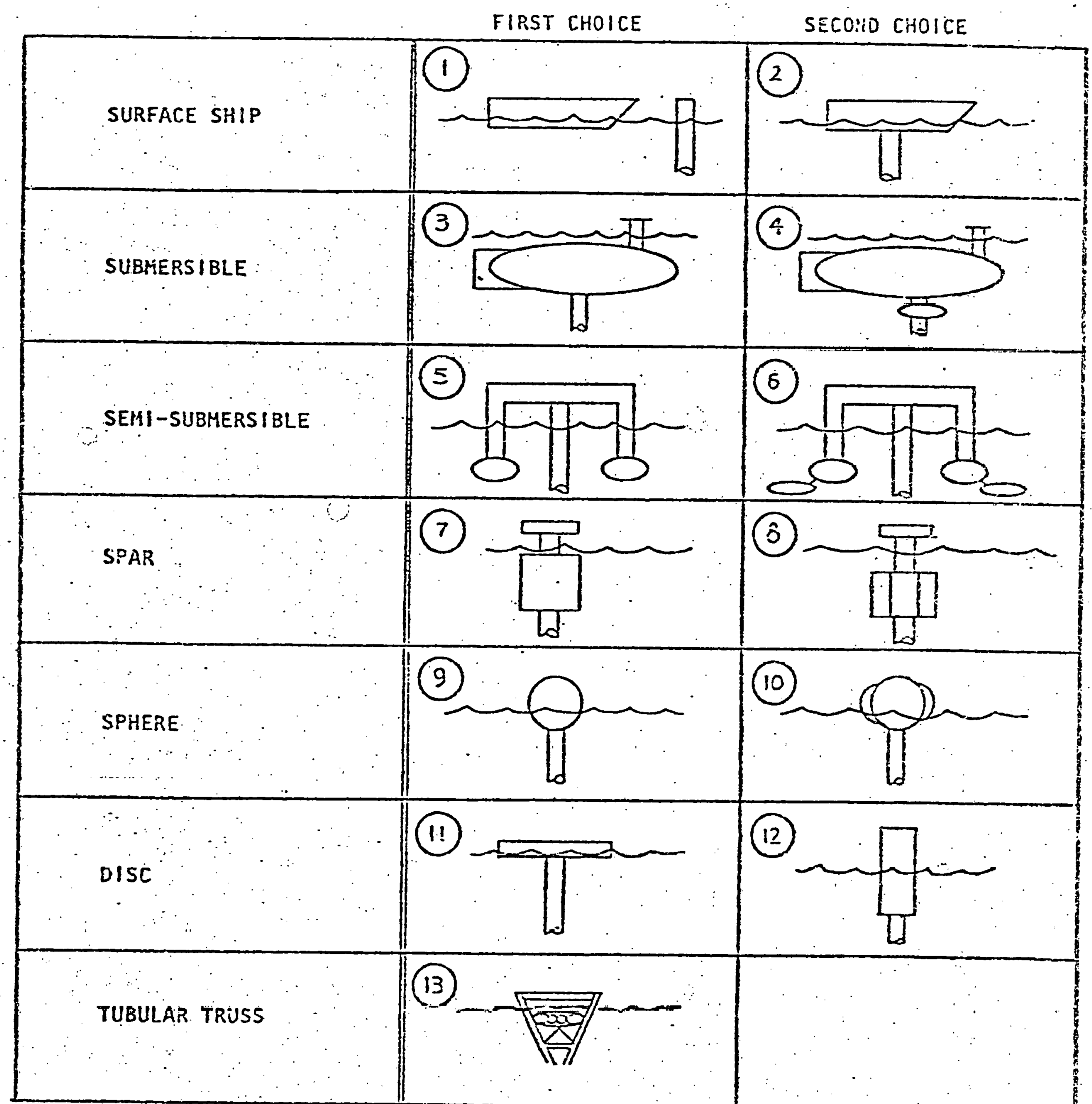


FIGURE 1

The concept arrangements for the 100 MW platforms are included in Figures 2 through 8 for different generic shapes. As it can be seen in these illustrations, an integral CWP was assumed for all shapes for purposes of uniformity.

The concept arrangements for the 200 MW and the 400 MW platforms were also developed on the basis of detailed calculations performed in establishing the platform sizes. The most important guideline, naturally, was to obtain a platform size capable of containing the necessary number of power modules to give the desired output and to provide sufficient buoyancy for supporting the complete ocean systems to be installed on board.

Drag calculations were performed for the generic platform hull configurations under consideration for the three sites: Key West, New Orleans, and Puerto Rico. Both normal and extreme conditions of wind and current were considered using the data from the site environmental package [4].

Only static drag was considered with the wind and current acting in the same direction. The total platform drag is broken into three components: wind hull drag, current hull drag, and cold water pipe drag.

Figure 9 is a plot of static drag force vs. plant size for the normal conditions at the Puerto Rico site.

2.3 Evaluation Procedure

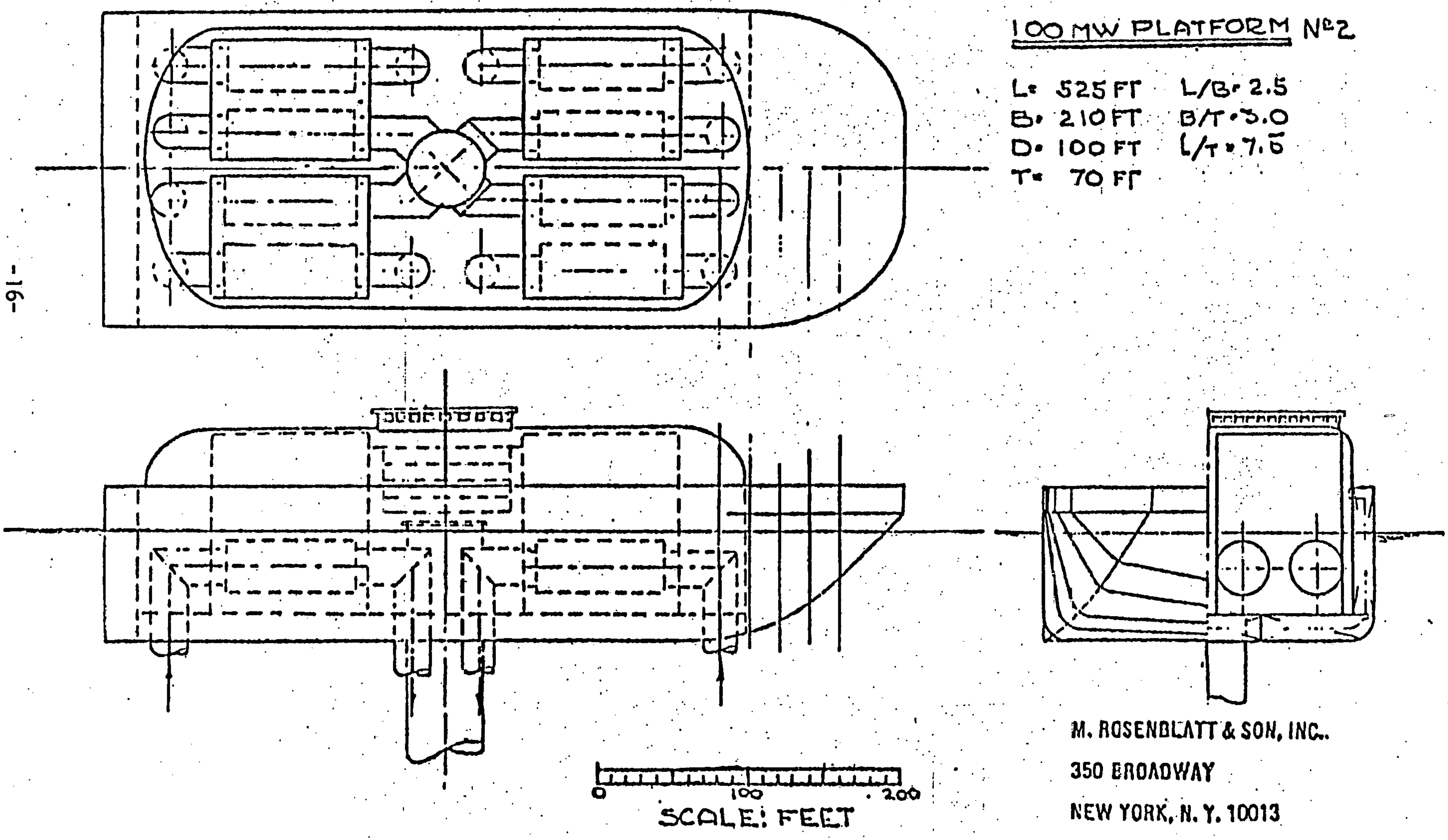
The evaluation methodology developed with the purpose of establishing the ranking of numerous generic hull shapes when integrated with other ocean systems, can be summarized as shown in Table 3. The methodology basically consists of a preliminary evaluation of the system and subsystem candidates and integration of various systems into the complete OTEC platform. The integrated candidates are then graded and evaluated using weighting factors developed for this purpose and the rankings for the final integrated platforms are thereby obtained.

The evaluation process, consisting of successive matrices for analyzing individual ocean systems as well as integrating them, is developed on the basis of a method outlined in [5].

When performing the preliminary evaluation of system and subsystem candidates, as shown in Table 3, it was established that the platform service and the mission support systems would not influence the selection of platform configurations most suitable to the intended OTEC operations. Therefore, the evaluation is restricted to a consideration of the platform hull, seawater, and the positioning systems.

The evaluation methodology is based on the characteristics or criteria relating to each individual major ocean system as shown on the left hand column of Table 4 which also lists the measures of merit used in analyzing the requirements for each criterion and the units of measurement and the basis for grade for each criterion.

The basic philosophy in performing the evaluation process was to grade the items of significance in the work breakdown structure in accordance with the degree to which they satisfy the requirements. In order to do this, weighting factors were determined for each item to reflect its degree of significant contribution to the requirements of applicable criteria. The assignment of weighting factors were based on cost, constructability, reliability, or similar considerations. They were quantified wherever possible or a logical approach was used where quantification


100 MW PLATFORM No2
L= 525 FT
B= 210 FT
D= 100 FT
T= 70 FT
L/B= 2.5
B/T= 3.0
L/T= 7.5
0
100
200
SCALE: FEET
M. ROSENBLATT & SON, INC.
350 BROADWAY
NEW YORK, N.Y. 10013

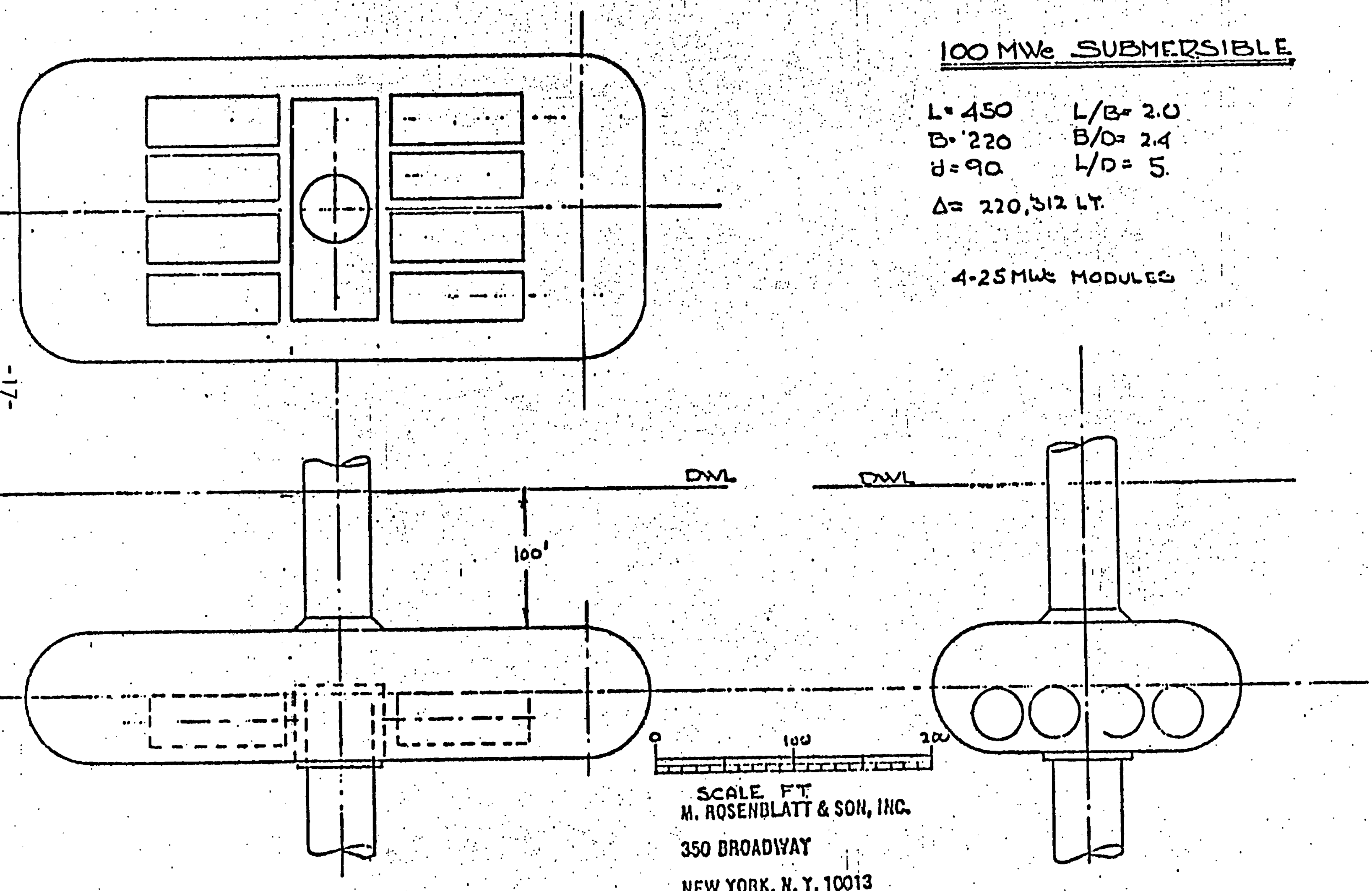

100 MWe SUBMERSIBLE
L= 450
B= 220
d= 90
L/B= 2.0
B/D= 2.4
L/D= 5.
Δ= 220,312 LT.
4-25MWe MODULES
DWL
DWL
100'
0
100
200
SCALE FT.
M. ROSENBLATT & SON, INC.
350 BROADWAY
NEW YORK. N.Y. 10013

FIGURE: 3

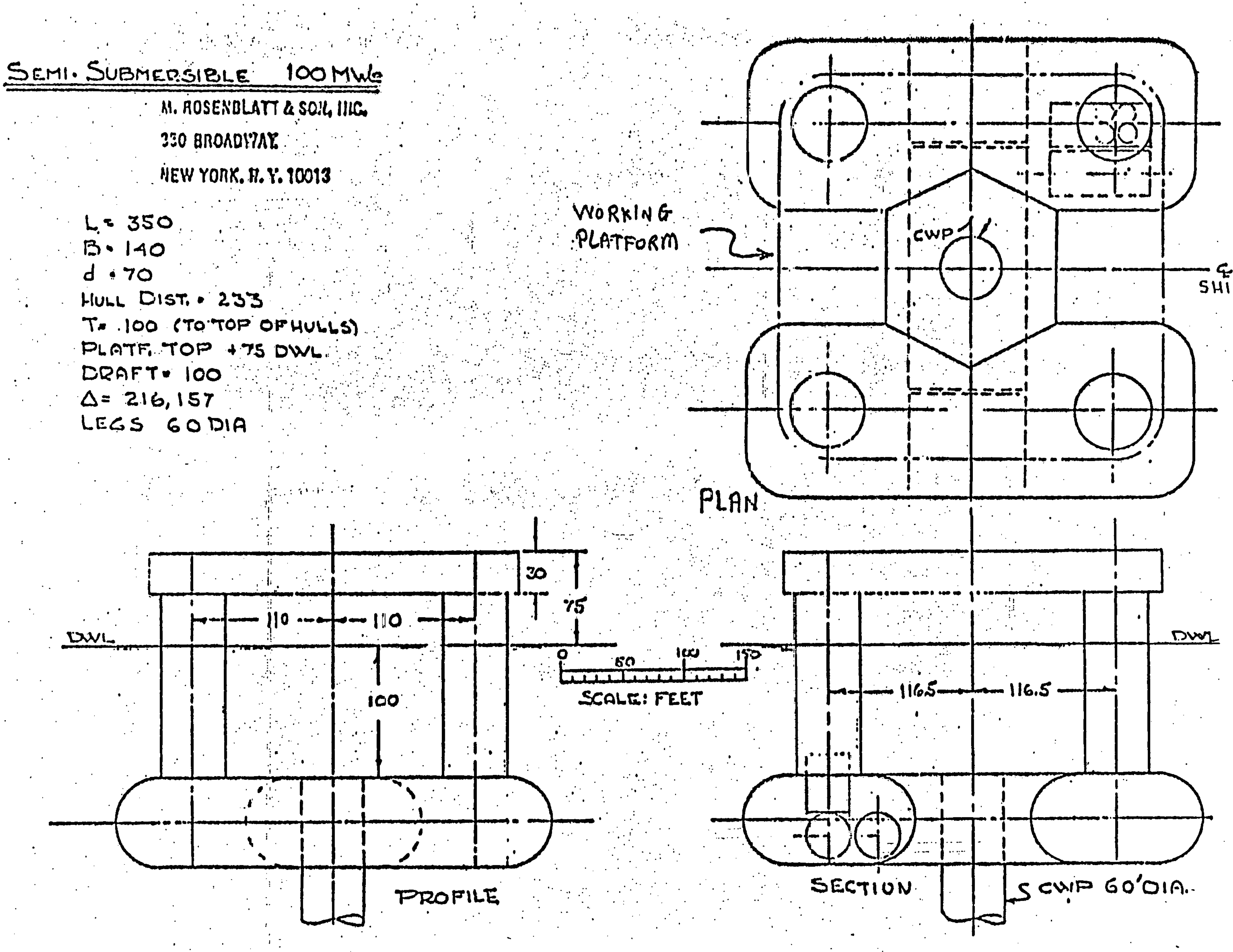

SEMI-SUBMERSIBLE 100 MWe
M. ROSENBLATT & SON, INC.
350 BROADWAY
NEW YORK, N.Y. 10013
L = 350
B = 140
d = 70
HULL DIST. = 233
T = 100 (TO TOP OF HULLS)
PLATF. TOP +75 DWL
DRAFT = 100
Δ = 216,157
LEGS 60 DIA
WORKING PLATFORM
CWP
℄ SHIP
PLAN
30
75
DWL
110
110
100
0
50
100
150
SCALE: FEET
116.5
116.5
DWL
PROFILE
SECTION
CWP 60' DIA.

FIGURE: 4

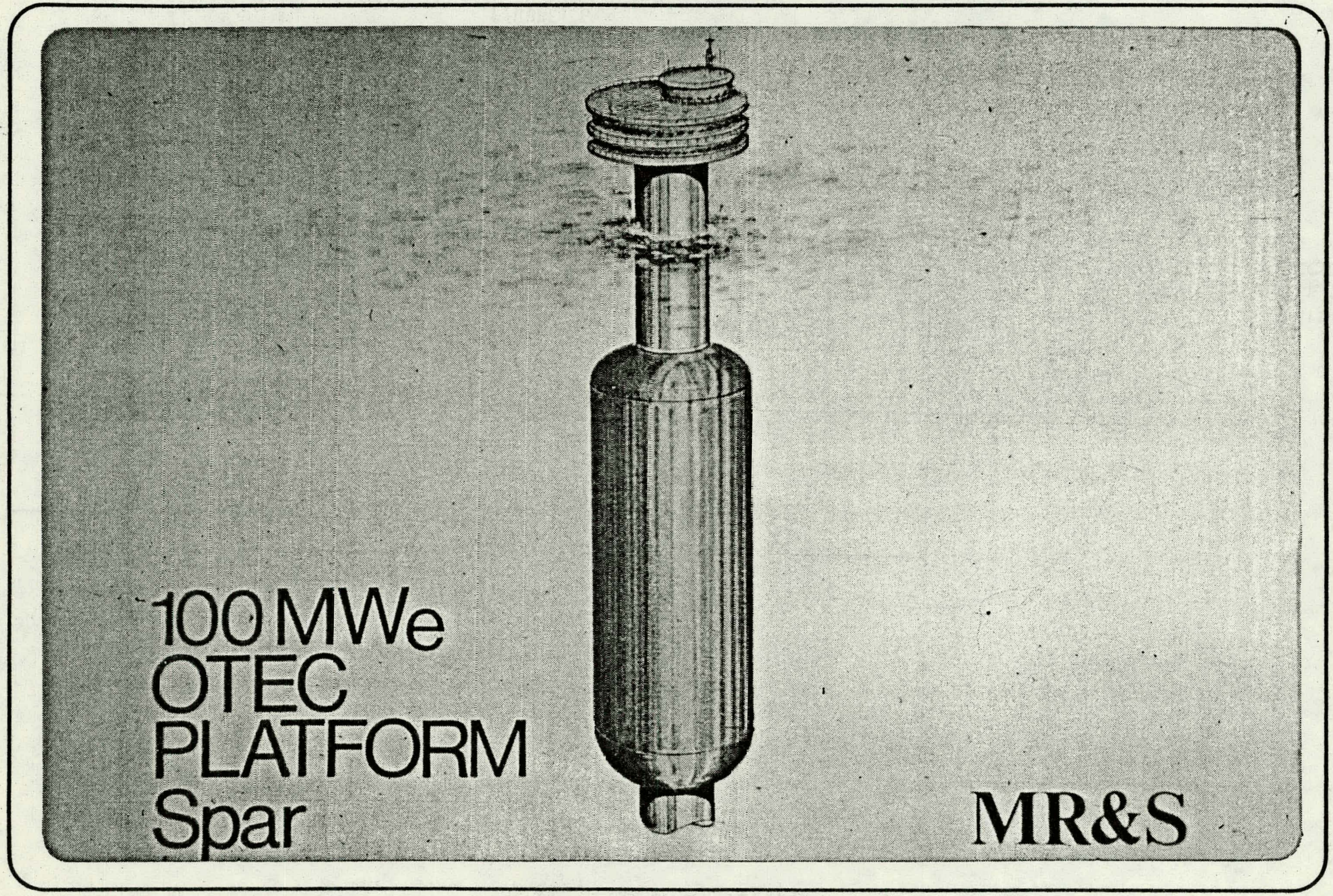


FIGURE 5: ARTIST'S CONCEPTION

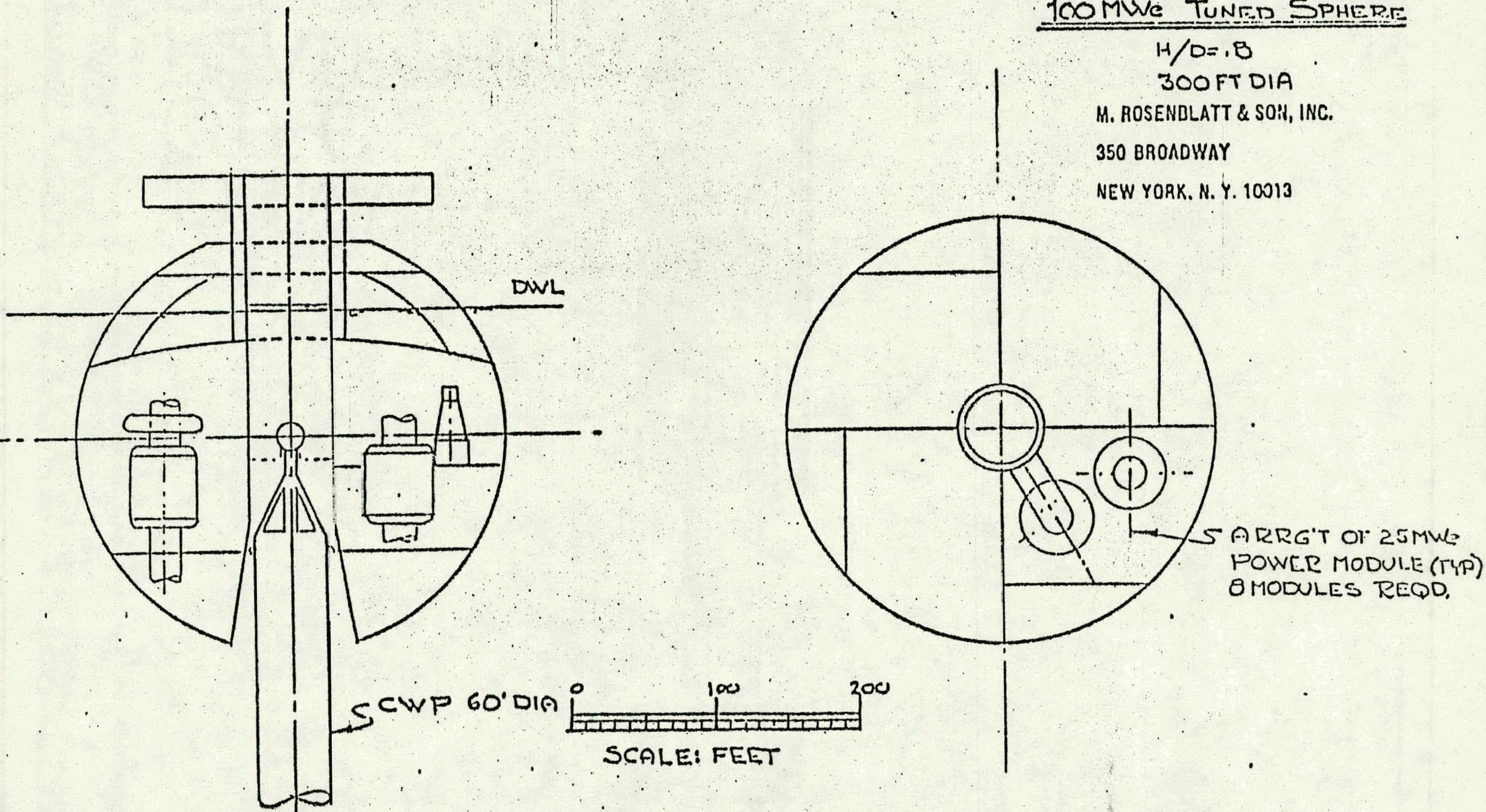

100 MWe TUNED SPHERE
H/D=.8
300 FT DIA
M. ROSENBLATT & SON, INC.
350 BROADWAY
NEW YORK. N. Y. 10013
DWL
ARRG'T OF 25MWe POWER MODULE (TYP)
8 MODULES REQD.
CWP 60' DIA
0
100
200
SCALE: FEET

FIGURE: 6

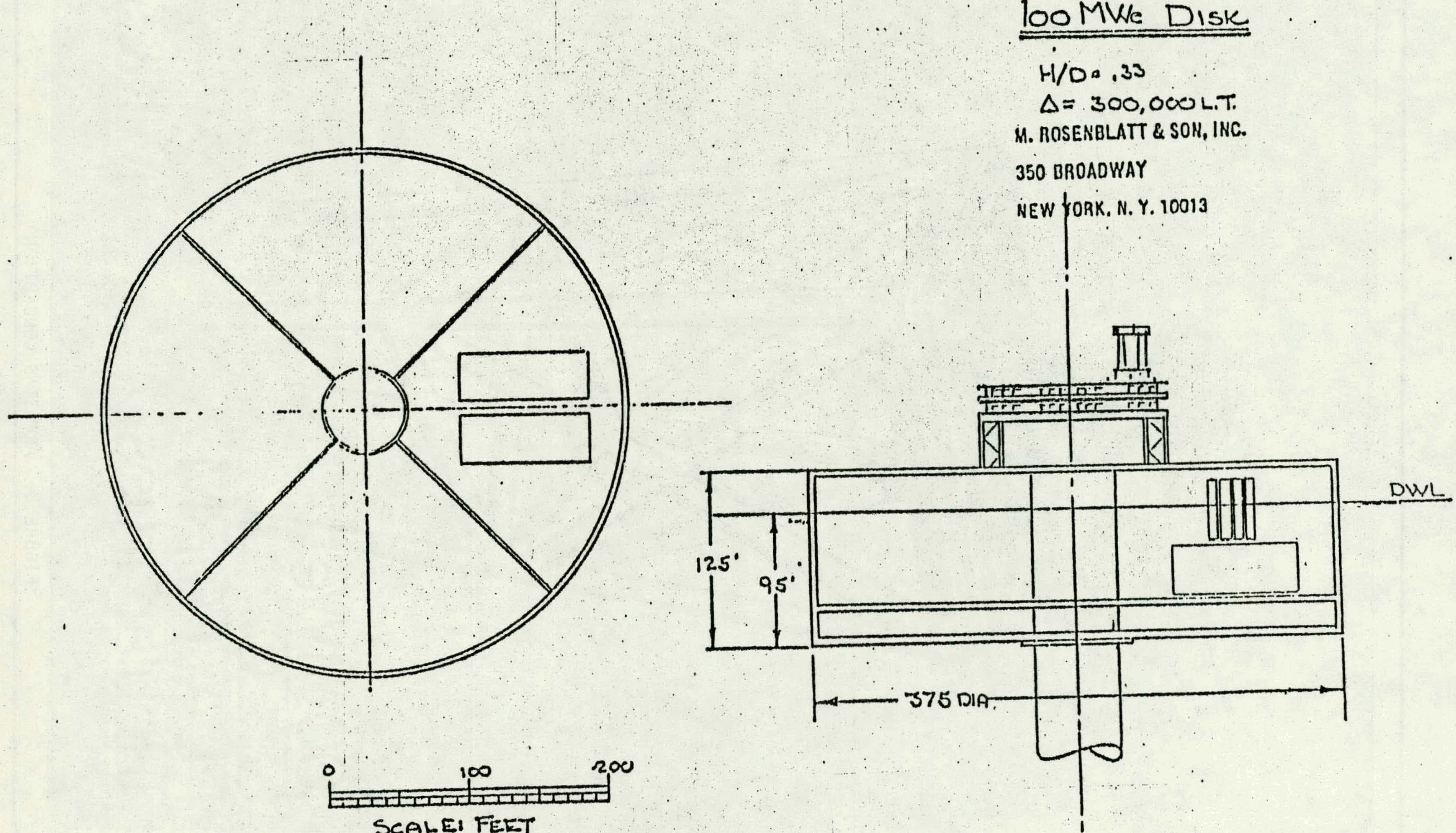

100 MWe DISK
H/D = .33
Δ = 300,000 L.T.
M. ROSENBLATT & SON, INC.
350 BROADWAY
NEW YORK, N.Y. 10013
DWL
125'
95'
375 DIA.
0
100
200
SCALE: FEET

FIGURE: 7

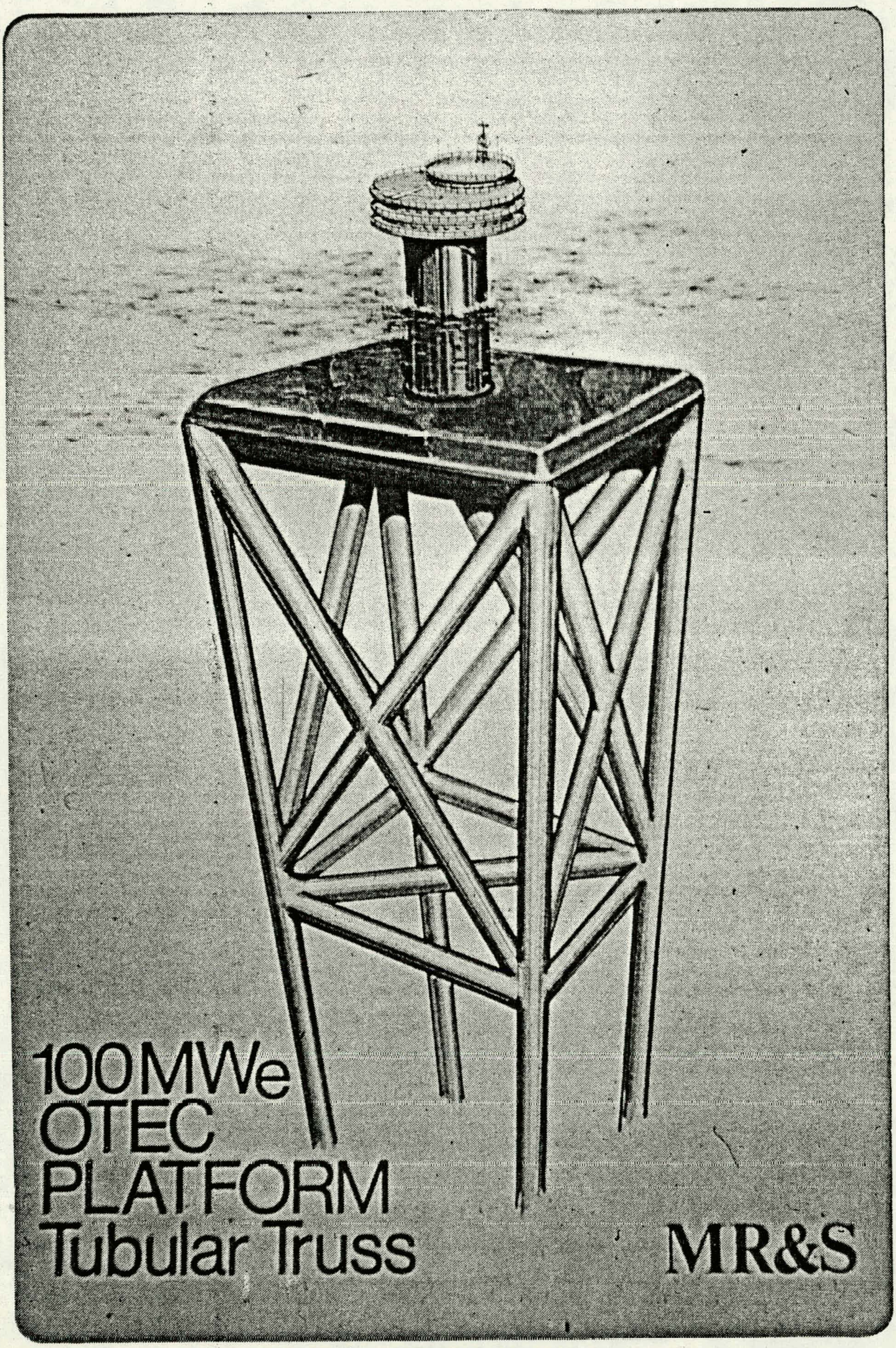
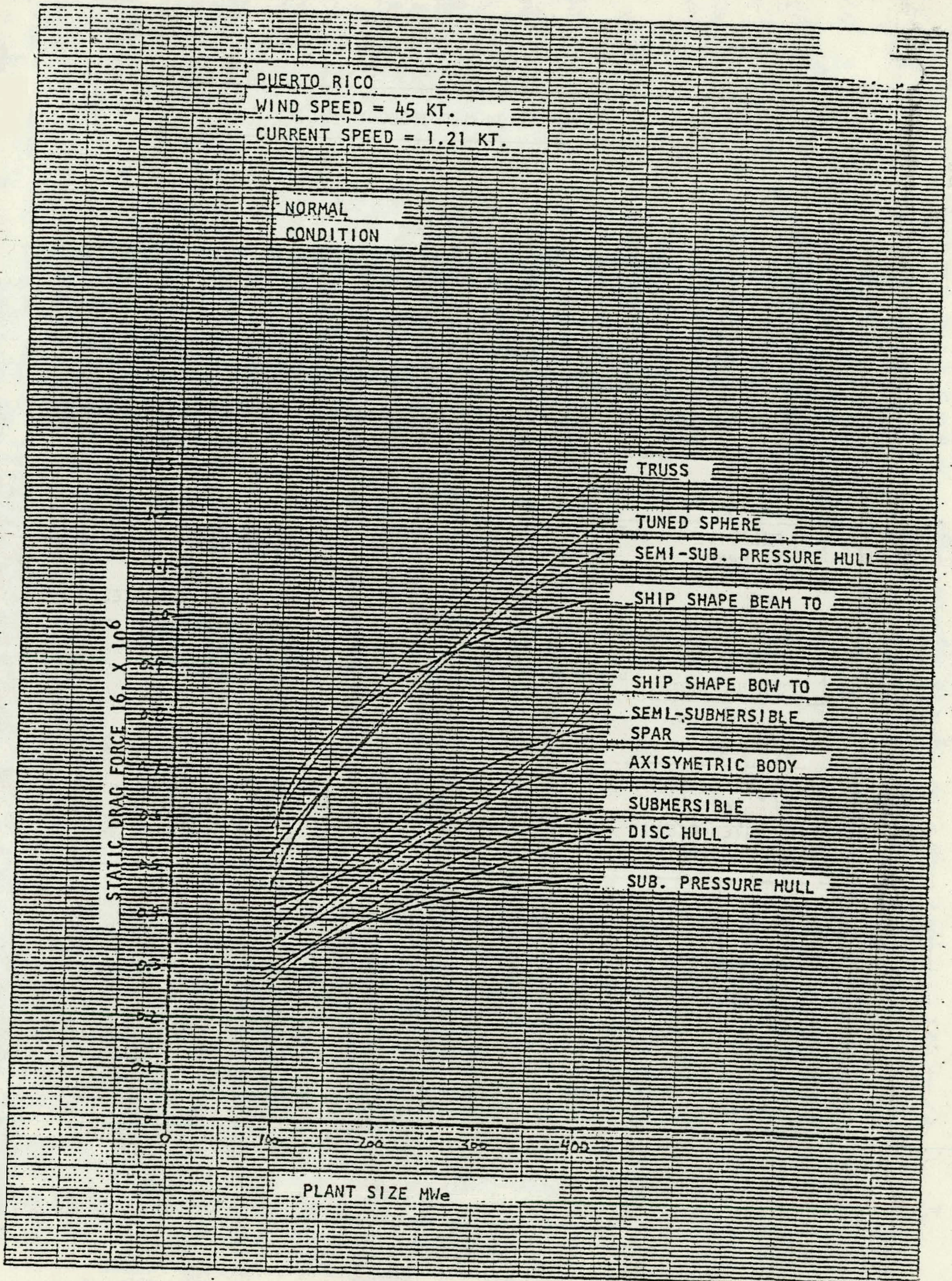


FIGURE 8: ARTIST'S CONCEPTION



PUERTO RICO
WIND SPEED = 45 KT.
CURRENT SPEED = 1.21 KT.
NORMAL
CONDITION
TRUSS
TUNED SPHERE
SEMI-SUB. PRESSURE HULL
SHIP SHAPE BEAM TO
SHIP SHAPE BOW TO
SEMI-SUBMERSIBLE
SPAR
AXISYMETRIC BODY
SUBMERSIBLE
DISC HULL
SUB. PRESSURE HULL
STATIC DRAG FORCE 16. X 10⁶
PLANT SIZE MWe

FIGURE 9

EVALUATION METHODOLOGY

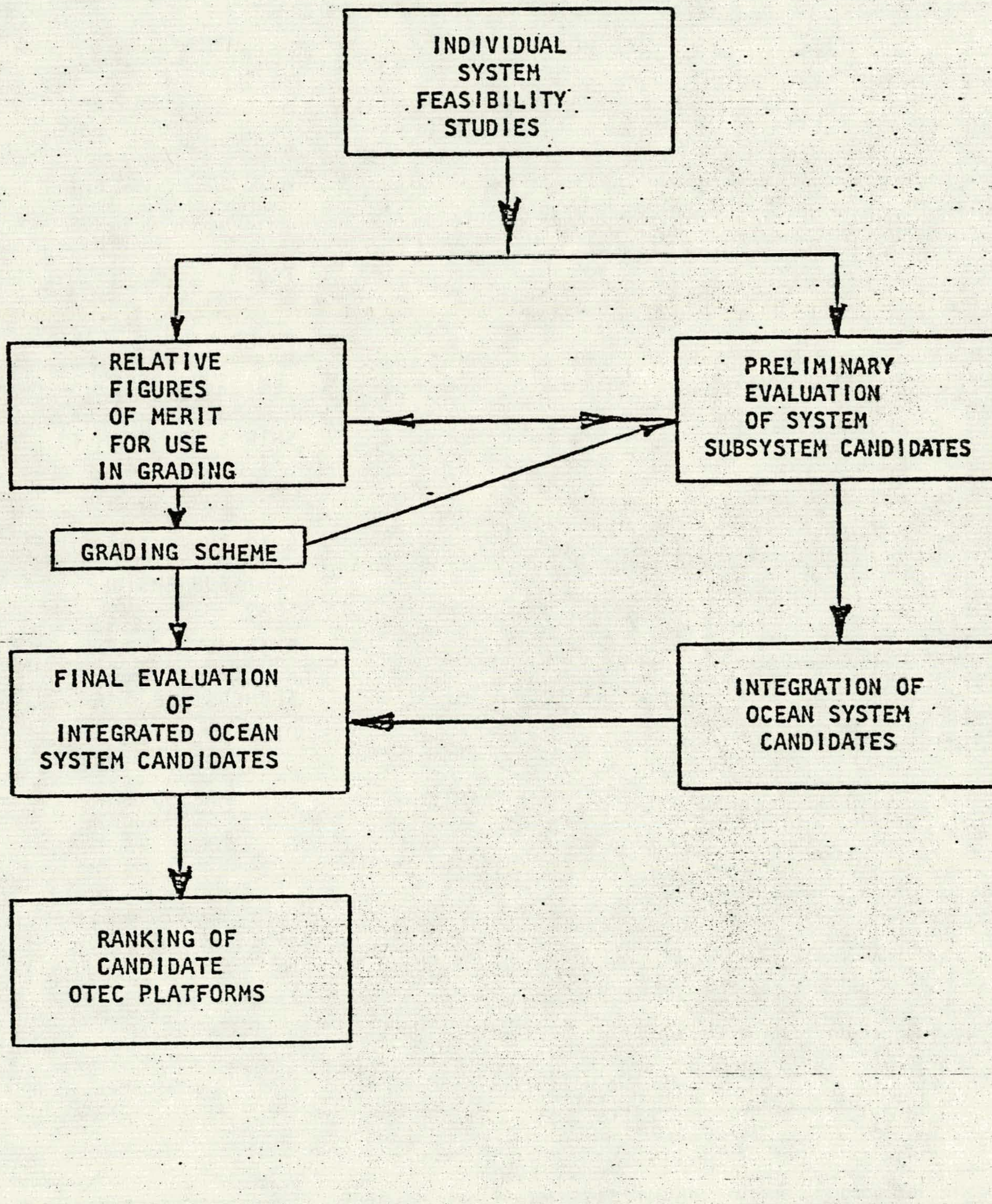


TABLE: 3

MEASURES OF MERIT

USED IN FINAL EVALUATION

Characteristic/ Criterion	Measure of Merit	Unit	Basis for Grade
Operability	Time on-line as a percentage of 40 years life	%	Higher grade for larger percentage
Reliability	For Hardware: Mean Time Between Failure For Design: Level of Confidence	Years/ Life %	Larger MTBF higher grade Higher LOC higher grade
Maintainability	Average time for Maintenance	Days/ Yr	Lower time higher grade
Survivability	Probability of Loss	%	Lower % higher grade
Safety	Personnel Man hours lost due to accidents Environment Probability of Damage due to accidents	MH/Man-Year %	Lower MH/MY higher grade Lower % higher grade
Constructability	Mean Time to Construct the Platform	Months	Smaller time higher grade
Technology Development	Time requested for R & D	Months	Smaller time higher grade
Acquisition Costs	Cost of construction and deployment	$/ KW	Higher grade for smaller $/KW
Operating Costs	Cost of Operating and Monitoring	$/ KW	Higher grade for smaller $/KW
Deployability	Mean time to deploy	Days	Higher grade for smaller time

TABLE: 4

was not possible.

2.4 Integration of Ocean Systems

Various individual ocean systems were considered to be parts of a whole, and the methods of integrating them into one commercial OTEC platform were established. The approach was to combine the most feasible ocean system with other corresponding best ocean systems. For example, the most suitable cold water pipe configuration for any one platform configuration should be the one that is incorporated into the final OTEC platform of that shape. Similarly, the best seawater system layout, the best positioning system candidate, and the best platform service and mission support system should be incorporated.

2.4.1 Platform Hull Candidates

The platform hull configurations selected as final candidates for integration with other ocean systems are:

a. Surface ship with integral and detached cold water pipe.
b. Submersible with inboard and outboard heat exchanger configurations.
c. Semi-submersible with inboard and outboard heat exchanger configurations.
d. Spar type platform of mono-hull and multi-hull configurations.
e. Spherical platform with inboard and outboard heat exchanger arrangements.
f. Surface disc type platform with respectively high and low L/D ratio.
g. Tubular truss configuration.

The above thirteen hull configurations were subjected to an evaluation process. The resulting eighteen top candidates are tabulated in Table 5. These are the platform hull candidates to be integrated with other ocean systems.

2.4.2 Seawater System/CWP Candidates

The three best candidates for the seawater system layouts all consist of shell and tube type heat exchangers of horizontal configuration. These are to be used in connection with surface type platforms. For platforms with submerged main bodies, the vertical heat exchanger configurations appear to be more suitable.

The cold water pipe configurations to be used with those platforms to which they are applicable and most suitable are shown in Table 6.

2.4.3 Positioning System Candidates

Table 7 lists the six positioning system candidates to be used for integration with other ocean systems. The best system for integration with an applicable platform is a hybrid positioning system with thrusters and warm water discharge. The second best positioning system is a multi-point mooring system with drag anchors. The third best is again a multi-point mooring system with thrusters and drag type anchors. The fourth and fifth best systems are three-legged hollow cylindrical link (HCL) mooring systems with gravity anchors and thrusters. The last best is a three-legged HCL mooring system with gravity anchors.

FINAL PLATFORM HULL CANDIDATES FOR INTEGRATION

PLACE	HULL	TYPE	HEAT EXCHANGERS	MATERIAL
1st	Ship			Steel
2nd	Disc	Low L/D		Steel
3rd	Semi-Sub		Inboard	Steel
4th	Semi-Sub		Inboard	Concrete
5th	Spar	Single Hull		Steel
6th	Ship			Concrete
7th	Truss		Inboard	Concrete
8th	Semi-Sub		Outboard	Concrete
9th	Submersible		Inboard	Steel
10th	Sphere		Inboard	Concrete
11th	Semi-Sub		Outboard	Steel
12th	Submersible		Inboard	Concrete
13th	Submersible		Outboard	Steel
14th	Spar	Single Hull		Concrete
15th	Submersible		Outboard	Concrete
16th	Axisymmetric	High L/D		Steel
17th	Disc	Low L/D		Concrete
18th	Spar	Multi-Hull		Concrete

TABLE 5

TABLE 6

FINAL COLD WATER PIPE CANDIDATES

FOR INTEGRATION

RANK	CWP CONCEPT	APPLICABLE PLATFORMS	MATERIALS
1	Rigid (Legs of Truss Structure)	Truss	STL, AL GRP. CNCT.
2	Pinned at hull, Free End Rigid Pipe	Spar	STL, AL GRP. CNCT
3	Pinned at hull Restrained End Rigid Pipe	Spar	STL, AL GRP, CNCT
4	Pinned at hull Free End Rigid Pipe	Submersible, Semi-Submersible Tuned Sphere	AL. GRP
5	Pinned at hull Free End Rigid Pipe	Surface Ship Surface Disk	AL, GRP
6	Pinned at hull Restrained End Rigid Pipe	Submersible Semi-Submersible Tuned Sphere	AL, GRP
7	Pinned at hull Restrained End Rigid Pipe	Surface Ship, Surface Disk	AL, GRP
8	Pinned at hull Free End Ball Joint Pipe	Submersible, Semi-Submersible Tuned Sphere	AL, GRP
9	Pinned at hull Pinned End Rigid Pipe	Submerged Buoy	STL, AL GRP, CNCT
10	Pinned at hull Restrained End Ball Joint Pipe	Surface Ship, Surface Disk	AL, GRP
11	Pinned at hull Restrained End Ball Joint Pipe	Submersible, Semi-Submersible Tuned Sphere	AL, GRP

FINAL POSITIONING SYSTEM
CANDIDATES FOR INTEGRATION

I	(IO) 6000 LP THRUSTER AND WARM WATER DISCHARGE
2	IO LEG MOORING WITH DRAG ANCHORS
3	IO LEG MOORING WITH (4) THRUSTERS AND DRAG ANCHORS
4	3 LEG HCL LINK MOORING WITH GRAVITY ANCHORS AND (II) 6000 LP THRUSTER
5	3 LEG HCL MOORING WITH GRAVITY ANCHOR AND (4) 6000 HP THRUSTER
6	3 LEG HCL MOORING WITH GRAVITY ANCHORS

TABLE 7

2.4.4 Integrated Platforms

A total of eighteen platform hull candidates, eleven cold water pipe configurations, and six positioning system configurations are used in integrating the final OTEC Commercial Platform Candidates. Tables 5 through 7 present these candidates in the order of rank as obtained from their individual evaluation processes.

However, not all of the eleven cold water pipe configurations and not all of the six positioning system candidates are applicable to each and every platform. Some of these candidates are applicable specifically for one or more types of platforms and these are identified in the tables.

The integration of these ocean systems, resulted in the final platforms listed in Table 8. The final candidates are listed simply in the order that they were integrated. Also listed are the candidate numbers and the description for each individual system used in integration. For example: the integrated candidate #1 is a ship shape type platform hull of steel construction integrated with a positioning system candidate #6 (due to the fact that only #6 positioning system candidate is applicable to a ship shape type platform).

Where there are more than one possible candidate for the positioning or the cold water pipe configurations for any one platform, these are presented as a different integrated platform candidate. In this manner, a total of 25 integrated platform candidates are named.

2.4.5 Evaluation of Integrated Platform Candidates

These twenty five candidates herein cover a complete spectrum of platform hull shapes, positioning system, and cold water pipe configurations.

In evaluating these integrated commercial platform candidates, the methodology briefly discussed above and shown in Table 3, is used. However, in order to assign grades to the candidates on the basis of costs (both acquisition and operating costs) a cost analysis study must be performed on the integrated platforms using the proposed ocean systems.

This cost analysis was performed in Phase I studies and construction, deployment, and operating costs for various integrated platform candidates were estimated and used in the evaluation.

The results of the detailed evaluation process for individual systems as well as for integrated platforms are in file at MR&S offices. Table 9 shows a sample evaluation matrix.

The results are summarized in Table 10. As it can be seen, the tubular truss type integrated platform appears to be the most viable candidate for use as a commercial OTEC platform with a Relative Figure of Merit (RFOM) of 4.63.

A close review of Table 10 reveals the following:

1. Candidates ranking #2, 5, 9 and 10 are all low L/D disc type platforn with varying positioning systems and construction materials.
2. #3, 4, 5, 7, 8 and 17 are all SUBMERSIBLE hulls with varying combinations of heat exchanger arrangements and construction materials.
3. #11, 12, 13, 15 and 18 are all SPAR type platform hulls with differen construction materials and cold water pipe configurations.

INTEGRATION OF FINAL INDIVIDUAL SYSTEM CANDIDATES WITH THE PLATFORMS

INTEGRATED CANDIDATE NUMBER	PLATFORM HULL DESCRIPTION & CANDIDATE NO.		POSITIONING SYSTEM CANDIDATE NO.	CWP SYSTEM CANDIDATE NO.
1	Ship/Steel	1	6	5
2	Disc/Steel	2	1	5
3	Disc/Steel	2	2	5
4	SemiSub/Steel	3	4	4
5	Semi-Sub/Concrete	4	4	4
6	Spar-Single Hull/Steel	5	4	2
7	Spar-Single Hull/Steel	5	4	3
8	Ship/Concrete	6	6	5
9	Truss/Concrete	7	2	1
10	Semi-Sub OB/Concrete	8	4	4
11	Semi-Sub IB/Steel	9	1	4
12	Semi-Sub IB/Steel	9	2	4
13	Sphere/Concrete	10	6	4
14	Semi-Sub OB/Steel	11	4	4
15	Submersible-IB/Concrete	12	1	4
16	Submersible-IB/Concrete	12	2	4
17	Semi-Sub-OB/Steel	13	4	4
18	Spar/Concrete	14	4	2
19	Spar/Concrete	14	4	3
20	Submersible-OB/Steel	15	1	4
21	Submersible OB/Steel	15	2	4
22	Vertical Axisymmetrical-H/ Steel	16	3	5
23	Disc/Concrete	17	1	5
24	Disc/Concrete	17	2	5
25	Spar-MH/Concrete	18	4	2

LEGEND:

OB: OUTBOARD HEAT EXCHANGER

H: HIGH L/D RATIO

IB: INBOARD HEAT EXCHANGERS

MH: MULTI HULL

TABLE 8

Criteria for Evaluation	WEIGHTING FACTOR		Integrated Platform Candidates								
		No	1	2	3	4	5	6	7	8	9
		Hull No	1	2	2	3	4	5	5	6	7
		Pos. Sys No	6	1	2	4	4	4	4	6	2
		CWP Conf. No	5	5	5	4	4	2	3	5	1
Operability	10		4.08	3.59	4.08	3.98	3.98	4.06	4.06	4.08	3.91
Reliability	6		3.47	4.99	3.83	3.91	3.91	3.75	3.75	3.47	4.24
Maintainability	7		4.12	5.29	4.12	3.74	3.82	3.60	3.60	4.20	3.98
Survivability	5		3.30	3.30	3.83	4.95	4.94	4.08	4.08	3.30	4.62
Safety	5		4.05	4.23	3.50	4.36	4.44	4.12	4.12	4.12	3.49
Constructability	8		3.77	5.17	4.75	3.39	3.24	3.83	3.83	3.39	4.96
Technology Development	15		3.53	4.88	4.4	3.52	3.51	4.02	3.41	3.51	5.66
Acquisition Cost	13		4.24	4.87	4.71	3.50	3.45	4.43	4.43	3.0	5.07
Operating Costs	10		3.88	4.06	4.53	3.89	3.96	3.80	3.53	3.95	4.48
Deployability	11		4.04	4.21	3.94	3.93	3.93	3.76	3.76	3.83	4.10
R.F.O.M.			3.86	4.57	4.31	3.77	3.76	3.95	3.84	3.62	4.63
RANK			14	2	5	19	21	11	15	24	1

Table: 9
Matrix #4: Final Ocean Systems Evaluation

Rank	Hull		Pos. Sys. #	CWP #	Hull Mat'l	Heat Exchg. Configuration	RFOM	Integrated Candidate #
	Type	#						
1	Truss	7	2	1	Conc.	1B	4.63	9
2	Disc	2	1	5	Steel	1B	4.57	2
3	Sub	9	1	4	Steel	1B	4.45	11
4	Sub	12	1	4	Conc.	1B	4.42	15
5	Sub	15	1	4	Steel ?	0B	4.31	20
5	Disc	2	2	5	Steel	1B	4.31	3
7	Sub	9	2	4	Steel	1B	4.18	12
8	Sub	12	2	4	Conc.	1B	4.16	16
9	Disc	17	1	5	Conc.	1B	4.05	23
10	Disc	17	2	5	Conc.	1B	4.04	24
11	Spar	5	4	2	Steel	1B	3.95	6
12	Spar	14	4	2	Conc.	1B	3.90	18
13	Spar Multi-Hull	18	4	2	Conc.	1B	3.88	25
14	Ship	1	6	5	Steel	1B	3.86	1
15	Spar	5	4	3	Steel	1B	3.84	7
15	Axi-Sym.	16	3	5	Steel	1B	3.84	22
17	Sub	15	2	4	Steel	0B	3.82	21
18	Spar	14	4	3	Conc.	0B	3.79	19
19	Semi-Sub	13	4	4	Steel	0B	3.77	17
19	Semi-Sub	3	4	4	Steel	1B	3.77	4
21	Semi-Sub	4	4	4	Conc.	1B	3.76	5
21	Semi-Sub	8	4	4	Conc.	0B	3.76	10
23	Semi-Sub	11	4	4	Steel	0B	3.70	14
24	Ship	6	6	5	Conc.	1B	3.62	8
24	Sphere	10	6	4	Conc.	1B	3.62	13

TABLE 10

FINAL EVALUATION OF INTEGRATED PLATFORMS

4. #14 and 24 are steel SURFACE SHIPS.
5. #15 is a VERTICAL AXISYMMETRIC hull with high L/D ratio.
6. #19 through 23 are all SEMI-SUBMERSIBLE hulls with different construction materials and heat exchanger configurations.
7. #24 is a SPHERE of concrete construction.

The above analysis indicates that a definite trend can be established when it is assumed that for each hull shape, the most promising CWP, heat exchanger arrangement, and the positioning system can be selected. The trend, which can be understood when the combination of individual ocean systems for the same type of platform are treated as one alternative appears to be as follows:

1. Truss
2. Disc
3. Submersible
4. Spar
5. Ship
6. Vertical Axisymmetric
7. Semi-submersible
8. Sphere

Furthermore, the results of preliminary stress analyses performed on surface ship type platforms with integral CWP indicate that wave induced bending moments for surface vessels are much larger than those for platforms with submerged main bodies, such as the submersible, spar, etc. Pending further investigation of the CWP stresses and verification of above statement by a more accurate analysis such as by the ANSYS or NASTRAN finite element programs, it may be said at this point in time, that any surface type platform will have a poorer stress performance with the integral CWP arrangement. If, on this basis, all surface type platforms are eliminated from the ranking, we would be left with the following eventual candidates for the commercial OTEC platform:

1. Tubular truss
2. Submersible
3. Spar
4. Semi-submersible
5. Sphere

SECTION 3.0

TECHNICAL CONCEPT

The Department of Energy "Hull Recommendations Board" reviewed inputs by the three contractors and made assignments for the Phase II work consisting of conceptual designs, cost estimates, and time schedules. To MR&S, the SPAR and SPHERE platforms were assigned. The other two contractors were assigned the "surface ship and semi-submersible", and "spar and surface ship" platforms respectively.

3.1 General Approach

The general approach in developing the conceptual designs for the two platforms was to maintain a design spiral and arrive at 5 iterations of the platform arrangements, structural scantlings, and installation techniques, as well as constructability and deployability considerations. Concept drawings were developed for the final iteration derived as a result of the design evolution. On the basis of the finalized conceptual design, cost estimates were prepared and time schedules developed for both the spar and the sphere platform. The hull output specified for the commercial OTEC application (by the DoE) was 400 MW_e net capacity. Eight of these platforms would be stationed at one OTEC site to constitute what is termed an OTEC Energy Park, and therefore, the net power generation capacity of one park was 3200 MW_e. Feasibility studies were improved for the major ocean systems of the spar and the sphere platforms of 400 MW capacity and critical facilities and equipment required for the construction, deployment, and operation of these platforms were also considered in detail and their availability was studied.

The designs and cost estimates, including facilities and equipment required for the two platforms, were prepared for the baseline site of "West Coast of Florida" as specified by the DoE. However, the costs as well as design modifications required for the other two sites "New Orleans and Puerto Rico" were also considered and a site sensitivity analysis was conducted for both platforms.

3.2 Energy Park

It is reported in [6] that OTEC should be viewed as a possible candidate for massive baseload electricity generation. Reportedly, on the basis of ERDA and DoE studies, there happens to be available a thermal resource capability of approximately 300,000 MW at about 190 miles off the West Coast of Florida. The West Coast of Florida is the baseline site that the MR&S project team was assigned for the conceptual studies. It is safe to assume, therefore, that there is that much exploitable thermal resource at the baseline site and that this resource is or can be made available to users over a wide cross section of the nation from a renewable solar energy source.

Given the 300,000 MW thermal resource available at the West Coast of Florida site, one can form an idea of how many OTEC platforms or Energy Parks may be possible to station at this site only. The idea of an OTEC Energy Park consisting of a number of platforms has been developed in the first phase studies. The OTEC Park energy output capacity for consideration in that first phase of the study was approximatley 3000 MW, however, for the second phase of the study, the net output size has been established as 400 MW and the OTEC Park size becomes, on the basis of 8 platforms to an OTEC Park, approximately 3200 MW net.

Shown in Figure 10 is an illustration of a probable OTEC Park arrangement. The 8 platforms of 400 MW capacity each would be spaced at a predetermined interval between them, established on the basis of thermal recirculation considerations.

It was found desirable to have accommodations on board each platform so that any normal operation as well as routine or emergency maintenance procedures can continue without depending on boats or helicopters in storm conditions or emergencies.

The electrical power generated aboard each OTEC platform would be transmitted to a central collection point by means of power conditioning equipment installed aboard the platform and a riser cable connecting it to a standoff buoy from which it is transmitted to a central collection platform. The central collection platform would then have its own riser cable leading to the bottom of the ocean and a submarine cable leading from the deployment site to the central distribution network at a shore based connection point.

3.3 Conceptual Design Studies

3.3.1 General

The evolution of arrangements for the SPAR and SPHERE platforms were developed on the basis of using 50 MW_e (net) capacity heat exchanger modules due to economy of scale.

The platform sizes to accommodate the heat exchangers, other OTEC equipment, platform service and support systems, and the crew were established and formalized after several design iterations.

3.3.2 Hull Structure

In the beginning of the design cycle steel and concrete were considered as possible materials for the structural hull. Phase I studies and other sources [7] indicated that for the size platform under consideration, a concrete hull would be significantly less expensive than steel although quite heavier. The steel plates necessary for the lower hull would be extremely thick and present severe fabrication and welding problems. Steel is much more prone to electrolytic action than concrete which has excellent long term properties to resist corrosion and failure from fatigue. A concrete of 7000 psi ultimate compressive strength and a density of 150 pounds per cubic foot was eventually selected for the Spar platform. For the Sphere, a lower ultimate compressive strength of 5000 psi can be used.

3.3.3 Stability

The weights, moments and centers of hull structure and of other systems were kept under surveillance during design iterations, and platform stability performance was investigated.

For intact stability, the available GM was found to be significant during all phases of construction, deployment and operation so that precise criteria need not be applied at this time.

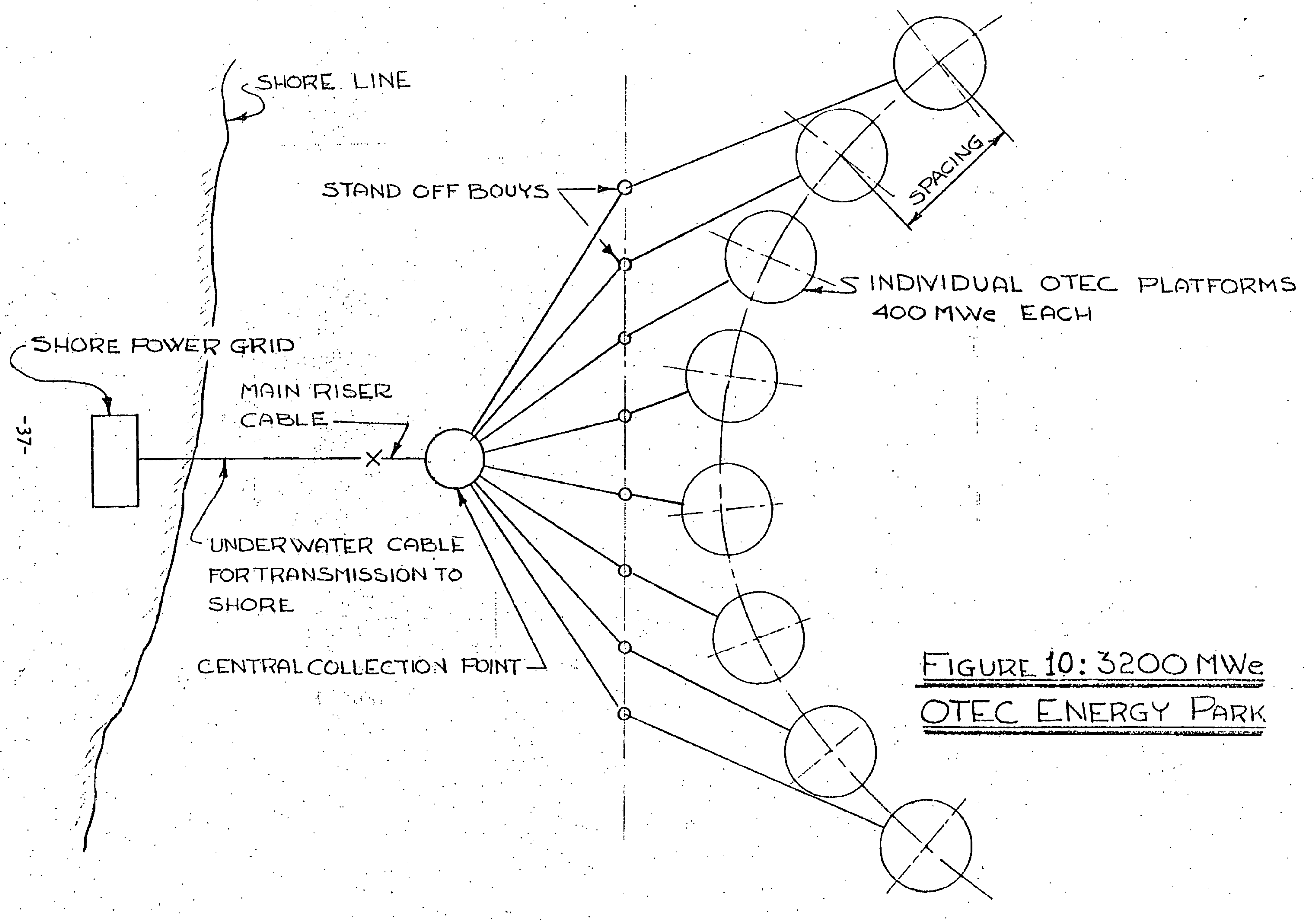


FIGURE 10: 3200 MWe OTEC ENERGY PARK

In the case of damage stability, it became evident that to allow for subdivision of the complete platform, or even a smaller portion, would introduce significant structural, weight, and cost problems. Further, due to the deep submergence of the operating platform, damage due to collision could only ocur through collision with the very largest oil tankers (350,000 tons DWT) or a submarine. It was felt that adequate navigational restrictions should and would be imposed for the general safety of the OTEC park such that the just mentioned collision possibilities could be eliminated. Consequently subdivision of the main hull would not be necessary. During construction the platforms would be vulnerable to collision from large ships. Adequate navigation protection would have to be taken to insure that this does not occur. Penetration of the main hull by smaller craft such as tugs, supply boats, and work barges is unlikely.

In the case of the surface piercing superstructure, damage can occur from supply and tranfer boats alongside even if adequate navigational restrictions are placed on other ships. Consequently, as a minimum, the requirements for drill ships [8] have been imposed on the superstructure.

3.3.4 Seawater System

Major systems and components selected for the seawater systems include:

Warm Seawater Intake Screen (static type)
Warm and Cold Seawater Pumps (bulb type)
Seawater Gates and Valves
Amertap System
Electrical System (for seawater system only)
Nitrogen Purging System (for ammonia system)

The conceptual designs of the seawater systems for (Figs. 11,12) for both platform configurations are derived from numerous design altetnatives, offering hydraulic, space utilization and power requirement advantages. Because of the low heat exchanger pressure drops, care was taken to provide smooth flow transitions and even flow distribution on the inlets to heat exchanger tube sheets. This prevents heat exchanger flow maldistribution which would seriously degrade heat exchanger performance; hence, reduce plant efficiency. Therefore, the seawater system/component symmetry and relative locations of heat exchangers, pumps, intakes, discharges, elbows and valves required critical evaluation and were arranged based on well developed hydraulic and heat transfer principles for the maintenance of optimum system performance. Hydraulic requirements for the operation of a large, high flow, low head pump are considerably different from that for small, low flow, high head pumps. OTEC size pumps are anticipated to be very sensitive to the design of intakes and discharge conditions.

3.3.5 Seakeeping and Platform Motions

The seakeeping analysis of the platforms was performed by using several different analysis procedures involving computer programs all using the hydrodynamic added mass, damping coefficients and wave exciting forces determined by the MR&S team.

After a survey of available procedures it was decided to employ Adee-Bai's [9] computer program. This program has been developed based on Newman's slender body theory [10] for computing motions of spar buoy platforms.

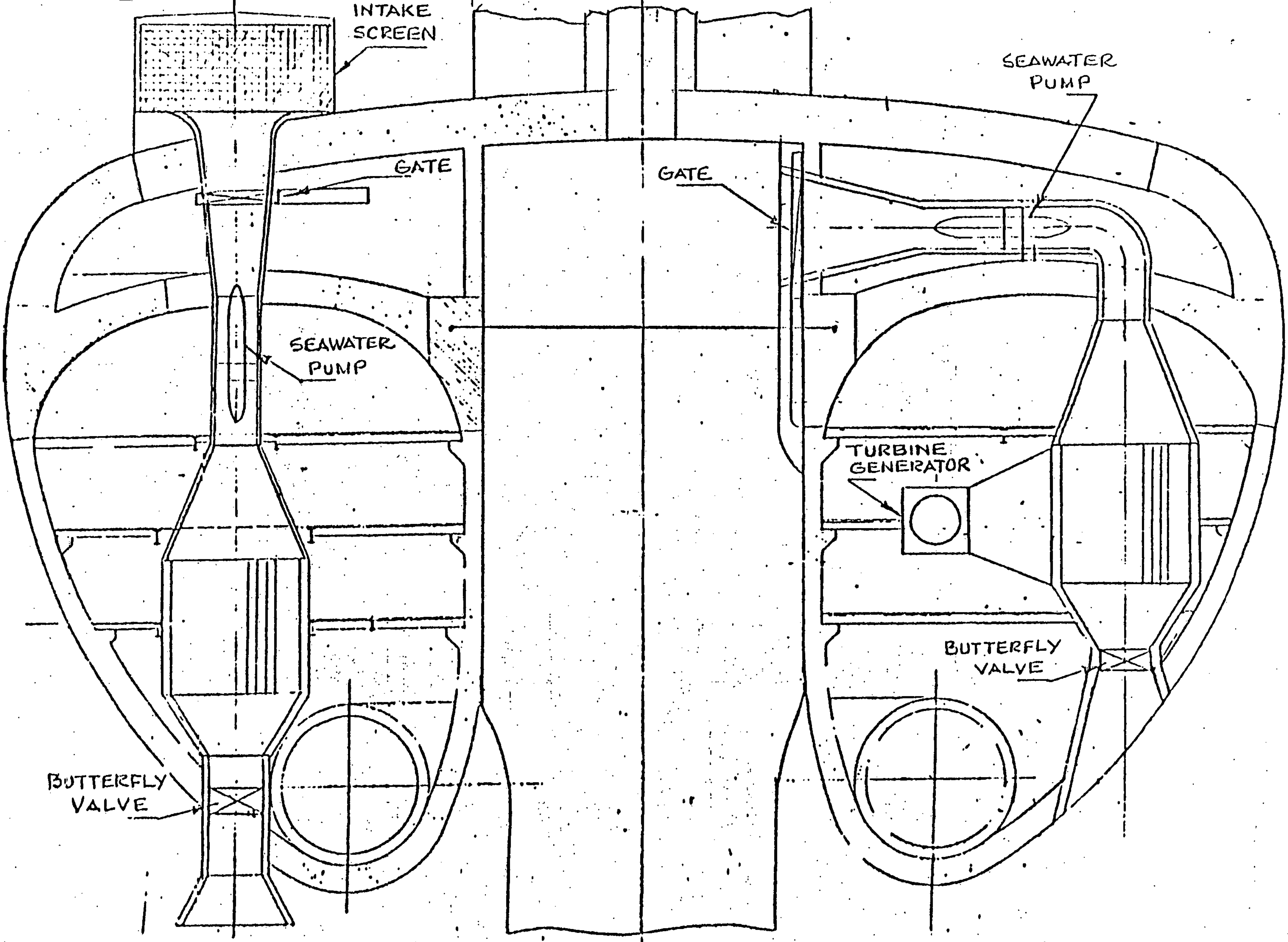
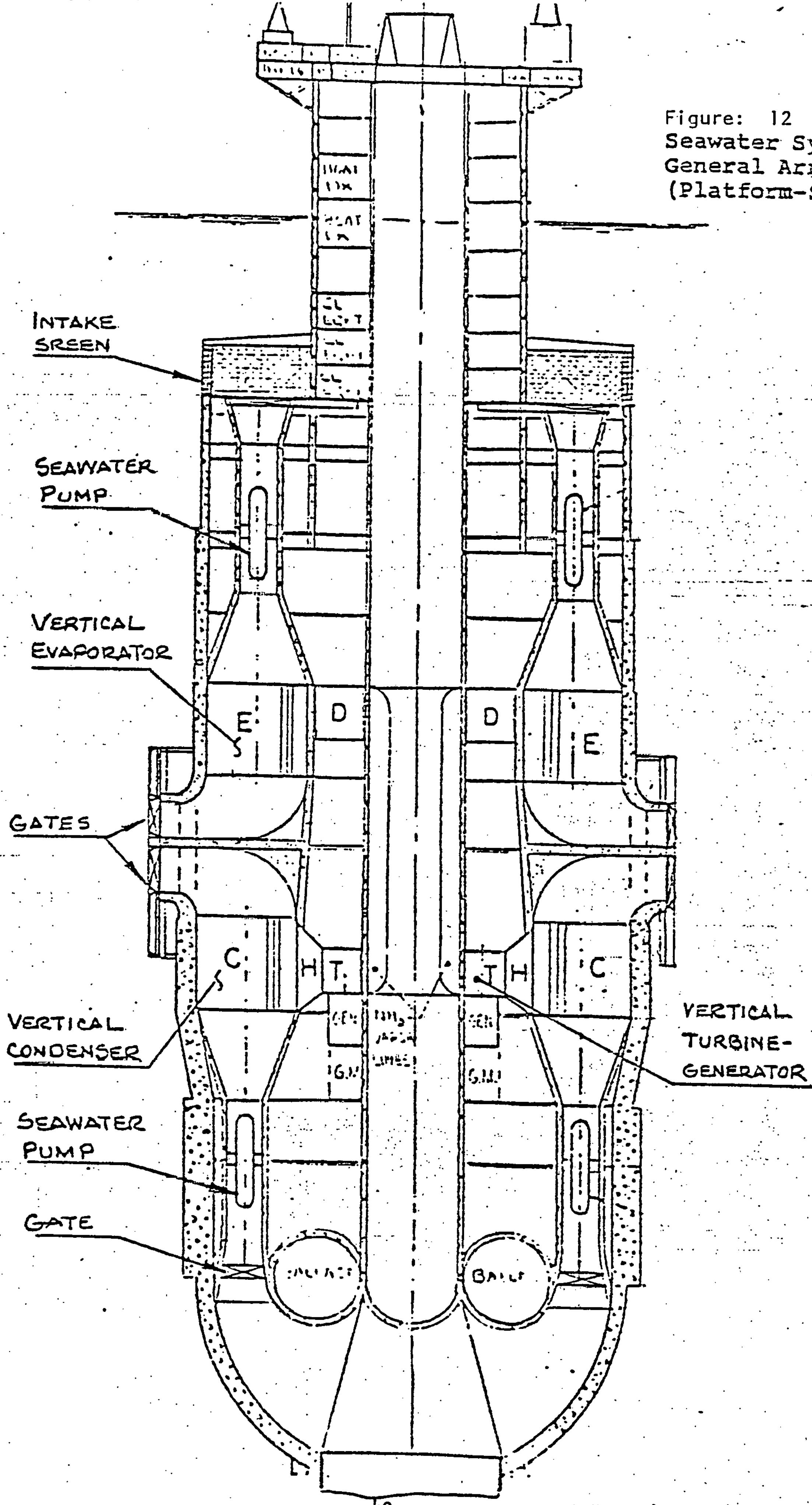


Figure 11: Seawater System General Arrangement (Sphere Platform)

Figure: 12
Seawater System
General Arrangement
(Platform-Spar)



For the SPAR hull, the regular wave motions at the platform center of gravity, as computed, are shown in Figure 13. The estimated natural frequencies of heaving and rolling motions are 0.113 and 0.19 rad/sec. The dip of the heave response in the neighborhood of the heave resonance is due mainly to similar behavior of the heave-exciting force. The hump and hollow of the sway response near the roll resonance frequency is attributed to the effect of the coupled motion of sway and roll motions.

The results of irregular sea analyses are shown in Table 11. The results marked "Earlier Coefficients" were based on the first set of hydromechanical quantities which were altered later. The results indicate, on a relative basis, that the presence of the CWP does not affect the vessel motions significantly, which is reasonable, since the mass of the pipe is small compared to the mass of the platforms, and the wave exciting forces on the pipe would have to be significantly reduced because of the submergence depth of the pipe.

Similar seakeeping analysis results for the Sphere platform are shown in Figure 14 and Table 12, respectively, for regular and irregular seas.

The results indicate that the Sphere motions are modest, but larger than those for the Spar.

The motions of the Spar and Sphere platforms in a severe storm are in general less than those for surface vessels in moderate conditions, so that the platforms should be operable under all circumstances from human and platform service systems standpoints.

3.3.6 Cold Water Pipe Analysis

The cold water pipe (CWP) analyses covered the following range of variables:

- o Configuration
- o Materials
- o Buoyancy
- o Connection Stiffness
- o CWP Structural Cross Section

The stress analyses considered stresses due to deadweight, waves, current, internal flow, and platform motions. Resistance to buckling was also checked.

The wave stress and platform motion stresses were determined using the Paulling [11] and Hydronautics Computer Programs [12].

Many different configurations of CWP's were considered. Tables 13 and 14 give the full scenario for the SPAR and SPHERE platforms respectively.

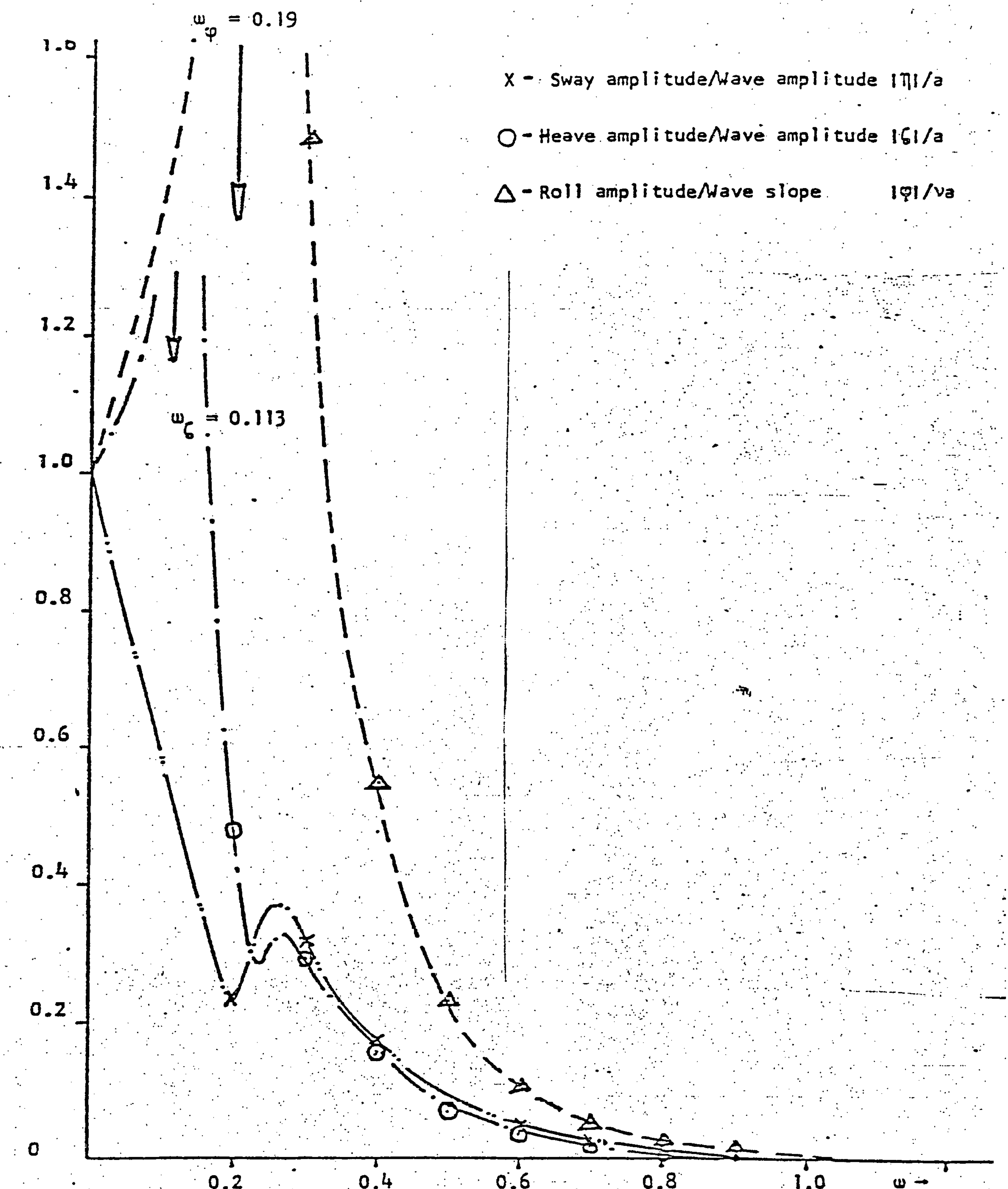


FIGURE 13 RESPONSE MOTIONS OF THE SPAR BUOY PLATFORM

TABLE 11

Summary of MR&S calculated results for the spar platform with and without CWP (Significant Response)

Significant Wave Height, H = 45.8 Ft.

Parameter Unit	Earlier Coeff. No CWP	24"GRP CWP	8" GRP CWP	4.5" Double Wall Steel CWP
Sway-Feet	3.7	3.6	6.80	6.9
Roll-Deg.	1.79	1.81	1.66	1.59
Heave-Feet	3.32		4.07	3.31

Significant Wave Height, H = 58.1 Ft.

Parameter Unit	Earlier Coeff. No CWP	24"GRP CWP	8" GRP CWP	4.5" Double Wall Steel CWP
Sway-Feet	6.95	6.69	10.28	10.26
Roll-Deg.	2.37	2.44	2.23	2.25
Heave-Feet	7.58	6.93	7.35	5.97

Significant Wave Height, H = 20.0 Ft.

Parameter Unit			8" GRP CWP	4.5" Double Wall Steel CWP
Sway-Feet			1.85	1.932
Roll-Deg.			.5584	.4912
Heave-Feet			.7184	.5864

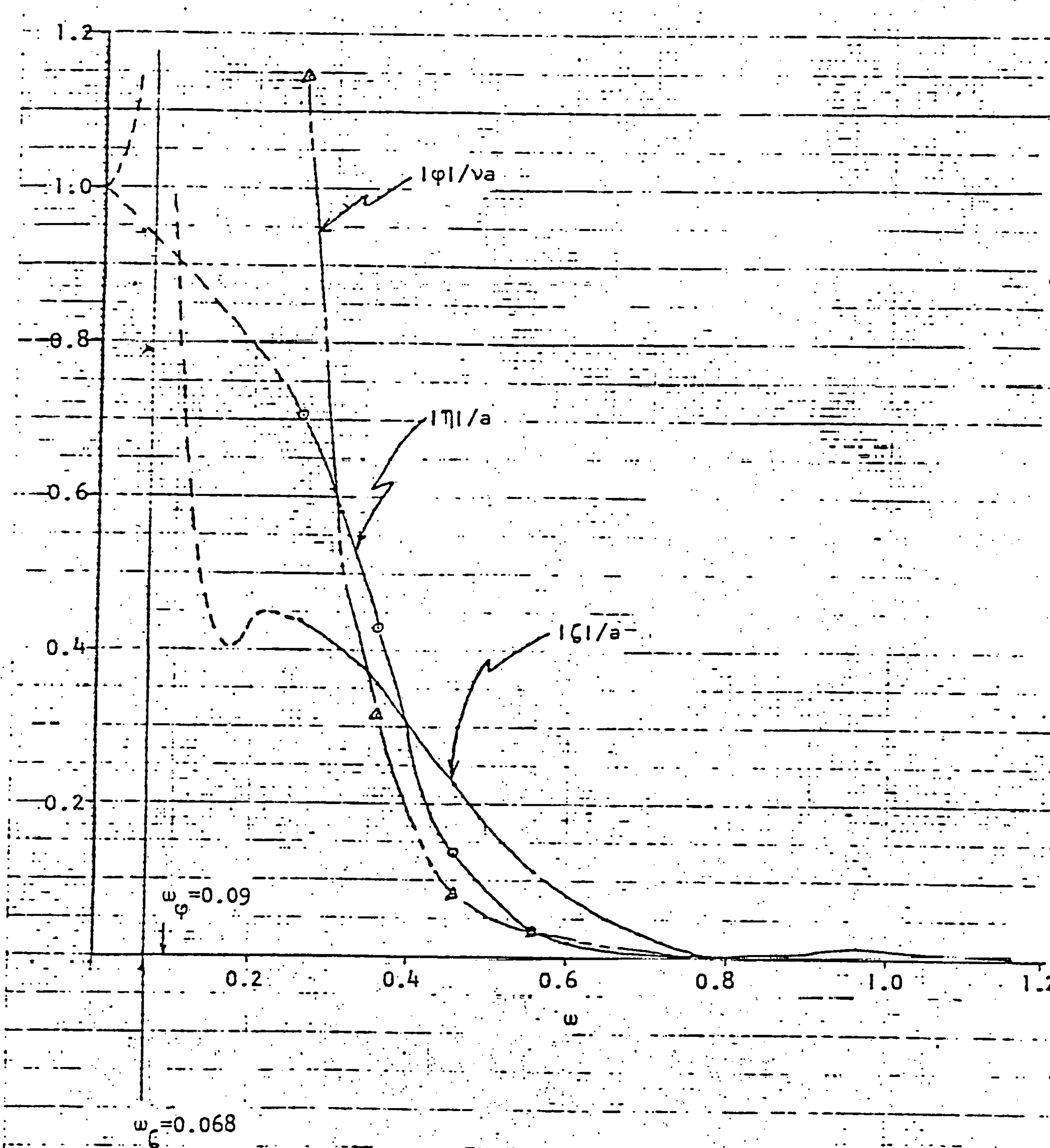


FIGURE 14 RESPONSE MOTIONS OF THE TUNED SPHERE WITH SINGLE COLUMN

TABLE 12

Summary of MR&S calculated results for the sphere platform with single column and GRP CWP (Significant Motion)

Parameter Units	Significant Wave Height, H=45. Ft.
Sway - Ft.	8.33
Roll - Deg.	1.02
Heave - Ft.	10.0

Parameter Units	Significant Wave Height, H=58.1 Ft.
Sway - Ft.	16.14
Roll - Deg.	2.11
Heave - Ft.	15.98

Parameter Units	Significant Wave Height, H=20.0 Ft.
Sway - Ft.	.954
Roll - Deg.	.1484
Heave - Ft.	1.94

TABLE 13 CWP CASES CONSIDERED

CONFIGURATION (All vertical lengths 2300")	MATERIAL	TYPE WALL AND THICKNESS	BUOYANCY	PLATFORM CONNECTION STIFFNESS	CWP JOINT STIFFNESS
Single Pipe (I.D.=101")	GRP	Solid-12",10",8"	None	Rigid	Rigid
"	"	" -12",	"	Pinned	"
"	"	" -12",	1/2 Buoyant	Rigid	"
"	"	" -12",	Fully Buoyant	"	"
"	Steel	" -12"	1/2 Buoyant	"	"
"	"	" -12",6",9"	Fully Buoyant	"	"
"	"	Built up-4.5"x 2 walls	1/2 Buoyant	Rigid	Rigid
"	Alternating GRP & Steel Sections	" -GRP 24" STL 12"	None	"	"
"	Concrete	" -24"	None	"	"
"	"	" -24"	1/2 Buoyant	"	"
"	"	" -24",60"	Fully Buoyant	"	"
Multiple Pipes (4 Pipe Cluster-Each Pipe ID = 50.5')	GRP	" -14" (each)	None	Rigid	Rigid
Truss (4 Pipes @ 170' to Diagonal each pipe ID = 50.5")	GRP	" -6" (each)	None	Rigid	Rigid
	Steel	" -6"	None	Rigid	Rigid
	Concrete	" -12"	Fully Buoyant	Rigid	Rigid

TABLE 14. CWP CASES CONSIDERED

CONFIGURATION	MATERIAL	TYPE WALL AND THICKNESS	BUOYANCY	PLATFORM CONNECTION STIFFNESS	CWP JOINT STIFFNESS
SINGLE PIPE (I.D. = 101')	GRP	SOLID - 6',8',15' 16',18',21',24'	NONE	RIGID	RIGID
"	"		NONE	PINNED	RIGID
"	STEEL	SOLID - 15',18"	1/2 BUOYANT	RIGID	RIGID
"	"	BUILT-UP - 4.5" x 2vaw	"	"	"
"	CONCRETE	SOLID - 60"	BUOYANT	RIGID	RIGID
TRUSS (4 PIPES @ 347' to DIAGONAL EACH PIPE = 50.5')	STEEL	SOLID - 6" (EACH)	NONE	RIGID	RIGID
	CONCRETE	SOLID - 12"	NONE	"	"

The materials considered in the CWP studies are shown in the tables. It can be seen that aluminum has been dropped from consideration, primarily due its higher cost, poorer properties in salt water, limited availability and more elevated and controlled construction requirements.

The stress analyses consisted of: separately determining the deadweight, wave, current, internal flow and platform motion induced stresses in the CWP; adding these stresses and comparing to allowable stresses; and checking pipe design against implosion and column buckling requirements.

The results of the stress analyses are summarized in Tables 15 and 16 for the SPAR and SPHERE platforms respectively. It should be noted that the calculations represent results for several design spiral iterations where slight modifications were made to the main hull. The results shown in these two tabulations are only partial. Complete results are contained in Volume II report.

The results are all for the 58.1 ft. significant wave height at New Orleans unless otherwise noted.

In considering the possible maximum motion and wave induced stresses, it should be noted that the "maximum expected" value of any physical quantity is usually two or three times that of the corresponding significant value for a linear system. It is known, however, that the non-linear response of ships in severe seas is usually smaller than the corresponding linear response. Consequently, it is felt that the average $1/10^6$ highest value should be a conservative maximum. This value is 5.26 RMS as shown in Tables 15 and 16.

It should be noted that in the MR&S computations the Sphere pipe stresses are generally larger than the Spar stresses, as was expected since the Sphere motions were greater.

To gain some insight into the observed decreased stresses of both thinner and thicker GRP CWP's, Figure 15 was plotted for the Sphere platform. It shows the natural frequencies of the CWP's in the range of significant wave energy. Figure 16 shows a similar plot for steel CWP's.

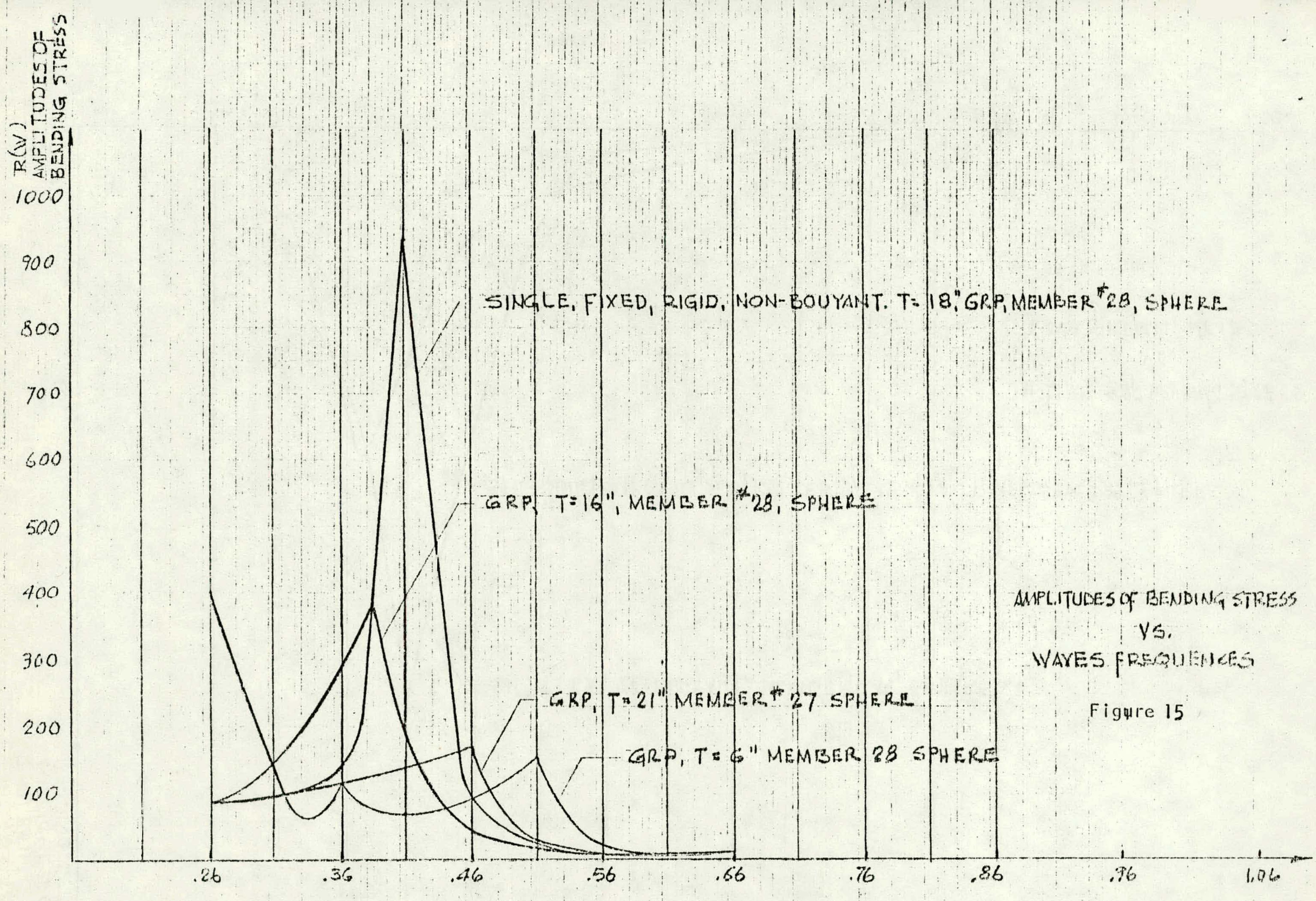
Figure 17 shows the basic manufacturing details of the Spar platform cold water pipe.

CASE NO.	PLATFORM	MATERIAL	STRESSES				RMS MOTIONS			TOTAL STRESS	MAXIMUM ALLOWANCE STRESS
			RMS WAVE	MAXIMUM RMS x 5.26	CURRENT	WEIGHT	HEAVE	SWAY	ROLL		
~~28~~	TR ~~SPH~~	~~C~~	~~1.795 E3~~	~~9.442 E3~~	~~81.5~~	~~1.52 E3~~				~~1.10 E4~~	~~1.8 E3~~
~~39~~	~~SPH~~	~~C~~	~~1.4799 E3~~	~~7.784 E3~~	~~52~~	~~0~~				~~7.736 E3~~	~~1.8 E3~~
2	S A	S	1.413 E4	7.432 E4	254	7083				8.166 E4	3.36 E4
4	S A	S	1.411 E3	7.423 E4	254	7083				8.157 E4	3.36 E4
19	S B TR	S	7.0199 E3	3.693 E4	311	7083				4.432 E4	3.36 E4
26	"	S	7.1 E3	3.735 E4	381	0				3.773 E4	3.36 E4
30	S B	S	5.8366 E3	3.07 E4	277	1.984 E3				3.296 E4	3.36 E4
31	"	S	6.1794 E3	3.25 E4	302	0				3.28 E4	3.36 E4
52	"	S	5.7152 E3 5.0953 E3	3.006 E4 2.68 E4	349 349	3.333 3.333	1.49 .83	2.57 1.73	.56 .40	3.374 E4 3.048 E4	3.36 E4 3.36 E4
25	"	Comp P/S	P-2.2077 E3 S-4.4544 E3	1.1613 E4 2.343 E4	127 254	2.822 E3 5.644 E3				1.4435 E4 2.933 E4	1.2 E4 3.36 E4
47	S	P	2.451 E3 1.7717 E3	1.289 E4 9.32 E3	383 383	700 700				1.397 E4 1.04 E4	1.2 E4 1.2 E4

Table 15 Results of MR&S Computer Analyses For Spar Platform

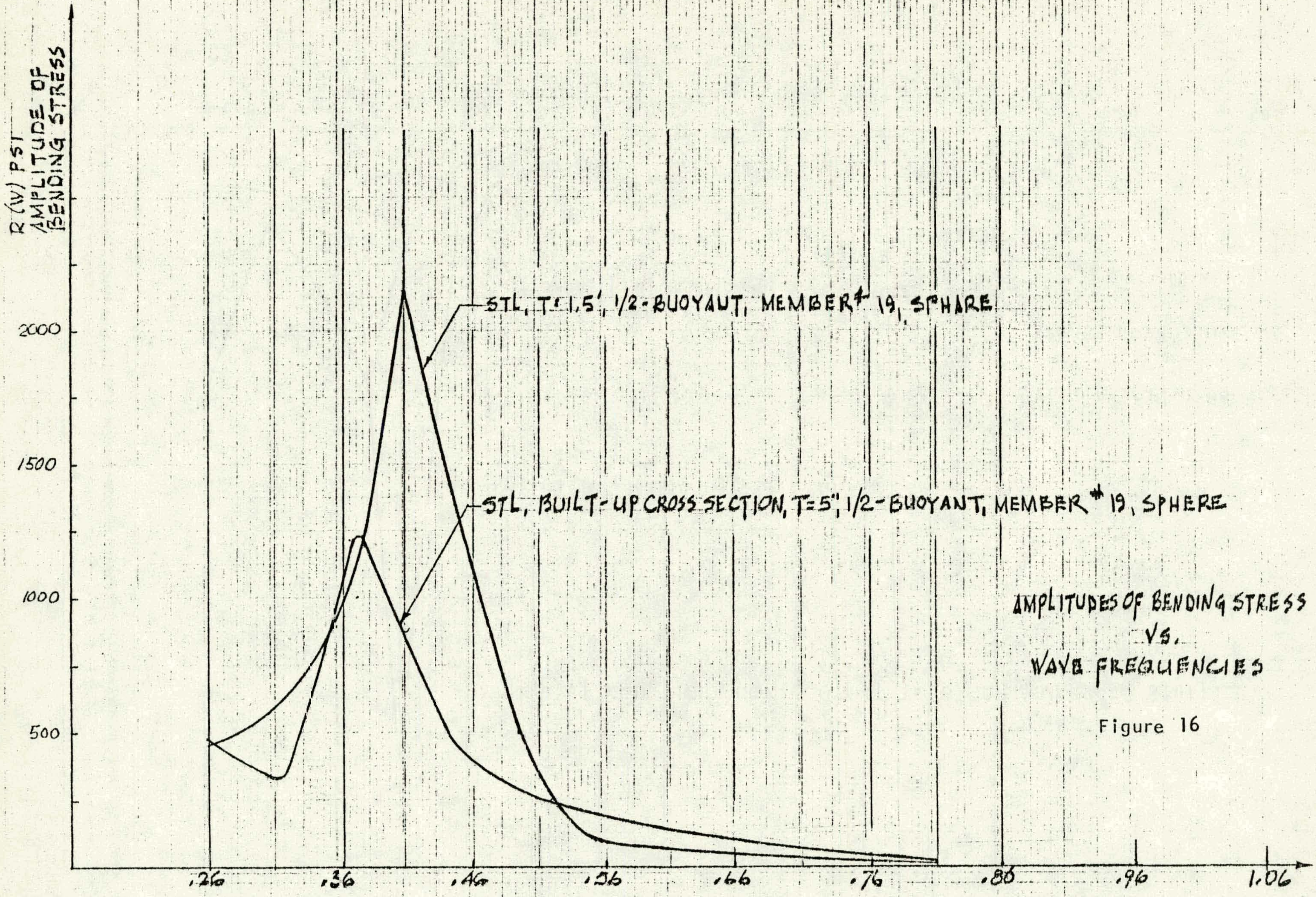
CASE NO.	PLATFORM	MATERIAL	STRESSES				RMS MOTIONS			TOTAL STRESS	MAXIMUM ALLOWANCE STRESS
			RMS WAVE	MAXIMUM RMS x 5.26	CURRENT	WEIGHT	HEAVE	SWAY	ROLL		
29	TR SPH	S	2.342 E4	1.232 E5	137	1.44 E4				1.3773 E5	3.36 E4
36	SPH	S	3.6265 E4	1.907 E5	225	4275	4.535	4.532	2.48	1.953 E 5	3.36 E4
40	〃	S	1.6038 E4	8.436 E4	199	4375	4.352	2.692	1.843	8.893 E4	3.36 E4
46	〃	S	(Fla) 4.2157 E3	2.217 E4	311	4383	1.81	1.31	.964	2.686 E4	3.36E4
10	SPH A	S	4.057 E4	2.134 E5	254	8854				2.225 E5	3.36 E4
48	SPH B+	S	(Fla) 6.695 E3	3.52 E4	311	4383	2.22	1.49	.996	3.99 E4	3.36 E4
51	〃	S	(Fla) 8.3835 E3	4.41 E4	349	3929	2.28	1.44	.95	4.838 E4	3.36E4
49	SPH C	S	(Fla) 4.4073 E4	2.318 E5	349	3929	2.28	3.64	.40	2.36 E5	3.36 E4
20	SPH	P	2.5915 E3	1.363 E4	203	875				1.471 E4	1.2 E4
21	〃	P	3.0427 E3	1.6 E4	203	875				1.708 E4	1.2 E4
37	〃	P	1.045 E3	5.5 E3	190	875	5.41	3.71	1.91	6.562 E3	1.2 E3

TABLE 16 Results of MR&S Sphere CWP Stress Computer Run



AMPLITUDES OF BENDING STRESS
VS.
WAVES FREQUENCES

Figure 15



AMPLITUDES OF BENDING STRESS
VS.
WAVE FREQUENCIES

Figure 16

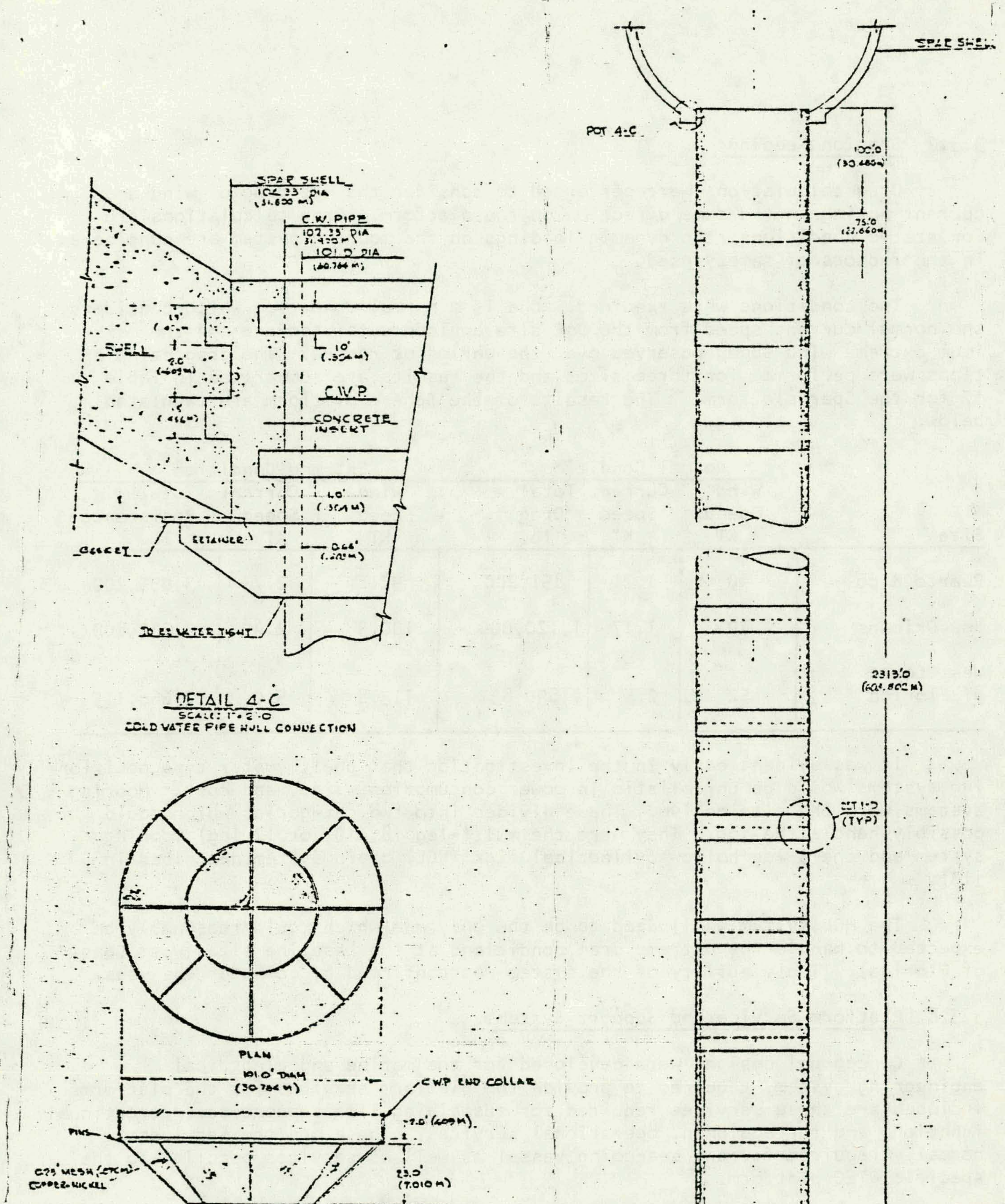


FIGURE: 17 CWP FOR SPAR

3.3.7 Station Keeping

Drag calculations were performed to consider the net drag of wind and current acting in the same direction on the platform. Drag calculations are for static conditions; the dynamic loadings on the mooring system are considered in the factors of safety used.

Two conditions were examined. One is a normal condition which considers the normal current speed from the DoE site environmental package and the maximum extreme wind speed observed over the period of record. The drag calculations were performed for three sites and the results are summarized in Table 17 for the Spar platform. The results of the Sphere platform are tabulated below:

	Normal Condition			Extreme Condition		
Site	Wind Speed KT	Current Speed KT	Total Drag lb.	Wind Speed KT	Current Speed KT	Total Resistance lb.
Puerto Rico	40	1.21	851,200	92.8	2.73	3,035,200
New Orleans	70	1.17	1,120,000	100.3	2.49	2,732,800
West Coast of Florida	52	2.5	1,890,831	113.8	5.0	7,666,115

It was evident early in the investigation that the thruster type positioning systems would be unrealistic in power consumption, size, and cost. Mooring systems were the alternative. These divided into two categories which could possibly handle the job. They were the multi-leg (8, 10, or 12 leg) mooring system and the 3-leg hollow cylindrical link (HCL) chain system described in [13].

The HCL system was judged to be the only one which could reasonably be expected to handle the extreme drag conditions at the baseline site (West Coast of Florida). The viability of the system was confirmed by computer analyses.

3.3.8 Platform Service and Support Systems

Conceptual designs were developed for the marine and electrical engineering systems required to provide the platform services for the platforms. Included are those services required for sustaining life support and recreational functions and for equipment operational services. These are the services normally required for any sea-going vessel as well as services peculiar to the specific OTEC platform.

Table 17 Current Conditions at Sites

te	VS	Conditions	Drag		
			Current	Wind	Total
Coast Fla.	2.5 KTs	Normal	578.8 (588.1)	45.3 (46.0)	624.1 (634.1)
	5.0 KTs	Extreme	2315.5 (2352.5)	181.1 (184.0)	2496.6 (2536.5)
erto Rico	1.21 KTs	Normal	279.0 (283.5)	45.3 (46.0)	324.3 (329.5)
	2.76 KTs	Extreme	595 2 (601.7)	181.1 (184.0)	773.3 (785 7)
v Orleans	1.17 KTs	Normal	258.2 (262.3)	45.3 (46.0)	303.5 (308.3)
	2.49 KTs	Extreme	451.7 (458.9)	181.1 (184.0)	632.8 (632.9)

te: All drag numbers are in longtons (metric tons).

Equipment and piping designs are in conformance with the applicable sections of ABS, USCG, USPH and EPA regulations regarding safety, materials, workmanship and environmental considerations. All systems are designed to accomplish the intended service.

The following systems are the major marine engineering systems required to provide platform services.

1. Hypochlorination Injection System
2. Fire Extinguishing and Detection System
3. Bilge, Ballast, and Stripping System
4. Sea Water Service System
5. OTEC Units Flooding and Dewatering System
6. Compressed Air System
7. Fresh Water System
8. Sea Water Sanitary System
9. Drain Collecting System
10. Heating, Ventilating, and Air Conditioning System
11. Diesel Oil System
12. Lubricating Oil System

The platform service electrical system was developed to satisfy the OTEC platform's operational needs and the requirements of regulatory bodies as it was anticipated that such requirements would apply to the OTEC platform.

An electrical load analysis and one-line diagram were prepared to determine generator capacity and sizes of associated equipment and to show conceptual electrical system configuration. The load analysis is shown in Table 18.

Platform service power will normally be provided by a 4000 KW tranformer and bus-tie cable system energized from the main OTEC generating plant. Stand-by power will be provided by two 2100 KW diesel generator sets and associated switchgear.

An emergency power plant, consisting of a single 1000 KW diesel generator set and associated switchgear would be provided in compliance with regulatory requirements. The emergency plant would be sized to energize emergency lighting, radio and interior communications, firefighting, control and personnel evacuation loads (including all elevators).

The support systems, as discussed in Volume I and in [5], are those installations which assist in the operation and maintenance of the platform. They consist mainly of:

1. Lifting Devices and Deck Gear
2. Boat Handling
3. Helicopter Handling
4. Replenishment Operations

The initial consideration for an operational scenario was that, during normal operation, each platform in the OTEC energy park, would have a crew of twenty people/shift in a "lunchbox" type operation where they would be ferried over from a central hotel facility for their 12 hour shift each day. These people would be responsible for the following duties:

LINE	NAME OF EQUIPMENT	NO	RATED HP/KW EACH	TOTAL CONN KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	REMARKS
1																	
2	SUMMARY SHEET				OTEC UP (1)		OTEC DOWN (2)		PEAK SERVICE (3)		EMERGENCY						
3																	
4	AUXILIARY MACHINERY			4723.4		2307.4		2307.4		2910.4							
5	OTEC SYSTEM SUPPORT			105 -		13 -		11 -		13 -							
6	DECK MACHINERY			140.1		-0-		12.5		-0-		808.2					
7	ELEVATORS			151.2		15.1		20.2		30.2		30.2					
8	SHOP EQUIPMENT			141.6		-0-		14.2		-0-							
9	HOTEL			12.4		3.3		3.3		3.3							
10	INTERIOR COMMUNICATIONS			1-		0.4		0.4		0.4		0.7					
11	LIGHTING			660 -		236 -		376 -		376 -		120 -					
12	MISC. ELEX & RF COMMUNICATIONS			2 -		48		0.8		0.8		1.4					
13	TOTAL			5936.7		2576 -		2745.8		3334.1		960.50					
14	ALLOWANCE FOR GROWTH (30%)							823.7		783.2 (4)							
15	NOTES		GRAND TOTAL:					3569.5		4117.3							
16	(1) POWER FROM OTEC PLANT VIA																
17	4MWe TRANSFORMER & BUS TIE - NORMAL OPERATIONS																
18																	
19	(2) POWER FROM PSS GENERATORS,																
20	BUS TIE TO OTEC PLANT DE-ENERGIZED - MAINTENANCE OPERATIONS																
21																	
22	(3) POWER FROM PSS GENERATORS,																
23	BUS TIE TO OTEC DE-ENERGIZED - BALLASTING/DEBALLASTING OPERATIONS																
24																	
25	(4) GROWTH FOR PEAK SERVICE DOES NOT																
26	INCLUDE GROWTH FOR BILGE AND BALLAST PUMPS																
27	USED FOR BALLAST/DEBALLAST OPERATIONS																
28																	

M. ROSENBLATT & SON, INC.
NAVAL ARCHITECTS AND MARINE ENGINEERS
SAN DIEGO NEW YORK ✓ SAN FRANCISCO WASHINGTON, D.C.

OTEC 400 MWe SPAR PLATFORM

ELECTRICAL LOAD ANALYSIS

SIZE	CONTRACT NO.	DATE	DRAWING NO.	REV.
	5142	Mar 30,'79	TABLE 12	
			SHEET 1 OF 4	

Table 18 ELECTRICAL LOAD ANALYSIS

- o Control Crew
  - OTEC power cycle monitoring
  - Power cycle data transmission
  - Administrative duties

- o Maintenance & Operations Crew
  - Routine maintenance & adjustment to the OTEC power cycle, auxiliaries, and platform equipment
  - Local repairs (on small scale)
  - Deck operations, supplies, boat & helicopter handling

Crew shoreside rotation would follow established offshore industry practices. A proposed crew organization chart is shown in Figure 18.

Maintenance, taken to mean major repair or overhaul operations rather than routine preventive actions, generally is seen to require a crew of specialists to augment the regular platform crew. Major component removal routes for the Spar platform are shown, as a sample, in Figure 19.

3.4 Construction and Deployment of Platforms

The enormous size and displacement of the 400 MW_e Commercial OTEC platforms dictate that the bases for the main hulls be fabricated on land and the hulls of the platforms constructed at an offshore site with completion and pipe installation at the final site. However, major components such as the sphere superstructure or spar deck house and cold water pipe sections are to be constructed in shore facilities. This scenario will reduce construction time, and minimize costs and risk of structural failure. The fiberglass cold water pipe in particular must be constructed in a facility which permits high quality control. A summary of the construction and deployment scenarios for the Spar and Sphere is shown in Table 19.

The two platforms have much in common with regard to the facilities and equipment required to construct and deploy them. However, differences in design necessitate some differences in equipment and procedure.

The base of the platform is constructed onshore to build as much of the platform as possible to produce a safe structure from which construction is continued at sea, while at the same time keeping the launch draft to a minimum. Both platforms have a launch draft of 46 feet so some dredging will be required.

It is assumed that the construction area will be self supporting with respect to erecting the concrete hull and all concrete components. The construction site should thus be supplied with bulk materials by either road, rail or barge. Due to the large quantities of cement and sand needed for the project, it is assumed that much of it would be delivered by barge.

The most promising construction sites appear to be in the Florida Panhandle as shown by the arrows in Figure 20. This site offers the particular advantages listed below.

- o Close proximity to industry and transportation.
- o Protection by the Mississippi Delta from loop currents.
- o Proximity to DeSoto Canyon, (Ease of deployment).

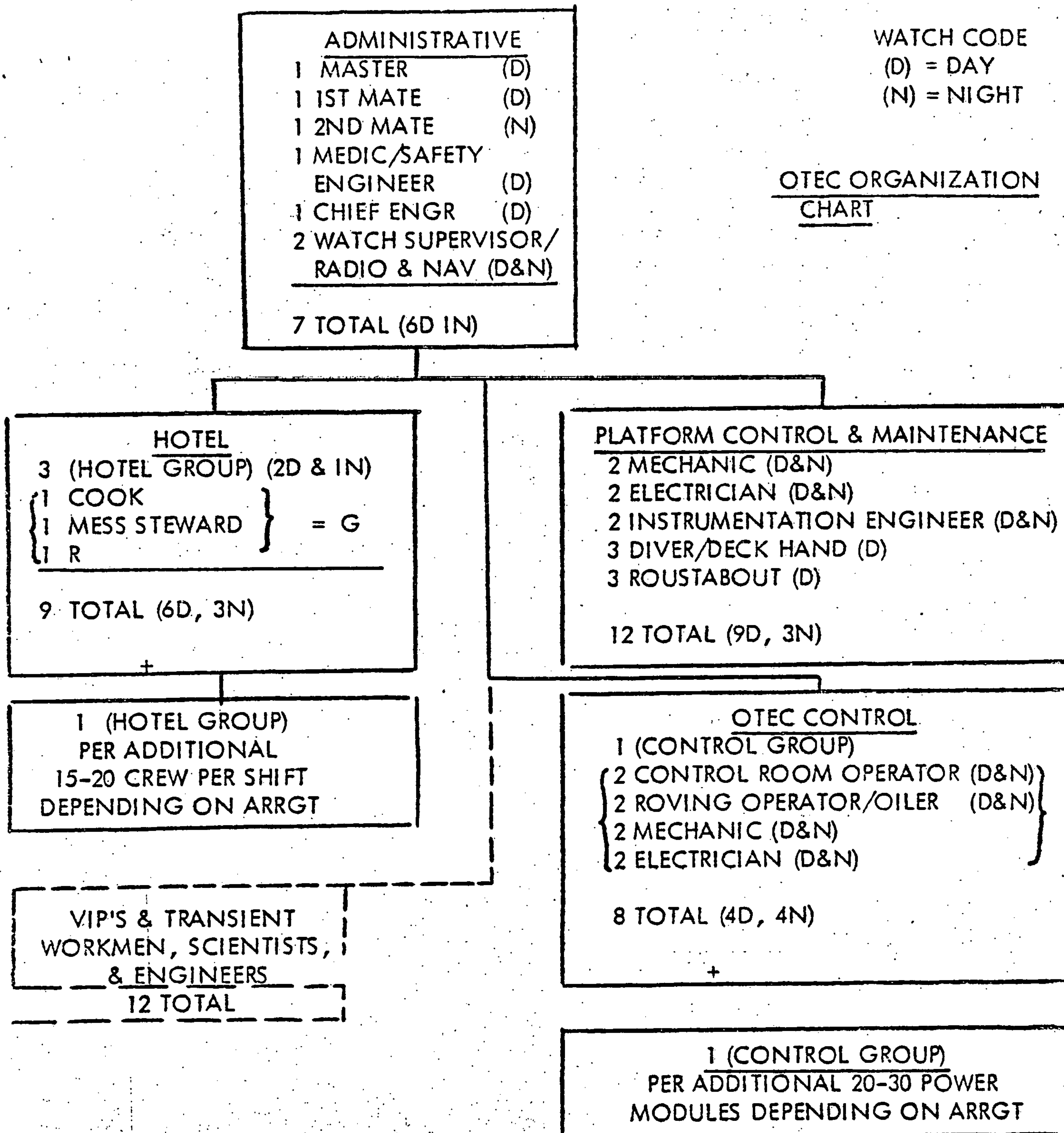

WATCH CODE
(D) = DAY
(N) = NIGHT
OTEC ORGANIZATION CHART
ADMINISTRATIVE
1 MASTER (D)
1 1ST MATE (D)
1 2ND MATE (N)
1 MEDIC/SAFETY ENGINEER (D)
1 CHIEF ENGR (D)
2 WATCH SUPERVISOR/ RADIO & NAV (D&N)
7 TOTAL (6D 1N)
HOTEL
3 (HOTEL GROUP) (2D & 1N)
1 COOK
1 MESS STEWARD
1 R
= G
9 TOTAL (6D, 3N)
+
1 (HOTEL GROUP) PER ADDITIONAL 15-20 CREW PER SHIFT DEPENDING ON ARRGT
VIP'S & TRANSIENT WORKMEN, SCIENTISTS, & ENGINEERS
12 TOTAL
PLATFORM CONTROL & MAINTENANCE
2 MECHANIC (D&N)
2 ELECTRICIAN (D&N)
2 INSTRUMENTATION ENGINEER (D&N)
3 DIVER/DECK HAND (D)
3 ROUSTABOUT (D)
12 TOTAL (9D, 3N)
OTEC CONTROL
1 (CONTROL GROUP)
2 CONTROL ROOM OPERATOR (D&N)
2 ROVING OPERATOR/OILER (D&N)
2 MECHANIC (D&N)
2 ELECTRICIAN (D&N)
8 TOTAL (4D, 4N)
+
1 (CONTROL GROUP) PER ADDITIONAL 20-30 POWER MODULES DEPENDING ON ARRGT

FIGURE 18

CONDENSER

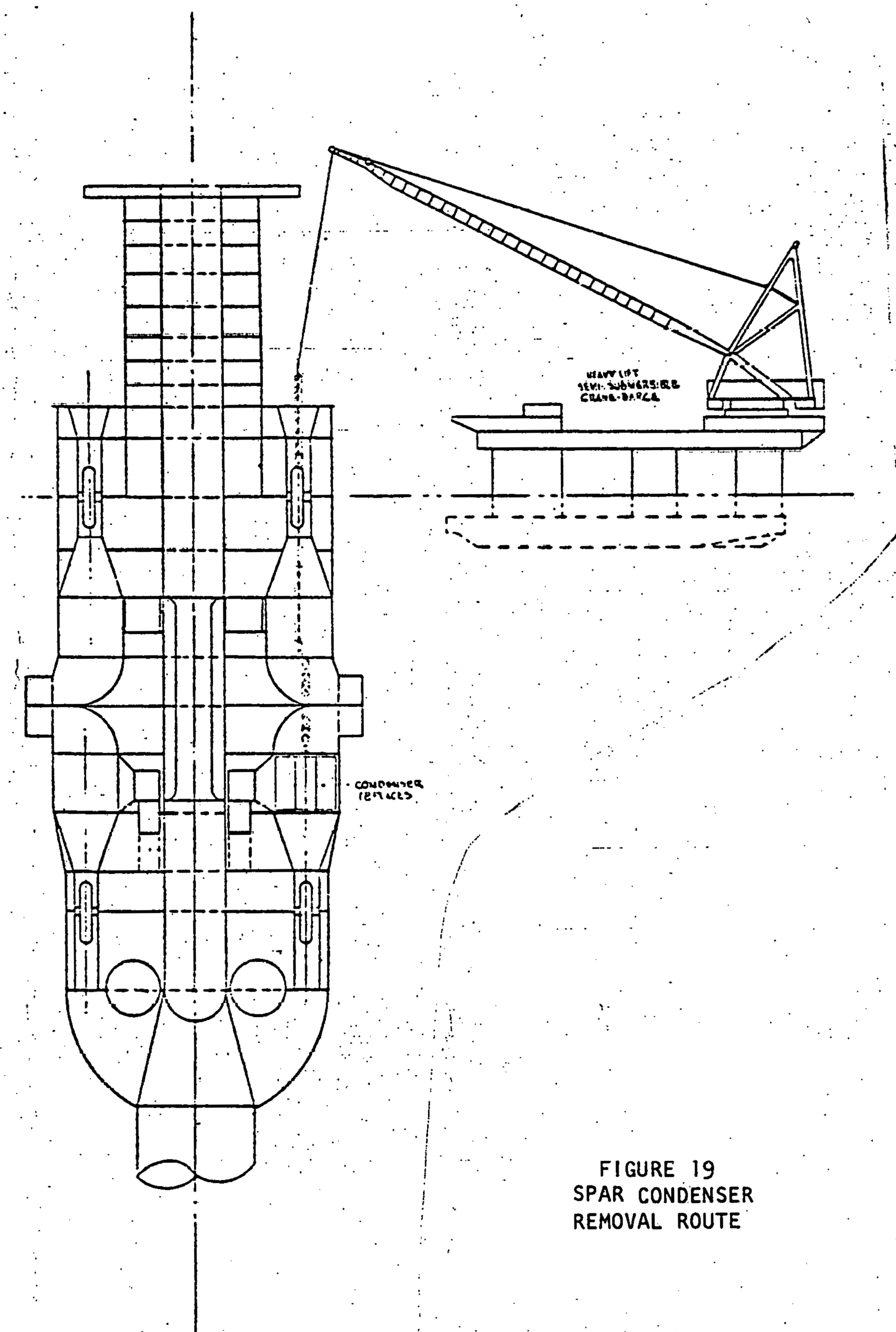


FIGURE 19
SPAR CONDENSER
REMOVAL ROUTE

TABLE 19

SUMMARY OF CONSTRUCTION/DEPLOYMENT PHASES

PART A - OTEC SPAR

PHASE I	The construction of the lowest section of the Spar, called the "grapefruit" is begun at a land site. This section is towed out to the intermediate site.
PHASE II	The platform is completed to the 440 ft. level at an intermediate site in relatively shallow water.
PHASE III	The partially completed platform is towed to the operational site for attachment of the CWP, the mooring system, completion of the platform, and startup.

PART B - OTEC SPHERE

PHASE I	During this Phase the lower portion of the concrete hull is constructed on shore and is launched.
PHASE II	The lower portion of the hull is towed to an offshore site, having a sufficient depth of water, and is moored. The remainder of the hull is completed and all seawater, power and auxiliary systems are installed with the exception of the cold water pipe and the superstructure.
PHASE III	During this Phase the completed hull is towed to its operating site and permanently moored. The cold water pipe is installed.
PHASE IV	The superstructure is erected, and the support and power transmission systems are installed. The plant is started.

(Key West to the Mississippi River)

11006

(formerly C&GS 1003)

SOUNDINGS IN FATHOMS - SCALE 1:375,000

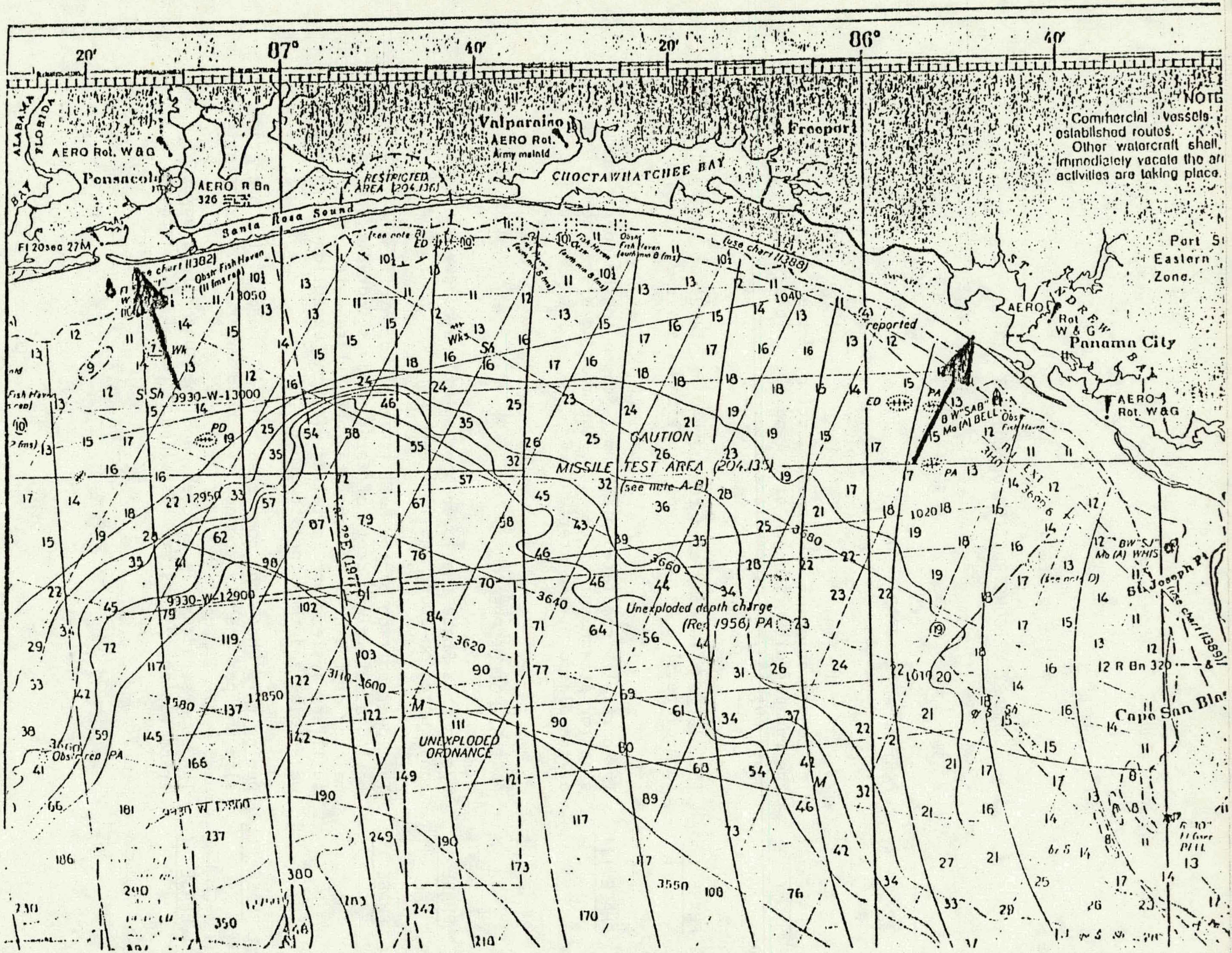


FIGURE 20: PROBABLE CONSTRUCTION SITE

- o Proximity to OTEC park sites at New Orleans, to baseline site of West Coast of Florida and to Puerto Rico site.
- o Potential to use loop current (Gulf of Mexico) to assist in deployment.

Whether it is preferable to construct an artificial offshore island or dredge a channel from the shore will depend on the results of a detailed study of the environmental impact, effect on local residents, cost and other considerations.

The offshore construction site for the main hull without the pipe will be temporarily located as close to shore as possible to minimize transportation costs of material and construction crew. Barges will be required for transportation of material and to provide a working platform around the hull. A temporary single point mooring sytem will be required to position the platform.

The HCL links of the mooring systems for both platforms are enormous. A shoreside steel fabrication facility will be required to produce these links.

Similarly, a concrete construction facility with equipment for producing floating concrete structures is required to produce the three free-fall deadweight anchors.

Several large pieces of construction equipment are anticipated to be required by both the spar and sphere construction scenarios at their shallow and deep-water construction sites.

Figures 21 and 22 show the last phases of construction sequences for the Spar and Sphere platforms.

3.5 Cost Estimates and Time Schedules

3.5.1 Cost Estimates

The basic guidelines used in developing the cost estimates are, briefly:

- o The OTEC Park consists of eight 400 MWe (net) platforms.
- o Cost estimates are to be developed in compliance with the "Work Breakdown Structure" (WBS) supplied by the DoE.
- o Estimates are to include all acquisition, deployment, and operating costs as well as site preparation costs for construction facilites.
- o OTEC Park baseline site is West Coast, Florida.

The costs for acquisition, deployment and operation of the individual platforms and the OTEC Park were generated by MR&S.

The cost estimates followed the standardized WBS for the OTEC plants. Specific WBS items given below were considered:

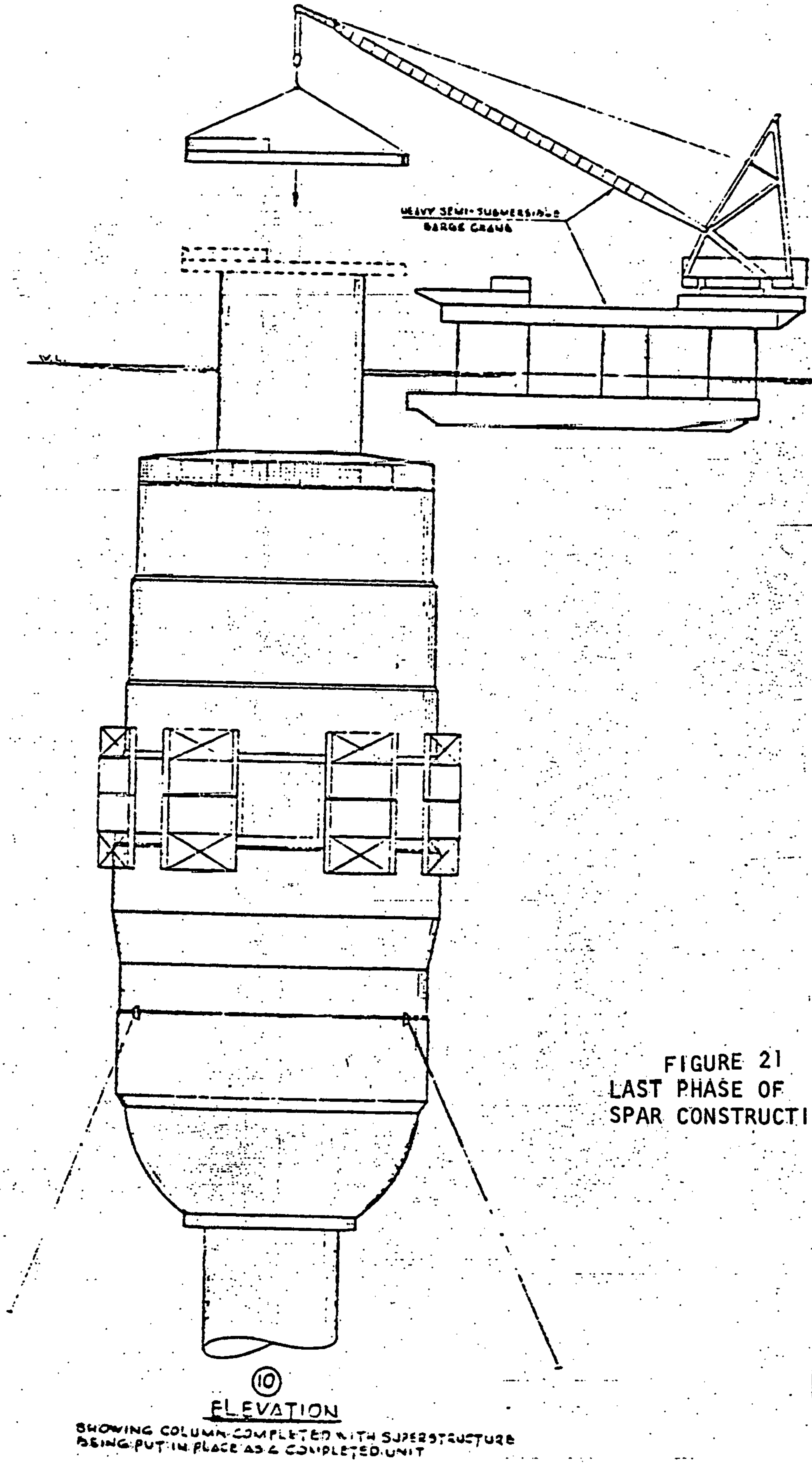


FIGURE 21
LAST PHASE OF
SPAR CONSTRUCTION

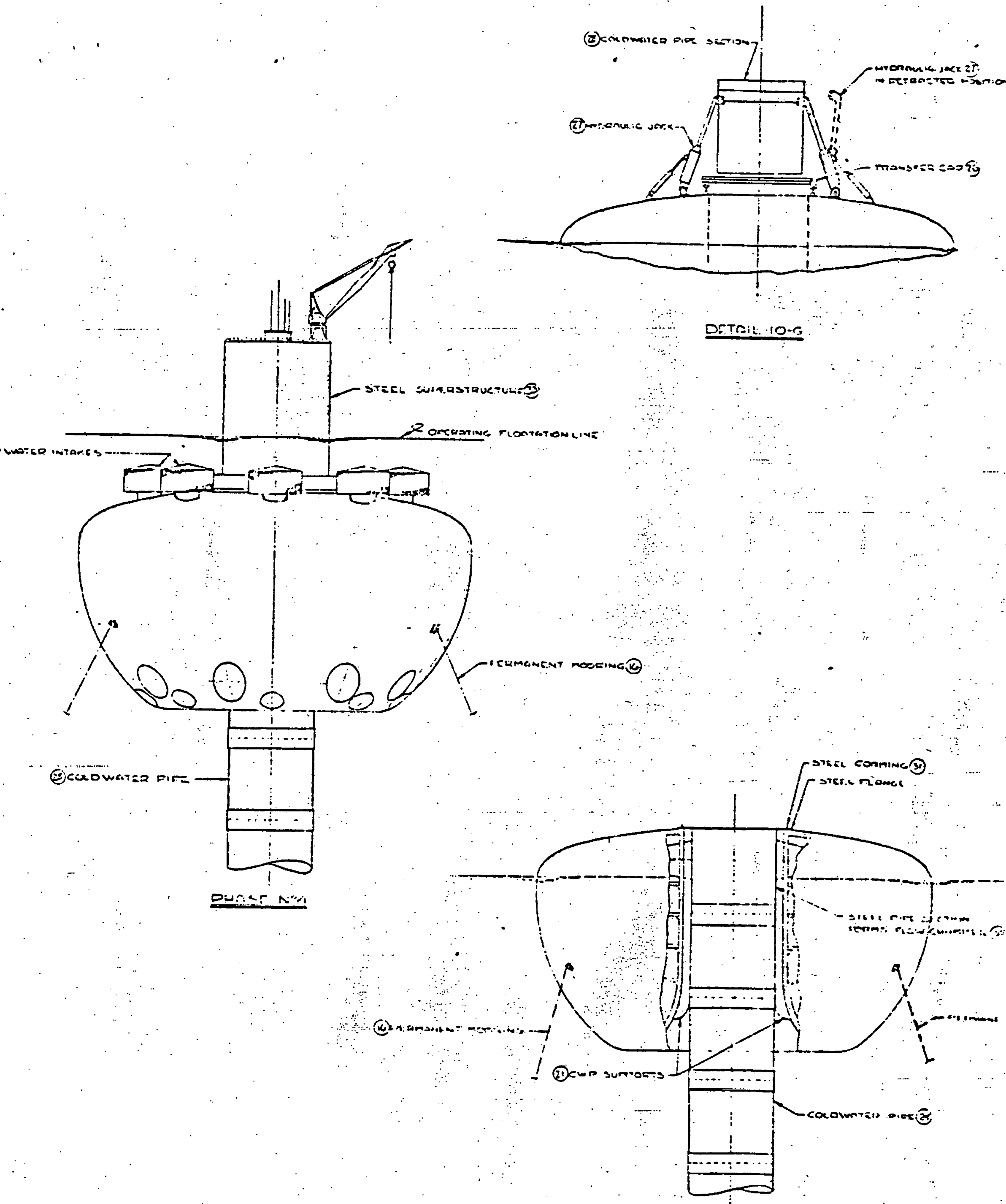


FIGURE 22
LAST PHASE OF
SPHERE CONSTRUCTION

1.0: Platform System
2.0: Cold Water Pipe System
5.0: System Engineering and Integration
6.0: System Test and Evaluation
8.0: Deployment Systems and Services
9.0: Industrial Facilities
10.0: Environmental, Legal, Licensing, Regulatory, and Insurance
11.0: Project Management

Power systems costs, Item 3.0 of the WBS, are not addressed by the platform contractors, nor are the energy transfer systems costs. However, the cost of installing the power sytems equipment on the platform are included in MR&S cost estimates.

Similarly, for the energy transfer systems, the installation of the electrical transmission system interface, i.e. the power conditioning equipment, on the hull, is included.

Detailed cost estimates are prepared for major systems and any other "cost drivers", i.e. items which make up 10% or more of the acquisition costs.

The costs for all other items in the WBS are based on parametric estimates. The parameters used are costs per weight of material, unit length, number of years service, etc.

Cost estimating efforts essentially consisted of determining the:

- Acquisition cost of platform
- Construction facilities cost
- Deployment costs
- Design, integration, and testing costs
- Cost of industrial facilities
- Cost of special test facilities

The summation of the above six cost categories resulted in a total acquisition cost for the first platform. It included, as such, the recurring as well as non-recurring costs, regardless of the number of platforms to be built. For the second platform, however, the non-recurring costs were deducted from the first platform cost and/or a percentage of the non-recurring costs were left in the total cost as required. Table 20 presents a listing of non-recurring costs.

Tables 21 and 22 summarize all costs and report the results of life cycle estimates as well as unit costs for the Spar and Sphere platform, respectively.

As pointed out, the costs reported in Tables 21 and 22 are for the baseline site at West Coast of Florida (Tampa). However, many cost items are quite sensitive to changing conditions at the deployment sites. Table 23 summarizes the cost differentials at various sites.

Table 20

NON-RECURRING COSTS	SPAR ($000)	SPHERE ($000)
PRELIMINARY DESIGN	888	1,013
CONTRACT DESIGN	1,776	2,026
DETAIL DESIGN	5,327	6,080
1.1 PLATFORM INTEGRATION ENGINEERING	888	1,013
1.6 ASSEMBLY SUPPORT SYSTEMS		
CONSOLIDATION .5 NR	100	125
PLUG .75NR	1,207	2,111
DREDGING .95NR	5,805	10,159
EXCAVATING .80NR	200	830
SHEET PILING NR	721	1,081
CARRIAGE, RAILS NR	1,000	1,000
2.1 CWP INTEGRATION		
5.1 SYSTEM DESIGN & ANALYSIS	20,000	20,000
5.2 SYSTEM INTEGRATION	2,000	2,000
6.1 TEST PLANNING	500	500
7.5 PERSONNEL (PART)	1,200	1,200
9.0 INDUSTRIAL FACILITIES	3,340	3,340
6.2 SPECIAL TEST FACILITIES	1,000	1,000
TOTALS	46,050	53,759

		($000,000) Cost For One Platform	Unit Cost $/KW	($000,000) Cost For OTEC Park	Unit Cost $/KW	REMARKS
ACQUISITION COSTS [1]	Hull Construction Cost	164	410	809	253	From Page
	Platform Acquisition Cost	360	900	1754	548	From Page (exclusive of Hull, Power Syst. Trans. Interface
	OTEC Power System Cost	400	1000	3200	1000	From Reference
	Electrical Transmission System Interface Cost	19	47.5	152	47.5	From Reference
	Transmission System Cost	-	-			Not included in estimate
	Central Accommodation Cost	-	-	54	17	From Page
	TOTAL ACQUISITION COSTS	943	2357.5	5,969	1,865	
OPERATING [2] COSTS	Independent Test & Evaluation	1	2.5	1	0.3	Non-Recurring
	Operational Support	421	1,052.5	3,368	1,052.5	From Page
	Insurance, etc.	213	532.5	1,725 [3]	539	From Page
	Project Management	3.2	8	25.8	8	From Page
	TOTAL OPERATING COSTS	638.2	1,595.5	5,119.8	1,599.8	
	LIFE CYCLE COSTS	1,581.2	3,953	11,088.8	3,464.9	Excluding Electrical Trans System Costs

Notes
[1] All costs are in terms of 1978 dollars without escalation.
[2] Operating costs are for 40 year platform life.
[3] Includes central accom. platform

TABLE 21:
COST SUMMARY FOR A 3200 MWe
OTEC Energy Park
(8 "SPAR" Platforms)

		($000,000) Cost For One Platform	Unit Cost $/KW	($000,000) Cost For OTEC Park	Unit Cost $/KW	REMARKS
ACQUISITION COSTS [1]	Hull Construction Cost	282	705	1,453	454	From Page
	Platform Acquisition Cost	375	9,375	1,932	604	From Page (exclusive of Hull, Power Syst. Trans. Interface
	OTEC Power System Cost	400	1,000	3,200	1,000	From Reference
	Electrical Transmission System Interface Cost	19	47.5	152	47.5	From Reference
	Transmission System Cost	-	-	-	-	Not included in estimate
	Central Accommodation Cost	-	-	54	17	From Page
	TOTAL ACQUISITION COSTS	1,076	2,690	6,791	2,122.5	
OPERATIONAL [2] COSTS	Independent Test & Evaluation	1	2.5	1	0.3	Non-Recurring
	Operational Support	429	1,072.5	3,432	1,072.5	From Page
	Insurance, etc.	269	672.5	2,179 [3]	681	From Page
	Project Management	3.2	8	25.8	8	From Page
	TOTAL OPERATING COSTS	702.2	1,755.5	4,637.8	1,761.8	
	LIFE CYCLE COSTS	1,778.2	4,445.5	11,428.8	3,884.3	Excluding Electrical Trans System Costs

Notes
[1] All costs are in terms of 1978 dollars without escalation.
[2] Operating costs are for 40 year platform life.
[3] Includes central accom. platform.

TABLE 22:
COST SUMMARY FOR A 3200MWe OTEC Energy Park (8 "SPHERE" Platforms)

Part A: Costs

Item	Tampa, Florida		New Orleans, LA.		Punta Tuna, P.R.	
	Sphere	Spar	Sphere	Spar	Sphere	Spar
Mooring	$ 75,957	$ 75,957	$ 27,079	$ 22,492	$ 30,076	$ 26,523
Cold Water Pipe	115,903	103,737	198,794	103,737	115,903	103,737
Platform Structure	281,557	163,885	298,450	171,696	281,557	163,885
Deployment	4,082	4,076	3,330	3,325	10,742	10,727
Power Transmission	19,000	19,000	20,055	20,055	633	633
Totals	496,499	366,655	547,708	321,305	438,911	305,505
% of Tampa Site	100	100	110	88	88	83

Part B: Site Characteristics

	Tampa, Fla. = Unity		New Orleans, La.		Punta Tuna, P.R.	
Thermal Resource	1.0	1.0	0.98	0.98	1.04	1.04
Site to Shore Oper. Sta. (N.M.)	180	180	190	190	6	6
Site to Shore Constr. Fac. (N.M.)	285	285	180	180	1215	1215

Table 23 OTEC COMMERCIAL PLANT (400 MW)
SITE COST DIFFERENTIALS ($000)

3.5.2 Time Schedules

A careful analysis of the operations, processes, and labor requirements involved in platform construction revealed that for the first SPAR platform the time periods for various phases could be:

First Phase:	6	months
Second Phase:	18	months
Third Phase:	12	months

A detailed analysis of the spar platform construction process is made in arriving at the required time periods. The total estimated construction time is 953 days. Allowing for effects of bad weather, the spar construction period is assumed to be 3 years.

Figure 23 shows a time schedule covering the SPAR construction process from the development of top level requirements to the start of construction on the first three platforms.

Figure 24 is a continuation of the time schedule covering the periods for construction, outfitting, deployment and testing of all eight platforms.

The construction scenario for the SPHERE essentially follows the same sequence as the one for SPAR.

An analysis of the construction process taking into account the added complexity of the forms required as well as the considerations mentioned above, leads us to believe that the construction of the SPHERE may take anywhere from 20% to 40% longer time than that required for the SPAR.

3.6 Site Sensitivity

There are several major areas which are sensitive to site characteristics:

- Mooring
- Cold Water Pipe
- Thermal Resource
- Replenishment and Crew Accommodations
- Platform Structure
- Deployment
- Power Transmission

Two effects on the site due to the presence of the OTEC platforms were considered: the perturbation of the thermal resource and the effects on the local sea surface and waves of removing large quantities of water nearby.

A comparison of the site characteristics affecting various OTEC functions and systems is compiled and presented in Table 24.

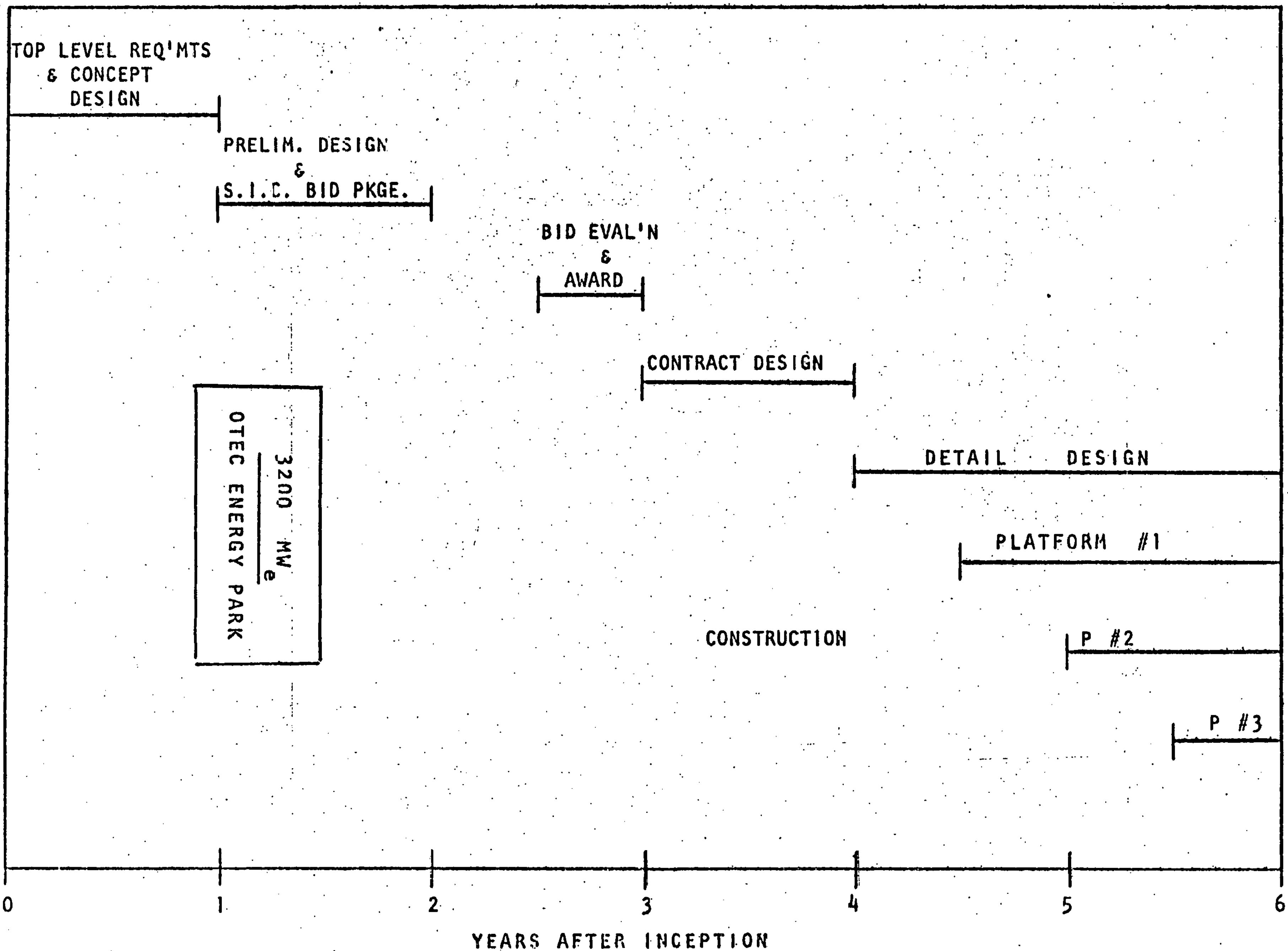
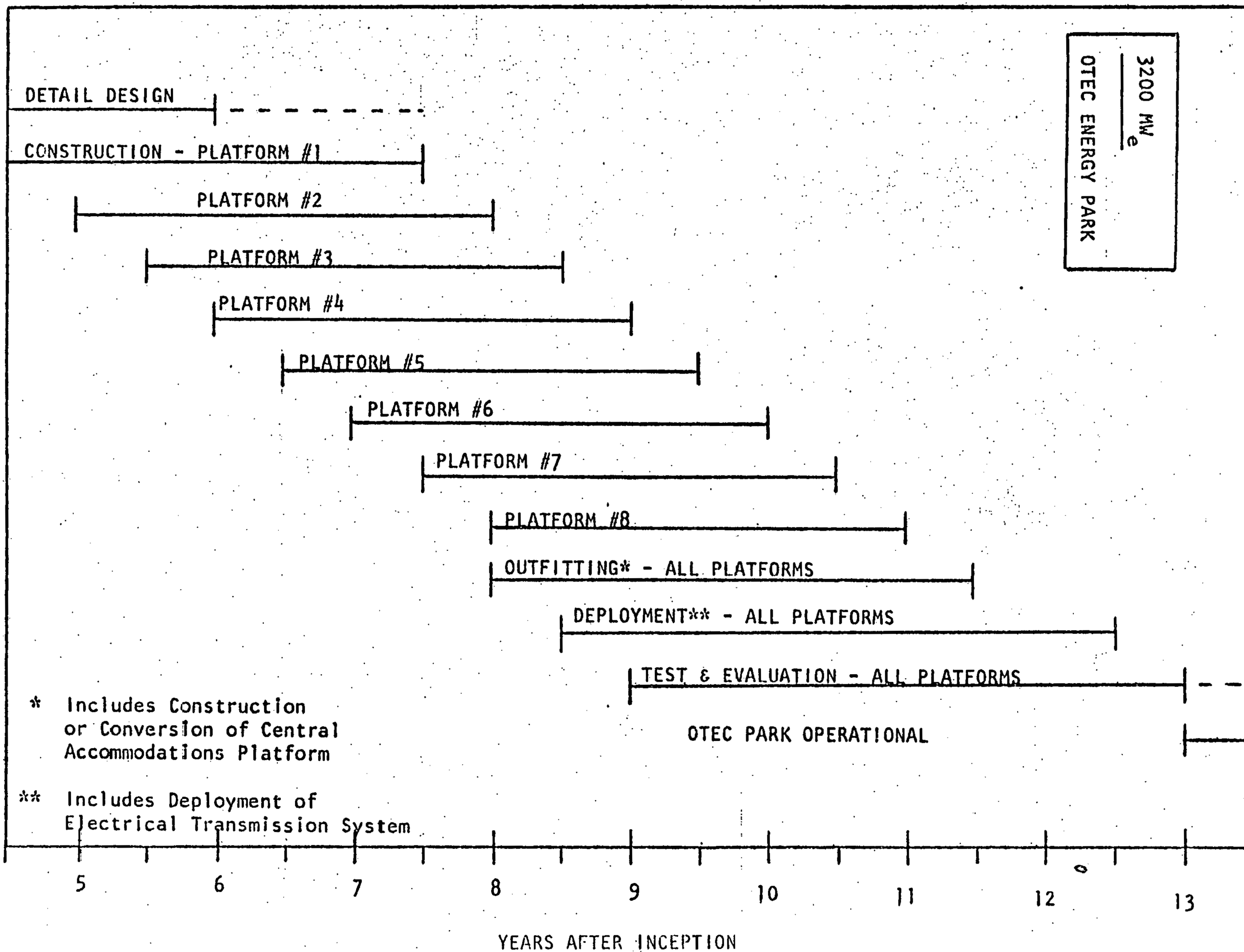


FIGURE 23
"SPAR" DESIGN & CONSTRUCTION SCHEDULE



"SPAR" TIME SCHEDULE -
(CONSTRUCTION, DEPLOYMENT, OPERATION)
FIGURE 24

CHARACTERISTIC	NEW ORLEANS		W. COAST FLORIDA		PUERTO RICO	
	SPHERE	SPAR	SPHERE	SPAR	SPHERE	SPAR
CWP Configuration	GRP, Fixed/ Rigid/N.B. ID= 101' T=16"	GRP, Fixed/ Rigid/N.B. ID= 101' T=8"	GRP, Fixed/ Rigid/N.B. ID= 101' T=8"	GRP, Fixed/ Rigid/N.B. ID= 101' T=8"	GRP, Fixed/ Rigid/N.B. ID= 101' T=8"	GRP, Fixed/ Rigid/N.B.ID= 101' T=8"
Total Drags in Extreme Condition (LTs)	1220	838.1	3422	2830.3	1355	988.3
Distance from Construction Site (Pennsacola)	180 N.M. or 210 Miles	180 N.M. or 210 Miles	285 N.M. or 330 Miles	285 N.M. or 330 Miles	1215 N.M. or 1400 Miles	1215 N.M. or 1400 Miles
Distance from Nearest PT of Land	65 N.M. or 77 Miles	65 N.M. or 77 Miles	150 N.M. or 170 Miles	150 N.M. or 170 Miles	3.4 N.M. or 4 Miles	3.4 N.M. or 4 Miles
Period During Which $\Delta T \geq 40°F$ (Month)	4.5	4.5	4.5	4.5	7.	7.
Annual Thermal Capacity (C-Month)	246.8	246.8	252.4	252.4	262.7	262.7

Table 24: COMPARISON OF SITE CHARACTERISTICS

SECTION 4.0

PROJECT PLAN FOR OTEC DEMONSTRATION UNIT

4.1 Background

In the course of the OTEC systems development, the power plant size has been increasing by steps. The first two platforms are test platforms of 1 MWe and 5 MWe output. The test platforms are followed by a pilot plant of 10 to 20 MWe output. The last platform size considered in the OTEC system development program is the 400 MWe commercial plant. The demonstration plant is intended to fill the gap between pilot plant and commercial plant development.

The responses received from utility companies suggested that the demonstration plant size should be no smaller than 10 MWe, and further that it would be desirable to have a demonstration plant equipped with commercial size modules with adequate redundancy so that a meaningful power system evaluation could be conducted. The reliability and economics of an OTEC power system must be demonstrated to gain acceptance by as well as support from the utility industry.

The internal arrangement of the spar and sphere platform must also be considered since the internal well or trunk in these platforms forces the selection of multiple power modules symmetrically arranged about the centerline. 100 MWe was chosen for the plant size since two 50 MWe modules could be installed which would permit testing of equipment recommended for use on the commercial plant.

4.2 Demonstration Platform

Since the hull size is substantially smaller than the projected commercial plant size, the possibility of constructing the vessel of steel was considered. However, it is already determined that the full size hull shall be constructed principally of reinforced concrete and thus, to fully demonstrate the feasibility of both construction technique and operation, concrete was chosen for the demonstration plant as well.

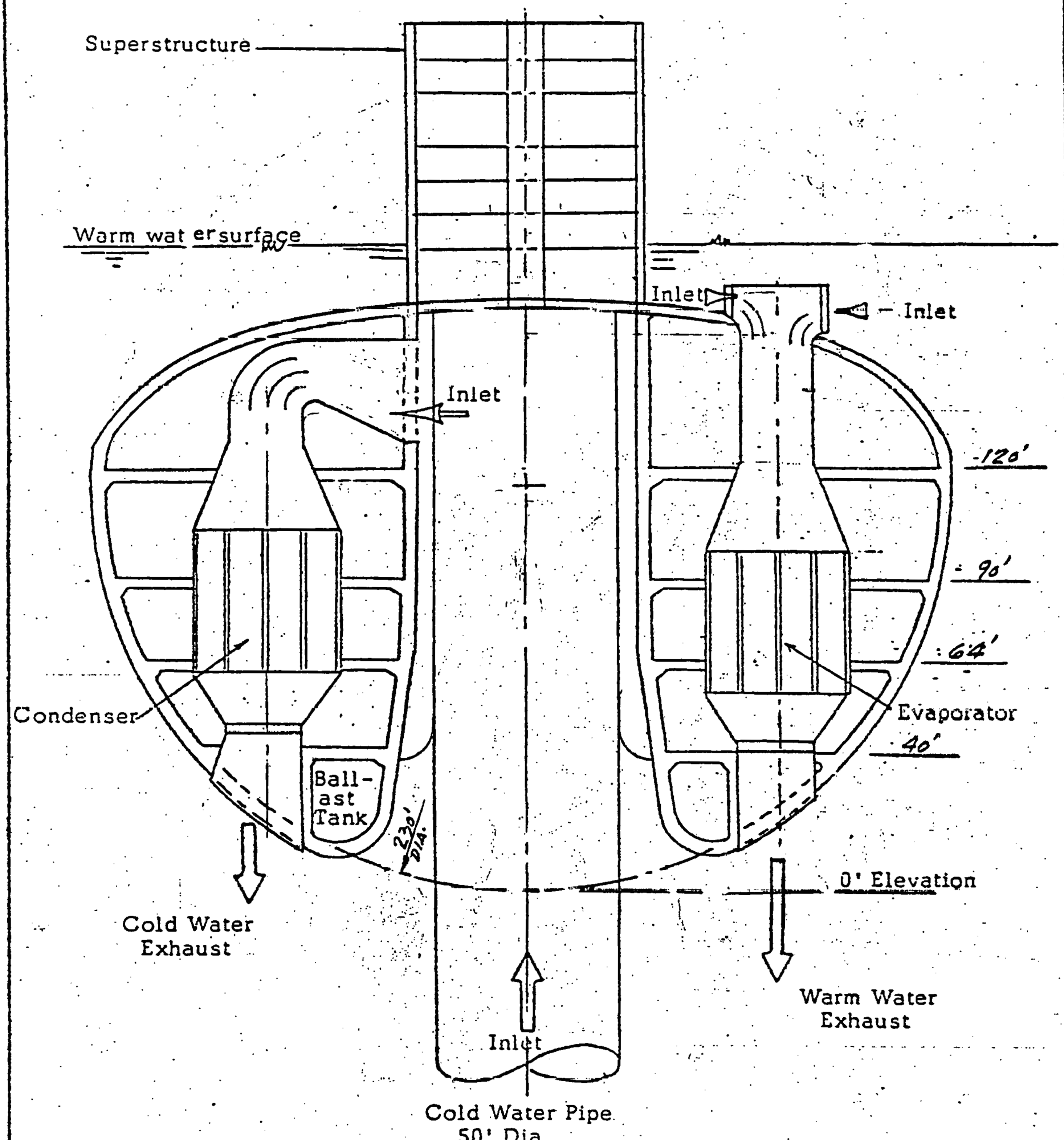
The construction of large concrete structures for offshore use is of course not new and the technology for forming massive structures on land and moving them to sea for completion has become almost commonplace for the construction of large offshore platforms for the North Sea. The application of this technology to construct a demonstration OTEC plant is thus considered fundamental, offering no new thresholds of expertise except perhaps in the forming of the Sphere's compound curvature hull.

a. Sphere Platform

The general layout of the Sphere OTEC demonstration plant is shown in Figure 25. The vessel is semi-spherical in shape with the entire main hull submerged in the operational condition. A cylindrical superstructure extends 75 ft. above the ocean surface to provide stability to the unit and to house the accommodation areas and test and data collecting facilities.

The proposed method of hull construction assumes, as previously suggested, that the vessel will be constructed in three separate stages at three different sites.

Inboard View of Demonstration Platform - 230' Diameter Sphere



Note: Pumps and other equipment not shown for clarity

FIG. No. 25
Scale 1:40

Phase I will be performed at the onshore site to the point of completion where the hull can be safely floated out to the Phase II offshore construction site, and with sufficient freeboard for Phase II construction.

Phase II will be carried out at an offshore site, such as 25 nautical miles off the mouth of Pensacola Bay in about 150 ft. of water, where the remaining hull structure and all outfit will be completed except for the superstructure and the cold water pipe.

Phase III will take place at the operational site where the cold water pipe will be installed, the permanent mooring system placed, the superstructure constructed and outfitted, and the electrical transmission line laid to shore.

b. Spar Platform

The general layout of the Spar OTEC demonstration plant is shown in Figure 26. The vessel is cylindrical in shape with the entire main hull submerged in the operational condition. A cylindrical superstructure extends 75 ft. above the ocean surface to provide stability to the unit and to house the accommodation areas and test and data collecting facilities. The superstructure is made of concrete with a steel deckhouse structure.

Construction of the hull and installation of all equipment is proposed to take place in three separate phases at three different sites.

Phase I shall be performed at the onshore site to the point of completion where the hull can be safely floated out to the offshore site.

Phase II shall be carried out at the immediate offshore site where the platform will be entirely constructed to deck level 410 requiring at least 150 feet of water depth.

Phase III shall take place at the operational site where the mooring system and CWP will first be connected and the remainder of the platform constructed.

4.3 Integration and Deployment

4.3.1 Cold Water Pipe

400 MWe Commercial Plant studies indicated that filament wound fiberglass reinforced plastic is the most feasible material for the cold water pipe. Therefore, this is the material selected for the CWP for the 100 MWe Demonstration Platform.

For the Spar, the cold water pipe GRP sections are proposed to be constructed at a shoreside facility. The section dimensions are 100 ft. long x 50' ID x 3.5" thick. The CWP sections are transported on barges to the operational site and assembled using a drop through method through the submersible barge similar to the scenario used for the 400 MWe Sphere.

The CWP for the Sphere is proposed to be fiberglass, fabricated in sections 50 ft. diameter by 100-125 ft. long.

100 MWe DEMONSTRATION PLANT
SPAR

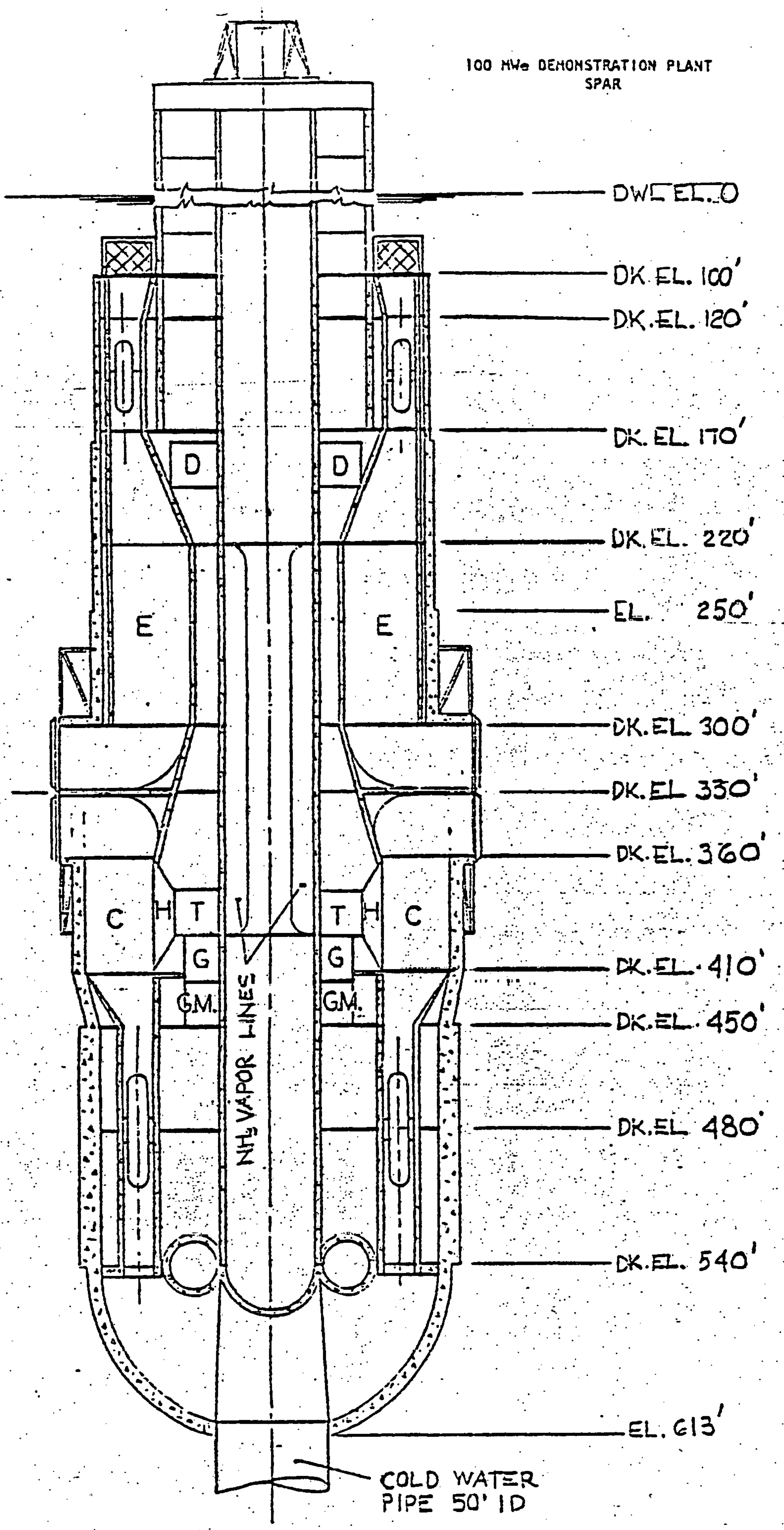


FIGURE 26

After the main hull is completed (less the superstructure) and is permanently moored at the operational site, the CWP is deployed by lowering each section through the 60 ft. diameter center well of the platform by a system of jacks similar to the method proposed for the 400 MWe platform.

Each section is brought out to the platform by barge, transferred by a wheeled dolly to the deck of the platform and individually lowered and attached to the previously deployed section until the full 3,000 ft. of pipe is deployed. The CWP string is then connected to the platform by means of the permanent connection in the well or on deck.

4.3.2 OTEC Equipment

The principal components of the OTEC plant consist of Vertical Condenser, Vertical Evaporator, Demister, Turbine, and the Generator.

The 230 ft. diameter Sphere and 146 ft. diameter Spar are sized to accept either 4-25 MW power modules (one module per hull quadrant) or 2-50 MWe modules (1 heat exchanger per hull quadrant).

4.3.3 Mooring

It has been determined that a passive mooring system utilizing the high holding strength to static breaking strength capabilities of the hollow cylindrical link (HCL) mooring leg is necessary. At one end the links will be attached to the platform, and at the other to a disc type, floodable, free fall designed deadweight anchor. Post-tensioning of the platform hull at the level where the links are attached is desirable.

It is estimated that the drag on the 100 MWe platforms, both Spar and Sphere, due to wind and current will be approximately one half and one third respectively of the 400 MWe designs. The sizing of the 100 MWe mooring system may be adjusted accordingly from the 400 MWe mooring designs.

4.3.4 Testing and System Checkout

The purpose of the 100 MWe demonstration plant is to test the OTEC system performance. Therefore, there shall be additional testing devices to check temperatures, flow rates, and pressures that would normally not be required for a commercially operated plant. The major systems which will necessitate such testing are the following:

- Heat Exchangers
- Warm and Cold Water Circulation Systems
- Cold Water Pipe
- Turbines and Generators
- Evaporator and Condenser Discharge
- Main Hull
- Mooring System
- Ammonia System

4.3.5 Operating Scenario

The operating personnel aboard the OTEC platforms shall consist of three distinct groups:

1. The OTEC crew, which would have the responsibility for operation, analysis, and maintenance of all OTEC equipment on the platform.

2. The Platform crew which would be responsible for operation and maintenance of the platform, and support of the OTEC crew, as required.

3. The catering staff, which would be responsible for preparation and distribution of food, and for hotel services such as cleaning of facilities and laundry. This staff would be contracted on a per-man/per-day rate from a catering service.

Platform work schedules are assumed to be similar to current drilling rig practices. These practices would employ personnel on the basis of a "one week on-one week off" type schedule. The working day would be divided into two 12-hour shifts for the platform crew and catering staff. This could be extended to a 13-hour day for the watch personnel to allow for adequate transition time during shift changes.

4.3.6 Maintenance Procedures

Routine maintenance is the duty of the OTEC crew. These duties include, but are not limited to, daily policing of the plant, cleaning, lubrication, maintenance of working fluid levels, routine repair and replacement, and similar duties. Most equipment of the platform is expected to have a periodic maintenance schedule which would be performed by the crew.

A transient work force would be available, to the OTEC platform for any duty the crew is not able to handle. This forces duties would include major casualty repairs. Major painting, coating, biofoulant removal, and inspection tasks could be assigned either to the platform crew or the transients. In the event that major repairs or maintenance could be performed by facilities on the platform, workboats or barges would probably servce as support vessels during the operation.

For the seawater system, corrosion control to extend heat exchanger tube life is accomplished by use of the Amertap system.

4.3.7 Contingency Plan

In severe weather conditions it has been proposed to submerge the OTEC platforms approximately 20 ft. lower than the normal operating condition. This will result in easing the platform heave motions expected due to greater wave heights and corresponding frequency excitation. It is estimated that lowering the platforms under severe weather conditions will help keep the warm water flow at the normal design rates. Otherwise an unspecified overall efficiency loss of the plant may occur.

4.4 Schedule and Major Milestones

The most optimistic construction period for the Spar is 1 1/3 years while for the Sphere it is 1 year. These periods do not allow time for float out of the partially completed structures from the shoreside construction site nor time to tow the platforms to the operational site, nor development time. These should be added to the above times to arrive at total time elapsed from commencement to completion of construction.

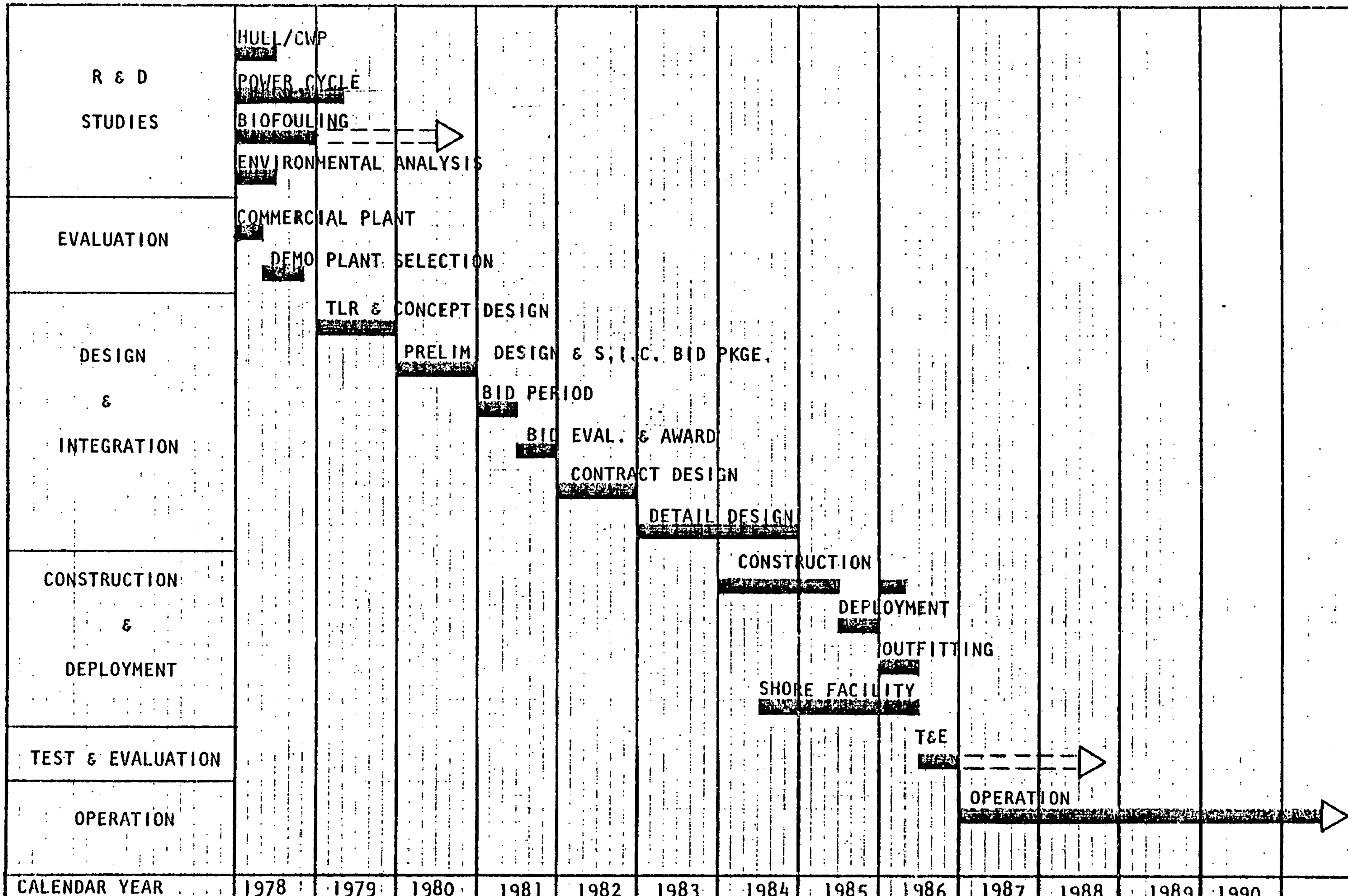
The schedule, Figure 27, shows the proposed R&D, Design and Integration, Test and Evaluation and Operational elements of the OTEC Demonstration Plant.

4.5 Cost Estimates

The cost estimates followed the same approach as for commercial plants and the same standardized WBS.

Again, the power systems costs, Item 3.0 of the WBS, nor the energy transfer systems costs were included. However, the cost of installing these equipment on the platform are included.

The cost estimates for the SPAR and SPHERE demonstration plants are shown in Tables 25 and 26.



SCHEDULE
OTEC 100 MW DEMONSTRATION PLANT

FIGURE NO. 27

TABLE 25

SPAR ACQUISTTION COST BREAKDOWN

COST ITEM	APPLICABLE WBS NO.	COST ($000)
Hull, Outfit, Machy. & CWP	1.2-1.8, 2.2-2.4, 3.0, 4.0	$241,230
Construction Site	1.6	5,978
Deployment	8.0	3,419
Engineering Design & Integration, T&E	1.1, 2.1, 5.0, 6.0 (part), PD, CD, DD	22,500
Industrial Facilities	9.0	1,689
Special Test Facilities	6.2	1,000
		$275,816

ANNUAL OPERATING COSTS

WBS NO.	TITLE	ANNUAL COST ($000)
6.3	Independent T&E	$1,000
7.1 (part)	Spare Parts	1,811
7.2	Expendable Materials	827
7.3	Peculiar Support Equipment	328
7.4	Common Support Equipment	264
7.5	Personnel	5,100
10.0 (part)	Insurance	97
11.6 (part)	Management	200
		$9,627

TABLE 26

SPHERE ACQUISITION COST BREAKDOWN

COST ITEM	APPLICABLE WBS NO.	COST ($000)
Hull, Outfit, CWP & Machy.	1.2-1.8, 2.2-2.4, 3.0, 4.0	$230,148
Construction Site	1.6	7,315
Deployment	8.0	3,352
Engineering Design & Integration, T&E	1.1, 2.1, 5.0, 6.0 (part), PD, CD, DD	22,500
Industrial Facilities	9.0	1,689
Special Test Facilities	6.2	1,000
		266,004

ANNUAL OPERATING COSTS

WBS NO.	TITLE	ANNUAL COST ($000)
6.3	Independent T&E	$1,000
7.1 (part)	Spare Parts	1,811
7.2	Expendable Materials	827
7.3	Peculiar Support Equipment	328
7.4	Common Support Equipment	264
7.5	Personnel	5,100
10.0 (part)	Insurance	97
11.6 (part)	Management	200
		9,627

REFERENCES

1. KNIGHT, H.G., NYHART, J.D. AND STEIN, R.E.: OCEAN THERMAL ENERGY CONVERSION: LEGAL, POLITICAL AND INSTITUTIONAL ASPECTS (AMERICAN SOCIETY OF INTERNATIONAL LAW, WASHINGTON, 1977)

2. FINK, CHARLES; FARMER, WALTER E.; WALLER, DAVID B.; HOMES, JOHN F.; THEORETICAL DETERMINATIONS OF THE SEAKEEPING RESPONSE OF TUNED SPHERE STABLE PLATFORM, OCTOBER 26, 1977, REPORT TSI-4032-2

3. "MARITIME AND CONSTRUCTION ASPECTS OF OTEC PLANT SHIPS", JHU/APL, EXECUTIVE SUMMARY, APRIL 1976.

4. DEPARTMENT OF ENERGY, "OTEC PLANT ENVIRONMENTAL PACKAGE", JANUARY 1978 REVISION.

5. D.C. THOMPSON, "DESIGN MODELING: THE ART OF SCIENTIFIC GUESSING", MACHINE DESIGN, NOVEMBER 1970.

6. TEFFTS, R.C., KELLY, R.L., DICK, C.M., JR., STEVENSON, K., TOWARD A LEGAL, INSTITUTIONAL AND FINANCIAL FRAMEWORK FOR OTEC DEMONSTRATION AND COMMERCIALIZATION, PAPER PRESENTED TO OTEC '78, MIAMI, FLORIDA, FEBRUARY 1978

7. LOCKHEED MISSILES AND SPACE COMPANY, PRESENTATION TO THE DEPARTMENT OF ENERGY FIRST PHASE RESULTS, DECEMBER 1977

8. AMERICAN BUREAU OF SHIPPING, RULES FOR BUILDING AND CLASSING OFFSHORE MOBILE DRILLING UNITS, NEW YORK, 1973

9. ADEE, BRUCE H. AND BAI, KWANJ, EXPERIMENTAL STUDIES OF THE BEHAVIOR OF SPAR TYPE STABLE PLATFORMS IN WAVES, REPORT NA-70-4, JULY 1970, COLLEGE OF ENGINEERING, UNIVERSITY OF CALIFORNIA, BERKELEY

10. NEWMAN, J.M., THE MOTIONS OF A SPAR BUOY IN REGULAR WAVES, DAVID TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER, REPORT NO. 1499, MAY 1963

11. PAULLING, PROFESSOR J.R., "SHIP MOTIONS/COLD WATER PIPE STRESSES" COMPUTER PROGRAM.

12. BARR, R.A. ET AL, "THEORETICAL EVALUATION OF THE SEAKEEPING PERFORMANCE AND RESISTANCE/PROPULSION CHARACTERISTICS OF FIVE CANDIDATE OTEC PLATFORMS." HYDRONAUTICS, INC. T.R. 7513-1, JULY 1976

13. LITTLE, T.E., ET AL, PLATFORM STATIONKEEPING STUDY, FINAL REPORT, WESTINGHOUSE CORPORATION, JANUARY 1978

14. GILBERT/COMMONWEALTH, DEPARTMENT OF ENERGY, DIVISION OF SOLAR TECHNOLOGY, OCEAN ENGINEERING PLAN, NOVEMBER 18, 1977

15. TRW SYSTEMS GROUP, "OCEAN THERMAL ENERGY CONVERSION RESEARCH ON AN ENGINEERING EVALUATION AND TEST PROGRAM", JUNE 1975

16. ROBERTS, G.O., "STRATIFIED TURBULENCE MODELING FOR THE NEAR FIELD EXTERNAL FLOW", 1977 ANNUAL OTEC CONFERENCE, MARCH 1977

17. ZENER, CO., "SITE LIMITATIONS OF SOLAR SEA POWERPLANTS", J. HYDRONAUTICS, VOL. 11, NO. 1, JANUARY 1977, PP. 2-3

18. JIRKA, G.H., FRY, D.J., JOHNSON, R.P. AND HARLEMAN, D.R.F., "INVESTIGATION OF MIXING AND RECIRCULATION IN THE VICINITY OF AN OCEAN THERMAL ENERGY CONVERSION PLANT", 1977 ANNUAL OTEC CONFERENCE, MARCH 1977