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FINAL REPORT

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OTEC PLATFORM CONFIGURATION & INTEGRATION

VOLUME II

"TECHNICAL CONCEPT"

└

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by

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FINAL REPORT
OTEC PLATFORM CONFIGURATION & INTEGRATION
VOLUME II
"TECHNICAL CONCEPT"

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by

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ABSTRACT

The configuration, integration, and evaluation studies performed in the first phase of this Department of Energy contract resulted in a ranking of the most feasible platform candidates for commercial OTEC applications. On the basis of the results obtained from three individual contractors performing the same study, the Department of Energy made selections of two platform hulls for each contractor to perform conceptual design studies on.

For Phase-II studies, M. Rosenblatt & Son, Inc. (MR&S) project team was given the SPAR and the SPHERE platforms to perform not only conceptual designs for, but also cost and time schedules and sensitivity analyses.

This is the second volume of a three-volume MR&S report, and it presents the results of conceptual designs for the two platforms, the facilities and equipment required for construction, deployment, and operation of these platforms, and cost estimates and time schedules. All conceptual design work is 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 are also presented.

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.

ACKNOWLEDGMENTS

The work for the second phase of the Department of Energy study on "OTEC Platform Configuration and Integration" was performed by M. Rosenblatt & Son, Inc. (MR&S) Basic Ship Design division, New York headquarters. The MR&S OTEC project team assigned to this study was led by Nedret S. Basar as the Project Manager; other MR&S employees participating in the study on a full-time basis were:

John C. Daídola, 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:

Stuart H. Grossman, Head - Electrical Engineering
Alfred D. Isaacson, Head - Marine Engineering
Zachary Awer, Head - Mechanical Engineering
John Johnson, Cost Estimates and Time Schedules
Walter Lu, Cold Water Pipe Computer Runs
Doug Graham, Cost and Time Schedules and Site Sensitivity

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 in the course of actual performance.

MR&S as prime contractor had the backing of the following subcontractors and consultants in performing the studies contained in this volume:

1. Messrs. Robert J. Vondrasek (Project Manager) and John Klein, and Dr. Han Liu (Project Engineer) of Burns & Roe, Inc. analyzed the seawater systems hydraulic portion and provided conceptual design information as well as cost and time estimates for individual components.
2. Dr. C.H. Kim of Davidson Laboratory investigated the hydrodynamic performance of the SPAR and SPHERE platforms throughout the design iteration process for all, and specifically for the final two, configurations and determined the hydrodynamic coefficients to be used as input to the cold water pipe stress analysis runs.
3. Dr. John McDermott of U.S. Steel Research Laboratory performed concrete structural analyses for the two platforms and made ANSYS computer runs to verify the scantlings established in the continuing design iteration process.

4. Mr. Eivind Hjellum of Shipping Research Services conducted a review of the MR&S conceptual designs and provided comments. Additionally, SRS performed a constructability analysis on the basis of Norwegian experience and provided cost estimates for the two platforms.
5. A team consisting of the following individuals contributed efforts to the respective design considerations for the SPHERE platform:
 - Mr. Charles Fink (Tuned Sphere International, Inc.)
 - o Overall coordination of spherical platform investigations
 - Mr. David Waller (Waller Associates, Inc.)
 - o Review of MR&S spherical platform design and development of a demonstration unit plan
 - Mr. Walter Farmer (Oceanic Development Company)
 - o Calculations of mooring forces and holding line loads on the SPHERE platform
 - Mr. James Childers (Childers Engineering Company)
 - o Review of sphere design comments on the structural configuration as well as critique of structural scantlings
 - Dr. Roderick Barr (Hydronautics, Inc.)
 - o Computer runs with the Davidson Lab generated hydrodynamic coefficients for the determination of motions and stresses acting on the cold water pipe/hull combination for the spherical platform

Hydronautic, Inc. also supplied similar cold water pipe/hull motions and stress analyses for the SPAR platform.

6. Professor Willard J. Pierson of the City College of New York conducted site sensitivity analyses in connection with the SPAR and SPHERE platforms.

The MR&S project team would like to express their thanks and acknowledge the guidance provided by the following individuals in various government departments and monitoring agencies: Messrs. Sigmund Gronich, William Sherwood, William Smith, and Drs. Lloyd Lewis and Abraham 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, and: Messrs. Walter Trzaskoma and Herbert Woods of Gilbert Associates, Inc.

When considering the design evolution of various ocean systems making up the commercial OTEC platform, the project team had to consult the industry from time to time and obtain factual data, physical dimensions, and costs for the specific arrangements or the systems involved. The following organizations have given us their time and attention in providing the necessary details and these have been used as found applicable to the eventual platform designs. We acknowledge, with gratitude, the help furnished by these organizations.

o Engelhardt Systems Corporation:

Mr. Walter F. Doring provided information on "CHLORPAC" marine chlorination units.

o Owens Corning Fiberglas Corporation:

Mr. James B. Ford provided information on the state-of-the-art of GRP pipe production and also on construction techniques and projected costs of GRP pipe.

o Parsons Brinckerhoff Quade & Douglas:

Messrs. Thomas Kuesel, Donald Tanner, and Thomas Hoover provided constructability and structural arrangement information on the cold water pipe based on their experience with harbor tunnel design and construction.

o Price Brothers, Co.:

Mr. Anthony Potter provided information on construction methodology and characteristics, as well as costs of, GRP pipes.

o Simplex Corporation:

Mr. Richard Traut provided interface information for the riser cable systems to be installed aboard OTEC platforms and also supplied costs and physical dimensions for the power conditioning equipment.

o Sperry Systems, Inc.:

Messrs. Gerold Manri, Don Huddleston, Bill Rafferty, and Robert F. Scanlon performed a conceptual analysis of the automatic positioning, data logging, telecommunications and remote control systems for an OTEC Park and provided the project team with estimated costs for automatic positioning as well as locally controlled positioning systems.

o Symons Corporation:

Messrs. T.J. Crowley and T.J. Vargo provided assistance to the project team in arriving at recommended concrete construction procedures and supplied estimates for the concrete form costs.

In addition to the above, the following industrial organizations or institutions provided valuable information to the project team, either through telephone conversations or by visiting the MR&S offices:

- o American M.A.N. Corporation
- o Amertap Corporation
- o B.F. Goodrich Corporation
- o Florida Power Corporation of St. Petersburg, Florida
- o Puerto Rico Water Resources Authority
- o Worthington Corporation

and many others.

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SECTION 1.0 INTRODUCTION

Commercialization of the "Ocean Thermal Energy Conversion" application 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:

- o 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.
- o 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.
- o Site environment: a study of site conditions, including parameters such as the wind, waves, current, depth, bottom conditions, and seasonal weather conditions at the specified OTEC sites.
- o 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.
- o 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].*

As stated in [2],

"The goal of the OTEC program is to demonstrate the commercial viability of generating electrical power from ocean thermal resources by the successful completion of the following program objectives:

- o Provide a seagoing platform for proof of concept testing and evaluation of 1 MWe heat exchangers and working fluid loops
- o Provide a platform for testing and evaluation of pilot plant power cycle modules which include heat exchangers, working fluid loops, generators, turbines, demisters, etc.

* The numbers in brackets denote similarly numbered references in Section 10.0.

- o Provide proof of technology of a demonstration size module system to demonstrate the overall economic viability of the system for commercialization."

Figure 1, reproduced from [2], indicates the OTEC system development program as established by the DoE. It is depicted that the test programs for power plants, heat exchangers, OTEC-1 test platforms, and a pilot plant test platform continue until early 1980's. The initiation of the design and construction of the surface demonstration platform would start about the middle of the calendar year 1982. Technology experiments would run parallel to all the feasibility and design studies being performed.

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 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 and for distribution.

In the first phase of the present study, which was reported in Volume I of this report, numerous candidate platform hull shapes were considered, they were subjected to a detailed evaluation on the basis of measures of merit and criteria to be met during operation, deployment, and construction.

The three individual contractors working on the first phase of the study arrived at different conclusions as far as the platform configuration and evaluation is concerned. The conclusions reached by the MR&S project team were that platforms with main submerged bodies would be more logical candidates to be used as marine vessels to house the OTEC plant equipment. Specifically, it was concluded that the ranking of candidate OTEC platforms would be as follows:

- o Tubular truss
- o Submersible
- o Spar
- o Semi-Submersible
- o Sphere

It was concluded that the surface floating type OTEC platforms would not be good candidates due to the fact that they would be subjected to very significant wave action and as such would not be suitable for the 40 year continuous operation that is foreseen to be the platform lifetime.

FIGURE 1
OTEC SYSTEMS DEVELOPMENT

OTEC-I

PILOT

DEMO

The ranking concluded by the other two contractors are shown in Table 1, along with the MR&S recommendations.

On the basis of these conclusions and recommendations, the Department of Energy "Hull Recommendations Board" reviewed all inputs by the three contractors and made the following 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 the semi-submersible and spar and surface ship platforms respectively.

Phase II studies performed by the MR&S project team had the backing of the following subcontractors and consultants:

- o Burns & Roe, Inc.
- o Davidson Laboratory
- o U.S. Steel Research Laboratory
- o Shipping Research Services
- o Tuned Sphere International
- o Hydronautics, Inc.
- o Professor W. J. Pierson

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 designs, 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 MWe 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 MWe. 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, as far as 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.

The results of the Phase II studies are presented in the following seven sections of the Volume II report. Conclusions and recommendations are included in Section 9.0. The conceptual design drawings, systems diagrams, as well as backup material for some of the sections, are included in the appendix.

GIBBS & COX		LOCKHEED		ROSENBLATT	
NO	HULL	NO	HULL	NO	HULL
1	SHIP	1	SPAR	1	TUBULAR TRUSS
1	CYLINDER	2	SHIP	2	SUBMERSIBLE
2	SPHERE	3	BARGE	3	SPAR
3	SEMI-SUBMERSIBLE	4	TUNED SPHERE	4	SEMI-SUBMERSIBLE
3	SUBMERSIBLE			5	SPHERE
3	SPAR				

TABLE 1

FINAL RANKING OF PLATFORMS BY THREE CONTRACTORS AT END OF FIRST PHASE STUDIES

SECTION 2.0 INTEGRATED PLATFORM AND OTEC PARK CONCEPT

A recent study on various OTEC missions maintains that there are several potential industrial applications for OTEC systems that offer significant contribution to the energy needs of the United States by the year 2000 [3]. As stated in this paper, as well as in [2], the commercialization of OTEC platforms to arrive at this objective would require that private industries be provided an incentive to produce the first OTEC platforms and that as early as in 1985, an initial deployment of the demonstration plant be made possible. The development of a demonstration plant, however, largely depends on certain decisions to be made regarding the commercial platforms that are eventually to be built.

The investigations performed by several DoE contractors on the potential domestic markets for OTEC generated electrical energy as against projected OTEC costs indicate that the OTEC application will be competitive before the year 2000.

The subject of the present study being conducted by MR&S and its subcontractors and consultants is the near shore production of baseload electrical energy to be delivered by means of a riser and submarine cable transmission system to a shore power grid. The OTEC platforms which will produce the electrical energy to be transmitted to the shore distribution networks will be based on the results of various studies performed by several DoE contractors on the platform hulls, ocean systems themselves, the cold water pipe systems, power systems, biofouling and corrosion considerations, and other platform service and support systems.

The eventual OTEC platform will be an integrated vessel incorporating all of these systems and/or their interfaces on board the vessel itself. For the purposes of this study, the integrated platform will accommodate a power cycle consisting of a sufficient number of 50 or 25 MW heat exchanger modules, bringing the platform net output to 400 MW net for each platform. As specified by the DoE, each OTEC site will probably have one or more OTEC Energy Parks, each consisting of 8 individual platforms, adding up to a total Park capacity of 3200 MW capacity.

Discussed in this section is the breakdown of the individual platform ocean systems and a preliminary scenario for the construction, deployment, and operation of the OTEC Park.

2.1 Platform Work Breakdown Structure

A standardized work breakdown structure was furnished by the DoE for use by the three individual contractors in the development of Phase II conceptual designs and cost estimates with the eventual objective of providing uniformity in reporting the results. Table 2 shows the standardized work breakdown structure as developed jointly by participating contractors and the government representatives and as eventually approved for use by the Department of Energy.

TABLE 2: DoE STANDARDIZED WORK BREAKDOWN STRUCTURE

OTEC

PLANT

4.0

ENERGY
TRANSFER
SYSTEMS ✓

4.1

TRANSFER SYS.
INTEGRATION &

4.2

POWER CONTROLS
& BUS

4.3

POWER
CONDITIONING

4.4

RISER
CABLE

4.5

BOTTOM
CABLE

4.6

FITTINGS
CONNECTIONS &
SUPPORT

4.7

TRANSFER
SYS.
BIOFOULING

4.8

ASSEMBLY &
DEVELOPMENT
SUPPORT SERV

5.0

SYSTEM ENGRG.
& INTEGRATION ✓

5.1

SYSTEM DESIGN
&
ANALYSIS

5.2

SYSTEM
INTEGRATION

6.0

SYSTEM
TEST &
EVALUATION ✓

6.1

TEST
PLANNING

6.2

SPECIAL TEST
FACILITIES

6.3

INDEPENDENT
TEST & EVAL

7.0

OPERATIONAL
SUPPORT ✓

7.1

SPARE
PARTS

7.2

EXPENDABLE
MATERIALS

7.3

PECULIAR
SUPPORT
EQUIPMENT

7.4

COMMON
SUPPORT
EQUIPMENT

7.5

PERSONNEL

7.6

TECHNICAL
MANUALS

TABLE 2 (CONTINUED)

TABLE 2 (CONTINUED)

Table 2 contains the following major systems or functions:

- o Platform system
- o Cold Water Pipe system
- o Power systems
- o Energy transfer systems
- o System engineering and integration
- o System test and evaluation
- o Operational support
- o Deployment systems and services
- o Industrial facilities
- o Environmental, legal, licensing, regulatory, and insurance
- o Project management

The contractors were asked to develop more detailed work breakdown structures to lower levels in order to accommodate contractual design concepts and "build" sequences as well as to provide reasonable accuracy in the cost estimates.

The definition and description of the terminology used in the DoE supplied work breakdown structure is contained in Appendix #1.

2.2 OTEC Park

It is reported in [4] that OTEC should be viewed as a possible candidate for massive baseload electricity generation. The same paper maintains that, as a result of ERDA and DoE studies performed on the subject, 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 happens to be 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. Reference [4] attempts to draw the framework for a legal, institutional, and financial development of OTEC demonstration and commercial plants to be deployed for this purpose.

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 approximately 3000 MW, however, for this second phase of the study, the platform 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 2 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. The concept of using one central accommodation platform to provide housing and recreational facilities for all platform personnel has been considered, and this facility is proposed as part of the OTEC Energy Park.

FIGURE 2 : 3200 MWe
OTEC ENERGY PARK

In addition it was found desirable to have accommodations on board each platform so that any normal operation as well as routine or emergency maintenance procedures will be possible to be continued aboard the platform without depending on boats or helicopters in storm conditions or emergencies. . . . Regardless of whether the accommodations are centrally located on an accommodations platform or provided on each platform, there will be a need for support services in the form of boats, helicopters, tug supply boats, and similar transportation equipment, to carry the personnel and supplies back and forth between the platforms as well as between platforms and the shore.

The possibility of using a centrally located OTEC startup generator barge was also considered. This consideration results from the need of providing startup electrical power to the OTEC equipment on board each platform. Upon consideration, it was found a more reliable method to install individual startup generators on each platform, rather than to use a central barge which would be transported back and forth between platforms wherever startup power is needed, so that with this scenario each OTEC platform would be self-sufficient. Thus, the startup power would be provided by the on board platform service generators and in case of breakdown of any one module, there would still be OTEC power available from other modules which may remain in operation. In case all modules had to be shut down due to a breakdown affecting all modules, then the platform generator would be providing the necessary power to all platform systems as well as the power needed to start up one module. Soon after one module is started up, by "boot-strapping" the remaining modules can be started up by using the already operating module power.

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.

The nominal net electrical energy generated aboard each platform would be 400 MW. However, since in the interest of saving fossil fuel and making use of the unlimited source of energy available in the ocean thermal differentials, the platform service and/or startup generators will be shut down during normal operation. The platform service systems, mission support systems, and the positioning system requirements, if any, would have to be met by the OTEC generated electricity source. This will put a drain on the amount of net electrical energy available for transmitting from the power conditioning equipment to the central collection point. In addition to this, there will be losses in the power conditioning equipment and also substantial losses in the transmission cables, both riser and submarine, which will reduce the amount of net power to be transmitted ashore. The amount of net electrical energy to be made available to shore distribution networks after all losses and parasitic loads are met by the platform OTEC generated electricity remains to be established at such time as the losses in transmission cables and power conditioning equipment are better defined. However, platform service, mission support, and positioning loads and transmission losses are estimated to be adequately provided for

in the 120 MW differential between the designed gross output of 520 MW and the net output of 400 MW per platform.

Basic requirements for the normal operation as well as maintenance and support services are discussed in greater detail in Sections 3.13 - 3.14, and 4.13 - 4.14 respectively for the SPAR and SPHERE platforms.

SECTION 3.0 CONCEPTUAL DESIGN OF 400 MWe SPAR PLATFORM

3.1 Evolution of Arrangements

3.1.1 Description

A spar, in nautical terms, implies a long, thin, axisymmetric body. Besides the ubiquitous channel marking buoys, the idea of a "slender" vertical column for use as a stable platform in waves has been used for several research vessels: SPAR, FLIP, TOTEM, and others, with favorable results.

MR&S was assigned to investigate the use of a submerged axisymmetric body, or spar, for possible use as an OTEC commercial platform. Axisymmetric bodies had evolved into three classes during investigations conducted in [5]. These were:

- o The low length to diameter ratio (L/D less than .5) body, or disc shape, with a slender surface access trunk.
- o The high L/D (greater than 2) body with the main hull penetrating the surface for access.
- o The high L/D body with a slender surface access trunk.

Using the results reported in [5], the high L/D body with a slender access trunk was selected as the general configuration for the 400 MWe OTEC commercial platform candidate.

3.1.2 Power Cycle Components

The evolution of the seawater system is covered in Section 3.8. MR&S had the flexibility of choosing two sizes and axis-orientations of heat exchangers. 25 and 50 MW net capacities in horizontally or vertically oriented cylinders were presented, giving a choice of four.

Data for these heat exchangers and their associated equipment is shown in Table 3.

3.1.3 Economy of Scale

After careful consideration of the heat exchanger data, two conclusions were drawn. The first was the obvious economy of scale which could be seen from the data. It would require serious arrangement, maintenance or equipment availability problems arising from the larger equipment to counteract such advantages. The second was the compatibility of the vertical axis orientation of the platform with the vertically oriented OTEC components. The vertical heat exchangers also weighed less and were smaller than their horizontally oriented counterparts. Based on these considerations, all arrangements would incorporate the 50 MWe net output equipment. The heat exchangers would only be considered with vertically oriented axes.

3.1.4 Preliminary Arrangements

Preliminary arrangements were developed around two independent concepts:

- o The modular design, where associated evaporators, condensers, turbogenerators, etc. are in close physical proximity, and individual modular power cycles are separated from each other.

TABLE 3
OTEC POWER CYCLE COMPONENTS

COMPONENT	RATED POWER	DIAMETER	LENGTH	DRY WEIGHT*	WET WEIGHT*
Horizontal Heat Exchanger	25 MW	50' (15.24m)	85' (25.91m)	1300 (1179)	3800 (3447)
do.	50 MW	65' (19.81m)	85' (25.91m)	1800 (1633)	6800 (6169)
Vertical Heat Exchanger	25 MW	40' (12.19m)	80' (24.38m)	800 (726)	2400 (2177)
do.	50 MW	55' (16.76m)	80' (24.38m)	1200 (1089)	4500 (4082)
Turbine	25 MW	20' (6.096m)	20' (6.096m)	50 (45)	50 (45)
do.	50 MW	25' (7.620m)	25' (7.620m)	75 (68)	75 (68)
Generator	25 MW	15' (4.572m)	20' (6.096m)	150 (136)	150 (136)
do.	50 MW	18' (5.486m)	30' (9.144m)	220 (200)	220 (200)
Demister	25 MW	20' (6.096m)	20' (6.096m)	300 (272)	300 (272)
do.	50 MW	30' (9.144m)	30' (9.144m)	450 (408)	450 (408)
Ammonia Storage Tank		25' (7.620m)	50' (15.24m)		300 (272)

*Short Tons (Tonnes)

- o The "grouped like components" concept where like components are in close physical proximity while the individual power cycles become spread out and separated.

Investigation showed that the latter concept was the preferable design philosophy for the OTEC spar for several reasons. The primary problem in arranging a spar using a modular concept was water transport. The maintenance of a relatively slender body while channeling large quantities of working fluid thru the platform (e.g. warm water to the lower modules or cold water to the upper modules) proved to be at cross purposes. The modular spar also presented challenges in the arrangement of the combined discharges for those modules above the thermocline.

The grouped like component concept eliminated both problems. Neither cold nor warm water would be transported over half the height of the platform. The combined discharges would be located amid ships, which is at a depth below the statistical thermocline.

The major penalty to be paid for this elegant solution to the problems of the seawater system would be the increased lengths of the ammonia liquid and vapor lines. This problem will be dealt with in Section 3.10.

3.1.5 Hull Arrangement Evolution

The OTEC spar hull exists only to support and protect the eight OTEC power cycles within. As the power cycle configurations evolved in the design spiral process the hull changed to suit. Design considerations placed on the hull by the power cycle were those of displacement, unrestricted passage of working fluids, and support and arrangement of components. The hull, in turn, placed the restrictions of dimensions and volume on the power cycle, along with considerations of weight distribution.

3.1.6 Incorporation of Other Systems

As the hull power cycle design effort stabilized, the other systems were introduced into the arrangement to the degree possible under a conceptual level of effort. Decisions regarding manning and plant startup were made with the consultation of the Department of Energy. These decisions primarily affected the superstructure and deck house. They will be discussed later. After several revolutionary and evolutionary stages the mooring system was finalized as the 3-leg HCL link mooring system as incorporated in the final design. This will be discussed in Section 3.7.

Platform service electrical and marine systems were also incorporated. These included the ammonia storage system, the purging system, the heat exchanger cleaning system (Amertap was selected) and the chlorination system.

3.1.7 Final Arrangement

The final arrangement of the OTEC spar commercial platform conceptual design appears in Drawing No. 47914. It consists of a series of four coaxial cylinders (moulded). Their dimensions appear in Table 4. The upper, surface piercing cylinder is capped by a rectangular 1 1/4 level deckhouse. A hemispherical dome is formed below the lowest cylinder. This dome forms the support and attachment for the integral cold water pipe. Part A of Table 4 shows the principle characteristics of the design. It is reproduced from Dwg.# 47914. The hull is subdivided into four quadrants. A cylindrical central trunk furnishes a natural vent exhaust and a removal route for large pieces of equipment. It is coaxial with the platform's vertical axis. The ammonia vapor lines are also located in the trunk amidships.

Vertical subdivision is provided by decks placed in the hull where required as covered in Table 4, Part C. The maximum moulded spacing is 50 Ft. (15.24m) and the minimum is 25 Ft. (7.62m) in the main hull. Decks are numbered in correspondence to their distance in feet below the design waterline. Level numbers correspond to the distance in feet above the DWL. All decks and bulkheads are designated gas tight with the exceptions of DKS.260,390&440, which are anticipated to have large sections of grating in way of equipment removal routes.

Access to the platform is provided by 8 primarily freight elevators, two per quadrant. The freight elevators for the main hull run between DK 100 and DK 590, equi-distant from both quadrant bulkheads at the shell. The superstructure elevators, of equal size, run from DK 175 into the deckhouse. Ladder trunks and/or motorized continuous belt people movers are also contemplated.

Watertight doors and large bolted plate panels serve as access to the central trunk from various levels. Watertight doors are to be provided as required to facilitate access between quadrants.

Reinforced concrete is the material of choice for the entire SPAR platform with the exception of the deckhouse, which is mild steel, and non-subdivision bulkheads surrounding elevator trunks and vent plenums, which are also steel. The outer hull is of stepped wall-sided construction. Decks are poured reinforced concrete slabs over steel beams. Main radial bulkheads are reinforced concrete. Thickness is generally equal to 4% of the moulded free height (between decks). Specific information on the structure can be found in Section 3.3.

Each quadrant of the spar platform contains two complete 50 MWe net OTEC power systems, each consisting of a condenser, turbine, generator, evaporator, demister, pumps, and associated working fluid piping (ammonia and water) and storage.

The upper half of the platform is largely devoted to the warm water systems while the lower half is an approximate mirror image for the cold water systems. The plane of symmetry is DK 350. The OTEC power seawater, and ammonia systems are discussed in Sections 3.8 and 3.10.

TABLE 4 SPAR PARAMETERS

PART A: PRINCIPAL CHARACTERISTICS

Maximum Outer Radius		
With Discharge Valve Assembly	=	140'-0" (42.67M)
Without Discharge Valve Assembly	=	131'-0" (39.93M)
Design Draft Without CWP	=	697' (212.45M)
Depth to Superstructure Deck Without CWP	=	772' (235.31M)
Design Displacement with CWP	=	807988.0 L/Tons (820916 MT)
Vertical Center of Buoyancy @ Design WL	=	372.5 below DWL (113.54M)
Estimated Length of Pipe	=	2,303 Ft. (701.96M)
Opening Cold Water Pipe	Radius	= 50.5 Ft. (15.39M)

PART B: HULL SECTIONS

ITEM	UPPER LIMIT	LOWER LIMIT	MOLDED RADIUS
A	75' (22.3m) ADWL*	100' (30.5m) BDWL	57' (17.4m)
B	100' (30.5m) BDWL**	310' (94.5m)	115' (35.1m)
C	310' (94.5m)	325' (99.1m)	Transition
D	325' (99.1m)	440' (134.1m)	120' (36.6m)
E	440' (134.1m)	490' (149.4m)	Transition
F	490' (149.4m)	590' (179.8m)	110' (33.5m)
G	590' (179.8m)	Hemisphere	110' (33.5m)

Net molded displacement 696 KLT (707 K Tonnes)

ADWL = Above Design Waterline BDWL = Below DWL

TABLE 4 (continued)

PART C: DECK ELEVATIONS & RADII

DECK	MOLDED ELEVATION	MOLDED RADIUS	REMARKS
LL 94	94' (28.7m) <u>ADWL</u>	Partial Deck	(<u>Deckhouse</u>)
LL 84.5	84.5' (25.8m)	<u>180' (54.9m) Side</u>	
LL 75	75' (22.9m)		
LL 55	55' (16.8m)	<u>57' (17.4m)</u>	<u>Superstructure Column</u>
LL 35	35' (10.7m)		
LL10	10' (3.0m)		
DK 15	15' (4.6m) <u>BDWL</u>		
DK 40	40' (12.2m)		
DK 60	60' (18.3m)		
DK 80	80' (24.4m)		
DK 100	100' (30.5m)	<u>115' (35.1m)</u>	
DK 125	125' (38.1m)		
DK 175	175' (53.4m)		
DK 220	220' (67.1m)		
DK 260	268' (79.3m)		
DK 310	310' (94.5m)		
DK 350	350' (106.7m)	<u>120' (36.6m)</u>	
DK 390	390' (118.9m)		
DK 440	440' (134.1m)	<u>110' (33.5m)</u>	
DK 525	525' (160.1m)		
DK 590	590' (179.8m)		

Space for the specified auxiliary equipment has been allotted as shown in Drawing No. 47914, General Arrgt. and Inbd. Profile. Larger items such as chlorinating units, pumps and ammonia storage tanks have been shown while smaller equipment is allotted only area and volume. This equipment will be discussed in the appropriate section.

An onboard control crew was sized according to power company manning recommendations Ref. [6]. Their stay on the platform is expected to be a "lunchbox" type operation. A central accommodations platform is proposed in addition to the accommodations provided on each platform, which are primarily for emergency situations.

Supplies and personnel may be brought aboard by sea or air. Boat dockings have been provided at both the design position and the "shallow draft" position (without ballast). Pedestal cranes can transfer supplies and equipment directly to the deckhouse from workboats or barges. The open deck areas have space and equipment designated for helicopter landing operations and Vertrep.

3.2 Displacement, Volume, Hydrostatics

3.2.1 Determination of Volume from Arrangements

A rough approximation of the volume displaced by the OTEC spar can be made by computing the volume of a totally submerged cylinder 600' (182.9m) long by 240' (73.2m) diameter with a 100' (30.5m) long by 120' (36.6m) diameter cylinder atop it. The result, 807.8 KLT (820.8 K Tonnes) is within 1% of the actual SPAR body volume.

The height of the main spar body is as small as possible while consistent with an efficient seawater system design. The distance between the lowest and topmost watertight boundaries is 490' (149.4m), a significant reduction from the 700' (213.4m) distance used in the early design spiral cycles. The stepped moulded diameters shown in Table 4 have also been reduced from the 250' (76.2m) contemplated earlier.

3.2.2 Determination of Displacement

The moulded displacement can be determined by adding the volumes of the individual cylinders in Part A of Table 4.

However, this figure, 696 KLT (707 K Tonnes) does not take into account the shell thickness, which becomes considerable as extra strength is needed to combat the increasing water pressure as depth increases. In fact, the shell thickness varies in steps from 3' (.914m) in the superstructure column to 13.33' (4.063m) between DK 525 and DK 590. The added displacement is over 110 KLT (112 K Tonnes) as can be seen in Appendix #2.

A summary of the SPAR weight estimate is presented in Table 5.

3.2.3 Hydrostatics

The geometry of the spar platform determines its hydrostatics, as is the case for any floating body. The curves of form based on the final platform configuration appear on drawing 47922. This drawing shows the displacement, KB, KM, and tons-per-foot submergence curves as functions of depth below the design waterline.

3.2.4 Ballast

The OTEC spar has very little solid or liquid ballast, only about 14,800 LT (15037 Tonnes) of liquid in the ballast torus at DK 590. This is primarily for fine-tuning the draft of the platform in operation to take advantage of surface (warm) water conditions. However, the platform contains a large quantity of seawater 84800 LT (86150 Tonnes) in its internal seawater piping. When this is drained the platform rises to its high maintenance waterline at approximately 180' (54.9m) below the DWL. This condition requires complete plant shutdown, as detailed in Section 2.2.

TITLE Summary

M. ROSENBLATT & SON, Inc.
NAVAL ARCHITECTS & MARINE ENGINEERS
NEW YORK CITY SAN FRANCISCO BOSTON

SHIP OTEC Spar

PLAN No. _____

SECTION _____ FRAMES _____ TO _____

WEIGHT GROUP Summary

TABLE 5

ESTIMATE OF WEIGHT

Piece No.	Description, - Material, - Dimensions - Weight Group	Unit (Pounds)	Number of Units	Weight (Pounds)	Above Base Line		Referred to Frame No.			
					C. G.	Vert. Moments	C. G. Fwd.	Forward Moments	C. G. Aft.	Aft. Moments
	1.2.1			273905	412	112876625				
	1.2.2			37733	459	17322988				
	1.2.3			31190	434	13527911				
	1.2.4			1673	13.6	22705				
	1.2.5			2692	15.9	42820				
	1.2.6			17332	351.0	6078472				
	1.2.7			319	-81.3	-25949				
	1.2 - Hull Structure Subtotal			364844	410.7	149845572				
	1.3 - Positioning System			6764	525	122850				
	1.4 - Platform Services			15954.0	554.4	8845686				
	1.7 - Sea Water System			321870	414.6	133459256				
	3.2 Power			50505	287.5	14519280				
	to Systems									
	3.10									
	TOTALS			759937	403.7	306792639				

Estimating by: _____ Computing by: _____ Estimate checked: _____ Computing checked: _____

3.3 Hull Structural Development

3.3.1 General

The hull structural development consisted of several considerations including structural material, codes for design, platform structural configuration and stress analyses.

The main material considerations were concerned with the adoption of steel or concrete for the main hull material. Various design approaches and design codes were considered for their applicability for the design of the platform. The structural configuration was altered in several ways to obtain structural efficiency and reduced weight. Finally, a number of stress analyses and finite element computer analysis were performed.

3.3.2 Material Selection

a. Hull

At the beginning of the design cycle steel and concrete were considered as possible materials for the structural hull. References [5] and [7] indicated that for the size platform under consideration, a concrete hull is significantly less expensive than steel although quite heavier. Further, 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. Although considered, lightweight concrete was not used because it has not been extensively used in a marine environment and with its lower available maximum compressive strength of 1,000 - 5,000 psi, a greater thickness would be required.

The 7,000 psi ultimate strength concrete was chosen because the spar structure would not be heavily reinforced and therefore placement of a stiffer mix would be possible, rendering thinner hull sections. Higher strengths were not considered because 7,000 psi concrete is the strongest concrete available in the Florida area due to strength limitations of the coarse aggregate that is available there.

b. Superstructure and Deckhouse

Like the hull, the surface piercing access column superstructure to the spar platform is concrete.

The deckhouse atop the column is constructed of steel and is identical to that of the sphere platform.

3.3.3 Design Codes

a. Steel Structure

In the case of steel structure design the American Bureau of Shipping Rules [8] and the Navy structural design practices [9] were used wherever appropriate. An additional corrosion allowance of 1/8 inch was incorporated on all exposed steel structure.

b. Concrete Structure

The primary sources of design procedures for the spar platform shell were the works by Haynes and Nordly [10], the American Concrete Institute Building Code [11] and the Federation Internationale de la Precontrainte [12].

It can be said that no specific design code for floating concrete structures exists and consequently the concrete thicknesses developed for the spar rely quite heavily on the assumptions which were made. The work by Haynes and Nordly [10] gives results based on experiments, where the mode of failure of cylinders was implosion buckling.

The ACI Code [11] is concerned only with ultimate strength design and does not cover implosion buckling of cylinders. The FIP [12] only gives load and material factors.

The final spar hull structural design is of reinforced concrete and based on the buckling criteria of Reference [10]. The formulas contained therein incorporate a long term factor (1.0 gives increased thickness), a load factor (1.0 gives increased thickness) and a material factor (1.0 gives increased thickness). The long term factor, which allows for creep (plastic flow) effects of concrete in buckling was taken as the lowest most conservative value of 0.7. The load factor was taken as 1.4 as suggested by the FIP and as specified by the ACI for fluid loads. The material factor is 1.5. This corresponds to the " ϕ " factor of 0.7 which is part of the ACI Code and takes into account material strength, workmanship, and dimensional variations. The factor of 1.5 should be on the conservative side.

It should be noted that the strength of the concrete in the SPAR could be reduced proportionately, if either the overall load factor or the materials factor is reduced or the penalty factor for long term loading is increased. There is some belief among experts in the design of offshore concrete structures that the cylinder implosion equations used in the design of the vertical outer shell of the spar are too conservative in certain aspects. Thus a more refined design could possibly lead to lesser concrete strength requirements given the present spar scantlings.

Most of the above statements also apply to the designs of the vertical surface piercing concrete access trunk and the cold and warm water conduit concrete piping. In the latter case the concrete is pre-compressed by post-tensioning so that there will be no net tension when tensile load is superimposed.

3.3.4 Platform Structural Configuration

The final structural configuration is shown in Appendix #3.1 on Dwg #47917.

3.3.5 Stress Analyses

a. General

The stress analyses of the spar proceeded through several iterations and ended with a finite element analysis in the ANSYS computer program.

It was assumed that the buckling criteria of Reference [10] would control the structural design as discussed in Section 3.3.3. The ANSYS computer analyses did not consider buckling. The structure required by ANSYS stresses would be less strong than that based on buckling; but the latter was adopted.

b. Loading

The structural loadings considered in the spar design were:

- o Static water head.
- o Dynamic water head due to the H 1/10⁶ severe storm wave at the West Coast of Florida.
- o Structural deadweight.
- o Major machinery and equipment concentrated loads.
- o An overall distributed deck load of 400 lbs/ft².

The static water head was based on a submergence to the top of the main deck of 100 ft. from the still sea surface. The dynamic water head was based on the H 1/10⁶ wave height at West Coast of Florida of 120.54 ft. with a frequency of .46 radians per second. The resulting expression for the pressure is therefore:

$$p(z) = \rho g [(z + 60.27 e^{-(.0066)z})]$$

Where:

- p(z) = pressure at depth "z"
- ρ = density of water
- g = gravitational constant
- z = water depth

c. Analyses

As previously mentioned, the structural analyses were performed using the data of Reference [10] which bases strength on buckling as the main criterion. Therein procedures applicable to short, moderately long and long thin and thick walled cylinders are given. It was determined that the spar outer shell thicknesses should correspond to that of moderately long thin-walled cylinders. The results are presented in Table 6.

The above mentioned buckling analysis did not consider the support given the spar shell by internal structure. It is felt that the vertical radially extending bulkheads would not contribute significantly to reducing the onset of implosion buckling.

It was decided, under the circumstances that at least the shell non-buckling stresses should be analyzed for comparison with the buckling results.

Table 6: Spar Hull Thicknesses Based on Moderately Long Thin-Walled Cylinders

<u>Range of Elevations below DWL</u>		<u>Required Thickness of Outershell (feet)</u>
<u>High</u>	<u>Low</u>	
100	175	4.25
175	260	6.33
260	310	7.17
310	325	7.42
325	350	8.08
350	390	9.08
390	440	10.42
440	490	11.75
490	525	12.67
525	590	13.33

In this respect an ANSYS finite element analysis using the axisymmetric shell stiffness element 11 was performed. A profile of the half model is shown in Figure 3. The computer analyses were based on a shell of homogeneous material. In comparison with stresses in gross sections obtained from the sphere platform analyses, it was obvious that the spar reinforced concrete design would not be overstressed and could have significantly less reinforcing steel. The lower outer shell stresses indicate that a reduction in material strength and/or hull thickness might be possible, but this has not been done due to the buckling results from the formula in [10].

3.3.6 Final Structural Configuration

The final structural configuration is shown in Appendix 3.1 on Dwg #47917.

FIGURE 3: PROFILE OF SPAR ANSYS FINITE ELEMENT MODEL

3.4 Weight Estimates

3.4.1 History

A running update was kept thru the design spiral sequence to assure that the displacement and the sum of the weights were in the same ballpark. To allow otherwise would mean at best that the platform would not float at the level it was supposed to or at worst it would become an ocean bottom structure before it was finished. A continual "sharpening of pencils" kept track of each new, better defined, or developed piece of information as it became available and recorded its impact on the weights, margins, and centers of gravity.

As the work breakdown structure became available, the weights data was re-organized slightly to reflect the uniform format desired by DOE. Weights calculations presented in this report follow this WBS, which is discussed in Section 2.1 more fully. The weight estimate appears as Appendix #2.

3.4.1 Hull Weights

As had been done in the first phase studies, [5], 150 lbs/ft³ (2403 Kg/m³) has been used for the density of the high strength (fcZ 5000 psi = 3.5×10^6 + Kg/m²) reinforced concrete for the hull material of the OTEC Spar platform. Weights are simply the volume occupied by the structure times the density.

The platform shell, is essentially composed of a series of wall sided cylinders of varying inner moulded diameters and thicknesses. The superstructure trunk is of a single diameter and thickness, while the central trunk varies only wall thickness holding the inside diameter at a constant 50' (15.2m).

Decks, with the exceptions of DK100 and DK590 are uniform watertight constructions of 6" (.152m) of concrete over steel beams. They are designed to take a 400 PSF (1953 Kg/m²) live load. Decks DK 100 & DK 590 are the horizontal watertight boundaries at their respective ends of the spar cylinder body. Each has been designed to take the full hydrostatic head at its depth plus a wave induced over pressure. Section 3.3 covers this in more detail.

Bulkheads are of concrete construction and are generally 4% of the moulded height (between decks) in thickness. Where this formula yields thicknesses under .5' (.457m), that figure is used.

The deckhouse is a module to be placed atop the superstructure column as a single unit upon completion of the column. It is to be constructed of mild steel using common marine construction techniques. Standard plate thicknesses and reinforcing structure weights were used in the estimate. Appendix #2 contains weights data on the deckhouse as well as the rest of the platform. The deckhouse is the location of the majority of command, control, communications, office, and hotel weights.

Foundations were developed only to the level of detail available for the equipment. As a general rule, the foundation is considered to represent 10% of the equipment weight. In the cases of the seawater system pumps, this is raised to 15% to cover reaction loads. An additional margin is included for miscellaneous foundations and structure.

3.4.3 OTEC Equipment

The sizes and weights of the main OTEC equipment and much of the associated auxiliaries are specified by the DOE in Reference [13]. The information contained therein has been used for the weight items in Appendix A. One of two notable exceptions is the wet weight of the heat exchangers. The MR&S OTEC spar design eliminates the waterbox at each end of the units, providing for direct flow into the tubesheets from the seawater ductwork. This design, which increases hydraulic efficiency, required modifications to the weight of the 50 MWe vertical heat exchanger given in [13]. This was accomplished by deducting the volume of seawater which would be contained in the waterboxes shown therein. The dry weight of the structure was left unchanged to serve as a margin.

The seawater system weights were based on the piping as sized in Section 3.8 and gaged in Section 3.3. Reinforced concrete weight estimation methods used above were applied. Table 3 contains the weights of the seawater pumps, intake and discharge valves, intake screens, heat exchanger cleaning equipment, purging system, and control and monitoring equipment. These weights also appear in Appendix #2 under their proper WBS groups.

The GRP cold water pipe design is included in this report as Sections 3.11 and 3.12. Its weight is taken as a lump sum at the hull attachment in the "grapefruit".

The major weights in the ammonia system are the working fluid itself, the pumps, the storage tanks, and the vapor piping assembly in the central trunk. The ammonia weights are rounded figures from [14] for NH_3 liquid and saturated vapor. The pumps and storage tanks are specified by the DOE. The ammonia vapor piping assembly was modified from the 14' (4.267m) diameter duct specified in Reference [5] using standard HVAC conversion formula E. Thicknesses were calculated based on a specified 250 PSI (175775 Kg/m^2) system pressure.

Other equipment was added as specified in Reference [13] or as found necessary. The chlorination system was modified from the one specified therein to a smaller number of larger units (36), saving weight, volume, and cost.

3.4.4 Mooring

The mooring system evolved into an HCL link system as covered in Section 3.7. The weight used was the sum of the mooring reaction and the weight of the hull attachment shown on Drawing #47916.

3.4.5 Platform Service System

The platform electrical, marine and hotel systems are covered in Section 3.9. Weights for these items have been distributed into the appropriate WBS groups in Appendix #2.

3.4.6 Support, Outfit & Furnishings

Weights for cranes, deck machinery, helicopter and boat handling equipment and other similar equipment are included. These items are covered in Section 3.13 and are recorded in appropriate WBS groups in Appendix #2.

3.4.7 Moments & Centers

Since the platform is symmetrical the "transverse" and "longitudinal" centers of gravity fall on the platform centerline. Individual vertical centers of gravity are determined for the platform components by their location on the arrangement. These CG's are used to compute weights/moments for the components, which were summed by WBS group. The sum of the group moments is divided by the sum of the weights to determine the platform CG. (403.7' (123.05m) below the DWL).

3.5 Stability

3.5.1 Stability Criteria

Various regulatory body and classification society stability criteria were mentioned in [29] as being the rules that could be applicable to OTEC platforms.

However, in considering the two deeply submerged platforms of the MR&S concept designs, it was decided to adopt an entirely different approach to stability criteria.

In the case of intact stability, the available GM is significant during all phases of construction, deployment and operation so that precise criteria need not be applied at this time.

In the case of damage stability, it becomes 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 occur through collision with the very largest oil tankers (350,000 tons DWT) or a submarine. It is felt by MR&S that adequate navigational restrictions should and will 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 will not be necessary. During construction the platforms are vulnerable to collision from large ships. Adequate navigation protection will 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 transfer boats alongside even if adequate navigational restrictions are placed on other ships. Consequently, as a minimum, the requirements for drill ships [15] have been imposed on the superstructure.

3.5.2 Intact Static Stability

The VCG of the spar is below the VCB, which yields a stable condition. Metastability, using the distance between the CG and the metacenter, or GM, is not required in this stability analysis, as it is normal for ships because of this favorable relationship. However, a KM curve is included on the curves-of-form drawing, Appendix #3.1, #47922 for reference.

3.5.3 Damaged Stability

a. Superstructure

The superstructure is subdivided for damaged stability up to the fifth deck level. The ventilation trunk is run alongside the central trunk so damage can occur up to 1/5 the beam penetration with damage to the vent trunk. In way of access trunk, watertight closures in way of the vent ducts are required to prevent progressive flooding.

b. Main Hull

As discussed above, subdivision of the main hull is not provided.

3.5.4 Stability during Construction

Analyses of the stability and freeboard of the platform at various phases of construction are considered necessary because of the extent of time the platform spends in a semi complete condition at sea. Preliminary checks which were performed using erection unit weights and curves-of-form data indicate a potential problem exists only during the earliest phases of construction. MR&S feels that, as a result of identifying the problem, sufficient safeguards are designed into the construction/deployment scenario (see Section 6.0) to avoid any risk.

3.6 Seakeeping Analysis

3.6.1 General

The seakeeping analysis of the spar platform has been performed by using several different analysis procedures involved in computer programs all using the hydrodynamic added mass, damping coefficients and wave exciting forces determined by Davidson Laboratory [16].

The seakeeping results themselves are of limited use in this concept design since the most that can be done in the absence of data on allowable OTEC equipment motions and accelerations is to observe whether or not the motions are acceptable from a human and platform service equipment standpoint, and to consider hull alterations if resonance of motion with the waves of significant energy should occur. As expected however, for these heavy submerged platforms, when considering human and platform service equipment tolerances the motions are small so that operation can continue from a seakeeping standpoint under any sea condition, including severe storms. The natural frequencies occurred at lower values than those of significant wave energy so that modification of the platform configurations to alter these frequencies is not necessary.

3.6.2 Hydrodynamic Coefficients

As previously mentioned, the hydrodynamic coefficients and wave exciting forces of the spar platform were determined at the Davidson Laboratory of Stevens Institute of Technology by Dr. C. H. Kim [16]. After a survey of available analysis procedures it was decided to employ Adey-Bai's [17] computer program. This program has been developed based on Newman's slender body theory [18] for computing motions of spar buoy platforms. The theory assumes that wavemaking damping and the diffraction effects are negligible. This assumption is valid when the body horizontal cross-section diameter is small relative to the wave length. Since the spar is axisymmetric about the vertical axis, it is sufficient to evaluate the hydrodynamic characteristics of three modes of motion only: sway, heave, roll.

The "hydromechanical" characteristics are usually expressed in the form of matrices. The heave, sway and roll have been designated by the mode numbers $M=2,3,4$ respectively. Therefore, for example, the element C_{22} of the stiffness matrix [18] indicates the heave restoring force per unit heave displacement. The matrices of the hydromechanical characteristics consist of $[A]$, $[B]$, $[C]$ and $[F]$. $[A]$ and $[B]$ represent the added mass and damping matrices, respectively, whereas $[F]$ indicates the wave-excitation matrix.

The geometrical shape of the spar buoy as used in the subject computations is shown in Figure 4. It is a body of revolution consisting of several coaxial circular cylinders attached to a hemisphere at the bottom.

The matrices of the hydromechanical characteristics $[A]$, $[B]$, etc. have been calculated and tabulated for an array of wave frequencies as shown in Table 7. The zero matrix elements have not been shown in the table.

FIGURE 4:

SKETCH OF THE SPAR BUOY PLATFORM
FOR HYDRODYNAMIC ANALYSIS

TABLE 7

VALUES OF THE MATRIX ELEMENTS
OF THE
HYDROMECHANICAL CHARACTERISTICS OF THE SPAR BUOY PLATFORM

$$\begin{aligned} A_{22} &= 0.4241 \text{ E07} & A_{33} &= 0.5635 \text{ E08} & A_{44} &= 0.1756 \text{ E13} \\ A_{34} &= 0.2204 \text{ E10} & C_{22} &= 0.7236 \text{ E06} & C_{44} &= 0.7098 \text{ E11} \end{aligned}$$

Frequency, ω	F_{12}	F_{23}	F_{24}
0.2	0.7269 E06	0.2901 E07	0.2202 E09
0.3	0.1280 E07	0.4007 E07	0.4811 E09
0.4	0.1281 E07	0.4010 E07	0.6985 E09
0.5	0.1018 E07	0.3484 E07	0.7926 E09
0.6	0.7230 E06	0.2893 E07	0.7866 E09
0.7	0.4788 E06	0.2404 E07	0.7363 E09
0.8	0.2988 E06	0.2044 E07	0.6801 E09
0.9	0.1758 E06	0.1798 E07	0.6350 E09
1.0	0.9738 E05	0.1642 E07	0.6047 E09
1.1	0.5072 E05	0.1548 E07	0.5872 E09
1.2	0.2483 E05	0.1496 E07	0.5788 E09
1.3	0.1142 E05	0.1470 E07	0.5759 E09
1.4	0.4942 E04	0.1457 E07	0.5759 E09
1.5	0.2008 E04	0.1451 E07	0.5772 E09
1.6	0.7673 E03	0.1448 E07	0.5790 E09
1.7	0.2754 E03	0.1447 E07	0.5808 E09

3.6.3 Comparison of Platform Motion Analyses

With the hydromechanical characteristics given in Table 7, the platform response motions without CWP were computed by Davidson Laboratory using the Adeebai [17] computer program, with and without CWP, by MR&S using the Paulling [19] computer program, and with CWP by Hydronautics, Inc. [20].

The regular wave motions at the platform center of gravity as computed by Davidson Laboratory are shown in Figure 5. 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. All responses are supposed to reach the value of unity when the wave frequency approaches an exceedingly small value. The theoretical responses near the resonance frequencies are regarded as overestimations, particularly roll, due to the neglecting of the damping factor in the motion equations.

Figures 6 to 8 give the regular wave results of the Hydronautics analyses of the spar platform with GRP, concrete, and steel cold water pipes rigidly attached to the platforms. The results are similar to the Davidson Laboratory results except that notably; the roll natural frequency has been decreased, probably due to the presence of the CWP; the secondary response peaks are larger, probably due to the motions being for a point at the sea surface rather than the C.G.; and the heave response shows no secondary peak while the roll does, which is probably due to the presence of the CWP.

In addition to the regular wave analyses, Hydronautics performed analyses for the storm conditions shown in Table 8 and a sea state six condition with a significant wave height of 20 feet. The motions were largest for the worst sea condition, and the results are shown in Table 9. The motions shown therein indicate that the spar motions, even in a severe storm, are quite modest, and that, from an absolute standpoint, the variations in CWP materials do not significantly affect the motions.

MR&S performed motion analyses of the spar with a number of CWPs using the Paulling program. Figures 9 to 11 give the regular wave results of two of the MR&S analyses using the Paulling Program for GRP and steel CWPs and rigidly attached to the platform. Like the Davidson results the motions are for the center of gravity of the platform. Both the heave and sway secondary peaks are less noticeable than the former results, while the motion magnitudes are very similar. Like the Hydronautics results the roll appears to have a secondary peak response.

MR&S also performed irregular sea analyses for the storm conditions shown in Table 8 and several lower sea states. The results are shown in Table 10. 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. Further, the small change in motion due to the variation in CWP materials for the final platform hydromechanical quantities, as shown in Table 8, also substantiates that vessel motions are little affected by the CWP.

FIGURE 5. RESPONSE MOTIONS OF THE SPAR BUOY PLATFORM

SPAR PLATFORM HYDRONAUTICS
REGULAR WAVE HEAVE MOTIONS AT SEA SURFACE.

○ GRP
 □ CONC
 △ STEEL

FIGURE 6

SPAR PLATFORM HYDRONAUTICS REGULAR WAVE ROLL MOTIONS AT SEA SURFACE.

○ GRP
 □ CONC.
 △ STEEL

FIGURE 7

SPAR PLATFORM HYDRONAUTICS REGULAR WAVE SWAY MOTIONS AT SEA SURFACE

FIGURE 8

TABLE 8
STORM MAXIMUM SEA STATES

Site	Significant Wave Height - Feet	Period of Peak Energy - Seconds
New Orleans	58.1	15.91
Florida	45.8	13.67
Puerto Rico	44.2	13.8

TABLE 9

Summary of Hydronautics calculated results for the spar platform with CWP.

Significant Wave Height, H = 45.8 Ft.

<u>PARAMETER</u> <u>UNITS</u>	<u>CWP OF</u>		
	<u>GRP</u>	<u>CONCRETE</u>	<u>STEEL</u>
Sway-Feet	6.66	8.00	6.74
Roll-Deg.	2.46	1.30	1.8
Heave-Feet	3.86	2.88	3.0

Significant Wave Height, H = 58.1 Ft.

<u>PARAMETER</u> <u>UNITS</u>	<u>CWP OF</u>		
	<u>GRP</u>	<u>CONCRETE</u>	<u>STEEL</u>
Sway-Feet	12.4	12.28	10.26
Roll-Deg.	3.66	2.66	2.42
Heave-Feet	7.48	5.58	5.78

SPAR PLATFORM M.R.E.S. ANALYSES
ON PAULLING PROGRAM - ROLL

○ STEEL CWP
□ GRP CWP

FIGURE 9

SPAR PLATFORM M.R.'S. ANALYSES
ON PAULLING PROGRAM - SWAY

○ STEEL CWP
□ GRP CWP

FIGURE 10

SPAR PLATFORM M.R.&S. ANALYSES
ON PAULLING PROGRAM - HEAVE

▣ STEEL CWP
○ GRP CWP

FIGURE 11

TABLE 10

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

Comparing Tables 9 and 10, it can be seen that the MR&S predicted motions are similar to those predicted by Hydronautics, and that in both cases they are in relatively good agreement and small. Further, the MR&S motions for a sea with 20 feet significant wave height shows that for all practical purposes the motions are negligible.

It should be noted that the motion calculations performed by Davidson Laboratory, Hydronautics and MR&S were performed with ship parameters that varied during the design spiral. All results are then for slightly different displacements, VCG's, gyradii, etc., and this is certainly one of the reasons for any differences in the results.

It is felt that all the various computations performed by various investigators indicate consistent results.

3.6.4 Seakeeping Performance vs Requirements

The seakeeping performance can be measured in 3 ways:

- .Effects on humans aboard.
- .Effects on platform service equipment.
- .Effects on OTEC equipment.

By inspection, it can be seen that the significant motions of the spar platforms in severe storm are less than those for surface vessels in moderate conditions, so that the platform should be operable under these circumstances from human and platform service systems standpoints.

In considering possible maximum motions it should be noted that humans and platform service equipment can usually perform under occasional extreme responses whereas a structural component might fail if not designed for that extreme. However, it should be pointed out that the "maximum expected" value of any physical quantity is usually two to 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. It would then seem that responses twice as large as the significant would be about the maximum expected on rare instances. The conclusion is that this should not effect humans and platform service equipment.

In regard to allowable motions and accelerations from the standpoint of the OTEC equipment, no data is available.

3.7 Mooring System

3.7.1 Drag Calculations

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 wind speed observed over the period of record. The other is an extreme current velocity and 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 11.

3.7.2 Mooring Line Holding Power

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 [5].

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 performed [22].

3.7.3 Mooring System Arrangement

The 3-leg HCL mooring system developed for the OTEC spar platform is detailed in Drawing #47916. As can be seen there, the spar hull connections are spaced at 120° intervals around the platform at DK525. These connections are tied into the structure by concrete anchors. The shell is locally post-tensioned to take the load, and reinforcing foundations are used to internally distribute the load. The links are 53.1' (16.18m) long by 5.3' (1.62m) in diameter. A scope of somewhat less than 2 is anticipated. Disc type free fall anchors, as detailed on the drawing, are designed to allow a stable vertical deployment with minimal drift. This is anticipated to be the simplest method of deployment. Table 37 gives the characteristics of the selected link. (Refer to Section 4.7).

Table 11. Current Conditions at Sites

<u>Site</u>	<u>VS</u>	<u>Conditions</u>	<u>Drag</u>		
			<u>Current</u>	<u>Wind</u>	<u>Total</u>
W. 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)
Puerto 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)
New 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)

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

3.8 Seawater System Analysis

3.8.1 General

Iterative conceptual investigations and layout development of the seawater systems and components, for the designated hull configurations, have been carried out for the second half of this project, Tasks 5, 6, 7 and 8. Presented herein are conceptual designs of seawater systems located in the most efficient way, consistent with the platform requirements and having cognizance of the needs of all phases of the plant life. 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)

Both the Spar and the Sphere platform Seawater systems are discussed in this section since much of the problems associated with their development are similar. Major variations in the systems for the sphere platform are presented out here and also repeated in Section 4.8.

3.8.2 Seawater System Conceptual Design

The conceptual designs of the seawater systems, discussed herein, for both platform configurations, spar and sphere, are the result of the fourth design iteration derived from numerous design alternatives, offering hydraulic, space utilization and power requirement advantages. The low pressure drop across OTEC heat exchangers (originally 2 psid and later changed to 3.5 psid by DOE/GAI) requires the use of high low heat pumps. 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. To obtain high pump performance the intake flow must be smooth and uniform with straight parallel stream lines through sufficient length to allow well developed flow approaching the pump. So required are the conditions in the waterways leading to the heat exchangers. In order to make the system waterway arrangement as compact as possible for optimum platform designs, baffles and flow guides are employed to improve flow distributions for cases where bends are necessary.

a. General Arrangement

The general arrangements of the seawater systems for the spar and sphere platforms are shown in Figures 12 and 13. Major system/component characteristics may be noted as follows:

1. Vertical evaporators and condensers are used for all cases.
2. Vertical turbines are adopted for spar platform design, and horizontal turbines are used for sphere platform design.
3. Seawater pumps are all located upstream of the heat exchangers.
4. Bulb type axial flow pumps are employed for all arrangements.
5. Warm seawater intakes are all vertically positioned with an inlet velocity of 6 ft/sec. Horizontal gates are located immediately below the main deck so that the flow disturbance, due to the gate seat at the intake entrance, can be dumped out through the seawater pipe before reaching the pump.
6. The seawater pipes are designed with a length of four diameter upstream of the central plane of the pump stator section and a length of two diameter downstream of the pump stator central plane before the transition water box to the heat exchanger, so that uniform water distributions to the heat exchanger may be obtained.
7. For both spar and sphere designs, separate warm and cold water discharges are used to avoid possible head loss and flow imbalance which may occur under some circumstances. However, all warm and cold water is discharged at the same depth range, 300-350 ft., to help reduce the possible direct recirculation into the warm intake.
8. A pipe bend in the cold water system is used for the sphere design. In order to improve the flow distributions to the condenser, flow guides are provided at the elbow section.
9. Vertical gates are employed at the discharges in spar design and butterfly valves are employed at the discharges in the

Seawater System General Arrangement (Sphere Platform)

Figure 13

Seawater System
General Arrangement
(Platform-Spar)

sphere design due to space limitation.

10. All gate and butterfly valves are hydraulically operated and remotely controlled from the main control room with override from the stations.
11. Layout and spacing between components in each platform configuration are not hydraulically optimized. Some reduction in space may be possible with more detailed design confirmed by hydraulic testing results.
12. Individual static screens are provided for each of the warm seawater intakes on the main deck of the sphere platform. For the spar platform a common intake screen is provided enclosing all eight (8) warm seawater intakes. The water velocity through the screen for the spar design exceeds the 1.5 ft/sec limitation due to the unavailability of deck space of the spar design.
13. Amertap mechanical tube cleaning system is provided for each heat exchanger. Since the system is integrated into the heat exchanger, it is not shown.

b. Warm Seawater Intake Screens

The proper selection of screening methods for warm seawater intakes is of paramount importance to the successful operation of an OTEC power plant. Factors for consideration include: thorough understanding of the actual biological and debris characteristics of the seawater at the particular OTEC plant site; the identification of seasonal and depth variation of material arrival rates and durations; as well as the equipment reliability and its economics. As it has been recognized that the conventional traveling screen is not practical for OTEC applications, other types of screening methods suitable for OTEC applications are being developed, or planned, for seawater testing under separate contracts with the DOE. For the cost estimating purposes for this conceptual design of the assigned platform configurations, static screen has been recommended by DOE/GAI with the design basis on a maximum water velocity through the screen of 1.5 ft/sec and a heat exchanger tube ID of one inch. A conceptual layout of the static screen system for each platform configuration has been formulated for the sole purpose of ballpark costing and weight estimates. It may be described as follows:

The fundamental concept for this passive, static screen conceptual design consists of the following elements:

- o Concrete piers are positioned at the perimeter of the intake to serve as structural supports for the screen system.
- o Trash bars at 12 inches on centers are located immediately upstream of the screen sections.
- o 55% screen efficiency is used for the screen material to withstand severe sea conditions.
- o Dual parallel screens of sectional design are employed to facilitate screen cleaning while keeping power units on line at all times. As designed, manual cleaning is required.

- o Automatic cleaning features could be incorporated into the design so that the outer sections of the dual parallel screens can be lifted up for periodical cleaning and service, and the inner section will be pushed forward to replace it as the outer section. The cleaned section is then placed back as the inner section. During normal operation the screens are protected by trash bars and can be serviced as required without unnecessary exposure to the sea conditions.
- o All screen sections are vertically positioned. The top of the screen enclosure is adequately covered to protect the seawater pump from being damaged by directly falling objects.

For the sphere platform configuration, each of the warm seawater intakes is equipped with its own 30 ft. high screen located upstream of the intake entrance above the main deck of the platform, as shown in Figure 14. The water velocity through the screen is 1.5 ft/sec. For the spar platform configuration, there is not enough space on the main deck for individual screens over each intake. As shown in Figure 15, the screen is designed to provide maximum possible screening surface by enclosing all eight intakes above the main deck. For a screen of the same height of 30 ft., the water velocity through the screen is 3.5 ft/sec with an approaching velocity of 1.9 ft/sec. This high velocity flow would probably hold fish or other types of marine life against the screen firmly. Therefore, frequent cleaning and service are required for this screen; hence, the operating and maintenance cost would be higher than that for the sphere platform. Since the performance specification of the static screen has not yet been well defined, only ballpark operating and maintenance procedures are projected and presented in the following sections.

Figure 14
 Warm Seawater Intake Screen Conceptual Layout
 (Sphere Platform)

SCALE: 1" = 25'

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Warm Seawater Intake Screen Conceptual Layout
(Spar Platform)

Figure 15

SCALE: 1" = 25'

c. Seawater Pumps

The pumping power required to move cold and warm seawater through an OTEC power plant represents 85 percent of the parasitic power requirement or 20 percent of the plant power output. Therefore, seawater pump performance, sizing and cost information are major controlling factors for the power plant system/platform design optimizations. From the consideration of the operating conditions experienced by an OTEC power plant, the head and capacity requirements of the seawater pumps lead directly to the selection of axial flow pump designs.

A self-contained bulb, direct drive, high flow, low head, axial flow pump has a distinct advantage in performance and arrangement flexibility. The diffuser section of the pump bulb unit, located downstream of the stator blade section, should be designed to reduce the relatively high water velocity discharged from the pump throat to a velocity that is more compatible with the power plant seawater flow path (approximate 6 ft./sec.) with the minimum loss of available energy. In other words, the diffuser section must be efficient to achieve minimum required pumping power. The self-contained bulb arrangement provides the compactness and shape that allows maximum freedom in shaping a high efficiency pump/diffuser unit and routing the seawater piping so that the seawater is flowing straight through with minimum turns and obstructions; hence, minimum viscous dissipation losses. Also the seawater system employing a bulb pump unit allows the entire integrated pump/diffuser unit to be manufactured as a "plug in" unit requiring minimal field assembly or alignment.

It has been suggested by several large pump manufacturers (Allis Chalmers, Hitachi, Westinghouse and Worthington) that the best seawater pump design, as discussed above, in terms of overall pumping efficiency and operational flexibility, will not be an off-the-shelf equipment, but will be a special design, custom built and hydraulically tested particularly for OTEC applications.

Under sea-state 9 conditions, structurally all pump/component designs must be capable of continuously operating with a maximum of 0.5g acceleration due to platform motion. The drive system components of the pump are required to operate at sea depth of 600 ft. as in the case of cold seawater pumps in the spar platform. The drive system components must also be isolated from seawater contact by using seals and/or pressure compensated pod packaging to protect the drive from being affected by the depth of submergence. Slow start-up capability is definitely desirable to prevent pump blade stall as the seawater is accelerated to the pump design flow rate.

Figure 16 shows a typical axial flow pump/diffuser configuration. The pump design configuration consists of a rotating nose cone with rotor blades, followed by stator blades fixed to a stationary pod structure and followed by the tail cone structure. Corrosion resistant stainless steels or titanium may be used for surfaces in contact with seawater. Electrical leads and service tubes to the pump motor, motor case, and seal cavity can be provided through stator blades for cooling, purging and atmosphere control of the motor and motor housing.

For the purpose of weight and cost estimating, on the 50 MWe power module basis, some seawater pumps are selected for the conceptual layout of seawater systems for both platform configurations, as shown below:

	Warm Seawater Pump	Cold Seawater Pump
Pumping Capacity	5000 cfs	6000 cfs
Total Dynamic Head	8 ft	12 ft
Power Required	11,250 BHP	6200 BHP
Power Source	13,800 V	13,800 V
Efficiency	0.75	0.75
Pump Casing Diameter	18 ft	20 ft
Overall Length	54 ft	60 ft
Pump Speed	73 rpm	73 rpm
Pump Weight		
Sphere Platform	425 sh. tons	495 sh. tons
Spar Platform	425 sh. tons	545 sh. tons

Figure 16: Axial Flow Seawater Pump/Diffuser Configuration

d. Seawater Gates and Valves

The seawater piping closure devices, gates and valves, for the OTEC power plant are not off-the-shelf equipment, but must be specifically designed for the required operating conditions to ensure that the installation is hydraulically sound and will neither be subject to cavitation damage nor create flow disturbance resulting in undesirable flow maldistribution problems. Designs of gates and valves employed in the OTEC seawater systems must be simple and rugged to withstand the OTEC platform operating pressures under all sea conditions, and must also be provided with a reliable seal and seating arrangement with easy access for service and maintenance.

As shown in the seawater system general arrangements, Figures 12 and 13, horizontal and vertical gates and butterfly valves are employed as waterway closure devices for the conceptual design. All gates and valves are designed to be operated hydraulically from the main control room with over-ride from the station. A preliminary schematic of the hydraulic system has been prepared by Engineering Incorporated of Hampton, Virginia, as shown in Figure 17. Vertical gates shall be equipped with counter-weights to reduce the power required to raise and lower the gates. Counter-weights are generally sized at 40% of the weight of the gate. All gate designs shall have multiple rollers to reduce rolling resistance to 0.01 or less for each rolling contact surface. The butterfly valves employed at the cold and warm seawater discharges are rubber seated with rubber covered steel body and disc suitable for ocean water service, complete with monel shaft and hydraulic operator. Figure 18 shows a general assembly butterfly valve.

Approximate dimensions, weights and power requirements for the operation of the gates and valves for both platform configurations are summarized as follows:

<u>Platform Config.</u>	<u>Waterway Closure Device</u>	<u>Dimensions ft</u>	<u>Weight Short Tons</u>	<u>Power Req'd HP</u>
Sphere	Warm Seawater Intake Gate	30'Dia.	43	110
	Warm Water Discharge BF Valve	25'Dia.	110	75
	Cold Seawater Intake Gate	30'x40'	84	360
	Cold Seawater Discharge BF Valve	28'Dia.	120	75
Spar	Warm Seawater Intake Gate	25'Dia.	30	75
	Warm Seawater Discharge Gate	20'x50'	70	300
	Cold Seawater Intake Gate	25'Dia.	30	75
	Cold Seawater Discharge Gate	24'x50'	84	360

Large waterway closure devices for ocean water services are custom built equipment, in general. The sizes of gates and valves employed for this seawater system conceptual design can be designed and fabricated as "plug-in" units requiring minimal field assembly and alignment.

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NOTE:

1. THIS DRAWING WAS PREPARED FOR EURNS L.D ROE AS A PRELIMINARY PROPOSAL DRAWING

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HYDRAULIC SYSTEM

Figure 17: Schematic Diagram of Hydraulic System (Preliminary)

ENGINEERING INCORPORATED, PC		
PROJECT TITLE OCEAN THERMAL GRADIENT STUDY		
DRAWING TITLE SLIDE GATE HYDRAULIC SYSTEM		
A400	DATE 10/4/71	10419 0

Assembly and details of 120-in. hydraulically operated ring-seal gate which was used at Boysen Dam.

Figure 18: Typical Waterway Closure Devices, Gates and Butterfly Valves

General arrangement and details of butterfly valve, based on the 13-ft-diameter valves designed by the Bureau of Reclamation for the Central Valley project power plants.

e. Amertap System

The Amertap continual tube cleaning system provides a method of maintaining heat exchanger tube cleanliness without necessitating system shutdown. This is accomplished by the passage of sponge rubber balls through the heat exchanger tubes while the system is in operating condition. The balls are injected in the system upstream of the heat exchanger and subsequently collected downstream of the heat exchanger by specially designed screens and returned to the upstream injection points for reuse. Figure 19 shows the general arrangement of a commercial Amertap system.

The application of the Amertap system to the OTEC plant poses problems in the areas of distribution at the heat exchanger inlet and collection strainer design and operation at the heat exchanger outlet. The normal, and apparently successful, method of randomly distributing the balls in the water piping upstream of the heat exchanger is not considered applicable for the size of equipment considered for OTEC. In order to ensure all heat exchanger tubes will receive a ball at regular intervals, a more precise injection method must be used. Such a method is not available commercially at this time, but discussions with Amertap Corporation indicate that devices can be designed which can be attached to the tube sheet and provide precise ball injection. One such device could comprise a pie-slice shaped mesh basket which rotates about the center of the tube plate at a predetermined rate. The balls could be injected at points along the basket from a header running the length of the basket.

The ball collection strainers used today are of a size such that the unitized strainer unit can be completely shop fabricated within a pipe section with inlet and outlet flanges matching those of the piping system. In the case of OTEC, this may not be possible due to the large size of the piping systems and/or the unique cross section of the pipe. A special strainer

design will be required which will comprise multiple angled screen sections of suitable shapes to match the piping internal profile and which can be readily installed in the pipe section. Each screen section will return the collected balls through individual headers to a common ball collector which can be isolated from the system, and where replacement of worn balls is accomplished. The balls are then forwarded to the injection system through large clearance pumps.

The Amertap system available today incorporates provisions for back washing the screens. This feature can also be incorporated into the OTEC design and accomplished by rotating the screens to such a position that the "outlet" face of the screens is subjected to the flow through the heat exchangers. Such a feature will ensure that minimal pressure drop is experienced across the collecting screens. This feature can be incorporated into the automatic control system using screen pressure drop as the initiation signal.

Though the Amertap system for OTEC application is not an off-the-shelf equipment, according to Amertap Corporation, the system can be specially designed for OTEC with equivalent reliability comparable to that of the commercial Amertap system which are currently in use for numerous power plant condenser applications. They have also reviewed the conceptual designs presented in this study and expressed their confidence in supplying an Amertap system for the seawater systems. Since new design patents are being filed by Amertap Corporation, detailed system description and price quotations are not available at this time. However, ballpark estimates were given and are presented in the cost summary of this report.

Figure 19: Typical installation, Amertap Condenser Tube Cleaning System

f. Electrical System

The following describes the conceptual design of the electrical system required for powering the seawater system of a 400 Mwe (8x50 MW) OTEC power plant. Figures 20 and 21 show one line diagrams of electrical systems for sphere and spar platforms respectively. 13,800 volts has been selected for powering the 11,250 HP cold water pumps and 6,200 HP warm water pumps. 480 volts has been selected for motors 360 HP and smaller. These voltage selections provide the most economical system based on the lowest capital cost considering motors, cables, switchgears and installation. These voltage selections follow normal practice for land based generating stations. It is further assumed that the OTEC power systems will provide two independent sources of 13,800 volt power of which each has the following characteristics: continuous rating of 72,000 KVA; 3 phase, 60 hertz; steady state voltage regulation not exceeding 5 percent and momentary dip not exceeding 15 percent where "across the line," starting the largest motor i.e., 11,250 HP cold water pump; frequency variation not exceeding 5 percent.

The 13,800 volt system directly powers eight 11,250 and eight 6,200 HP warm and cold seawater pump motors. In accordance with normal generating plant practice constant speed squirrel cage induction motors are assumed to drive the pumps. Indoor drawout 13.8 KV metal clad switchgear rated 1,200 amperes continuous and 1,000 MVA interruption capacity is indicated for "across the line," starting and protection of the induction motors.

The 480 volt system consists of four unit substation 1000/1333 FVA AA/FA, transformers which supply power to motors rated 360 HP and smaller. Indoor drawout metal clad switchgear are indicated to control and protect motors rated 360 HP to 180 HP. The main transformer circuit breakers and the motor circuit breakers are rated 1,000 amps continuous and 50,000 amps interruption capacity. Larger motors for gates and valves are provided with forward and reversing circuit breakers.

Motor control centers are provided for controlling 480 V motors rated 75 HP and smaller. Motor control centers are fed from the switchgear bus via a reactor to reduce the short circuit current to 22,000 amps. Combination circuit breaker reversing starters are provided to control the small motors.

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Figure 20:

ELECTRICAL ONE-LINE DIAGRAM OF ELECTRICAL SYSTEM
 FOR SEAWATER SYSTEM FOR SPHERE PLATFORM
 TO 13.8 KV SOURCE

	SPHERE
Bus #1	4- COLD WATER PUMP 11250 HP
	4- WARM WATER PUMP 6200
Bus #2	(SAME AS BUS #1)
Bus #1A	4- AMERTRIP WATER PUMP 180
	2- WARM WATER INTAKE GATE 110
	2- WARM WATER DISCHARGE BF VALVE 75
	2- COLD WATER INTAKE GATE 360
	2- COLD WATER DISCHARGE BF VALVE 75
Bus #1B	
Bus #2A	(SAME AS BUS #1A)
Bus #2B	

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ELECTRICAL ONE-LINE DIAGRAM OF ELECTRICAL SYSTEM
FOR SEAWATER SYSTEM FOR SPAP PLATFORM
TO 13.8KV SOURCE

g. Nitrogen Purge System

The ammonia used in the OTEC power conversion cycle can be dangerous in certain concentrations of oxygen. Therefore, the amount of oxygen in the system that contains ammonia must be controlled. The flammability limits of ammonia in air ranges from 15.5 percent ammonia to 27 percent ammonia. During normal operation the concentration of ammonia in the power system will always be above the upper limit; therefore, no internal hazard exists in this mode of operation. However, during the time that the ammonia system is being filled there exists the hazard when the concentration of ammonia in the system passes through the critical hazardous range. For the safety of the plant and personnel, the entire system will be purged with nitrogen prior to the introduction of ammonia. During the normal shutdown or when the ammonia system must be opened for service, the ammonia system must also be purged similarly. The nitrogen purge system is designed to purge the air from the system leaving a 99 percent nitrogen mixture.

The nitrogen purge system consists of two 9,300 gallon cryogenic nitrogen storage tanks, ten ambient air vaporizers, one pressure/temperature control manifold, one transfer system (from mobile transport system to storage tank) and a mobile transport system. Since it is expected that only one power module will require purging at any one time, there is only one nitrogen purge system provided to serve all eight modules on the platform. The capacity of the nitrogen storage on board has the capability to accomplish two complete purges without refill. Permanent piping to the ammonia systems of all eight modules is included.

Figure 22 shows a typical liquid nitrogen tank installation, and Figure 23 shows a typical equipment layout, foundation and pad detail.

Each storage tank is 8 feet in diameter and 40 feet tall, and weighs 16 short tons when empty, and 46 short tons when full. The storage tanks are double-walled vessels. The inner vessel which contains the liquid nitrogen is made of aluminum. The outer vessel is fabricated from carbon steel with special coating for marine application. The annular space between the vessels is filled with a powdered insulation and evacuated to a minimum of 100 microns of mercury when the tank is cold.

The vaporizers are air cooled finned-tube heat exchangers. Each has a shipping dimension of 2 feet by 2 feet by 12 feet tall and a shipping weight of 205 pounds. Each unit is rated at 3,000 scfh for continuous operation, with ten vaporizers in parallel; the system capacity is 30,000 scfh continuous flow. The liquid nitrogen is vaporized using ambient air as a heat source through the finned-tube vaporizer.

The control manifold is designed to deliver the gas at a constant pressure and a temperature within 10°F of ambient. This system has an economizer loop which allows vapor to be drawn off the top of the storage tank directly if tank pressure is high. If tank pressure is low, a small amount of liquid will be vaporized automatically and routed back to the tank to maintain the pressure at the preset level.

The transfer system consists of a high pressure liquid pump and 1/2" ID high vacuum double walled cryogenic transfer line and associated valves, fittings, flexible sections and controls. The transfer system is capable of filling the tank from top or bottom. Top fill will be used if the vapor space pressure is high. The cold liquid falling through the vapor will condense some vapor and therefore lower the pressure. If vapor space pressure is low, bottom fill will be used to maintain the vapor space pressure. The mobile transport consists of two ship-mounted horizontal tanks which will deliver the liquid nitrogen from land based facilities.

The complete purge of the ammonia system of a 50 MWe power module requires approximately 670,000 scf of nitrogen. It is anticipated that the nitrogen system will be refilled after every purge. Since the system has the storage capacity to purge two modules, there will be no expected delay if a second purging is necessary before a nitrogen refill could be accomplished. The equipment weight of this complete purging system on the platform is 35 short tons.

The nitrogen purging system is currently commercially available. It is a standard off-the-shelf design being used in many industries for various types of system environmental control purposes. The reliability of this system is excellent due to its standard design and long experience history.

Typical Liquid Tank Installation

Figure 22:

TYPICAL LIQUID TANK INSTALLATION

INDUSTRIAL GAS DIVISION

SECTION A-A

NOTES:

1. LOX installations shall not be located where LOX spillage can flow into buildings, storm sewers, pits or other hazardous exposures or on asphalt or other flammable materials. Such exposures should be protected by proper sloping or curbing of pads and apron.
2. LOX delivery trailer apron may be clear gravel or concrete pad 12 ft. wide x 8 ft. long, minimum dimensions.
3. Refer to layout and foundation detail sketch for specific tank to be installed.
4. Use non flammable materials for LOX system concrete expansion joints, caulking, etc. Use 1/2" Glycerine impregnated asbestos for expansion joints. Refer to IGD SKETCH NO. 1590 for detail.
5. Provide well compacted crushed stone 1/2" min. x 2" max. size under concrete foundation and pads to locally accepted frost depth, but in no case less than 6".
6. All piping (especially Cold LOX piping from tank to Vaporizer) shall not be installed directly against concrete pad, but should be elevated a min. 6" above pad.
7. Size separate pad for remote equipment (Vaporizers, houseline control station, reserve gas supply) as required. 4" thick pad adequate for normal soil conditions. Make pad 6" thick for extremely bad soil conditions. Use 6 x 6 #6 x #6 wire mesh.
8. Fencing should be provided around all equipment exposed to the general public. Fencing may not be required if system is inside an industrial complex or otherwise fenced in area.
9. Provide minimum 12" spacing between separate pad for remote equipment and tank foundation to prevent frost heaving of tank foundation due to vaporizer frost condition. For extreme condition where ambient air vaporizers are used for a continuous product withdrawal and severe frost condition may be expected the distance between tank pad and remote equipment pad should be 6 ft. min. Further elevation of Ambient Air Vaporizers to allow better air flow will also alleviate some of this frost condition.
10. General Concrete Design Data:
 - a. Soil bearing must be 2000 PSF min.
 - b. Ultimate concrete strength: 3000 psi @28 days.
 - c. Anchor bolts, nuts and washers: ASTM Spec. A-7 or A-107.
 - d. Reinforcing steel: Deformed type, ASTM A-305.

TYPICAL EQUIPMENT LAYOUT, FOUNDATION AND PAD DETAIL FOR BULK LIQUID OXYGEN INSTALLATIONS

3.8.3 Miscellaneous Studies

a. Sphere Platform Vent Pipe

A vent pipe of 25 feet diameter is recommended to be provided as an extension of the cold water pipe above the main deck of the sphere platform. It is selected to serve the following functions:

- a. To function as a surge tank to relieve the upward pressure imposed on the main deck superstructure by the cold water mass during the downward movement of the platform when it heaves in severe sea conditions.
- b. To function as a vacuum relief during the upward movement of the platform when it heaves in severe sea conditions.
- c. To function as a degasification vent when the cold water is pumped from 3000 ft. depth to the platform level.
- d. To function as a service access when required.

It has been further recommended that the vent pipe for the demonstration and future commercial units should be designed on the basis of a detailed computer analysis of: the transient hydraulic characteristics of the platform heave movement; the cold water behavior in the cold water pipe; and the interaction among the platform structure, the cold water in the pipe and the sea waves.

b. Cold Water Pipe Friction Losses

A calculation of the friction losses in the cold water pipes has been performed for various diameter pipes of three different materials, fiber-reinforced plastic, concrete and steel. Figure 24 shows the plots of friction losses in cold water pipes of three materials and diameters ranging from 101 ft. to 75 ft. The cold seawater pump selected for the 101 ft. dia. cold water pipe has a total dynamic head of

12 feet. The table below shows the percent changes of total pump head increases for the cases of replacing the 101 ft. diameter pipe by the 75 ft. diameter pipe and by four 50 ft. diameter pipes. Observing the magnitude of these changes, it may be concluded that the selection of the cold water pipe diameter would have very small impact on the cold seawater pumping power requirement.

	<u>FRP</u>	<u>Concrete</u>	<u>Steel</u>
Fiction Losses for			
101 ft. Dia. Pipe	0.105 ft	0.12 ft	0.16 ft
75 ft. Dia. Pipe	0.45	0.51	0.68
4 x 50 ft Dia. Pipes	0.25	0.29	0.38
Total Pump Head Increase			
75 ft. Dia. Pipe	2.9%	3.3%	4.3%
4 x 50 ft. Dia. Pipes	1.2%	1.4%	1.8%

Figure 24: Frictional Loss in Cold Water Pipes

3.9 Platform Service Systems

3.9.1 Marine Engineering System

a. General

The marine engineering systems required to provide the platform services for the spar are contained in this section. 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.

Equipment and piping designs will be in conformance with the applicable sections of ABS, USCG, USPH and EPA regulations regarding safety, materials, workmanship and environmental considerations. All systems will be designed to accomplish the intended service and equipment and material will be of good quality, sufficient to withstand the marine environment.

b. Marine Systems

The following systems are the major marine engineering systems required to provide platform services. The applicable systems diagrams are included in the appendix.

1. Hypochlorination Injection System

The function of this system is to supply a chlorine solution for injection into seawater intakes to reduce the deleterious effects of seawater upon condenser, piping and pump internals. The effect is to reduce the required maintenance and its resultant OTEC failures.

The systems operation consists of generating a chlorine solution from seawater which is then directed to the various OTEC plant seawater intakes. For each 4,000 gallons of seawater, one pound of solution is required.

2. Fire Extinguishing and Detection Systems

°EXTINGUISHING SYSTEMS

-Water System

The firemain is a stereotype system except that it has an elaborate pressure control which will distribute the flow to nozzles as required depending upon total flow required.

Fire stations will be distributed throughout the platform. Each station has a 2½" twin hose valve, 50 ft. of hose, and nozzle and spray applicator. All areas of the platform may be covered by 2 independent jets from 7/8" nozzles at an exit pressure of 50 psi.

The installation will be in accordance with U.S. Coast Guard regulations. Hose racks or reels outside will be located on side of deck houses and be enclosed in corrosion resisting steel cabinets recessed where possible, and arranged so that the valve is within the cabinet. Cabinets will be fitted with corrosion resistant steel hinges and anti-rattle CRES latches and snubbers.

Hose racks and hydrants inside will be recessed in bulkheads where practical; no doors or other covers are required.

In addition to the required fire hose, there will be provided three 50 foot lengths of 1-1/2 inch diameter rubber covered deck wash hose. Each length will be fitted with a smooth bore type nozzle and reducing coupling for connecting to the fire hydrants.

The system provides fire protection for the large OTEC areas. Maximum flow is limited by an orifice restricting total flow to about 1500 GPM when all the sprinklers are open.

The submerged part of the SPAR platform is divided into four sections, i.e., one section for each compartment. Each section is covered by 82 nozzles which are controlled by one motor operated valve which is turned on by the smoke detector in that section.

Temperature and smoke actuated automatic sprinkling systems with alarm indication will be installed in unmanned machinery spaces and unmanned spaces such as flammable stores compartments, paint mix rooms, etc.

The fire pump and the s.w. service pump (used for fire service) will be located at about 15 ft. below sea level, and in different compartments. Both pumps will be operable from two independent power sources.

-CO₂ Systems

Fixed carbon dioxide extinguishing systems employing 100 pound capacity cylinders will be installed to protect the OTEC control EOS, crane machinery and auxiliary machinery rooms.

The carbon dioxide smothering system will be arranged for total flooding of the serviced room. Alternately a 1301 system may be supplied. Selection of the medium will depend upon U.S. Coast Guard approval and the state of the art at time of installation.

The installation, including header, cylinder bracketing, header, sirens, valve, controls and other devices will comply with the rules of the U.S.C.G.

The following equipment is required for each system:

- 100-pound size cylinders
- 3-1/2" Stop valve (normally closed)
- Break glass remote manual controls
- Time delay release
- Pressure operated sirens
- Pneumatic switches
- Flexible discharge bends
- Header manifold
- Set cylinder bracketing
- Set discharge nozzles
- Beam type scale
- Set instruction plates, nameplates, and warning plates

Release of CO₂ will be controlled by any one of the following independent sources:

- (1) Thermostats located in each room,
- (2) remote stations with manual pull at the exit of each room and
- (3) local stations in the CO₂ storage room.

Fire dampers to each room will be closed by pressure operated trip. The fans and engines will also be stopped automatically.

Predischarge warning alarm should be capable of being heard throughout the space protected by CO₂.

-Portable Fire Extinguishers

The location, type and quantity of hand portable fire extinguishers will be as required by U.S. Coast Guard. The fire extinguishers in the accommodation spaces will be installed in the fire stations.

-Rescue Breathing Apparatus

Breathing apparatus will be provided. It will consist of one Coast Guard approved self-contained oxygen unit. Two extra oxygen cylinders, fully charged, will be supplied. Stowage will be provided for breathing apparatus and spare cylinders.

-Detection Systems

A unified fire alarm system, providing capabilities for fire and smoke detecting, and for automatic and manual alarms will be installed. The system shall meet the requirements of United States Coast Guard as set forth in 46CFR, Parts 76.27 and 113.10 (Electric Fire Detection); and Parts 76.35 and 113.15 (Manual Alarm Systems). The requirements of Parts 76.33 and 113.70 (Smoke Detecting Systems) also apply, except as modified herein.

A single control and indication unit will be provided, which meets the requirements of Part 161.002-10 of the above cited regulations. This unit will alarm and indicate for any off-normal input from the installed sensors or manual fire alarm switches.

Equipment will also have United States Coast Guard approval for the specific application to Fire and Smoke detection and alarm systems.

The approved alarm and indication panel will be installed at the main control. An additional audible alarm will be installed adjacent to the Engineers Alarm Panel. Sensors will be installed throughout the platform, in accordance with Table 76.05-1(a) of the above cited regulations.

Where "Smoke Detecting" is specified, approved ionization or photo-electric detectors will be installed, and connected to an appropriate indication and

alarm station on the panel. The use of such detectors which have been specifically approved for this application will be considered as meeting the requirements of Part 76.33 of the regulations for Smoke Detector Systems.

115 Volts, 60 Hertz, single phase power to operate the systems will be supplied from an ungrounded delta System. Two feeders, one from the main switchboard 117 volt bus, and one from the emergency lighting load center shall be installed, and connected to a changeover switch adjacent to the panel, as specified in Part 161.009(a). Power for trouble indication and alarm circuit will be via another circuit, from a nearby emergency 117 Volt lighting or power panel.

Manual alarm switches, meeting the requirements of Part 161.002-12, will be installed at locations throughout the platform as specified in Part 76.35. These switches will be connected to the alarm panel to provide alarm and indication of the zone in which an activated switch is located.

(3) Bilge, Ballast and Stripping Systems

°Water Systems

Due to the size of the platform, the bilge and ballast system will be automatically and remotely controlled.

As shown in the flow diagram, during ballasting, seawater flows through the strainer plate, sea chest, and the motor operated valves to enter the ballast tank of ring shape. The air in the tank escapes through the solenoid operated vent valves.

The vent line of the sea chest has a three way, four port valve which will close the vent and bring in the compressed air during blow-out at the sea chest.

The two bilge and ballast pumps will be used for deballasting through overboard discharge valves. The manually operated gate and stop-check valves at each pump will be kept open and be used for maintenance purposes only.

These pumps can be primed with flooding by seawater when the small solenoid valves of their vent lines are opened to the sea. They can be used to support the fire pump if necessary. They will be automatically started and pump the bilge water overboard when the level controller senses the rise of bilge water and decides whether one or both pumps are to be used. The pressure controller at the outlet of each pump can sense the loss of pump priming and automatically prime the pump.

A level indicator and alarm system will inform and alert the crew. For normal bilge pumping, in accordance with U.S. Coast Guard Pollution Control regulations, two small stripping pumps will normally run under the control of the level controller which senses the water level in the small pit on the bottom level of the platform. The discharge will go through an oily water separator. The separated oil will enter a contaminated oil storage tank while the

clear water is discharged overboard. The storage tank will be subsequently discharged to a service vessel.

For emergency operation, the stripping pumps will be bypassed when the bilges are flooding and any of the bilge high level alarm indicators have been activated.

°Compressed Air Deballasting System

The air deballasting system has been designed to permit partial deballasting of one ballast tank section by inflow of air from air storage tanks (flasks). Air control valves will normally open or close in response to the draft indicator system to automatically maintain a certain fixed draft. Push-button operation from the control space will be provided as over-ride.

Air compressors will be set to automatically cut in on low storage pressure and stop when designed pressure is regained. Two compressors will normally respond; the third or standby compressor will cut in only if the other units do not start.

The deballast control valves are similar to that used on submarines, the design of which utilizes a built in air solenoid pilot valve to load or unload the main valve operating piston to open or close the valve.

The units are the largest dependable units which today's "State of The Art" provides. Higher pressure, equal volume, compressors could be obtained but only by sacrificing dependability. The pressure rating chosen permits wall thickness in flasks and pipes to remain within the present "State of The Art."

In view of the large capacity of the ballast tanks the deballasted quantity is 3.3% of Ballast tank section. However the operation is accomplished in minutes by opening one valve. Modulation is anticipated and customary.

(4) Sea Water Service System

This system takes sea suction through sea chests and supplies sea water to equipment heat exchangers. The water is then discharged overboard. Equipment requiring sea water includes diesel engines and generators, air conditioning equipment and air compressors. Each system contains suction strainers, pumps, piping, valves and controls as well as heat exchangers.

(5) -OTEC Units Flooding and Dewatering

The function of this system is to pump out the warm water and cold water OTEC systems when required for maintenance, servicing overhaul or test. The system interconnects the OTEC units with the bilge and ballast pump suction. When flooding is required to equalize pressures inside an OTEC unit that has been serviced, water flows by gravity through the Sea Chest and via the connected pipe to the unit being flooded. The vent valves automatically open when this system is in operation.

(6) Compressed Air Systems

Separate compressed air systems are supplied for diesel engine starting, automatic controls, instrumentation and platform services.

Diesel engine starting systems contain two individually driven compressors, air receivers which store starting capacity for six complete starts and motors, controllers, indication and supporting piping and wiring.

Control air systems are similar but include air dryers and filters as required. Capacity is that required for service.

Platform service air system contains sufficient air to supply air nozzles throughout the platform for general use, usually at 80 psi and 25 psi. The services include facility for operation of portable air motors, air blowing (cleaning), pressurizing of water tanks, etc. Service air system may be interconnected with other air systems for redundancy or back-up of the other systems.

(7) Fresh Water Systems

Fresh water is delivered to the platform by the service vessels and stored in a fresh water tank. Transfer of water for engine makeup, potable or domestic services, is via conventional hydropneumatic pressure sets (complete with pumps).

Potable water (drinking water) is distributed to all points via a system designed in accordance with the requirements of U.S. Public Health. Disinfection capability is supplied.

Each pressure set will supply water to its required source, i.e., Hot Water, Potable Water, Heat Exchanger and chilled water make up, etc.

(8) Sea Water Sanitary System

Water for the sanitary flushing system and miscellaneous washdown systems is taken from the sea.

The system utilizes a conventional hydropneumatic pressure set with Sea Water as the medium. Pressure set pumps take suction from the same suction header which supplies the fire pump.

(9) Drain Collecting Systems

Waste Water Drains

The drains from showers, sinks, washing machines, etc., will be run by gravity to discharge overboard through scuppers. Drains from food preparation areas will contain grease traps and be run overboard. Deck drains will discharge overboard.

°Sewage Drains

The sewage drains will be collected and routed to a U.S. Coast Guard certified type II Marine Sanitation Device where they will be processed. The clean effluent will discharge overboard through a scupper valve. Any sludge will be periodically discharged to a service boat for subsequent disposal.

(10) Heating, Ventilation and Air Conditioning Systems

°General

These systems will control the environment in the platform to maintain the platform compartment design temperatures. The designs will meet the applicable, requirements of ABS, U.S. Coast Guard, IEEE, USPH, and ASHRAE.

Design temperature conditions will be as follows:

	<u>Cooling</u>	<u>Heating</u>
Weather Air	95°F Dry Bulb 84°F Wet Bulb	30°F Dry Bulb
Air Conditioned Space	80°F Dry Bulb 50% Relative Humidity (Maximum)	70°F Dry Bulb

Toilet and shower spaces shall have exhaust based on a 4 minute compartment rate of change.

Minimum replenishment air (outside air) requirements: 12CFM/person or 20 minute compartment rate of change whichever is greater.

The outside air volume requirements shall be in balance with the exhaust air volume requirement.

°Heating - Heating will be supplied using electric heaters in the ventilation system. Requirements will be minimum since the areas of platform operation offer moderate to warm ambient temperatures.

°Air Conditioning

The air conditioning system will consist of unit coolers in the ventilation system. Multiple units will be utilized for efficiency in operation and to afford maintainability. Cooling loads will be absorbed by a chilled water system with Air Conditioning chillers centrally located. A minimum of two separate chilled water units will be installed cross-connected for redundant reliability and efficient utilization at divergent seasonal requirements. Sea water circulating systems will be installed to service the A.C. chilled water units.

The chilled water system will contain flow meters for balancing the plants. The chilled water system will operate at 45°F. Unit coolers, cooling coils, chilled water mains, risers and branch lines will be installed as well as chilled water pumps and expansion tanks. Lines will be sized to target fluid velocities at 6 f.p.s. Maximum fluid velocity is 9 f.p.s.

°Ventilation

The ventilation system is designed to recirculate and supply make-up air in accordance with equipment and habitability requirements.

Ventilation fans and associated ducts, registers and exhausts will be installed in all spaces. The vent ducts will contain the air conditioning cooling coils and the heating convectors.

Spaces will be designed as recirculating systems with replenishment of outside air as required by the particular space utilization. Heat transfer loads will be calculated utilizing SNAME Technical and Research Bulletin No. 4-7. Conditions for each space will be as follows:

All staterooms, lounges, recreation rooms, offices, dispensary, and operating control rooms will be air-conditioned.

All air-conditioned spaces with doors opening to the weather will have a slight positive pressure to prevent infiltration. Minimum outside air-CFM/person in lounges, recreation rooms, dining rooms and mess rooms, and 15CFM/person in other spaces.

Minimum outside air changes/hour - 3 for lounges, recreation rooms, and mess rooms, and 2 for other spaces, but not over 50 CFM/person.

Systems will be complete including filters, fans, cooling coils, heating coils, duct work, terminals, closure, louvers, dampers, thermostatic controls, drains, insulation, vapor sealing and lagging.

Ventilation system ductwork will be designed for 2500 feet per minute maximum, with lower velocities preferred.

Natural ventiation ductwork will be designed for 1000 feet per minute maximum, with lower velocities preferred.

Convectors, water coils, central cooling coils and unit heaters will be of good commercial marine quality. Unit heaters will be selected for a final air temperature of 125°F.

Central cooling coils will have at least six rows of tubes and 25% more rows than required by the manufacturer's published ratings, and will be based on an inlet water temperature of 42°F with a temperature rise of about 10°F.

Water coils will be sized for a face velocity of 500 FPM maximum. All supply systems having cooling or heating coils will be provided with manual roll renewable marine type air filters.

Air filters will be designed for a maximum velocity of 500 f.p.m.

11. Diesel Oil Systems

The diesel oil service systems consist of service tanks, pumps, strainers, filters, piping and valves which supply sufficient diesel oil to the generator engines and heaters to maintain their operation.

The diesel oil transfer system consists of components and tankage sufficient to store the operating diesel oil and transfer required amounts to the service tanks. A filling system has the capability of filling and discharging the diesel oil as required.

These systems are designed for compliance with U.S. Coast Guard safety and pollution abatement requirements.

12. Lubrication Systems

The lubrication systems consist of storage facility for both make-up capability and contaminated lubrication storage, transfer capability and purification capability for the various types of lubrication required by both the platform service diesels and the OTEC plant.

3.9.2 Electrical System

a. General

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. Operational needs of the OTEC platform are based on descriptions and scenarios contained in MR&S memorandum 5142-138, dated 3/10/78, updated wherever possible to reflect concurrent design development by other engineering groups.

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 and a table of weights and dimensions of the major system components follow herein as Tables 12 and 13, respectively. The electrical one-line diagram is included in the Appendixes.

b. Platform Service Power Plant

Platform service power will normally be provided by a 4000 KW transformer and bus-tie cable system energized from the main OTEC generating plant. Standby power will be provided by two 2100 KW diesel generator sets and associated switchgear. Standby generator sets will be provided in compliance with regulatory requirements and to service platform operational loads in the event of casualty or planned shutdown of the OTEC generation plant or failure of the normal bus-tie power source.

Standby generators will be arranged for automatic startup and paralleling upon failure of normal platform service power. Although such shutdowns are anticipated as rare events, they could potentially last several months during which time the standby generators would be the normal platform service power source.

c. Emergency Power Plant

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 emergency generator plant satisfies an important operational need for power during planned shutdown of the OTEC plant. In such operations, the emergency generator plant provides an essential backup power source to the standby generators to insure platform operational integrity and personnel safety.

d. Platform Service Distribution System

Due to the size and anticipated locations of platform service electrical loads, two load centers are planned for power distribution in the lower hull. One lower hull load center will be powered via a bus-tie cable system to the main platform service switchboard; the other lower hull (emergency) load center will be powered via a bus-tie cable to the emergency switchboard. For additional flexibility and reliability, the two lower hull switchboards will also be connected to each other via a local bus-tie cable system, thus forming a ring bus capable of maintaining power to vital platform service loads, even after loss of any one of the bus-ties. Bus-tie cables would be physically separated for maximum protection.

e. Lighting

As the lower hull is arranged with high overheads and large open areas, it is anticipated that general illumination will be provided by metal halide or mercury vapor type floodlights. Supplemental detail lighting will be provided by fluorescent fixtures. All lighting fixtures in spaces subject to ammonia leakage will be explosionproof.

Approximately 30% of the normal lighting system will be energized from an emergency power supply.

In addition to navigational lighting required for offshore structures and artificial islands, special deck lighting will be installed to make the platform especially visible at night, and to permit night-time landing of work crews by boat or rotary wing aircraft.

LINE	NAME OF EQUIPMENT	NO	RATED HP/KW EACH	TOTAL CONTH KW											REMARKS
					LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	
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 12: ELECTRICAL LOAD ANALYSIS

Table 12: CONTINUED

LINE	NAME OF EQUIPMENT	NO	RATED HP/KW EACH	TOTAL CONTH KW	OTEC UP ¹		OTEC DOWN ¹		PEAK SERVICE ²		EMERGENCY						REMARKS
					LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	
1	AUXILIARY MACHINERY																* estimated
2	D.O. XFER PUMP	1	10 hp*	8.5	.1	0.85	.1	.85	.1	.85							
3	L.O. XFER PUMP	1	5 hp*	4.4	.1	0.44	.1	.44	.1	.44							
4	STARTING AIR COMPRESSOR	1	10 hp*	8.5	.1	0.85	.1	.85	.1	.85							
5	D.O. FILTER COALESCER	1	5 hp*	4.4	.1	0.44	.1	.44	.1	.44							
6	L.O. FILTER COALESCER	1	15 hp*	12.8	.3	3.84	.3	3.84	.3	3.84							
7	BILGE & BALLAST PUMP	3	500 hp†	1206-	.1	120.60	.1	120.60	.9	723.6	1	402-					PEAK = 2 pumps; 80 KW EACH EMER = 1 pump; 402 KW PUL
8	FIRE PUMP	1	500 hp	402-	.2	80.40	.2	80.40	.2	80.40	1	402-					
9	AIR COMPRESSOR	2	25 hp*	42-	.1	4.20	.1	4.20	.1	4.20	.1	4.20					
10	OILY WATER SEPARATOR	1	6 *	6-	.1	0.60	.1	0.60	.1	0.60							
11	VENT FANS	46	75 hp	2852-	.7	1996.40	.7	1996.40	.1	1996.40							63 BRAKE HP, EACH
12	POTABLE WATER PUMP	2	1.5 hp*	2.8	.3	0.84	.3	0.84	.3	0.84							
13	HOT WATER HEATER	1	6 KW*	6-	.4	2.40	.4	2.40	.4	2.40							
14	HOT WATER PUMP	2	0.5 hp*	1-	.6	0.60	.6	0.60	.6	0.60							
15	AIR CONDITIONING COMPRESSOR	2	30 hp*	50-	.7	3.50	.7	3.50	.7	3.50							
16	SEA WATER PUMP	2	7.5 hp*	13-	.7	91-	.7	91-	.7	91-							
17	SEWAGE TREATMENT PLANT	1	3 KW*	3-	.1	0.30	.1	0.30	.1	0.30							
18	TRASH COMPACTOR	1	1 KW	1 KW	.1	0.10	.1	0.10	.1	0.10							
19	SUB TOTAL			4723.4		2307.36		2307.36		2910.36		808.2					
20																	
21																	
22																	† 420 BRAKE HP
23																	
24																	
25																	
26																	
27																	
28																	SHEET 2 OF 4

LINE	NAME OF EQUIPMENT	NO	RATED HP/KW EACH	TOTAL CORR KW	OTEC UP ¹		OTEC DOWN ²		PEAK SOURCE ³		EMERGENCY						REMARKS
					LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	
1	OTEC SYSTEM SUPPORT																
2	CONTROL & LOG POWER			5	.6	3-	.2	1-	.6	3-							
3	LO XFER PUMPS	4	30hp	100-	.1	10-	.1	10-	.1	10-							
4	SUBTOTAL			105		13-		11-		13-							
5																	
6	DECK MACHINERY																
7	DECK CRANE	3	50hp	124.5	0		.1	12.45	0								
8	MOWER WINCH	2	15hp	25.6	0		0	--	0								
9	SUBTOTAL			140.1				12.45									
10																	
11	ELEVATORS																
12	PLATFORM ELEVATOR	4	30hp	100-	.1	10-	.2	20-	.2	20-	.2	20-					
13	LOWER HULL ELEVATOR	4	15hp	51.2	.1	5.1	.2	10.2	.2	10.2	.2	10.2					
14	SUBTOTAL			151.2		15.1		20.2		30.2		30.2					
15																	
16	SHOP EQUIPMENT																
17	MACHINE TOOLS	4	1.5hp	5.6	0		.1	0.56									
18	BRIDGE HOIST	4	20hp	68-	0		.1	68									
19	BRIDGE TRANSIT	4	20hp	68-	0		.1	68									
20	SUBTOTAL			141.6				14.16									
21																	
22																	
23																	
24																	
25																	
26																	
27																	
28																	

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Table 12: CONTINUED

Table 12: CONTINUED

LINE	NAME OF EQUIPMENT	NO	RATED HP/KW EACH	TOTAL CONN KW	OTEC UP ¹		OTEC DOWN ²		PEAK SINK ³		EMERGENCY				REMARKS
					LF	KW	LF	KW	LF	KW	LF	KW	LF	KW	
1	<u>HOTEL</u>														
2	MICROWAVE OVEN(S)	1	3 KW	3 -	.2	0.6	.2	0.6	.2	0.6					
3	HOT PLATE	1	3 KW	3 -	.2	0.6	.2	0.6	.2	0.6					
4	COFFEE URN	1	3 KW	3 -	.3	0.9	.3	0.9	.3	0.9					
5	TOASTER	1	1.8 KW	1.8	.3	0.54	.3	0.54	.3	0.54					
6	REFRIGERATOR	1	0.33 hp	0.4	.5	0.2	.5	0.2	.5	0.2					
7	WATER FOUNTAIN	4	0.25 hp	1.2	.4	.48	.4	0.48	.4	0.48					
8	SUBTOTAL			12.4		3.32		3.32		3.32					
9															
10	<u>INTERIOR COMMUNICATIONS</u>														
11	SOUND POWERED PHONES														
12	INTERCOM (DIRL)														
13	PUBLIC ADDRESS														
14	GENERAL ALARM/FIRE ALARM														
15	ENTERTAINMENT														
16	MISC ALARM														
17	SUBTOTAL			1 -	.4	0.4	.4	0.4	.4	0.4	.7	2.7			
18															
19															
20	<u>LIGHTING</u>														
21	INTERIOR, PLATFORM			30 -	.6	18 -	.6	18 -	.6	18 -	.9	10 -			11 KW Conn.
22	INTERIOR, LOWER HALL			500 -	.4	200 -	.6	300 -	.6	300 -	.9	100 -			111 KW Conn
23	EXTERNAL, PLATFORM & NAV			30 -	.6	18 -	.6	18 -	.6	18 -	.9	10 -			11 KW Conn
24	CENTRAL SERVICE COLUMN			100 -	0	0 -	.4	40 -	.4	40 -	0	0 -			
25	SUBTOTAL			660 -		236		376 -		376 -		120 -			
26															
27	MISC ELEV & RE COMMUNICATION			2 -	.4	0.8	.4	0.8	.4	0.8	.7	1.4			
28															

SHEET 4 OF 4

TABLE 13
OTEC 400 MWe SPAR CONFIGURATION
WEIGHT & DIMENSIONS FOR PSS ELECTRICAL SYSTEM

	Initials	Date
Prepared By		
Approved By		

ITEM	UNIT		TOTAL		UNIT		DIMENSIONS (1)	
	WT (kip)	WT (kip)	WT (kip)	WT (kip)	LENGTH	LENGTH	WIDTH	HEIGHT
PSS GENERATOR	(2)	70.9	141.8	28' - 4"	72" - 9'	5'	(2)	
EMER. GEN.	(1)	48.8	48.8	21' - 9"	72" - 9'	5'	(2)	
PSS SWGR	(1)	13.5	13.5	15' - 6"	52"	91"		
EMER SWGR	(1)	5.4	5.4	7' 4"	40"	91"		
LOWER HULL L.C.	(1)	5.95	5.95	7' 8"	36"	91"		
LOWER HULL EMER L.C.	(1)	5.15	5.15	5' 4"	36"	91"		
BUS TIE X FMR	(2)	10 -	20 -	7' 8"	50"	100"		
MAIN PLATF LTG X FMR	(3)	0.65	1.95	22.5"	23.5"	36.3"		
EMERG LTG X FMR	(3)	0.26	0.78	11.7"	10.1"	20"		
PLATF LC	(3)	1.1	3.3	30"	34"	63"		
EMERG LC	(3)	.65	1.95	22.5"	23.5"	36.3"		
TOTAL			248.6					
ESTIMATED CABLE WT - APPROX -			51.4					
TOTAL WT (kip)			300 -					

PRELIMINARY

kip = POUNDS $\times 10^{-3}$

LC = LOAD CENTER

LTG = LIGHTING

DATA PRESENTED TO NUMBER OF SIGNIFICANT FIGURES
AVAILABLE FOR EACH INDIVIDUAL LINE ITEM.

(1) DIMENSIONS SHOWN DO NOT INCLUDE ALLOWANCES FOR FOUNDATIONS OR CLEARANCES FOR MAINTENANCE AND OPERATION.

(2) ALLOW 2'-1" ADDITIONAL CLEARANCE ABOVE UNIT FOR DUCTWORK.

3.10 OTEC Equipment Arrangement

As was mentioned in Sect. 3.1, the OTEC System, with primary emphasis on the seawater system, was the primary governing force in the arrangement of the main hull of the OTEC Spar. The power and working fluid cycles played the second largest role in the development of these arrangements.

Ammonia on the OTEC Spar is either in the working fluid loop or in storage. Storage is simply a series of 16-50' (15.24M) long by 25' (7.62M) diameter tanks located on DK220 and above the toroidal ballast tank. These are accompanied by associated pumps and valve manifolds.

The working system, however, consists of a closed loop which takes liquid ammonia from a condenser on DK440 to its associated evaporator on DK260 via the NH₃ pump cluster at DK390. The NH₃ is evaporated there and sent thru the adjoining demister to have any remaining droplets of NH₃ liquid removed. The NH₃ vapor flows by gravity and pressure from the evaporating fluid behind it down the vapor duct in the central trunk into the single-stage turbine. Between DK390 and DK440. It is pushed through the turbine by the vapor behind it and pulled through by the low pressure created by the condensing vapor ahead of it, turning the turbine in the process. The vapor flows through the connecting hood back into the condenser, completing the loop.

The geometry of the components is assumed to be as defined by [13]. What was left to MR&S was to produce an efficient arrangement from the given information.

The demister is required to be as close as possible to the evaporator. Since it is of a smaller diameter (30', 9.14M) than the evaporator (55', 16.76M), it is logical to place it inboard of the evaporator. Using close packing and radial symmetry, the 115' (35.05M) radius of the outer shell is easily determined, and the 25' (7.62M) radius central trunk appears. The inboard placement allows for better maintenance, also (See Dwg. #47920).

The given geometry of the demister points the vapor discharge inboard and raises the unit's base 17' (5.18M) off DK260, allowing a 1' (.30M) clearance between the bottom of the connecting vapor line and the unit. This allows for liquid NH₃ removal through the foundation. By the same criterion of geometry, the top of the demister discharge line is 1' (0.30M) below the top of the unit.

The vapor lines, if left as circular pipes, would protrude too far into the central well to permit one of its functional uses, as a removal route for large pieces of equipment. Using a duct flow formula from Ref. [23], an annular ring is formed in which each octant would carry the ammonia vapor for a power cycle, while leaving a 27' (8.23M) clear opening for access. This line terminates at the turbine inlet.

The vertical orientation of the turbogenerators is decided on for several reasons. It allows for efficient packing. (Once again the central trunk is a natural product of the symmetrical arrangement). It allows easier removal scenarios for the turbine and generator rotors. (Dwg. #47920).

The maintenance deck, DK490 allows ample room for on-platform service, or a staging area for removal through the central trunk. The generator stator passes through DK440 which would form an excellent foundation for the units.

The hood is felt by MR&S to be the most likely transition from the turbine to the condenser. It offers better flow distribution to the condenser than the two-pipe system indicated in [13].

All equipment surfaces which are not protected by the naturally insulating properties of concrete may be subject to a coating of insulation to prevent thermal losses or gains. This insulation is not shown.

A gas purging system consisting of tie-ins to the ammonia storage system, a nitrogen flushing system, and gas removal equipment is to be installed in proximity to each condenser. An 8' (2.438M) diameter by 40' (12.19M) long liquid N₂ storage tank is to be placed in the space allotted on DK350. This tank serves all 8 systems. This system is designed to eliminate the explosion hazard which could exist if ammonia and free oxygen in unpurged lines came into proximity during the cycle charging process.

3.11 Cold Water Pipe Strength Analysis

3.11.1 General

The spar 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 Computer Program (19) and the Hydronautics Program (20).

3.11.2 Configurations

Many different configurations of CWP's were considered. Table 14 gives the full scenario.

It can be seen that the basic configurations are a single pipe of 101 ft. inside diameter, bundle of four pipes of 50.5 ft. inside diameter, and a set of four pipes of 50.5 ft. inside diameter spaced so that the centerline of each passes through the corner of a square of 170' diagonal, or truss type.

3.11.3 Materials

The materials considered in the CWP studies are shown in Table 14. It can be seen that aluminum has been dropped from consideration, primarily due to its higher cost, poorer properties in salt water, limited availability and more elevated and controlled construction requirements. The specific properties of the materials used are given in Table 15. Allowable stresses for the materials are discussed in Volume I of this report and also shown in Table 17.

3.11.4 Buoyancy

The buoyancy of the various CWP's analyzed is as shown in Table 14. Buoyancy was varied primarily to vary pre-tension and relieve deadweight stresses.

3.11.5 Connection Stiffnesses

Previous studies for Volume I have indicated that connections of low stiffness at the platform and between pipe sections of 200 ft. to 300 ft. would result in reduced stresses.

TABLE 14: 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 Concrete	" -GRP 24"	None	"	"
"		" STL 12"	None	"	"
"		" -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 15: PROPERTIES OF MATERIALS USED FOR CWP's

Characteristic	GRP	Concrete/ Foam	Steel/ Foam
Modulus of Elast:PSI	2 x 10	2.95x10	30x10 ⁶
Density	3.29	3.42/1.09	15.19/1.09
Poisson's Ratio	0.30	0.18	0.30

However, in this study, the design, construction, operation and cost of those joints was determined to be a severe hindrance. The projected costs based on current flexible joints indicated astronomical expense.

Since it was anticipated that the submerged spar and sphere platforms would have small motions and therefore lower CWP motions and wave reduced stresses, and because of the other reasons cited above, only rigid connections at the hull and along the length of the CWP were subsequently analyzed.

It should be noted however, that one of the CWPs analyzed consisted of alternate 75 Ft. long GRP sections and 225 Ft. long steel sections rigidly attached to each other. This is in effect a pipe with "semi-pinned" sections, where the reduced stiffness GRP provides the "semi-pin" for the steel.

3.11.6 CWP Structural Cross Section

In all cases but one, the structural cross section was considered to be a solid wall as indicated in Table 14. For the exception, two 4.5 inch thick walls separated by webs of 7 feet width with foam in between were used for the CWP cross section.

3.11.7 Stress Analyses

a. General

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.

Below, each stress type will be discussed in detail, the allowable stresses will be presented, and the total stress analysis results given.

b. Platform Motion Induced Stresses and Wave Stresses

As the OTEC platform oscillates under the influence of waves, its motion and large mass will tend to drive the CWP in a dynamic motion. In addition, the surface waves will impose varying pressures directly on the CWP itself.

In order to quantify the phenomena just mentioned, two theories embodied in computer programs were used. First, MR&S used the Paulling Computer Program [19] to do extensive analyses of CWPs. Second, Hydronautics [20] was requested to do a few limited analyses.

In the case of both the analyses mentioned above, the hydrodynamics, added mass, damping, and wave exciting forces on the hull must be input. There happens to be very little data in the literature on sphere and spar shapes for this purpose and there are few general available programs for the computation of the hydrodynamic coefficients of these type hulls.

With this in mind, MR&S had the Davidson Laboratory perform the computations for the necessary quantities using the programs available to them. The results of the analyses are contained in Reference [16]. A more detailed discussion of this subject can be found in Section 3.6 Seakeeping Analysis.

The necessary hydrodynamic quantities were then used in the Paulling and Hydronautics programs. The wave forces acting directly on the CWP are computed internally by these programs, but should be small due to the deep submergence of the CWP.

The results of the stress analyses are presented in Tables 17 and 18 for the MR&S and Hydronautics computations respectively. It should be noted that the MR&S calculations represent results for several design spiral iterations, where slight modifications were made to the main hull. A matrix of computer runs made for both the SPAR and the Sphere platforms is shown in Table 16.

The wave characteristics and sea states considered in the analyses are given in Table 19. The MR&S results in Table 17 are all for the 58.1 ft. significant wave height at New Orleans unless otherwise noted.

Table 20 shows a stress comparison between the MR&S and Hydronautics analyses for the GRP CWP. The results show that the Hydronautics predicted stresses are more than two and a half times larger than those from the MR&S calculations on the Paulling program. Because of time constraints, a thorough effort could not be made to explain these trends. However, since the motion predictions of Section 3.6 indicate good MR&S and Hydronautics correlation, one would tend to deduce that the differences arise in the pipe computations. This situation is serious, because Table 17 indicates that even with the lower MR&S values for motion and wave induced bending stresses, they are by far the most significant.

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 Table 17.

c. Deadweight Stresses

The deadweight stresses were determined based on the material densities given in Table 15. The results for all CWP's are shown in Table 17.

d. Internal Flow Stresses

The internal cold water flow of 6.6 ft/sec carries an internal pressure reduction of approximately .3 psi which is well below critical implosion buckling critical stress for an 8" thick GRP CWP. This stress has therefore been assumed negligible.

e. Current Stresses

The currents for all sites were taken from the Site Environment Package (21). Figure 25 shows the current for the West Coast of Florida.

The current stresses were determined by using the currents along with a drag coefficient of .7 and integrating the drag force along the length of the CWP.

f. Buckling

Implosion buckling of the cylindrical CWP structure was briefly analyzed for the 8" GRP CWP, considering reduced internal pressure due to internal cold water flow and external pressure due to current drag forces. In both cases the stresses were less than the critical implosion stresses.

Buckling of the CWP as a column was also analyzed. This was found not to be a problem.

g. Results

The total stresses of all CWPs analyzed are shown in Table 17. The results indicate:

- o No concrete configuration gave acceptable stresses.
- o A built up steel section CWP and an alternative GRP and steel composite CWP were the only steel candidates that gave acceptable stresses.
- o Multi-pipe and truss configurations did not show significant advantage to consider them and their attendant increased weights and costs.

A thin walled (8") GRP CWP appears reasonable.

3.11.8 Final Configurations

The final spar CWP configuration is given at the end of Table 17 (Case No. 53). It is an 8 inch thick GRP. The steel candidate was not selected because of greater cost. The cold water pipe is shown on Dwg #47918 in Appendix 3.1.

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CASE NO.	PLATFORM	DISPLACEMENT LONG TONS	ATTACH POINT	C.W.P. MATERIAL	C.W.P. TYPE	I.D. FT.	t	FIXITY	BUOYANCY
1	Spar A			GRP		101	2 Ft.	Fixed/Rigid	0
2	Spar A			Steel		101	1 Ft.	Fixed/Rigid	0
3	Spar A			GRP		101	2 Ft.	Pinned/Rigid	0
4	Spar A			Steel		101	1 Ft.	Pinned/Rigid	0
5	Spar A 4 Pipe			GRP		50.5	1.5 Ft.	Fixed/Rigid	0
6	Spar A Truss			GRP		50.5	1 Ft.	Fixed/Rigid	0
7	Spar B			GRP		101	2 Ft.	Fixed/Rigid	0
8	Spar B Truss			GRP		50.5	1 Ft.	Fixed/Rigid	0
9	Sphere A			GRP		101	2 Ft.	Fixed/Rigid	0
10	Sphere A	SPH-A		Steel		101	1 Ft.	Fixed/Rigid	0
11	Sphere A			GRP		101	2 Ft.	Pinned/Rigid	0
12	Sphere B			GRP		101	2 Ft.	Fixed/Rigid	0
13	Spar B			GRP		101	1 Ft.	Fixed/Rigid	0

TABLE: 16 MATRIX OF CWP/HULL STRESS ANALYSIS COMPUTER RUNS

CASE NO.	PLATFORM	DISPLACEMENT LONG TONS	ATTACH POINT	C.W.P. MATERIAL	C.W.P. TYPE	I.D FT.	t	FIXITY	BUOYANCY
14	Spar B			GRP		101	1 Ft.	Pinned/Rigid	0
15	Spar B Four Pipe			GRP		50.5	1.167 Ft.	Fixed/Rigid	0
16	Spar B Truss			GRP		50.5	0.5 Ft.	Fixed/Rigid	0
17	Spar B			GRP		101	1.0 Ft.	Fixed/Rigid	1/2
18	Spar B			Concrete		101	2 Ft.	Fixed/Rigid	0
19	Spar B Truss			Steel		50.5	0.5 Ft.	Fixed/Rigid	0
20	Sphere			GRP		101	1.25 Ft.	Fixed/Rigid	0
21	Sphere			GRP		101	1.25 Ft.	Pinned/Rigid	0
22	Spar B			Concrete		101	2 Ft.	Fixed/Rigid	Full
23	Spar B			Concrete		50.5	1 Ft.	Fixed	0
24	Spar B			GRP		101	1.0 Ft.	Fixed/Rigid	Full
25	Spar B			Composite GRP/Steel		101	2 Ft./ 1 Ft.	Fixed/Rigid	0
26	Spar B Truss			Steel		50.5	0.5 Ft.	Fixed	Full

TABLE: 16 MATRIX OF CWP/HULL STRESS ANALYSIS COMPUTER RUNS

CASE NO.	PLATFORM	DISPLACEMENT LONG TONS	ATTACH POINT	C.W.P. MATERIAL	C.W.P. TYPE	I.D FT.	t	FIXITY	BUOYANCY
27	Spar B Truss			Concrete		50.5	1 Ft.	Fixed	Full
28	Sphere Truss			Concrete		50.5	1 Ft.	Fixed	0
29	Sphere Truss	SPH TR.		Steel		50.5	0.5 Ft.	Fixed	0
30	Spar B			Steel		101	1.0 Ft.	Fixed/Rigid	1/2
31	Spar B			Steel		101	1.0 Ft.	Fixed/Rigid	Full
32	Spar B			Concrete		101	2 Ft.	Fixed/Rigid	1/2
33	Spar B			Concrete		101	2 Ft.	Fixed/Rigid	Full
34	Spar B			GRP		101	10 inch	Fixed/Rigid	0
35	Spar B			Concrete		101	5 Ft.	Fixed/Rigid	Full
36	Sphere	SPH		Steel		101	1.3 Ft.	Fixed/Rigid	1/2
37	Sphere	1033000	103	GRP		101	16 inch	Fixed/Rigid	0
38	Sphere			GRP		101	18 inch	Fixed/Rigid	0
39	Sphere			Concrete		101	5 Ft.	Fixed/Rigid	Full

TABLE: 16 MATRIX OF CWP/HULL STRESS ANALYSIS COMPUTER RUNS

CASE NO.	PLATFORM	DISPLACEMENT LONG TONS	ATTACH POINT	C.W.P. MATERIAL	C.W.P. TYPE	I.D FT.	t	FIXITY	BUOYANCY
40	Sphere			Steel		101	1.5 Ft.	Fixed/Rigid	1/2
41	Sphere			GRP		101	21 inch	Fixed/Rigid	0
42	Sphere			GRP		101	16 inch	Fixed/Rigid	0
43	Sphere		103	GRP		101	16 inch	Fixed/Rigid	0
44	Sphere			GRP		101	6 inch	Fixed/Rigid	0
45	Sphere	103300	103	GRP		101	8 inch	Fixed/Rigid	0
46	Sphere	1033000	103	Steel	Built up Section	101	5 inch	Fixed/Rigid	1/2
47	Spar			GRP		101	8 inch	Fixed/Rigid	0
48	Sphere B ⁺	1033000	103	Steel	Built up Section	101	5 inch	Fixed/Rigid	1/2
49	Sphere C	1066536	103	Steel	Built up Section	101	4.5 inch	Fixed/Rigid	1/2
50	Sphere C	1066536	103	GRP		101	8 inch	Fixed/Rigid	0
51	Sphere B ⁺	1033000	103	Steel	Built up Section	101	4.5 inch	Fixed/Rigid	1/2
52	Spar B			Steel	Built up Section	101	4.8 Ft.	Fixed/Rigid	1/2

TABLE: 16 MATRIX OF CWP/HULL STRESS ANALYSIS COMPUTER RUNS

[illegible]

TABLE: 16 MATRIX OF CWP/HULL STRESS ANALYSIS COMPUTER RUNS

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	3.006 E4	349	3.333	1.49	2.57	.56	3.374 E4	3.36 E4
			5.0953 E3	2.68 E4	349	3.333	.83	1.73	.40	3.048 E4	3.36 E4
25	"	Comp P/S	P-2.2077 E3	1.1613 E4	127	2.822 E3				1.4435 E4	1.2 E4
			S-4.4544 E3	2.343 E4	254	5.644 E3				2.933 E4	3.36 E4
47	S	P	2.451 E3	1.289 E4	383	700				1.397 E4	1.2 E4
			1.7717 E3	9.32 E3	383	700				1.04 E4	1.2 E4

Table 17: 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		
1	S A	P	1.719 E3	9.04 E3	127	700				9.853 E3	1.2 E4
3	S A	P	1.413 E4	7.432 E4	254	7083				8.166 E4	3.36 E4
5	S A 4-P	P	2.658 E3	1.398 E4	144	700				1.483 E4	1.2 E4
6	S A TR	P	3.272 E3	1.721 E4	178	700				1.809 E4	1.2 E4
7	S B	P	9.11 E2	4.792 E3	127	700				5.619 E3	1.2 E4
8	S B TR	P	1.492 E3	7.85 E3	157	700				8.706 E3	1.2 E4
13	S B	P	1.7175 E3	9.034 E3	254	700				9.988 E3	1.2 E4
14	S B	P	1.5998 E3	8.415 E3	254	700				9.369 E3	1.2 E4
15	S B 4-P	P	1.5463 E3	8.134 E3	202	700				9.036 E3	1.2 E4
16	S B TR	P	2.96 E3	1.557 E4	311	700				1.658 E4	1.2 E4
17	S B	P	1.7255 E3	9.076 E3	205	350				9.631 E3	1.2 E4

Table 17 Cont'd

CASE NO.	PLATFORM	MATERIAL	STRESSES				RMS MOTIONS			TOTAL STRESS	MAXIMUM ALLOWANCE STRESS
			RMS WAVE	MAXIMUM RMS x 5.26	CURRENT	WEIGHT	HEAVE	SWAY	ROLL		
24	S B	P	1.813 E3	9.536 E3	255	0				9.79 E3	1.2 E4
34	S B	P	2.0157 E3	1.06 E4	306	700				1.161 E4	1.2 E4
53	S B ⁺	P	1.85 E3 1.47 E4	9.731 E3 7.732 E3	383 383	674 674	1.837 1.018	2.57 1.70	.56 .42	1.079 E4 8.789 E4	1.2 E4 1.2 E4
22	S B	C	1.1487 E3	6.04 E3	132	0				6.174 E3	1.8 E3
23	S B	C	1.8756 E3	9.8657 E3	155	985				1.1 E4	1.8 E3
18	S B	C	1.2447 E3	6.547 E3	127	960				7.634 E3	1.8 E3
27	S B TR	C	1.8692 E3	9.832 E3	162	0				9.994 E3	1.8 E3
32	S B	C	1.162 E3	6.112 E3	129	701				3.28 E4	3.36 E4
33	S B	C	1.1498 E3	6.048 E3	132	0				6.18 E3	1.8 E3
35	S B	C	1.0442 E3	5.492 E3	52	0				5.544 E3	1.8 E3

Table 17 Cont'd

Table 18

Summary of Hydronautics calculated results for the Spar platform with CWP.

Significant wave height, H = 45.8 ft.

PARAMETER UNITS	GRP	CONCRETE	STEEL
CWP MAX. BEND MOM. - LB FT.	0.80×10^{10}	1.42×10^{10}	4.5×10^{10}
CWP MAX. BEND STRESS - PSI	8.3×10^3	3.2×10^3	38.3×10^3
CWP BOTTOM MOTION - FT.	10.5	8.7	14.4

Significant wave height, H = 58.1 ft.

PARAMETER UNITS	GRP	CONCRETE	STEEL
CWP MAX. BEND MOM. - LB FT.	0.105×10^{11}	0.36×10^{11}	0.59×10^{11}
CWP MAX. BEND STRESS - PSI	10.9×10^3	6.0×10^3	50.5×10^3
CWP - BOTTOM MOTION - FT.	17.22	20.3	19.9

TABLE 19: WAVE CHARACTERISTICS AND SEA STATES

SITE	SIGNIFICANT WAVE HEIGHT- FEET	PERIOD OF PEAK ENERGY-SECONDS
NEW ORLEANS	58.1	15.91
FLORIDA (WEST COAST)	45.8	13.67
PUERTO RICO	44.2	13.8
SEA STATE SIX	20	10.3

TABLE 20: COMPARISON OF RESULTS BETWEEN MR&S AND HYDRONAUTICS OUTPUTS

SPAR, SINGLE/FIXED/RIGID/NON-BUOYANT GRP CWP, ID=101'

T=10"

	PAULLING'S (RMS)	PAULLING'S σ (SIGNIFICANT)	HYDRONAUTICS σ (SIGNIFICANT)	$\sigma/\sigma\%$
MAX. BENDING STRESS (PSI), $H/3 = 58.1$ FT.	2.016E3	4.032E3	1.09E4	270%
MAX. BENDING STRESS (PSI), $H/3 = 45.8$ FT.	1.643E3	3.286E3	8.3E3	252%

Depth Below Water Surface in Meters

100

200

300

400

500

600

700

800

900

1000

1

2

3

4

5

FIGURE 25

EXTREME CURRENT PROFILE FOR ALL
SITES EXCEPT KEY WEST

V_s = SURFACE CURRENT = 5 KNOTS
 V = CURRENT AT DEPTH D

3.12 CWP Configuration and Hull Connection

3.12.1 CWP Configuration

Throughout the concept design iterations, various physical embodiments of the CWPs analyzed in Section 3.11 were considered. Although GRP, concrete, and steel were all analyzed, only the GRP pipe is discussed in this section since it was the final material selection for the cold water pipe.

Through private communication [24,25] with parties possibly interested in the construction future OTEC CWPs in GRP, it was learned that the general consensus is that the CWP would be manufactured in sections on land and assembled at site.

The sections as manufactured on land might differ in size and shape depending on the construction method. However, MR&S has decided that regardless of the method, it would seem reasonable to assemble complete pipe sections of 100 ft. in length and collars of identical thickness of 25 ft. in length on land. These sections, as shown in Dwg # 47918 of Appendix 3.1, could then be joined at site by bonding and/or mechanical fastening to form the CWP as shown in Drawing Nos. 47918 and 47919 of Appendix 3.1. The collars, besides acting as the joining device, would serve to transfer the forces from one section to the other since structural continuity of the fiber material would be disrupted at the 100 ft. section ends and could not be reinstated to its strength by means of end bonding only.

3.12.2 Hull Connection

As pointed out in Section 3.11, MR&S has adopted a CWP which is fixed rigidly to the platform. Prior to obtaining favorable stress results with such a configuration the ball joint and gimbal configuration were analyzed but will not be discussed herein.

The type of attachment of the CWP to the spar has been almost completely guided by the problems of construction and deployment.

The connection is shown in Drawing 47918, Appendix 3.1. It consists of a poured concrete seal and structure between the spar concrete hull and the GRP CWP. It should be noted that detailed stress analyses of the connection area were not performed and that the penetration of the CWP into the hull to provide a fixed end might be marginal as shown herein. Extension of the penetration should only affect the spar grapefruit design to a minor degree.

3.13 Support Systems

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

3.13.1 Lifting Devices and Deck Gear

Lifting devices on the OTEC spar platform can be divided into four main categories, excluding elevators. These are the pedestal cranes, the gantry crane, the monorails and overhead hoists, and the self-propelled units such as air pallets and forklifts. All are state-of-the-art.

The gantry crane is considered the workhorse of the major equipment removal sequences. As detailed on Drawing #47920, the large majority of the equipment (pump motors, turbine and generator rotors, power transformers, etc.) are lifted through the central well for deposit on deck. The gantry crane, selected as a 100 ton lift capacity cannot perform overside handling. Functions are handled locally or from the Deck Control Station.

Pedestal cranes are used to perform overside handling tasks. The 20 ton crane is normally used for smaller lifts and replenishment at sea (RAS) operations. The 100 ton crane complements the gantry crane by its ability to move the equipment brought up to the deck over the side.

Overhead cranes are used below decks where large pieces of equipment must be lifted and moved. To limit the number of crane heads required, the units should have a uniform rail configuration (e.g. a monorail). A method of transferring heads between quadrants and/or levels is anticipated.

Fork lifts are anticipated as being the prime movers of supplies and equipment in the horizontal direction. Most of the material is to be palletized, following the general trend in the marine industry. All elevators on the platform are big enough to handle a forklift with pallet.

Air Pallets are large structures which slide on a cushion of pressurized air generated by the unit, thus lowering the peak and live deck loads to be designed for. These are state-of-the-art in industry. Pallets or interchangeable cradles would be needed for each type of equipment.

3.13.2 Boat Handling

Boat handling is largely as treated in Ref. [5]. Overside handling is accomplished by the pedestal cranes mentioned above. There are also four boat landings, two at DK15 and two at LL10, on either side of the superstructure column. The lower set is primarily for use when the Spar is in the unballasted condition for calm operations or maintenance. The upper platforms are to be equipped with highlines for RAS operations.

3.13.3 Helicopter Handling

All helicopter operations are carried on at the helicopter landing platform, although vertical replenishment (Vertrep) operations could alternately be conducted from other designated spots on the open deck. Instrument homing equipment and 24 hour landing equipment are to be provided.

Helicopter operations are controlled from the Deck Control Station. Tiedowns for securing the helicopter are to be located on the platform to prevent damage in heavy weather.

3.13.4 Replenishment Operations

Without a resident crew (living on the platform round-the-clock) the replenishment operations would be limited to replacing those fluids and stores used up during operational routine. A scenario involving both types of boat handling operations and helicopter handling operations is envisioned. Most replenishment operations would take place during the watch changes, which would occur twice daily.

3.14 Manning

3.14.1 Operations Scenario

The initial consideration was that, during normal operation, each SPAR platform in the OTEC power park, would have a crew of twenty people/shift in a "lunch-box" 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:

- 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 the industry practices described in Volume I and Ref. [5].

The OTEC central facility would be the common hotel, administrative, storage, and major maintenance facility for the eight plants of the OTEC power park. An estimated 500 men would be required for total park operation. This could be a significant saving from the crew size required to man eight separate platforms, which is estimated at 600.

However, as a result of discussions and correspondence with power utility companies by the project team, it was found that such an operating scenario would not be considered reliable. The utility companies would recommend accommodating crews aboard the platforms themselves. Accommodations are provided on each platform in addition to the central accommodation platform.

3.14.2 Maintenance Scenarios

Maintenance, in this case 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 maintenance scenarios are given on Dwg #47920. This drawing shows major equipment required for the operation, and proposes a time frame. It is anticipated that overhaul crews would be housed on the central platform.

3.14.3 Hotel Facilities

Hotel facilities on individual spar platforms would be minimal, in the case of central hotel facility, offering mainly a place to work, clean up, and sit down to eat. A bunkroom would be provided on the contingency that weather makes leaving the platform unacceptably risky, as in a storm. Provisions for the crew for a 72 hour stay would be allowed for in the dry and reefer stores (see Dwg #47914).

SECTION 4.0 CONCEPTUAL DESIGN OF 400 MW(e) SPHERE PLATFORM

4.1 Evaluation of Arrangements

4.1.1 Assignment of Hull Configuration

The hull configuration considered is a spherical shaped platform with the main hull immersed for normal operation and one or more towers extending to the surface for access, ventilation, and stability. The previous work performed by Tuned Sphere International (TSI) and by MR&S in the feasibility design effort was used as a starting point for the development of the platform arrangement, (References 5, 26, 27, and 28).

4.1.2 Power Plant Components

The weights and principal outline dimensions of the power plant components were provided by DOE. A principal design objective was to arrange the components to obtain the best hydraulic performance of the seawater pumps and best heat exchanger efficiency while at the same time minimizing the cost of the supporting platform.

4.1.3 Power Cycle Arrangement Evaluation

a. Elimination of Incompatible Layouts

The development of the power cycle and platform arrangement passed through seven design cycles before a final generic power cycle arrangement was established. Practical considerations forced the elimination of many layouts early in the conceptual design sequence.

Twenty-five MW(e) modules were eliminated early in the study since 50 MW(e) modules were found to have a lower unit cost and to yield more efficient space utilization within the platform thus reducing the platform cost.

The initial concept hull designs were patterned after the TSI baseline design (Refs. 26, 27) with a central cold water well extending up to the atmosphere and a warm water gallery over the main deck. Horizontal heat exchanger layouts as shown in Figures 26 and 27 were considered first. The sphere diameter would be in excess of 500 feet in order to accommodate the pipe runs and the platform VCG for both layouts would be high. The discharge location for the layout in Figure 27 is too high. The only advantage offered by the Figure 27 layout is that screening can be accomplished more easily and the screens are not directly exposed to waves but because of the small radius from the sphere centerline to the inlet, the minimum depth of water is larger than desired. The biggest problem presented by horizontal heat exchangers is that it did not appear possible to reduce the diameter to less than 500 feet.

In an effort to lower the vertical center of gravity as much as possible and have the discharge location as close to the bottom of the sphere as possible, the heat exchangers were located on the same level as shown in Figures 28 and 29.

Of the two layouts, Figure 29 is preferred since it presents a far superior seawater pipe run (from what was learned later in the study, the layout in Figure 28 would probably not work) and the warm water inlets are located on a larger radius from the sphere centerline permitting operation closer to the surface. The principal disadvantage of these layouts is a large sphere diameter which yields excessive volumetric displacement and a large ballast ratio.

In an effort to reduce the sphere diameter and displacement, the heat exchangers were located on about the same radius from the sphere centerline. The configuration in Figure 30 is possible but the condenser weight was higher than desired. It became apparent at this point in the study that there will be a problem of the cold water in the central well being warmed up by the surrounding warm water and the atmosphere, as the cold water well was capped off at the main deck level. A surge pipe was installed to permit the escape of gases coming up the cold water pipe and to prevent excessive surge pressures on the deck and cold water pumps.

4.1.4 Final Generic Power Cycle Arrangements

Figures 31 and 32 show the final generic power cycle arrangement with a modified platform configuration above the main deck. The seawater system is essentially the same for each with the heat exchangers side by side on about the same radius from the sphere centerline. This layout allows the heat exchangers to be located as low as possible thus improving platform stability, the ammonia piping run lengths are minimized and the seawater ducts are the optimum length and orientation for maximum hydraulic efficiency. The sphere diameter to house this configuration is 475 feet which is the smallest diameter attained in the study. The evaporations are located as far outboard as possible to permit closer operation to the surface and somewhat lower than the condensers to facilitate the run of the ammonia vapor line and to lower the vertical center of gravity. Adequate lay-down area is provided for the turbine and generator. The layouts in Figures 31 and 32 were evaluated in greater detail for their impact on other platform systems as described below.

4.1.5 Interface with Other Platform Systems

a. Platform With Stability Columns

The platform in Figure 31 has twelve 35 foot diameter stability columns equally spaced around the perimeter of the main deck and four 30 foot diameter for support of the superstructure. The widely spaced legs provide a larger metacentric height for the same waterplane area and computer analysis indicates that platform motions are slightly better than for the single column configuration, but the platform has many serious disadvantages. The outboard stability columns interfere greatly with flow into the warm water intakes. The extensive structure of 16 separate columns plus decks and connecting trusses is very expensive and heavy. The rise in vertical center of gravity works to offset the gain made by the increase in metacentric height. Access from the superstructure to the main hull is poor and offloading from supply barges is difficult.

The stability calculations performed early in the study indicated it might be possible to keep the vertical center of gravity below the center of buoyancy in all operating modes of the sphere. If so, then the stability legs could be eliminated and the four internal support columns would be replaced by a single column with sufficient waterplane area to resist variable vertical loads from the mooring legs and regular platform operation. This consideration led to the development of the configuration in Figure 32.

b. Single Access Column

The generic power cycle arrangement of Figure 32 was selected as the best possible configuration. The interference of flow into the warm water intakes is minimized although there may still be a problem of flow constriction between the superstructure and the intake. The heat exchangers are located as low as possible and the evaporator as far outboard as possible. The cold water is isolated from the warm water by the main deck and a surge pipe minimizes the pressure variation on the cold water pumps resulting from platform heave.

4.1.5 Final Platform Arrangement

The final platform arrangement is a refinement of the layout in Figure 32 and is shown on MR&S Drawing #47923.

TABLE 21
PRINCIPAL CHARACTERISTICS

Displacement (Operating Draft)	972,882 LT. (988,448 MT)
Displacement {Minimum w/o ball., seawater, in systems, mooring loads	859,916 LT. (873,674 MT)
Diameter	475 FT. (144.77 M.)
Draft to Baseline (Operating)	380 FT. (115.8 M.)
Ballast (solid)	32,000 LTONS (32,513.4 MT)
Ballast (liquid)	40,052 LTONS (40,694.6 MT)
Power Plant	400 MW(e) consisting of eight 50 MW(e) power modules
KG (Operating Draft)	179.2 FEET (54.62 M.)
KB (Operating Draft)	193.8 FEET (59.07 M.)
GM (Operating Draft)	15.0 FEET (4.57 M.)
Tons Per Foot Immersion Operating Draft	342.23 TONS (347.7 MT)
	FEET FT
CWP Inside Diameter	101 Ft. (30.78 M.)
CWP Length	2,723 FT. (829.9 M.)
HEAVE PERIOD	59 Sec.
ROLL PERIOD	32.73 Sec.

The arrangement presented in this concept design provides the most effective and flexible seawater system for a sphere platform. The top of the warm water intakes are generally 45 feet below the calm water surface (operating waterline) and can be lowered to 60 feet below for storm conditions. When a calm sea exists the platform can be raised by deballasting so the intake is 35 feet below the surface. This is the minimum amount of water cover to permit an inlet flow of 1.5 feet per second to the warm water intakes. The ability of the platform to operate over a 25 foot range of draft greatly improves OTEC plant efficiency over a wide range of sea conditions.

Pipe runs were established to maximize hydraulic efficiency but at the same time keep the platform diameter and displacement to a minimum. The discharge locations are about 340 feet below the surface and the cold water discharge is slightly above the warm water which will help prevent disruption of the thermocline.

Other ocean platform systems such as service systems, OTEC equipment and support systems are discussed in more detail in the following section.

FIG. 26 HORIZONTAL 50 MWe MODULES

SPHERE DIA. = 500'

DRAFT = 400'

$H/D = 0.8$

FIG. 27 HORIZONTAL 50 MWe MODULES

SPHERE DIA. = 500'
 DRAFT = 400'
 $H/D = 0.8$

FIG. Z.8 VERTICAL 50 MWe MODULES

SPHERE DIA. = 540'
 DRAFT = 432'
 $H/D = 0.8$

FIG. 29 VERTICAL 50 MWe MODULES

SPHERE DIA. = 550'

DRAFT = 440'

$H/D = 0.8$

FIG. 30 VERTICAL 50 MWe MODULES
ELEVATED CONDENSER

FIG. 31 VERTICAL 50 MWe MODULES
ON THE SAME LEVEL

FIG. 32 VERTICAL 50 MWe MODULES

4.2 Displacements, Volume, Hydrostatics

4.2.1 Displacement & Volume

The platform diameter is principally volume determined by the seawater pipe runs within the platform. As presently configured the volumetric displacement is slightly higher than it needs to be. This is indicated by the 32,000 long tons of permanent ballast which is not required for stability and could be eliminated. This could be accomplished by sloping the main deck downwards more and by increasing the inside diameter of the cold water well.

In computing the volumetric displacement, the volume of the sphere was computed to the outside of the structural shell and the volume of the cold water well was considered to be free flooded. The superstructure is added to the main hull and is considered in the curves of form but the access trunk from the main hull to the superstructure is treated as an appendage.

Weights and moments are computed for the hull structure, positioning system service systems and cold water pipe and are summarized in accordance with the work breakdown structure (WBS). Table 25 shows a summary of the weight breakdown. The weight summary includes liquids in the cold water and warm water ducting, but does not include water in the cold water well. In locating the center of gravity, only the vertical center was computed since the weights which are not symmetrical about the centerline are small and have a small moment arm.

The ballast system forms the largest variable weight and in a sense, the water in the seawater ducting can also be treated as ballast. The superstructure tank is used to ballast or deballast the platform over the range of operating drafts to adjust for changing sea conditions. Deballasting of the liquid ballast in the bottom tank allows the platform to surface and expose the warm water intake screens for maintenance. Further deballasting by pumping out the seawater ducts raises the access hatches in the main deck for major maintenance operations.

4.2.2 Hydrostatics

The curves of form shown on MR&S Dwg. #47930 show values for displacement, KM, KB and tons per foot immersion. Dwg #47927 shows the same but considers the platform with the bottom of the cold water well plugged. The access trunk connecting the superstructure to the main hull is not included in the curves but is treated as an appendage if high accuracy is desired.

4.3 Hull Structural Development

4.3.1 General

The hull structural development consisted of several considerations including structural material, codes for design, platform structural configuration and stress analyses.

The main material considerations were concerned with the adoption of steel or concrete for the main hull material. Various design approaches and design codes were considered for their applicability for the design of the platform. The structural configuration was altered in several ways to obtain structural efficiency and reduced weight. Finally a number of stress analyses and a finite element computer analysis were performed.

4.3.2 Material Selection

a. Hull

At the beginning of the design cycle steel and concrete were considered as possible materials for the structural hull. References 26, 27, 5, and 7 all indicated that for the size plant under consideration, a concrete hull is significantly less expensive than steel although quite heavier. 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 5000 psi ultimate compressive strength and a density of 150 pounds per cubic foot was eventually selected. Although considered, lightweight concrete was not used because it has not been extensively used in a marine environment and with its lower available maximum compressive strength of 4,000 - 5,000 psi, a greater thickness might be required.

The lower concrete strength of 5000 psi was chosen for the sphere for several reasons, all having to do with quality control. The final sphere scantlings are heavily reinforced with steel bars which will make the concrete placement more difficult. Also, the complex shape of the sphere platform will be a further detriment to good quality control during placement.

b. Superstructure

In the case of the single surface piercing column which supports the superstructure and provides access to the main hull, steel structure was used primarily to reduce the negative impact on the platform center of gravity.

In addition, the use of the steel in the superstructure served to keep the platform weight lower. It should be noted that because of the accessibility to the superstructure it can be more readily maintained than the platform hull.

4.3.3 Design Codes

a. Steel Structure

In the case of steel structure design the American Bureau of Shipping Rules

[8] and the Navy structural design practices [9] were used wherever appropriate. An additional corrosion allowance of 1/8 inch was incorporated on all exposed steel structure.

b. Concrete Structure

The American Concrete Institute Building Code [11] and the Federation Internationale de la Précontrainte [12] were the prime sources of design procedures for concrete structures. It can be said that no specific design code for surface floating concrete structures exists and consequently the concrete thicknesses developed for the sphere rely quite heavily on the assumptions which were made.

The final sphere structural design is of reinforced concrete although pre- and post-tensioned concrete was considered at previous design stages. The structure is based on an ultimate strength design according to the ACI. The analysis involved the use of a factor which takes into account material strength, workmanship and dimensional variations and an overall "load factor" to allow for uncertainties in the loads. The factor used was 0.7 which is the most conservative of those possible and intended for critical structures. The "load factor" selected for use was 1.4 as suggested by the FIP and as specified in the ACI for fluid loads.

4.3.4 Platform Structural Configuration

a. Main Deck

The large diameter sphere with large spans required between bulkheads posed difficult structural problems. With the main deck several alternatives were considered. Early in the design stage it was felt that a flat deck with column support would be the most efficient structure but in order for the columns to provide effective support they would have to extend continuously all the way to the bottom of the sphere with an estimated spacing of 25 ft. between column centers which was impossible from the standpoint of arrangement. A curved arch or straight conical deck supported only at the side was considered next but the basic problem here was that a great deal of camber was required in order to obtain a realistic thickness. Another approach considered was to use a steel deck with web supports, either flat or arched, but preliminary calculations indicated a web depth of about 12 feet of closely spaced girders which would also result in problems in making a connection to the concrete shell. Again the spans were too large for efficient girder design. Another idea was to consider the main deck and 2nd deck tied together to form one large girder. This would also make it possible to have the second deck as a subdivision deck. The concept involved the use of 4 foot thick concrete diaphragms with a spacing of 25 feet. This structure was nearly as heavy as the thicker main deck and had the disadvantage of making removal of equipment through the main deck almost impossible.

The final configuration decided upon is a single curved concrete deck with a small radius turn at the shell edge. This deck is supported by the light vertical equally spaced bulkheads which extend from top to bottom of the sphere.

b. Lower Decks

Lower decks in the early design cycles were considered to be subdivision decks but their scantlings were enormous because of the high pressure loadings. In steel the lowest deck for example would have 16 to 18 feet deep webs with a 160 inch square cross section area flange plate. The interference with major equipment was unacceptable as were the weight and cost of the structure. With consideration of different subdivision requirements (see section 4.5) the lower decks were changed to non-water-tight decks and only equipment loads considered. Major equipment such as the heat exchangers and turbine-generator set are supported on their own foundations independent of the decks. The seawater ducts are utilized as columns to provide support for deck girders.

c. Side Shell and Bottom

The side shell and bottom structure are for the most part spherical in shape and of single wall construction.

d. Cold Water Well and Seawater Ducts

The cold water well and seawater ducts are cylindrical and conical in shape.

e. Superstructure

The superstructure is all steel construction. The outer shell is accessible for maintenance so a protective coating may be applied when required. Steel was used instead of concrete to keep the weight and VCG as low as possible. The structure is of standard steel plate and girder construction.

The final structural configuration is shown in MR&S Drawing #47925 in Appendix 3.1.

4.3.5 Stress Analyses

a. General

The stress analyses of the sphere proceeded through several iterations and culminated with both small and large deflection finite element analyses on the ANSYS computer program. The large deflection analyses were performed in order to detect any signs of potential buckling, while the more readily performed small deflection computation were for stress analysis.

b. Loading

The structural loadings considered in the sphere design were:

- o Static water head.
- o Dynamic water head due to the $H 1/10^6$ severe storm wave at West Coast of Florida.
- o Structural deadweight.
- o Major machinery and equipment concentrated loads.
- o An overall distributed deck load of 200 lbs/ft^2 .

The static water head was based on a submergence to the top of the main deck of 80 ft. from the still sea surface. The dynamic water head was based on $H 1/10^6$ wave height at West Coast of Florida of 120.54 ft. with a frequency of .46 radians per second. The resulting expression for the pressure is therefore:

$$p(z) = \rho g [(z + 60.27e^{-(.0066)z})]$$

where:

- $p(z)$ = Pressure at depth z
- ρ = density of water
- g = gravitational constant
- z = water depth

c. Analyses

Both small and large deflection analyses were performed on the ANSYS computer program. Figures 33 and 34 show the finite element models of the top deck and the hull respectively for both analyses. It should be noted that both models span the vertical radially extending bulkheads which were assumed to be support points for both deck and shell. Both models are assumed to be fixed at the peripheries. A shell finite element, ANSYS stiffness 63, was used for all studies.

The computer analyses were based on a shell of homogeneous material. The thrusts and bending moments thus determined were then used to obtain reinforced concrete cross sections.

The large deflection analyses performed indicated no significant increases in deflection and stress so that buckling is not expected as the limiting criterion.

The results of the stress analyses are given in Tables 22 and 23 for the deck and hull bottom respectively. The deck results are given for various overall deck thicknesses. The results indicate that there is significant bending present in the deck and shell at the points of maximum stress. A detailed review of all computer data to determine the range of severe stress was not performed, but inspection indicates that in certain areas of the deck and shell membrane compres-

sion dominates and superimposed bending is minimal.

Reinforced concrete was then selected as the hull construction material, although pre-stressed and post-tensioned concrete were considered in earlier design iterations. The concrete design is shown in Table 24 for the stresses given in Tables 22 and 23. Where stresses are less, the reinforcement, which is rather substantial in Table 24 will be reduced significantly.

4.3.6 Final Structural Configuration

The final structural configuration is shown in Appendix 3.1 on Drawing Number 47925.

FIGURE 33: FINITE ELEMENT MODEL OF SPHERE
TOP DECK

BOUNDARY AT COLD
WATER WELL

BOUNDARY
AT BULKHEAD

BOUNDARY AT
BULKHEAD

SHELL BOUNDARY

FIGURE 34: FINITE ELEMENT MODEL OF SPHERE HULL

2773

2496

2218

1941

1664

1386

1109

832

555

272

0

277

Table 22 : Results of Sphere Ansys Stress Analysis for the Main Deck
Maximum Stresses

Deck Thickness	Stress Location on Element	Type Stress (Principal)	Stress (PSI)
84"	Top (Outboard)	Max. (Tension)	2988.16
		Min. (Compression)	- 3737.95
	Bottom (Inboard)	Max.	1888.5
		Min.	-4585.16
96"	Top	Max.	2473.35
		Min.	-2970.49
	Bottom	Max.	1604.56
		Min.	-3688.15
120"	Top	Max.	1785.58
		Min.	-2047.12
	Bottom	Max.	1198.36
		Min.	-2559.46
144"	Top	Max.	1362.97
		Min.	-1523.84
	Bottom	Max.	928.12
		Min.	-1901.08

Table 23 : Results of Sphere Ansys Stress Analyses for the Bottom
Maximum Stresses

Bottom Thickness	Stress Location on Element	Type Stress (Principal)	Stress (PSI)
120" *	Top (Outboard)	Max. (Tension)	1484.02
		Min. (Compression)	-3985.79
	Bottom (Inboard)	Max.	1877.65
		Min.	-3850.22
* Thickness at most highly stressed element			

Table 24: Shell Reinforcement

Solution		Thickness t, in.	M= fy* C.85fe'	Computer Results			With 1.4 Environmental Factor		Ult.Str	Design	PM	Req'd	
Location	fe! psi			Max comp Stress psi	A Max Comp Str		P 16/in.	M in-16/in.	P** fc' bt	M** fc'bt ²	From Inter- action Chart***	Steel Ratio	
					P'	M'							
Top Deck	84**	5000	14.2	-4585	74,439	4,348,730	104,200	6,090,000	0.248	0.1726	0.45++	0.0319	16.1
	96	↓	↓	-3688	65,796	4,611,380	92,100	6,460,000	0.192	0.1402	0.53+++	0.0375	18.9
	120	↓	↓	-2560	53,956	5,063,040	75,500	7,090,000	0.126	0.0985	0.33++	0.0234	13.5
	144	↓	↓	-1501	46,155	5,461,860	74,600	7,650,000	0.090	0.0738	0.21++	0.0149	10.7
Bottom Hull	120	** 5000	14.2	-3974	172,368	6,091,200	241,300	8,530,000	0.402	0.1185	0.15++	0.0106	9.2
											0.31++	0.0220	15.8

USE 12 #11 BARS (1.41" DIA.) EVERY 12 3/4"
 $= (12)(1.56) = 13.72 \text{ " PER FOOT OF SHELL}$
 $\left(\frac{12}{12.75} \right) = 17.6 \text{ " PER FOOT OF SHELL}$

$$\gamma_{\text{TOP}} = \frac{84-21}{84} = 0.75$$

$$\gamma_{\text{BOT}} = \frac{120-21}{120} = 0.82$$

* $f_y = 60,000 \text{ PSI}$
 + AT ELEMENT MOST HIGHLY STRESSED
 ** SELECTED
 *** $b = 12 \text{ INCHES}$
 WITH $\phi = .7$

$b = 1 \text{ INCH}$

MAX REQUIREMENTS FOR REBAR
EACH FRAME

4.4 Weight Estimates

A complete weight estimate was prepared at the beginning of conceptual design and continuously updated as the design progressed. Table 25 provides a summary of the weights and Appendix #4 provides a detailed weight breakdown in accordance with the work breakdown structure along with supporting calculations.

In determining weights for hull structure, 150 pounds per cubic foot was used for concrete which includes all reinforcement. Structural weight of concrete will probably increase in later design studies when full consideration is made for stress concentrations at hard points such as hatch openings and connections of the shell to internal structure. For this reason a substantial margin of 20% of the concrete weight is added. A margin of 10% was used for foundation structure which is principally concrete and 5% of the superstructure weight was used for a steel margin.

Weights for power plant equipment were obtained from DoE. The weight of the heat exchangers were modified to allow for the deduction of water contained in the waterboxes. Much of the equipment weight is the same as that for the spar but the seawater duct runs are shorter. Seawater weights include the weight of water in piping but not in the cold water well.

Permanent ballast has been used to obtain the full operating draft but with a reduction of hull volume could be eliminated entirely. For a discussion of the liquid ballast arrangement, see Section 4.2.1.

The cold water pipe wet weight is included in the weight estimate and the center of gravity is taken at the attachment point which is quite conservative for stability considerations.

The mooring load considers only the weight of the legs plus the initial horizontal pretension load of 1000 kips. As the environmental load increases to the extreme value the platform will sink down only a few feet.

The polar and axial mass moment of inertia was computed for determination of the hull natural frequency of roll.

TITLE Weights

M. ROSENBLATT & SON, Inc.
 NAVAL ARCHITECTS & MARINE ENGINEERS
 NEW YORK CITY SAN FRANCISCO BOSTON

SHIP OTEC Sphere Concept

TABLE 25

PLAN No. _____

SECTION _____ FRAMES _____ TO _____

ESTIMATE OF WEIGHTWEIGHT GROUP Summary

Piece No.	Description, Material, Dimensions	Unit (Pounds) L.T.	Number of Units	Weight (Pounds) L.T.	Above Base Line		Referred to Frame No.			
					C. G.	Vert. Moments	C. G. Fwd.	Forward Moments	C. G. Aft.	Aft. Moments
1.2.1	Hull Structure									
1.2.1	Shell			358103	187.4	67105883				
1.2.2	Decks			251544	174.7	43945845				
.3	Bulk Heads									
.4	Super Structure									
.5	Super Decks			4886	402	1964172				
.6	Super Stanchions									
	Sub Total 1.2			614533	183.9	113015900				
1.3	Positioning System			6764	126	852264				
	Platform System									
1.4.1	Marine Service System			493.68	277.5	136979				
1.4.2	Piping									
1.4.3	Electrical Services			133.3	422.6	56326				
1.4.4	Hotel Services			130.0	503.9	65510				
1.4.5	Ballast			72052.0	109.6	7897537				
	Sub Total 1.4			72809.0	112.0	8156352				
1.7	Sea Water System			231917	191.7	44461185				
	Power Systems									
3.2-3.4	W.W., CW & Working Fluid System			32150	155.4	4997539				
3.5-3.7	NH ₃ Storage, Purge & Generation System			12137.7	179.8	2182095				
3.8-310	Electrical, Control & Auxiliary Systems			571.2	145	82824				
	TOTALS			970882	179.0	173748159				

Estimating by: _____ Computing by: _____ Estimate checked: _____ Computing checked: _____

4.5 Stability

4.5.1 Stability Criteria

(See Section 3.5.1)

4.5.2 Intact Stability

Intact stability is easily provided when the main deck is above the surface since KM is quite large. The KM curve is shown on the curves of form, MR&S Drawing number 47930.

The worst condition of intact stability occurs when the sphere just immerses the main deck. Even in this condition KG is always less than KB and the GM is never less than eight feet. This does not include consideration of the access trunk waterplane area which would increase the GM.

Ample reserve stability is provided for lifting of weight over the side. With a 100 ton lift and 60 foot outreach the heel angle is only 0.05 degrees when the platform is operating at a 380 foot waterline.

Stability during construction is provided by the large GM which exists in all phases.

4.5.3 Damaged Stability

a. Superstructure

The superstructure is subdivided for damaged stability up to the fifth deck level. The ventilation trunk is run alongside the central trunk so damage can occur up to 1/5 the beam penetration with damage to the vent trunk. In way of the access trunk, watertight closures in way of the vent ducts are required to prevent progressive flooding. The platform can sustain four compartment damage (a bulkhead and deck are struck) with sinkage limited to 30 feet and heel to 1.12 degrees. If only a deck is struck then sinkage is 14.7 feet and heel 0.86 degrees.

b. Main Hull

As discussed in Section 3.5.1, the subdivision of the main hull is not provided. If it were desired to provide limited subdivision by making the second deck watertight, the costs would be quite high, and the displacement of the platform would be increased by at least 100,000 tons.

4.5.4 Stability During Construction

a. Main Hull

Stability was checked for various stages of construction of the main hull. Stability is easily attained by the large metacentric height and low vertical center of gravity

yielding a very high GM of 339 feet at the time of launch to a GM of 100 feet near the end of the main hull construction.

b. Superstructure

The superstructure is stable during deployment without the support of barges by ballasting the lowest compartment with 6,053 LT. of seawater. All equipment including the deck crane may be stowed on board. The draft during deployment is 34 feet and the GM is 3.74 feet. With a 70 knot wind acting on the structure the heel angle is only 0.112 degrees.

4.6 Seakeeping Analysis

4.6.1 General

The seakeeping analysis of the sphere platform has been performed by using several different analyses procedures embodied in computer programs all using the hydrodynamic added mass, damping coefficients and wave exciting forces determined by Davidson Laboratory [16].

The seakeeping results themselves are of limited use in this concept design since the most that can be done in the absence of data on allowable OTEC equipment motions and accelerations is to observe whether or not the motions are acceptable from a human and platform service equipment standpoint, and to consider hull alterations if resonance of motion with the waves of significant energy should occur. With partial regard to this latter aspect two sphere configurations were evaluated, one with a single surface piercing column and one with a multiple set of 16 smaller surface piercing columns separated by large distances.

As expected however, for these heavy submerged platforms, when considering human and platform service equipment tolerances, the motions are small so that operation can continue from a seakeeping standpoint under any sea condition, including severe storms. The natural frequencies occurred at lower values than these of significant wave energy so that modification of the platform configurations to alter these frequencies is not necessary.

4.6.2 Hydrodynamic Coefficients

As previously mentioned, the hydrodynamic coefficients and wave exciting forces of the sphere platform were determined at the Davidson Laboratory of Stevens Institute of Technology by Dr. C. H. Kim [16]. Since the sphere is axisymmetric about the vertical axis, it is sufficient to evaluate the hydrodynamic characteristics of three modes of motion only: sway, heave, roll.

The tuned sphere platform with multi-stabilizing columns is a modification of the original design configuration [26], which has multi-stabilizing columns over the extended spherical surface from the deck of the hemisphere-like submerged main hull. These curved stabilizing columns have been replaced in the new design by straight vertical multi-columns as shown in Figure 35.

Calculations of the hydrodynamic characteristics have been carried out under the following assumptions:

- .The hydrodynamic interactions between the structural members are neglected.
- .The stripwise computational technique may be utilized for the submerged body, while evaluating the three-dimensional effect by application of a reduction factor.
- .The opening at the bottom of the main hull for the cold-water pipe is assumed to be closed.

The first assumption is realistic in the low frequency regime. It enables us to evaluate separately the characteristics of the columns and the main hull. Whether the second assumption is realistic or not is principally a matter of the availability for comparison purposes of the three-dimensional solution of a similar geometrical model. Since the submerged body is fairly close to the form of a hemisphere, Havelock's calculations of the added mass and damping factor of a heaving hemisphere on the free surface may be used as a comparison reference for evaluation of the reduction factor for added mass and damping factor of the hemisphere-like main hull. The reduction factor for the wave-exciting forces and moments are then indirectly derived by applying the Hanskind-Newman relationship [18] between the damping factor and excitation force. The third assumption is reasonable since the water contained within the opening behaves as a solid body fixed to the platform in both radiation and diffraction conditions.

Computations of the hydrodynamic characteristics of the columns have been carried out first by employing the Adey-Bai program [18]. Each column's hydrodynamic characteristics are then evaluated by making use of the foregoing results assuming that the sixteen columns are geometrically identical. The effect of the location of each column has been taken into consideration by evaluating the phase shift due to the spatial displacement of the column from the origin 0, the intersection of the vertical body axis with the waterplane and the direction and frequency wave.

Figures 36 and 37, respectively, illustrate the comparison of the heave added mass and damping factor computed by Havelock and by the strip method.

The reciprocals of the reduction factors, i.e., the ratios of the values due to strip method and Havelock are also illustrated in Figures 36 and 37. The reduction factors have been used approximately for correcting the strip calculations of the submerged main hull. These factors have also been applied to the corrections of the different mode added masses and damping factors of the submerged body.

Just prior to carrying out a mechanical stripwise computation of the hydrodynamic characteristics of the submerged main hull, it is desirable to establish the two-dimensional computation procedure for the submerged body.

To assure the reliability of the stripwise computation for the submerged main hull, an extra computation of C_H and δ_H has been carried out for the hull when the submergence d of the center of the hemisphere is lowered to 0.66 times the sphere's diameter $2\bar{a}$. The same computation has also been done for a sphere of the same diameter $2\bar{a}$ and submergence d of its center. Comparison of both results is shown in Figure 38. The behavior of the values C_H and δ_H of the sphere is similar, as expected, to that for a submerged circular cylinder of the same diameter and submergence, which is well-known, [30,31]. Hence, the behavior of C_H and δ_H of the main hull at the submergence d is expected to demonstrate behavior similar to that of the sphere at the same depth.

Relying on the above study, the stripwise computation of all hydrodynamic characteristics of the main hull has been carried out and the above reduction factors have been applied to the results of the strip computation.

The resultant hydrodynamic characteristics of the platform are obtained by adding those of the stabilizing columns and the main hull. They are illustrated in Figures 39-42 as functions of the dimensionless frequency $\sqrt{a}\omega$ = wave number times radius. In the figures M' and N indicate the added mass and damping factor, respectively, whereas F is the wave-exciting force. The suffixes ξ, η and ψ indicate the motions, heave, sway and roll, respectively. The suffix $\eta\psi$ indicates a coupled term.

The hydromechanical matrices $[A]$, $[B]$, $[C]$, and $[F]$ of the platform have been tabulated as shown in Table 26.

The tuned sphere platform with a single stabilizing column has a large column at the center of the platform. Figure 43 illustrates this platform and the points of input data of the hull geometry.

The stripwise computation has been carried out for the sliced sections of the hull shown in Figure 43. A routine investigation has been done for the effect of number and mode distribution of the input points on the accuracy of the computation. All hydrodynamic forces and moments evaluated by the strip method have been corrected by employing the same reduction factors as those used for the multi column platform. The hydrodynamic characteristics have been tabulated as shown in Table 27 and are also illustrated in Figures 44-47.

4.6.3 Comparison of Platform Motion Analyses

With the hydromechanical characteristics given in Tables 26 and 27, the platform response motions without CWP were computed by Davidson Laboratory, with CWP by MR&S, and with CWP by Hydronautics, Inc.

Using the values shown in Table 26 for the multi-column sphere, the heave, sway and roll regular wave response motions were evaluated by Davidson Laboratory by solving the uncoupled equations of heave, sway and roll motions. The responses are shown in Figure 48 as a function of frequency.

The estimated heaving and rolling natural frequencies are $w_{\text{heave}} = 0.076$ and $w_{\text{roll}} = 0.1$. The dip in heave near the resonance frequency is mainly due to the similar behavior of the wave exciting force. Since the sway response has been computed on the assumption that it is uncoupled with roll, it is expected as is shown that the response is relatively monotonous in the neighborhood of the roll natural frequency while it asymptotically reaches the value of unity as frequency tends to approach zero. Regarding the roll response, it reaches, as the extrapolating dotted line illustrates, to the resonance condition in the low frequency range below that of significant wave energy for any sea condition or state.

For the single column sphere platform the regular wave motions were computed by using the hydrodynamical quantities of Table 27. Again, the heave, sway and roll responses have been determined by assuming that the sway and roll are uncoupled to each other. The results are presented in Figure 49. The heave resonance frequency w_s is about 0.068 whereas roll $w_\phi = 0.09$. The dip of the heave response is a characteristic behavior pattern of the semi-submerged body [30] as previously shown for the spar buoy and in Figure 48 for the tuned sphere with multi columns. The sway and roll responses indicate overall similarity in trend and behavior to those of the multi column sphere.

Comparison of the response motions of the two sphere configurations shows, however, that in the low frequency region, sway and roll responses of the multi column type appear to be smaller than those of the single column type, while the heave appears to be larger.

The question why the lateral and vertical responses of the single column type are higher and lower, respectively, than the corresponding values of the multi column type can be clarified by comparison and analysis of the numerical values of the hydromechanical characteristics of both models. For this purpose, Tables 28-30 have been prepared. The tables represent the values of the hydromechanical characteristics of each sphere for the three modes of motion

at two frequencies $\omega = 0.26$ and $\omega = 0.36$. Model 1 is designated as the multi-column type and Model 2 the single column type.

On observing the heave characteristics in Table 28, the following facts are recognized: 1) the heave added mass of Model 2 is about twice that of Model 1; 2) the damping factor of Model 2 is 1/3 that of Model 1, and 3) the restoring factor and exciting force of Model 2 are 82 percent of those of Model 1. The results are due mainly to the difference of submergence of the platform hulls which were 55 feet to the main deck for the multi column type and 110 feet for the single column.

The effect of the amount of submergence of a circular cylinder on the hydrodynamic characteristics of heave and sway has been investigated both theoretically and experimentally by Kim and Chou [30] and Chung [31]. It is concluded from the studies that 1) as the amount of submergence increases, the added masses increase, whereas the wavemaking damping and wave-exciting forces decrease, 2) the dipping behavior of the added mass appears in a certain low frequency regime for all submergences except for the infinite, and 3) the dip of the added mass may fall below zero value.

Indeed, the heave characteristics indicate that Model 2 is not only more sluggish but also less damped and excited, thus leading to a lower heave response than that for Model 1. A similar explanation can be applied to the 0.36 frequency case.

By investigating the sway characteristics at frequency 0.26 in Table 29 the following facts are identified: 1) the added mass of Model 2 is half of Model 1; 2) the damping factor of Model 2 is about twice that of Model 1, and 3) the exciting force of Model 2 is slightly larger than that of Model 1. The foregoing conclusions regarding the effect of the amount of submergence of a circular cylinder on the hydrodynamic characteristics is also applicable to the analysis of the sway response. With regard to sway Models 1 and 2 may be regarded as relatively deep and shallow submerged bodies, respectively, because the contributions of the small-size multi-columns on the characteristic values of Model 1 are negligibly small, while the relatively large single column attached to the main hull of Model 2 acts to induce a fairly large wavemaking disturbance. The above-mentioned difference in sway characteristics between Model 1 and Model 2 is readily understood by comparing the two-dimensional hydrodynamic characteristics of their respective midship sections, as illustrated in Figure 50. The geometry of the midship sections has been shown in Figures 35 and 43. A similar description can be applied to the case of frequency 0.36.

For the roll hydromechanical characteristics, we refer to Table 30. Four facts are outstanding: 1) the roll added inertial moment of Model 2 is twice that of Model 1; 2) the damping moment of Model 2 is six times that of Model 1; 3) the restoring moment of Model 2 is half that of Model 1; and 4) the exciting moment of Model 2 is five times that of Model 1. The roll characteristics are similar to and related to the sway characteristics. There is, however, an exception which is revealed in foregoing Item 1. Items 2 and 4, on the other hand, show a behavior similar to the sway characteristics.

The fact (in Item 1) that the roll added inertial moment of Model 2 is twice that of Model 1 is due to the deep submergence of the center of gravity. The sway induced roll added moment $M_{\eta\psi}^{IIO}$ (Fig. 47) behaves in a similar manner

as the sway added mass, as shown in Figure 50, and the roll added inertial moment $M''_{\varphi\varphi}$, with respect to the center of gravity, G, is given by

$$M''_{\varphi\varphi} = M''_{\varphi\varphi}{}^0 - 2 \cdot \overline{OG} \cdot M''_{\eta\varphi}{}^0 + \overline{OG}^2 M''_{\eta\eta}$$

where

$M''_{\varphi\varphi}{}^0$ = Roll added inertial moment about "0" in the waterplane

$\overline{OG}$ = distances between 0 and G

$M''_{\eta\eta}$ = sway added mass

From the above, we have $M_{\varphi\varphi} \approx M''_{\varphi\varphi}{}^0$ since the remaining terms approximately cancel out each other. The large added inertial moment of Model 2 with respect to 0 is due to its configuration with a large $\overline{OG}$ which resembles a full-shaped bottle with a fairly long narrow neck. The presence of the large damping and exciting moments is also due to its bottle-like configuration.

As in the case of the spar, Hydronautics performed regular wave analyses in the multi column sphere with GRP, concrete and steel cold water pipes rigidly attached to the platform. The results for 2 feet thick GRP CWP are shown in Table 31. The motion, except for roll, are generally slightly larger than those computed by Davidson Laboratory, but the fact that the motions are for a point at sea surface in this case will influence the results in that direction. The roll is significantly damped in the case of the Hydronautic results due to the presence of the CWP so that motions near resonance are significantly reduced.

In addition to the regular wave analyses, Hydronautics performed analyses for the storm conditions shown in Table 32 and a sea state six condition with a significant wave height of 20 feet. The motions were largest for the worst sea condition and the results are shown in Table 33. The results indicate that the motions of the sphere and CWP are modest even for the most severe sea state, although slightly larger than for the spar platform. Also, it is shown that from an absolute standpoint the motions are not significantly affected by changes in CWP materials.

As in the case of the spar, MR&S performed analyses of both the multi and single column spheres with a number of CWPs using the Paulling computer program. Figure 51 gives the regular wave results for the multi column sphere with steel CWP and Figure 52 for the single column sphere with GRP CWP.

MR&S also performed irregular sea analyses for the storm conditions shown in Table 32 and several lower sea states. The results are shown in Tables 34 and 35 for the multi column and single column spheres respectively. The results indicate that the sphere motions are modest but larger than those for the spar. As observed by Davidson Laboratory for regular waves, the sway of the single column Configuration is greatest while generally the roll and heave are less than those of the multi column sphere. The MR&S results for the 20 feet significant wave height indicate that for all practical purposes the platform motions are negligible.

Comparing Tables 33, 34 and 35, it can be seen that the MR&S predicted motions are larger than those predicted by Hydronautics as was the case with the spar. Here however, the agreement is not so good, but the motions are still modest in both cases.

It should be noted that the motions calculations performed by Davidson Laboratory, Hydronautics, and MR&S were done using ship parameters that varied during the design spiral. All results are then for slightly different displacements, VCG's, gyradii, etc, and this is certainly one of the reasons for any differences in the results.

It is felt that all computations performed by various investigators indicate consistent results.

4.6.4 Seakeeping Performance vs Requirements

The seakeeping performance can be measured in 3 ways:

- o Effects on humans aboard
- o Effects on platform service equipment
- o Effects on OTEC equipment

By inspection it can be seen that the motions of the sphere platforms in a severe storm are in general less than those for surface vessels in moderate conditions, so that the platforms could be operable under all circumstances from human and platform service systems standpoints.

In regard to allowable motions and accelerations from the standpoint of the OTEC equipment, sufficient data is not available. However, MR&S and Burns & Roe did consider the effects of heave on the cold water intake ducts at the top of the cold water well. The possibility of suction being developed at the top of the inlet to the duct was considered. Since the heave motions are small the problem can be corrected by supplying sufficient camber to the main deck so a head of water exists above the intake. In addition, a large surge pipe is provided to reduce the pressure differential at the top of the well and at the seawater pumps.

FIGURE 35 SKETCH OF THE TUNED SPHERE PLATFORM — WITH MULTI-COLUMNS

10 X 10 TO 1; INCH 7 X 10 INCHES
LL & CO. WASH. D. C.

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FIGURE 36 REDUCTION FACTOR FOR ADDED MASS OF HEMISPHERE

N = damping factor

$\bar{a}$ = radius of the hemisphere

ρ = density of water

ω = frequency

ν = wave number

FIGURE 37 REDUCTION FACTOR FOR DAMPING FACTOR OF HEMISPHERE

FIGURE 38. COMPARISON OF HEAVE ADDED MASS AND DAMPING FACTOR OF SPHERE AND THE MAIN HULL WITH THE SAME DIAMETER (STRIP METHOD)

FIGURE 39 HEAVE ADDED MASS, DAMPING FACTOR AND EXCITING FORCE OF MULTI COLUMN SPHERE

FIGURE 40 SWAY ADDED MASS, DAMPING FACTOR AND EXCITING FORCE OF MULTI COLUMN SQUARE

FIGURE 41 ROLL ADDED MASS MOMENT OF INERTIA, DAMPING AND EXCITING MOMENTS OF MULTI COLUMN SPHERE

FIGURE 42 SWAY-INDUCED ROLL ADDED AND DAMPING MOMENTS OF MULTI

FIGURE 43 SKETCH OF TUNED SPHERE
MODEL 2 AND POINTS OF INPUT DATA

FIGURE 44 HEAVE ADDED MASS, DAMPING FACTOR AND EXCITING FORCE OF MODEL 2

FIGURE 45 SWAY ADDED MASS, DAMPING FACTOR AND EXCITING FORCE OF MODEL 2

FIGURE 46 ROLL ADDED MOMENT OF INERTIA, DAMPING AND EXCITING MOMENTS OF MODEL 2

FIGURE 47 SWAY-INDUCED ROLL ADDED AND DAMPING MOMENTS OF MODEL 2

FIGURE 48 RESPONSE MOTIONS OF THE TUNED SPHERE WITH MULTI-COLUMNS

FIGURE 49 RESPONSE MOTIONS OF THE TUNED SPHERE WITH SINGLE COLUMN

FIGURE 50: ADDED MASS COEFFICIENTS OF MIDSHIP SECTIONS OF MODEL 1 & MODEL 2

FIG. 51 : REGULAR WAVE MOTIONS FOR TUNED
SPHERE WITH MULTI-COLUMNS.

RUN DATE : 4-4-78

CWP : STEEL, RIGID, RIGID HULL CONNECTION,
50% BUOYANCY, 9" TOTAL WALL THICKNESS.

FIG. 52 : REGULAR WAVE MOTIONS FOR TUNED
SPHERE WITH SINGLE COLUMN

RUN DATE : 4-4-78

CWP : GRP, RIGID, RIGID HULL CONNECTION,
 ZERO BUOYANCY, 8" TOTAL WALL THICKNESS.

4-4-78

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TABLE 26

VALUES OF THE MATRIX ELEMENTS
OF THE
HYDROMECHANICAL CHARACTERISTICS OF THE TUNED SPHERE
WITH MULTI-COLUMNS

Frequency, ω	$A_{22} 10^{-7}$	$A_{33} 10^{-7}$	$A_{34} 10^{-7}$	$A_{44} 10^{-10}$
0.26	6.22	6.0833	33.079	36.943
0.36	0.745	1.418	-133.94	29.164
0.46	1.453	1.200	-180.45	15.018
0.56	2.485	1.758	-147.17	7.21
0.66	3.133	1.964	-102.16	6.685
0.76	3.564	2.154	-87.97	8.799
0.86	3.813	2.233	-88.78	10.44
0.96	3.983	2.304	-88.78	11.156
1.06	4.053	2.346	-88.78	11.475
1.16	4.152	2.401	-88.78	12.024
1.26	4.152	2.401	-88.78	12.024
Frequency, ω	$B_{22} 10^{-7}$	$B_{33} 10^{-7}$	$B_{34} 10^{-7}$	$B_{44} 10^{-10}$
0.26	2.004	0.741	20.587	0.802
0.36	1.508	0.842	47.684	4.088
0.46	0.778	0.313	33.507	7.528
0.56	0.208	0.119	-2.352	6.591
0.66	0.048	0.0952	-14.142	3.224
0.76	0.052	0.0695	-12.382	0.7842
0.86	0.046	0.0228	0	0
0.96	0.051	0	0	0
1.06	0	0	0	0
1.16	0	0	0	0
1.26	0	0	0	0

$$C_{22} = 0.098 \text{ E07} , \quad C_{44} = 3.0537 \text{ E10}$$

[Cont'd]

TABLE 26 (Cont'd)

Frequency, ω	$F_{12} 10^{-7}$	$F_{13} 10^{-7}$	$F_{14} 10^{-7}$	$F_{22} 10^{-7}$	$F_{23} 10^{-7}$	$F_{24} 10^{-7}$
0.26	-0.5638	0.231	3.983	-0.413	-0.438	- 2.074
0.36	-0.2472	0.299	15.462	-0.536	-0.391	- 6.135
0.46	-0.2006	0.182	23.336	-0.313	-0.228	- 5.813
0.56	-0.1205	0.0223	20.977	-0.106	-0.1358	- 1.582
0.66	-0.0259	-0.0368	11.948	-0.0119	-0.0614	3.725
0.76	0.0306	-0.0187	4.568	0.0187	-0.0236	1.439
0.86	0.0402	0	0.547	0.0072	-0.0003	4.369
0.96	0.0328	0	0	0	-0.0178	5.359
1.06	0.0214	0	0	0	-0.062	13.194
1.16	0.007	0	0	0	-0.0726	15.333
1.26	0.008	0	0	0	-0.01	2.096

TABLE 27

VALUES OF MATRIX ELEMENTS
OF THE
HYDROMECHANICAL CHARACTERISTICS OF TUNED-SPHERE WITH SINGLE COLUMN

Frequency, ω	$A_{22} 10^{-7}$	$A_{33} 10^{-7}$	$A_{34} 10^{-9}$	$A_{44} 10^{-12}$
0.26	11.633	2.894	-3.011	0.637
0.36	6.149	-0.195	-0.567	0.273
0.46	3.646	0.803	-1.162	0.241
0.56	3.304	1.662	-1.474	0.225
0.66	3.50	2.10	-1.55	0.210
0.76	3.90	2.317	-1.513	0.196
0.86	4.07	2.380	-1.540	0.190
0.96	4.174	2.542	-1.542	0.204
1.06	4.30	2.60	-1.560	0.210
1.16	4.35	2.649	-1.581	0.213
1.26	4.35	2.649	-1.581	0.213
Frequency, ω	$B_{22} 10^{-7}$	$B_{33} 10^{-7}$	$B_{34} 10^{-9}$	$B_{44} 10^{-12}$
0.26	0.612	1.30	-0.582	0.053
0.36	1.202	1.056	-0.475	0.069
0.46	1.075	0.435	-0.157	0.056
0.56	0.622	0.147	-0.162	0.066
0.66	0.37	0.13	-0.235	0.075
0.76	0.171	0.128	-0.311	0.079
0.86	0.130	0.120	-0.295	0.068
0.96	0.119	0.118	-0.256	0.053
1.06	0.070	0.080	-0.185	0.038
1.16	0.013	0.044	-0.108	0.028
1.26	0.013	0.044	-0.108	0.028

$$c_{22} = 8.0754 \times 10^5, \quad c_{44} = 1.6078 \times 10^{10}$$

[Cont'd]

TABLE 27 (Cont'd)

Frequency, ω	$F_{12} 10^{-7}$	$F_{13} 10^{-7}$	$F_{14} 10^{-9}$	$F_{22} 10^{-7}$	$F_{23} 10^{-7}$	$F_{24} 10^{-9}$
0.26	-0.56	0.453	-0.176	-0.132	-0.323	0.14
0.36	-0.646	0.436	-0.184	-0.195	-0.183	-0.031
0.46	-0.581	0.243	-0.068	-0.063	-0.096	-0.106
0.56	-0.408	0.101	-0.036	0.064	-0.044	-0.104
0.66	-0.2	0.06	-0.045	0.08	-0.022	-0.045
0.76	-0.022	0.027	-0.062	0.053	-0.007	0.012
0.86	0.085	0.010	-0.04	0.01	-0.01	0.07
0.96	0.141	0.004	0.008	0.012	-0.018	0.127
1.06	0.06	0	0.025	0	-0.016	0.115
1.16	-0.068	-0.006	0.029	-0.01	-0.015	0.06
1.26	-0.068	-0.006	0.029	-0.01	-0.015	0.06

TABLE 28

VALUES OF THE HEAVE HYDROMECHANICAL CHARACTERISTICS
OF THE TUNED SPHERE PLATFORMS.

Model #1 - Multi Column

Model #2 - Single Column

	ω			
	0.26		0.36	
	Model #1	Model #2	Model #1	Model #2
$M_{\zeta\zeta}^{II}$	6.22 E07	11.633 E07	0.745 E07	6.149 E07
$N_{\zeta\zeta}$	2.00 E07	0.612 E07	1.508 E07	1.202 E07
$B_{\zeta\zeta}$	0.098 E07	0.081 E07	0.098 E07	0.081 E07
$ F_{\zeta} /a$	0.699 E07	0.575 E07	0.59 E07	0.675 E07
$ G /a$	0.673	0.439	0.480	0.354

where

ω = wave frequency

$M_{\zeta\zeta}^{II}$ = heave added mass

$N_{\zeta\zeta}$ = heave damping force/unit heave velocity

$B_{\zeta\zeta}$ = heave restoring force/unit heave displacement

$|F_{\zeta}|/a$ = heave-exciting force/unit wave amplitude

$|G|/a$ = heave response, ft/ft

TABLE 29

VALUES OF THE SWAY HYDROMECHANICAL CHARACTERISTICS
OF THE TUNED SPHERE PLATFORMS

Model #1 - Multi Column

Model #2 - Single Column

	ω			
	0.26		0.36	
	Model #1	Model #2	Model #1	Model #2
$M_{\eta\eta}''$	6.08 E07	2.894 E07	1.418 E07	-0.195 E07
$N_{\eta\eta}$	0.74 E07	1.300 E07	0.842 E07	1.056 E07
$ F_{\eta} /a$	0.495 E07	0.566 E07	0.492 E07	0.473 E07
$ T_{\eta} /a$	0.492	0.708	0.372	0.430

where

$M_{\eta\eta}''$ = sway added mass

$N_{\eta\eta}$ = sway damping force/unit velocity

$|F_{\eta}|/a$ = sway-exciting force/unit wave amplitude

$|T_{\eta}|/a$ = sway response, ft/ft

TABLE 30

VALUES OF THE ROLL HYDROMECHANICAL CHARACTERISTICS
OF THE TUNED SPHERE PLATFORMS

Model #1 - Multi Column

Model #2 - Single Column

	ω			
	0.26		0.36	
	Model #1	Model #2	Model #1	Model #2
$M''_{\varphi\varphi}$	33.8 E10	63.7 E10	26.1 E10	27.3 E10
$N_{\varphi\varphi}$	.802 E10	5.3 E10	4.09 E10	6.90 E10
$B_{\varphi\varphi}$	3.05 E10	1.607 E10	3.05 E10	1.607 E10
$IF_{\varphi} l/a$	4.49 E07	22.48 E07	16.6 E07	18.65 E07
$ \varphi /va$	0.394	1.147	0.337	0.316

where

$M''_{\varphi\varphi}$ = roll added mass moment of inertia

$N_{\varphi\varphi}$ = roll damping moment/unit roll velocity

$B_{\varphi\varphi}$ = roll restoring moment/unit roll displacement

$IF_{\varphi} l/a$ = roll-exciting moment/unit wave amplitude

$|\varphi|/va$ = roll response, rad/rad

TABLE 31

Hydronautics Multi Column Sphere Regular Wave Motion* Results for 2'
thick GRP

Frequency Rād/Sec	Sway/ Wave Ampl	Heave/ Wave Ampl	Roll/ Wave Slope
.26	.5454	.7366	.0826
.36	.6439	.5639	.5056
.46	.3408	.2177	.0901
.56	.0785	.0564	.0141
.66	.0541	.0066	.0130

* For point on vertical at sea surface.

TABLE 32

STORM MAXIMUM SEA STATES

Site	Significant Wave Height - Feet	Period of Peak Energy - Seconds
New Orleans	58.1	15.91
Florida	45.8	13.67
Puerto Rico	44.2	13.8

Table 33: Summary of Hydronautics, Inc. of Calculated Results for the Multi-Column Tuned Sphere Platform with rigidly attached CWP.

Significant Wave Height, $H_{1/2} = 45.8$ ft.

Parameters	GRP	Concrete	Steel
Sway, ft.	4.33	4.46	4.56
Roll, deg.	1.07	0.35	0.77
Heave, ft.	5.50	4.40	4.08

Significant Wave Height, $H_{1/3} = 58.1$ ft.

Parameters	GRP	Concrete	Steel
Sway, ft.	7.35	8.30	6.13
Roll, deg.	2.02	0.76	1.04
Heave, ft.	10.18	8.22	7.62

TABLE 34

Summary of MR&S calculated results for the sphere platform with multi-columns and steel CWP (Significant Motions)

<u>Significant Wave Heights, H=45. Ft.</u>	
<u>Parameter</u> <u>Units</u>	
Sway - Ft.	5.75
Roll - Deg.	3.82
Heave - Ft.	9.14

<u>Significant Wave Heights, H=58.1 Ft.</u>	
<u>Parameter</u> <u>Units</u>	
Sway - Ft.	12.33
Roll - Deg.	6.45
Heave - Ft.	18.96

<u>Significant Wave Heights, H=20.0 Ft.</u>	
<u>Parameter</u> <u>Units</u>	
Sway - Ft.	.635
Roll - Deg.	.644
Heave - Ft.	1.06

TABLE 35

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

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

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

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

4.7 Positioning System

4.7.1 Drag Calculations

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 wind speed observed over the period of record. The other is an extreme current velocity and 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 36.

Table 36 Results of Drag Calculations

Site	Normal Condition			Extreme Condition		
	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

4.7.2 Mooring Line Holding Power

The research performed in the feasibility analysis, study, Volume 1 and 5, indicated that use of thrusters or the seawater discharge was not practical or economical for the sphere platform. Because of the high drag forces at all three sites a hollow cylindrical link (HCL) system was chosen. This system has not yet been developed or deployed but it appears to be the only concept that is viable within the state of the art.

The basic requirement of the mooring system is to develop about eight million pounds of horizontal holding force to withstand an extreme storm and at all times maintain a watch circle excursion of less than 30 percent of the depth to avoid a disconnect of the power transmission cable.

A preliminary determination of leg size was made on the basis of the feasibility study (Ref. 5) and the results obtained by Westinghouse 32. It appeared that a 146 MN HCL 3-leg mooring could develop 40 MN of holding force at half the breaking strength with a 5 per cent watch circle excursion. The characteristics of the selected link are given Table 37. It should be noted that the reserve strength of one-half the breaking strength is for dynamic effects.

Table 37 Mooring Leg Properties

Mooring Array - 3 leg tri-moor

Leg Material - HY 80 Steel

Design Depth - 4922 Ft. (1500 M)

Diameter of Link - 5.32 Ft. (1.62 M)

Length of Link - 53.2 Ft. (16.2 M)

Wall Thickness - 0.176 Ft. (5.35 CM)

Static Breaking Strength - 32.79×10^6 lb. (146 MN)

In an effort to verify the feasibility of this system, a limited static analysis was performed by Oceanic Development Company [22]. Essentially the analyses consisted of computing the statically indeterminate catenary equations for two, three and four leg multipoint mooring arrays. Since line stiffness was large, line elongation was neglected as the current drag acting on the line was considered.

From the cases examined the 3-leg mooring appears to be best. The excursion of a 2-leg platform in a normal environment nearly exceeds the allowable excursion value so this configuration is not considered viable. Acceptable, but rather small, excursion limits are attainable with both the three and four leg mooring arrays so that the 3-leg system is the best arrangement for cost considerations. If time permitted, the design of the HCL leg would have been refined by checking a smaller leg size to allow for greater excursion since this would be acceptable. The design considered here is somewhat conservative.

4.7.3 Mooring Arrangement

The mooring configuration is shown on MR&S drawing number 47929. Note that the system is a passive system with the legs connected to the hull. If a winch system were required, the cost could double. The 3-legs are equally spaced at 120° around the sphere and the connection point is located at the fifth deck level.

The anchor is a free fall gravity type which will be deployed with two barges to provide buoyancy in transit to the site.

4.8 Seawater System Analysis

The analysis of the seawater systems hydraulic portion presented in Section 3.8 under the SPAR platform conceptual design is applicable to the SPHERE platform as well in many aspects. As pointed out there, many of the problems associated with the development of flow patterns and arrangements for both platforms are identical. Major variations were pointed out in Section 3.8.2, and the evolution of arrangements were discussed and described in Section 4.1.

Given below are the most important differences for the SPHERE platform:

- o Horizontally oriented turbines are used in the Sphere platform (Spar uses vertical turbines).
- o In the Sphere design, butterfly type valves are employed at the seawater discharges due to space limitations (Spar employs gates).
- o Sphere warm water intake screens are 30 ft. high (Spar screens are only 10 ft. high).
- o Sphere platform is provided with a vent pipe of 25 ft. diameter which extends above the main deck to serve the purposes of relieving the upward pressure on the deck, functioning as a degasification vent, and providing service access.

4.9 Platform Service Systems

4.9.1 Marine Engineering System

a. General

This section describes the marine engineering systems required to service the Sphere. All systems are similar to those described in Section 3.9.1 for the Spar except as noted.

b. Marine Systems

(1) Hypochlorination Injection System

Function is the same as the Spar. Layout of equipment is different.

(2) Bilge, Ballast and Stripping Systems

These systems function similarly to the Spar except that the air deballast quantity is 5.7% of the ballast tank capacity.

(3) HVAC

These systems are similar in function to the SPAR. Quantities and pressures in the ventilation systems will vary.

4.9.2 Electrical Systems

The electrical systems for the Sphere are identical to the ones for the Spar as presented in Section 3.9.2.

4.10 OTEC Equipment Arrangement

As was mentioned in section 4.1, the OTEC system with primary emphasis on the seawater system was the primary consideration in the arrangement of the Sphere hull.

Ammonia on the OTEC sphere is either in the working fluid loop or in storage. Storage is simply a series of 16-50' (15.24M) long by 25' (7.65M) diameter tanks located on the third deck outboard of the warm water duct. These are accompanied by associated valves and pump manifolds.

The working fluid system consists of a closed loop which tubes liquid ammonia from a condenser between the third and fifth decks to its associated evaporator below the fourth deck via the NH_3 pump cluster on the fifth deck. The NH_3 is evaporated there and sent through the demister to remove any remaining droplets.

The NH_3 vapor flows by gravity and pressure through the vapor duct to the turbine on the fourth deck below. The vapor drives the turbine and exhausts through the connecting load back into the condenser completing the loop.

The demister is located as close as possible to the outboard side of the evaporator. This permits the shortest possible run of NH_3 vapor line.

The turbo-generator units are horizontally positioned on the fourth deck for optimum packing and operation. Maintenance is possible by lifting off the upper and lower covers about the turbine casing. Removal is possible through the overhead deck hatch. The hood connection to the condenser offers the best possible flow distribution.

A gas purging system consisting of tie ins to the ammonia storage system, a nitrogen flushing system and gas removal equipment is to be installed in proximity to each condenser. An 8' (2.44 M) diameter by 40' (12.19 M) long liquid N_2 storage tank is to be placed in the space designated on the third deck. This tank serves all eight systems. The system is designed to eliminate an explosion hazard which could exist if ammonia and free oxygen in unpurged lines come into proximity during the cycle charging process.

4.11 Cold Water Pipe Strength Analysis

4.11.1 General

The Sphere Cold Water Pipe (CWP) analyses covered the following of variables:

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

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 Computer Program (19) and the Hydronautics Program (33).

4.11.2 Configurations

Many different configurations were considered. The cases considered are tabulated in section 3.11 for both platforms. Table 14 therein gives the full scenario. The Sphere computer runs are separately summarized in Table 38. In addition, four more or less different Sphere platforms shown in Table 39 were considered. It should be noted, however, that the MR&S calculations represent results for several design spiral iterations where slight modifications were made to the Spheres given in Table 39. It can be seen that the basic CWP configurations of Table 38 are a single pipe of 101 ft. inside diameter, and a set of four pipes of 50.5 ft. inside diameter spaced so that the centerline of each passes through the corner of a square of 347' diagonal, or truss type. A bundle of smaller pipes was not considered for the Sphere because it did not indicate advantage in the Spar.

4.11.3 Materials

The materials considered in the CWP studies are shown in Table 38. It can be seen that aluminum has been dropped from consideration, primarily due to its higher cost, poorer properties in salt water, limited availability and more elaborate and controlled construction requirements. The specific properties of the materials used are given in Table 40.

Allowable stresses for the materials were given previously by MR&S in (5) and are also shown in Table 40.

4.11.4 Connection Stiffness

Previous studies ([5] for instance) have indicated that connections of low stiffness at the platform and between pipe sections of 200 ft. to 300 ft. would result in reduced stresses.

However, in this study, the design, construction, operation and cost of those joints was determined to be a severe hindrance. The projected costs based on current flexible joints indicated astronomical expense.

Since it was anticipated that the submerged sphere platform would have small motions and therefore lower CWP motions and wave induced stresses, and because of the other reasons cited above, only rigid connections at the hull and along the length of the CWP were subsequently analyzed.

It should be noted however, that one of the CWPs analyzed consisted of alternate 75 ft. long GRP sections and 225 ft. long steel sections rigidly attached to each other. This is in effect a pipe with "semi-pinned" sections, where the reduced stiffness GRP provides the "semi-pin" for the steel.

4.11.5 CWP Structural Cross Section

In all cases but one the structural cross section was considered to be a solid wall as indicated in Table 38. For the exception, two 4.5 inch thick walls separated by webs of seven feet width with foam in between were used for the CWP cross section.

4.11.6 Stress Analyses

a. General

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.

Below, each stress type will be discussed in detail, the allowable stresses will be presented, and the total stress analysis results given.

b. Platform Motion Induced Stresses and Wave Stresses

As the OTEC platform oscillates under the influence of waves, its motion and large mass will tend to drive the CWP in a dynamic motion. In addition, the surface waves will impose varying pressures directly on the CWP itself.

In order to quantify the phenomena just mentioned two theories embodied in computer programs were used. First, MR&S used the Paulling Computer Program(19) to do extensive analyses of CWPs. Second, Hydronautics(33) was requested to do a few limited analyses.

In the case of both the analyses mentioned above, the hydrodynamic added mass, damping, and wave exciting forces on the hull must be input. There happens to be very little data in the literature on Sphere shapes for this purpose and there are few general, available programs for the computation of the hydrodynamic coefficients of this type hull.

With this in mind, MR&S had the Davidson Laboratory perform the computations for the necessary quantities using the programs available to them. The results of the analyses are contained in Reference 33. A more detailed discussion of this subject can be found in Section 4.6, Seakeeping Analysis.

The necessary hydrodynamic quantities were then used in the Paulling and Hydronautics programs. The wave forces acting directly on the CWP are computed internally by these programs, but should be small due to the deep submergence of the CWP.

The results of the stress analyses are presented in Tables 41 and 42 for the MR&S and Hydronautics [33] computations respectively. It should be noted that the MR&S calculations represent results for several design spiral iterations where slight modifications were made to the main hull. All results should be indicative of the characteristics of the final platform, however.

The wave characteristics and sea states considered in the analyses are given in Table 43. The MR&S results in Table 41 are all for the 58.1 ft. significant wave height at New Orleans unless otherwise noted.

Table 44 shows stress comparison between the MR&S and Hydronautics analyses for the GRP CWP. The results show that the Hydronautics predicted stresses are about 25-30% less than those from the MR&S calculations on the Paulling program. Because of time constraints no effort was made to explain these trends. However, since the motion predictions of Section 4.6 indicate good MR&S and Hydronautics correlation, one would tend to deduce that the differences arise in the pipe computations, particularly since the MR&S' platform motions are less than the motions of Hydronautics.

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.

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 nonlinear 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 would be a conservative maximum. This value is 5.26 RMS as shown in Table 41.

To gain some insight into the observed decreased stresses of both thinner and thicker GRP CWP's, Figure 53 was plotted. It shows the natural frequencies of the CWP's in the range of significant wave energy as shown in Figure 54. Comparing Figure 53 to Figure 54, it can be seen that a 16" thick GRP pipe on the Sphere can have greater response than both a 6" and 21" thick pipe because of the alignment of peak response with maximum energy. The results in Table 41 bear this out. Figure 55 shows a similar plot for steel CWP's.

c. Deadweight Stresses

The deadweight stresses were determined on the basis of material densities given in Table 40. The results for all CWP's are included in Table 41.

d. Internal Flow Stresses

The internal cold water flow of 6.6 ft/sec causes an internal pressure reduction of approximately .3 psi which is well below critical implosion buckling critical stress for an 8" thick GRP CWP. This stress has therefore been assumed negligible.

e. Current Stresses

The currents for all sites were taken from the site Environmental Package (21). Figure 25 of Section 3.11 shows the current for the West Coast of Florida.

The current stresses were determined using the currents along with drag coefficient of .7 and integrating the drag force along the length of the CWP.

f. Buckling

Implosion buckling of the cylindrical CWP structure was briefly analyzed for the 8" thick GRP CWP, considering reduced internal pressure due to internal cold water flow and external pressure due to current drag forces. In both cases the stresses were less than the critical implosion stresses.

Buckling of the CWP as a column was also analyzed. This was found not to be a problem.

g. Results

The total stresses of all CWP's analyzed are in Table 41. The results indicate:

- o No concrete configuration gave acceptable stresses.
- o Truss configurations did not show any promise.
- o A thin walled GRP CWP appears reasonable.

4.11.7 Final Configuration

The final Sphere CWP configuration is given on Sheet 2 of Table 41 as Case No. 54 and is the 8 inch thick GRP for the West Coast of Florida. The steel candidate was not selected because of greater cost. The cold water pipe is shown on Drawing No. 47926 in Appendix 3.1.

TABLE 38 : 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	"	"

TABLE 39 : SPHERE PLATFORMS CONSIDERED

SPHERE 1	<ul style="list-style-type: none"> o Multi-Surface Piercing Columns o Draft to main deck 55 Ft. above still water surface o CWP attachment 187.4 Ft. above baseline o GM = 30.0 Ft.
SPHERE 2	<ul style="list-style-type: none"> o Sphere 1 with CWP attachment at 103.0 Ft. above baseline
SPHERE 3	<ul style="list-style-type: none"> o Sphere 2 with GM = 17.7 Ft.
SPHERE 4	<ul style="list-style-type: none"> o Single-Surface Piercing Column o Draft to main deck 110 Ft. above still water surface o CWP attachment 103.0 above baseline o GM = 6.5 Ft.

TABLE 40 : PROPERTIES OF MATERIALS USED FOR CWPS

CHARACTERISTIC	GRP	CONCRETE/ FOAM	STEEL/ FOAM
Modulus of Elast: PSI	2×10	2.95×10	30×10^6
Density	3.29	3.42/1.09	15.19/1.09
Poisson's Ratio	0.30	0.18	0.30

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 E5	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	3.36 E4
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	3.36 E4
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 41: Results of MR&S Sphere CWP Stress Computer Run

CASE NO.	PLATFORM	MATERIAL	STRESSES				RMS MOTIONS			TOTAL STRESS	MAXIMUM ALLOWANCE STRESS
			RMS WAVE	MAXIMUM RMS x 5.26	CURRENT	WEIGHT	HEAVE	SWAY	ROLL		
38	SPH	P	5.7707 E3	3.035 E4	169	875				3.140 E4	1.2 E4
41	"	P	1.361 E3	7.159 E3	144	875				8.178 E3	1.2 E4
42	"	P	2.006 E3	1.055 E4	190	875				1.162 E4	1.2 E4
43	"	P	1.287 E3	6.77 E3	190	875	5.93	4.22	2.31	7.835 E3	1.2 E4
44	"	P	1.7174 E3	9.034 E3	512	875	6.12	3.93	2.21	1.042 E4	1.2 E4
45	"	P	1.262 E3 1.5123 E3	6.638 E3	383	875				7.896 E3	1.2 E4
9	SPH A	P	2.408 E3	1.267 E4	127	875				1.367 E4	1.2 E4
11	"	P	2.448 E3	1.288 E4	127	875				1.388 E4	1.2 E4
12	SPH B	P	1.178 E3	6.196 E3	127	875				7.198 E3	1.2 E4
50	SPH C	P	4.2594 E3 2.0591 E3	1.083 E4	383	794	2.5	2.18	0.16	1.2 E4	1.2 E4
54	SPH C+	P	4.1359 E3 2.0394 E3	2.175 E4 1.073 E4	383 383	794 794	4.0 2.5	4.04 2.08	.527 .256	2.293 E4 1.19 E4	1.2 E4 1.2 E4

TABLE 41: Cont'd

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	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	S	1.413 E4	7.432 E4	254	7083				8.166 E4	3.36 E4
4	"	S	1.411 E3	7.423 E4	254	7083				8.157 E4	3.36 E4
15	S-B	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	3.005 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	1.284 E4 9.32 E3	383 383	700 700				1.397 E4 1.04 E4	1.2 E4 1.2 E4

Table 41: Cont'd

TABLE 42
SUMMARY OF HYDRONAUTICS CALCULATED RESULTS FOR THE SPHERE
PLATFORM WITH CWP

Significant Wave Height, $H - 1/3 = 45.8$ ft.

Parameters	GRP	Concrete	Steel
CWP Max. Bend Mom., lb., ft.	0.83×10^{10}	1.0×10^{10}	5.0×10^{10}
CWP Max. Bend Stress, P.S.I.	1.7×10^3	1.7×10^3	28.3×10^3
CWP, bottom Motion, ft.	11.5	4.9	12.2

Significant Wave Height, $H - 1/3 = 58.1$ ft.

Parameters	GRP	Concrete	Steel
CWP Max. Bend Mom., lb., ft.	0.453×10^{11}	2.0×10^{10}	$.68 \times 10^{11}$
CWP Max. Bend Stress, P.S.I.	0.87×10^4	0.32×10^4	3.88×10^4
CWP, bottom Motion, ft.	21.85	11.1	47.7

TABLE 43 : WAVE CHARACTERISTICS AND SEA STATES

SITE	SIGNIFICANT WAVE HEIGHT-FEET	PERIOD OF PEAK ENERGY-SECONDS
New Orleans	58.1	15.91
Florida (West Coast)	45.8	13.67
Puerto Rico	44.2	13.8
Sea State Six	20	10.3

Table 44: Comparison of Results Between MR&S and Hydronautics Outputs

SPHERE, SINGLE/FIXED/RIGID/NON-BUOYANT GRP ID-101' T=18"

$H_{1/2} = 58.1'$

		①	②	② / ①
	Paulling's (RMS)	Paulling's (Significant)	Hydronautics (Significant)	2/1%
Max. Bending Stress (psi), $H_{1/3} = 58.1$ ft.	5.771E3	1.154E4	.869E4	75.3%
Max. Bending Stress (psi), $H_{1/3} = 45.8$ ft.	1.643E3	3.286E3	8.3E3	250%

3/29/79

AMPLITUDES OF BENDING STRESS
VS.
WAVE FREQUENCIES

Figure 55

4.12 CWP Configuration and Hull Connection

4.12.1 CWP Configuration

See the discussion for the Spar in Section 3.12.1 which is also applicable to the Sphere. The pertinent drawings in Appendix 3.1 for the Sphere are #47926 and 47927.

4.12.2 Hull Connection

As pointed out in Section 4.11, MR&S has adopted a CWP which is fixed rigidly to the platform. Prior to obtaining favorable stress results with such a configuration, the ball joint and gimbal configurations were analyzed, but will not be discussed herein.

The attachment of the CWP to the Sphere has been facilitated by the deployment scenario of the CWP, which is through the top of the Sphere as shown in Drawing #47927, and the fact that the entire center of the Sphere is a cold water well.

The GRP CWP extends two thirds of the way into the Sphere and is then connected to the uppermost section which is of steel with a top that is permanently connected to the Sphere main deck. Cutouts in this steel section provide the opening to the cold water ducts. The CWP is then supported almost entirely by a steel/concrete sleeve fabricated in place as the CWP construction proceeds.

4.13 Support Systems

The support systems as discussed in Volume I and in (5) are those systems which assist in the operation and maintenance of the platform.

4.13.1 Lifting Devices and Deck Gear

Lifting devices on the sphere platform would include a 100 ton whirley crane on rails, overhead hoists and forklifts.

The whirley crane serves as an all purpose crane which can lift cargo from supply boats and drop it through hatches in the 07 deck level to the supply rooms or can remove equipment through the superstructure surge pipe. Drawing number 47928 shows the removal route for auxiliary equipment and the cold water pumps and motors. The whirley crane cannot lift the turbine-generator sets or the tube bundles through the outboard main deck hatches. This operation is performed by a barge crane. The crane moves along a circular track at the perimeter of the 07 level deck to permit operation anywhere alongside the superstructure.

Fork lift trucks would move equipment from the boat supply landings to the elevator and from there to the storage spaces. Most of this material would be palletized.

An overhead lift mounted on underside of the main deck would permit removal through the lower hull deck hatches of the turbine generator sets. Once above the second deck the trolley is moved outboard so the crane barge can lift the T-G set through the main deck hatch.

4.13.2 Boat Handling

The 03 and 02 level decks contain boat landings to permit supply boat tie up and offloading for the complete range of operating drafts. Three landings are installed on each deck to permit unloading on the leeward side of the structure away from wave action. Small pedestal crane will unload palletized cargo from the supply boats or alternatively the whirley crane may be used.

4.13.3 Helicopter Handling

All helicopter operations are carried out at the helicopter landing platform on the 07 level. Instrument homing and 24 hour landing equipment are to be provided. Helicopter operations are controlled from the Deck Control Station. Tiedowns for securing the helicopter are to be located on the platform to prevent damage in heavy weather.

4.13.4 Replenishment Operations

Without a resident crew (living on the platform round the clock), the replenishment operations are limited to replacing those fluids and stores used during routine operation. A scenario involving both types of boat handling operations and helicopter handling operations is envisioned.

4.14 Manning

The scenario for manning of the Sphere platform is the same as that for the Spar, refer to section 3.14.

SECTION 5.0 FACILITIES & EQUIPMENT

5.1 General

The enormous size and displacement of the 400 MWe 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. Details of the construction and deployment scenarios for the spar and sphere are found in Section 6.0.

The two platforms have much in common with regard to the facilities and equipment required to construct and deploy them. However, differences in design force some differences in equipment and procedures. Other differences are presented primarily to offer alternatives for consideration, and are not necessarily limited in use to one design. These, too, are noted.

5.1.1 Hull Construction

a. Onshore Construction Site

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.

The possibility of dredging channels deeper to facilitate movement of a larger structure may be investigated with respect to cost and economic advantage, but the time to file environmental impact statements and receive all necessary permits must be considered. Time to acquire U.S. Corps of Engineers' and other permits for excavating the construction site and sheet piling the dam should be considered during site evaluation and planning.

Evaluation of sites should be carried out with the following aspects in mind that will directly affect the cost and efficiency of the entire construction project:

1. Proximity to sea and deep water.
2. Unobstructed route to the deep-sea sites.
3. Area sufficient to construct demonstration plant and possible expansion for construction of commercial plants.
4. Soil or bed rock sufficient to support high static loads.
5. Area to be in close proximity to relatively large population centers and skilled labor markets.

6. Area to be served by good roads, rail and water transportation.
7. Adequate utility supply, especially power and fresh water.
8. Easy passage of permit applications through local and federal agencies.
9. Support of local authorities and labor unions, if any.

The construction site shall be planned, with room for future expansion, to cover all phases of the construction process and support functions. The following structures, equipment, machinery and services will be necessary to complete the project.

1. Facility boundaries marked, fenced and secured.
2. General administration buildings for management staff, engineering, purchasing, material and quality control and personnel.
3. Electrical, water, telephone, and compressed air supply.
4. Sewage disposal.
5. Equipment, machinery and material warehousing.
6. Consolidation of ground in working areas and access roads to support heavy tracked vehicles.
7. Bulkheading of waterfront barge berths, offloading equipment and dam enclosure.
8. Excavation of actual construction area and consolidation of ground.
9. Pumping facilities to maintain a dry area and drainage provisions.
10. Steel fabrication shop and necessary equipment.
11. Machine shop.
12. Hull outfitting shops and support equipment.
13. Heavy lift tower cranes.
14. Heavy lift, mobile, crawler cranes
15. Concrete manufacturing plant should be nearby.
16. Pre-tensioning and post-tensioning equipment.
17. Subassembly manufacturing area and equipment.
18. Supports, forms, towers, scaffolding, etc. for hull construction.

19. General transportation.

20. Bulk storage facilities - cement, sand, gravel.

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 shall 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. Supply capacity at the site should contain at least 25,000 tons/week of aggregate, 5,000 tons/week of reinforcement and 7,000 tons/week of cement.

With the above considerations in mind, the most promising construction sites appear to be in the Florida Panhandle as shown by the arrows in Figure 56. 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).
- 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 Sphere is shown as requiring a land-based site on existing land, while the Spar is shown on an artificial island. The facilities are interchangeable.

b. Offshore Construction Site

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 system will be required to position the platform.

5.1.2 Construction of CWP

The cold water pipe is to be constructed on shore in a facility located very near the water edge possibly adjacent to a shipyard. The pipe will be built in sections approximately 100 feet high and 100 feet in diameter with a 25' pipe connection joint attached. Rails will be built to the water edge to permit a carriage to transport the pipe section to a barge.

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11006

(Key West to the Mississippi River)

A mandrel will be required to serve as a form for the fiberglass pipe sections. This unit would be reused for each of the sections produced.

5.1.3 Construction & Deployment of the Mooring System

The HCL links of the mooring systems for both platforms are enormous. A shore-side steel fabrication facility will be required to produce these links. This facility can be independent of the platform hull land-based construction site, since no interface between the hull and mooring system will be required until arrival at the final deployment site.

Similarly, a concrete construction facility with equipment for producing floating concrete structures is required to produce the three free-fall deadweight anchors. The facility must have a clear channel to the sea large enough to accommodate these anchors when they are towed out for deployment. Both of these facilities should be in reasonable proximity to the final deployment site.

5.1.4 Offshore Construction Support

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. These pieces of equipment are considered to be state-of-the-art for large floating concrete construction projects. Acquisition of some of these items may present availability problems. These pieces of equipment may either be chartered or purchased commercially:

- o Floating concrete manufacturing facility, such as those used in the North Sea construction projects.
- o Heavy-lift floating cranes of 100-1000 ton and 2000+ ton capacity. The units exist, but scheduling and availability may be a problem.

A host of other equipment (barges, crewboats, etc.) is not considered a problem.

5.2 Special Facilities and Equipment Required for the OTEC "Spar" Platform

5.2.1 Shore Construction Facility

The OTEC Spar's base is to be constructed on an artificial island specifically built to support the land-based construction effort. Such facilities are currently in use for construction of large floating concrete structures (Ref. [34]). The island offers several distinct advantages over a shoreside site:

- o The construction of the island shortens the required amount of dredging and helps to solve the dredging material disposal problem when this material is from the island.
- o The land, being newly created, lessens the problem of finding and acquiring a suitable building site.
- o It can provide the required "unobstructed route" to the sea.

- o It is more aesthetically acceptable to local residents than a plant in their back yards.
- o Its size and shape can be tailored specifically to the needs of the construction program.
- o It is potentially useful after the program is finished, having a "salvage value".
- o The island and causeway, as shown in Dwg. #47919, provide a sheltered harbor for barges and floating construction equipment.

It should be noted that the use of an artificial island could be applied to the Sphere construction scenario.

The deckhouse can be constructed using standard techniques in any facility similar to the J.R. McDermott yard in Louisiana.

5.2.2 Critical Equipment

Besides the equipment listed in Section 5.1, the Spar construction scenario requires two specialized pieces of equipment. Both are depicted on drawing 47921. The units are both reusable and only one or two of each would be required.

a. Spar Cold Water Well Plug

A method of assuring the watertightness of the hemispherical section during early construction is necessary so that sufficient buoyancy is available throughout these stages. The plug is built at a shipyard using normal practices and brought to the land-based construction site. Construction then proceeds as outlined in Section 6.0.

b. The CWP Construction Barge

Because of the Spar's arrangement, the CWP cannot be deployed thru the center of the platform. A barge, also constructed in a shipyard using standard practices, is used as a substitute assembly platform as depicted in Section 6.0.

5.3 Special Facilities and Equipment for Construction of the OTEC Sphere Platform

5.3.1 Land-Based Construction Facilities

Selection of a site for the construction of the lower portion of the Sphere must be made with care. Besides meeting the criteria of Section 5.1, the site should preferably be along a sheltered river, channel or bay having direct, unobstructed access to the sea. While it would be extremely advantageous to locate the site within close proximity to deep water, it will prove impossible to do so along this coast line. The 10 fathom line is normally at least one mile from the coast and all ports, harbors, anchorages, etc., in the area do not exceed 35 to 40 feet. Construction on the land based site is thus limited to floating out the hull in this water depth.

The all steel superstructure can easily be built in a floating drydock. "Avondale Shipyards" in New Orleans currently has a drydock of 216 foot width and Ingalls has one of 176 foot width which can accommodate the 127 foot wide structure. Indeed two or three superstructure sections could be built simultaneously if desired. The channel depth leading from both yards is adequate to float out the completed superstructure fully outfitted.

5.3.2 Special Equipment for Integration and Deployment of the Hull/CWP/Superstructure

The hull after the main deck is installed can be moved to the final OTEC site and permanently moored. The CWP sections are then transported to the site by a barge specifically built or modified for this purpose. A series of hydraulic jacks must be provided to lift CWP sections onto the carriage and off the carriage on to the platform. Such jacks would have to be specifically designed for this purpose but are well within current state-of-the-art. After deployment of the CWP the superstructure may be floated out and installed on the main deck by ballasting the sphere down to 40 foot submergence and deballasting to install the superstructure.

SECTION 6.0 CONSTRUCTION AND DEPLOYMENT SCENARIOS

6.1 General

The commercial OTEC platforms are both immense structures. They have much in common in their construction/deployment sequences due to the size, choice of materials, mission requirements and internal components. Besides the specified components of the power systems, MR & S has used similar systems and concepts in the design of the platforms adapted where necessary to reflect obvious differences in configuration. Examples of this philosophy are the cold water pipe and the mooring system.

6.1.1 Sites/Construction Phases

Both platforms, because of their size, cannot be completed in a shoreside facility because of their great displacement and draft. For this reason, a phased construction scenario was developed for each platform along similar guidelines -

- o The construction at the land-based site (Phase I) is limited due to ability to deploy the constructed body. A dredged channel depth of 50' (15.24m) was felt to be a constraint for both environmental and economic reasons.
- o An intermediate site (Phase II) for construction of the next segments of the platform was selected as the preferred alternative to immediate towout to the final deployment site for several reasons:
 - The economics of the intermediate site were superior when transportation of materials and personnel to and from the construction site were considered.
 - The factor of safety in building at a site in relatively shallow water was considered important. A relatively sheltered position at the shallow end of the DeSoto Canyon is recommended.
 - The problems of mooring the uncompleted hulls and construction equipment in the loop current are delayed, and cut to the minimum possible time.
- o The deep water site is the site where the platform is to be permanently located. The platform is completed at this site, connected to its mooring system and shore power connection, and made operational. This site is used for completion of Spar Phase III and Sphere Phases III and IV. See Table 45.

TABLE 45

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.

6.2 Construction/Deployment Scenario For The OTEC Spar Platform

The Spar platform is a modular unit which is divided into six vertical construction zones. These zones, which correspond to stages in the construction/deployment process, are further divided into modules, generally ending at decks and hull thickness changes. The modules are further divided into units, the smallest division used. The units receive serial numbers in order of erection within modules, and the similarly modules within zones, so that by finding a unit's number, (given zone-module-unit) one should determine where in the sequence it belongs. See Table 46.

The following descriptions refer to similarly captioned and numbered sketches on Drawing Number 47919, "OTEC Spar Construction and Deployment Sequence".

6.2.1 Phase 1 Construction At Land-Based Site

a. Site Preparation

- o Prepare the artificial island construction site and dredge floatout channel to a depth of 50' (15.24 M).
- o Lay in hydraulic "dredge" piping for sand removal during floatout.
- o Dump traprock and sand to level and tamp, forming a base for the plug assembly.
- o Place sheet steel piles as required except at opening for plug. (See Sketch #1 on Dwg. #47919).
- o Construct a reusable plug (Drawing No. 47921) at a local shipyard and float into position in the building site.
- o Place remaining sheet piling and push sand up around pilings into a dike.
- o Dewater building site to a depth of 5-6 feet.
- o Locate final plug placement and pump out remaining water so plug will land in place.
- o Place tower crane on plug.
- o Push up sand roughly in shape of the lower part of the "grapefruit" section.
- o Set up form work and pour lower ring footing.
- o Upper and lower tracks are placed for traveling form. (See Sketch #2)
- o Consolidate the sand on the shaped surface using lime, Portland cement or other suitable cementing agent.

Table 46
Spar Zones and Modules

Zone	Module	Extent
I	I-1 I-2	Land Based Construction to DK590
II	II-1 II-2 II-3 II-4	DK590 to DK525 DK525 to DK490 DK490 to DK440 Central Trunk Closure
III	III-1 III-2 III-3 III-4	DK440 to DK390 DK390 to DK350 DK350 to DK310 DK310 to DK260
IV	IV-1 IV-2 IV-3 IV-4	DK260 to DK220 DK220 to DK175 DK175 to DK125 DK125 to DK100
V	V-1 to 4	Superstructure Trunk
VI	VI-1	Deckhouse
VII	VII-1	Cold Water Pipe

- o Construct an annular footing at the top of the excavation just outside the limits of concrete placement. This footing is to be in segments on the seaward side to facilitate removal.
- o Erect circumferential rails on the upper footing and on top of the plug.
- o On these rails mount a carriage subtending an angle of 22.5° , and spanning the entire surface.
- o Attach to this carriage movable shaped forms with pouring doors.

b. Initial Construction on Land Site

- o Reinforcing steel is placed on chairs to hold it in place. Rebars are welded together.
- o Lower "grapefruit" segments are formed over $22\frac{1}{2}^\circ$ arcs. Segments are poured in opposite pairs until completed, filling the open segments after the initial shrinkage of the concrete already in place.
- o Prepare unit for float-out by removing sand from around casting and sheet pilings in way of float-out channel. Forms, carriages, and rails are removed at this time.
- o Tugs and towboats are positioned and lines secured to "grapefruit" while remaining sand being washed away by hydraulic piping installed beneath bed. The grapefruit will float with approximately 10.5' (3.20 m) freeboard and 1' (0.30 m) channel clearance.
- o Work platforms and two deck barges, each capable of supporting two thirds the flooded weight of the platform to deck 590, are attached to the platform for safety.
- o Unit is towed to intermediate site. (See Sketch #3).
- o Mooring at the intermediate site is accomplished using the attached work barges.

6.2.2 Phase II Intermediate Construction Site and Phase III Deep-Water-

a. Construction Site

- o The upper part of the grapefruit is formed in segments.
- o Attach cantilever forms to the outside spherical surface near the top.
- o These forms are anchored to and strutted from the completed hull as the construction moves upward, reinforcing steel positioned and welded.
- o Position similar cantilever forms on the inside spherical surface of the hull and brace to the existing structure. Construct the outer hull up to DK590.

b. Interior Structure and First Deck Constructed

- o "Grapefruit" bulkheads are formed using standard vertical wall forming techniques.
- o The "torus" segments are precast on shore and barged to the construction site, with the segments being placed by crane barge and tower crane.
- o Deck 590 and valve foundations are placed.
- o Cold water intake valves are mounted to their individual foundations.

Note: The foregoing intermediate construction steps are considered relatively high risk operations because of the open nature of the assembly to the point where deck 590 is intact.

c. Basic Modular Step Sequence

This sequence is repeated for each construction module with exceptions noted for individual modules as they apply.

- o The slipforms for the shell are erected in 22 1/2° segments.
- o Reinforcing steel is placed on chairs and welded.
- o Concrete is placed into the forms, vibrated, and cured.
- o The above steps are repeated until the shell is complete.
- o Sections of the central trunk are either preformed and put in place or are formed in place.
- o Radial bulkhead sections are preformed and put in place or formed in place.
- o Water pipe sections are preformed and put in place.
- o The overhead deck beams are placed, followed by forms. Reinforced concrete slab decking is placed to complete the module.

d. Modular Variations

- o 11-1, install NH₃ storage tanks and foundations prior to CW duct placement (Sketch #4)
- o 11-2, install CW pumps and foundations.
- o Install power conditioning equipment and foundations on DK525.
- o Install mooring line attachments in shell.

- o II-3, install generator foundations at DK440.
- o III-general, after towout to deep-water site and prior to construction, detach plug, attach CWP and mooring system (Sketches #6 & 7).
- o III-1, install condensers, turbo-generators, and hoods prior to placing DK390.
- o III-2, place CW discharge assemblies in parts during shell construction.
- o Install CW discharge valve assemblies after shell completion and close.
- o III-3, place WW discharge assemblies during shell construction.
- o III-4, install WW discharge valve assemblies after shell completion.
- o Install evaporators and demisters prior to placing DK260. (Sketch #8)
- o IV-2, install NH_3 storage tanks and foundations.
- o IV-3, install WW pumps and foundations prior to WW duct placement.
- o Place superstructure trunk prior to placement of bulkheads.
- o IV-4, place superstructure trunk prior to placement of bulkheads.
- o Install WW valves and foundations.
- o V-4, install WW intake screens upon completion (Sketch #9)

e. Superstructure Deckhouse

The deckhouse is lifted into place atop the superstructure column after the platform is ballasted down. A 1000-2000 ton lift crane is needed for this operation which follows oil drilling rig assembly practice. (Sketch #10)

f. Cold Water Pipe Assembly

The cold water pipe is assembled in sections on the cold water pipe construction barge, detailed on Dwg. 47921. The pipe is then attached to the hull upon arrival at the deep water site, prior to mooring system attachment (Sketches 5 & 6).

6.3 Construction/Deployment Scenario For The OTEC Sphere Platform

The following steps and items numbers refer to plans and sections on Drawing No. 47927, "OTEC Sphere Construction and Deployment Key Plan."

6.3.1 Phase No. 1 - Construction at Land-Based Site

a. Site Preparation

Step 1:

- o Drive sheet steel piling (1) forming a circular enclosure about 440 ft. (134.1m) in dia.
- o Dewater the sand (2) enclosed and excavate to a shaped circular surface as shown.
- o Fill on seaward side as required.
- o Excavate for and pour a circular concrete footing (3) to support the structure.
- o Consolidate the sand on the shaped surface (4) using lime, Portland cement or other suitable cementing agent.
- o Construct an annular footing (5) at the top of the excavation just outside the limits of concrete placement. This footing is to be in segments on the seaward side to facilitate removal.

b. Initial Construction

Step 2:

- o Install eight (8) precast concrete evaporator pipe sections six (6) and eight (8) precast concrete condenser pipe sections (7) in locations as shown. Each shall be fitted with a temporary W.T. plug at its lower end. These plugs are to be fitted with piping to inject water between the concrete structures and the sand mold.
- o Construct and install a circular steel buoyant plug (8) which will serve as a mold for the lower portion of the coldwater well and will seal the well when floating.

Step 3:

- o Erect circumferential rails (9) on the upper footing (5) and on top of buoyant steel plug (8).
- o On these rails mount a carriage (10), subtending an angle of 22.5° , and spanning the entire surface. Attach to this carriage movable shaped forms with pouring doors (11).

- o Pour concrete shell in alternate 22.5° segments, filling the open segments after the initial shrinkage of the concrete already in place. The entire outer shell up to the 64.5 ft. (19.66m) level is formed. Forms are to be arranged to fit around the evap./condenser pipe sections (6) (7) already in place.

Step 4:

- o Remove forms (11) carriage (10) and rails (9) used in Step No. 3.
- o Erect forms on the buoyant steel plug (8) to complete the coldwater pipe well up to the 64.5 ft. (19.66m) level.
- o Remove these forms.

Step 5:

- o Siphon or pump seawater through the pipes in the cold water well, (8) condenser pipes (9) and evaporator pipes (6) until the water level inside the form is the same as the water level outside. The structure will float free.
- o Remove the upper footing (5) on the seaward side.
- o Remove the sheet steel piling (1) on the seaward side.
- o Excavate the seaward side and connect to the dredged channel.

6.3.2 Phase No. 11 - Construction at Intermediate Shallow Water Site

Step 1:

- o Tow the completed hull section to an intermediate construction site which has sufficient depth of water (220 ft.) to complete the hull.
- o Moor the completed section temporarily.
- o Position a number of work barges (12) around the floating structure to support temporary work platforms (13).
- o Install a 100 ton tower crane (14) on the C.W. Well Plug (8) and brace to existing structure.
- o Attach cantilever forms (15) to the outside spherical surface near the top. These forms are anchored to and strutted from the completed hull as the construction moves upward.
- o Position similar cantilever forms (16) on the inside spherical surface of the hull and brace to the existing structure.
- o Construct the outer hull up to the second deck.

Step 2:

- o Erect progressively rising jump forms (17) and pour the cold water well up to the top of the second deck level.

Step 3:

- o Erect forms for a ballast tank (18) and complete tank as shown.
- o Erect forms and pour eight radial bulkheads (19) up to the second deck.
- o Erect the steel beams and pour four inch slabs for the 5th, 4th, 3rd and 2nd decks. Leave openings to install condenser and evaporator shells, (6) (7).
- o Install precast condenser (7) and evaporator (6) pipes and shells, leaving the tops open for installation of valves and tube bundles.
- o Install three permanent mooring attachments (16).
- o Attach mooring links as needed while the connection points are still above the water.

Step 4:

- o Install evaporator and condenser valves and pipe bundles while the shells (6) (7) are open at the top.
- o Install foundations, marine engineering components, power plant, piping, wiring and all subsystems while the hull is still open and before completing the water bearing main deck.

Step 5:

- o Install precast evaporator and condenser piping (6) (7).
- o Complete radial bulkheads up to the level of the main deck.
- o Erect forms and complete the cold water pipe up to the top of the main deck.

Step 6:

- o Erect forms and pour the spherical main deck allowing for access hatches.
- o Install eight (8) towing attachments (20).
- o Erect steel cold water pipe supports on the inner surface of the cold water well (21). These supports should extend up to the third deck level and be in segments at the top to allow the jackdown legs (22) in Phase No. 3 to reach their full extension

Step 7:

- o Dismantle and remove the 100 ton tower crane (14).
- o Flood the cold water well.
- o Ballast and remove the buoyant steel plug (8). Save this plug for use in subsequent construction.
- o Remove the W.T. plugs (6) (7) in the evaporator and condenser pipes.
- o Secure mooring links (16) to hull for towing.

6.3.3 Phase No. III - Final Hull Construction at Deep Water Site

Step 1:

- o Tow completed hull to its permanent operating site and moor.
- o Install a temporary track (23) on the main deck, which will line up with a similar track on a work barge (24) and be able to support one section of the cold water pipe (25) along with its transfer car (26).

Step 2:

- o Install four hydraulic jacks (27), two on either side of the tracks.
- o Move a section of the cold water pipe (25) on its transfer car (26) over the cold water pipe well.
- o Engage the four (4) hydraulic jacks (27) and lift the section of cold water pipe (25) clear of its transfer car (26).
- o Move the transfer car out from under the cold water pipe section and remove.

Step 3:

- o Install a series of eight (8) air jacks (28) and jackdown legs (27) around the cold water pipe section.
- o Engage the lower edge of the coupling and lower this first section until the top of the coupling is just above the main deck.

Step 4:

- o Mount eight (8) hydraulically operated holding devices (29) in the condenser inlet pipes. These devices are to engage the lower edge of the cold water pipe coupling and will support the weight of the pipe string.
- o Disengage the jackdown legs (22) and remove those jacks and legs which will interfere with moving a second section of cold water pipe over the first.

Step 5:

- o Using hydraulic jacks (27) raise second section of pipe (25), remove transfer car (26), and jackdown second section into coupling of first section and cement in place.
- o Repeat steps 2, 3, 4 and 5 with each new section of pipe until the entire length of cold water pipe (25) is in place.

Step 6:

- o The last section of the cold water pipe (30) is fabricated of steel and forms a cold water flow chamber. It has a flange on the upper edge which is supported by the vertical wall of the cold water well.
- o A steel coaming (31) is welded to this flange to accept the superstructure.
- o Secure the cold water pipe (25) to the hull using a cement and a series of pins driven through the cold water pipe well and the pipe supports (25).

Step 7:

- o Remove all temporary rails, bracing jacks, holding devices, etc. The platform is now ready for the installation of the superstructure (25).

6.3.4 Phase No. IV - Completion of Platform at Deep-Water Site

Step 1:

- o Tow steel superstructure (33) to the platforms operating site. It will float with about 35 Ft. (10.67m) draft.
- o Ballast the sphere until the main deck is below this draft.
- o Float the superstructure over the sphere and line up with coaming plate (31).
- o Slowly deballast sphere, seating superstructure (33) inside coaming plate (31).
- o Continue deballasting until main deck is above water.

Step 2:

- o Complete permanent attachment of superstructure to hull.
- o Add W.T. lower portion and connect all services, vents, access, wiring, etc.

- o Complete installation of auxiliary systems, and power transmission system.
- o Install screens for warm water intakes.
- o Ballast sphere to operating depth and start plant.

SECTION 7.0 COST ESTIMATES AND TIME SCHEDULES

7.1 General

This section summarizes the results of MR&S's cost studies on the Spar and Sphere Commercial OTEC Platforms. The results were already presented to the DOE by Task VIII report [35].

The basic guidelines used in developing the cost estimates are contained in [36]. Briefly, they are:

- 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 and presented in Section 2.1.
- o Estimates are to include all acquisition, deployment, and operating costs as well as site preparation costs for construction facilities.
- o OTEC Park baseline site is West Coast, Florida.

The costs for acquisition, deployment and operation of the individual platforms and the OTEC Park include numbers generated by MR&S. These costs are entered onto the cost reporting formats (OTEC Cost Estimating Sheets) supplied by the DOE.

Those costs that are used in developing an engineering cost estimate, but not directly generated by MR&S (such as the cost of the OTEC power cycle equipment, cost of the electrical transmission system, etc), are not entered onto the cost sheets.

7.2 Approach Used In Cost Estimates

The cost estimates, as requested in (36), are to follow the standardized WBS for the OTEC plants. A discussion of specific WBS items is given below followed by a statement of basic assumptions made in arriving at the cost estimates for major WBS items and a description of the approach used in estimating both the detailed costs and the parametric cost estimates for relatively minor items.

7.2.1 Work Breakdown Structure

The systems for which cost estimates are required by the platform contractors are the following:

- 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 to be addressed by the platform contractors, nor are the energy transfer systems costs. However, the cost of installing the power systems 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, with the hull, is included.

The costs for all of the above WBS items are based on the conceptual designs developed by MR&S for the two platforms. Costs for systems integration are based on the conceptual design and on the construction and deployment sequence as well as on the operating scenario.

The deployment costs for the cold water pipe and the platform hull are also developed on the basis of the conceptual design. They reflect the costs for the West Coast of Florida site which is baseline site assigned to MR&S.

Industrial facilities costs (item 9 of the WBS) are analyzed in the light of the construction methodology developed for the two platforms. A detailed description of the construction scenario can be found in Section 6.0.

A different approach is used in developing an engineering cost estimate for each individual platform and an estimate of the life cycle costs for the complete OTEC Park. This can be summarized as follows:

(1) All material, labor, overhead, profit, and all other related costs, such as forms, staging, scaffolding, etc., to construct the first platform are developed for specified WBS items and labelled "PLATFORM COST". This cost includes the construction of the platform complete with all systems, excluding, however, the cost of the electrical transmission system, the OTEC power cycle equipment acquisition costs and any deployment or operating costs. All costs are in terms of 1978 dollars.

(2) The cost of OTEC power cycle equipment as reported in [37] and the cost of electrical power conditioning equipment as reported in [38] are added to the PLATFORM COST to obtain the "ACQUISITION COST".

(3) Construction facility costs are added to the ACQUISITION COST due to the fact that no existing facility at or near the ocean site appears to be capable of constructing the platforms of this size. Accordingly MR&S has studied probable geographical sites for construction as far as their proximity to the deployment sites, and their suitability as to the depth of water available. The area selected as a suitable construction site is discussed in Section 5.0.

7.2.2 Assumptions

In developing cost estimates for individual systems, assumptions had to be made on the basis of literature search, contact with manufacturers, and actual experience gained from previous design studies. Listed below are the unit or basic costs developed as a result of these investigations and actually used in estimating costs.

a. Concrete construction costs:

Unit cost for reinforced concrete

- 650 \$/CY for Spar Platform
- 750 \$/CY for Sphere Platform
(includes all but deployment costs)

Unit cost for precast cold and warm water piping ducts: 500 \$/CY

Unit cost for concrete poured for site preparation: 350 \$/CY

b. Steel new construction unit cost: 1.00 \$/lb.

c. Aluminum new construction unit cost: 3.00 \$/lb.

d. Preliminary Design/Engineering Cost: 0.10%
of acquisition costs (exclusive of site preparation and deployment costs)

e. Contract Design/Engineering Costs: 0.20 %
of acquisition cost as above.

f. Detail Design/Engineering costs: 0.60%
of acquisition costs.

g. Platform integration engineering costs: 50%
of contract design costs.

h. Cold Water Pipe cost: 1.90 \$/lb. for GRP
pipe (Source: [24, 25])

i. Towing and transportation costs: (Source: [39])

Crane Barge (140T) Charter Rate: \$10,000/day
(operating charter - includes all costs)

Operating Charter Rate for Tugs: \$3,000/day

Tug-Barge Combination Rate: \$6,000/day

Crane-Barge (3,000T) Rate: \$75,000/day

j. Mooring System Costs:

Hollow Cylindrical Link (HCL) sections used for mooring
lines are built of HY-80 steel weldments at 1.50 \$/lb. (Source: [40])

Deadweight anchors built of concrete at 500 \$/CY

Connections and guards at 1% of mooring line costs

k. Site Preparation Costs:

Excavating at 5 \$/CY (Source: [41])

Dredging at 12.5 \$/CY (Source: [42])

l. Warm Water Inlet Screens:

made of stainless steel at \$3.00 per lb.

m. Transportation costs for CWP Sections:

3,300 \$/day

For each 100 CWP Section, 4 days in transportation

n. Industrial Facilities:

Cold Water Pipe Mandrel cost: \$1 million (Source: [43])

Building for CWP manufacture:

150'W x 200'L x 125'H @ \$78/ft² = \$2,340,000

7.3 Costs for Individual WBS items

An effort is made to prepare detailed cost estimates for major systems and any other "cost drivers", i.e. items which make up 10% or more of the acquisition costs. Differing degrees of detailed estimates are made for the following systems:

o Hull and Structure:

The structural arrangements and the hull weights of the two platforms are well defined and documented both in the form of calculations and structural drawings as a result of the conceptual designs. If found necessary, a reasonably detailed cost estimate can be developed on the basis of structural breakdown. In the back-up sheets for hull costs, (Appendix #4), the weights of concrete, steel, and aluminum for different elements of the hull structure and their total quantities are calculated. However, the probable costs can only be estimated for a specific construction facility. Since this facility does not exist, all concrete, steel, and aluminum weights are lumped together, and an overall hull structural cost is estimated on the basis of unit cost figures assumed.

o Seawater System:

Costs for the components of Seawater Systems (warm and cold water) are carefully estimated. They are substantiated by contacts with the manufacturers of these components. Unit costs are developed for pumps, intake screens, intake and discharge valves constituting a 50 MWe module. Heat exchanger tube cleaning system selected is the "AMERTAP" system, and its cost of \$1.5 million per module is assumed to be included in WBS No. 3.0. Other components such as the nitrogen purging system and instrumentations/controls are treated as parametric cost estimates.

o Mooring Line Costs

A 3-leg static mooring system is selected as the positioning system. Based on a computer analysis of the configuration, the holding forces are calculated, and the sizes of HCL links are determined for use as mooring lines. No conventional material such as chain or rope has sufficient strength for use in this application. The costs of HCL sections are estimated on a conceptual design of the link and using HY-80 steel.

o Cold Water Pipe Sections

Concrete as a CWP material is ruled out due to very large thicknesses, and therefore weights and associated problems, that would result if it is used. The computer runs performed on CWP/hull hydrodynamic analyses using two different programs revealed that the stresses acting on the CWP along its length far exceed the allowable stresses afforded by ordinary or lightweight prestressed concrete. Of the remaining CWP materials, aluminum is ruled out due to its excessive cost. With solid wall thickness or built-up sections of steel CWP an acceptable configuration

within the allowable stress limits was obtained, only if provided with 50% buoyancy through use of floatation material. With GRP pipe, which several manufacturers claim is constructable up to 100' diameter, acceptable thicknesses and configurations were also obtained without any buoyancy provision. A cost trade-off was found to favor the GRP pipe.

o Assembly Support Systems

Specifically in relation to a newly developed construction facility, a reasonably detailed breakdown of equipment and services needed was performed and the costs were estimated accordingly. Details of the breakdown are given in (35) and a complete description of the proposed facility can be found in Section 5.0.

o Deployment Systems and Services

For both the SPAR and the SPHERE platforms, detailed "Construction and Deployment Scenarios" are prepared. These scenarios as well as drawings showing the construction sequence and deployment operations, can be found, respectively, in Section 6.0 and Appendix #3:1 (dwgs # 47919 and 47927). The costs for deployment equipment and services were developed in accordance with the scenarios to a level of detail that would seem reasonable at this conceptual design stage.

The costs for all other items in the WBS are based on parametric estimates. The parameters used are costs per unit weight of material unit length, number of years service, etc. The details of parametric weight estimates are presented in MR & S Report No. 5142 - 5 (35).

The costs for individual WBS items developed by detailed breakdowns or by a parametric approach are entered onto appropriate locations of the cost estimating sheets, Tables 47 and 48. These costs, however, cover only those WBS items which are developed by MR&S. In order to obtain an all-inclusive engineering cost estimate for the individual platforms as well as for the OTEC Park, the following costs must be added:

- Otec Power Cycle Equipment costs
- Electrical transmission and power conditioning system costs.
- Losses in the electrical transmission system

The development of an engineering cost estimate is described in detail in Section 7.4 for both the SPAR and the SPHERE platforms. Also treated in that section are the unit costs in terms of \$/KW for various phases of OTEC Park development.

Table 47, sheets 1-3, and Table 48, sheets 1-3, presents a summary of the cost estimate of the SPAR and SPHERE platforms, respectively, as entered onto the "OTEC Cost Estimate" sheets. All preliminary design, contract design, and detail design costs are treated as a lump sum for the complete platform.

"Fabrication/Construction", "Deployment/Installation", and "Test/Operation" costs are included in the total costs for all items. However, for WBS items that are subjected to a detailed cost estimate, these three cost categories are also separately developed and indicated on the cost estimate sheets of Table 47 in proper columns.

The cost totals shown include recurring and non-recurring costs for one platform for WBS items 1.0, 2.0, 5.0, 6.0, 8.0, 9.0, and 10.0. For WBS items 7.0 and 11.0 (operational support and project management) the costs shown are 40 year costs in terms of 1978 dollars.

Costs reported for WBS item 10.0 are only very rough estimates since no clear analysis of all the environmental, legal, and licensing problems could be made within the time restraints.

OTEC COST ESTIMATING SHEET 3/7/78

(\$000)

NO.	TITLE	ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
						TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.0	PLATFORM SYSTEMS													379,702
1.1	PLATFORM INTEGRATION ENGINEERING	P												888
1.2	HULL & STRUCTURE	B				18,501	74,121	71,263						163,885
1.3	POSITION CONTROL SYS.	B				1,391	56,113	18,453						75,957
1.4	PLATFORM SERVICE SYSTEMS	P												13,300
1.5	OUTFIT & FURNISHINGS	P												2,746
1.6	ASSEMBLY SUPPORT SYS.	B				3,731	3,718	7,678						15,127
1.7	SEA WATER SYSTEMS	B						76,525		7,587	16,179	423	423	100,714
1.8	BIOFOULING & CORROSION CONTROL	P												7,085
2.0	COLD WATER PIPE SYSTEM													103,737
2.1	CWP SYSTEM DESIGN & INTEGRATION	P												1,000
2.2	PIPE SECTIONS	B					52,086	47,526						100,332
2.3	INLET & SCREENS	B					600	300						900
2.4	CWP TO HULL TRANSITION	B					1,158	347						1,505
2.5	CWP BIOFOULING & CORROSION CONTROL	--												--
2.6	CWP MOORING & FLotation	--												--
3.0	POWER SYSTEMS	(BY OTHERS)						Estimated @ 1,000/MW					400,000	--
4.0	ENERGY TRANSFER SYS.	(BY OTHERS)						Estimated @ 47.5/MW					19,000	--

* ESTIMATE CODE: Insert "P" for Parametric or "B" for Bottom-up.

TABLE 47. SPAR

Sheet 1 of 3

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OTEC COST ESTIMATING SHEET 3/7/78
(\$000)

NO.	TITLE	+ ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
						TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
5.0	SYSTEM ENGINEERING & INTEGRATION	P												22,000
5.1	SYSTEM DESIGN & ANALYSIS													20,000
5.2	SYSTEM INTEGRATION													2,000
6.0	SYSTEM TEST & EVALUATION	P												2,600
6.1	TEST PLANNING													500
6.2	SPECIAL TEST FACIL.													1,000
6.3	INDEPENDENT TEST & EVALUATION													1,100*
7.0	OPERATIONAL SUPPORT	P												424,221
7.1	SPARE PARTS													46,304*
7.2	EXPENDABLE MTLs.													22,567*
7.3	PECULIAR SUPPORT EQUIP'T													61,388*
7.4	COMMON SUPPORT EQUIP'T													45,172*
7.5	PERSONNEL													246,000*
7.6	TECHNICAL MANUALS													750
7.3	(Non-recurring)													204
7.4	(")													636
7.5	(")													1,200

*40 Year Costs

*ESTIMATE CODE: "P" for Parameter c or "B" for Bottom-up.

TABLE 47: SPAR - cont'd.

Sheet 2 of 3

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(\$000)

*40 Year Costs

* ORIGIN of : In field "P" for Parametric or "B" for Bottom-Up.

TABLE 47: SPAR- cont'd.

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OTEC COST ESTIMATING SHEET 3/7/73 (\$000)

NO.	TITLE	ESTIMATE CODE*	PRELIM. DESIGN	CONTRACT DESIGN	DETAIL DESIGN	FABRICATION/CONSTRUCTION			DEPLOYMENT/INSTALLATION			TEST & OPERATION		TOTAL COST
						TOOLING	LABOR	MATERIAL & OTHER	TOOLING	LABOR	MATERIAL & OTHER	LABOR	MATERIAL & OTHER	
1.0	PLATFORM SYSTEMS													
1.1	PLATFORM INTEGRATION ENGINEERING	P												1,013
1.2	HULL & STRUCTURE	B				39,909	83,236	158,412						281,557
1.3	POSITION CONTROL SYS.	B				1,390	56,114	18,453						75,957
1.4	PLATFORM SERVICE SYSTEMS	P												13,300
1.5	OUTFIT & FURNISHINGS	P												2,746
1.6	ASSEMBLY SUPPORT SYS.	B				6,574	6,247	9,577						22,398
1.7	SEA WATER SYSTEMS	B						84,493		7,895	2,283	482		95,153
1.8	BIOFOULING & CORROSION CONTROL	P												7,085
2.0	COLD WATER PIPE SYSTEM													115,903
2.1	CWP SYSTEM DESIGN & INTEGRATION	P												1,000
2.2	PIPE SECTIONS	B					58,597	54,277						112,874
2.3	INLET & SCREENS	B					600	300						900
2.4	CWP TO HULL TRANSITION	B					869	260						1,129
2.5	CWP BIOFOULING & CORROSION CONTROL	P												--
2.6	CWP MOORING & FLOTATION	--												--
3.0	POWER SYSTEMS	(BY OTHERS)						Estimated @ 1,000/MW					400,000	
4.0	ENERGY TRANSFER SYSTEMS	(BY OTHERS)						Estimated @ 47.5/MW					19,000	

*ESTIMATE CODE: "P" For Parametric or "B" For Bottom-up.

TABLE 48: SPHERE

Sheet 1 of 3

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(\$000)

*40 Year Costs

(\$000)

*40 Year Costs

TABLE 48: SPHERE - cont'd

Sheet 3 of 3

7.4 Life Cycle Costs

7.4.1 General

Cost estimating efforts essentially followed the sequence described below:

1. Determination of the acquisition cost of platform
2. Determination of the construction facilities cost
3. Determination of the deployment costs
4. Determination of all design, integration, and testing costs
5. Determination of the cost of industrial facilities
6. Determination of the 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 49 presents a listing of non-recurring costs.

A learning curve factor was then applied to both the construction and deployment phase costs only. For platforms #2 through 8, the acquisition costs were obtained in a similar manner, only with different learning curve factors, [44]. In this manner, total acquisition costs for platforms # 1 through 8, constituting one complete OTEC Park, are obtained. In order to obtain an engineering cost estimate, the operating costs must also be added to these sums, and also the cost of a central accommodation platform. Similarly to be included in the total cost are the environmental, legal, etc., costs and project management costs.

The operating costs are based on an estimate of the annual costs relating to personnel, to spare parts, to maintenance operations, and to the support services required for transport between platforms, as well as between the OTEC Park and the shore. These are extended for the full lifetime of the platforms, however, no escalation factor is allowed. Simply, the total cost for one year of operating the platform is multiplied by the total number of years in the lifetime, so that the total costs as reported, inclusive of the operating costs, are always in terms of 1978 dollars without escalation.

Unit costs per stages of the development of the OTEC Park from construction through deployment, operation and electrical transmission to the utility companies at the land distribution points are also analyzed.

7.4.2 Life Cycle Costs for the SPAR Platform

The development of acquisition costs for the SPAR platform is tabulated in Table 50. Item #1 in Table 50 is what can be labelled as the "platform cost", i.e.

Table 49

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

PLATFORM #1
ACQUISITION COST BREAKDOWN

No.	Cost Item	Applicable WBS Item Number	Cost (\$000)
1	Hull, Outfit, CWP & Mach'y.	(1.2 - 1.5), 1.6 Partial, (1.7 - 1.8), (2.2 - 2.4), 3.0, 4.0, 7.3 Partial, 7.4 Part.	887,873
2	Construction Site Costs	(1.6 Partial)	13,518
3	Deployment Costs	(8.0)	4,076
4	Engineering, Design & Integration	(1.1 + 2.1 + 5.0 + 6.1 + P.D. + C.D. + D.D.)	32,379
5	Industrial Facilities	(9.0) + (7.5 Partial)	4,540
6	Special Test Facilities	(6.2)	1,000
Platform #1 Acquisition Cost			943,385

PLATFORM #2

Platform #1 Acquisition Cost	943,385
Deduct Non-Recurring Costs	46,050
<u>Platform #2 Acquisition Cost</u>	<u>897,335</u>

Table 50: "SPAR" Platform Acquisition Costs

Platform No.	(\$000) Acquisition Cost	Learning Curve Factor [13]	(\$000) Adjusted Acquisition Cost
1	943,385	1.0	943,385
2	897,335 x .816 = 732,225	897,335 x .870	780,681
3	"	" .830	744,788
4	"	" .796	714,279
5	"	" .784	703,511
6	"	" .760	681,975
7	"	" .750	673,001
8	"	" .745	668,515
8 Platform Total			5,910,135
Hotel/Control Platf.			53,700
"Energy Park" Total Acquisition Cost			5,963,835

Table 51: "SPAR" OTEC ENERGY PARK
Acquisition Costs

COST SUMMARY FOR A 320MW
OTEC ENERGY PARK
(8 "SPAR" PLATFORMS)

TABLE 52:

		(\$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	237.5	5,969	1,865	
OPERATING COSTS [2]	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

the cost of constructing a platform with all machinery including OTEC cycle equipment and electrical transmission system interface equipment. This can be seen by reviewing the applicable WBS numbers listed in the next column.

Table 50 also shows the cost of constructing the second platform without non-recurring costs and the benefit of the learning curve factor.

Table 51 indicates the adjusted acquisition costs for platforms 1 through 8. The central accommodation platform is also included in the total acquisition cost for the SPAR energy park.

Table 52 summarizes all costs and reports the results of life cycle estimates as well as unit costs. The top half of the table reflects the acquisition costs only:

- Hull Construction Cost: The cost of constructing concrete platform(s) exclusive of any equipment and machinery costs
- Platform Acquisition Cost: Cost of acquisition for the hull and platform systems but excluding OTEC related installations
- Total Acquisition Cost: All acquisition costs including hull, platform service systems, OTEC power equipment, transmission system interface equipment, and the central accommodation platform

It must be noted that the total acquisition cost, as reported, does not include the acquisition nor the deployment costs for the electrical transmission system consisting of the:

- Riser Cables from each Platform
- Stand-off Buoy (s)
- Central Collection Platform
- Riser Cable from Central Collector
- Submarine Cable to shore

The bottom half of the table reflects operating costs, both in terms of actual costs and unit costs, for one platform and for the complete OTEC Park.

7.4.3 Life Cycle for the SPHERE Platform

The development of acquisition costs for the SPHERE platform are summarized in Tables 53 and 54.

Life cycle costs covering acquisition and operation are reported in Table 55.

PLATFORM #1
ACQUISITION COST BREAKDOWN

No.	Cost Item	Applicable WBS Item Number	Cost(\$000)
1	Hull, Outfit, CWP & Mach'y.	(1.2 - 1.5), 1.6 Partial, (1.7 - 1.8)	1,013,356
2	Construction Site Costs	(2.2 - 2.4), 3.0, 4.0, 7.3 Partial, 7.4 Part. (1.6 Part.)	19,583
3	Deployment Costs	(8.0)	4,082
4	Engineering Design & Integration	(1.1 + 1.1 + 5.0 + 6.1 + P.D. + C.D + D.D)	33,126
5	Industrial Facilities	(9.0)+(7.5 Partial)	4,540
6	Special Test Facilities	(6.2)	1,000
Platform #1 Acquisition Cost			1,075,687

PLATFORM #2

Platform #1 Acquisition Cost	1,075,687
Deduct Non-Recurring Costs	<u>53,759</u>
<u>Platform #2 Acquisition Cost</u>	1,021,928

Table 53: "SPHERE" Platform Acquisition Costs

Platform No.	Acquisition Cost	Learning Curve Factor [13]	($\$000$) Adjusted Acquisition Cost
1	1,075,687	1.0	1,075,687
2	$1,021,928 \times .816 = 833,893$	$1,021,928 \times .870$	889,077
3	"	" .830	848,200
4	"	" .796	813,455
5	"	" .784	801,192
6	"	" .760	776,665
7	"	" .750	766,446
8	"	" .745	761,336
8 Platform Total			6,732,058
Hotel/Control Platf.			53,700
"Energy Park" Total Acquisition Cost:			6,785,758

Table 54: "SPHERE" OTEC ENERGY PARK
Acquisition Costs

**COST SUMMARY FOR A 3200 MWe
OTEC Energy Park
(8 "SPHERE" PLATFORMS)**

TABLE 55:

		(\$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.

7.4.4 Unit Costs

The cost of generating OTEC electrical energy, in terms of dollars per kilowatt, are indicated in Tables 52 and 55 respectively for the SPAR and SPHERE platforms. Summarized below is a comparison of the unit costs:

Cost Item	\$/KW		\$/KW	
	SPAR		SPHERE	
	First Platform	Park	First Platform	Park
Hull Construction	410	253	705	454
Platform Cost (w/o OTEC)	900	548	938	604
Total Acquisition	2358	1865	2690	2123
Life Cycle	3953	3465	4446	3884

The cost figures quoted above are subject to following qualifications:

- Total acquisition costs do not include the cost of purchasing, installing, and deploying the electrical transmission system.
- In obtaining unit costs, the net generated electrical output of 400 MWe nominal is used as a basis. In actual operation of the OTEC energy park, all platform service systems requiring electrical power will be fed from OTEC generated power switchboards by means of proper power conditioning equipment. A gross OTEC power output of 520 MWe is provided which allows 120 MWe for platform service systems.
- Also reducing the amount of net power to be transmitted to the land-based utility networks will be the transmission losses in the riser and submarine cables. No information could be obtained from cable manufacturers to use as a guide in considering the effects of transmission losses.
- The costs reported are for the baseline site at West Coast of Florida. The cost differentials for the other two sites (Puerto Rico and New Orleans) are discussed in Section 7.5.

7.5 Cost Differentials for Other Sites

As discussed earlier, the costs reported in Sections 7.3 and 7.4 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.

The effects of site conditions on the platform characteristics, especially those influencing its cost and operational performance, are discussed in detail in Section 8.0. Given in Table 56 are the cost differentials at various sites for the following cost items:

- o Mooring
- o Cold Water Pipe
- o Platform Structure
- o Deployment
- o Power Transmission

As it can be seen in Table 56, if the overall costs for the baseline site of Tampa are taken to be 100%, the costs for the New Orleans and Puerto Rico sites are estimated to be 110% and 88%, respectively for the SPHERE platform. The corresponding costs for the SPAR platform are 88% at New Orleans site and 83% at Puerto Rico site.

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

Thermal Resource	Tampa, Fla. = Unity		New Orleans, La.		Punta Tuna, P.R.	
	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 56: OTEC COMMERCIAL PLANT (400 MW)
SITE COST DIFFERENTIALS (\$000)

7.6 Time Schedule

The construction and deployment scenario for the SPAR and SPHERE platforms are described in Section 6.0. On the basis of this scenario, the construction process for the SPAR is to take place in three distinct phases:

- Construction of the lower "grape-fruit" section in the shore construction facility.
- Second stage construction and initial installation and outfitting phase at an interim off-shore location.
- Final construction and outfitting phase at the specified OTEC site.

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 Stage:	6	months
Second Stage:	18	months
Third Stage:	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 57 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 58 is a continuation of the time schedule covering the periods for construction, outfitting, deployment and testing of all eight platforms.

In both of these schedules, the construction period for one platform is taken to be 3 years. Actually, there will be a learning curve effect on the construction time as well, and possibly the periods for subsequent platforms will be somewhat reduced. However, due to the uniqueness of operations involved, and specifically due to the ocean site construction and outfitting phases, the 3 year period is maintained for all platforms to make up for unpredictable difficulties.

It can be seen from Figure 58 that the OTEC Park can be expected to become operational 13 years after inception.

"SPAR" DESIGN & CONSTRUCTION SCHEDULE
FIGURE 57

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

The construction scenario for the SPHERE essentially follows the same sequence as the one for SPAR. However, the complexity of the shape, in comparison to the SPAR, will result in longer construction periods. The amount of concrete to be mixed and poured, and the amount of reinforcing required are also greater for the SPHERE.

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.

Assuming, as a conservative measure, that it will take 30% longer, it is estimated that approximately 4 years will be required for the construction of one SPHERE platform. This will result in 14 years being necessary before the OTEC Park can be operational.

7.7 Uncertainties in Cost and Time Schedules

The cost estimates and time schedules presented in this section reflect the best efforts of the MR&S project team on all systems which comprise the complete platform. They are not, necessarily, based on detailed designs or breakdowns in all cases, nor are they supported by any actual quotations from builders and vendors. Additionally, some of the systems requirements necessitate substantial extensions of existing technology.

It is therefore very nearly impossible to come up with a reasonably accurate cost estimate.

Some of the uncertainties involved in the preparation of cost estimates are described below, and an attempt is made to determine the upper and lower bounds, as applicable.

7.7.1 Confidence Levels

Certain of the unit costs used in the estimates may be low and will be subject to further refinement in the final cost estimate. These cost items include:

- o Concrete cost
- o Glass Reinforced Plastic cost
- o High strength steel costs for HCL mooring
- o Aluminum fabrication costs

7.7.2 Concrete Construction Costs

The unit costs of \$650/cy used for the SPAR and \$750/cy for the SPHERE reflect the more complicated construction methods, primarily forming, required to construct the SPHERE. These figures are in line with the costs estimated by Shipping Research Services, Inc., of Norway based on recent large concrete marine structures. However, costs of construction in the U.S. range from \$350 to \$1,000/cy with a figure of \$800/cy for a recent ARCO barge.

Placing the \$650/cy figure at the center of the range of cost with \$800 as the upper boundary would indicate a range of 23% above and 23% below the assumed cost or a range of 46%. Similarly, for the \$750 figure the range would be 7% above and 7% below or a range of 14%.

7.7.3 Glass Reinforced Plastic Pipe Costs

The \$1.90/lb cost of fabricated GRP was obtained from Owens Corning and is based on large GRP items.

Costs of filament wound pipe catalog prices range from \$2.60 to \$3.65 per lb depending on type of plastic required. Using \$2.60 as a top figure, the range would be 37% above and 37% below or a range of 74%.

7.7.4 Other Material Costs

High strength steel:

The cost for fabricated HY-80 steel has been estimated at \$1.50/lb.

Aluminum:

The cost for fabricated aluminum has been estimated at \$3.00/lb.

7.7.5 Summary

In general, the real overall costs hopefully fall within a +10% and -10% range of the estimated costs. Items with a lower than average confidence level should fall within a +20% and -20% range.

Additionally, it must be stated that the concrete hull platform construction costs reflect the 4th iteration design results. The scantlings recently were reduced and the effect on the costs have been determined and included in this final report.

SECTION 8.0 SITE SENSITIVITY

8.1 General

Site sensitivity can be analyzed on the basis of the following two considerations:

- o Effects on the site due to the presence of OTEC platforms.
- o The effects on the OTEC platforms due to conditions at the site.

With respect to the latter consideration, the effects at any site or the differences in effects for different sites can be considered.

Although the site related effects are quite complex and that the important parameters were considered in earlier sections of this study, they will be discussed in greater detail in this section.

It can be stated at the outset however, that there are several major areas which are sensitive to the site characteristics. They are:

- o Mooring
- o CWP
- o Thermal Resource
- o Replenishment and Crew Accommodations
- o Platform Structure
- o Deployment
- o Power Transmission

The specific sites to be considered by MR&S were the West Coast of Florida as the baseline site and New Orleans and Puerto Rico as alternatives. Table 57 gives the wave and current characteristics for the three sites, and Table 58 and Fig. 59 give the monthly available thermal gradients and total annual thermal capacity.

8.2 Effects on the Site

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.

8.2.1 Thermal Resource

The detailed studies performed by the MR&S team on thermal resource are presented in Reference [5] and summarized in Volume I of this report. These studies considered the possible perturbation of the thermocline structure and the possibility of immediate recirculation of the slightly cooler discharged water back through the warm water intake. The latter aspect is of course platform oriented.

FIG. 59: THERMAL RESOURCE (THERMAL GRADIENT BETWEEN AMBIENT TEMP. AND A DEPTH AT 3000' BELOW WL)

CHARACTERISTIC	NEW ORLEANS		W. COAST FLORIDA		PUERTO RICO	
	SPHERE	SPAR	SPHERE	SPAR	SPHERE	SPAR
Significant Wave Height (Ft.)	58.1	58.1	45.8	45.8	44.2	44.2
Period of Max. Energy (Secs)	15.91	15.91	13.67	13.67	13.8	13.8
Extreme Surface Current Vel (Knots)	2.45	2.49	5.0	5.0	2.76	2.76
Max. Wind Speed (Knots)	100.3	100.3	113.8	113.8	92.8	92.8
Max. Spectral Density (FT ² -Sec)	4804.9	4804.9	2565.6	2565.5	2412.6	2412.6

Table 57: Site Wave and Current Characteristics

TABLE 58: MONTHLY AVAILABLE THERMAL GRADIENTS (Between Ambient Temp and Temp at 3000' below water surface) & ANNUAL TOTAL THERMAL CAPACITY

Available to a Depth of 3000'

Month of Yr.	West Coast of Florida	New Orleans	Puerto Rico
JAN.	19.0	18.0	20.8
FEB.	19.0	17.1	20.2
MAR.	18.0	16.5	20.1
APR.	20.	18.5	20.7
MAY.	20.7	20.0	22.7
JUN.	22.8	23.5	22.3
JUL.	24.0	24.0	22.4
AUG.	24.0	24.1	22.7
SEP.	23.1	23.1	23.2
OCT.	22.0	22.5	23.0
NOV.	20.5	20.0	23.0
DEC.	19.3	19.5	21.6
Annual Thermal Capacity (°C - Month)	252.4	246.8	262.7

The effects on the site due to these considerations are described by the determination of maximum plant size and minimum plant spacing, which indirectly are an indication of the disturbance introduced by an OTEC plant in the near and far fields, respectively.

8.2.2 Effects on Sea Surface and Waves

With respect to the effects of removing large quantities of water from the sea surface, it has been found [45] that the currents caused by the warm water pumps within the first 10 feet from the sea surface will be very weak and hardly detectable against the average ocean current present around the platform. Near the surface, the dominant flow pattern will be the classic non-divergent horizontal flow around a cylinder, as shown in Figure 60 for the spar platform. There are two stagnation points along the current vector on each side of the platform. The perturbation in the horizontal current field will extend three to four platform radii in all directions.

The effect on larger waves will be small, but small choppy waves will behave strangely at the sea surface near the platform.

8.3 Site Effects on the OTEC Platforms

8.3.1 Effects at Any Site

The considerations that must be taken into account in designing an OTEC platform to survive and operate safely at an ocean site are many. In this section it is intended to discuss a few aspects which received some special attention.

a. Shoaling

Since it is desirable to submerge the platforms to the least depth allowed by motion considerations from a structural standpoint, the effects of large waves breaking on the platform main decks were considered.

It was found [45] that there will be little shoaling effect because shoaling occurs only over distances of many hundreds of gravity wave lengths. The largest diameters of the OTEC platforms are of the order of the lengths of waves with 8 second periods. The flow field due to the passage of the waves is difficult to treat analytically, but for all but the hurricane conditions it is relatively small compared to the currents generated by the near surface sink and to the ocean currents at the three sites.

The most evident feature of the possible wave motion effects at the intake grills for the warm water is that the oscillatory currents in the waves can reinforce the flow into the intakes at times; and at other times cancel it. For waves that just happen to be 370 ft. long for the sphere or 230 ft. for the SPAR the wave currents will be into, or out from, the grills on both sides at the same time, and zero at right angles.

These currents at the intakes can be as follows at the screens:

SPAR

FIGURE : 60
OCEAN CURRENT, 4 FT/SEC
90 FT DEPTH
HORIZONTAL FIELD
OF FLOW
COMBINED SINK AND
FLOW AROUND A
CYLINDER

	Hurricane Significant Wave	Hurricane Max Wave	20 Ft SS6	Max SS6	12 Ft SS5	Max SS5
SPAR	5.5 Ft/Sec	10 Ft/Sec	2.67	3.7	0.8	1.6
SPHERE	11 Ft/Sec	20 Ft/Sec	3.3	7.4	1.44	2.9

Period.
= 12 Sec

Period.
= 13 Sec

It should be noted, however, that even sea state 5 will be rare. The currents can be quite different from one side to the other of the platform. The wave currents at 90 ft. will be comparable to the currents caused by the combined mean flow and ocean currents.

b. Operability and Survivability at Sites

In general there should be no problem with operational reliability and survivability due to site considerations. If problems arise they will occur when hurricanes pass nearby and the waves become large, however both winds over 20 knots and the attendant waves are relatively infrequent at all sites. It should be noted though, that the submergence of the two platforms appears to be adequate to place them out of the range of trouble.

8.3.2 Variations in Platforms Due to Site Changes

Each of the potential deployment sites possesses its own peculiar characteristics in waves, currents, wind and isothermal layer distribution. Each of these also have various degrees of impact on the OTEC platform design, operation, deployment and costs. In general, the platform hull, seawater and positioning systems are most sensitive to site characteristics, and the platform service, and mission support systems are sensitive only to a lesser degree.

a. CWP Configurations

The forces and bending moments along a CWP are greatly influenced by the structural properties of the CWP, the motion characteristics of the OTEC platform to which the CWP is attached, and the profile of the wave spectrum.

Table 57 shows that the maximum spectral density during extreme conditions at the New Orleans site is almost twice that at either the Florida or Puerto Rico sites. As a result, the CWP stress of a GRP pipe, fixed attachment, rigid along the length, non-buoyant section are less for the Spar at either the Florida or Puerto Rico sites, than at the New Orleans site. The total stresses for the Spar are less than that for the Sphere at the corresponding site. Because of buckling criteria consideration, the minimum wall thickness for a GRP CWP of 101' ID, is 8 inches. The final CWP configurations are as follows:

- o GRP, fixed attachment, rigid, non-buoyant section, 10-101', wall thickness 8" for the spar for all three sites.
- o The same GRP pipe for the sphere for both the Florida and the Puerto Rico sites, but 16" thick pipe for the New Orleans site, (Table 59).

b. Mooring Configurations

The mooring size is determined by the drag forces acting on the platform. The drag is greatly influenced by the site characteristics, such as surface current velocity, current profile, max. wind speed. The current characteristics are the most significant factors. Table 57 shows that the Florida site has the worst current condition, and the New Orleans and the Puerto Rico sites are comparable to each other. The total drag in the extreme condition at the Florida site is about three times that at either the New Orleans or the Puerto Rico sites.

Because of the large drifting drag experienced by the platform at the Florida site, a three-leg HCL link mooring system was employed as discussed in Section 3.6. Since drags at the other two sites are only one third that of the Florida site, a less costly HCL link and/or more conventional wireline mooring configurations will meet the operational requirements for both sites. MR&S has proposed that a three-leg HCL 30MN link with free-fall anchors be used for the sphere and a ten-leg mooring 5" wire leg with free-fall anchors be used for the spar, as shown in Table 59.

c. Thermal Energy Resources

The maximum power output of an OTEC platform is heavily dependent on the thermal resources available at the deployment site. The thermal energy resources are, among other things, a function of thermal gradients between surface temperatures and temperatures at a depth 3,000' below the water surface, of the energy capacity and of the thermal profile. The base line power output for an OTEC plant is 400 MWe Net, based on a thermal gradient of 40°F (i.e. 22.2°C). When the thermal gradient is other than 22.2°C, the power output can be represented by the following relationship, as given in [13]:

$$P_A = \frac{\Delta T_A}{\Delta T_O} \times P_O \quad (1)$$

where

$T_O = 40^\circ \text{ F or } 22.2^\circ \text{ C} = \text{base line thermal gradient}$

$P_O = 400 \text{ MWe} = \text{base line power output}$

$T_A = \text{Actual thermal gradient available}$

$P_A = \text{Actual maximum possible power output}$

The relationship is also depicted in Fig. 61. Table 58 and Fig. 59 show that there are only 4 1/2 months a year at the New Orleans and Florida sites during which the thermal gradients are 40°F (or 22.2°C) or more; whereas, there are 7 months a year at the Puerto Rico site. The annual thermal capacity which is the sum of products of thermal gradient and time span during which the gradient

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 (Pensacola)	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 (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 59: COMPARISON OF SITE CHARACTERISTICS

FIGURE : 61

exists, can be represented in terms of °C-months which then can readily be converted to MWe-months, according to Formula (a). The Puerto Rico site possesses the largest annual thermal capacity of the three, 262.7 °C-month. The Florida site is the second and the New Orleans site the third with annual thermal capacities of 252.4 °C-month and 246.8 °C-month respectively, Table 58. In order to meet the base-line power output requirement, the annual thermal capacity has to be 226.6 °C-months which is met by the three sites.

d. Deployment

MR&S has developed a deployment scenario in which a single construction site at Pensacola for all OTEC platforms is proposed. The semi-completed platforms are then towed to three OTEC sites for completion of construction and deployment.

Based on this construction and deployment scenario, the distance from the construction site to the OTEC site becomes a significant factor in deployment and construction costs of which transportation cost is directly associated with transportation distance.

The New Orleans site, located approximately at 27° 59'N, 88° 55'W, is about 180 nautical miles (210 miles) from the proposed construction site. The West Coast of Florida site is located approximately at 23° 55'N, 81° 54'W, and is about 285 N.M. (330 miles) from the site. The Punta Tuna site, located approximately at 17° 57'N, 65° 52'W, is 1215 N.M. is approximately 1400 miles from the site. In other words, if we assign transportation distance from Pensacola to the West Coast of Florida as unity, then it will be 0.6 for the New Orleans site and 4.2 for the Puerto Rico site.

e. Main Hull Structures

The main hull structure of the MR&S platforms is primarily based on the submergence depth of the platform and the height of the maximum storm wave. The minimum submergence depth for a storm has been considered as one half the $H_{1/10^6}$ wave height plus a 20 ft. green-water margin. It has been determined that this submergence depth is 80 ft. at both Tampa and Punta Tuna and about 97 ft. at New Orleans. Neglecting the differences in storm wave heights and considering a typical design depth at one-half of design draft, the design static heads at this depth are about 297', 297' and 314' for the sphere at the FL., P.R. and LA. sites; and 425', 425' and 445' for the spar at the same three sites.

Assuming a linear weight load relationship, then the main hull structure weight, excluding super-structure, for the sphere at the New Orleans site is about 646,226 LT. and for the spar is about 359,969 LT. The structure weight for the platforms at the Punta Tuna site are the same as that at the Florida site, Table 59.

f. Replenishment and Crew Transportation and Accommodation

The distance from the platform site to shore plays an important role on the replenishment, crew transportation and accommodation and operations. In general, the proximity of the platform site to shore results in easy replenishment and crew accommodation and transportation, and is therefore highly desirable.

The New Orleans site is about 65 N.M. (75 miles) from the nearest point of land, Mississippi Delta. The West Coast of Florida site is about 150 N.M. (170 miles) off shore of Charlotte Harbor on Tampa Bay; whereas, the Puerto Rico site is only 3.4 N.M. (4 miles) off the Punta Tuna point.

SECTION 9.0 CONCLUSIONS AND RECOMMENDATIONS

9.1 General

Based on the results obtained during the studies performed in connection with this study, the MR&S project team has arrived at conclusions regarding each phase of the work. The conclusions for the first phase of the work are contained in Volume I and the individual considerations and conclusions reached in connection with each detail study performed in Phase II with the conceptual designs for the spar and sphere platforms are summarized below in the order of detail of the respective subject areas.

9.2 Conclusions

9.2.1 OTEC Concept

- o The project team is convinced that the OTEC concept is workable. Many of the problems associated with OTEC thermal difference utilization have already been solved or are near a solution as a culmination of efforts of various DoE contractors. Specifically in relation to the heat exchanger technology and performance, very promising results were reported in the fifth OTEC Conference (1978). Also reported as having recorded major improvements are the biofouling and corrosion technology studies.
- o The OTEC Park concept, a number of platforms spaced equidistantly from each other within the bounds of thermal resource availability, appears to be commercially acceptable to power utility corporations; at least the few that the project team has been in contact with.
- o The other major problem areas that still remain were at the onset of this study the cold water pipe, the electrical transmission system, and perhaps to some extent, the positioning systems. It can be stated with a degree of certainty that at the termination of this study, the confidence level for the design and construction of a suitable mooring system for commercial size OTEC platforms has been increased considerably. Similarly, the confidence level for the design and construction of a cold water pipe configuration and hull attachment has reached a point where it is now considered practically feasible by the project team.

9.2.2 Platform/Hull and Systems

- o The two submerged platforms considered, the spar and the sphere, appear to be completely operable regardless of the sea conditions. They are operable under all sea conditions, and will survive the environmental conditions prevailing at each of the three sites. However, from the standpoint of comparing one platform to the other, the following are noteworthy:

- The acquisition, operating, and life cycle costs in terms of \$/KW for the sphere and spar platforms on the basis of one platform as well as for the OTEC Park, are shown below:

	SPHERE		SPAR	
	One Platform	Park	One Platform	Park
Total Acquisition Cost	2690	2122	2358	1865
Total Operating Cost	1756	1762	1595	1600
Life Cycle Cost	4446	3884	3953	3465

- As it can be seen in this table, the sphere costs appear to be higher than the spar costs.
- The motions of both platforms are moderate, however, the spar is superior in motions characteristics to the sphere for the baseline site of West Coast of Florida, as well as for the other two sites.
- The mooring costs and mooring performance and requirements for the sphere are more stringent for the New Orleans and Puerto Rico sites as compared to the spar. They appear to be about equal for the West Coast of Florida site.
- The length of cold water pipe for the spar is considerably shorter than the length for the sphere platform due to the nature of the spar shape. Additionally, the cold water pipe location is out of the high surface current velocity region.
- The seawater discharges on the spar are at a level below the thermocline as they are also for the sphere. The two platforms are equally acceptable as far as this specific requirement goes.
- o By adjusting ballast, the platforms can be raised to take advantage of the warmer surface waters during good weather (applicable to Sphere only).
- o Considering specifically the costs and operational performance parameters, the MR&S project team is inclined to conclude that spar may be a more logical choice compared to the sphere for a commercial OTEC plant.
- o As far as the systems making up the platform hull are concerned:
 - For the hull materials of OTEC platforms, reinforced concrete of 5,000 to 7,000 psi ultimate compression strength appears to be a feasible selection.

- A specific code for ocean floating concrete structures does not exist.
- The construction of the concrete hulls can be performed by using various methods.
- Steel and aluminum do not appear to be viable materials due to costs, long term properties, and difficulties in the construction.
- o Both the spar and the sphere cold water pipe connection to the hull can be designed in a number of alternative ways. After considering gimbaled and pinned type connections, MR&S project team has decided to use a cold water pipe that is rigidly attached to the platform, on the basis of cold water pipe stress calculations. The hull connection selected consists of pouring a concrete seal and structure between the Spar concrete hull and the GRP cold water pipe. In the case of the Sphere, the GRP cold water pipe extends two thirds of the way into the sphere and is then connected to the uppermost section made of steel and is permanently connected to the main deck.
- o As far as the service and support systems are concerned, there are no major problems in the designs and/or construction stages that should not be possible to solve at the time of deployment of OTEC platforms.
- o The OTEC equipment arrangement as developed by the MR&S project team reflects the optimum hydraulic efficiency available within the sizes and capacities of the heat exchanger, turbine generator, and pump combinations. The design of a most suitable seawater system does not appear to be a problem nor are any difficulties foreseen in the installation of individual OTEC cycle components.
- o The manning requirements for the OTEC platforms has been considered in some depth by the MR&S project team based on the recommendations of power utility companies.

9.2.3 Seawater System

- o The seawater system design reflected in the MR&S conceptual design drawings offers the optimum hydraulic, space utilization, and power requirement advantages. Sphere seawater system is more hydraulically efficient.
- o The system and component symmetry and the relative locations of heat exchangers, pumps, intakes, discharges, etc., were arranged on the basis of well developed hydraulic and heat transfer principles for the maintenance of optimum system performance.
- o The development of seawater system pumps, intake screens, and the large size gates and valves required to keep the system under control appears to be feasible and does not present any major extensions of the state-of-the-art.

9.2.4 Seakeeping Characteristics

- o Both platforms, the spar and the sphere, experience only small to moderate motions due to waves in a severe storm.
- o Shoaling effects from large waves are not expected to be serious.
- o The cold water pipe does not significantly affect the seakeeping characteristics of the platform.
- o The spar platform from a motion response standpoint appears to be preferable to the sphere platform.

9.2.5 Cold Water Pipe

- o Concrete cold water pipes do not appear feasible due to very high stresses.
- o Aluminum and steel cold water pipes appear much too expensive.
- o A rigid fiberglass reinforced plastic (GRP) cold water pipe appears feasible and represents a good balance between stress and buckling criteria.
- o Joints and gimbals along the pipe should be discarded because of risk, cost, construction problems, and difficulties in deployment and operational maintenance.

9.2.6 Positioning System

- o The drag forces for both platforms are very large, and the water depths of 4,000-6,000 ft. range generally renders the use of conventional mooring lines for positioning the platforms unfeasible.
- o The hollow cylindrical link concept appears to be a satisfactory answer to the mooring line requirements.
- o Accurate deployment of the mooring system will probably be a difficult operation.
- o Dynamic thrusters are not considered feasible from the standpoint of requiring very high parasitic loads on the OTEC generated electrical energy supply as well as from operational and maintenance requirements.

9.2.7 Facilities and Equipment

- o Existing steel and concrete construction facilities cannot be used to build the 400 MW size commercial OTEC spar and sphere platforms.
- o The West Coast of Florida around Pensacola provides a good area for the construction of both platforms.

- o Currently used concrete fabrication procedures can be employed to build both the platform types.
- o Because of the large drafts of both the spar and the sphere, a significant portion of the construction process will have to be carried out at an intermediate depth site and to be continued on the final deployment site for completion. This introduces an element of risk during storms and also makes for long supply lines.
- o As an alternative, the concept of the "artificial island" appears to be extremely promising to be used as a building site for OTEC demonstration and commercial plants for both the spar and the sphere designs.

9.2.8 Site Sensitivity

- o It appears feasible to design OTEC platforms for all of the three assigned deployment sites (West Coast of Florida, New Orleans, and Puerto Rico).
- o Platforms to be deployed at the West Coast of Florida site will require significantly stronger and costlier mooring systems because of greater currents.
- o Platforms at the New Orleans site will require significantly heavier and costlier hull structure and cold water pipes due to larger storm waves.
- o The distance to the nearest landfall is greater for the baseline site of West Coast of Florida than for either of the secondary sites. The Florida site is three times further from shore than the New Orleans site and two times further from the shore than the Puerto Rico site. This will introduce costly penalties in both size and length of the shore power transmission cable, life cycle power transmitted (due to inter-cable resistive losses, and the increased transportation costs for crew, supplies and equipment).
- o The available thermal resource at the Puerto Rico site is greater than at the other two sites, including the baseline site of West Coast of Florida.

9.2.9 Costs and Schedules

- o As mentioned earlier, the acquisition costs for the spar platform (\$943^M) are smaller than the acquisition costs for the sphere platform (\$1,076^M).
- o Similarly, the total operating costs for the spar, both per platform and per OTEC Park of eight platforms are smaller for the spar than for the sphere.
- o The corresponding life cycle costs for both platforms also compare in a similar fashion in that the spar platform costs in terms of \$/KW are \$3,953 and the corresponding figure for the sphere platform is \$4,446.

These are per platform costs. For an OTEC Park consisting of 8 platforms each, the corresponding life cycle costs are \$3465 /KW for the spar and \$3,884 /KW for the sphere platforms.

9.3 Recommendations

The conclusions outlined above lead to the following recommendations for any future OTEC research and development projects or actual design/construction studies involving both platforms:

- o Efforts should continue to further develop the OTEC energy park state-of-the-art and to answer the significant questions in terms of operational and deployment scenarios.
- o The ongoing DoE contracts for the riser and submarine cables making up the electrical transmission system should continue into actual constructability and economics studies. As it stands now, no cost economics predictions are possible with the existing information.
- o With respect to the specific Spar and Sphere platform designs, the following recommendations can be made at the termination of detailed conceptual designs for both:
 - Permanent ballast may be eliminated from the platform configurations and the volumetric displacement can be reduced accordingly.
 - Efforts should be made to agree on a specific procedure or code to cover all the factors of safety to be used in designing OTEC concrete platforms. The results of this procedure should then be verified by the industry.
 - The possibility of further increasing the maximum operating draft for the sphere and spar platforms to improve seawater system efficiency in extreme storm conditions should be investigated.
 - A more detailed finite element analysis of the main hull structural scantlings should be made.
 - The effects of long term immersion of the reinforced concrete structure in the seawater environment should be studied. Advanced technological methods of fabrication should be researched and a data bank should be established for use in future designs.
 - Studies of the latest offshore drilling and power industry automation techniques should be applied in a sufficiently detailed manner to the OTEC operational scenarios. The central hotel facility concept appears to be cost effective. The reliability of using such a system should be investigated and if found feasible and viable, it should be adopted.
- o Regulations to cover the platform service and support systems installations should be refined and drafted by the regulatory bodies so that future design efforts will have specific standards which can directly be applied to the design studies.

- Alternative arrangements should be considered for the OTEC equipment and other cycle components.
- o The possibility of using OTEC cycle components of different sizes, such as 25 MW heat exchangers along with 50 MW heat exchangers, should be investigated and a certain amount of redundancy should be provided. Constructability investigations appear to be necessary for large pumps and valves needed on the OTEC seawater systems. The estimates of physical parameters currently used are mere predictions and therefore not totally dependable.
- o Determination of the actual physical appearance of the heat exchangers will make their incorporation into future design efforts much easier. In this connection it is recommended that the results of power system contractors' studies on OTEC components be made available to platform designers as soon after their completion as possible.
- o The modular tube bundle design is used in the performance of this design study and it is recommended that it be incorporated into future designs as well.
- o Shell-less heat exchangers, in which the surrounding structure serves as the shell, should also be considered.
- o The design of hollow cylindrical links should be scrutinized, particularly from the standpoint of corrosion and long term joint effectiveness.
- o Studies should be performed to verify whether the factor of safety for the line breaking strength of 2.0 is adequate to account for the dynamic forces of the platform, particularly the slow drift oscillation forces.
- o The positioning of the mooring leg connection appears to be quite critical. Most likely, the leg connection point should be moved to a lower portion of the hull.
- o The cold water pipe design must be further investigated and finite element analyses of the stresses acting on the cold water pipe/hull combination should be verified; various analysis procedures used to date should be confirmed.
- o Even though the fiberglass reinforced plastic cold water pipe appears to be the most feasible choice as far as the 400 MW spar and sphere platforms are concerned, should any advances in other probable materials be obtained in the meantime, such as the elastomeric pipe or perhaps a builtup steel section, these should be investigated further and trade-offs should be performed between various materials to determine the final material for the cold water pipe.
- o Further studies on the seakeeping performance of selected platforms should be made to determine the improvements obtainable with slight hull and surface piercing column variations and submergence depths.

- o More detailed data development for the selected OTEC deployment sites must be continued so that the detail design studies for commercial plants as well as demonstration plants can be based on a more reliable data base.

SECTION 10.0
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. GILBERT/COMMONWEALTH, DEPARTMENT OF ENERGY, DIVISION OF SOLAR TECHNOLOGY, OCEAN ENGINEERING PLAN, NOVEMBER 18, 1977
3. TSCHUPP, E.J., COHEN, R., ANALYSIS OF VARIOUS OTEC MISSIONS, OTEC '78 PAPER PRESENTED IN MIAMI, FLORIDA, FEBRUARY 1978
4. 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
5. M. ROSENBLATT & SON, INC., REPORT NO. 5142-4, OTEC COMMERCIAL PLATFORM, RESULTS OF TASK 4, SYSTEMS INTEGRATION AND EVALUATION, NEW YORK, NEW YORK, MARCH 20, 1978
6. PRIVATE CONVERSATION BETWEEN BURNS & ROE, INC. AND UTILITY COMPANIES
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 STEEL VESSELS, NEW YORK, 1978
9. STRUCTURAL DESIGN MANUAL FOR NAVAL SURFACE SHIPS, NAVSEA 0900-LP-097-4010
10. HAYNES, H.H., NORDLY, B.A., CONCRETE CYLINDER STRUCTURES UNDER HYDROSTATIC LOADING, ACI JOURNAL, FEBRUARY 1976
11. AMERICAN CONCRETE INSTITUTE, BUILDING CODE REQUIREMENTS FOR REINFORCED CONCRETE, (ACI 318-71), 1972
12. FEDERATION INTERNATIONALE DE LA PRECONTRAINTE, RECOMMENDATIONS FOR THE DESIGN AND CONSTRUCTION OF CONCRETE SEA STRUCTURES, JULY 1977
13. DEPARTMENT OF ENERGY LETTERS TO PLATFORM CONTRACTORS DATED JANUARY 10, '78 AND FEBRUARY 15, 1978
14. HANDBOOK OF CHEMISTRY AND PHYSICS, 38th EDITION, CHEMICAL RUBBER PUBLISHING COMPANY, NEW YORK, 1957
15. AMERICAN BUREAU OF SHIPPING, RULES FOR BUILDING AND CLASSING OFFSHORE MOBILE DRILLING UNITS, NEW YORK, 1976
16. KIM, C.H., CALCULATION OF HYDRODYNAMIC FORCES AND MOMENTS OF ROSENBLATT OTEC PLATFORMS, DAVIDSON LABORATORY, TECHNICAL REPORT SIT-DL-78-2017, APRIL 1978
17. 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

18. 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
19. PAULLING, J.R., A LINEARIZED DYNAMIC ANALYSIS OF A COUPLED OTEC COLD WATER AND HMB-1 BARGE SYSTEM, PREPARED FOR MORRIS GURALNICK ASSOCIATES, INC. 1977
20. ANKUDINOV, VLADIMIR, BARR, RODERICK A., SEAKEEPING PREDICTIONS FOR OTEC SPAR PLATFORMS WITH VARIOUS CWP DESIGNS, HYDRONAUTICS, INC., TECHNICAL NOTE 7874-1, APRIL 1978
21. DEPARTMENT OF ENERGY, OTEC DEMONSTRATION PLANT ENVIRONMENTAL PACKAGE, REVISED JANUARY 1978
22. FARMER, WALTER E., MOORING ANALYSIS OF MULTIPOINT OTEC MOORING SYSTEM, OCEANIC DEVELOPMENT COMPANY, 10 APRIL 1978
23. AMERICAN SOCIETY OF HEATING, REEFER, AND AIR CONDITIONING ENGINEERS GUIDE (ASHRAE), F468 CH25, AIR DUCT DESIGN METHODS, 1972
24. PRIVATE COMMUNICATION BETWEEN M. ROSENBLATT & SON, INC., AND PRICE BROTHERS, INC., MARCH 16, 1978
25. PRIVATE COMMUNICATION BETWEEN M. ROSENBLATT & SON, INC., AND OWENS CORNING FIBERGLAS CORPORATION, MARCH 23, 1978
26. FINK, CHARLES; FARMER, WALTER E.; WALLER, DAVID B.; HOMES, JOHN F.; THEORETICAL DETERMINATIONS OF THE SEAKEEPING RESPONSE OF TUNED SPHERE STABLE PLATFORMS, OCTOBER 26, 1977, REPORT TSI-4032-2
27. FINK, CHARLES; FARMER, WALTER; WALLER, DAVID; MASCAROLA, DAVID B.; CHILDERS, JAMES B.; TUNED SPHERE PLATFORM ANALYSES FOR OTEC POWER PLANTS, NOVEMBER 10, 1977, REPORT NO. TSI-2485-1
28. M. ROSENBLATT & SON, INC., REPORT NO. 5142-1, RESULTS OF TASK 2A, SYSTEMS AND REQUIREMENTS ANALYSES, OCTOBER 7, 1977
29. M. ROSENBLATT & SON, INC., REPORT NO. 5142-3, RESULTS OF TASK 3, TECHNOLOGY REVIEW, OCTOBER 31, 1977
30. KING, C.H., CHOU, F., MOTIONS OF A SEMI-SUBMERSIBLE DRILLING PLATFORM IN HEAD SEAS, MARINE TECHNOLOGY, VOLUME 10, No. 2, APRIL 1973
31. CHUNG, J.S., FORCES ON SUBMERGED CYLINDERS OSCILLATING NEAR A FREE SURFACE, JOURNAL OF HYDRONAUTICS, VOLUME 11, NO. 3, JULY 1977
32. LITTLE AND DAVIDSON, H., OCEAN THERMAL POWER PLANTS, COLD WATER PIPE, SEAWATER PUMPS AND PLATFORM STATION KEEPING, WESTINGHOUSE ELECTRIC CORPORATION, SEPTEMBER 27, 1977
33. ANKUDINOV, VLADIMIR, AND BARR, RODERICK, A., SEAKEEPING PREDICTIONS FOR AN OTEC TUNED SPHERE PLATFORM WITH VARIOUS CWP DESIGNS, HYDRONAUTICS, INC., TECHNICAL NOTE 7882-1, APRIL 1978

34. CUMMINGS, GEORGE, LEARNING CURVE FOR CONCRETE PLATFORMS NOT YET COMPLETED, OCEAN INDUSTRY MAGAZINE, VOLUME 13, NO. 3, MARCH 1978
35. M. ROSENBLATT & SON, INC., REPORT NO. 5142-5, RESULTS OF TASK 8, SPAR AND SPHERE PLATFORM COSTS AND TIME SCHEDULE, MARCH 31, 1978
36. NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION LETTER TO M. ROSENBLATT & SON, INC., DATED MARCH 9, 1978
37. GILBERT/COMMONWEALTH MEMORANDUMS TO NOAA DATED AUGUST 15, 23, 26, 1977
38. SIMPLEX CORPORATION LETTER TO M. ROSENBLATT & SON, INC., DATED MARCH 22, 1978
39. PRIVATE COMMUNICATION WITH MCDONOUGH MARINE SERVICE, MARCH 16, 1978
40. LITTLE, T.E., ET AL, PLATFORM STATIONKEEPING STUDY, FINAL REPORT, WESTINGHOUSE CORPORATION, JANUARY 1978
41. PRIVATE CORRESPONDENCE BETWEEN U.S. STEEL RESEARCH LABORATORY AND SYMONS CORPORATION, FEBRUARY-MARCH, 1978
42. 1978 DODGE GUIDE TO PUBLIC WORKS AND HEAVY CONSTRUCTION COSTS, MCGRAW-HILL, 1977
43. PRIVATE COMMUNICATION WITH MR. A. POTTER OF PRICE BROTHERS, INC., DATED MARCH 20, 1978
44. COUCH, J.C., THE COST SAVINGS OF MULTIPLE SHIP PRODUCTION, UNIVERSITY OF MICHIGAN, MARCH 1969
45. PIERSON, WILLARD J., JR., PROFESSOR, STUDY ON SITE SENSITIVITY FOR ROSENBLATT OTEC PLATFORMS, APRIL 1978
46. HAVELOCK, T., WAVES DUE TO A FLOATING SPHERE MAKING PERIODIC HEAVING OSCILLATIONS, PROCEEDINGS OF THE ROYAL SOCIETY, VOLUME 231, 1955
47. GARRISON, C., HYDRODYNAMIC COEFFICIENTS FOR TUNED SPHERE PLATFORMS, APPENDIX A OF THEORETICAL SEAKEEPING STUDIES FOR A TUNED SPHERE OTEC PLANT BY R.A. BARR, P. MURPHY, AND P. MAJUMDAR, OCTOBER 1977, HYDRONAUTICS, INC., TECHNICAL REPORT 7780-1
48. FRANK, W., OSCILLATION OF CYLINDERS IN OR BELOW THE FREE SURFACE OF DEEP FLUIDS, DTMSRDC REPORT 2375, OCTOBER 1967