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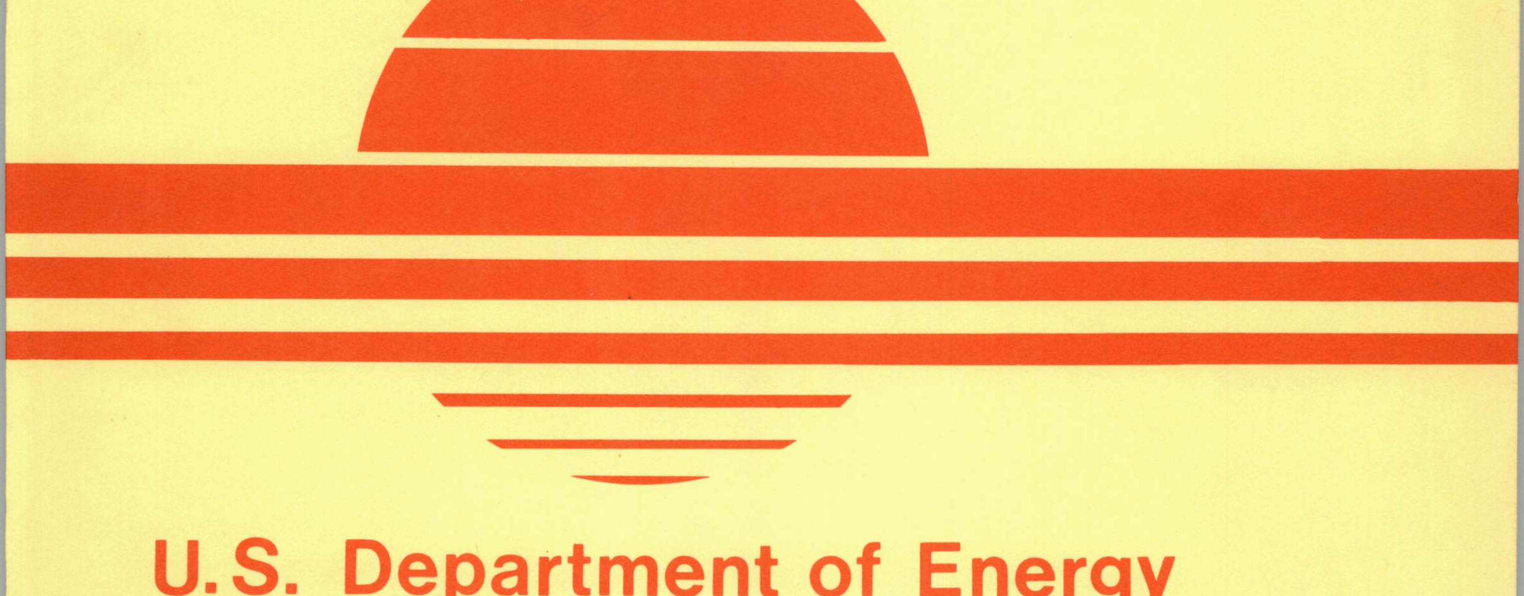
# REVIEW OF REPORTS BY GIBBS AND COX, INC., LOCKHEED MISSILE AND SPACE CORPORATION, M. ROSENBLATT AND SONS, ON 400 MWe COMMERCIAL OTEC PLANTS

Final Report

June 1979

Work Performed Under Contract No. ET-78-C-02-4931

John J. McMullen Associates, Inc.
New York, New York



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# REVIEW OF REPORTS BY
# GIBBS AND COX, INC.
# LOCKHEED MISSILE AND SPACE CORPORATION
# M. ROSENBLATT AND SONS
# ON 400 MWe COMMERCIAL OTEC PLANTS

FINAL REPORT

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Prepared Under Contract to
VSE CORPORATION
2550 Huntington Avenue
Alexandria, Virginia 22303

June 1979

Prepared by
U.S. DEPARTMENT OF ENERGY
Under Contract No. ET-78-C-02-4931

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# I. INTRODUCTION

## 1.1 GENERAL

The Department of Energy contracted with Gibbs and Cox, M. Rosenblatt and Son and Lockheed Missile and Space Corporation to prepare conceptual designs, cost estimates and analyses for a 400 MWe OTEC Commercial Size platform.

Each contractor was directed to investigate two predetermined hull configurations and to relate them to one operating site, selected by DOE.

A total of 6 designs, covering sphere, spar, ship and semisubmersibles were studied by the three contractors. The results of their investigations were presented to DOE in Washington on May 8, 1978.

The presentations showed that whereas a considerable data base had been built, no clear conclusions had emerged with respect to the direction that future design of the commercial platform should take.

JJMA has been directed by Value Engineering on behalf of DOE to review the conceptual designs and the accompanying data base prepared by the three contractors. The intent of this review is to propose to DOE the answers to the following questions, based on the results of studies by the three contractors:

1) If DOE were to build a 400 MW OTEC plant, starting now, what should they build?

2) What are the reasons for the decisions?

3) What would it cost?

## 1.2 BACKGROUND MATERIAL AND BASIC DESIGN INPUT

The following table shows the distribution of candidate platform configurations among the three contractors.

| | SHIP | SPHERE | SPAR | SEMI-SUB |
|---|---|---|---|---|
| Gibbs and Cox | X | | | X |
| MR&S | | X | X | |
| Lockheed | X | | X | |

LMSC was directed by DOE to base their study on a site off New Orleans. Gibbs and Cox was to utilize Keahole Point off Hawaii and Rosenblatt was to utilize the West Coast of Florida.

The principal environmental criteria given as characteristic of each of the selected sites are summarized below.

| SITE | HAWAII | NEW ORLEANS | W.COAST FLORIDA |
|---|---|---|---|
| Water depth, ft. | 3150 | 4650 | 4592 |
| Depth for 36°F T: | | | |
| Max. ft. | 3280 | 4650 | 4592 |
| Min. ft. | 1560 | 1560 | 1476 |
| Current Velocities: | | | |
| Extreme, kts. | 2.18 | 2.49 | 5.0 |
| Normal, kts. | 1.13 | 1.17 | 2.5 |
| 100 Year Return Period: | | | |
| Max. wind, kts. | 65.7 | 100.3 | 113.8 |
| Gusts, kts. | 95.2 | 145.4 | 165.0 |
| Period Max. Energy Sec. | 12.71 | 15.91 | 13.28 |
| Sign. wave ht. ft. | 35.9 | 58.1 | 45.8 |

The designs were required to satisfy the following basic DOE requirements:

- o They should be suitable for a plant of 400 MWe
- o They should be designed for 100 year return period storm conditions.
- o The required minimum operational life at sea is 40 years.

The documents generated by the three contractors as part of the conceptual study are listed in References 1-3. Documents generated by the same contractors as part of an earlier commercial plant integration study, and listed in References 4-6 constitute a supporting data base with partial applicability to the present designs.

## 1.3 DEFINITION OF THE PROBLEM

The intent of the concept design studies prepared by the three contractors was to generate the information from which decision makers at the DOE could select a platform configuration for further development. A review of the contractor's output showed that due to differences in approach and to other causes discussed in this report additional work would have to be performed before the data generated by the contractors could be used for its intended purpose.

A main cause for concern was the extent of cost variations in what appeared, superficially, to be comparable items.

The following comments extracted from a cost analysis by Doty Associates (Reference 7), illustrate the extent of these differentials.

1. Platform System Cost varies by a factor of two and one-half from the lowest cost platform to the highest cost platform; CWP System Cost varies by almost a factor of two from the lowest cost CWP to the highest cost CWP and Industrial Facilities Cost varies by a factor of one hundred from least to most expensive.

2. Significant differences between contractors' cost exist for Sea Water System with estimates ranging from $91.3 to $160.6M.

3. The CWP was specifically excluded from the Sea Water System, and is treated as a separate item. The CWP systems cost ranged from $35.6M to $112.9M.

4. Estimates for Position Control Systems range from $15.3M to $52.1M. Estimates for platform Support Systems range from $14.7M to $35.6M. Biofouling and Corrosion Control for the platform is variously estimated at $0.5M for Gibbs and Cox steel configuration and zero (Lockheed) or $7.1M (Rosenblatt).

Another area of concern was the existence of differences between the three contractors with regard to major design options and subsystems. Some of these differences resulted from a design and optimization process associated with a given platform configuration. Others, such as site location were the result of direction from DOE. Some of the variations however, reflected differences in design philosophy between the Contractors which required justification or resolution before the platforms could be compared on an equal basis.

Finally, it was felt that the various proposals represented different levels of attainment with respect to the state of the art and that consequently they also represented different levels of confidence with respect to the validity of the cost estimates. These differences in the level of confidence and in the probability of an overrun needed recognition in a realistic cost assessment. While this had been done in most cases it had not been uniformly treated by the three contractors and a uniform methodology was required, applicable to all the platforms.

## 1.4 SCOPE OF EXAMINATION, LIMITATIONS AND ASSUMPTIONS

Each contractor had studied in depth two, 400 MWe platform configurations and selected a preferred concept as listed below on the basis of a consistent life cycle cost analysis.

| CONTRACTOR | LMSC | GIBBS ANC COX | ROSENBLATT |
|---|---|---|---|
| Preferred Concept | Ship Shape | Ship Shape | Spar |

The task that remained was to compare on a common basis these three preferred concepts. In addition, and by direction from DOE, LMSC's spar was also to be studied and compared to the Rosenblatt's spar concept in order to obtain a comparison of internal versus external heat exchangers for the spar. The selected concepts are shown, in outboard profile in Figures 1.1 through 1.4.

Practical limitations imposed by schedule and budgetary constraints required that the scope of JJMA's activities be directly related to the realization of the intent of the review.

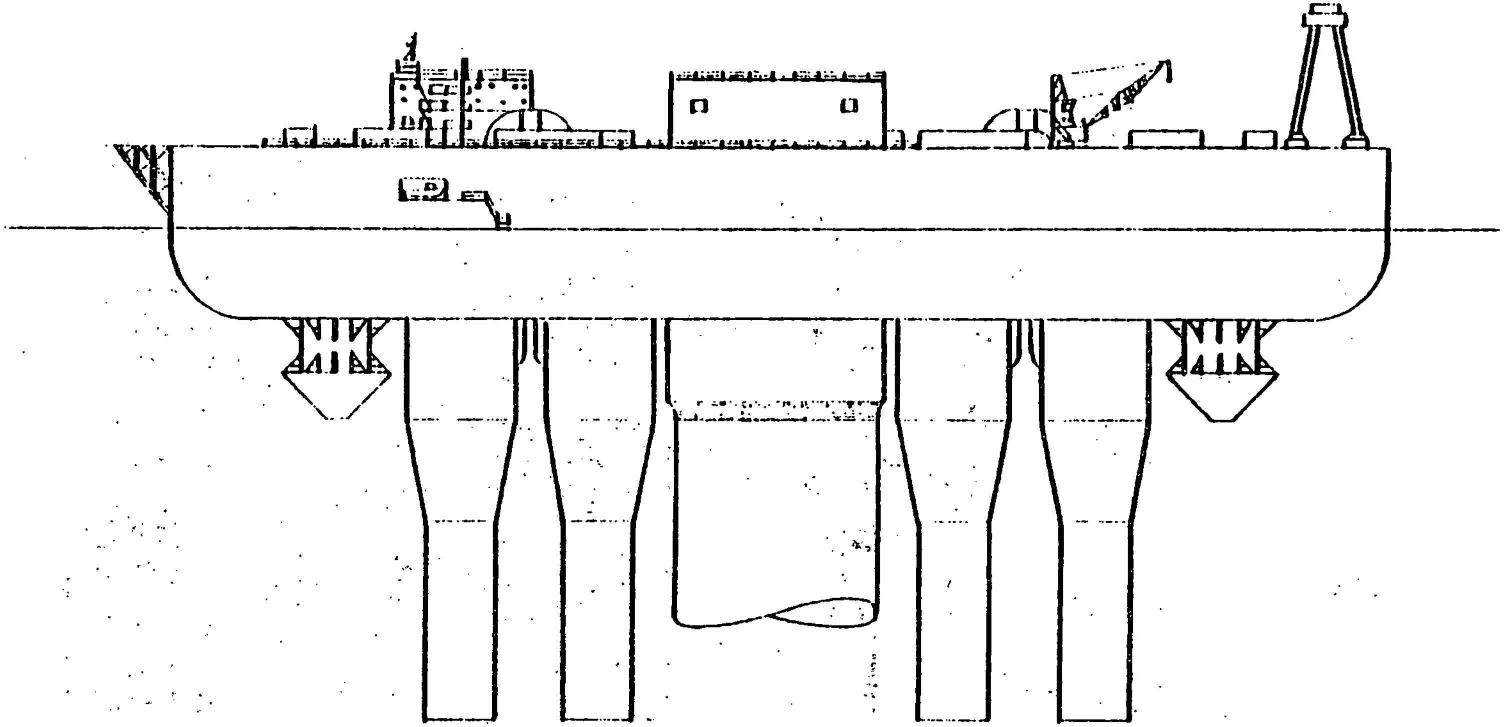
The following guidelines were accordingly established.

- One site only, off Tampa, Florida was to be considered.
- The information required for this review was to be taken from the data base generated by the three consultants. Independent technical work by JJMA was to be kept to a minimum consistent with the intent of this review.
- In developing evaluation criteria and costing models the maximum utilization was to be made of data and models already generated by the Contractors.

JJMA carried out its evaluation by addressing sequentially the following areas of examination:

- Identify differences in approach between the three contractors requiring engineering studies for their resolution. Carry out trade offs or engineering analysis as appropriate and resolve these differences.
- Modify as required the OTEC platforms systems to suit the unified site location determined by DOE.
- Review Commercial Plant reports to identify discrepancies in costing approaches, and modify costs as required to reflect the above findings.

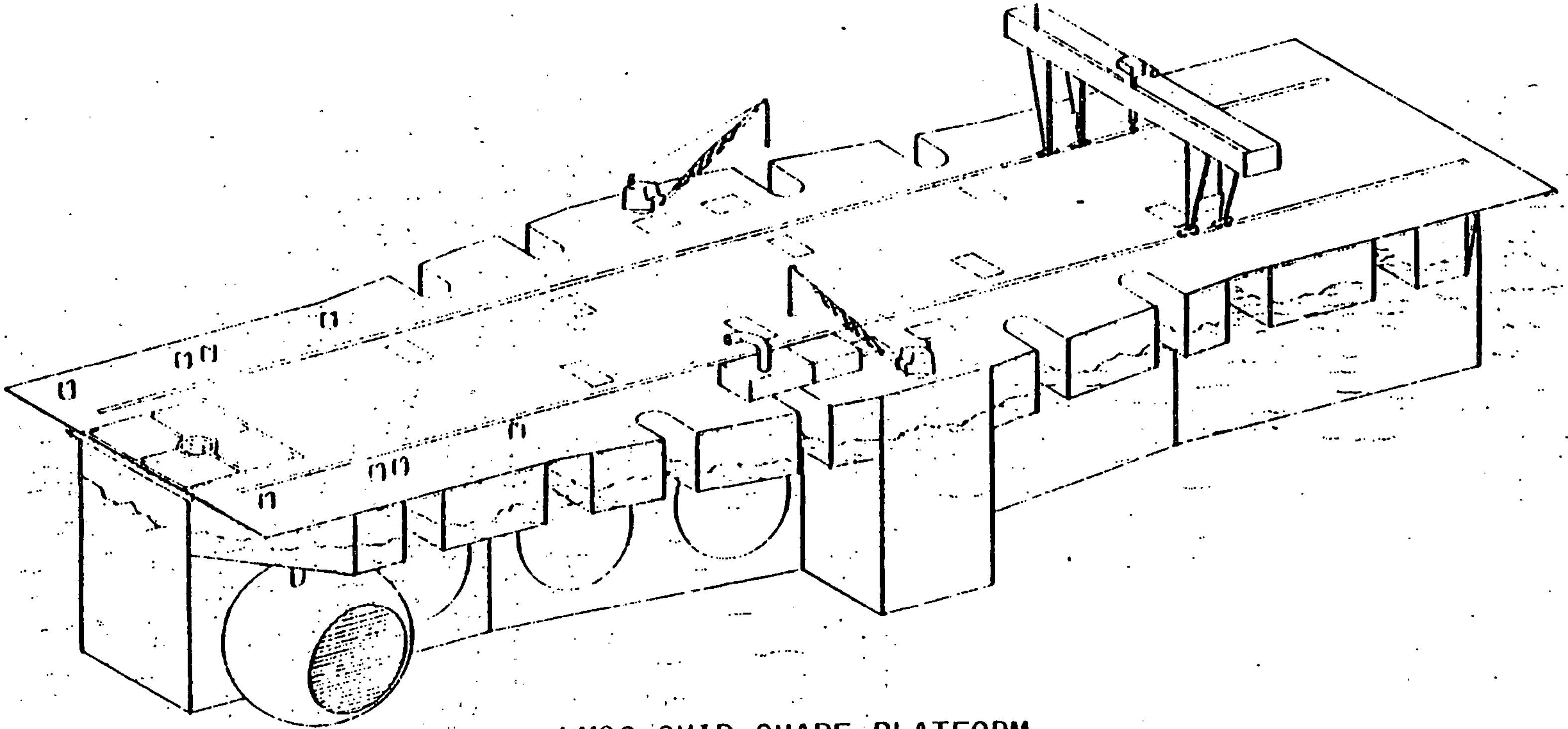
- Develop evaluation criteria, apply these criteria to the data generated in this study, rank the platforms and select a preferred concept.



GIBBS AND COX SHIP

| | |
|---|---|
| LENGTH OVERALL | 189.0M |
| BEAM | 91.0M |
| DEPTH | 25.9M |
| DRAFT | 13.7M |
| DISPLACEMENT | 315,000 TONS |

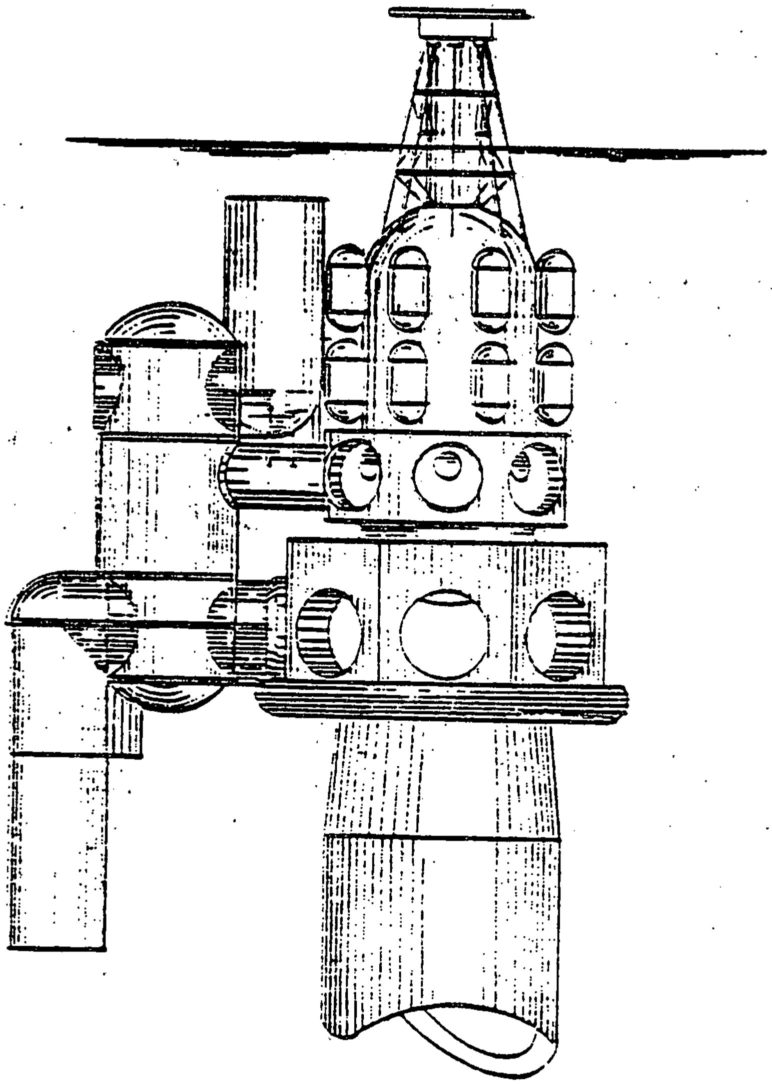
FIGURE 1.1



LMSC SHIP SHAPE PLATFORM

| | |
|---|---|
| L.O.A. | 210M |
| BEAM (MAX.) | 58M |
| DEPTH | 34M |
| OPERATING DRAFT | 28M |
| DISPLACEMENT | 258,000 TONS |

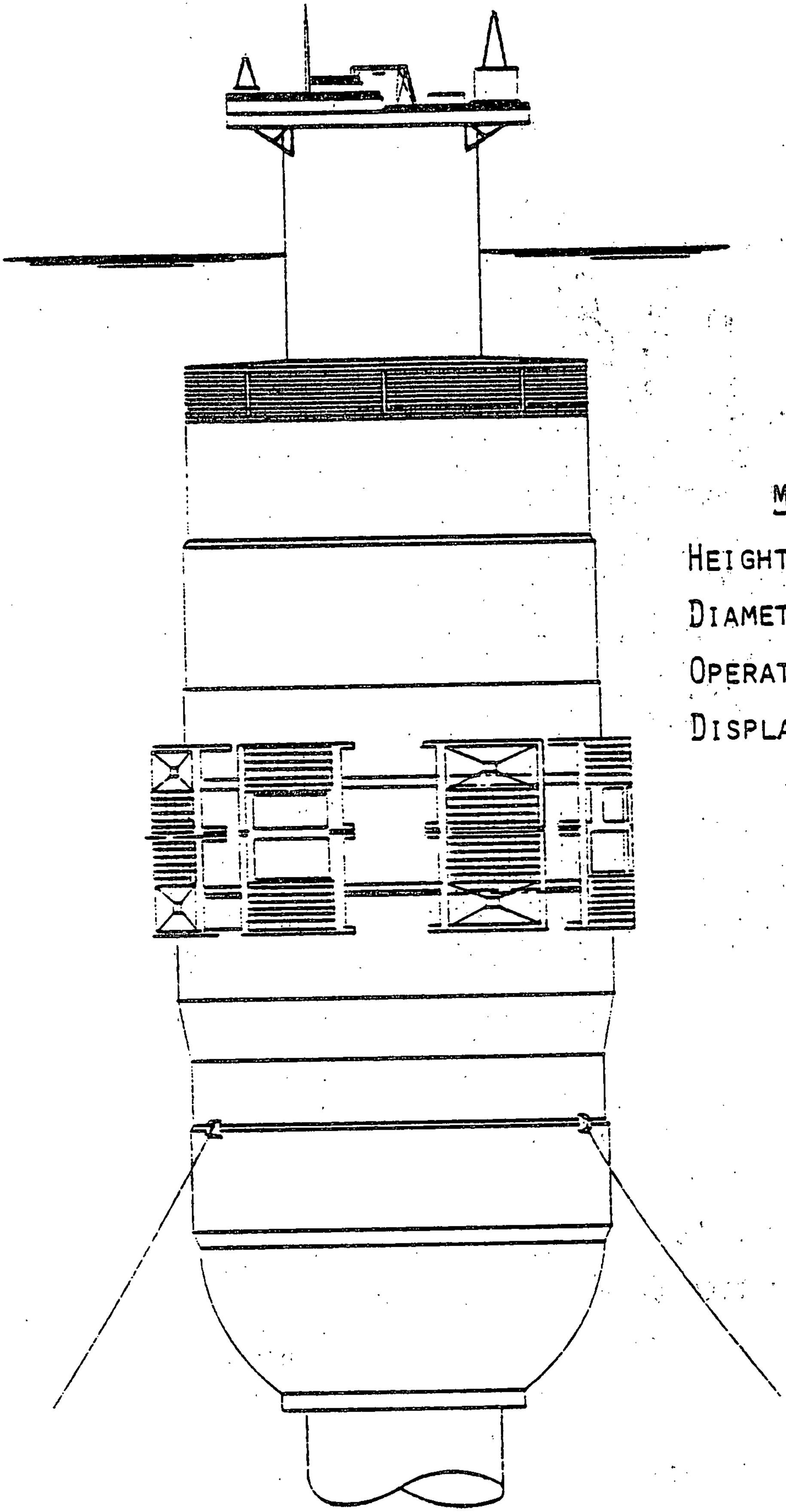
FIGURE 1.2



LMSC SPARE SHAPE

|  |  |
|---|---|
| HEIGHT OVERALL | 126M |
| WIDTH, MAX. | 58M |
| OPERATION DRAFT | 100.9M |
| DISPLACEMENT | 246,000 TONS |

FIGURE 1.3



MR&S SPAR

| | |
|---|---|
| HEIGHT OVERALL | 235.4M |
| DIAMETER, MAX. | 84.5M |
| OPERATING DRAFT | 212M |
| DISPLACEMENT | 308,000T |

FIGURE 1.4

## 2. ENGINEERING STUDIES

### 2.1 GENERAL

A study of the reports by the three contractors showed that engineering and trade off studies would be required in the areas listed below:

a) CWP System

The CWP systems had been designed by the three contractors through the application of differing design philosophies and levels of conservatism. Engineering studies were required to identify basic differences in design approach and to resolve these to the extent possible. The pipes also required modification to suit the new platform location selected by DOE.

b) Position Control Systems

The three contractors had designed their mooring systems for the sites designated to them by DOE. Each of these sites has its own pattern of environmental energy and as a result they had come up with radically different mooring loads and mooring concepts. The selection of a new site, applicable to all the platforms made it necessary for JJMA to redesign the mooring systems for all four platforms.

c) Sea Water Systems

The Seawater System is the biggest and costliest of the platform systems. An engineering review appeared appropriate prior to a cost comparison, both to ensure uniformity of approach and to check for technical adequacy.

d) Trade Off Study - Long versus Short Diffuser Ducts

It was noted that MR&S was using long diffuser ducts for the seawater systems to minimize parasitic loads, thereby increasing platforms size, whereas the other contractors were using shorter diffusers and accepting the larger parasitic losses as the penalty for reduced platform costs. Trade off studies were required to resolve those differences.

e) Hull and Structure

The platforms are different in concept and material and show cost differentials in the order of 3.5 to 1. Engineering analysis is required, before differentials of this magnitude are accepted, in order to ensure that loading concepts and design criteria reflect approximately similar standards and that uniform costing approaches are employed.

Moreover basic design changes resulting from the engineering studies discussed in paragraphs 2.1a through c required integration within the hull structure and development of corresponding hull structure costs.

f) Biofouling and Corrosion Control

A comparison was made of biofouling and corrosion control methods to ensure consistency of approach and costing.

g) Cold Start up Provisions

Cold start up provisions by the three OTEC contractors were reviewed for adequacy.

The results of the engineering studies are discussed in the following pages.

## 2.2 COLD WATER PIPE DESIGNS

### 2.2.1 Overview of CWP Design by the Three DOE Contractors

#### a) M. Rosenblatt and Son

MR&S reasoned that the work carried out up to that time on OTEC platforms had shown that wave induced motions of spar platforms were relatively low with correspondingly small CWP bending stresses. They accordingly concluded that the high cost associated with flexible connections would not be justified for a spar and directed their analysis to a CWP pipe rigidly connected to the OTEC platform and with rigid connections along its length.

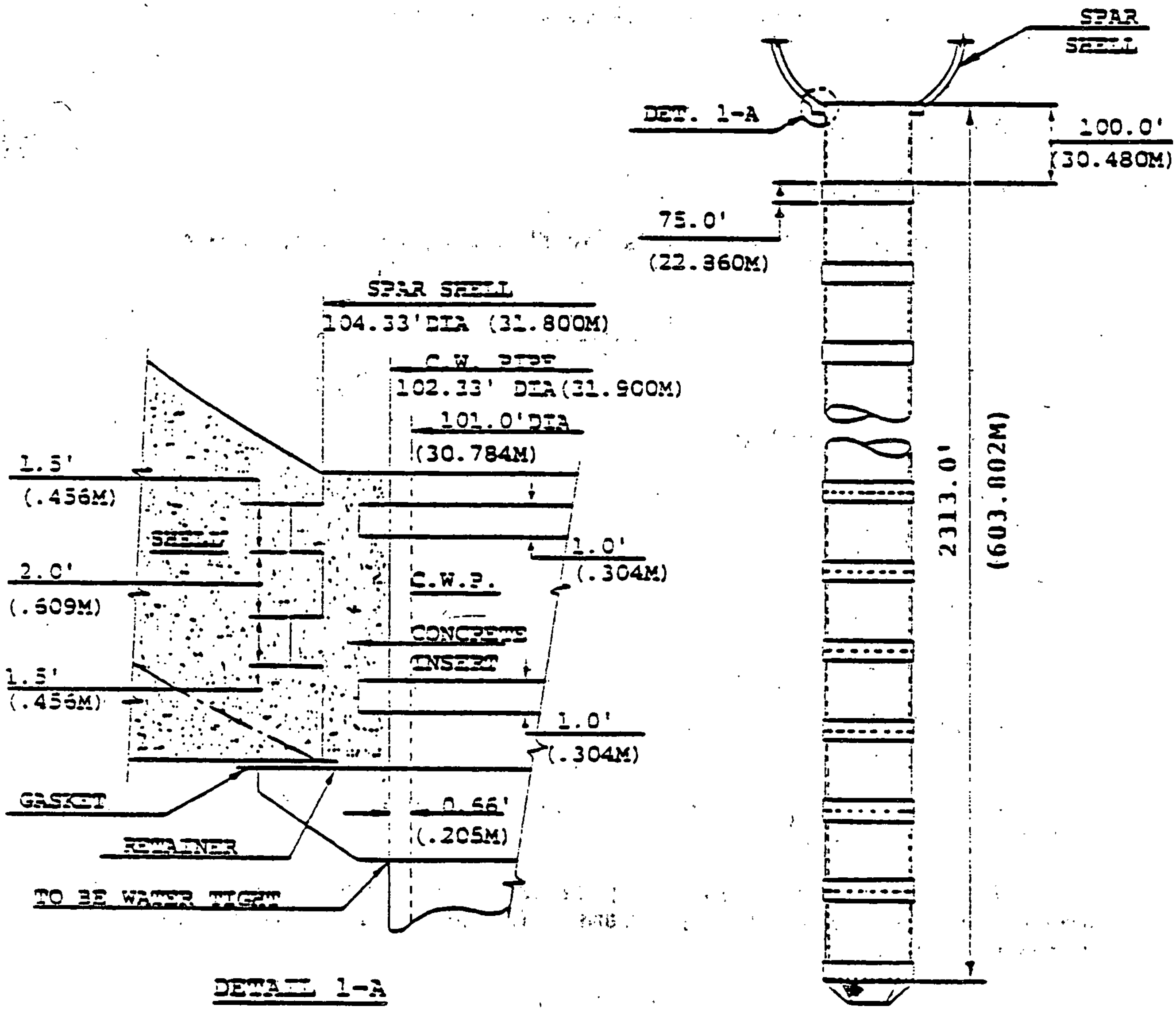
Figure 2.2.1 depicts the basic configuration of the MR&S spar/CWP arrangement.

MR&S investigated three basic CWP construction materials, namely GRP, steel, and concrete, with properties as listed below.

| MATERIAL | ALLOWABLE STRESS (KSI) | YOUNGS MODULUS (KSI x $10^3$) | DENSITY (LBS/$FT^3$) |
|---|---|---|---|
| GRP | 12.0 | 2 | 106 |
| STEEL (HT) | 33.6 | 30 | 490 |
| CONCRETE | 2.7 (comp.)<br>1.8 (tension) | 2.95 | 110 |

A stress analysis was carried out, utilizing Professor Paulling's program. Some calculations were also carried out by Hydronautics; however the level of agreement between the two programs was not always satisfactory. The Davidson Laboratory provided hydrodynamic coefficients for use in these programs.

The investigation covered GRP pipe wall thickness of 8, 10 and 12 inches, steel pipes of 6,9 and 12 inches and reinforced concrete pipes 24" and 60" thick. Several cases with composite steel and GRP pipes were considered. In addition a limited study was made of the effect of incorporating partial buoyancy along the pipe length.



DETAIL 1-A

COLD WATER PIPE HULL CONNECTION

COLD WATER PIPE ASSEMBLY

MR&S COLD WATER PIPE

FIGURE 2.2.1

None of the reinforced concrete configurations investigated by MR&S gave acceptable stress levels. GRP and steel both gave acceptable stress levels. Steel was rejected on the ground that it was too expensive and a CWP with the following characteristics was selected:

| | |
|---|---|
| Material | GRP |
| Pipe Diameter | 101" |
| Pipe Thickness | 8" |

The following stress levels (in KSI) were computed, by MR&S.

TABLE 2.2.1

| | Tampa |
|---|---|
| Significant Stresses | 2.94 |
| Max. Stresses | 7.73 |
| Current Stress | 0.38 |
| Weight Stress | 0.67 |
| Total Stress | 8.79 |
| Allowable Stresses | 12 |

A minimum pipe thickness of 8" was determined by MR&S to be necessary to satisfy buckling criteria.

The stresses for a 10" GRP pipe were calculated using both Paulling's program and the Hydronautics programs. The computed stresses using both approaches are shown below.

TABLE 2.2.2

| Site | | Tampa |
|---|---|---|
| Paulling | Significant | 3.29 ksi |
| | Max. expected | 8.65 ksi |
| Hydronautics | Significant | 8.30 ksi |
| | Max. expected | 21.83 ksi |

It can be seen that the correlation between the two sets of results is unsatisfactory.

b) Gibbs and Cox

The method of CWP attachment selected by Gibbs and Cox was characterized by the use of a universal joint, supported by a shaft which in its turn was supported by the ship's structure. Connection between pipe sections was assumed to be rigid.

Figure 2.6.2 depicts the basic configuration of the G&C CWP arrangement.

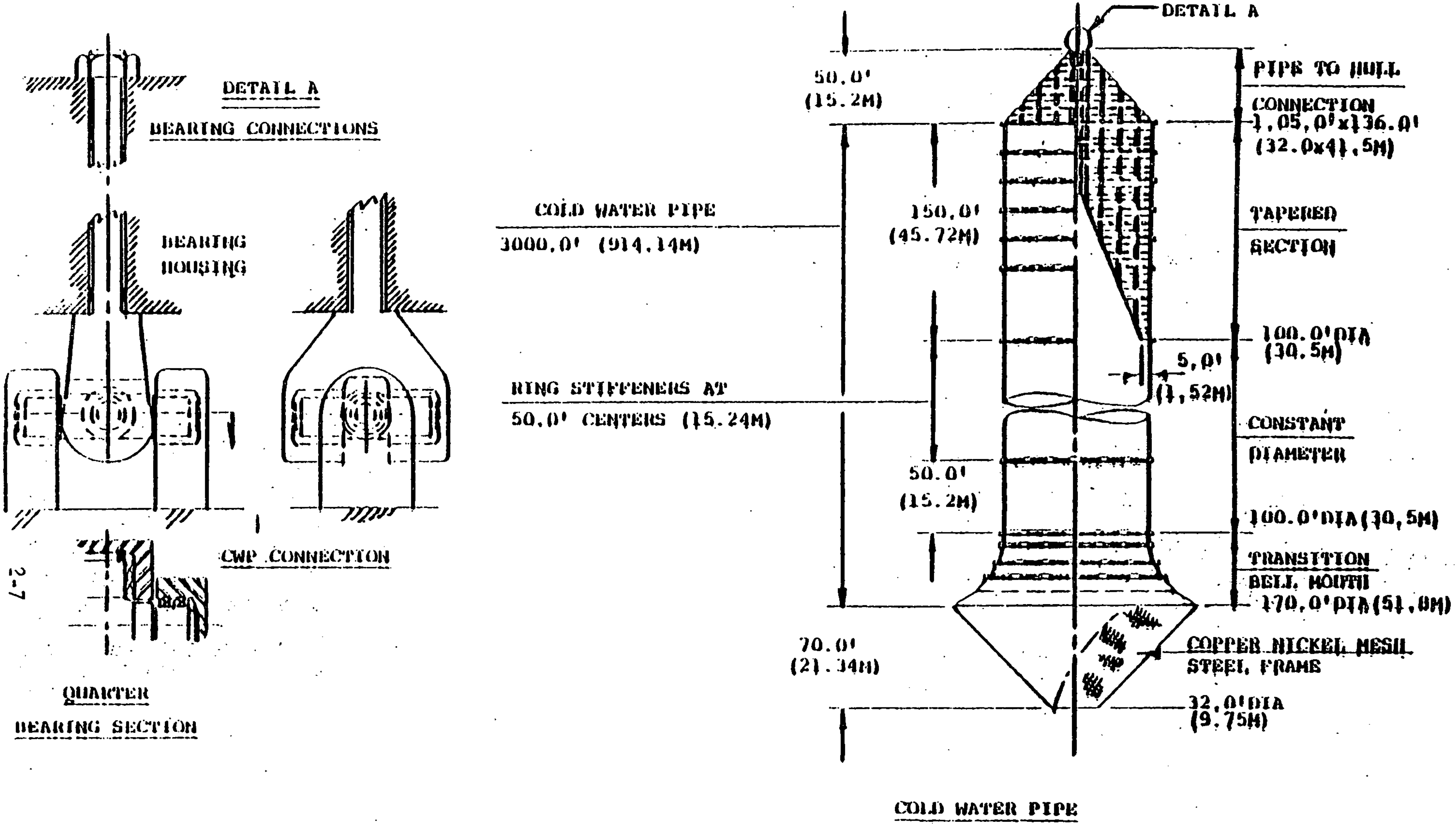
G&C investigated mild steel, high tensile steel, aluminum, reinforced concrete, and glass reinforced plastic CWP constructions with the properties listed below.

TABLE 2.2.3

| MATERIAL | ALLOWABLE STRESS (KSI) | YOUNG MODULUS (KSI X $10^3$) | DENSITY LBS/CU FT |
|---|---|---|---|
| Steel (Mild) KSI | 27 | 30 | 490 |
| Steel (HT) KSI | 33 | 30 | 490 |
| Aluminum | 19 | 10 | 160 |
| Concrete | 2 | 3.4 | 165 |
| GRP | 19 | 2.9 | 112 |

For all except reinforced concrete, the structural approach consisted of a thin wall construction reinforced externally by vertical and horizontal stiffeners, each wall thickness corresponding to a predetermined moment of inertia.

Stress analysis was carried out, using Paulling's program. For each material curves were prepared for pipe diameters from 60 to 120 ft., plotting the computed dynamic bending stress against the equivalent wall thickness. By entering the curves at the permissible stress levels, the equivalent wall thickness for any pipe diameter is read off. The weight per foot is then calculated for each diameter and material.



G&C COLD WATER PIPE

FIGURE 2.2.2

Weights were transformed to costs utilizing unit cost values developed for each material. In order to rank the alternatives G&C developed figures of Merit using a method described in Reference (4).

G&C concluded that the 100 ft. diameter mild steel pipe was the most cost effective and selected a CWP with the following characteristics.

| | |
|---|---|
| Material | Mild steel |
| Pipe diameter | 100 ft. |
| Pipe Thickness | 0.1 ft. |

The following stress levels were computed for the selected CWP.

TABLE 2.2.4

| | HAWAII | TAMPA | NEW ORLEANS |
|---|---|---|---|
| Total Stress KSI | 25 | 30.2 | 45 |
| Allowable Stress | 27 | 27 | 27 |

c) Lockheed Missiles and Space Corporation

LMSC utilized a 60 ft. radius spherical graphite bearing with zero stiffness in roll and pitch for the connection of the pipe to the platforms. Flexible joints were also assumed at the pipe connections.

Figure 2.2.4 depicts the basic configurations of the LMSC CWP arrangement.

Aluminum, GRP and lightweight reinforced concrete having properties as listed below were investigated by LMSC:

TABLE 2.2.5

| MATERIAL | ALLOWABLE STRESS, KSI | YOUNG'S MODULUS PSI, $10^6$ | DENSITY LBS/$FT^3$ |
|---|---|---|---|
| Lightweight Concrete | 2.5 | 3 | 110 |
| GRP | 10.0 | 2 | 93.7 |
| Aluminum | 23.0 | 10.2 | 176.6 |

Conceptual design of the CWP was carried out in two stages. In the first stage, trade off studies were carried out to determine pipe length and diameter. LMSC concluded that capital cost were insensitive to diameter changes in a size range between 70 and 90 ft. and selected a pipe with 73 ft. diameter, on the grounds that small diameter pipes would be easier to manufacture and handle.

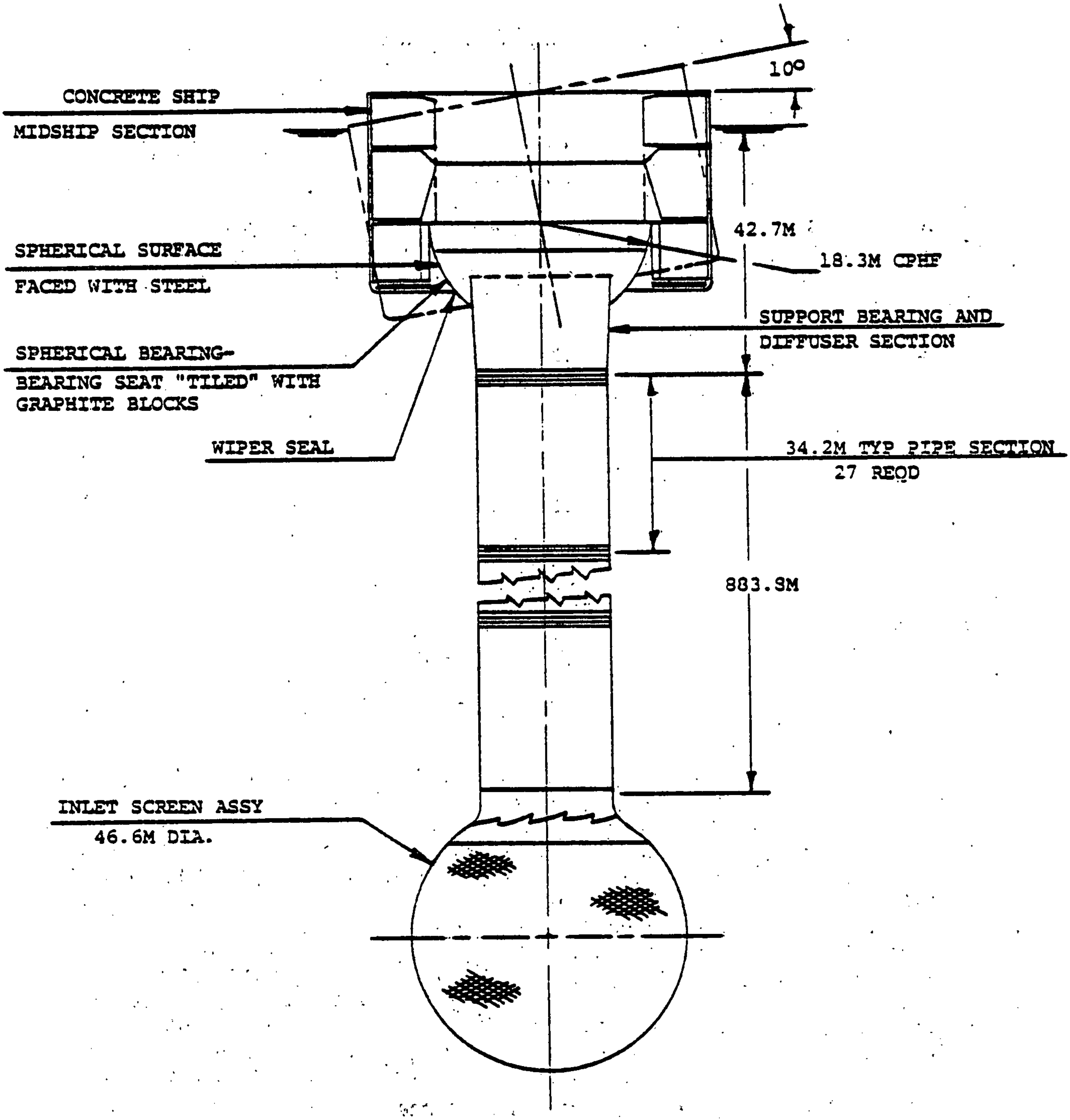
Dynamic loads were derived in the second stage from a data set generated by Hydronautics for the 100 MW internal spar and ship designs of Phase 1. Based on the similarity of Froude scale factors it was assumed that the pipe loads for the 100 MWe platforms could be applied to the 400 MWe platforms. Expressions believed by LMSC to be conservative were then applied to define approximate functional dependence of shear and bending moment on axial position, wave height and pipe stiffness.

A further study was made of a "soft" pipe consisting of inner and outer tubes of rubber-nylon fabric connected by radial webs in the annulus. A static pressure of about 7 PSI was maintained continuously in the annulus to provide stability of configuration. The allowable strength of the material was taken at 1000 PSI.

The characteristics of the two CWP designs and the estimated stress levels for New Orleans are as follows:

TABLE 2.2.6

| Material | Rubber Nylon | Lightweight Reinforced Concrete |
|---|---|---|
| Pipe diameter | 73 ft. | 73 ft. |
| Pipe thickness | 0.25 in. | 1-1.75 ft.<br>(varies along length) |
| Total stress (KSI) | | 2.48 |
| Allowable stress | 1 | 2.50 |



COLD WATER PIPE ASSEMBLY

LMSC

FIGURE 2.2.3

### 2.2.3 Discussion of CWP Design Approaches by the OTEC Contractors

#### a) Stress Analysis

LMSC used a program developed by Hydronautics for their stress analysis whereas both MR&S and G&C used Paullings program.

A comparison, of both programs made by Gilbert Associates in 1978 had concluded that CWP maximum bending moments and stresses predicted using the Paullings method were typically 50 to 70 percent of these predicted using the Hydronautics method.

A comparison of stress predictions on a 10" GRP pipe obtained by MR&S using both programs is shown in Table 2.2.2 and also demonstrates a poor level of correlation.

Moreover LMSC did not carry out a rigorous stress analysis for their CWP. Instead they used data developed by Hydronautics for a 100 MWe ship shaped hull, with appropriate correction factors. An unknown degree of approximation is involved in this approach.

There is additionally a difference of approach between all three contractors in passing from significant to maximum stresses for the 100 years storm. MR&S uses a multiplier of 2.63 whereas LMSC uses a multiplier of 2.0. G&C stated that they used significant stresses without applying a multiplier. They justify this on the grounds that by using a material with yield properties some plastic deformation could occur but the CWP would not fail on the temporary application of higher stresses.

There is an obvious inconsistency in approach between the three contractors.

#### b) Material Selection

MR&S material selection is largely a consequence of their decision to use rigid connections only. This conclusion was reached on the grounds that flexible connections would be prohibitive in cost. It is not supported by the results presented by G&C and by Lockheed and on the basis of data presented for the Commercial OTEC Plant, it appears to have resulted in an unduly expensive solution. More recent data on GRP with reduced pipe thickness seem however, to show GRP in a more favorable light.

G&C carried out an extensive and well conceived material trade off study. However, they considered concrete with a density of 165 lbs per cubic feet instead of lightweight concrete which has been shown to give more favorable results. G&C also assumes an allowable stress of 2000 PSI. This is lower than the stress levels associated with lightweight concrete and results in an unnecessarily thick pipe.

LMSC also carried out material trade off studies but did not include mild steel among the materials investigated. Neither LMSC nor G&C conclusively demonstrates the advantage of either steel or concrete over the other.

LMSC proposes an alternative CWP design utilizing a nylon rubber pipe of annular construction. This material is potentially promising and is presented in Reference 3 as cost effective. Its application to the commercial OTEC platforms appears premature for the following reasons:

There is no generally accepted rubber CWP design available today at a level of development such that it is ready for immediate application.

There is no experience with this material on ocean platforms which approaches the available data for steel or concrete and no realistic assessment as to its long term durability and reliability in the ocean.

Price estimates from different authorities vary largely and there are no reliable estimates of the cost of a rubber CWP over the lifespan of the platform.

### c) CWP System Costs

The CWP costs breakdown, in millions of dollars, for the three contractors at the sites designated by DOE, are shown below.

TABLE 2.2.7 - CWP SYSTEM COSTS

| | MR&S | G&C | LMSC |
|---|---|---|---|
| Site | Tampa | Hawaii | New Orleans |
| Material | GRP | Steel | Concrete |
| CWP System Design and Integration | 1.0 | 4.6 | 5.0 |
| Pipe Sections | 100.3 | 58.8 | 33.0 |
| Inlet and Screens | 0.9 | 8.3 | 17.4 |
| CWP to Hull Transition | 1.5 | 8.0 | 4.4 |
| Biofouling and Corrosion Control | - | 2.0 | - |
| Deployment and Assembly | - | 6.9 | 5.1 |
| TOTAL | 103.7 | 89 | 64.9 |

## 2.2.4 Comparison of LMSC, G&C and MR&S Designs on a Unified Basis

### a) General

The cost differentials indicated in Table 2.2.7 result primarily from differences in design philosophy and material selection. If these figures were utilized in a comparison of platform system costs, they would introduce an error in the comparison since they are related only to a limited extent to the platform configurations.

In order to properly evaluate the impact of platforms configuration upon CWP costs, it was decided, after consultations with Value Engineering to develop a unified CWP concept. The pipe thicknesses for the four platforms were to be estimated using the NOAA/Hydronautics computer program and the pipes then costed on a consistent basis. Table 2.2.8 shows the characteristics of the baseline CWP concept.

TABLE 2.2.8 - CWP SYSTEM CHARACTERISTICS

| | | |
|---|---|---|
| I. | CWP Length | 3000 ft. below WL |
| II. | CWP Material: | Lightweight Concrete |
| | Modulus of Elasticity | $3 \times 10^6$ psi |
| | Unit Weight | 85#/ft.$^3$ |
| | Compressive Strength = | 5000 psi |
| | Allowable Stress = | 2250 psi |
| | Maximum Stress = | 4 RMS |
| III. | CWP/Hull Connections: | Pin joint or very low rotational stiffness. |
| IV. | CWP Flexible Joints | |
| | Segment Length = | 112'-2" |
| | Rotational Stiffness = | $9.5 \times 10^{10}$ ft. x lbs/rad. |

b) Discussion of Hydronautics Results

The analysis carried out by Hydronautics is described in Reference 20, copy of which is included in this report as Appendix A. Platform motions and CWP stresses are based on the DOE defined hurricane spectrum for the proposed OTEC site.

This is a Bretschneider two parameter spectrum with a significant wave height of 45.8 ft. and a period of maximum energy of 13.67 seconds.

The Hydronautics stress analysis program had to be modified to include the effect of the large discharge pipes on the ship shaped platforms. This effect is stated in Reference (20) to require further study and clarification. Hydronautics calculates the pipe thicknesses for both beam and head seas and shows that savings in pipe thickness are possible for the ship shaped platforms provided that directional control of the platform is feasible. These savings however are not achievable with the fixed platform moorings assumed in this instance and the CWP must be capable of withstanding maximum wave energies from any angle of attack.

Table 2.2.9 presents the characteristics of CWP designs satisfying the above criteria. It should be noted that a pipe thickness of 1.165' is adequate for wave induced loads on the CWP of the MR&S spar but the thickness was increased to 1.5 ft. to ensure resistance to buckling.

Table 2.2.10 shows the estimated platform motions. The selected pipes are shown in Figures 2.2.4 through 2.2.6.

c) Costs

CWP costs have been recalculated for the pipes shown in Table 2.2.9. The cost of lightweight concrete was taken at $425 per ton. The joints for the LMSC 73 ft. pipes were taken at $512,000 per joint, this being LMSC estimate in Reference 5. The cost of the joints was pro-rated on a lineal basis for the larger diameter of the MR&S and G&C pipes.

The estimated CWP costs for all the platforms are shown in Table 2.2.11.

## TABLE 2.2.9

## CWP CHARACTERISTICS

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Inner Diameter(ft) | 101 | 73 | 73 | 100 |
| Length(ft) | 2955 | 2947 | 2721 | 2339 |
| No of Joints | 26 | 26 | 24 | 20 |
| Pipe Thickness (ft) | 2.2 | 2.4 | 1.75 | 1.5 |
| Weight in air (tons) | 79,170 | 63,560 | 42,380 | 42,170 |
| Weight in Water(tons) | 30,870 | 24,790 | 16,530 | 16,480 |

## TABLE 2.2.10

## TABULATION OF CALCULATED PLATFORM MOTIONS AT C.G. FOR 1.5 FOOT CWP WALL THICKNESS

RMS MOTION AMPLITUDE, FEET OR DEGREES

| Motion | Lockheed Spar | Rosenblatt Spar | Lockheed Ship | G&C SHP |
|---|---|---|---|---|
| HEAD SEAS | | | | |
| Surge-ft | 2.7 | 1.8 | 3.8 | 1.3 |
| Heave-ft | 2.3 | | 5.2 | 4.8 |
| Pitch-deg. | 0.2 | 0.7 | 2.3 | 1.8 |
| BEAM SEAS | | | | |
| Sway-ft | - | - | 6.5 | 3.6 |
| Heave-ft | - | - | 13.4 | 8.7 |
| Roll-deg. | - | - | 7.7 | 2.7 |

## TABLE 2.2.11

### CWP SYSTEM COSTS
### (MILLIONS OF DOLLARS)

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| CWP Pipes | 33.69 | 27.05 | 18.02 | 18.11 |
| Pipe Joints | 18.40 | 13.30 | 12.28 | 14.16 |
| Inlets and Screens | 8.30 | 8.30 | 8.30 | 8.30 |
| CWP to Hull Transition | 4.40 | 4.40 | 4.40 | 4.40 |
| TOTAL | 64.79 | 53.05 | 43.00 | 44.97 |

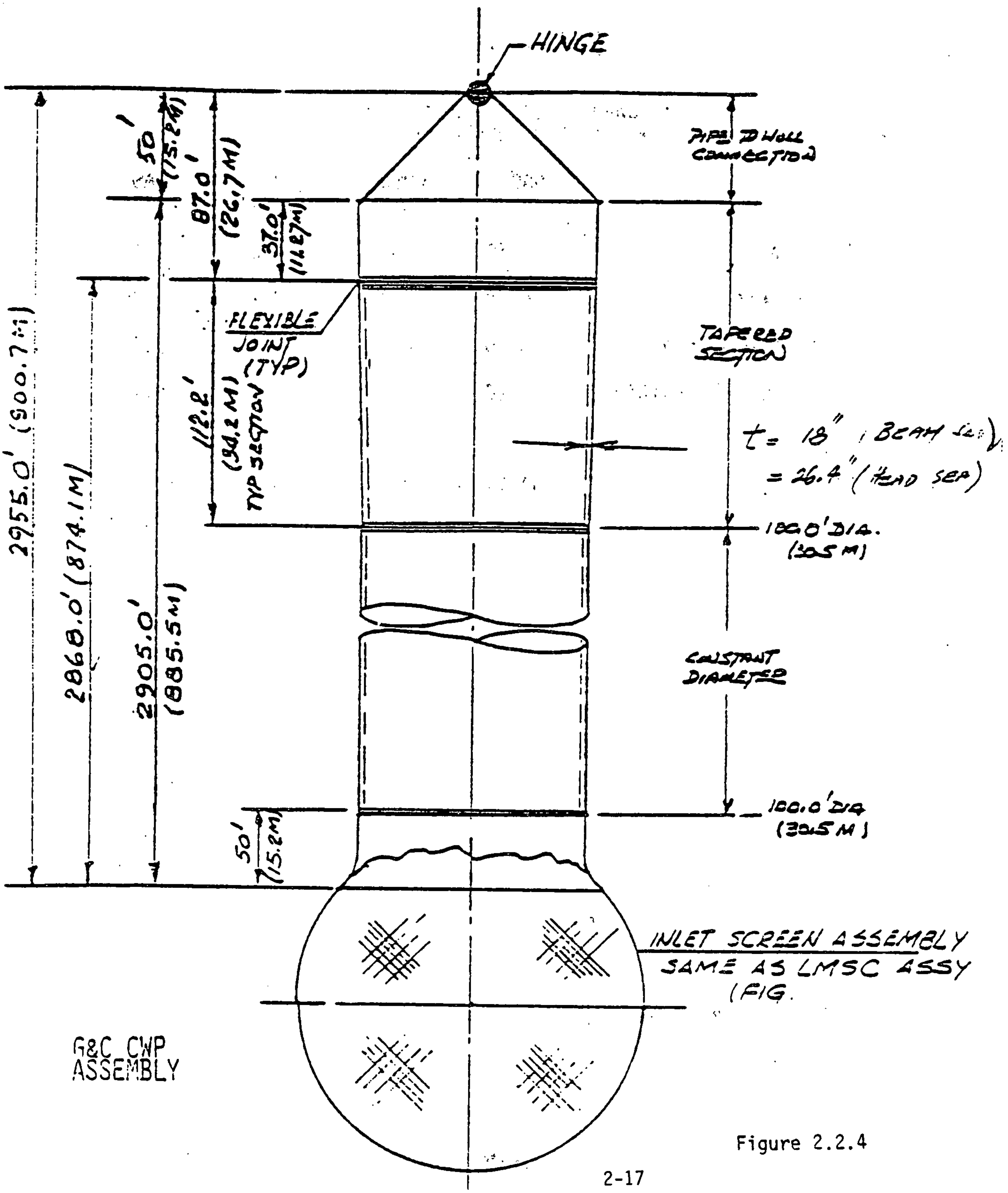

HINGE
PIPE TO HULL CONNECTION
50' (15.2M)
87.0' (26.7M)
37.0' (11.27M)
FLEXIBLE JOINT (TYP)
112.2' (34.2M) TYP SECTION
TAPERED SECTION
t = 18" (BEAM SEA)
= 26.4" (HEAD SEA)
100.0' DIA. (30.5 M)
2955.0' (900.7M)
2868.0' (874.1M)
2905.0' (885.5M)
CONSTANT DIAMETER
100.0' DIA (30.5 M)
50' (15.2M)
INLET SCREEN ASSEMBLY SAME AS LMSC ASSY (FIG.
G&C CWP ASSEMBLY

Figure 2.2.4

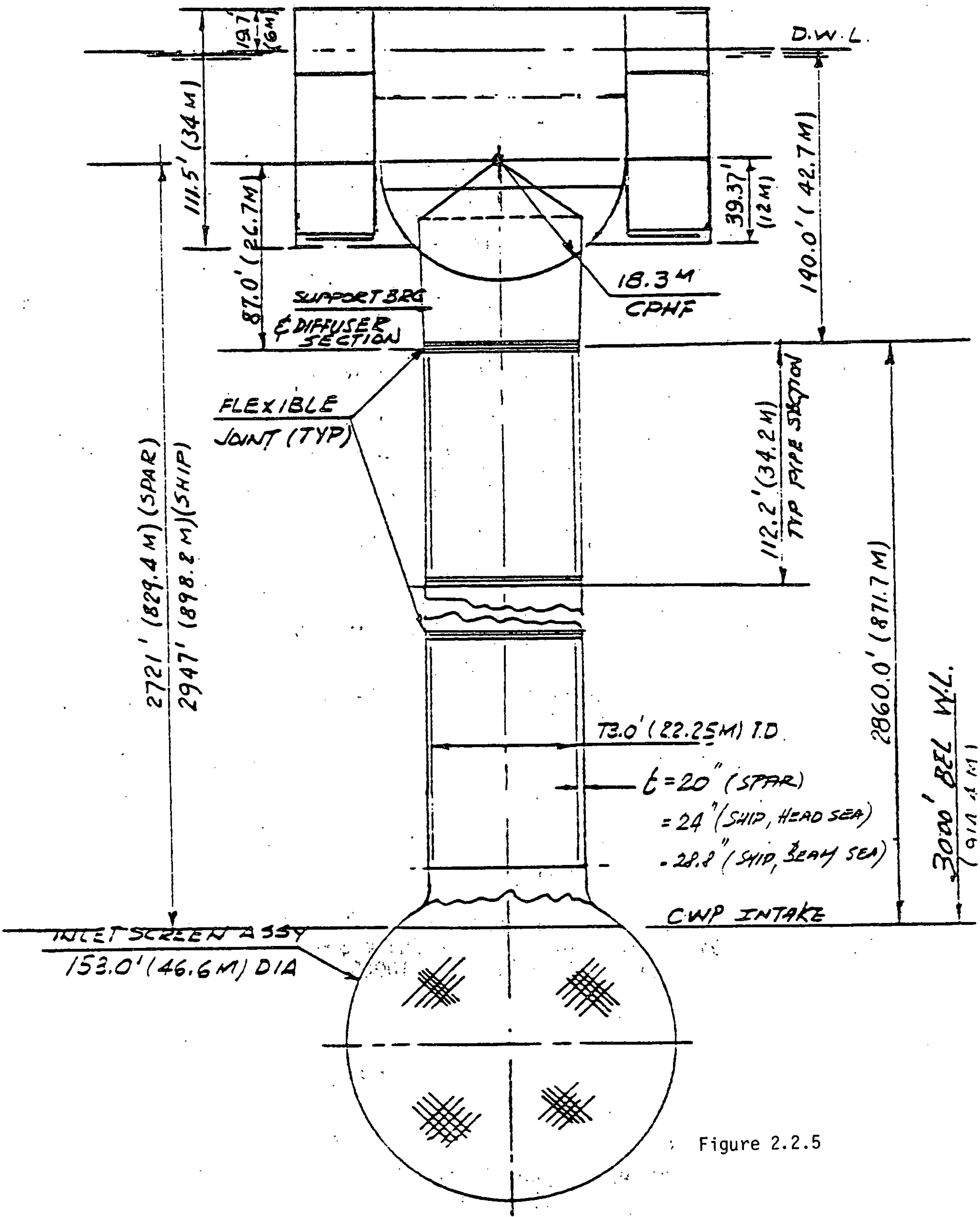
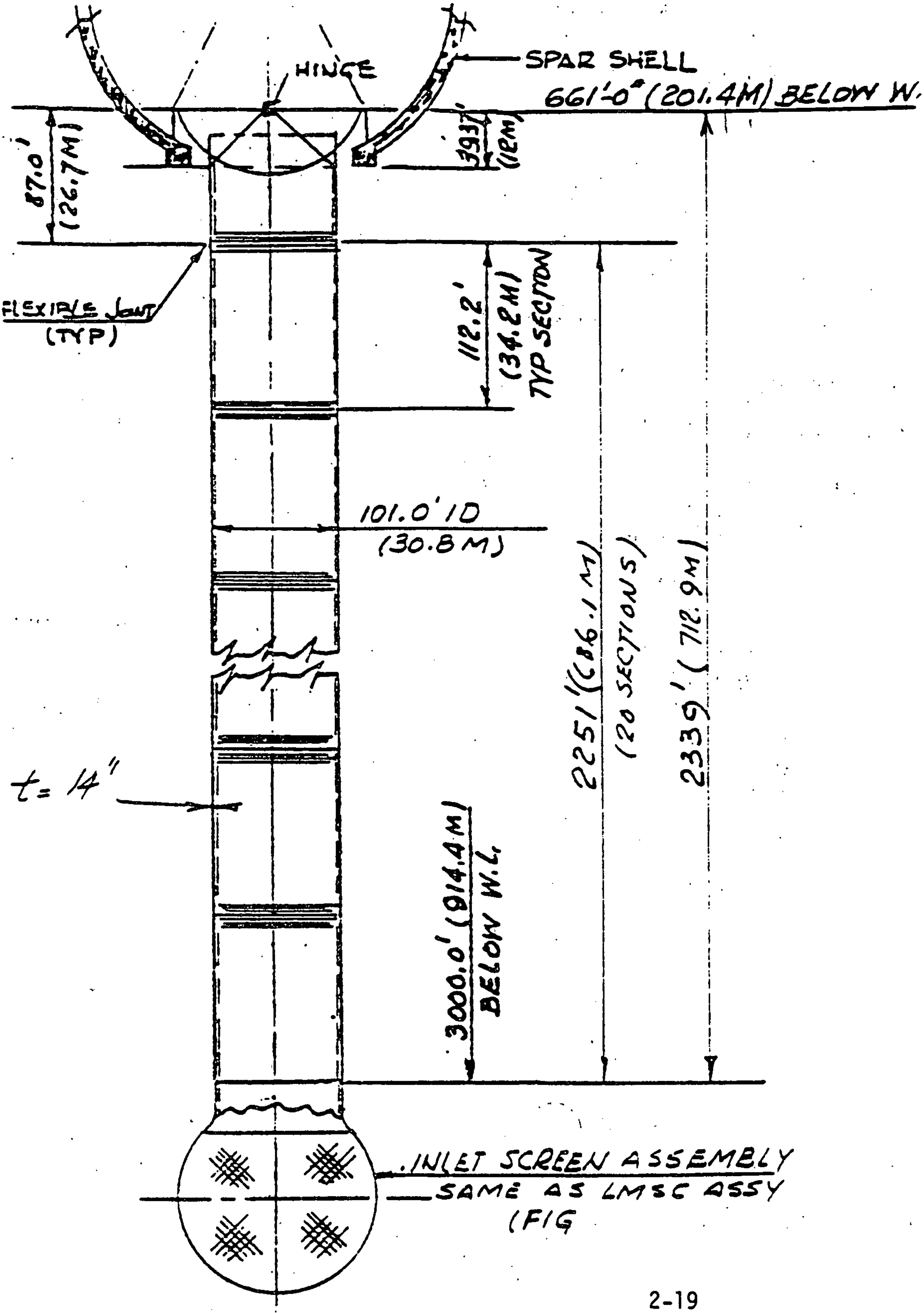


Figure 2.2.5

LMSC COLD WATER PIPE ASSY



MR&S COLD WATER PIPE ASSY

Figure 2.2.6

## 2.3 POSITION KEEPING SYSTEMS

### 2.3.1 Overview of Designs by the Three DOE Contractors

#### a) M. Rosenblatt and Son

The following drag forces were calculated by MR&S for their spar, off the West Coast of Florida:

| | Load in Tons | | |
|---|---|---|---|
| Condition | Current | Wind | Total |
| Normal | 578.8 | 45.3 | 624.1 |
| Extreme | 2315.5 | 181.1 | 2496.6 |

MR&S selected a static 3 leg mooring system to resist these loads. They decided that the mooring loads were beyond the capability of conventional chain cables and selected cables formed by hollow cylindrical links as proposed by Westinghouse in Reference (11). The links are of high tensile steel, 53.1 ft. long each and 5.3 ft. in diameter. Each chain is secured at its base to a disc type free fall anchor. The cables are secured to the spar at points about 525 ft. below the waterline. Traction winches are not provided and no provision is made for weathervaning since this is not required for cylindrical spar shapes.

Figure 2.3.1 shows the MR&S mooring concept.

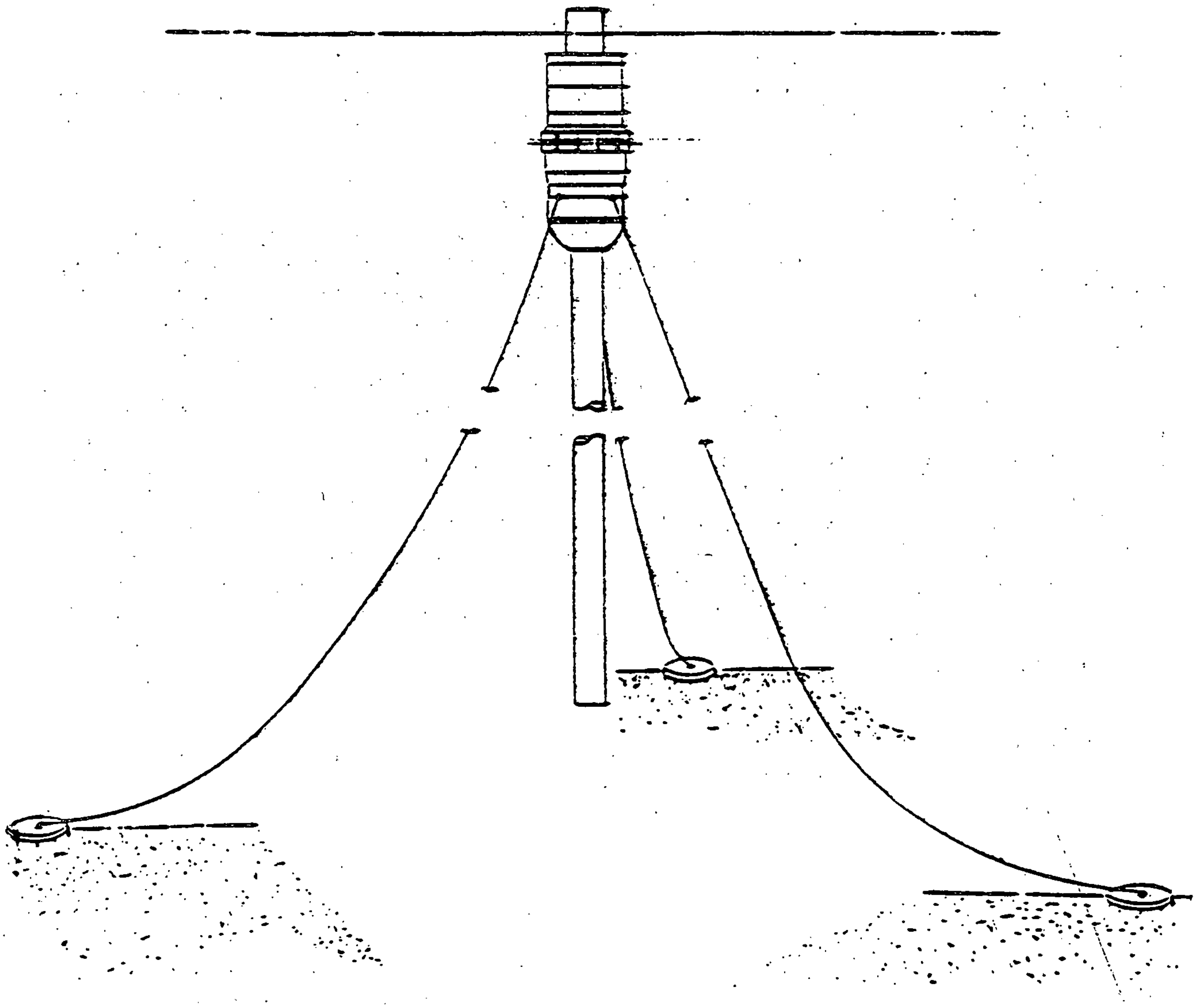
#### b) Gibbs and Cox

G&C calculated the following drag forces for their ship shaped platform, off the coast of Hawaii.

| | Load in Tons | |
|---|---|---|
| Condition | Fore and Aft | Athwartships |
| Normal | 566.1 | 669.6 |
| Extreme | 1,088.9 | 1,178.1 |

G&C do not differentiate in their report between wave and current induced forces, beyond a statement that they have assumed that the maximum loadings for two components occur simultaneously. As in the case of MR&S, drag loads only are considered and G&C was of the opinion that wave induced drift forces would be of negligible magnitude.

HCL CABLES, H.T. STEEL, 93.1 FT LONG x 5.5 FT DIA



MR & S SPAR PLATFORM

Figure 2.3.1

G&C have selected a fourteen point static mooring system, consisting of two legs at each end, four legs on the shallow water (shoreside) and six legs in the deep water (offshore side). The cables consist of chain wire combinations with 4" diameter 6 x 37 IWRC galvanized wire ropes and a short length of 3-3/4" diameter chain at the upper end. Deadweight anchors, of concrete, are proposed.

At their upper ends the chains are connected to winches located on the OTEC platform with a pull capacity of 200 tons each, at slow speed. The winches facilitate deployment and serve to equalize the load between the cables.

No provision is made for weathervaning and the system is designed to take loads both from head seas and beam seas.

Figure 2.3.2 shows G&C's mooring concept.

c) LMSC - Ship Shape

The methodology used by LMSC for calculating environmental loads is described in Volume 1 of LMSC's report and includes wind, current and wave drift loads.

LMSC gives the mooring line load for the ship shaped platform as 692 long tons. The corresponding load for the spar is given as 878 tons. No derivation is given as to the distribution of this load among its different components. The load is calculated for a head sea and wind condition and assumes that the platform can weathervane to keep mooring loads to a minimum.

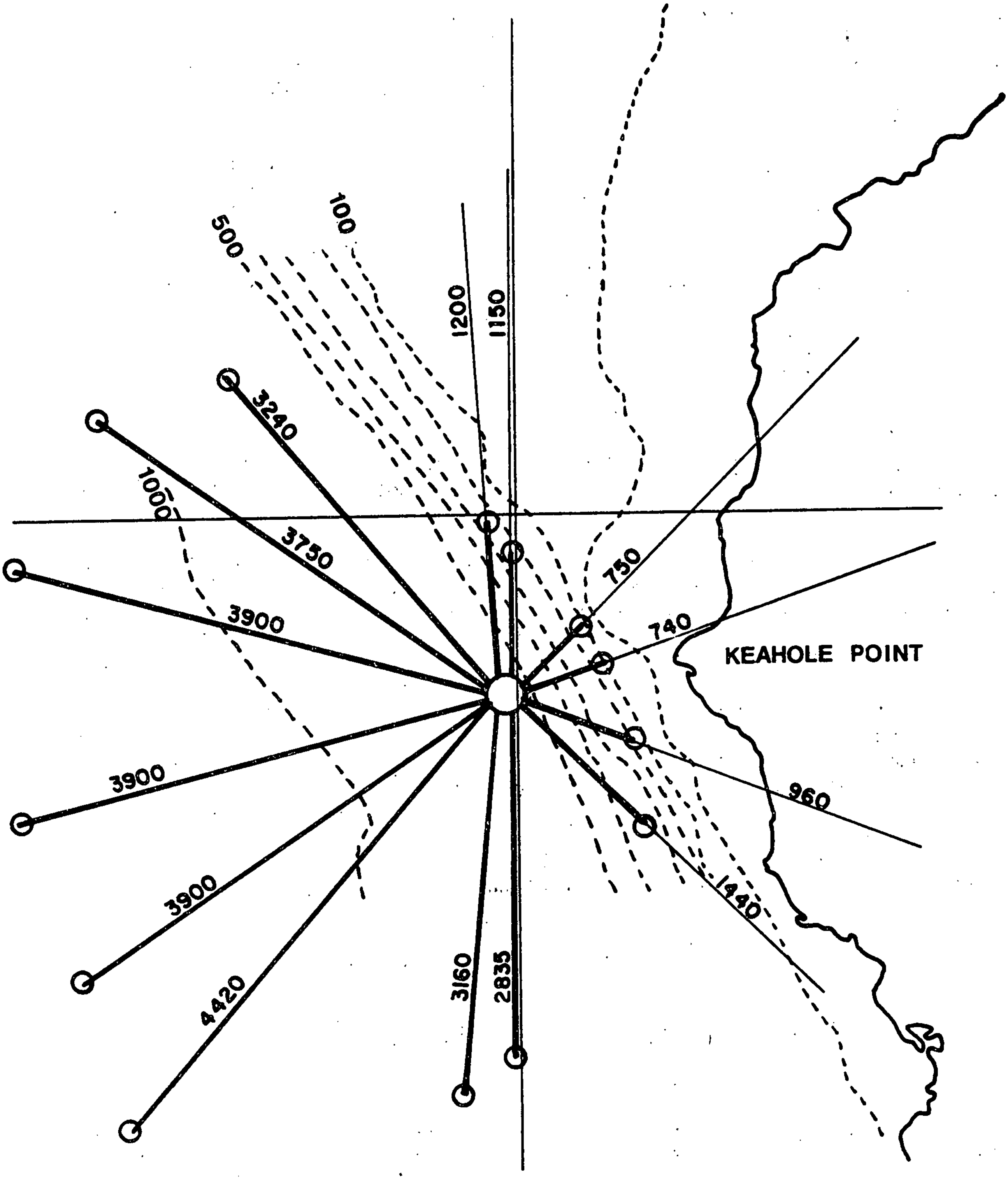
A single point spread mooring system is proposed for the ship with three legs consisting of 10" nylon lines, with short chain cables at their lower ends. Each chain is connected at its base to a deadweight anchor. At their upper ends the mooring lines are connected to a buoy. The platform is moored by lines from the bow to the buoy. In order to provide weathervaning capability, swivel type connections are provided at the buoy to allow rotation of the ship and the transmission line. An auxiliary thruster is provided at the stern to maintain tension in the transmission line in calm weather and to assist in directional control.

Figure 2.3.3 shows the mooring concept proposed by LMSC.

### 2.3.2 Discussion of Position Control System Design Approaches by Three Contractors

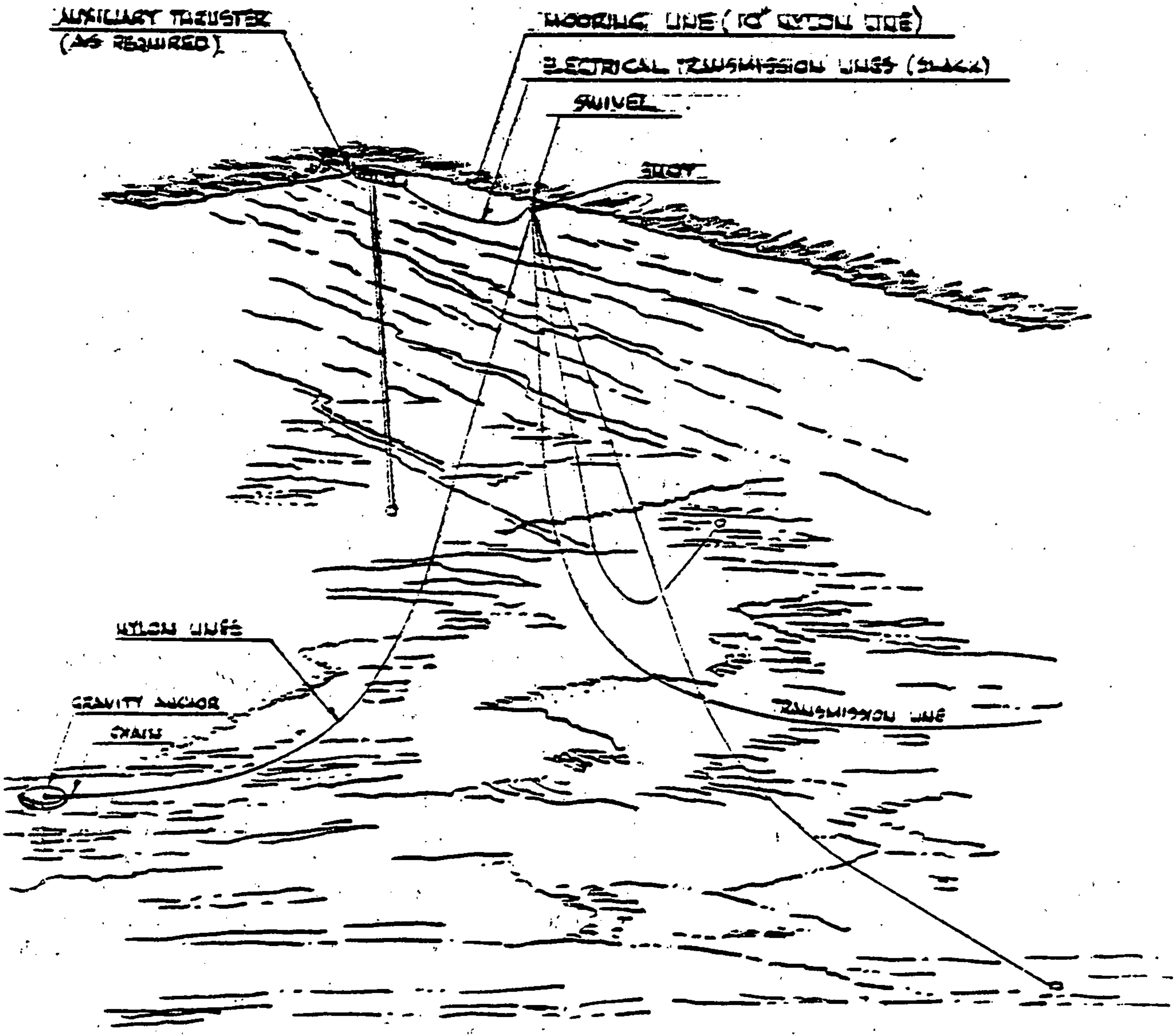
a) Position Control Systems

Three concepts, i.e. static mooring, dynamic positioning and a combination of both were studied by all three contractors. In every case the contractors concluded that dynamic positioning is impractical on account of its power requirements and recommended the use of a static mooring concept.



G & C SHIP'S SHAPE PLATFORM

Figure 2.3.2



LMSC SHIP PLATFORM

Figure 2.3.3

### b) Loads

Essentially the three contractors use similar methods to calculate drag. MR&S and G&C calculated wind and current induced drag forces only, disregarding wave induced forces whereas LMSC added a wave drift component to their calculations.

The calculated loads, vary from 2496 tons for MR&S to 692 tons for LMSC, a 350% difference. This is mainly due to variations in environmental conditions although drag is also dependent upon the form of the platform.

LMSC postulates a weathervaning capability to limit loads and in order to provide this capability they moor the platform by lines to a buoy. There are a number of disadvantages inherent in this approach. Under certain circumstances the cold water pipe may foul the mooring cables. A swivel connection is required at the buoy for the transmission lines. This is a large and costly fitting and is believed to be beyond the present state of the art. Auxiliary power thruster may be required to assist in directional control, in keeping the mooring line tight and in avoiding drift of the ship on the buoy. This increases first costs and decreases the reliability of the system. Elimination of the weathervaning capability would on the other hand, increase the mooring loads by an order of magnitude of 250%.

### c) Mooring Cables

Both G&C and LMSC have utilized state of the art materials currently employed in offshore platforms and single point mooring systems. This approach however was only made possible by the relatively low loads associated with the benign environment which they studied.

LMSC's integration studies had shown that drag loads could increase by a ratio of approximately 3 to 1 in passing from a site off New Orleans to Key West. The ratio in passing from Hawaii to Key West would be of the order of five to one. At these higher loads the cable materials proposed by LMSC and G&C could no longer be used. Both the materials proposed by LMSC and by G&C have relatively short mooring lives and will entail high replacement costs in the deployment position.

MR&S proposes to use cables consisting of hollow cylindrical links. This concept, proposed by Westinghouse in Reference (11) extends the holding capability of cables beyond the present limits, making it attractive for very high loads. In theory the HCL should have a greater holding power at less weight than chain and wire cables. This is a new and unproven concept however and there is no background of experience on which to assess its reliability and durability. The cost of HCL cables will be significantly higher than the cost of chain cables of the same weight.

d) Mooring Anchors

Deadweight anchors are relatively easy to deploy in deep ocean and do not run the risk of losing holding power by being dislodged due to earthquakes or storms. All three contractors selected deadweight anchors for their concept designs.

e) Cost Estimate

The cost estimates for the position control system proposed by three contractors are listed in Table 2.3.1.

TABLE 2.3.1. COST ESTIMATE FOR POSITION CONTROL SYSTEM

| CONTRACTOR | SITE | PLATFORM | SYSTEM | ESTIMATED COST($M) | COST RATIO |
|---|---|---|---|---|---|
| MR&S | WEST COAST FL | SPAR | STATIC MOORING | 75.95 | 5.5 |
| LMSC | NEW ORLEANS | SPAR | STATIC MOORING | 36.8 | 2.67 |
| G&C | HAWAII | SHIP | STATIC MOORING | 13.8 to 15.3 | 1.0 |
| LMSC | NEW ORLEANS | SHIP | STATIC MOORING | 26.8 to 32.7 | 1.94 |

### 2.3.3 Comparison of Position Keeping Systems for LMSC, MR&S and G&C on the Basis of a Unified Site Off Tampa, Florida

#### a) General

The discussion on mooring loads in Section 2.3.2 have shown that the position keeping systems proposed for LMSC and G&C would have to be redesigned as they are unsuitable for the high mooring loads at a site off Tampa, Florida. The MR&S spar is already intended for this environment however it was decided that for the sake of consistency it would be redesigned on similar lines to those selected for G&C and LMSC. In all cases a static mooring concept was utilized. Mooring line sizes and numbers were varied to suit the individual platforms however the same materials and same types of anchors were used in all cases.

#### b) Loads

The environmental criteria off Tampa are given in Section 1.2. JJMA calculated the mooring forces for the four platforms utilizing these criteria. For the ship shaped platforms, calculations were carried out both for head and beam loads.

The calculations included wave drift loads, wind drag, current drag on the platform and current drag on the CWP. Wave forces were calculated using a method described by Remery and Herman at the Offshore Technology Conference. (Reference 12). Wind forces were calculated using the methodology of the American Bureau of Shipping for Offshore Drilling Units. (Reference 13). The current load on the CWP was calculated in accordance with Reference 14 and the current load on the platform was calculated using a method described by J.W. Dailey in Fluid Dynamics (Reference 15).

Spring loads exerted by the mooring lines as a result of wave induced motions are not included in the calculation. It is believed that for the relatively long lines used in this application, the spring constants would be quite low and that this is a refinement which can be neglected in a comparative study of this nature.

The results of the load calculations are shown on Table 2.3.2.

The mooring loads for MR&S have increased by 25%. Approximately one half of this increase is due to the introduction of a wave drift component. The rest is due to differences in the method of calculation. The mooring loads for G&C are approximately three times the loads calculated for Hawaii and the mooring loads for LMSC are rather more than four times the estimated loads for New Orleans when considering head seas. This is primarily due to the higher energy environment in the new site but is also attributable in part, to the introduction of a wave drift component for G&C.

## TABLE 2.3.2 DRAG LOADS ON CANDIDATE PLATFORM AT NEW SITE (IN TONS)

| CANDIDATE PLATFORM | LMSC'S SHIP (HEAD) | LMSC SHIP (BEAM) | G&C'S SHIP (HEAD) | G&C SHIP (BEAM) | MR&S'S SPAR | LMSC'S SPAR |
|---|---|---|---|---|---|---|
| WIND DRAG | 73 | 264. | 378. | 593. | 169 | 27 |
| WAVE DRIFT | 328. | 1189. | 515. | 1069. | 209 | 57 |
| CURRENT DRAG,HULL | 2115. | 5489. | 1711. | 2557. | 2371. | 2010. |
| CURRENT DRAG,CWP | 469. | 469. | 611. | 611. | 387. | 387. |
| TOTAL (COLINEAR) | 2985. | 7411. | 3215. | 4830. | 3136. | 2481. |

Loads for beam seas and winds are also given for the ship shaped platform and illustrate the substantial nature of the increase when weather vaning is not provided.

c) Mooring Concept Designs

Table 2.3.2 shows that the two spar platforms and the two ship shaped platforms when operating in head seas were subject to mooring loads of similar orders of magnitude. Consequently it was possible to use the same mooring concept in these four cases without paying any penalty in efficiency.

A static mooring concept with three legs arranged 120° apart and with each leg composed of four super alloy steel mooring chains was selected as baseline design for the spar platforms. Simple catenary formulae were employed to calculate the chain loading and characteristics. In determining the size of the chain, 75% of the link minimum breaking strength was used as the maximum allowable working strength.

For the ship shaped platforms, two mooring concepts were studied.

The first consisted in providing a fixed spread mooring with enough cables to resist mooring loads associated with beam as well as head seas. For G&C, this consists of ten legs, each with two cables, arranged with three legs at each end and two legs on each side. Fourteen legs, each with two cables are required for the LMSC ship shape.

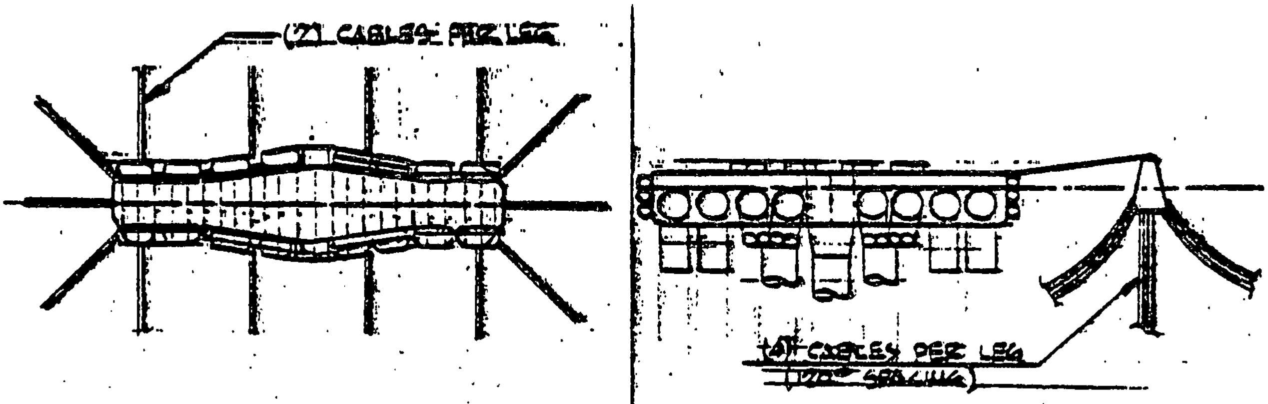
The alternative approach consisted in providing a weathervaning capability to reduce mooring loads as proposed by LMSC for their New Orleans site. This approach requires a single point moor, with three legs each with 4 cables. The disadvantages associated with this approach are discussed in Section 2.3.2.

Figure 2.3.4 illustrates the proposed concepts. Their characteristics are given in Table 2.3.3.

d) Cost Comparison

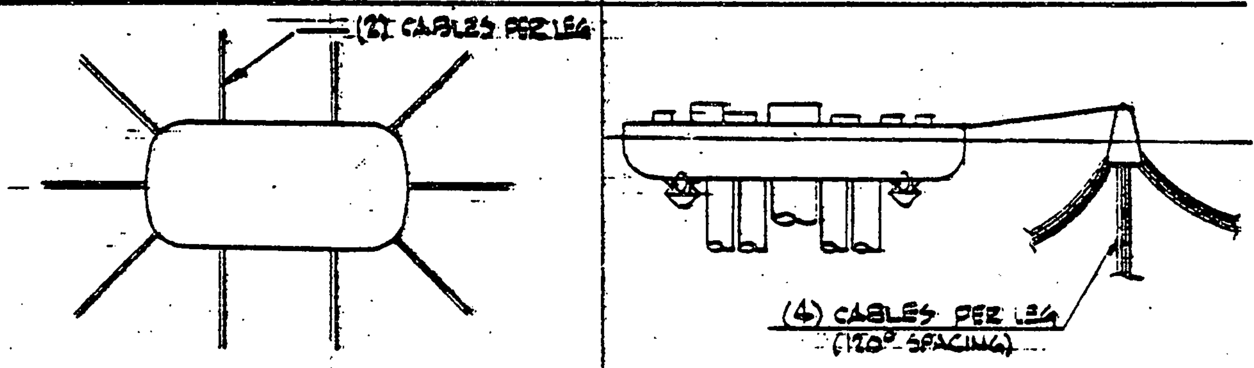
A functional cost model was developed to establish prices for the position keeping systems. Cable costs were taken at $0.74 per lb., based on information supplied by chain manufacturers. Anchors were assumed to cost $0.128 per lb., this is the figure used by MR&S in their cost estimate. Fittings and fairleads are assumed to cost 5% of chain cost.

Some of the platforms may require winches for tension control load sensing devices, and other equipment which cannot be defined at this stage. An allowance of 10% was made to cover these contingencies.



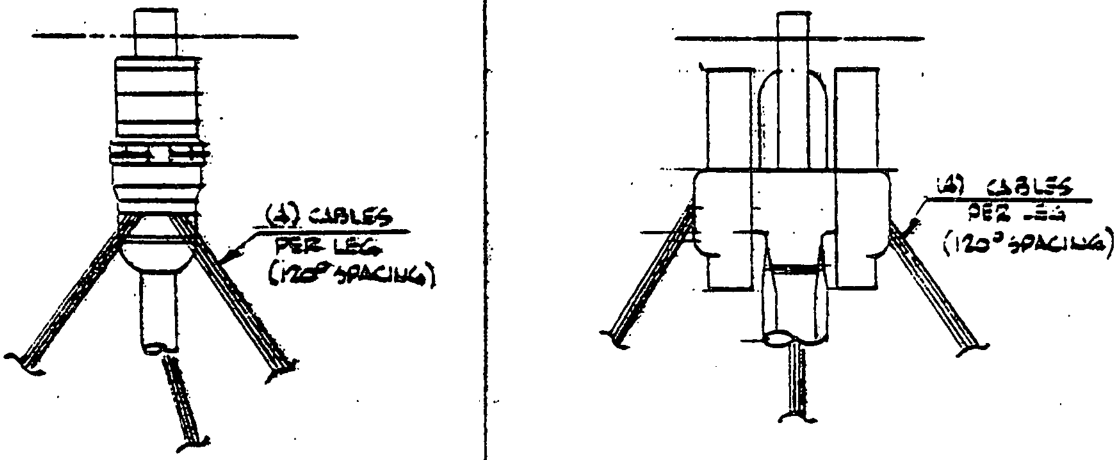
LMSC SHIP SHAPE
FIXED SPREAD MOORING

LMSC SHIP SHAPE
WEATHER VANING SPREAD MOORING



G & C SHIP SHAPE
FIXED SPREAD MOORING

G & C SHIP SHAPE
WEATHER VANING SPREAD MOORING



MR & S SPAR
FIXED SPREAD MOORING

LMSC SPAR
FIXED SPREAD MOORING

UNIFIED MOORING SYSTEM
OFF TAMPA FLORIDA

Figure 2.3.4

## TABLE 2.3.3 UNIFIED MOORING SYSTEM OFF TAMPA, FLORIDA

| | CONTRACTOR | LOCKHEED | LOCKHEED | GIBBS&COX | GIBBX&COX | ROSENBLATT&SON | LOCKHEED |
|---|---|---|---|---|---|---|---|
| | PLATFORM | SHIP | SHIP | SHIP | SHIP | SPAR | SPAR |
| | MOORING SYSTEM | WEATHER-VANING SPREAD MOORING | FIXED SPREAD MOORING | WEATHER-VANING SPREAD MOORING | FIXED SPREAD MOORING | FIXED SPREAD MOORING | FIXED SPREAD MOORING |
| | NUMBER OF LEGS | 3 | 14 | 3 | 10 | 3 | 3 |
| COMPONENTS PER EACH LEG | ANCHORS (DEADWT) CONCRETE) | 4@<br>3,343,000 LB/EA | 2@<br>3,343,000 LB/EA | 4@<br>3.600,800 LB/EA | 2@<br>3,600,800 LB/EA | 4@<br>3,512,300 LB/EA | 4@<br>2,778,700 LB/EA |
| | SIZE OF CHAIN | 5½" | 5¼" | 5½" | 5½" | 5½" | 4 3/4" |
| | NUMBER OF CHAIN PER LEG | 4 | 2 | 4 | 2 | 4 | 4 |
| | LENGTH OF EA.CHAIN | 9,201 FT | 9,201 FT | 9,266 FT | 9,266 | 9,051 FT | 9,248 FT |
| | UNIT WT OF CHAIN* | 277.6 lb/ft | 277.6 lb/ft | 304.6 lb/ft | 304.6 lb/ft | 304.6 lb/ft | 227 lb/ft |
| | MATERIAL OF CHAIN* | RAMNAS BRUK SUPER ALLOY STEEL OR EQ. | RAMNAS BRUK AUPER ALLOY STEEL OR EQ. | RAMNAS BRUK SUPER ALLOY STEEL OR EQ. | RAMNAS BRUK SUPER ALLOY STEEL OR EQ. | RAMNAS BRUK SUPER ALLOY STEEL OR EQ. | RAMNAS BRUK SUPER ALLOY STEEL OR EQ. |
| | MIN BREAKING STRENGTH* OF CHAIN (APPROX.) | 3,675.000 lbs | 3,675,000 lbs | 3,989,800 lbs | 3,989,800 lbs | 3,989,800 lbs | 3,298,800 lbs |
| | STRESS IN CHAIN AT THE UPPER END | 2,780,558 lbs | 2,780,558 lbs | 3,017,290 lbs | 3,017,290 lbs | 3,972,240 lbs | 2,298,580 lbs |
| | % OF MBS | 75.6% | 75.6% | 75.6% | 75.6% | 74.5% | 74.7% |

An allowance was made for auxiliary thrusters for the design options dependent on weathervaning for load control. This was calculated on the basis of $30,000 per installed ton of thrust. The thrust load was taken at 15% of mooring load. This was estimated by assuming that the platform would have to remain colinear with the current and should in this case be capable of controlling its heading against the wind drag and wave drift components.

15% is an average figure, based on the assumption that the center of gravity of the drag load would be at midlength of the platform.

The cost of a buoy for the LMSC concept was estimated by assuming that the amount of installed steel on the buoy would be 12% of the buoyancy required at the buoy. Steel was taken at $3300 per ton and to this figure an allowance was added for the fittings on the buoy. The cost of the power cable swivel is not included in this estimate.

The estimated costs of the position keeping systems are given in Table 2.3.4. These figures do not include deployment costs. The four fixed concepts in Table 2.3.4 have been retained for the purpose of this investigation as the preferred concepts.

## TABLE 2.3.4 ESTIMATED COSTS OF POSITION KEEPING SYSTEM

| | LMSC (SHIP) | LMSC (SHIP) | G&C (SHIP) | G&C (SHIP) | MR&S (SPAR | LMSC (SPAR) |
|---|---|---|---|---|---|---|
| MOORING SYSTEM | WEATHER VANING | FIXED | WEATHER VANING | FIXED | FIXED | FIXED |
| MOORING CABLES | 22.68 | 52.92 | 25.06 | 41.76 | 24.48 | 18.64 |
| DEADWEIGHT ANCHORS | 5.15 | 12.02 | 5.53 | 9.18 | 5.40 | 4.26 |
| FITTING AND FAIRLEADS | 1.13 | 2.63 | 1.25 | 2.07 | 1.22 | 0.93 |
| MISCELLANEOUS | 2.3 | 5.27 | 2.5 | 4.15 | 2.4 | 1.9 |
| BUOY | 5.65 | - | 6.24 | - | - | - |
| HEADING CONTROL | 13.5 | - | 14.9 | - | - | - |
| TOTAL | 50.41 | 72.84 | 55.48 | 57.16 | 33 50 | 25.73 |

## 2.4 SEA WATER SYSTEMS

### 2.4.1 Introduction

This presentation summarizes the findings of an evaluation by JJMA of the sea water systems (i.e., the warm water system and the cold water system, exclusive of the cold water pipe) proposed by the three contractors as part of their commercial plant designs.

In performing this analysis, the following approach was adopted:

(a) DOE power module characteristics were reviewed to determine the various features required for proper operation.

(b) Each contractor's design was reviewed to identify key elements of the proposed sea water systems.

(c) The contractors' designs were compared to identify major similarities and differences.

(d) Major differences identified above were analyzed to determine their rationale. Those differences considered to be inherent in basic platform configuration were identified and differentiated from differences in design approach, assumptions, etc. not related to platform configuration. The latter cases were carefully analyzed to ensure that unwarranted biases were eliminated between platform candidates. If insufficient rationale was found to exist for differences design modifications were recommended.

(e) Each contractor's data was normalized to reflect plant installations at a West Coast of Florida site near Tampa selected by DOE.

(f) Cost related parameters were identified and adjusted to reflect the new unified site and recommended modifications and resultant costs for each concept comparatively evaluated.

(g) The designs were ranked and recommendations offered relative to the selection of the most cost effective design features.

### 2.4.2 Basic Design Input to DOE Contractors

DOE specified a net power output of 400 MWe for each OTEC platform and 3200 MWe for each OTEC park. A typical OTEC power module is depicted schematically in Figure 2.4.1. The power modules that comprise an OTEC plant are sized with a 30 percent margin for parasitic electrical loads (i.e. sea water pump power, power conditioning equipment, platform services, etc.). DOE parameters for a 50 MWe (net) OTEC power module are shown in Table 2.4.1.

| | |
|---|---|
| Net Power Output | 50 MWe |
| Gross Power Output | 65 MWe |
| Sea Water Flow | |
| o Evaporator | 5000 cfs |
| o Condenser | 6000 cfs |
| Sea Water P | |
| o Evaporator | 3.5 psid |
| o Condenser | 3.5 psid |
| Sea Water T | |
| o Total | 40°F |
| o Across Evaporator | 4°F |
| o Across Condenser | 4°F |

Table 2.4.1 50 MWe OTEC POWER MODULE CHARACTERISTICS

### 2.4.3 Overview of Sea Water Systems Design by the Three DOE Contractor

Each of the proposed concepts incorporates eight 50 MWe (net) power modules yielding a net platform output of 400 MWe. Each of the four designs analyzed draws cold water from an approximate depth of 3000 ft. and warm water from an approximate depth of 100 ft.

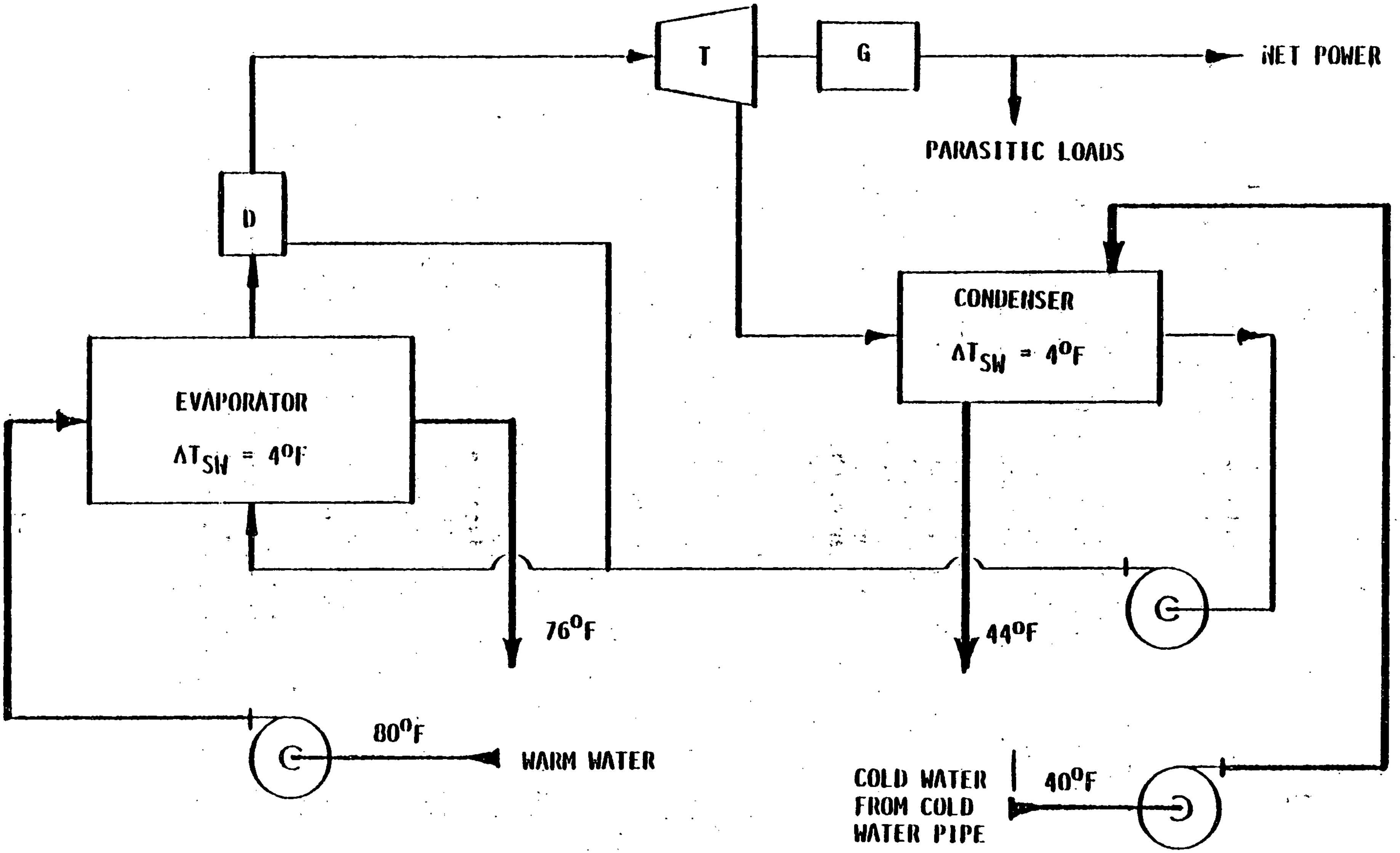
The following paragraphs provide a brief description of the sea water systems designed by each contractor.

a) M. Rosenblatt and Son

The MR&S Spar Platform consists of vertical spar enclosing sixteen vertical heat exchangers. Each heat exchanger is provided with a separate sea water system as follows:

- The warm water systems are grouped about the upper regions of the spar. Each system consists of a vertical warm water pump taking suction from the ocean through an inlet screen and tailpipe and discharging downward through a diffuser, vertical evaporator and short radius 90 degree bend to the ocean. Inlet and discharge gate valves are provided.

- The cold water systems are grouped about the lower regions of the spar. Each system consists of a vertical cold water pump taking suction on the cold water plenum through a tailpipe and discharging through a diffuser, vertical condenser and short radius 90 degree bend to the ocean. Inlet and discharge gate valves are provided.



NOTE: D=DIMISTER

T=TURBINE

G=GENERATOR

Figure 2.4.1
OTEC Power Plant Schematic
(Typical)

### b) Gibbs and Cox

The G&C ship platform utilizes a symmetrical barge-type hull with vertical heat exchangers suspended below the platform. Each of the sixteen heat exchangers is provided with a separate sea water system as follows:

- The Warm water system for each power module consists of a vertical warm water pump suspended below the platform taking suction from a truncated conical inlet screen and discharging through a sharp radius (0.5 times pipe diameter) 180 degree bend to the vertical evaporator and warm water discharge pipe back into the ocean. No system closures are provided.

- The cold water system for each power module consists of a vertical cold water pump suspended below the platform within the cold water pipe upper plenum taking suction from the cold water pipe and discharging through a sharp radius (0.5 times pipe diameter) 180 degree bend to the vertical condenser and cold water discharge pipe back into the ocean. No system closures are provided.

### c) Lockheed Missle and Space Corporation

The LMSC ship platform consists of a central hull, external heat exchangers attached to both sides of the hull and external sea water pump in the sea water discharge piping. The eight condensers are located in the central portion of the platform, four on each side. The evaporators are located four at each end. The sixteen heat exchangers are provided with sea water systems as follows:

- The warm water systems are located at the ends of the hull. At each end, sixteen vertical warm water pumps (four per evaporator) take suction on a warm water plenum and discharge to the ocean via two discharge pipes. Water is drawn into the warm water plenum through the horizontal evaporators. Each evaporator is protected by an inlet screen. No system closures are provided.

- The cold water systems are grouped at the center portion of the hull surrounding the cold water plenum. The cold water systems are combined into two groups of four. Two horizontal cold water pumps take suction on the cold water plenum via a horizontal condenser for each system. The four pairs of cold water pumps for each group discharge into a common annular discharge pipe back into the ocean. No system closures are provided.

The LMSC Spar Platform utilizes a central spar supporting horizontal heat exchangers located externally about the spars periphery. Each of the sixteen heat exchangers is provided with a separate sea water system as follows:

- The warm water systems are located around the upper portions of the spar. Each warm water system consists of four vertical pumps taking suction through an inlet pipe and inlet screen and discharging through a vaned sharp radius 90 degree bend through the evaporator and short discharge pipe to the ocean. No system closures are provided.
- The cold water systems are located around the lower portion of the spar directly below the warm water systems. Each cold water system consists of four vertical pumps taking suction on the cold water pipe via an inlet gate valve, inlet pipe, condenser and vaned short radius 90 degree bend and discharging to the ocean through a vertical discharge pipe.

### 2.4.4 Discussion of Sea Water Systems Design Approaches by the OTEC Contractors

Key elements of the four OTEC sea water systems designs were identified and set down in a matrix format to distinguish the contractors (see Table 2.4.2). A discussion of these key elements follows.

#### a) OTEC Power Modules

All three contractors used eight 50 MWe (net) power modules with characteristics as described in Section 2.4.2 to make up the 400 MWe (net) OTEC platforms. The power modules each contain two heat exchangers, an evaporator and a condenser. The heat exchangers can be obtained for either vertical or horizontal sea water flow orientation. As noted in Section 2.4.3 G&C and MR&S selected vertical heat exchangers and LMSC selected horizontal heat exchangers to suit the particular configuration of their respective platform designs.

The heat exchanger characteristics indicate a head loss of 3.5 psig (7.9 ft) with a flow rate of 5000 cfs for the evaporator and 6000 cfs for the condenser. Characteristics utilized by the design agents varied somewhat as follows:

- G&C preferred to use a head loss of 8.6 ft for each heat exchanger because they felt that the DOE figure did not include entrance and exit losses.
- LMSC preferred to use flow rates of 6250 cfs for each heat exchanger with heat losses of 6247.7 psf (9.8 ft) for the evaporators and 443.3 psf (6.9 ft) for the condensers based on previous LMSC OTEC heat exchanger studies.

## TABLE 2.4.2

## OTEC CONCEPTS
## SEA WATER SYSTEMS COMPARISON MATRIX

| | G&C | LMSC(SHIP) | LMSC(SPAR) | MR&S |
|---|---|---|---|---|
| CONTRACTOR | Gibbs & Cox, Inc. | Lockheed Missile and Space Corporation | Lockheed Missile and Space Corporation | M. Rosenblatt&Son,Inc. |
| TYPE PLATFORM | Ship-Shape | Ship-Shape | Spar | Spar |
| PLATFORM LOCATION | Hawaii | New Orleans,La. | New Orleans, La. | Tampa, Florida |
| PLATFORM RATING | | | | |
| o GROSS | 520 MWe | 520 MWe | 520 MWe | 520 MWe |
| o NET | 400 MWe | 400 MWe | 400 MWe | 400 MWe |
| POWER MODULES | | | | |
| o QUANTITY | 8 | 8 | 8 | 8 |
| o NET RATING | 50MWe | 50 MWe | 50 MWe | 50 MWe |
| HEAT EXCHANGERS | | | | |
| o ORIENTATION | | | | |
| - Evaporators | Vertical | Horizontal | Horizontal | Vertical |
| - Condensers | Vertical | Horizontal | Horizontal | Vertical |
| o LOCATION | | | | |
| - Evaporators | External | External | External | Internal |
| - Condensers | External | External | External | Internal |
| o SEA WATER FLOW | | | | |
| - Evaporators | 5000 cfs | 6250 cfs | 6250 cfs | 5000 cfs |
| - Condensers | 6000 cfs | 6250 cfs | 6250 cfs | 6000 cfs |
| o SEA WATER AP | | | | |
| - Evaporators | 8.6 ft | 624.7 psf=9.8 ft | 624.7 psf=9.8 ft | 3.5 psid=7.9 ft |
| - Condensers | 8.6 ft | 443.3 psf=6.9 ft | 443.3 psf=6.9 ft | 3.5 psid=7.9 ft |
| COLD WATER PIPE | | | | |
| o Depth (length) | 3050 ft(2950 ft) | 2950 ft(2650 ft) | 2950 ft(2650 ft) | 3000 ft(2300 ft) |
| o Diameter | 100 ft (ID) | 73 ft (ID) | 73 ft (ID) | |
| o Flow | 4800 cfs | 50000 cfs | 50000 cfs | |
| - Rate | 6.1 fps | 12.0 fps | 12.0 fps | |
| - Velocity | (all cold water sys. piping losses=2.8 ft) | 82.86 psf=1.3 ft | 73.7 psf=1.2 ft | |
| - AP | | 236.29 psf=3.7 ft(total cold water sys.piping losses) | 162.9 psf=2.5 ft (total cold water sys. piping losses) | |

TABLE 2.4.2(continued)

## OTEC CONCEPTS
## SEA WATER SYSTEMS COMPARISON MATRIX

| | G&C | LMSC(SHIP) | LMSC(SPAR) | MR&S |
|---|---|---|---|---|
| **WARM WATER PUMP** | | | | |
| o Type | Axial Flow Propeller type | Impeller Pump | Impeller Pump | Axial Flow |
| o Capacity | 5000 cfs=2,25x$10^6$gpm | 3126 cfs=1.4x$10^6$gpm | 3125 cfs=1.4x$10^6$gpm | 6000 cfs=2.26x$10^5$ gpm |
| o Rated head | 10.9 ft=4.9 psi | 671.6 psi=10.5 ft=4,7psi | 674.6psf=10.5ft=4.7psi | 8.0ft=3.6 psi |
| o Water H.P. | 6342 HP | 3818 HP | 3818 HP | 4655 HP |
| o Pump Eff. | 90% | 86% | 86% | 90% Overall eff=75% |
| o Transmission Eff. | 100%(included w/motor) | 100%(included w/motor) | 100%(Included w/motor) | 100%(Included w/motor) |
| o Brake H.P. | 7046HP | 4440 HP | 4440 HP | 5172 HP |
| o Driver Eff. | 85% | 90% | 90% | 83%(assumed) |
| o Total Req'd. | | | | |
| - H.P. (Unit/Ttl) | 8290 HP/66320 HP | 4933 HP/78928 HP | 2466 HP/78928 HP | 6207 HP/49653 HP |
| - MWE(Unit/Ttl) | 6.18 MWe/49.4 MWe | 3.68 MWe/58.9 MWe | 1.98 MWe/58.9 MWe | 4.63 MWe/37,0 MWe |
| o Dimensions | 26.4' Lx24' Dia. | 60.7' Lx29.5' Dia. | 60.7' Lx29.5' Dia. | 54' Lx18' Dia. |
| o Weight | 762000 lbs | 1120000 lbs | 1120000 lbs | 850000 lbs |
| o Cost(Unit/Ttl) | \$5300K/\$42400K | \$2090K/\$33440K | \$2090K/\$33440K | \$3623K/\$28984K |
| o Vendor | Worthington Pump Corp. | | | |
| o Material | 316 L stainless steel | Steel | Steel | |
| o Orientation | Vertical | Vertical | Vertical | Vertical |
| o Location | External,Upstream | External,Downstream | External, Upstream | Internal,Upstream |
| o Quantity | 8 | 16 | 32 | 8 |
| **WARM WATER PUMP MOTOR** | | | | |
| o Rated power | 8000 HP | Included with warm water pump | Included with warm water pump | 6200 HP |
| o Dimensions | 21' Hx20' Dia. | | | Included w/pump |
| o Weight | 239000 lbs | | | Included w/pump |
| o Cost(Unit/Ttl) | \$1400K/\$11200K | | | Included w/pump |
| o Vendor | - | | | - |
| o Orientation | Vertical | | | Vertical |
| o Location | Internal | | | Internal |
| **WARM WATER PUMP TRANSM.** | | | | |
| o Type | Direct Drive(41 rpm) | Direct Drive | Direct Drive | Direct Drive(73 rpm) |

* This figure appears too low, should be approximately 9.2 ft. Heat exchanger $\Delta$P alone is 7.0 ft.

## TABLE 2.4 2 (continued)

## OTEC CONCEPTS
## SEA WATER SYSTEMS COMPARISON MATRIX

| | G&C | LMSC(SHIP) | LMSC(SPAR) | MR&S |
|---|---|---|---|---|
| COLD WATER PUMP | | | | |
| o Type | Axial Flow Propeller Type | Impeller Pump | Impeller Pump | Axial Flow |
| o Capacity | 6000 cfs= 2.7x$10^6$gpm | 3125 cfs=1.4x$10^6$gpm | 3125 cfs=1.4x$10^6$gpm | 6000 cfs=2.7x$10^6$gpm |
| o Rated head | 12.9 ft | 12.5 ft | 11.3 ft | 12.0 ft |
| o Water H.P. | 8657 HP | 4545 HP | 4109 HP | 8378 HP |
| o Pump Eff. | 90% | 86% | 86% | 90% Overall eff= 75% |
| o Transmission Eff. | 100%(included w/motor) | 100%(included w/motor) | 100%(included w/motor) | 100%(included w/motor) |
| o Brake H.P. | 9619 HP | 5285 HP | 4778 HP | 9309 HP |
| o Driver Eff. | 85% | 90% | 90% | 83%(assumed) |
| o Total Req'd. | | | | |
| - H.P. (Unit/Ttl) | 11316 HP/90528 HP | 5872 HP/93952 HP | 5309 HP/84944 HP | 11170 HP/ 89360 HP |
| - MWe(Unit/Ttl) | 8.44 MWe/67.5 MWe | 4.38 MWe/70.1 MWe | 1.98 MWe/63.3 MWe | 8.33 MWe/66.6 MWe |
| o Dimensions | 28' Lx25.5' Dia. | 60.7' Lx29.5' dia. | 60.7' Lx29.5' dia. | 60' Lx20' dia. |
| o Weight | 906000 lbs | 1120000 lbs | 1120000 lbs | 1090000 lbs |
| o Cost | $6300K/$50400K | $2090K/$33440K | $2090K/$33440K | $4329K/$34632K |
| o Vendor | Worthington Pump Corp. | | | |
| o Material | 316 L Stainless Steel | Steel | Steel | |
| o Orientation | Vertical | Vertical | Vertical | Vertical |
| o Location | External,Upstream | External,Downstream | External,Downstream | Internal,Upstream |
| o Quantity | 8 | 16 | 32 | 8 |
| COLD WATER PUMP MOTOR | | | | |
| o Rated Power | 11000 HP | Included with cold water pump | Included with cold water pump | 11250 HP |
| o Dimensions | 24'Lx21' dia. | | | Included w/pump |
| o Weight | 295000 lbs | | | Included w/pump |
| o Cost | $1800K/$14400K | | | Included w/pump |
| o Vendor | - | | | - |
| o Orientation | Vertical | | | Vertical |
| o Location | Internal | | | Internal |
| COLD WATER PUMP TRANSM. | | | | |
| o Type | Direct Drive(41 rpm) | Direct Drive | Direct Drive | Direct Drive(73 rpm) |

- MR&S utilized the DOE flow and head loss figures.

As mentioned in reference 2 the DOE estimates appear to be based on a heat exchanger tube size of one inch. It was noted that heat exchanger losses could be reduced to approximately 4.1 ft by using two inch tubes. The heat exchangers contribute a significant amount of parasitic losses (approximately 20 percent of rated net power output). Losses are equivalent to 75 percent for warm water systems and 79 percent for cold water systems, exclusive of cold water pipe and density effects. Such a significant reduction of the potential parasitic losses bears further investigation.

b) <u>Sea Water System Closures</u>

Depending on the design approach used by the contractor, sea water closures may be required for any of the following reasons:

- Isolation of sea water system(s) from the sea or from adjacent sea water systems for maintenance access or equipment removal.
- Isolation of sea water system(s) from adjacent sea water systems when a power module is secured. This is necessary to prevent flow through the secured units from the adjacent sea water systems pumps and is especially important for the cold water systems which share a common suction at the cold water plenum/cold water pipe.

Of the four designs reviewed, only the two spars contain sea water system closures. The MR&S spar contains an inlet and outlet gate valve for each warm and cold water system. These valves allow each sea water system to be isolated and drained if necessary for maintenance purposes. If, for any reason a power module is secured, its respective cold water system can be isolated using either one or both valves to prevent intermediate temperature water from being drawn into the cold water plenum through a secured cold water system. Also, the valve arrangement provides additional biofouling protection of secured sea water systems.

The LMSC spar contains a butterfly valve at each cold water system/cold water plenum interface to prevent intermediate temperature water from being drawn into the cold water plenum through a secured cold water system. Since each of the warm water systems is completely separate from the others, no closures would be necessary unless so determined by further investigation into biofouling control measures as discussed in Section 2.7.

The G&C ship contains no sea water closures. This presents no difficulties with respect to warm water systems operation since each system is completely separate. However, the possibility of intermediate temperature water being drawn through a secured condenser and into the cold water plenum exists whenever a power module's sea water systems are secured. In order to prevent this backflow a design modification will have to be made to either install a system closure or raise the condenser above the waterline and install a vent to serve as a vacuum break. Otherwise, no closures would be necessary unless so determined by further investigation into biofouling control measures as discussed in Section 2.7.

The LMSC ship also contains no sea water system closures. Review of this design shows the need for systems closures to be vital. The present design combines each of two warm water systems into two groups of four each, with all warm water pumps in each warm water system taking suction on a common warm water plenum which draws sea water through four evaporators. If a power module were secured, its warm water pump would have to be kept operating to prevent reduction in flow to the other evaporators. Without a means of isolating the pumps or evaporators from the plenum or the common warm water pump outlet pipe removal of a pump or evaporator would require complete shutdown of four power modules. The situation for the cold water systems is even more critical since all eight modules share the same cold water plenum.

c) Sea Water Pumps

All three contractors selected axial flow pump designs. MR&S and LMSC opted for designs containing the motor in an integrated pod within the water flow stream. G&C chose a component type system with separate pump and motor, with the motor located in an enclosed compartment within the hull of the platform.

The choice of pump material varied among the design agents. The initial G&C pump utilizes stainless steel to minimize corrosion. A second alternative of steel is also available which yields significant savings.

The ease of pump maintenance varies from one concept to another. The G&C design permits ready and convenient access to the pump motors and thrust bearings for inspection and maintenance. The pump can be pulled directly up through the hull bottom, provided that adequate trunking is installed. With the incorporation of cold water systems closures as discussed in section 4.b above, pump removal could be accomplished for any one power module without adversely affecting any other power module. Since warm water systems are completely separate, no interference is likely.

The LMSC ship design incorporates neutrally buoyant pump/pipe units for each module to make removal relatively simple, although divers, will be required and the depth is not inconsequential (92 feet and greater). Due to lack of piping system closures removal of a warm water pump is not feasible without securing 50 percent of the plant and removal of a cold water pump is not feasible without securing 100 percent of the plant for the reasons given in Section 4.b above.

The MR&S design incorporates inlet and discharge closures in each sea water system. To remove or inspect a pump, the valves must be closed and piping system drained. Pump may be moved laterally, then up through the central access trunk. The major problem with this design is that the closures must be capable of withstanding great pressures without leaking since the piping system is within the pressure hull (the lowest closure is located 590 ft below the design waterline). Due to independent system layout, maintenance of one module does not effect others.

Due to the integrated pump/motor designs adopted by LMSC and MR&S routine inspection and maintenance of the pump motor will be immensely more difficult and costly than in the G&C design.

d) Redundancy

Each of the designs incorporates eight fully redundant power modules. The G&C ship platform and MR&S spar platform contain no equipment redundancy within each power module. The LMSC spar platform contains four pumps per heat exchanger, however without any means of closing the flow path this redundancy is of little value. The LMSC ship platform is highly redundant on the warm water side in that for each of two systems any of eight pumps can serve any of four evaporators via a warm water plenum. However, lack of closures nullify this redundancy. The LMSC cold water systems are served by two sea water pumps for the ship platform and four sea water pumps for the spar platform.

### 2.4.5 Comparison of LMSC, G&S, and MR&S Design on a Unified Basis

As noted in Section 2.4.4 several major differences exist among the four sea water systems designs. The following paragraphs address these differences to determine if they are due to differences in basic approach by the contractors or if they result from independent value judgements by the contractors. Those differences resulting from the latter were arbitrarily normalized to a uniform value for each design in order to evaluate only true elements and set down in Table 2.4.3 in a matrix format similar to Table 2.4.2. Parameters changed from Table 2.4.2 are denoted in Table 2.4.3 by an asterisk. Rationale for these changes is presented in the following paragraphs.

### a) Location

The location of the OTEC platforms was specified to be Tampa, Florida for the purposes of this analysis by DOE. The only impact on the sea water systems of this standardization is a slight change in cold water pipe length. This difference in depth is less than two percent and therefore has a negligible effect on cold water system head loss and therefore parasitic load.

### b) OTEC Power Modules

Differences in heat exchanger orientation and location were direct functions of the basic design approach selected by each contractor. However, differences in heat exchanger sea water flow rate and heat loss are due to contractor judgement. Therefore, for the purpose of this analysis, these parameters were standardized on those values promulgated by DOE.

### c) Sea Water Pumps

As noted in Section 2.4.4c, numerous differences exists in the sea water pumps selected by the three contractors. The major differences were as follows:

- G&C utilized a separate pump and motor installation while LMSC and MR&S utilized an integrated pump motor unit.
- G&C and MR&S utilized one sea water pump per heat exchanger while LMSC utilized two.
- G&C utilized highly corrosion resistant material while LMSC and MR&S apparently did not.

For the purposes of this study, each contractor would select pumps of similar characteristics i.e. overall pump efficiency was assumed to be 75 percent, which is similar to the overall efficiencies given by the contractors. Pump heads for the G&C and LMSC designs were recalculated based on standardized DOE heat exchanger flow and head loss characteristics. Moreover, it was assumed that all pumps would be of carbon steel,with a stainless steel liner in the impeller case and a stainless steel impeller.

### d) Sea Water System Closures

As noted in Section 2.4.4b, the G&C and LMSC ship designs require the addition of closures in the sea water systems in order to operate power modules either independently or in combination with other modules. Valve costs (material and labor) were deduced from MR&S data as follows:

## TABLE 2.4.3

## OTEC CONCEPTS
## SEA WATER SYSTEMS COMPARISON MATRIX

| | G&C | LMSC(SHIP) | LMSC(SPAR) | MR&S |
|---|---|---|---|---|
| CONTRACTOR | Gibbs&Cox,Inc. | Lockheed Missile and Space Div. | Lockheed Missle and Space Div. | M.Rosenblatt&Son,In |
| TYPE PLATFORM | Ship-Shape | Ship-Shape | Spar | Spar |
| PLATFORM LOCATION | *Tampe,Florida | *Tampa,Florida | *Tampa,Florida | Tampa,Florida |
| PLATFORM MODULES | | | | |
| o Quantity | 8 | 8 | 8 | 8 |
| o New Rating | 50 MWe | 50 MWe | 50 MWe | 50 MWe |
| HEAT EXCHANGERS | | | | |
| o Orientation | | | | |
| - Evaporators | Vertical | Horizontal | Horizontal | Vertical |
| - Condenser | Vertical | Horizontal | Horizontal | Vertical |
| o Location | | | | |
| - Evaporators | External | External | Esternal | Internal |
| - Condensers | External | External | External | Internal |
| o Sea Water Flow | | | | |
| - Evaporators | 5000 cfs | *5000 cfs | *5000 cfs | 5000 cfs |
| - Condensers | 6000 cfs | *6000 cfs | *6000 cfs | 6000 cfs |
| o Sea Water ΔP | | | | |
| - Evaporators | *7.9 ft | *7.9 ft | *7.9 ft | 7.9 ft |
| - Condensers | *7.9 ft | *7.9 ft | *7.9 ft | 7.9 ft |
| COLD WATER PIPE | | | | |
| o Depth(Length) | *3000 ft(2900 ft) | *3000 ft(2700 ft) | *3000 ft(2700 ft) | 3000 ft(2300 ft) |
| o Diameter | 100 ft(ID) | 73 ft (ID) | 73 ft (ID) | |
| o Flow | 48000 cfs | *48000 cfs | *48000 cfs | 48000 cfs |
| - Rate | 6.1 fps | 12.0 fps | 12.0 fps | |
| - Velocity | (211 cold water sys, piping losses=2.8 ft) | 82.86 psf=1.3 ft | 73.7 psf=1.2 ft | |
| - ΔP | | 238.29 psf=3.7 ft(total cold water sys.piping losses) | 162.9 psf=2.5 ft(total cold water sys piping losses) | |

## TABLE 2.4.3 (continued)

## OTEC CONCEPTS
## SEA WATER SYSTEMS COMPARISON MATRIX

| | G&C | LMSC(SHIP) | LMSC(SPAR) | MR&S |
|---|---|---|---|---|
| **WARM WATER PUMP** | | | | |
| o Type | Axial flow propeller Type | Impeller pump | Impeller pump | Axial flow |
| o Capacity | 5000 cfs=2.25x$10^6$ gpm | *2500 cfs=1.1x$10^6$ gpm | *2500 cfs=1.1x$10^6$ gpm | 5000 cfs=2.25x$10^6$ |
| o Rated head | *10,2 ft | *8.4 ft | *8,4 ft | *9.2 ft |
| o Water H.P. | *5935 HP | *2443 HP | *2443 HP | * 5353 HP |
| o Pump effi. | 90% | 90% | 90% | 90% |
| o Transmission eff. | *98% | *98% | *98% | *98% |
| o Brake H.P. | *6729 HP | *2771 HP | *2771 HP | *6069 HP |
| o Drive eff. | 85% | *85% | *85% | *85% |
| o Total Required | | | | |
| - HP (Unit/Ttl) | *7916 HP/63327 HP | *3259 HP/52152 HP | *1630 HP/52152 HP | *7140 HP/57119 HP |
| - MWe (Unit/Ttl) | 5.90 MWe/47.2 MWe | *2.43 MWe/38.9 MWe | *1.22 MWe/38.9 MWe | *5.32 MWe/42.6 MWe |
| **COLD WATER PUMP** | | | | |
| o Type | Axial flow propeller | Impeller pump | Impeller pump | Axial flow |
| o Capacity | 6000 cfs=2.7x$10^6$ gpm | *3000 cfs=1.4x$10^6$ gpm | *3000 cfs=1,4x$10^6$ gpm | 6000 cfs=2.7x$10^6$ g |
| o Rated head | *11.7 ft | *13.1 ft | *12.1 ft | 12.0 ft |
| o Water HP | *8169 HP | *4373 HP | *4189 HP | 8378 HP |
| o Pump eff. | 90% | *90% | *90% | 90% |
| o Transmission eff. | 98% | *98% | *98% | *98% |
| o Brake HP | *9262 HP | *5185 HP | *4750 HP | *9499 HP |
| o Driver eff. | 85% | *85% | *85% | *85% |
| o Total Required | | | | |
| - HP (Unit/Ttl) | *10896 HP/87168 HP | *6100 HP/97598 HP | *2794 HP/89403 HP | 11170 HP/89365 HP |
| - MWe(Unit/Ttl) | *8.12 MWe/65.0 MWe | *4.55 MWe/727 MWe | *2.08 MWe/66.6 MWe | 8.33 MWe/66.6 MWe |

Warm Water Piping - $\$5.9\text{x}10^6$
Cold Water Piping - $\$10.7\text{x}10^6$
Warm Water Pumps - $\$29.0\text{x}10^6$
Cold Water Pumps - $\$34.6\text{x}10^6$
Warm Water Screens - $\$11.1\text{x}10^6$

Sub Total - $\$91.3\text{x}10^6$

Sea Water Systems Cost - $\$110.7\text{x}10^6$
Sea Water Valve Costs - $\$19.4\text{x}10^6$
Cost per Valve (32 Valves) - $\$0.60\text{x}10^6$

The G&C ship would require an additional eight valves for the cold water systems. The LMSC ship would require a minimum of sixteen valves, eight each for the cold water and warm water systems.

#### e) Parasitic Loads

Table 2.4.4 contains a summary of the sea water system parasitic loads and their relative effect on net power plant output. For the purpose of this study, the G&C ship was assumed to have a net power output of 400 MWe and the output of the other plants were adjusted based on the differences between their sea water system parasitic loads and the G&C ship sea water parasitic load.

### 2.4.6 Acquisition Cost

The acquisition costs were determined using the contractor furnished cost data and are shown in Table 2.4.5.

The costs of the seawater pumps were revised to reflect unified pump materials as discussed in Section 2.4.5c. G&C gives a cost of \$95.2m for their platform for pumps to this material specification. G&C also indicate that the cost differential, between carbon steel pumps and the material specification indicated in 2.4.5.c is in the order of 32%. This correction was applied to the LMSC and MR&S pumps costs. The resulting figures are given in Table 2.4.5 and show a reasonable level of agreement between the three contractors.

An allowance was also made for the addition of sea water system closures to ensure proper operation of each power module either independently or in combination with other modules. Valve costs were assumed to be $\$0.60\text{x}10^6$ each, as deduced from the MR&S data. An allowance of \$7.1m was made for all contractors to cover the cost of chlorinating systems as discussed in Section 2.7. MR&S diffuser costs were reduced to allow for savings through reduction in diffuser length as discussed in Section 2.5.

## TABLE 2.4.4

## SEA WATER SYSTEMS INCLUDED PARASITIC LOADS

| PLATFORM | PARASITIC | | LOAD |
|---|---|---|---|
| G&C Ship | Warm Water | - | 47.2 MWe |
| | Cold Water | - | 65.0 MWe |
| | Total | - | 112.2 MWe |
| LMSC Ship | Warm Water | - | 38.9 MWe |
| | Cold Water | - | 72.7 MWe |
| | Total | - | 111.6 MWe |
| LMSC Spar | Warm Water | - | 38.9 MWe |
| | Cold Water | - | 66.6 MWe |
| | Total | - | 105.5 MWe |
| MR&S Spar | Warm Water | - | 42.6 MWe |
| | Cold Water | - | 66.6 MWe |
| | Total | - | 109.2 MWe |

## TABLE 2.4.5

## SEAWATER SYSTEMS ACQUISITION COSTS
(MILLIONS OF DOLLARS)

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| CW Pumps Motor, Transmissions | | | | |
| WW Pumps, Motor, Transmissions | 95.2 | 88.3 | 88.3 | 84.0 |
| CW Piping including Diffusers | 3.1 | N.A. | N.A. | 5.9 |
| WW Piping including Diffusers | 3.4 | N.A. | N.A. | 10.7 |
| Valves | 4.8 | 9.6 | N.A. | 19.4 |
| Screens, Filters(Except those in CWP) | 6 | 14.3 | 14.3 | 11.1 |
| Pump Module, Housing Interface | N.A. | 2.2 | 2.2 | N.A. |
| Heat Exchanger/Hull Interface | N.A. | 1.0 | 1.0 | N.A. |
| Condenser Water Boxes | N.A. | 2.3 | 2.3 | N.A. |
| Discharge Hoses | N.A. | 2.6 | 2.6 | N.A. |
| Controls and Purge,Miscellaneous | N.A. | 2.6 | 2.6 | N.A. |
| Biofouling and Corrosion Control | 7.1 | 7.1 | 7.1 | 7.1 |
| SUB TOTAL | 119.6 | 130 | 120.4 | 138.2 |
| Margin 10% | 12.0 | 13 | 12.0 | 13.8 |
| TOTAL | 131.6 | 143 | 132.4 | 152 |

## 2.5 TRADE OFF STUDY OF SHORT VERSUS LONG SEA WATER SYSTEMS

The purpose of this study was to compare the design of the present sea water systems on the MR&S spar with a design utilizing shorter diffusers in an attempt to decrease spar length and hence platform costs.

As stated in Reference 1, the MR&S spar platform size and configuration was driven by the sea water systems which were designed to provide optimum flow to the heat exchangers, to maximize heat exchanger efficiency and to minimize system head losses and hence parasitic losses.

G&C, in the development of their ship platform, conducted a trade off study of short-radius (.5 times pipe diameter) vs. long-radius (1.5 times pipe diameter) bends. It was concluded that the short radius design advantages(decreased platform size and first costs) outweighed the disadvantages(increased parasitic looses and decreased revenue) from a life-cycle standpoint.

Based on the above, it was decided to conduct a similar trade off study for the MR&S spar platform.

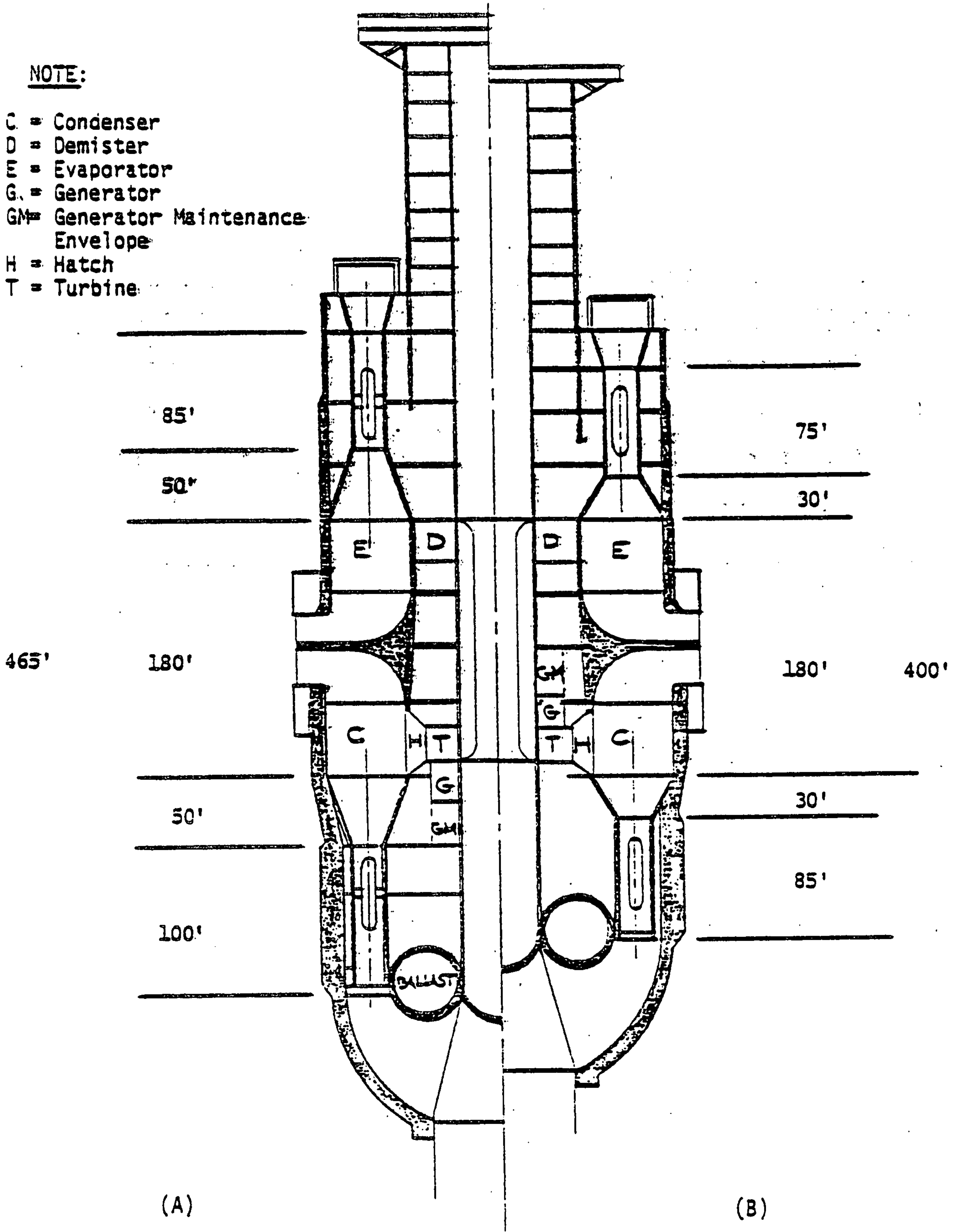
The MR&S spar platform sea water systems design was reviewed. It was determined that the warm water piping could be reduced approximately 9 percent (30 feet) and the cold water piping could be reduced approximately 15 percent (35 feet) as shown on Figure 2.5.1. The system components shortened and the amounts are shown in Table 2.5.1. The warm and cold water discharge elbows were not modified since the present design appears to be as compact as practicable.

A comparison of the head losses is shown in Tables 2.5.2 and 2.5.3 for the warm water and cold water systems respectively. These indicate a net increase of warm water head loss of 0.96 ft. (12.0 percent) and cold water loss of 0.52 ft. (4.3 percent). The net increase of sea water system induced parasitic loads would be 4.3 percent for the warm water system, 2.8 percent for the cold water system, and 7.1 percent for the combined warm water/cold water systems.

The MR&S spar platform arrangements were then reviewed in more detail to determine if this degree of reduction was practicable from an arrangements standpoint. Present arrangement of the spar in the cold water area (elevations 250 ft. through 590 ft.) is quite saturated with equipment. However, relocating the generators to a position above the turbine would provide adequate room. With the reduction of the cold waterpump diffuser by 20 ft. the distance between the generators and the power conditioning equipment and switchgear would not be significantly increased. The cold water pump tailpipe shortening could be accomplished by reducing the deck height in the ammonia storage area and by relocating the ballast torus downward. Considerable unassigned space exists in the warm water area (Elevations 100 ft. through 350 ft.) and achievement of 30 ft. reduction is possible with minimum modification.

NOTE:

C = Condenser
D = Demister
E = Evaporator
G = Generator
GM = Generator Maintenance Envelope
H = Hatch
T = Turbine



(A)
Existing
MR&S Spar Design

(B)
Minimum Length
MR&S Spar Design

FIGURE 2.5.1

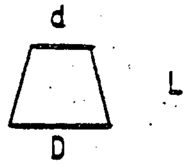
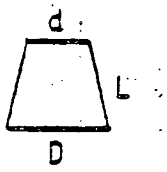
## Table 2.5.1

### SEA WATER SYSTEM PIPING COMPONENT LENGTHS

| COMPONENT | EXISTING | MODIFIED | DECREASE |
|---|---|---|---|
| W.W. Pump Tailpipe | 31 ft | 21 ft | 10 ft |
| W.W. Pump Diffuser | 50 ft | 30 ft | 20 ft |
| C.W. Pump Tailpipe | 40 ft | 25 ft | 15 ft |
| C.W. Pump Diffuser | 50 ft | 30 ft | 20 ft |

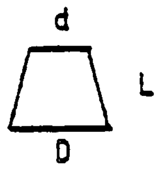
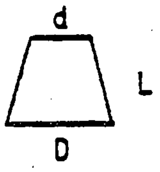
## TABLE 2.5.2

## Warm Water System Head Losses

| Existing MR&S Design | Modified MR&S Design |
|---|---|
| 1. **Warm Water Pipe** | 1. **Warm Water Pipe** |
| Length (L) = 31' | Length (L) = 21' |
| Diameter(D)= 18' | Diamter(D) = 18' |
| Flow Rate (Q)= 5000 cfs | Flow Rate (Q)= 5000 cfs |
| Velocity (V) = 19.65 fps | Velocity (V) = 19.65 fps |
| Friction Factor (f)=0.00783 | Friction Factor (f)= 0.00783 |
| Head Loss (h<sub></sub>L): | Head Loss (hL): |
| $h_L = f \frac{L}{D} \frac{V^2}{2g}$ | $h_L = f \frac{L}{D} \frac{V^2}{2g}$ |
| $h_L = 0.00783 \frac{31}{18} \frac{(19.65)^2}{2x32.2}$ | $h_L = 0.00783 \frac{21}{18} \frac{(19.65)^2}{2x32.2}$ |
| $h_L$ = 0.0808 ft. | $h_L$ = 0.0548 ft. |
| 2. **Warm Water Diffuser** | 2. **Warm Water Diffuser** |
| Major Dia.(D)=55' | Major Dia.(D)=55' |
| Minor Dia.(d)=18'  | Minor Dia.(d)=18'  |
| Length(L)= 50' | Length(L)=30' |
| Angle = 40.61° | Angle 63.32° |
| Geometry Factor (k)=0.9x0.82 | Geometry Factor(k)=1.1 x 0.82 |
| ∴ k = 0.738 | ∴ k = 0.902 |
| Head Loss ($h_L$): | Head Loss ($h_L$): |
| $h_L = k \frac{V^2}{2g}$ | $h_L = k \frac{V^2}{2g}$ |
| $h_L = 0.738 \frac{(19.65)^2}{2x32.2}$ | $h_L = 0.902 \frac{(19.65)^2}{2x32.2}$ |
| $h_L$ = 4.425 ft. | $h_L$ = 5.408 ft |

## TABLE 2.5.3

## Cold Water System Head Losses

| Existing MR&S Design | Modified MR&S Design |
|---|---|
| 1. Cold Water Pipe | 1. Cold Water Pipe |
| Length (L) = 40' | Length (L) = 25' |
| Diameter (D)= 20' | Diameter (D)= 20' |
| Flow Rate(Q)= 6000 cfs | Flow Rate(Q)= 6000 cfs |
| Velocity (V)= 19.1 fps | Velocity (V)= 19.1 fps |
| Friction Factor(f)= 0.0076 | Friction Factor (f)= 0.0076 |
| Head Loss ($h_L$): | Head Loss ($h_L$): |
| $h_L = f \frac{L}{D} \frac{V^2}{2g}$ | $h_L = f \frac{L}{D} \frac{V^2}{2g}$ |
| $h_L = 0.0076 \frac{40}{20} \frac{(19.1)^2}{2x32.2}$ | $h_L = 0.0076 \frac{25}{20} \frac{(19.1)^2}{2x32.2}$ |
| $h_L$= 0.086 ft. | $h_L$= 0.0538 ft. |
| 2. Cold Water Diffuser | 2. Cold Water Diffuser |
| Major Dia.(D)= 55' | Major Dia.(D)=55' |
| Minor Dia.(d)=20' | Minor Dia.(d)=20' |
| Length (L)=50' | Length (L) = 30' |
|  |  |
| Angle 38.6° | Angle 60.52° |
| Geometry Factor (k)=0.9x0.7 | Geometry Factor (k)= 1.1x0.7 |
| ∴ k=0.63 | ∴ k=0.77 |
| Head Loss ($h_L$): | Head Loss ($h_L$): |
| $h_L = k \frac{V^2}{2g}$ | $h_L = k \frac{V^2}{2g}$ |
| $h_L = 0.63 \frac{(19.1)^2}{2x32.2}$ | $h_L = 0.77 \frac{(19.1)^2}{2x32.2}$ |
| $h_L$= 2.48 ft. | $h_L$= 3.03 ft. |

## TABLE 2.5.4
## CONSTRUCTION COST SAVINGS

| COST FACTOR | CALCULATION | SAVINGS |
|---|---|---|
| $\$650/cy$ | Hull-Reduction of length reduces draft and therefore pressure at lower extremity. Therefore all reduction taken between 490 and 590 ft.<br>ID=220 ft OD=246 ft $\Delta L$=65 ft<br>$S=\frac{\$650}{cy}\;\frac{\pi(OD)^2}{4}-\frac{\pi(ID)^2}{4}\;\frac{\Delta L}{27}$ | $\$14.9x10^6$ |
| | $\$650$<br>Internal structure 15% | $\$2.1x10^6$ |
| $\$500/cy$ | Ducting-(Assume average 2 ft thickness)<br>● Diffusers<br>- CW avg ID=37.5'<br>avg OD=41.5'<br>$\Delta L$ = 20'<br>Svgs = $1.47x10^3$ cy | $\$0.74x10^6$ |
| | - WW avg ID= 36.5'<br>avg OD= 40.5'<br>$\Delta L$ = 20'<br>Svgs = $1.43x10^3$ cy | $\$0.72x10^6$ |
| | ● Piping<br>- CW ID=20'<br>OD=24'<br>$\Delta L$=15'<br>Svgs =$0.61x10^3$cy | $\$0.31x10^6$ |
| | - WW ID=18'<br>OD=22'<br>$\Delta L$=10'<br>Svgs =$0.36x10^3$cy | $\$0.18x10^6$ |
| $\frac{\$40x10^6}{2300\ ft}$ = | Cold Water Pipe - Draft reduction requires increase in CWP length of 65 ft | |
| $\frac{\$.0174x10^6}{ft}$ | $65' \times \frac{\$.0174x10^6}{ft}$ | $\$1.13x10^6$ |
| | Net Savings | $\$17.8x10^6$ |

The reduction in platform costs was calculated as indicated in Table 2.5.4. Cost factors were obtained from Reference 1. Other cost reductions may be obtained due to saving in interior bulkheads, decreased bottom thickness and reduced mooring loads, but their impact is unknown at this time and were not included in the calculations. The net construction savings was found to be $17.8 million.

A life cycle cost analysis was carried based on the MR&S life cycle costs estimates summarized in Table 52 of Reference 1. Changes in net power output were plotted against reductions in length and are shown in Figure 2.5.2. Cost savings were calculated for length reductions of 20, 40 and 65 feet. The resultant life cycle costs per megawatts are shown in Table 2.5.5 for length reductions up to 65 ft. Optimum life cycle costs occur at a reduction of approximately 20 ft.

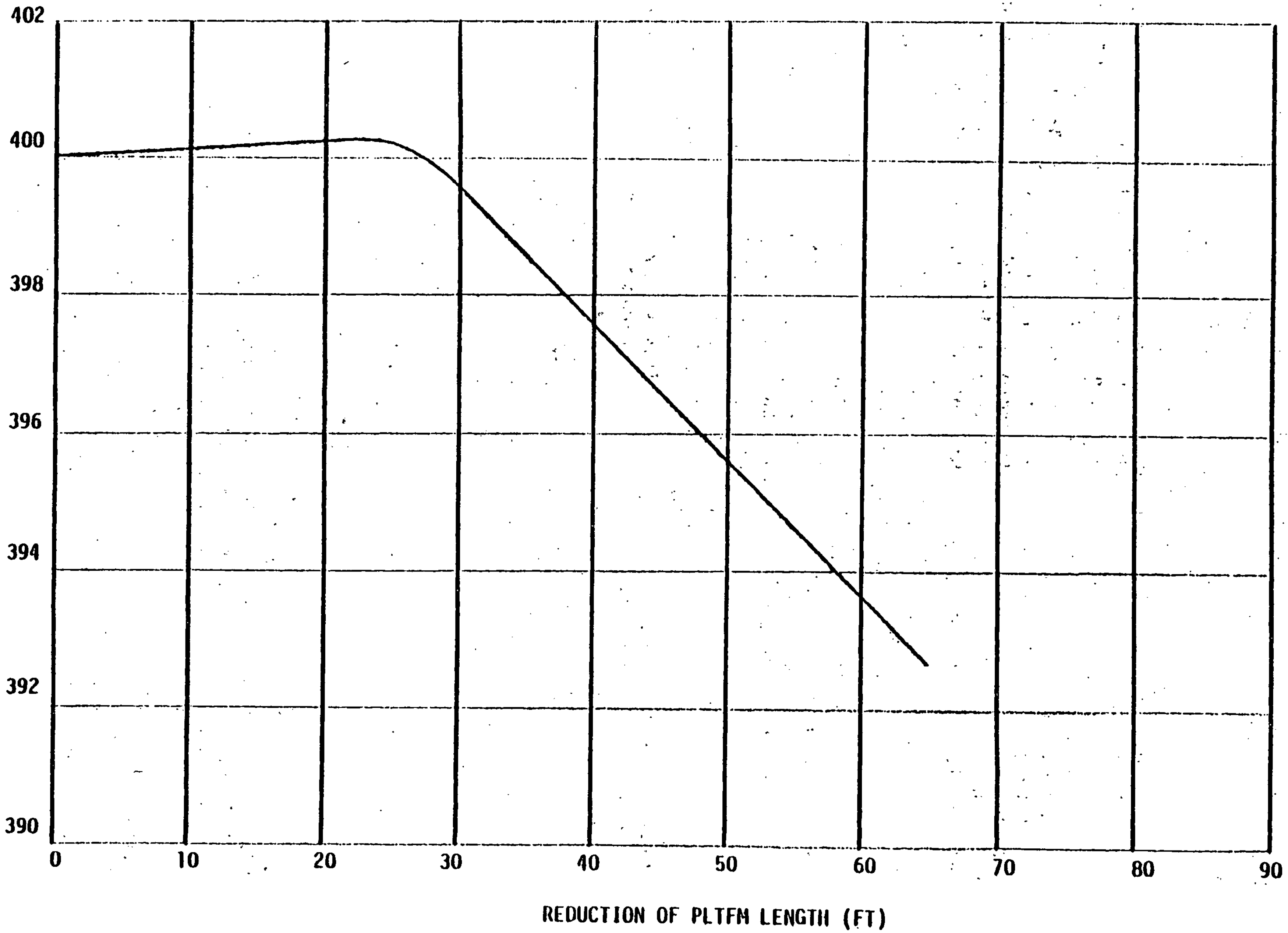
TABLE 2.5.5

LIFE CYCLE COST ANALYSIS

| REDUCTION (FT.) | 0 | 20 | 40 | 65 |
|---|---|---|---|---|
| SAVINGS | - | 5.48 | 10.96 | 17.8 |
| LIFE CYCLE COST | 1581.2 | 1578.5 | 1570.2 | 1563.4 |
| POWER IN MWe | 400 | 400.3 | 397.5 | 393 |
| COST/MWe | 3953 | 3936.3 | 3950 | 3978 |
| COST RELATIONSHIP | 1 | 0.995 | 0.999 | 1.006 |

FIGURE 2.5.2

PLATFORM NET POWER VS. ΔL



## 2.6 HULL AND STRUCTURE

### 2.6.1 Overview of Structural Designs by the three Contractors

#### a) M. Rosenblatt and Son

MR&S approached material selection by arguing that the work already carried out by them and by LMSC on OTEC platforms had shown that concrete hulls would be significantly less expensive than steel. They therefore selected as a construction material a concrete mix with an ultimate compressive strength of 7000 psi and a density of 150 pounds per cubic foot. Although they considered lightweight concrete, MR&S did not use it because in their opinion it has not been extensively used in the marine environment and because its compressive stress is less than that of conventional concrete.

The platform shell is essentially composed of a series of wall sided cyliners of varying inner moulded diameters and thickness. Decks are a uniform watertight concrete construction laid over steel beams, the bulkheads are of concrete, their thickness taken as 4% of their moulded height with a lower limit of 1.5 ft. The deckhouse is constructed of aluminum.

The final structural configuration is shown on Figure 2.6.1.

#### b) Gibbs and Cox

G&C investigated both steel and concrete platforms and compared their costs on the basis of a trade off study. This showed very slight differences in favour of steel which, however, were not judged adequate to justify its selection as the hull material without consideration of secondary criteria. Steel was eventually selected on the ground that it showed advantages in respect of risk and constructability because of the well developed shipbuilding technology.

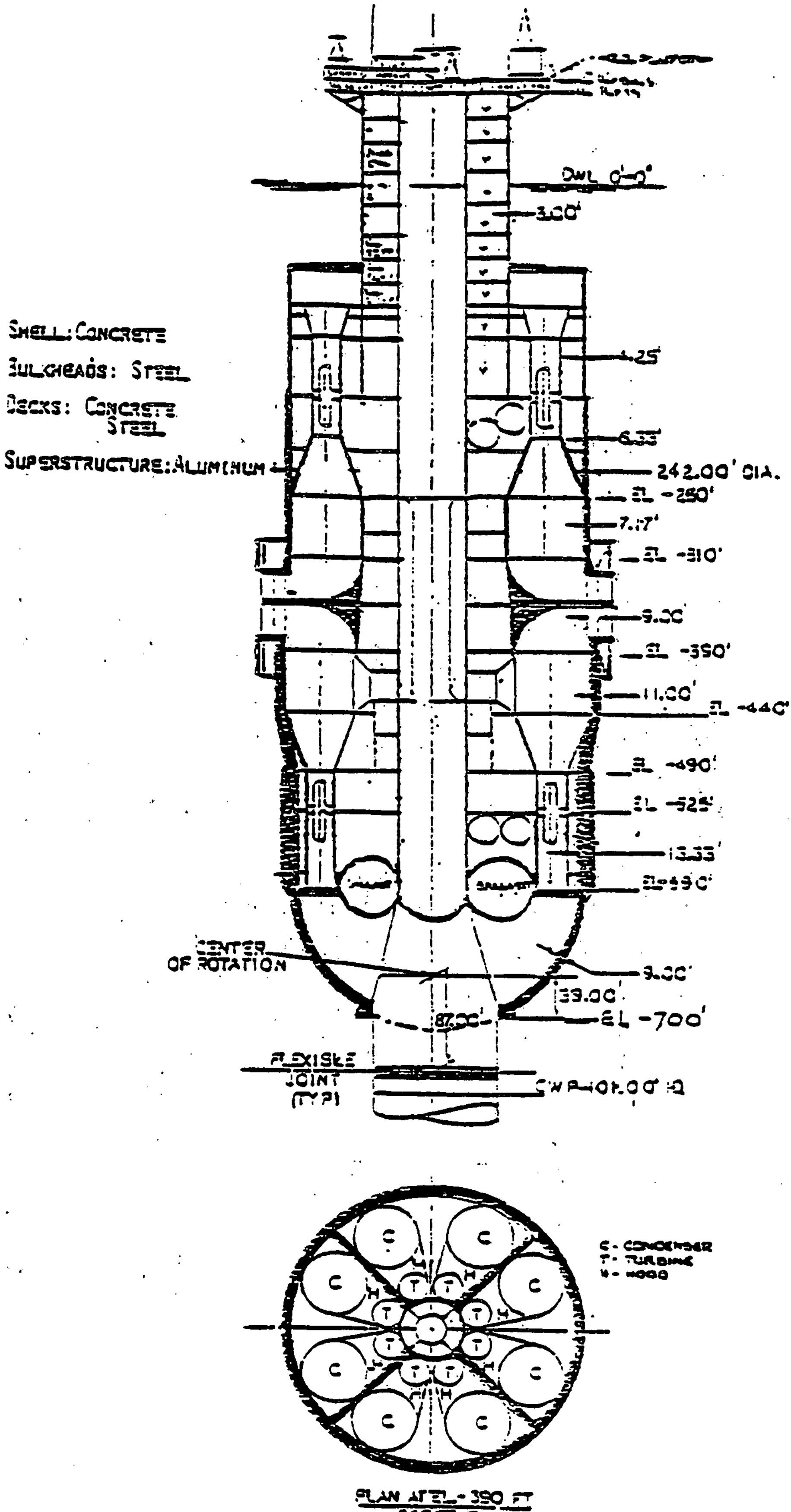
The structural configuration consists of a rectangular platform framed longitudinally and with deep webs spaced 18 ft. apart. Nine transverse watertight bulkheads and six watertight longitudinal bulkheads are provided.

Figure 2.6.2 shows the structural configuration of the platform.

#### c) Lockheed Missiles and Space Company

LMSC's design is based on lightweight concrete weighing 110 lbs. per cubic foot. The preference for concrete over steel results from the trade off studies during the Systems Integration and Evaluation which preceeded the concept design of the OTEC commercial platforms.

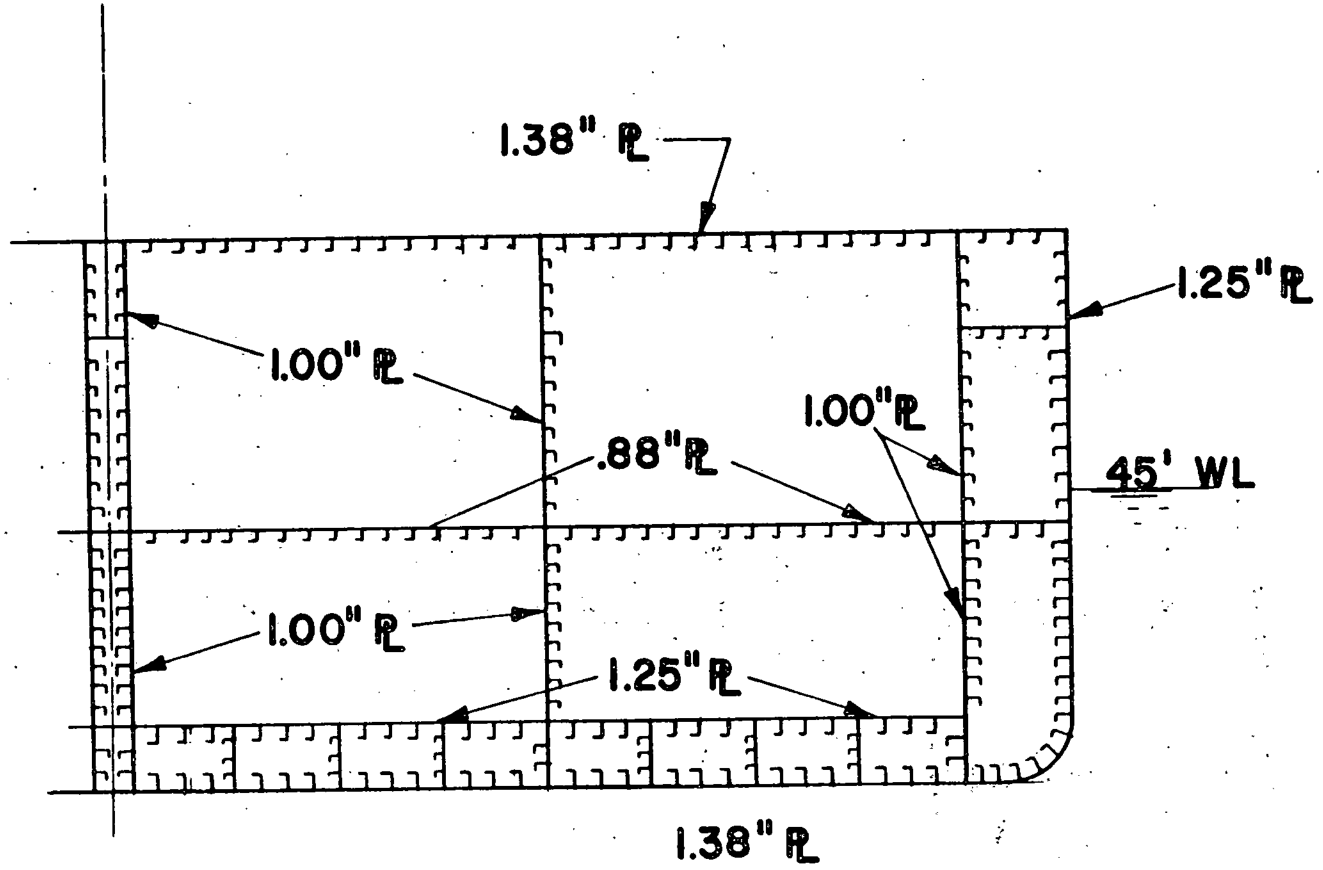
The material selected has an ultimate compressive stress of 5000 lbs. per square inch. For long term consideration the weight per cubic foot is composed of 110 lbs. concrete, 5 lbs. reinforcement and 20 lbs. water absorption, i.e. 135 lbs. in all.



PLAN AT EL.-390 FT
240FT D

MR&S SPAR DESIGN

Figure 2.6.1



TYPICAL MIDSHIPS SECTION 400 MW SHIP

Figure 2.6.2

The ship structural system consists essentially of a long box, with variable width. Transverse girders extend beyond the sides of the box to hold and support the buoyant heat exchangers. The CWP is supported on a ring beam at the bottom of the vessel which is in turn supported by the longitudinal walls. The ship is prestressed longitudinally in the two side walls, transversely in the transverse girders and vertically in the section uninterrupted by the side openings. Precast structural elements are used in the construction of decks to save formwork and staging. The structural configuration is shown on Figure 2.6.3.

The spar structure consists of a cylindrical, watertight core, with hemispherical ends, providing the necessary buoyancy for the platform to float. Below the core and integral with its base, a system of structural framing is arranged around a concrete base to provide the foundations for the cold water pipe and the power modules. The structural configuration is shown in Figure 2.6.4.

## 2.6.2 Discussion of Design Approaches by the three Contractors

### a) Design Analysis

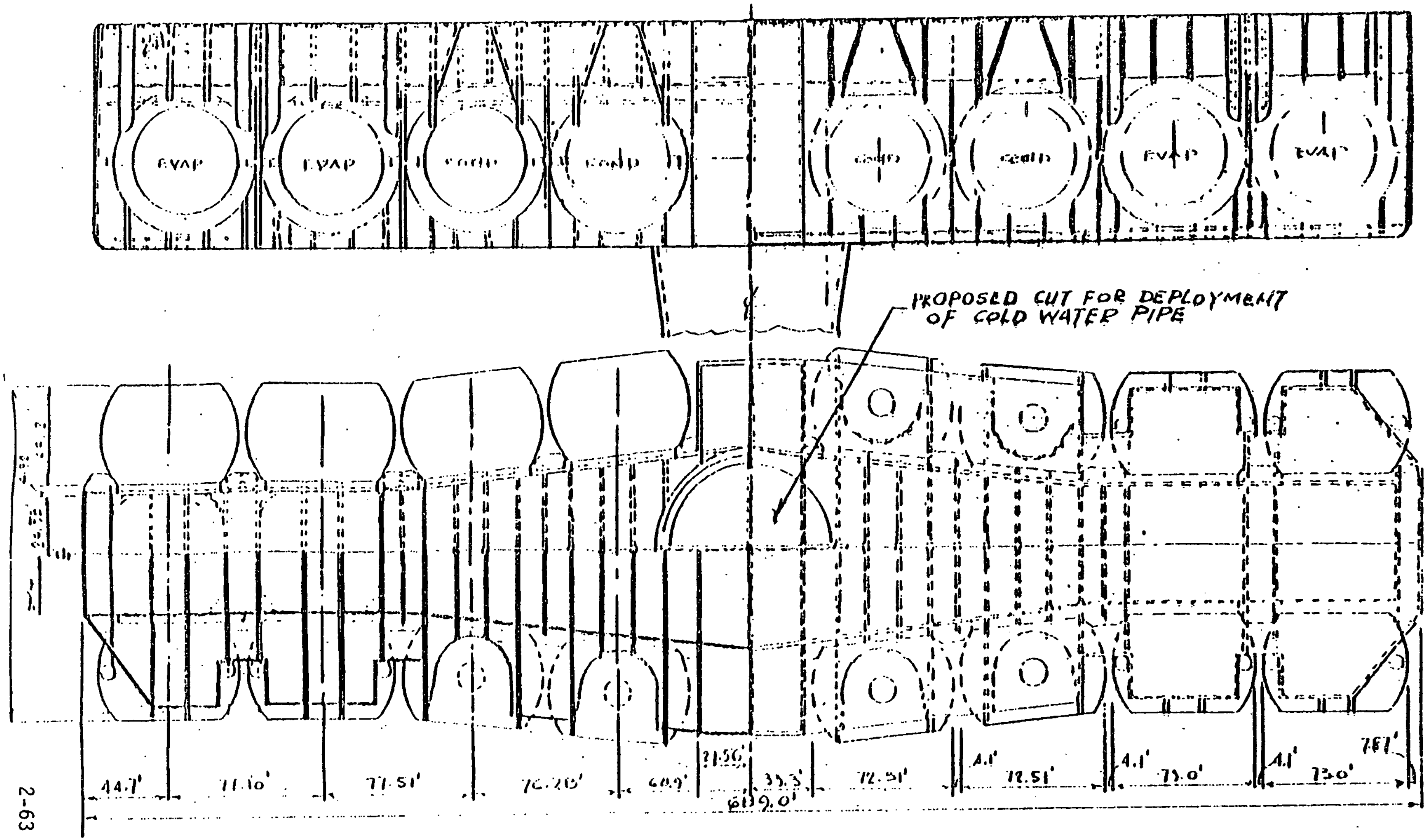
MR&S' design analysis for the concrete shell was carried out following procedures developed by Haynes and Nordly (Reference 8) the American Concrete Institute (Reference 9) and the Federation International de la Precontrainte (Reference 10). The stress analysis proceeded through several iterations and ended with a finite element analysis in the ANSYS computer program.

The calculations are based on failure of cylinders by implosion buckling as the primary criteria. The design loads described in their report, assume a wave height with a probability of occurrence of $10^{-6}$, corresponding to a wave height of 120.54 ft. The general approach appears to be conservative and in the absence of published codes for floating concrete structures MR&S rely on first principles calculations supported by conservative assumptions.

G&C designed their ship hull in accordance with current ship structural design methods. ABS rules were used as a baseline guide. The Navy design manual was used to evaluate local panel conditions. The hull midship section was calculated by treating the ship as a beam, with non-uniform loading, in a design wave height equal to 1.1 times the square root of the platform length. The allowable primary stress was taken at 10.36 tons.

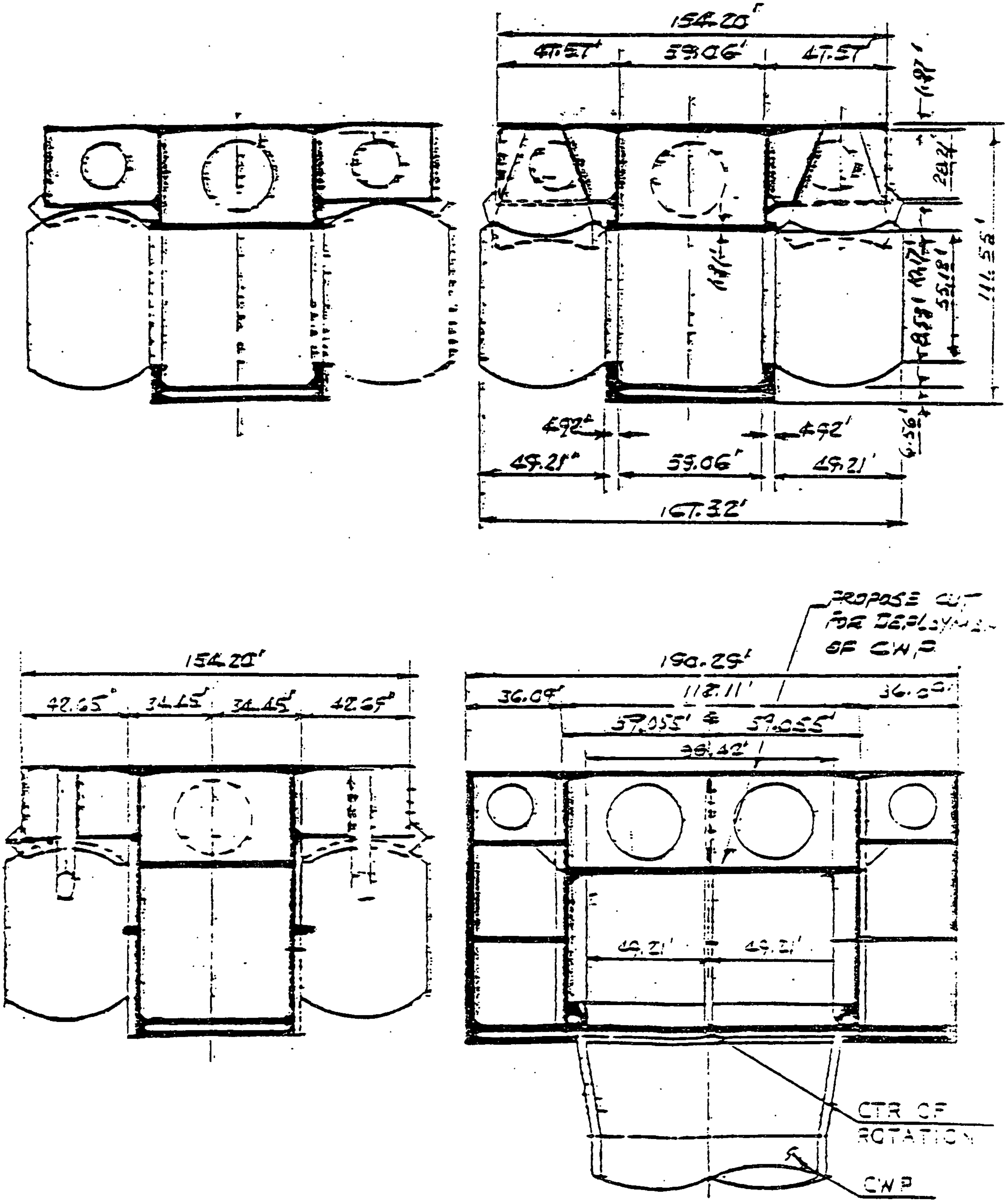
The bending moment calculated by G&C is given as follows:

| | |
|---|---|
| B.M. Sagging | 1,368,888 meter tons |
| B.M. Hogging | 2,059,525 meter tons |



LMSC SHIP SHAPE DESIGN

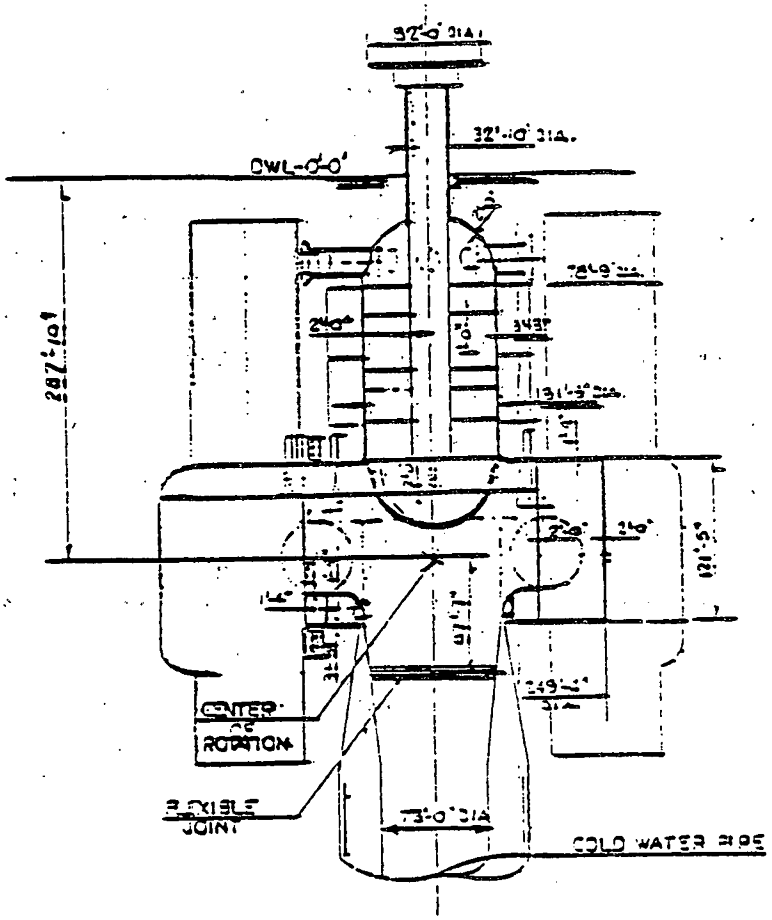
Figure 2.6.3.a



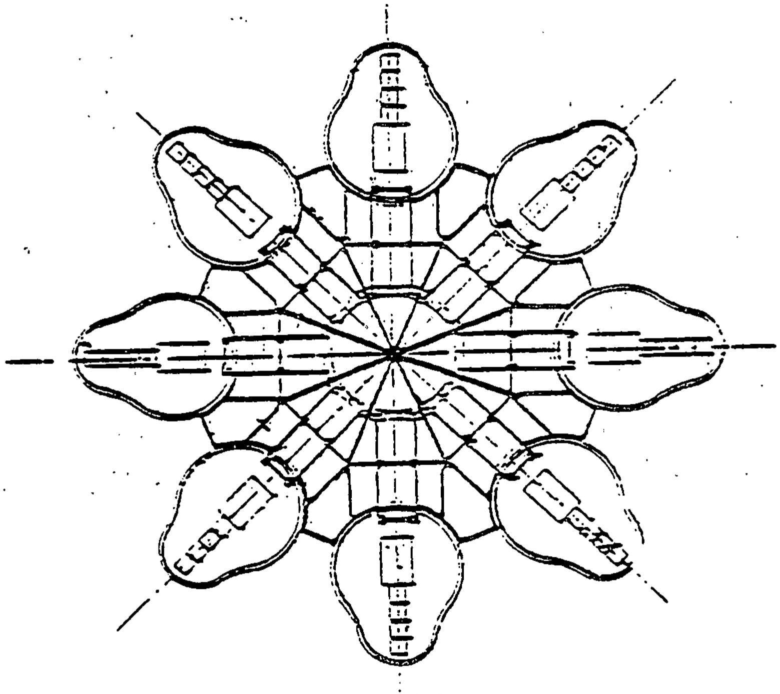
MATERIAL: LIGHTWEIGHT CONCRETE

LMSC SHIP SHAPE DESIGN

Figure 2.6.3.5



ELEVATION



PLAN AT 183'-9" BEL DWL

MATERIAL: LIGHTWEIGHT CONCRETE

LMSC SPAR DESIGN
Figure 2.6.4

A check was made by JJMA of the strength modulus in the areas where bottom openings provide the greatest potential for structural discontinuities. This showed the structure to be adequate.

LMSC relies on a design analysis carried out by T.Y. Lin International. A sample design analysis is given in an Appendix to Reference 3 and follows conventional reinforced concrete practice. In carrying out this analysis, LMSC indicates loads as listed below for the ship shape:

B.M. Sagging = 360,000 M-t

B.M. Hogging = 340,000 M-t

These are considerably below the figures obtained by G&C for their ship shaped platform. LMSC's bending moment calculations are given in an Appendix to Reference 3 and are based on empirical formulae, developed in Reference 16. Approximations based on empirical formulae are not very reliable for this application as they do not recognize the unique load distribution typical of OTEC platforms. Consequently bending moment calculation were run by JJMA on the computer, utilizing a weight distribution curve developed from LMSC's weight data with a wave height corresponding to ABS rules. The calculations were run both for rubber CWP pipes and for lightweight concrete pipes with a weight of 85 lbs. per cubic foot. The resultant bending moments are indicated below:

| | Nylon Rubber CWP | Lightweight Concrete 85 LBS. |
|---|---|---|
| Wave | ABS | ABS |
| Max. Bending Moment (Metre-tons) | 360,000 | 872,000 |

It can be seen that there is excellent correspondence between JJMA's calculated values and those of LMSC for rubber CWP. This correspondence breaks down, however, once the concrete pipes are used. If a wave height 1.1 times the square root of the length wave were used, the bending moment would increase by approximately ten percent.

The calculations for the LMSC spar structure, in the Appendix to Reference 3 show that the scantlings of the core are based on an average draft of 45m. This draft is based on a distance of 10 meters (33 ft.) from the hot water inlet opening to the surface of the water which appears inadequate. A minimum submergence for the hot water inlet is as follows:

| | |
|---|---|
| 50% max. wave height | 23 ft. |
| Heave | 9 ft. |
| Min. Head | 20 ft. |
| TOTAL | 52 ft. |

The calculations also disregard the dynamic loads resulting from wave heads which according to MR&S can be as high at 36 meters. These two omissions would result in underdesigning the spar structure however, a 36m core radius was inadvertently used in the T.Y. Lin calculation instead of a 36m diameter thus largely offsetting the effect of these omissions.

b) Material

As indicated in Section 2.6.1, MR&S propose concrete as a construction material.

Reinforced concrete has a history of previous utilization in offshore structures and has advantages with respect to reducing life cycle maintenance costs which make it attractive for non weight critical configurations. Additional research is however required in such areas as construction joints fatigue strength and the behaviour of concrete shapes under bi-axial and tri axial loads.

G&C have selected steel on the basis of a trade off study. The major disadvantage connected with steel is its exposure to corrosion. This may be set up for a number of reasons such as oxygen in water, electrolytic action on the platform with the moorings serving as grounding lines and differences in electrical potential. The magnitude is difficult to assess. It would be unreasonable to assume that corrosion over a 40 years period would not be extensive. Repairs, on site, would prove both costly and difficult to carry out.

LMSC uses lightweight concrete without however, justifying why they prefer it to conventional concrete. A discussion on this point is given by T.Y. Lin International in an Appendix to Reference 3, in which lightweight concrete is proposed as a means of reducing hull structure weight. T.Y. Lin adds that this material has been used extensively onshore but that although it is relatively untried at sea, there is evidence to show that it should behave well in the ocean environment.

There is no incentive to save weight in the LMSC ship shape platform and therefore no demonstration of the advantage of lightweight concrete. The spar is however deadweight limited and the choice of lightweight concrete reduces the buoyancy required from its core and therefore the size of the core.

### 2.6.3 Comparison of LMSC, G&C and MR&S Designs on a Unified Basis

a) Effect of Lightweight Concrete CWP

For reasons indicated in Section 2.2, JJMA had concluded that selection of a rubber CWP is dependent upon an extension to the state of the art which could not be justified at this stage and had selected instead a light weight concrete CWP with a weight of 85 lbs. per cubic foot.

In order to determine the impact on hull costs of the increased bending moment resulting from the heavier concrete CWP amidships, JJMA has calculated the effect on the volume of concrete of increasing the platform strength modulus, utilizing the same basic approach and stress levels as T.Y. Lin in Reference (2). The results are given in Table 2.6.1 and show an increase in weight of 74% over the figures estimated by LMSC. With a wave height corresponding to 1.1 times the square root of the platform length, the increase in weight becomes 79%.

b) <u>Unit Costs</u>

In developing cost estimates for their steel structure, G&C assumes labor and material costs varying from $2900 a ton for deck structure to $11,500 for foundations. The overall average is $3610 a ton.

MR&S's costs are based on a structure built principally of concrete but with an extensive use of steel in the areas of decks and divisional bulkheads. MR&S uses a value of $650 per cubic yard for the concrete construction of the spar platform and $2240 per ton for the steel construction.

LMSC's prices are based on estimates prepared by T.Y. Lin International for the U.S. Gulf and West Coast as follows:

| | |
|---|---|
| First Unit-Hull | \$ 980/$m^3$ (\$ 750/$yd^3$) |
| Follow On-Hull | \$ 850/$m^3$ (\$ 650/$yd^3$) |

LMSC reduced the first unit price by about 25% on the grounds that this figure includes the cost of design and assembly jigs which are accounted elsewhere.

The resultant unit price was then applied to all the platforms. LMSC assumes a cost of $750 per cubic meter, corresponding to $574 per cubic yard.

There are obvious discrepancies in unit prices between the three contractors. For the purpose of obtaining consistent cost estimates JJMA has allocated unit cost values for all three contractors which they believe to be consistent while recognizing differences in levels of complexity in the structure.

Utilizing this approach a value of $3600 was used for steel bulkheads in the MR&S spar design and $3000 for the beam structure supporting their decks. Construction costs for aluminum were taken at $6700 per ton. A figure of $650 per cubic yard was used for concrete for the LMSC ship shape construction. In this respect it was assumed that the greater complexity of the LMSC structures when compared to Rosenblatt's spar would be offset by the increased level of repetitiveness.

## TABLE 2.6.1

## SUMMARY OF SHIP-PLATFORM HULL WEIGHT ESTIMATE (BASED ON LMSC'S CONCRETE SHIP, MODIFIED TO SUIT DIFFERENT CWP)

| | Column 1 | Column 2 |
|---|---|---|
| | NYLON-RUBBER CWP | LIGHTWEIGHT CONCRETE CWP( 85 lbs)<br>ABS |
| Max.Hull Girder BM(M-t mtr) | 360,000. | 872,000 |
| Section Modulus, at Section C ($M^3$) | Sm Dk 924. | 2,445. |
| | Sm Btm 1,002. | 2,450. |
| Primary Stress at Section C ($t/M^2$) | T Dk 398. | 354. |
| | T Btm 359. | 353. |
| Effective Cross Section A, at Section C ($M^2$) | 80.54 | 196.6 |
| Ineffective Cross Section A, at Section C | 70.60 | +85.2 |
| Total Leng'l Cross Section A, at Section C | 151.14 | 281.8 |
| Req'd Volume of Concrete($M^3$) | | |
| For Long'l Members | 31,739. | 59,178. |
| Less Hole cuts | -5,829 | -6,412. |
| Net Vol for Long'l Members | 25,910. | 52,766. |
| Plus Vol. for Transv. Members | 10,592. | 10,592 |
| Total Req'd Volume ($M^3$) | 36,502. | 63,358. |
| Estimated Hull Weight | 74,800. | 129,900. |

MR&S's construction approach does, however, introduce an additional factor insofar as it requires construction of a portion of the spar in exposed waters about 200 miles offshore, with increased risk of downtime and loss of production. This is discussed further in Section 5.

c) MR&S Spar Length

The Sea Water System trade off study in Section 2.5 showed that a reduction in the MR&S spar length of the order of 20 ft. was feasible and that it would result in cost savings of the order of $5,230,000.

d) Maintenance Costs for G&C Ship Shape Platform

An equitable comparison between the platforms must recognize the difference in maintenance costs between the LMSC and MR&S concrete platforms, for which maintenance costs would be negligible and the G&C steel platform.

Historical data from Classification Societies indicates that corrosion rates of 0.01 inch per year occur in immersed hulls in tropical waters. While the corrosion rate will be considerably lower at first it will increase rapidly after a few years, with onset of paint deterioration and could substantially exceed the above rate in the second half of the platform life.

The allowable wastage on commercial ships is 20-25% of plate thickness. Plate renewal is required when these figures are exceeded. Assuming plate thicknesses of 0.75" to 1.25", it seems clear that the majority of the underwater plating will have to be renewed at least once during the platform's lifetime. There are approximately 40,000 tons of steel on the ships 16,000 of which are in the bottom plating, and their stiffeners. In order to limit the renewals in these areas JJMA has assumed that a corrosion allowance of 0.250 inches would be added to the rule thickness to plates below the waterline and up to 18m above base on the sides. This would add 1320 tons to the weight of the hull structure. It was further assumed, for the purpose of this analysis, that about 2000 tons of steel would require renewal in the upper areas of the hull structure and the interior plating during the platform's lifetime.

Allowing $10,000 per ton of steel, an allowance of $0.5m is required annually to distribute this cost over the life of the platform.

e) LMSC Spar

The dimensions of the LMSC spar have been selected to meet buoyancy requirements for a design using a nylon rubber CWP. If a lightweight concrete CWP is used, with a specific weight of 85 lbs. per cubic feet, an additional 16,000 tons of buoyancy is required to offset the increased weight of the CWP.

To obtain this additional buoyancy the diameter of the core would have to be increased from 36m to 42 meters. Assuming a constant thickness to diameter ratio for the hull envelope, the cost of the core would increase by approximately 36% and the cost of the spar structure would increase by about $4m.

### 2.6.4 Costs

The cost estimates by the three contractors, have been corrected to reflect the comments in 2.6.3. The resultant figures are indicated in Table 2.6.2 below:

TABLE 2.6.2

PLATFORM HULL STRUCTURE COSTS

| | G&C | LMSC (SHIP) | LMCS (SPAR) | MR&S |
|---|---|---|---|---|
| Hull and Structure (1st unit) | 139.3 | 46.7 | 79.5 | 163.885 |
| Less Non-Recurring Costs | | -10 | -10 | -18.501 |
| SUB TOTAL | 139.3 | 36.7 | 69.5 | 145.384 |
| Corrections | | | | |
| Steel Unit Costs (MR&S) | | | | +15.125 |
| Aluminum Unit Cost | | | | +1.118 |
| Concrete Unit Costs (LMSC) | | +4.9 | +9.3 | |
| B.M. Increase | | +32.8 | | |
| Increase in Core Diameter | | | +4 | |
| Saving due to Length Reduction | | | | |
| Corrosion Allowance | +4.0 | | | -5.23 |
| Revised Cost (No margin) | 143.3 | 74.4 | 82.8 | 156.4 |
| Margin (10%) | 14.3 | 7.4 | 8.3 | 15.6 |
| TOTAL | 157.6 | 81.8 | 91.1 | 172.0 |

## 2.7 COMPARISON OF BIOFOULING AND CORROSION CONTROL METHODS

Two basic approaches to biofouling control are evident in the three candidate OTEC platform concepts. These two approaches may be described as "active" and "passive" as follows:

- Active - The G&C ship and MR&S spar utilize chlorination systems to inhibit biofouling of the sea water system. For example, the G&C design utilizes two biofouling control systems per power module, one for the warm water system and one for the cold water system. Each biofouling control system consists of chlorine generators with associated pumps and piping. Each system injects chlorine into the sea water in sufficient quantities to maintain a chlorine concentration of 0.25 ppm. The quantities of chlorine injected are shown in Table 2.7.1 for each power module, for an OTEC platform and for an OTEC Park. As noted by G&C in Reference 2, the 0.25 ppm is considered to be a maximum concentration. It may be possible to reduce the concentrations and the biofouling potential of the warm and cold water at the selected site.

- Passive - The LMSC ship utilizes passive means of inhibiting biofouls. These passive means consist of anti-fouling coatings and impregnation fouling inhibitions within the concrete structure.

A comparison of the various requirements and characteristics of the active and passive biofouling control systems is shown in Table 2.7.2.

The corrosion control systems proposed by the three contractor are essentially the same. The basic requirements are as follows:

- Use non-corrosive material wherever practical.
- Minimize use of dissimilar material to reduce galvanic corrosion.
- Coat or otherwise treat non-corrosion resistant material.
- Installation of a cathodic protection system.

The design of the biofouling and corrosion control systems must be integrated to ensure uniformity of approach. If corrosion protection is to be provided by using a coating that must be periodically renewed, then the use of passive biofouling control approach may prove more cost effective. It must be remembered that periodic renewal of corrosion biofouling inhibitors represents a loss of revenue and will tend to increase life cycle costs.

It is concluded that more development is required, especially in the area of biofouling control. The recommendation of this comparison are basically the same as those put forth by G&C in Reference 2 and are as follows:

o Conduct tests at the site to determine the minimum required chlorine concentration to provide full biofouling protection for each the warm and cold water systems.

o Determine whether an epoxy, or some other type of paint system will provide full corrosion protection for non-corrosion resistant materials for 40 years. If not, determine what the periodic maintenance and replacement costs, and lost revenue, would be. Investigate the feasibility of providing corrosion protection to the warm water system, and to eliminate galvanic corrosion fouling problems and by using a single fully corrosion resistant alloy (90-10 cuns) throughout.

The effectiveness of passive and active cathodic protection systems should also be evaluated.

o Investigate the environmental impact of chlorine discharge into the sea.

o Utilize OTEC-1 as a test platform for various methods of biofouling and corrosion control.

## TABLE 2.7.1

## CHLORINATION REQUIREMENTS TO MAINTAIN 0.25 PPM CONCENTRATION

| | Sea Water | | | Chlorine | |
|---|---|---|---|---|---|
| System | Cfs | #/Hr | #/Day | #/Hr | #/Day |
| **Power Module** | | | | | |
| Warm Water Sys | $5x10^3$ | $1.15x10^9$ | $27.6x10^9$ | $0.288x10^3$ | $6,90x10^3$ |
| Cold Water Sys | $6x10^3$ | $1.38x10^9$ | $33.2x10^9$ | $0.345x10^3$ | $8.28x10^2$ |
| Total | $11x10^3$ | $2.53x10^9$ | $60.8x10^9$ | $0.633x10^3$ | $15.18x10^2$ |
| Platform | | | | | |
| Warm Water Sys | $40x10^3$ | $9.22x10^9$ | $221x10^9$ | $2.30x10^3$ | $55.2x10^3$ |
| Cold Water Sys | $48x10^3$ | $11.1x10^9$ | $265x10^9$ | $2.76x10^3$ | $66.2x10^3$ |
| Total | $88x10^3$ | $20.3x10^9$ | $487x10^9$ | $5.06x10^3$ | $12.1x10^3$ |
| OTEC Park | | | | | |
| Warm Water Sys | $320x10^3$ | $73.7x10^9$ | $1769x10^9$ | $18.9x10^3$ | $441.6x10^3$ |
| Cold Water Sys | $384x10^3$ | $88.4x10^9$ | $2123x10^9$ | $22.1x10^3$ | $529.9x10^3$ |
| Total | $709x10^3$ | $162.2x10^9$ | $3893x10^9$ | $40.5x10^3$ | $971.5x10^3$ |

## Table 2.7.2

## BIOFOULING CONTROL SYSTEMS COMPARISON

| PARAMETER | ACTIVE | PASSIVE |
|---|---|---|
| LIFE SPAN | 40 YEARS | APPROX 7 TO 10 YEARS |
| Maintenance | Routine maintenance of mechanical equipment required. Power module shutdown not required for maintenance or repair, Maintenance can be performed within hull structure without need for divers. | Relatively little routine maintenance required. However, anti-fouling coatings will require renewal approximately every 7 to 10 years. Power module shutdown and divers will be required |

Table A-2(Continued)

| | | |
|---|---|---|
| Effectiveness | Potentially more effective than passive method. Chlorine concentration can be adjusted to meet anti-fouling requirements. No degradation of sea water systems should occur due to fouling over the 40 year life span.<br>The chlorination systems are effective only when the sea water systems are operating. When the sea water systems are secured, alternate means of biofouling must be provided. For the MR&S span, the sea water systems inlet and outlet valves could be closed and the sea water either drained or closed with a main concentration of chlorine. No such means are really | Degradation of anti-fouling container will occur with times. Renewal of coatings will have to be scheduled so as to prevent degradation of sea water systems performance.<br>Anti-fouling coatings will be effective. Whether the sea water systems are operation or secured. |
| Costs | | |
| oAcquisition | oHigh | oLow |
| oMaintenance | oMedium | oHigh |
| oLife cycle | oDifficult to determine at this time. Tests required at site to determine close requirements. May permit decreasing system size and costs by reducing concentration | oDifficult to determine at this time. Service life of the various coatings needs to be determined |
| Environmental Impact | Impact of discharging large quantities of chlorineated sea water into the sea in the vicinity of the OTEC platform needs to be determined. see Table B-1 for quantities. | Minimal impact |

## 2.8 OTEC START-UP

During the course of the study it was noted that Gibbs and Cox had made a large cost allowance to cover a start-up power barge. A review of the provisions for start up operations for each of the other platforms was made to ensure that equal provisions were made, with the following results:

- Lockheed report stipulates that each auxiliary space per module will include a 4000 KW diesel generator set. It is the Lockheed intention to provide initial start-up from outside sources with subsequent start-up power being derived from operating modules. Lockheed did not indicate what these outside sources were, or how the function would be performed. No cost allowance appeared to be made for start-up equipment.

- The Rosenblatt report states that under normal conditions the OTEC power system will energize the platform service switchboard and the emergency switchboard via the emergency bus-tie system. Upon failure of the OTEC system the circuit breaker in the switchboard will open, the two standby generators will automatically start-up, parallel and energize the switchboard; the bus-tie circuit breaker in the emergency switchboard will open and the emergency generator will automatically start up and energize the emergency switchboard. The emergency generator can be normally taken off the line and the emergency switchboard can be energized via the emergency bus-tie cable system after it has been ascertained that emergency generator operation is no longer required. The generators are rated at 2100 KW each.

  However, there is no provision in the Rosenblatt report for initial start-up procedures or costs.

- The Gibbs and Cox report provides for two diesel generators each rated at 2000 KW to supply emergency power. One of these units would serve at stand-by. According to the report, consideration was originally given to having three 8000 HP (5960 KW, ea.) start-up generators installed on each module to provide self back start-up capability. Gibbs and Cox determined that such an installation was not cost effective. As a consequence, the report recommends that a separate barge be designated as a start-up barge. This barge would carry enough fuel to operate the three diesel generators at required output for two full day's operation. Moving of the barge from platform to platform would be effected by the Service Tug.

Only two of the three reports, therefore, discuss the subject of initial start-up. The Lockheed report merely addresses the intent to provide an external power source. The Gibbs and Cox report is definitive with regard to what is recommended and as to how it should be accomplished.

Gibbs and Cox offers the opinion that 10,000 HP (7,450 KW) will be required for start-up. Using the Work Breakdown Structure for the "Ship" mode in the Gibbs and Cox report, the following tabulation of equipments and power needs can be made:

| Qty. | Equipment | KW Per Equip. |
|---|---|---|
| 2 | Winch | 372.5 |
| 4 | Vent fans | 2.2* |
| 4 | Vent fans | 1.5* |
| 12 | Vent fans | 3.0* |
| 16 | Vent fans | 26.0* |
| 16 | Vent fans | 3.8* |
| 16 | Vent fans | 5.6* |
| 8 | Vent fans | 1.1* |
| 2 | Air Cond. Plants | 37.0 |
| 2 | A/C Ch. W. Pumps | 7.5 |
| 2 | A/C S.W. Pumps | 3.7 |
| 8 | A/C Fans | 0.75 |
| 2 | S/S Refrig. Plant | 3.7 |
| 4 | Ballast Pumps | 56.0* |
| 4 | Fire Pumps | 18.6 |
| 2 | Distillers | 28.5 |
| 2 | Dist. Fd. Pumps | 0.2 |
| 2 | Pot. Water Pumps | 1.5 |
| 1 | Pot. Water Pump | 0.2 |

| Qty. | Equipment | KW Per Equip. |
|---|---|---|
| 2 | Dist. Water Xfr Pumps | 0.37 |
| 1 | Hot Pot Water Pump | 0.2 |
| 1 | Hot Water Htr. | - |
| 2 | F.O. Xfr. Pumps | 3.7 |
| 1 | Helo F.O. Serv. Pump | 3.7 |
| 1 | Incinerator Pump | 1.5 |
| 2 | L.P. Air Compressors | 2.2* |
| 2 | H.P. Air Compressors | 3.7 |
| 16 | Bilge Pumps | 5.6* |
| 2 | Oily Waste Pumps | 7.5 |
| 2 | Sewage Pumps | 3.7 |
| 1 | Trash Compactor | 2.2 |
| 2 | S.W. Booster Pumps | 22.3 |
| 1 | Cold Water Pump | 8,195.0* |
| 2 | Cold Water Cooling Pumps | 7.5* |
| 1 | Warm Water Pump | 5,960.0* |
| 2 | Warm Water Cooling Pumps | 7.5* |
| 3 | Ammonia Feed Pumps | 745.0* |
| 3 | Ammonia Reflux Pumps | 30.0* |
| 4 | Transformer Pumps | 1.5 |
| 12 | Transformer Pumps | 1.1 |
| 2 | General Cooling Pumps | 22.3* |
| 3 | Chlorine Gens. | 448.0 |
| 2 | Chlorine Pumps | 22.3 |

| Qty. | Equipment | KW Per Equip. |
|---|---|---|
| 2 | Chlorine Gens. | 350.0 |
| 2 | Chlorine Pumps | 15.0 |
| 16 | Transformer Pumps | 15.0 |
| 1 | Ammonia Compressor | -# |
|  |  | 15,092.9 KW for * Items |

# The Gibbs and Cox report notes that definition of ammonia handling system components must be developed during the later stages of design.

* Subjective selection of components considered to be required for start-up function.

It will be noted that 15,100 KW would be required for start-up based on the above * numbers. As mentioned earlier, the Gibbs and Cox, Inc. report indicates that 7500 KW will be needed for start-up, although, as noted, 17,880 KW are available if all three barge generators are used. (11,920 KW if two barge generators used).

The Lockheed report does not provide any indication as to their start-up load requirements other than to state that external sources will be used. The 4000 KW set installed on the module would appear to be incapable of providing adequate initial start-up power.

The Rosenblatt report does not appear to address cold start-up. The two diesel generator sets provided per module, total 4200 KW and would be questionable candidates as start-up power sources.

A key consideration in all of the foregoing must be recognition of the fact that the data available is quite soft insofar as operational aspects are concerned. It may be noted, for example, that there are no power requirements given for the ammonia compressor and that one contractor notes the need for definitive compressor data. It can also be noted that just two components, the cold water pump (8,195 KW) and the warm water pump (5,960 KW) total 14,155 KW or almost twice the 7500 KW suggested by Gibbs and Cox, Inc. for initial start-up. One very evident indicator of this data scarcity is spelled out in the Gibbs and Cox report wherein it is stated that the platform will be started by supplying power to the first module from the start-up barge and that any unusual or transient requirements which will be imposed on sea water or ship's auxiliary system during start-up must be identified. The length of time allowed for start-up also requires definition.

# 3. COSTING RECONCILIATION

## 3.1 GENERAL

This section summarizes the findings by JJMA of a comparison of the cost elements developed by the three contractors for the construction of 400 MWe commercial OTEC plants.

The cost elements are divided according to a work breakdown structure developed by the Department of Energy and are intended to provide a unified costing structure. A copy of this work breakdown structure is shown as Figure 3.1.

A comparison of cost estimates carried out by Doty Associates in May 1978 had shown the necessity for costing reconciliation. The present review is intended to ensure that cost estimates are brought to the level of consistency required for the selection of a preferred platform configuration.

The following work was carried out by JJMA:

1) The costs of major subsystems were corrected to reflect the findings of engineering studies described in Section 2.

2) The components of the cost elements developed by the three contractors were compared, omission were identified and corrected. Costs were reallocated within the work breakdown structure where necessary to ensure uniformity of approach.

3) Differences in costing approaches were identified and major cost discrepancies were corrected as appropriate.

The cost breakdowns are discussed in the following sections which also show the revised figures proposed by JJMA. Generally, the costs are arranged in accordance with the WBS and are shown to the third or fourth level as appropriate. Some deviation from the format of the WBS was however, considered unavoidable. For example, items not presently shown in the WBS have been added in some cases at the fourth level of the WBS to cover features peculiar to one platform configuration.

The WBS also allocates engineering/integration costs for each of the ocean systems. In the present instance all engineering/integration costs have been grouped in WBS 5 for reasons explained in Section 3.3.8.

In reviewing the cost sheets JJMA's prime objective has been to select a preferred platform configuration. Relative accuracy between the candidate platforms is required, rather than absolute accuracy of estimates. In keeping with this approach, JJMA has on occasion taken costs estimates from one contractor and applied them with appropriate correction factors to the other platforms where in their opinion the work scopes were comparable.

Cost estimates for the lease of floating equipment were obtained from specialist firms. The unit costs listed below obtained from U.S. and foreign operators were utilized in preparing deployment and support cost estimates. Where a range of prices is given the higher figure was used.

a) Crane Barges

| | |
|---|---|
| 3000 ton lifting capacity | $50-60,000 per day |
| 1600 ton lifting capacity | $41,000 per day |

Figures include crew and towing vessel.

b) Supply Vessel

| | |
|---|---|
| 165 ft vessel with 2200 HP | $1600 per day |
| 180 ft with 4500 HP | $3000 per day |

c) Tugs

| | |
|---|---|
| Tug/workboat with 1500 HP | $1500 per day |
| 4800 HP | $5000 per day |
| 5000 HP | $6000 per day |
| 8000 HP | $7000 per day |

d) Barges

| | |
|---|---|
| Medium size, 240x75x16/1500 ton DWT | $1400 |
| Large size | $2500 |

e) Submersible

f) Hydraulic Jacks

No jacking system was found in the U.S. with lifting capacities of an order of magnitude of 20,000 tons as required for the OTEC platforms. The deLong jacks have a capacity of 500 tons each and would require up to 10 jacks per leg. These jacks rent at $310 per day. These values were extrapolated for the purpose of this analysis, to give rentals of $10,000 per day for LMSC and $12,000 per day for G&C and MR&S.

g) Heavy Lift Ship

| | |
|---|---|
| Lifting capacity 900 tons | $10,000 per day |

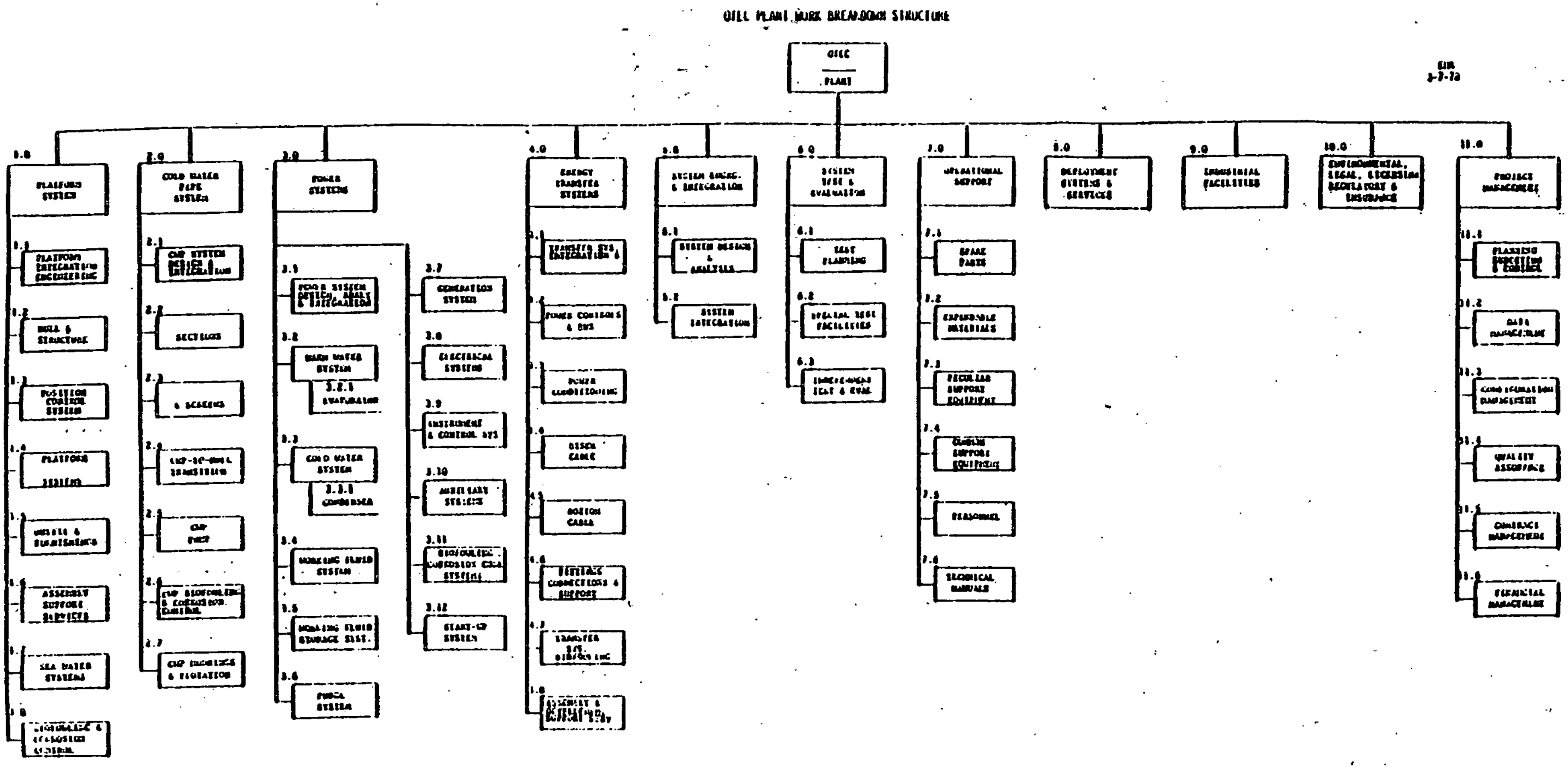


Figure 3.1 WBS Chart

## 3.2 PLATFORM COST ESTIMATES

Table 3.1 through 3.15 show JJMA's cost estimates for the four candidate OTEC platforms. The costs for the Platform Systems (WBS 1) are given in Table 3.1. The costs for the remaining systems in WBS 2 through 11 are given in Table 3.2.

Table 3.3 through 3.15 show the composition of the cost elements summarized in Tables 3.1 and 2. With the exception of WBS 1.2, 1.3, 1.7 and 2 which are discussed and costed in the engineering studies in Section 2. The rationale and methodology in developing these costs is discussed in Section 3.3.

The costs in Tables 3.1 and 3.2 include the non recurring costs chargeable to the first platform only. These non recurring costs and the annual operating costs of the OTEC park are shown in Tables 3.7, 3.9, 3.12, 3.13 and 3.14. Their derivation is also discussed in Section 3.3. The treatment of recurring, non recurring and annualized costs in obtaining comprehensive cost estimates for the OTEC park is described in Section 4.

## TABLE 3.1

## WBS 1 - PLATFORM SYSTEMS

| | | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|---|
| 1.1 | Platform Integration | - | - | - | - |
| 1.2 | Hull and Structure | 157.6 | 81.8 | 91.1 | 172.0 |
| 1.3 | Position Control | 57.16 | 72.84 | 25.73 | 33.5 |
| 1.4 | Platform Support | 29.51 | 24.97 | 32.67 | 41.47 |
| 1.5 | Outfit and Furnishing | 25.56 | 4.2 | 4.2 | 6.1 |
| 1.6 | Assembly Support | 10.90 | 5.5 | 6.4 | 11.0 |
| 1.7 | Seawater Systems | 131.60 | 143.0 | 132.4 | 152.0 |
| 1.8 | Biofouling and Corrosion Control | 0.5 | - | - | - |
| | TOTAL | 412.8 | 332.3 | 292.5 | 416.1 |

## TABLE 3.2

## WBS 2-11 OTHER SYSTEMS

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| WBS 2 CWP | 64.8 | 53.1 | 43.0 | 45.0 |
| WBS 3 Power Systems | - | - | - | - |
| WBS 4 Energy Transfer | - | - | - | - |
| WBS 5 Systems Integration | 19.9 | 26.3 | 26.3 | 31 |
| WBS 6 Test and Evaluation | 8.7 | 8.7 | 8.7 | 8.7 |
| WBS 7 Operations Support | 27.5 | 82.8 | 82.8 | 81.5 |
| WBS 8 Deployment | 47.71 | 56.82 | 35.13 | 30.38 |
| WBS 9 Industrial Facilities | - | 60.0 | 80.0 | 16.3 |
| WBS 10 Legal, etc. | 0.9 | 0.9 | 0.9 | 0.9 |
| WBS 11 Project Management | 7.3 | 7.3 | 7.3 | 7.3 |

## TABLE 3.3

## WBS 1.4 - PLATFORM SUPPORT SYSTEMS

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Fire Detection, Extinguishing | 1.7 | 1.2 | 1.2 | 1.3 |
| Fire Mains and Sprinklers | 0.3 | 0.3 | 0.3 | 0.6 |
| Ventilation and Airconditioning | 4.3 | 2.5 | 5.1 | 7.6 |
| Refrigeration | 0.9 | - | - | - |
| Plumbing Drains and Scupper | 0.5 | 0.3 | 0.3 | 0.4 |
| Vents Sounding Tubes, Overflow | 1.5 | 1.5 | 1.5 | 1.5 |
| Miscellaneous Piping | 1.5 | 1.2 | 1.2 | 1.3 |
| Drainage and Ballast | 1.3 | 1.3 | 5.2 | 6.5 |
| Pollution Control | 0.55 | - | - | - |
| Deck Machinery (Cranes, Hoists, Bitts, Chocks) | 1.88 | 3.3 | 3.3 | 3.3 |
| Ship Service/Emergency Generators | 2.58 | 2.0 | 2.0 | 9.3 |
| Electrical Support Services and Interior Communications | 3.92 | 3.7 | 3.7 | |
| Monitoring and Control | 1.0 | 1.0 | 1.0 | 1.0 |
| Data Processing, Telemetry | 1.5 | 1.5 | 1.5 | 1.5 |
| Helicopter Control | 0.3 | 0.3 | 0.3 | 0.3 |
| Ammonia Detection System | 2.6 | 2.6 | 2.6 | 2.6 |
| Elevators, Hoists | 0.5 | 0 | 0.5 | 0.5 |
| Aircraft Fittings | - | - | - | - |
| Operating Fluids | - | - | - | - |
| Sub Total | 26.83 | 22.7 | 29.7 | 37.7 |
| Margin 10% | 2.68 | 2.27 | 2.97 | 3.77 |
| TOTAL | 29.51 | 24.97 | 32.67 | 41.47 |

## TABLE 3.4

## W.B.S. 1.5 Outfit and Furnishings

| | G&C | LMSC | MR&S |
|---|---|---|---|
| Masts, Kingposts | 1.3 | - | - |
| Castings, Forgings | 0.13 | - | - |
| Rails, Stanchions and Ladders | 1.78 | 0.80 | 0.80 |
| Miscellaneous Fittings | 0.70 | 0.70 | 0.70 |
| Doors, Closures | 0.50 | 0.2 | 0.2 |
| Insulation, Sheathing | 1.13 | - | (1) |
| Deck Covering | 0.30 | - | 0.1 |
| Joiner Work(Non-structural Bulkheads) and Furniture | 2.40 | 0.2 | .80 |
| Boats, Boat Handling | 0.30 | 0.3 | 0.3 |
| Paint | 11.50 | - | 0.5 |
| Commissary Equipment | 0.50 | - | 0.2 |
| Damage Control Equipment | 0.50 | 0.5 | 0.5 |
| Utility Space Equipment(Laundry. Medical, Offices) | 0.60 | 0.1 | 0.2 |
| Stowages | 0.60 | - | 0.2 |
| Laboratories and Shops | 1.0 | 1.0 | 1.0 |
| Sub Total Group 1.5 | 23.24 | 3.8 | 5.5 |
| Margin 10% | 2.32 | 0.4 | .6 |
| TOTAL | 25.56 | 4.2 | 6.1 |

(1) Deckhouse insulation included in joiner work.

## TABLE 3.5

## WBS 1.6 - Assembly Support System

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Indirect costs and Support Systems | 10 | 5 | 6 | 9 |
| Major Production Tools | | | | 6.1 |
| Total | 10 | 5 | 6 | 15.1 |

## <u>TABLE 3.6</u>

## WBS T.8-BIOFOULING AND CORROSION CONTROL

| G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|
| 0.5 | - | - | - |

## TABLE 3.7

### WBS 5 Systems Engineering and Integration

| | | G&C | LMSC | MR&S |
|---|---|---|---|---|
| 1.2 | Hull and Structure | | 10 | |
| 1.3 | Position Control | | 2 | |
| 1.4 | Platform Service | | 2 | |
| 1.5 | Outlet and Furnishing | | | |
| 1.6 | Assembly Support | | 0.3 | |
| 1.7 | Seawater System | | 2.0 | |
| Preliminary Design | | | | 0.9 |
| Contract Design | | | | 1.8 |
| Detail Design | | | | 5.3 |
| Total Platform Systems | | 5.05 | 16.3 | 8.0 |
| 2. | CWP | 4.55 | 5.0 | 1 |
| 3. | Power Systems | 2.55 | - | - |
| 4. | Energy Transfer | 1.00 | - | - |
| 5.1 | System Design Analysis | 3.80 | 2.5 | 20 |
| 5.2 | System Integration | 2.95 | 2.5 | 2 |
| | | 19.9 | 26.3 | 31 |

## TABLE 3.8

## WBS 6-SYSTEM TEST AND EVALUATION

| | ALL CONSULTANTS |
|---|---|
| Test Planning | 0.9 |
| Special Test Facilities | 2 |
| Ind. Test and Evaluation | 5.8 |
| Total | 8.7 |

## TABLE 3.9

## WBS 7 - OPERATION SUPPORT

Non Recurring Costs Charged Against First Platform

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| 7.1 Spare Parts | | | | |
| Shoreside spares | 13 | 13 | 13 | 13 |
| Spares during construction | 1 | 1 | 1 | 1 |
| Initial inventory | 1 | 1 | 1 | 1 |
| 7.3 and 7.4 Support Equipment | | | | |
| Start up generator | 5.3 | 5.3 | 5.3 | 5.3 |
| Boats and Service Craft | (1) | (1) | (1) | (1) |
| Shore Buildings | 6.7 | 8 | 8 | 6.7 |
| Hotel barge | - | 54 | 54 | 54 |
| 7.6 Technical Manuals | 0.5 | 0.5 | 0.5 | 0.5 |
| Total | 27.5 | 82.8 | 82.8 | 81.5 |

(1) Assumed these are leased. See Item 7.3/7.4 in Table 3.10.

## TABLE 3.10

## WBS 7 - OPERATION SUPPORT

Annualized Recurring Costs Applicable to all Eight Platforms

| | | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|---|
| 7.1 | Spare parts | 8 | 6 | 6 | 8 |
| 7.2 | Expendable material | 6 | 6 | 6 | 6 |
| 7.3/4 | Support equipment | 3.9 | 7.9 | 7.9 | 7.9 |
| 7.5 | Personnel | 36.5 | 36.5 | 36.5 | 36.5 |
| 7.7 | M&R | 12 | 26 | 26 | 8 |

## TABLE 3.11

## W.B.S. 8 - DEPLOYMENT

Recurring cost charged against all platforms.

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| 8.1 Platform | 3.3 | 1.3 | 1.5 | 2.47 |
| 8.2 CWP | 8.24 | 8.24 | 6.60 | 6.37 |
| 8.3 Moorings | 7.07 | 8.93 | 4.38 | 4.38 |
| 8.4 Power Systems | 0.85 | 4.5 | 4.1 | - |
| Total | 19.46 | 22.97 | 16.58 | 13.22 |

## TABLE 3.12

## W.B.S. 8 - DEPLOYMENT

Non recurring costs charged against first platform.

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| 8.1 Platform | 7.0 | 15.0 | - | 1.61 |
| 8.2 CWP | 19.20 | 16.80 | 13.50 | 13.50 |
| 8.3 Moorings | 2.05 | 2.05 | 2.05 | 2.05 |
| 8.4 Power Systems | | | 3 | |
| Total | 28.25 | 33.85 | 18.55 | 17.16 |
| Table 3.11 | 19.46 | 22.97 | 16.58 | 13.22 |
| Total 3.11 and 3.12 | 47.71 | 56.82 | 35.13 | 30.38 |

## TABLE 3.13

## WBS 9 - INDUSTRIAL FACILITIES

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Hull Construction Basin | - | 60 | 40 | |
| Platform Construction Dock | - | | 40 (40) | |
| Power System Dock | - | | | |
| Site Preparation | - | | | 8.3 |
| Support Facilities | - | | | 8.0 |

## TABLE 3.14

### W.B.S. 10 - Environmental, Legal, Licensing, Regulatory and Insurance

| | | G&C | LMSC | MR&S |
|---|---|---|---|---|
| 10.1 | Environmental Impact | 0.7 | 0.7 | 0.7 |
| 10.2 | Regulatory Approval | - | - | - |
| 10.3 | Legal/Licensing | 0.2 | 0.2 | 0.2 |
| 10.4 | Insurance, Annual (0.8%) | 3.6 | 2.6 | 3.2 |
| | Insurance on Power System | 3.2 | 3.2 | 3.2 |

## TABLE 3.15

## WBS 11 - Project Management

| | | Eight Platforms | Per Platform |
|---|---|---|---|
| 11.1 | Planning, Budgeting and Control 12 years at 10 men | 6,000,000 | 750,000 |
| 11.2 | Data Management 12 years at 3 men | 1,800,000 | 225,000 |
| 11.3 | Configuration Management k2 years at 8 men | 4,800,000 | 600,000 |
| 11.4 | Quality Control (On site per unit) 4 years at 8 men | | 1,600,000 |
| 11.4 | Quality Control - Plan Approval (All units) 80 men years | | 500,000 |
| 11.5 | Control Management 12 years at 10 men | 6,000,000 | 750,000 |
| 11.6 | Financial Management 12 years at 6 men | 3,600,000 | 450,000 |
| | | | 4,875,000 |
| | Contingency *50% | | 2,425,000 |
| | | | 7,300,000 |

## 3.3 APPROACH IN RECONCILING PLATFORM COSTS

### 3.3.1 WBS 1.4 - Platform Support Systems

MR&S's worksheets cover two items only, Hull Engineering and Electrical Installation which are priced at $4m and $10.695m respectively. The engineering systems are listed in Reference (1) and comprise the fire extinguishing and detection systems, bilge, ballast and stripping systems, sea and fresh water, drains, and HVAC.

G&C's worksheets cover roughly the elements of groups 17-19 of MarAd's weight breakdown. They do not include any costs related to power elements of the electrical systems since these are treated in WBS 3.0.

LMSC shows a measure of agreement with G&C in so far as support systems cover approximately the same scope. LMSC includes engineering costs in their estimates, and provides an ammonia detection system which the other contractors do not specifically identify. The piping systems are grouped in a heading called ancilliary systems which is defined in Volume 1 of LMSC's report. LMSC's costs for the spar also show $2m for miscellaneous piping and $6.3m for drainage and ballast. No comparable figures are shown for their ship shape. Several of the piping and control systems provided by G&C appear to have been omitted by LMSC in both the spar and the ship.

Cost estimates differ sharply between G&C and LMSC for some comparable systems.

The support systems, though obviously related to platform size and configuration, should not differ to any large extent for the three contractors except where services peculiar to one platform configuration are required. In view of the differences noted above, it was felt that in order to obtain consistency of approach a unified format should be set up and applied to all the platforms.

G&C's format is the most complete and was therefore selected as a baseline for this comparison. G&C's cost estimates were modified in one respect only. The seawater power suport systems were deleted as not consistent with the intent of the WBS.

Cost factors were developed for the principal piping and ventilation systems for all 3 contractors reflecting differences in system complexity resulting from platform configuration or contractor maintenance and operating philosophy. These values were factored into the G&C cost estimates to obtain system costs for LMSC and MR&S. The rationale for these cost factors is explained below:

## 1. Fire Detection, Estinguishing

Fire detection and extinguishing systems are required by all candidate OTEC concepts. These systems include fire detection systems (IR and smoke) for all spaces, fixed $CO_2$ or HALON 1301, flooding system for machinery spaces, AFFF systems in the vicinity of the Helicopter landing platform, SSDG rooms and fuel/lube oil handling areas as well as portable fire extinguishers throughout the platforms. Cost factors for the various platforms are as follows:

| | |
|---|---|
| G&C Ships | 1.4 (additional living space and S.W. pump motor room) |
| LMSC Ship | 1.0 |
| LMSC Spar | 1.0 |
| MR&S Spar | 1.05 (addition living spaces) |

The present G&C cost estimate includes the ammonia detection system which is estimated by LMSC as $\$2.6 \times 10^6$.

## 2. Firemain and Sprinkling

Firemains and sprinkling systems are required for fire fighting, washdown, sanitary flushing, auxiliary cooling and emergency cooling by all candidate systems. Designs with increased living spaces will require a more extensive system than those without. MR&S spar will require a more complex system due to the larger vertical distances involved. Cost factors for the various platforms are as follows:

| | |
|---|---|
| G&C Ship | 1.1 |
| LMSC Ship | 1.0 |
| LMSC Spar | 1.0 |
| MR&S Spar | 2.05 |

## 3. Ventilation and Air Conditioning

Ventilation is required for all machinery, working and living areas of all the OTEC concepts. Air Conditioning is required for all office, control and living spaces. Designs with increased living facilities will require more extensive air conditioning systems. Ventilation system complexity increases for designs with increased machinery spaces (G&C) and for MR&S Spar due to the vertical distances involved. Cost factors for the various platforms are as follows:

| | |
|---|---|
| G&C Ship | 1.7 |
| LMSC Ship | 1.0 |
| LMSC Spar | 2.0 |
| MR&S Spar | 3.0 |

## 4. Plumbing Drains and Scuppers

Plumbing drains and scuppers are required for all of the OTEC Concepts. Designs with increased living facilities will require increased systems capability. No basic difference between ship or spar platforms exist since living areas are above the waterline in all designs. Costs factors are as follows:

| | |
|---|---|
| G&C Ship | 1.0 |
| LMSC Ship | 0.5 |
| LMSC Spar | 0.5 |
| MR&S Spar | 0.75 |

## 5. Vents, Sounding Tubes and Overflows

Vents, sounding tubes and overflows are required for all of the OTEC concepts for fuel tanks, ballast tanks, potable water tanks, etc. There is no basic difference in cost from one concept to the next, therefore all cost factors equal 1.0.

## 6. Miscellaneous Piping

- Compressed Air - Requirements approximately the same for all platforms since no change in services from one to the other.
- S.W. Service - Requirements approximately the same for all platforms.
- Fresh Water Systems - Increased habitability increases complexity of F.W. systems as follows:

| | |
|---|---|
| G&C Ship | 2.0 |
| LMSC Ship | 1.0 |
| LMSC Spar | 1.0 |
| MR&S Spar | 1.5 |

- Fuel and Lube - G&C fuel system more complex to allow refueling of helos and supply boats. Would be wise to incorporate capability on all platforms unless central hotel facility can handle it.

  Cost factors are:

  | | | |
  |---|---|---|
  | G&C Ship | 1.5 | |
  | LMSC Ship | 0.5 | (hotel barge) |
  | LMSC Spar | 0.5 | (hotel barge) |
  | MR&S Spar | 0.5 | (hotel barge) |

Total miscellaneous piping systems cost factors are as follows:

| | |
|---|---|
| G&C Ship | 1.3 |
| LMSC Ship | 1.0 |
| LMSC Spar | 1.0 |
| MR&S Spar | 1.1 |

## 7. Drainage and Ballasting

Drainage and ballasting systems are required by all concepts. Spar designs require a more complex system due to greater hull depth plus, in the case of LMSC, outer ballast compartments. Cost factors are as follows:

| | |
|---|---|
| G&C Ship | 1.0 |
| LMSC Ship | 1.0 |
| LMSC Spar | 4.0 |
| *MR&S Spar | 5.0 |

*Also includes OTEC Systems Flooding/Dewatering System.

## 8. Ammonia Detection System

All concepts will require an ammonia detection system of approximately the same complexity. The G&C ship ammonia detection system was included with the fire detection system in their initial cost breakdown. Cost factors for all designs are equal to 1.0.

The electrical costs by the three contractors which have been worked out in some detail have been accepted without charges. The cost for deck machinery, for the LMSC spar also considered applicable to the MR&S spar.

Costs of the electrical monitoring and control systems developed by G&C were applied across the board to all platforms.

The revised costs are shown in Table 3.3.

### 3.3.2 W.B.S. 1.5 - Outfit and Furnishing

G&C supplied worksheets for this item showing it as $24.46 millions. LMSC shows it as $0.5 millions in a third level breakdown, without any indications as to how this figure was reached.

MR&S indicates a third level breakdown of $2.746 millions. No worksheets are given.

A review of the designs shows partial justification for the cost differentials. LMSC provides all accommodation and control facilities on a barge. They assume that the platforms are unmanned, with maintenance personnel sent on an "as required" basis. Consequently they make no provision for furniture, deck covering, commissary equipment, etc. MR&S also provides accommodation on a hotel barge for the entire park, however, they assume that people are ferried daily for their shift. Accommodations and catering facilities for a 72 hour stay are provided on board in case the weather makes leaving the platform unacceptability risky as in a storm. Both for MR&S and for G&C provision of a concrete structure reduces drastically the need for painting and insulation which are major items in the G&C cost estimate.

The same basic approach was followed for Outfit and Furnishings as for the platform support systems. A unified format was set up based on G&C's format. G&C's cost estimates were retained as presented by G&C. Cost estimates were prepared for MR&S and LMSC by JJMA using cost data in JJMA's files. Where these were judged closed enough to G&C's figures, the latter were adopted in order to maintain uniformity of approach. G&C's estimates for damage control equipment were also applied across the board.

An allowance of $1m was applied across the board to all contractors for laboratories and shops.

LMSC had assumed that the same costs would apply to both their ship shape and to their spar platform. This approach was maintained for the sake of simplicity.

The revised costs for the three contractors are shown in Table 3.4.

### 3.3.3 WBS 1.6 - Assembly Support Systems

The WBS describes this cost item as efforts and materials associated with the construction of the ship and which cannot practicably be identified as a cost elements. Included in this are stagings, scaffoldings, forms, cribbing, temporary utilities and services, molds, templates, jigs, fixtures, special production tools, drydocking and inspection. In addition to the above the cost Classification System of the Maritime Administration lists under this heading the insurance costs, for the vessel and its equipment, the cost of supervision above shop level, the replacements of lost, damaged and defective components and the cost of launching, trials and guarantee repairs.

Both LMSC and G&C treat this element parametrically without identifying its build up. G&C uses a figure of $3m whereas LMSC uses $6.8m for ship shape and $12.8 for the spar. MR&S treats the site preparation and special equipment under this item and allow $15.127m.

Most of the estimates used in cargo ship construction show indirect costs and support systems broken up in terms of labour and material components but with an overall value in an order of magnitude of 8-12% of acquisition cost. Some of the expenses defined in ship construction are not applicable to these platforms, others such as launching and trials are treated separately in the work breakdown structure. Consequently a figure somewhat below those used for ship construction appears appropriate for application to the OTEC platforms. JJMA assumed that support costs would be 5% of the cost of construction of the platform, its support systems and furnishing and that the same percentual figure was applicable to both steel and concrete hulls.

This percentage does not include the cost of major tooling and site preparation which are peculiar to MR&S and result from their construction method. MR&S' estimate includes the following.

| | |
|---|---|
| Site preparation | $ 7.428 m |
| Construction barges | $ 1.095 m |
| Tower crane | $ 0.250 m |
| Crane ship | $ 3.650 m |
| Tugs | $ 1.095 m |
| Buoyant plug | $ 1.609 m |

The cost of site preparation has been reallocated to WBS 9, Industrial Facilities. In order to maintain uniformity of approach with the other contractors, the cost of the Buoyant plug has been reallocated to WBS 7, Deployment Costs. The construction barges, tower crane, crane ship and tugs are considered to be production tools within the intent of this WBS. On this basis, the figures shown on Table 3.5 were adopted.

### 3.3.4 WBS 1.7 - Seawater Systems

Differences in scope of supply and in material selection between the various Seawater Systems are treated in Section 2.4. They are listed below only to the extent that they affect costing.

For the sake of reducing cost estimates to a comparable technical levels, the stainless steel pumps proposed G&C and the carbon steel pumps offered by LMSC and MR&S are replaced by carbon steel casings with stainless inner components.

The Amertap tube cleaning system which MR&S introduced as a cost element has been deleted on the grounds that it is part of the power systems and outside the scope of supply outlined in the WBS for the Seawater Systems.

A number of items peculiar to their platform configurations which have been introduced by LMSC are also included. These refer to housing interfaces and to a special design of condenser water boxes to suit the submerged heat exchanger arrangements selected by LMSC.

Design costs shown on WBS 1.7 by LMSC have been transferred to WBS 5 for reasons explained in Section 3.3.8.

An allowance is made for Biofouling control. This is also discussed in Section 2.7.

The revised figures after allowing for the corrections indicated above are shown in Table 3.1. A breakdown to the fourth level of the WBS is given in Table 2.4.5.

### 3.3.5 WBS 1.8 - Biofouling and Corrosion Control

MR&S allows $7,085m in WBS 1.8 for biofouling and corrosion control. MR&S were questioned on the intent of this cost item and stated that this was intended to provide a Chloropac system, consisting of two chlorinators, for the protection of the seawater systems on the platform.

The WBS provides under WBS 1.7 for biofouling and corrosion control of the seawater system. WBS 1.8 is intended to "protect surfaces exposed to the ocean environment", which LMSC and G&C interpret as meaning the platform exterior surfaces. Consequently the cost of the MR&S chlorinating system has been transferred to WBS 1.7.

LMSC and MR&S consider that protection is not required for the concrete exterior surfaces of their platforms and make no allowance for it. G&C shows $0.5m for a Hull Cathodic Protection System. This is necessary for the G&C ship which has a steel hull.

Table 3.6 shows the estimated costs of biofouling and corrosion controls.

### 3.3.6 WBS 2 - Cold Water Pipe

CWP System Costs and the impact on those costs of relocating the platforms for a site off Florida are discussed in Section 2.2.

### 3.3.7 WBS 3 - Power Systems

### WBS 4 - Energy Transfer Systems

These two cost elements were to be excluded from the workscope of the three contractors by direction from DOE. Some recognition of these costs is present however in all three estimates.

All three contractors include the foundations and the installation costs for the main components of the power system in their construction costs. Both MR&S and LMSC make the point, however, that all other costs connected with Power and Energy Transfer Systems are excluded from their scope of costing.

G&C allows $12.3m for WBS 3 and $5.4m for WBS 4. In both instances these costs refer to labour, with some allowance for engineering, but without any allowance for material.

The intent of DOE's guidelines appears to have been that these items were to be excluded. In so far as two of the contractors have omitted them, and that their impact on platform selection is not large JJMA has also omitted them in this comparison. Installation and interface costs connected with these systems must however be included in a comprehensive cost estimate of the complete platforms including power and energy transfer.

Some of cost elements presented by G&C under WBS 3 and 4 appear elsewhere in MR&S and LMSC estimates. JJMA has adopted a unified approach for these items as described below:

a) Integration and Engineering

All costs connected with these items are grouped in WBS 5.

b) Biofouling and Corrosion Control

Amertrap was estimated by MR&S at $24,592,000 and allocated to WBS 1.7. This item was omitted by G&C and LMSC. Amertrap has now been omitted for all three contractors.

Chlorination was estimated by MR&S at $7,085,000 (Labour and material) under WBS 1.8. G&C estimated it at $1,500,000, (Labour only) under WBS 3, LMSC made no allowance for it, MR&S's allowance was applied across the board under WBS 1.7 which provides for biofouling and corrosion control in seawater systems.

c) Ammonia Systems

MR&S provides an ammonia purge system ($557,000) in WBS 1.7. LMSC provides an ammonia detection system ($2,600,000) in WBS 1.4. G&C provides a purge system, ($500,000, Labor only) under WBS 3.6. The ammonia system is retained under WBS 1.4 at $2.6m as proposed by LMSC.

### 3.3.8 Systems Engineering and Integration

Table 3.7 shows the Systems Engineering and Integration costs proposed by the three contractors and their distribution among the cost elements of the work Breakdown Structure.

G&C provides system engineering and integration costs to the second level of the WBS. Platform systems are treated as an individual item in WBS 1.1 without differentiation between the third level elements. Design costs are also given for the CWP, Power System, and Energy transfer in WBS 2.1,3.1 and 4.1. System design analysis and Systems Integration are then added as separate line items in WBS 6. The values are derived parametrically, the actual methodology is not descrived in the report.

LMSC uses a somewhat different approach. System engineering and Integration costs are estimated in WBS 5 to amount to roughly 2% of the basic cost of the 1st vessel, and are divided equally between System Design Analysis and Integration. Engineering design costs are estimated for WBS elements 1.2,1.3,1.4 and 1.6 and 2. These are order of magnitude figures based on engineering judgement. No integration and engineering costs are proposed for Power Systems (WBS 3) or Energy Transfer (WBS 4).

MR&S considers the design costs as a composite of platform design (WBS 1.1), CWP design (WBS 2.1), Systems Integration (WBS 5) Test Planning (WBS 6), Preliminary, Contract and Detail Design. The derivations for WBS 5 are given in the work sheets. They are based on an estimated monthly cost developed by Gilbert Associates, amounting to $500,730 and prorated over a three year period. The derivation for Preliminary, Contract and Detail design is also given in the worksheets and stated to be 0.075% of Acquisition Cost for Preliminary Design. 0.015% for contract design and 0.045% for detail design.

In view of the wide discrepancies in the method of distributing engineering costs among the elements of the WBS, it was felt that the best approach would consist in combining all the Engineering and Integration Cost elements under WBS 5. Discrepancies in scope would then tend to cancel each other out and the resultant total values would cover similar work scopes. The results are shown in Table 3.7.

Plan maintenance for follow up platforms is taken at 25% of these figure.

### 3.3.9 System Test and Evaluation

All three contractors give third level breakdowns for the costs associated with this WBS element. LMSC uses a parametric approach based on 4% of procurement cost for the first unit and 2% of procurement costs for the remaining units. LMSC arrives at a figure of $10m for the first unit and $5m for subsequent units.

G&C uses a bottoms up approach, identifying and estimating each cost component separately for the first ship and for the 2nd to eight units. Planning is distributed between Preliminary, Contract and Detail Design. Tests and trials are identified and costs are distributed between fabrication, deployment and operation stages for the first and subsequent units. A detailed breakdown is given in Reference 2, and shows a total cost of $6.7m per unit.

MR&S also uses a bottoms up approach for each of the three third level elements of the WBS. Tests and evaluation are shown as a constant figure of 8000 manhours annually, distributed between OTEC, Biofouling and Miscellaneous and spread over a 10 year period. The resultant figure is divided evenly over 8 platforms and rounded upwards to $1m. MR&S' total figure for test and evaluation is $2.5m per platform.

JJMA has sought a method of applying a consistent methodology for all three consultants. LMSC's parametric approach relating these costs to platforms procurement cost was first considered. There is no rational reason however why system test and evaluation costs should vary with changes in platform costs. G&C's approach is the more systematic and appears equally applicable to all the platforms. This approach was therefore selected. An allowance of $2m representing somewhat less than 1% of procurement cost was however added for unidentified tooling,based on a study of tooling costs from shipyards building costs for complex special purpose commercial vessels.

The revised cost proposed by JJMA are shown in Table 3.8.

### 3.3.10 WBS 7 - Operation Support

This cost element covers materials, systems and services necessary for assuring operation of the OTEC plant at intended service levels. The costs related to support services are broken into two groups as follows:

#### a) Capital Costs Charged Against the First Platform

This comprises the cost of tools and equipment required to maintain and operate the platforms. The cost of shoreside spares inventory is also charged as a non recurring cost.

b) Operating Costs

This covers all items chargeable to all eight platforms on an annualized basis.

Many of the components of the Operation Support Costs are not related to platform configuration and should be quite similar for all the platforms. Variations between the proposals by the three contractors seem related to differences in operating philosophies rather than in platform design. Where this occurs, JJMA recalculated the operation costs, using consistent criteria. Where differences are attributable to differences in platform configuration, they are commented upon and quantified.

WBS 7.1 - Spare Parts

MR&S estimated the intial spare parts parametrically by taking them at 2% of the cost of the OTEC plant. G&C allow \$13m for shoreside spare inventory, \$1m for initial platform inventory and \$1m for spares inventory during construction, totalling \$15m. No provision is made by LMSC for shoreside spares.

Both the approach by G&C and by MR&S are valid in the conceptual design stage. G&C differentiates between recurring and non recurring costs and their estimates for initial inventory have been retained as a baseline for application to all three contractors.

Annualized spare parts costs were estimated by JJMA at ¼ of 1% of the platform cost.

7.2 Expendable Material

These have been estimated as follows:

| | G&C | MR&S | LMSC |
|---|---|---|---|
| Fuel oil (diesel gen) | .08 | .085 | .16 |
| Lube oil 10% of fuel consumption | .032 | .033 | .063 |
| A/C Fuel (taken from G&C) | .1 | .1 | .1 |
| $NH_3$ | .27 | .27 | .27 |
| Misc. 20% of above | .15 | .10 | .15 |
| Total/Platform | 0.92 | 0.6 | 0.75 |

Fuel oil cost is based on operating the auxiliary diesel/generators for one month per year at 75% load. .5 #/HP-HR sfc, oil cost/BBL=\$16.50

Lube oil cost = \$65/BBL

$NH_3$ - 5% leakage/day of 200,000 ft$^3$ capacity and \$150/2000 ft$^3$ $NH_3$

## WBS 7.3 - Peculiar Support

## WBS 7.4 - Common Support

The distinction between those two items is rather tenuous. Since all the support equipment listed by the contractors is common to all platforms, WBS 7.3 and 7.4 have been grouped into a single cost element.

Capital costs shown by the contractors under this cost element are:

| | G&C | LMSC (SHIP)&(SPAR) | MR&S |
|---|---|---|---|
| Start up generator | 5.3 | | |
| Boats and service craft | 24 | (1) | |
| Shore building:etc. | 6.7 | 8 | 1.2 |
| DACS | | 5 | |
| Hotel barge | | 12 | 54 |

(1) not included as equipment is leased.

### a) Start up Generator

Only G&C provided for a start up generator. The start up study in Section 2.8 shows that about 15 MW will be required to start up the first power unit. None of the platforms have this amount of generating capacity independently of the power units. Consequently all platforms will require start up generators.

### b) Boats and Service Craft

G&C allows $24m for a fleet of service craft whereas LMSC proposes leasing them. In order to resolve this difference, JJMA carried out a trade off study, assuming that a support fleet as listed below would have to be leased:

| | | | |
|---|---|---|---|
| 1 | Supply boat | @ | $3000 / day |
| 1 | Service Tug | @ | $1500 / day |
| 1 | Work/Crew Boat | @ | $1500 / day |
| 1 | Service Barge | @ | $1500 / day |
| 1 | Liquids Barge | @ | $2500 / day |

The cost of leasing these vessels was estimated at $3,600,000 annually. A further $300,000 was allotted for periodical leasing of a submersible, totalling$3,900,000 annually.

The capital costs for the support fleet proposed by G&C were annualized, assuming 20 years depreciation and 8% return on capital. The annualized costs amounted to $2,500,000. Approximately $1,200,000 should be added for crew and operating costs. Provided therefore that the fleet listed above is adequate and that the estimated leasing costs are achievable there is little apparent advantage with either approach. Leasing was selected as the simpler approach for a comparison.

c) Shore Buildings

MR&S makes no allowance in their estimate for piers, warehouses, offices, etc. Their costs has been increased to \$6.7m to bring their scope of supply in line with LMSC and G&C.

d) Hotel Barge

Both LMSC and MR&S provide centralized accommodation on an hotel barge whereas G&C provides all accommodation on the platform.

LMSC assumes that 160 berths will be required and estimates the cost of the barge at \$12,000,000. MR&S allows \$54,000,000 for a hotel barge for 600 people. Operating costs for the hotel barge consist in consumables for power generating, crew and some maintenance. Annual costs have been taken at \$2.2m for LMSC and \$4m for MR&S.

## 7.5 Personnel

A basic difference in approach exists in so far as LMSC assumes that the platforms will not be manned and that operations will be controlled from a DACS located in the central hotel barge whereas G&C and MR&S both assume that all the platforms will be fully manned.

In order to compare the economics of the two concepts two calculations, corresponding respectively to the basic approaches by LMSC and G&C/MR&S have been carried out. Both calculations assume operations in two twelve hours shifts.

| Platform | Local Operation | Centralized Operation |
|---|---|---|
| Platform Operation and Maintenance Personnel | 44 | 90 |
| Allowance for Sick etc. | 4 | 9 |
| 100% Margin | 48 | 99 |
| Total Platform Personnel | 96 | 198 |
| Say | 100 | 200 |
| At 40K/m. year | \$4m | \$8m |
| Catering @ \$10/day/m | 0.365 | 0.73 |
| Total | 4.365 | 8.73 |
| Total for 8 platforms | 34.92 | 8.73 |

| Platform | Local Operation | Centralized Operation |
|---|---|---|
| Shore Base | | |
| 40 men @ $30,000 | $1,28m | $1,28m |
| Catering @ $25/day/m | 0.365 | 0.365 |
| | $1.65 | $1.65 |
| Total, Platform and Base | $36.5 | $10.4 |

The advantages of LMSC's approach, in terms of operating costs are obvious. The practicality of this concept and its acceptable by the utilities is still an open question. Moreover this concept if acceptable is not tied to any one configuration and therefore it is related to platform operating costs but not to platform selection.

In order to be consistent in this comparative analysis, JJMA has assumed that all four platforms will be manned in service, LMSC's manpower and hotel barge requirements have been correspondingly increased. The savings from a centralized operation are discussed in Section 5. These savings are equally applicable to all the platforms.

## 7.7 Maintenance Costs

Neither LMSC nor G&C show any provision in their cost estimates for maintenance and repair of platform and platform support systems. MR&S cost appendices shows $106.6m, allocated under WBS 7.3 and 7.4 for a 40 year span to cover M&R expenses for power generating machinery, platform support systems and platform maintenance.

The costs of maintenance personnel are already covered in 7.5. The cost of spare parts for the power systems are covered in 7.1. Neither of these require duplicating. An allowance of $1m annually has been applied to all the platforms to cover maintenance and repair costs on platform support systems.

Maintenance costs associated with the G&C ship platform are discussed in Section 2.6.3. They have been estimated at $0.5m per year.

Maintenance costs for the LMSC submerged power units are expected by LMSC to cost $18m annually, one half of these is accounted for by drydock costs and one quarter each by tug fees and maintenance costs proper. Distributed over eight platforms this represents $2.25m per platform per year.

Cost for Operation Support Systems, revised as indicated above are shown in Tables 3.9 and 3.10.

## 3.3.11 WBS 8 - Deployment Costs

This item covers deployment costs for the platform, the Cold Water Pipe, and the Station Keeping System. The LMSC and G&C concepts, with external power system components also requires deployment costs for some elements of the power systems.

The Cold Water Pipe and the Station Keeping System for all the platforms have been redesigned to suit conditions off the West Coast of Florida. Consequently the costs of deploying these systems have been recalculated to suit the new designs.

All of the costs comprised non recurring components and recurring costs. The capital costs are treated differently by the three contractors, G&C charges them against improvements to industrial facilities, MR&S charges them in the construction costs of the platform structure. They are treated consistently here, with non recurring capital costs charged against deployment costs for the first platform and recurring costs charged against deployment costs for all eight platforms.

### 8.1 Platform Deployment

This item has been limited by all three contractors to cost connected with the assembly of the platform. In the case of LMSC and G&C this does not include towing out to the operating site. In so far as this element covers costs for different construction methods the figures by the three contractors are predictably different.

G&C build their platform in two halves, in a building dock and join them afloat. Their deployment sequence is shown in Figure 3.2. A non recurring costs of $7m is provided for the construction of floatation barges which are required to give additional buoyancy when undocking the half hulls to allow them to float. G&C has recurring costs of $3.3m per platform. Out of this amount, $2.6m are budgeted for joining together afloat the two halves of the platform and $0.7m is for the erection of the deckhouse.

G&C's figures do not include either the cost of towing the platform to its operating site or of installing the heat exchanger, discharge duct units.

LMSC build the hull structure of their ship shape platforms in a graving dock and then complete them afloat. Their deployment sequence is shown in Figure 3.3. The deployment costs are the costs associated with the float out operation and consist in provision for 4 buoyancy chambers to increase waterplane moment of inertia when undocking the ship shaped platform. This is budgeted at $15m under non recurring costs. Recurrent costs connected with these operations appear as $1.3m in the recurring deployment costs. As for G&C the costs connected with towing the platform on site and installing the discharge ducts are not included in the platform deployment estimates.

The LMSC spar is built in a specially constructed facility, the costs for which are budgeted under "Industrial Facilities". Their deployment sequence is shown in Figure 3.4. No capital equipment is required for floatation purposes. A recurring cost of $1.5m is budgeted for expenses associated with floatation.

MR&S differ radically in their construction concept from G&C and LMSC. The spar is built in part on a specially prepared site. It is then floated to deeper water where it is made watertight. The incompleted platform is then towed to its operating site where construction is completed. Their deployment sequence is shown in Figure 3.5. MR&S have treated the whole deployment as a unified operation to which they have allocated $4.076m. $1.609m, is a non recurring cost for a plug over the CWP opening during float out. $0.95 is a recurring cost for tow during various stages of construction and the balance of the $4,076 is the cost of transporting concrete to the construction sites offshore for completion of the platform.

The costs for the four platforms are listed below:

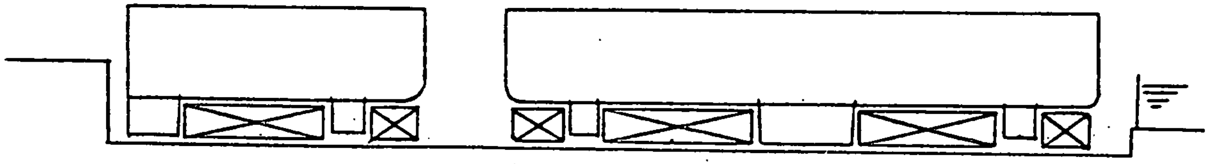
WBS 8.1 - Platform Deployment

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Non recurring | | | | |
| Floatation barges | 7.0 | 15 | | |
| Plug for CWP opening | | | | 1.609 |
| Recurring | | | | |
| Assembly costs | 3.3 | 1.3 | 1.5 | |
| Transport and towing costs | | | | 2.467 |

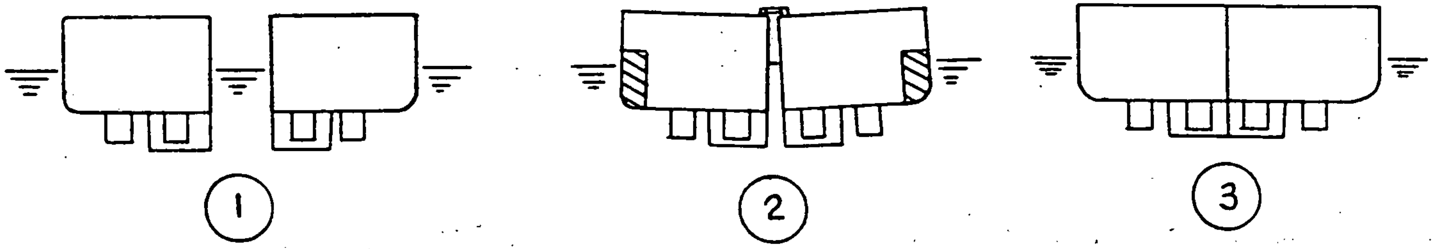
## 8.2 CWP Deployment

The studies described in Section 2.2.1 have led to the selection of a unified lightweight concrete pipe design for all the platform configurations.

The platform arrangements are such that the CWP cannot be assembled and deployed from the platform. Consequently the deployment sequence assumes that the pipes are transported on barges to the deployment site in 112 ft sections and transferred by floating cranes to a specially designed barge in which they are assembled vertically. The pipes are supported during assembly on hydraulic cylinders, similar to those used in offshore jack up rigs which lower the CWP gradually into the water



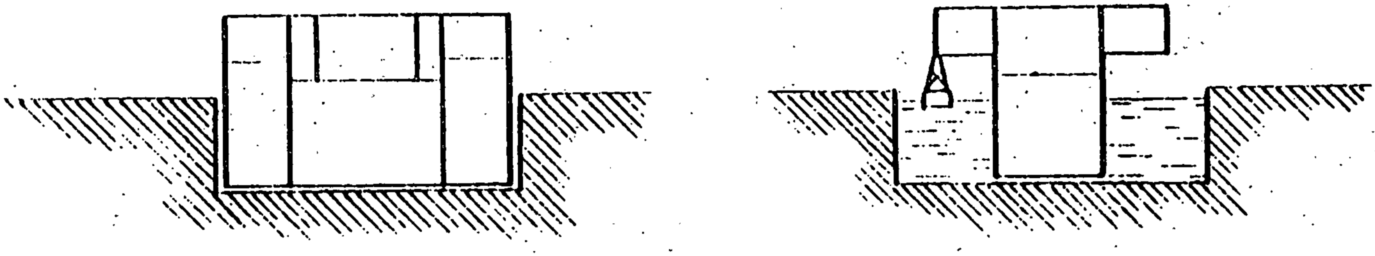
Flotation barges emplaced and first half hull along with first portion of second half hull fabricated. Pumps and cold water plenum emplaced.



① Ballast down and remove flotation barges, align hull halves.
② Join hull halves along the main deck using alignment pins and hydraulic jacks. Bring the bottom edges together by ballasting the hull halves.
③ Weld halves together, remove jacks.

G&C SHIP SHAPE PLATFORM
DEPLOYMENT PROCEDURE

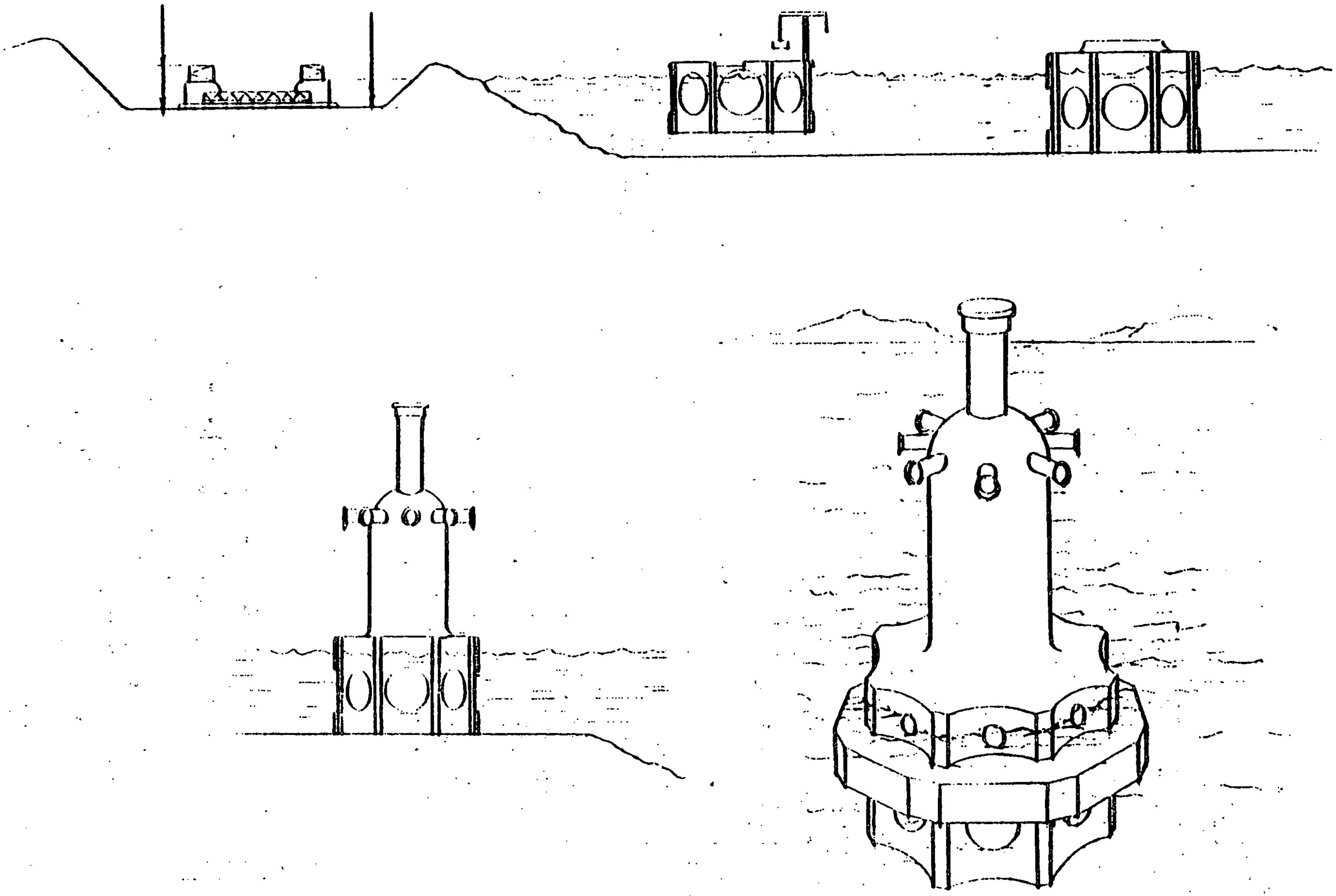
Figure 3.2



LMSC SHIP

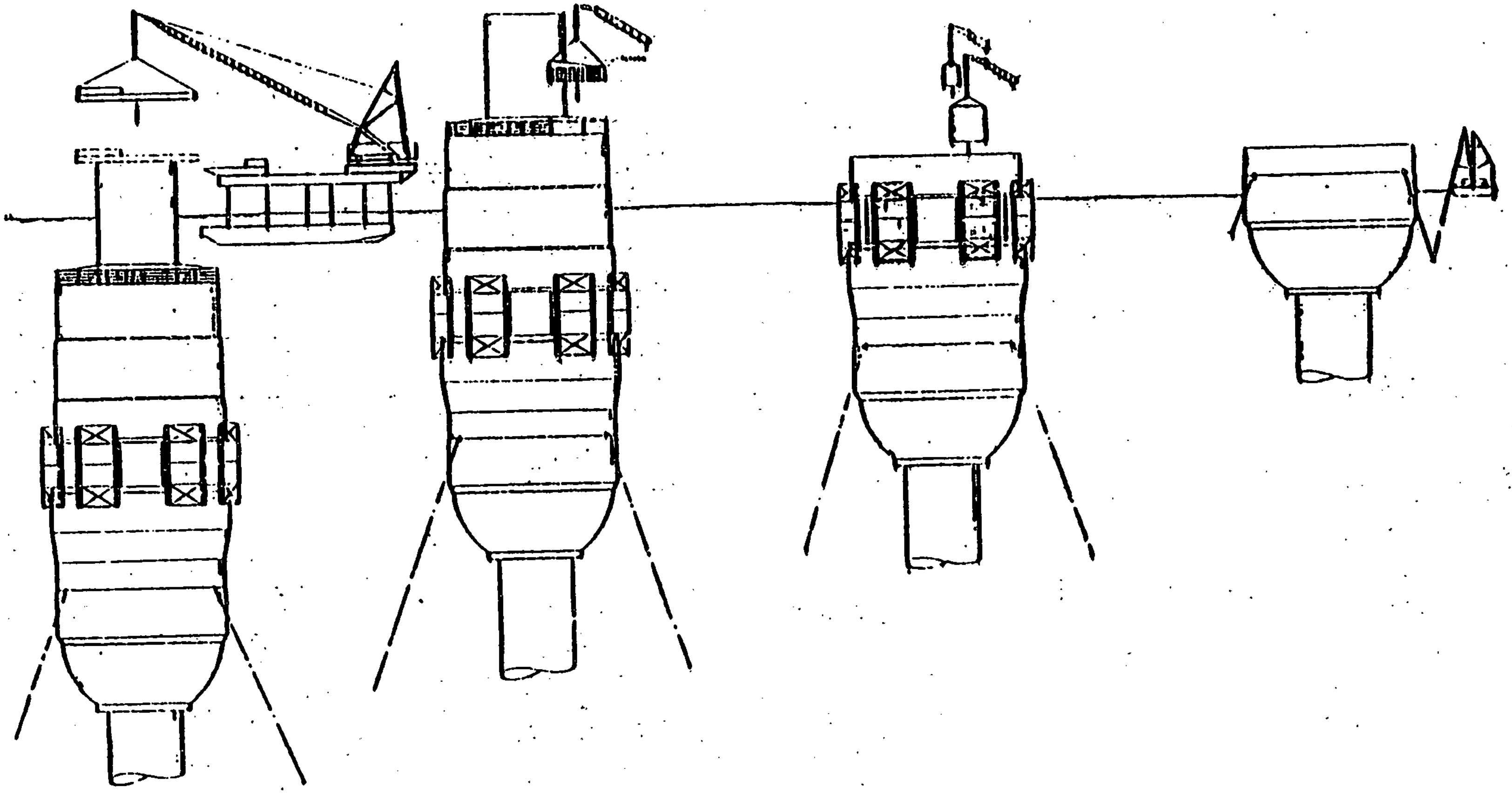
DEPLOYMENT SEQUENCE

Figure 3.3



LMSC SPAR - DEPLOYMENT SEQUENCE

Figure 3.4



MR&S SPAR
DEPLOYMENT SEQUENCE

Figure 3.5

as each successive pipe section is assembled. Once the whole pipe is assembled, the barge is flooded so as to lower the CWP below the platform level. The pipe is then positioned below the platform connection, the barge is deballasted and the CWP is attached to the platform. Figure 3.6 illustrates this operation for the G&C ship but is also applicable in principal to the other platforms. This operation involves large scale underwater work, extending over several days, in exposed areas and in water depths of as much as 400 ft for some of the spars. Alternatives to this hazardous procedure are discussed in Section 5.

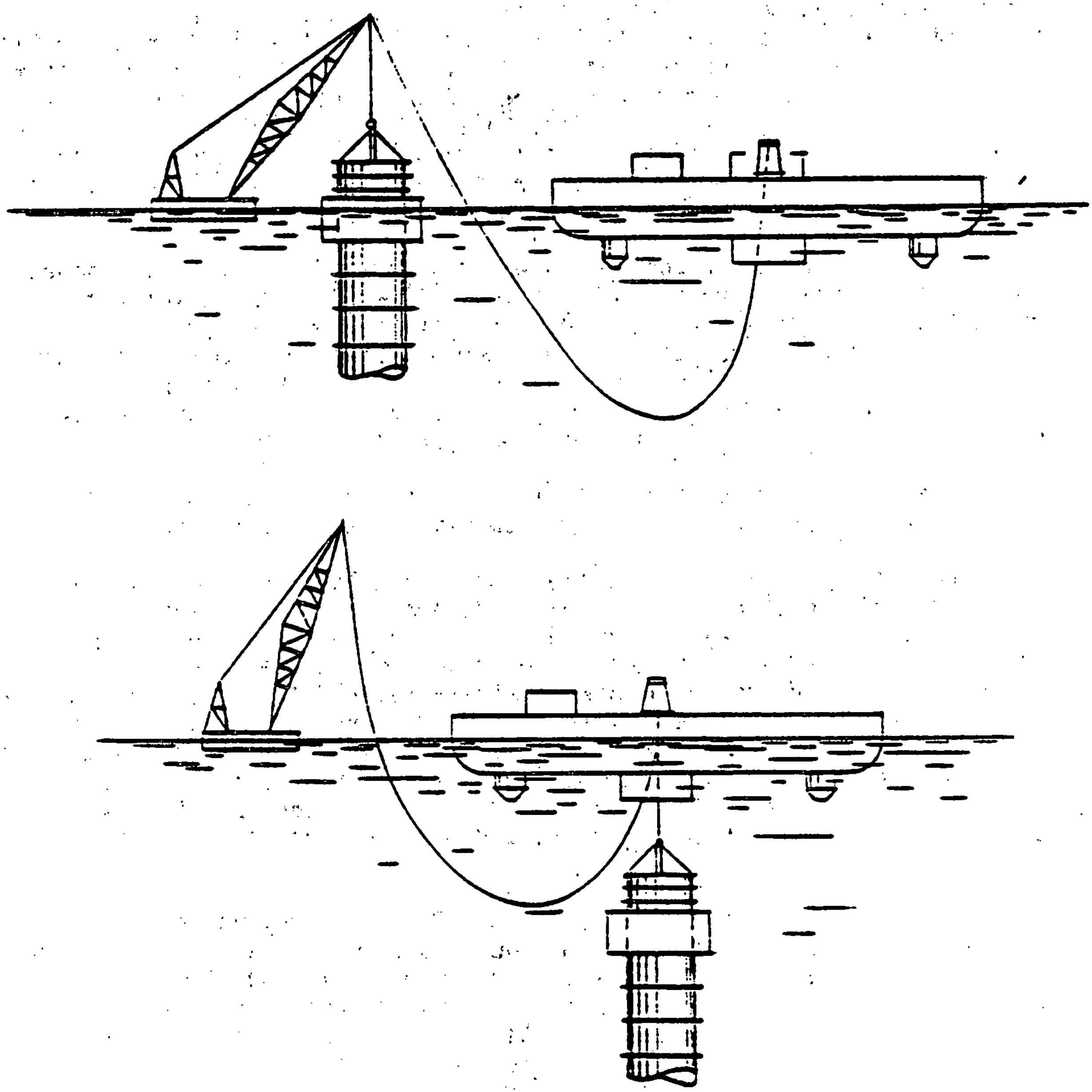
The development procedure assumes that the CWP, once it is landed on an appropriate platform on the barge is lowered into the water by hydraulic cylinders similar to those on jack up rigs. 8 cycles of the hydraulic cylinders are required to lower one pipe section at two hours per cycle. A further 36 hours is allowed to make each pipe joint, this being the time assumed by LMSC in reference 5. Allowing 25% downtime each pipe section will require up to 65 hours to assemble.

Twenty six pipe sections are required for the LMSC and G&C ship shapes, twenty for the MR&S spar and twenty three for LMSC spar.

Four pipe sections can be transported simultaneously on one barge. Assuming that the pipe loading station ashore is 200 miles from the deployment site, six days are required for a barge to deliver the pipes and return to its base. Allowing some down time for weather conditions as well as waiting time while the pipes are removed from the barge to the crane platform an eight days round trip is required to deliver four pipes. On this basis one tug and one barge is adequate to ensure continuity of supply without work interruptions. A self propelled floating crane would be required for handling the pipes. The lifting capacity is estimated at 2000 tons for the spars and 3000 tons for the ship shaped platforms.

The pipe assembly barge must have sufficient buoyancy to support a pipe weight, in water of up to 30,000 tons plus the weight of one pipe section in air, as well as the weight of pipe lowering equipment, in all about 33,000 tons. Since this barge may be submerged as much as 400 ft when positioning the CWP below the platform, it must be built as a pressure vessel. For the purpose of estimated the cost of the barge it has been assumed that the weight of the steel hull will be about 25% of the buoyancy, for the smaller barges associated with the spars and 20% of the buoyancy for the larger barges required for the ship shaped platforms. Steel costs were taken at $3000 per ton.

The cost of the tug barge combination has been taken at $4000 per day. The 3000 ton floating crane was taken at $60,000 per day. The hydraulic cylinders at $10,000 per day for the spar and $12,000 per day for the ships.



G&C CWP DEPLOYMENT METHOD

Figure 3.6

Two twelve hour shifts of 30 men, at an average rate of $400 per shift, including subsistence have been assumed for personnel on the barge during CWP assembly.

Seven days have been allowed for pipe submergence and connection to the platform. One crane barge and four large tugs will be required during this operation.

The resultant costs, as calculated by JJMA are listed below.

WBS 8.2 - CWP Deployment

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Crane | 4,800,000 | 4,800,000 | 3,501,000 | 3,375,000 |
| Hydraulic Cylinders | 840,000 | 840,000 | 680,000 | 650,000 |
| Transport Pipes | 224,000 | 224,000 | 192,000 | 192,000 |
| Personnel-pipe Assembly | 1,680,000 | 1,680,000 | 1,630,000 | 1,500,000 |
| Pipe Connection | 700,000 | 700,000 | 595,000 | 595,000 |
| Total Recurring Costs | 8,244,000 | 8,244,000 | 6,607,000 | 6,372,000 |
| Buoyancy Vessel (Non recurring) | 19,200,000 | 16,800,000 | 13,500,000 | 13,500,000 |

## 8.3 Moorings

All three contractors have estimated the moorings deployment costs and given a cost breakdown.

The studies described in Section 2 have however led to the development of completely new mooring systems designed to suit the environmental conditions off Tampa. The cost of deploying the moorings has therefore been recalculated to suit the new mooring concepts.

The chains and anchors are loaded on barges and towed to the deployment site. The deadweight anchor is lowered in place by a floating crane, while the chain is paid out from the barge. To control pay out speed one barge is provided with an anchor windlass.

As the anchors and chains are paid out they are connected to buoyancy tanks, designed to take the weight of the chains and deploy them in their correct geometrical form. When a set of three cables has been deployed they are connected to the platform and the buoyancy tanks are released. This operation is repeated until all the moorings have been connected.

Each cycle of laying the chain on the barge, transporting it to the site, paying out the cable and returning the barge to its loading site is estimated at 10 days as follows:

| | |
|---|---|
| Load chain on barge | 2 days |
| Tow barge to site(200 miles at 6 mph) | 1½ days |
| Connect chain to anchor and lower | 2½ days |
| Return to base | 1½ days |
| Down time and contingency | 2½ days |

A barge, about 400x100x30 ft is required to take one chain, its anchor and its buoyancy tanks. Four barges are required to transport the cables on site at a rate ensuring continuity of labour. In addition, a barge fitted out with a windlass is required permanently on site.

The barge rental has been assumed at $2500 per day and its tug at $1500. The cost of the windlass was taken at $500,000. A further $500,000 was allowed for modifications to the barge. A crew of fifteen people per shift has been assumed on the barge with 2 12 hour shifts.

The G&C platform has 20 cables, the LMSC ship has 28 cables, the LMSC and MR&S spar have 12 each. Allowing 2½ days average time to lower each cable and its anchor, their deployment times will be 50,70 and 30 days respectively.

The costs associated with deploying the mooring systems are listed below.

WBS 8.3 - MOORING DEPLOYMENT

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Recurring Costs | | | | |
| Tugs, Work Boat | 395,000 | 525,000 | 237,000 | 237,000 |
| Submersible | 300,000 | 420,000 | 180,000 | 180,000 |
| Crane | 2,460,000 | 3,280,000 | 1,640,000 | 1,640,000 |
| Barges | 400,000 | 560,000 | 240,000 | 240,000 |
| Windlass Barge | 160,000 | 200,000 | 240,000 | 240,000 |
| Platform Tug | 504,000 | 644,000 | 364,000 | 364,000 |
| Equipment | 800,000 | 1,000,000 | 600,000 | 600,000 |
| Personnel | 1,200,000 | 1,680,000 | 720,000 | 720,000 |
| TOTAL Platforms 2-8 | 6,219,000 | 8,309,000 | 4,101,000 | 4,101,000 |
| Non Recurring | | | | |
| Equipment | 2,050,000 | 2,050,000 | 2,050,000 | 2,050,000 |
| TOTAL, 1st Platforms | 8,269,000 | 10,359,000 | 6,515,000 | 6,515,000 |

## 8.4 Power Systems

Both G&C and LMSC keep the size of their platform to a minimum by placing a portion of the power systems outside the platform. A portion of this equipment is installed afloat, after the platforms have been built. This section deals with the costs associated with this installation. There are no such costs incurred by MR&S since their power systems are contained within the spar.

G&C uses external heat exchangers and pumps in their ship shaped concept. A portion of the appendages are installed during the process of platform assembly, leaving the eight heat exchanger/discharge ducts to be installed in deep water. The deployment operation is described in Reference (2). It consists in floating the units, weighing 910 tons each, towing them to the assembly site, and rotating them to a vertical configuration by controlled ballasting. The units are then submerged, brought into position below the platform and connected to it.

Reference (2) does not give any costs for this operation. JJMA has assumed that the work is done most safely and expenditiously by chartering a small heavy lift ship. The vessel could carry two heat exchangers per trip, from a loading port to the deployment site and assist in their installation.

The cost of chartering a heavy lift ship has been estimated at $10,000 per day. A work boat will cost $1500 per day. Deployment time for 2 heat exchangers would be as follows:

| | |
|---|---|
| Loading | 1 day |
| Travel | 2 days |
| Launch and Fit 2 heat exchangers | 5 days |
| Return to port | 2 days |
| Downtime and Contingency | 2 days |

Fitting the 8 pipe would require 48 days.

A further 12 days are assumed for the boat to reach its operation site starting from its base. On this basis deployment costs are estimated as follows:

| | | |
|---|---|---|
| Heavy lift ship | 60 days at $10,000 | $600,00 |
| Work boat | 40 days at $1500 | 60,000 |
| Personnel | 40 days 12 men @ $400 | 192,000 |
| | | 852,000 |

LMSC's construction sequence provides for installing afloat the heat exchangers on the ship shaped platform.

Deployment procedures connected with these are described in Reference (3). LMSC allows $4.5m per platform for this operation.

The power units for the spar platforms are built in a concrete module, forming a watertight enclosure. The modules are towed to the deployment site when they are rotated to a vertical configuration by controlled ballasting. They are then connected to the spar platform. The costs for power systems deployment are as listed below:

### WBS 8.4 - POWER SYSTEMS DEPLOYMENT

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| Non Recurring | | | | |
| Floatation ring | | | 3 | - |
| Recurring | 0.85 | 4.5 | 4.1 | - |

### 3.3.12 WBS 9 - Industrial Facilities

The three contractors used basically different approaches to the construction of the platforms and the industrial facilities which they require are quite different.

#### a) M. Rosenblatt and Son

The construction sequence proposed by MR&S requires that the lowest section of the spar is assembled in a specially prepared landsite. This portion is launched in about 46 ft of water, towed to relatively shallow water where it is built by slip form to about 360 ft above the baseline. The partially completed platform is then towed to the operational site for attachment to the CWP, the mooring system and completion of the platform.

Reference (1) lists the following costs for site preparation.

| | First platform | Following Platforms (each) |
|---|---|---|
| Consolidation | 0.200 | 0.100 |
| Dredgint | 6.111 | 0.305 |
| Excavating | 0.250 | 0.05 |
| Sheet piling | 0.721 | - |
| Carriage, Rails, etc. | 1.000 | - |
| | $8,282m | $0.455m |

The above costs make no provision for such items as access roads, administrative buildings, material storage and handling, power, electricity, and other services required for operation an industrial facility. Nor do they make any allowance for shore based support during offshore construction.

MR&S's figure should therefore be considered a partial estimate and do not represent the full cost of the production facility.

Development of a realistic cost for a building site is a major operation, which is beyond the scope of the present study. Moreover, its value is quite limited as long as a tentative land site has not been selected. JJMA believe however, based on the work done by LMSC and G&C on landbased support facilities for the OTEC park, that at least $8m should be added to the cost of the land preparation in order to obtain an operating industrial facility.

For the present analysis the following estimates are proposed for the MR&S land facility:

| | First Platform | Following Platforms (Each) |
|---|---|---|
| Land Preparation | 8.3 | 1.2 |
| Support Facilities | 8 | - |
| Total | 16.3 | 1.2 |

b) LMSC

LMSC states that the ship platform requires a large construction basin for the hull and eight graving docks, each capable of absorbing simultaneously two heat exchanger/sea water pump sub assembles. The spar platform requires a smaller basin, a deep water dock and eight graving docks for power module construction. LMSC assumes that dedicated facilities will be used in all cases and allows the following for industrial facilities.

| | SHIP | SPAR |
|---|---|---|
| Platform construction basin | 60 | 40 |
| Platform construction dock | | 40 |
| Power systems docks (8) | 120 | 120 |
| Total | 180 | 200 |

A subsequent construction feasibility study, reference 17, confirm that there is no existing facility capable of building the spar. Reference 17 does propose an alternative method of construction in which the lower portion of the spar is built on a barge, followed by slipforming in sheltered waters.

This method has the potential of worthwhile savings in facility costs, however a far more complete evaluation than is practical at this stage is required before it is adopted. Consequently the budget proposal by LMSC has been retained.

Reference (17) also studies construction facilities for the ship shape platform and concludes that there are no facilities on the Atlantic or Gulf Coast capable of building the ship shape platform in concrete. Consequently the estimate by LMSC for the construction basin has also been retained.

Graving docks for the power systems are available. There is however a serious question as to whether docks in such numbers will be available for the time spans required by the construction of the OTEC park. On the other hand, construction of the power modules need not be restricted to one geographical location. The possibility also exists that improved construction techniques may limit the stay in dock of the power modules. Considerably more work is required before the minimum docking requirements for the modules are ascertained with any degree of accuracy. Meantime it has been assumed that these requirements can be met by existing facilities.

c) Gibbs and Cox

G&C has assumed that for construction purposes the ship will be divided along its centerline into two watertight hulls which will be joined afloat. This construction can be carried out in existing shipyards and does not require a dedicated facility. Special equipment connected with floating and joining the vessel are included in the deployment costs. Consequently no allowance is required for industrial facilities.

The costs of industrial facilities for the three contractors are shown in Table 3.13.

### 3.2.13 Environmental, Legal, Licensing, Regulatory and Insurance

LMSC calculate this unit on the basis of 3% of basic first unit cost and 2% of follow on units. Both G&C and MR&S utilize a bottom up approach, giving dollar values to each of the third level elements.

Environmental impact is hopefully, a one time operation applicable to the first platform only. Costs related to regulatory approval, legal and licensing are applicable to each platform. Insurance costs are a recurring annual expense connected to capital cost. Each of these should therefore be identified separately in order to have its costs correctly distributed in the life cycle analysis.

In estimating this item the following approach has been applied.

1. A uniform value has been used for environmental impact statement taken from G&C's estimate.
2. Regulatory approval has been assumed to be included in Systems Engineering and Integration.
3. $200,000 have been allowed per platform for legal and licensing costs.
4. Insurance costs have been based on a yearly rate of 0.8 percent of acquisition cost. The insturance costs have been extended to include the cost of the power system, since this will form part of the operating unit and will also be insured.

The costs for each of the contractors are shown in Table 3.14.

### 3.2.14 WBS 11 Project Management

LMSC and G&C both priced this cost element parametrically. LMSC assumed management costs at 9% of first unit costs and 6% of the other units, representing $22.5m for this first unit and $15m for each of the following units. G&C does not give any back up documentation but estimates the cost at $1.7m per platform, without cost differentiation between the first and the follow up units.

MR&S uses a bottom up approach, assuming a 12 year design and construction period. Quality assurance is assumed to last eight years during the construction phase, all the other items are spread over 12 years, except financial management which is assumed to last 40 years. The calculated costs are then divided evenly over the eight platforms. MR&S estimated costs are $3.725m per platform, utilizing an estimated value of $50,000 per man year.

In estimating this item JJMA has used a bottom up approach similar to the one proposed by MR&S. Planning, data, configuration and contract management have been taken over a 12 years period as for MR&S. Financial management, assumed by MR&S to last 40 years has been estimated also over the 12 years planning and construction period. Quality assurance has been calculated individually for each platform and includes an allowance for attendance at major subcontractors.

The resultant costs are shown on Table 3.15. These costs represent an idealized situation, with minimum duplication and dispersal of effort. It should be recognized however that some dispersal will be inevitable and that this will result both in the necessity for increased liaison effort between geographical locations over which this effort will be distributed and in some overlapping and duplication. The impact of this dispersal on management costs will depend upon the geographical location of the building sites and of the supervising bodies and will vary with the number of construction sites and with the organizational set up. A contingency allowance of 50% was therefore added to the figures in Table 3.15 to allow for this and is shown as a one line item at the bottom of the table.

## 4. PLATFORM EVALUATION

### 4.1 GENERAL

The previous sections have described the process of reducing the OTEC platform designs to consistent engineering standards and environmental conditions and of developing cost estimates for the four candidate paltforms on a comparable basis. This section covers the process of evaluating the material generated in Section 2 and 3 and selecting the preferred platform configuration.

#### a) Evaluation Criteria

The basic consideration in selecting evaluation criteria is that a commercial OTEC platform is intended as a capital investment, capable of generating electric power on a competitive basis and the best tangible measure in comparing several candidate designs is their profitability.

The earlier studies of the commercial OTEC plants compared them on the basis of their life cycle cost. Acquisition and deployment costs were calculated for eight unit OTEC parks and added to the costs of the industrial facilities required for their construction and to the costs of operating the platforms for a forty years life span. Revenues were assumed to be constant for all the platforms so that the life cycle costs gave a ranking of platform desirability.

This method has the advantage of simplicity. It is unsound in so far as it implies the same worth to capital investments spent today and to operating costs forty years hence.

A better approach when revenues can be predicted is to deduct from the revenues the operating costs and then calculate the rate of return on the capital invested. The alternative promising the highest return on the capital is the most profitable.

In the present case, where revenues cannot be predicted, it can be argued that the platform producing the required service at least cost to the consumer, is the optimum platform.

The method selected for this investigation is therefore a comparison of the platforms on the basis of the annual cost of generating electricity. This is done in three stages.

1) Acquisition costs are developed for an eight unit park.

2) Acquisition costs are transformed into average annual costs through the application of a capital recovery factor.

3) The operating costs are added to the anualized costs to obtain total annual costs.

4) The annual costs divided by the output of electricity give a unit production cost on the basis of which the candidate configurations are judged.

b) Capital Recovery Factor

For the purpose of this analysis the following simplifying assumptions have been made:

1) No allowance is made for inflation.

2) No allowance is made for the effect of taxes on returns.

3) No allowance is made for predelivery financing.

While the effect of these factors on both costs and revenues is significant, it is believed that they would not ffect the outcome of a comparative study like the present one.

It was further assumed, in determining capital recovery factors that the capital costs would be financed to the extent of 100%.

A survey of industrial corporations carried out some years ago, by the University of Michigan showed that expected rates of return, on capital investments, on non speculative projects in existing fields of operation were expected to run from 9 to 12%.

The present operation which carries the risks associated with a new field would require a higher rate of return. A recovery factor of 0.134 was assumed. This corresponds to a 20 years write off period with a return on capital of 12%.

c) Learning Curve

Savings in cost will result from multiple production, as labour efficiency increases. Reference (18) suggests that cost reduction factors for cargo ships approximate a log linear curve with a slope of 0.93. Reference (19) shows that these factors vary with the degree of mechanization and efficiency of the operation and that the slope of the curve could be 0.96 in a highly mechanized operation in a modern, efficient ship construction facility and as low as 0.91 in an inefficient operation.

A slope 0.93 was adopted for this study and appears to be a good average figure. Table 4.2 shows the derivation of a multiplier, based on this slope for passage from a single platform to an eight unit OTEC park.

## 4.2 ACQUISITION COST ESTIMATES

Table 4.1 summarizes the estimated acquisition costs for 400 MWe OTEC Commercial Platforms.

The costs for each platform are shown in two columns. The first columns shows all charges against the first platform including non recurring costs. The second columns shows the distribution of non recurring costs in the Work Breakdown Structure and their magnitude.

The recurring costs in Table 4.1 are multiplied by the multiple production factor in Table 4.2 to obtain the recurring costs for an eight unit OTEC park. The non recurring costs chargeable to the first platform are then added to this figure. The results are shown in Table 4.3 and give the acquisition costs for OTEC parks for the four candidate platforms.

It can be seen that the LMSC spar is the cheapest platform system to build, followed by the LMSC ship, the MR&S spar and the G&C ship.

## 4.3 OPERATING COSTS

Table 4.4 lists the annual operating costs for the OTEC platform. The derivation of these costs is discussed in Section 3.3.9 and 3.3.13 and the costs summarized in Tables 3.10 and 3.14.

The costs associated with personnel and support vessels assume that all platforms will be fully manned. The rational for this costing approach is discussed in Section 3.3.9. The cost impact of a centralized operation is discussed in Section 5.

The insurance costs are based on an annual premium of 0.8% of insured value. A departure has been made from the approach used by the three contractors in the commercial plant studies in so far as the insured value has been extended to include the cost of the energy systems. This is in keeping with normal marine practice where no distinction is made, in terms of insurance between the ships hull and its propulsive systems.

The spread between the costs for the three contractors is quite small, with MR&S showing the least cost, followed by G&C and LMSC.

## 4.4 COMPARISON OF ANNUALIZED COSTS

Table 4.5 shows the ranking of the candidate OTEC commercial platform. The annualized investment costs and the operating costs are summarized to obtain annual operating costs. The net power generated by the park is obtained by subtracting the parasitic loads in Table 2.4.4 from a gross output of 520 MW. Dividing the annual operating cost by the net output gives a unit cost per megawatt per year. These costs are normalized around the most cost effective concept to obtain relative costs per unit of electrical power.

It can be seen that the most cost effective concept is the LMSC spar, followed by the LMSC ship, the MR&S spar and the G&C ship. The total spread between the cheapest and the most expensive concepts is 28%. The spread between the LMSC ship and the LMSC spar is 11%.

# TABLE 4.1

## ACQUISITION COSTS FOR FIRST PLATFORM

| | G&C | | LMSC (SHIP) | | LMSC (SPAR) | | MRNS | |
|---|---|---|---|---|---|---|---|---|
| W.B.S. TITLE | TOT | N.R. | TOT | N.R. | TOT | N.R. | TOT | N.R. |
| 1.0 Platform Sys. | 412.8 | | 332.3 | | 292.5 | | 416.1 | |
| 2.0 Cold Water Pipe Sys. | 64.8 | | 53.1 | | 43.0 | | 45.0 | |
| 3.0 Power System | - | | - | | - | | - | |
| 4.0 Energy Transfer Sys. | - | | - | | - | | - | |
| 5.0 System Eng. Integration | 19.9 | 14.9 | 26.3 | 19.7 | 26.3 | 19.7 | 31 | 23.3 |
| 6.0 System Test and Evaluation | 8.7 | | 8.7 | | 8.7 | | 8.7 | |
| 7.0 Operational Support | 27.5 | 27.5 | 82.8 | 82.8 | 82.8 | 82.8 | 81.5 | 81.5 |
| 8.0 Deployment | 47.7 | 28.3 | 56.8 | 33.9 | 35.1 | 18.6 | 30.4 | 17.2 |
| 9.0 Industrial Facilities | - | - | 60 | 60 | 80 | 80 | 16.3 | 16.3 |
| 10.0 Environmental Etc. | 0.9 | 0.7 | 0.9 | 0.7 | 0.9 | 0.7 | 0.9 | 0.7 |
| 11.0 Project Management | 7.3 | - | 7.3 | - | 7.3 | - | 7.3 | - |
| Cost of 1st Platform | 589.6 | 71.4 | 628.2 | 197.1 | 576.6 | 201.8 | 637.2 | 139 |
| Platform Cost After Exclusion of Non Recurring Items | 518.2 | | 431.1 | | 374.8 | | 498.2 | |

## TABLE 4.2

## MULTIPLIER FOR 8 PLATFORM PARK

| | | |
|---|---|---|
| PLATFORM | 1 | 1.000 |
| | 2 | 0.930 |
| | 3 | 0.891 |
| | 4 | 0.865 |
| | 5 | 0.845 |
| | 6 | 0.829 |
| | 7 | 0.816 |
| | 8 | 0.804 |
| | | |
| MULTIPLIER FOR 8 UNIT PARK | | 6.98 |

## TABLE 4.3

## CAPITAL INVESTMENT COSTS

## ( 8 UNIT PARK)

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| NON RECURRING COSTS | 3,617 | 3,009 | 2,616 | 3,477 |
| RECURRING COSTS | 71 | 197 | 202 | 139 |
| TOTAL | 3,688 | 3,206 | 2,818 | 3,616 |
| ANNUALIZED AT 0.134 | 494 | 430 | 378 | 485 |

## TABLE 4.4

## ANNUAL OPERATING COSTS - 8 PLATFORMS

## (BASED ON FULLY MANNED PLATFORMS)

| | | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|---|
| 7.1 | Spares | 8 | 6 | 6 | 8 |
| 7.2 | Expendable Material | 6 | 6 | 6 | 6 |
| 7.3/7.4 | Support Vessels | 3.9 | 7.9 | 7.9 | 7.9 |
| 7.5 | Personnel | 36.5 | 36.5 | 36.5 | 36.5 |
| 7.7 | Maintenance and Repair | 12 | 26 | 26 | 8 |
| 10.4 | Insurance | 54.4 | 46.4 | 46.4 | 51.2 |
| | TOTAL | 120.8 | 128.8 | 128.8 | 117.6 |

## TABLE 4.5

## PLATFORM RANKING

| | G&C | LMSC (SHIP) | LMSC (SPAR) | MR&S |
|---|---|---|---|---|
| CAPITAL INVESTMENT COSTS | 494 | 430 | 378 | 485 |
| ANNUAL OPERATING COSTS | 121 | 129 | 129 | 118 |
| TOTAL | 615 | 559 | 507 | 603 |
| POWER GENERATED | 3262 | 3267 | 3316 | 3286 |
| COST/MWe/YEAR | 0.1885 | 0.1711 | 0.1529 | 0.1835 |
| PLATFORM RANKING | 1.23 | 1.12 | 1 | 1.20 |

## 5. TECHNICAL AND COST UNCERTAINTIES

### 5.1 GENERAL

The costs developed in Section 4 will be impacted upon by

a) Assumptions made with respect to financing
b) Areas of technical and cost uncertainty
c) Impact of site selection

The assumptions with respect to financing are discussed in Section 4 and have been developed only to the extent necessary for comparatively ranking the candidate platform configurations. They would require further development as well as a definition of the operators financing philosophy before realistic total cost estimates could be obtained. This level of accuracy is not necessary for this report, particularly so since major cost elements such as the cost of transmitting electrical power and the cost of the pwoer generating units are excluded from the comparison by direction from DOE. Major areas of technical uncertainty, their impact on cost and the operating limitations associated with them are also discussed. Finally, the impact of changes in operating site on the selection of platform type is considered briefly.

### 5.2 HULL STRUCTURE

The G&C and LMSC hulls are built and assembled either in a construction facility or in relatively sheltered waters. A substantial portion of the MR&S hull is built at the deployment site, in an exposed area, at a large distance from shore. Compared to the other platforms, this method of construction introduces an increased risk of labour inefficiency resulting from work stoppages due to weather conditions, from more complex supply lines and from reduced levels of mechanization. This enhanced risk is not recognized in the method of cost estimating which relies on unit construction costs. To evaluate its effect, it has been assumed that the unit labour costs at the deployment site could be 30% higher than at the construction facility. At the same time, the learning curve slope was taken at 0.91 instead of 0.93, to recognize the greater improvements in learning curves generally associated with reduced mechanization and lower levels of efficiency. Assuming that 50% of the platform structure is assembled at the deployment site the increase in cost for the eight unit part has been estimated to be in the order of $115 million.

### 5.3 STATION KEEPING SYSTEM

Section 2 considers the availability of both fixed and weathervaning mooring concepts for the shipshaped platforms and shows that a significant cost differential exists between the two concepts when applied to the LMSC ship.

The weathervaning concept result in a cheaper design if the shipshaped platform is allowed to take a position colinear with the current.

The technical objections to its use are discussed in Section 2.3 and as a result of these objections the more expensive fixed moor is used as the baseline for this analysis. A potential exists for a cost reduction in the order of $157 million for the OTEC park if the technical feasibility of applying weathervaning to the LMSC spar can be demonstrated.

## 5.4 COLD WATER PIPE

### a) Material

A unified CWP design, utilizing light weight concrete as a construction material has been proposed for all four platforms. The impact of a light weight concrete CWP on the LMSC designs has been discussed in Section 2. The problems associated with its deployment are discussed in 5.4 (b).

Introduction of a lightweight concrete CWP has a major effect on the design of the LMSC spar configuration and a significant cost impact. This redesign is believed necessary within the present state of the art of CWP design, however CWP material and characteristics may change radically within a relatively short time span as more knowledge is gained through the studies presently under way. The impact of CWP design must therefore be qualified as tentative until such time as CWP design reaches a more definitive stage.

### b) CWP Deployment

That portion of the CWP deployment procedure which consists in connecting the pipe to the bottom of the platform is considered a high risk operation. It involves submerging the massive CWP undersea, in open waters, maneuvering it below the platform, connecting it with divers to the bottom of the platforms, disengaging the barges from the CWP and guiding them again to the surface to repeat this operation on the next platform. The operation requires a barge, with a deadweight capacity in the order of 30,000 tons. The barge structure must be designed to withstand pressures associated with depths up to 400 ft and must be provided with capability for ballasting and deballasting in the submerged condition by remote control from above the surface.

A better approach would be to deploy the CWP from the top of the OTEC platform, gradually lowering the pipe into the sea, generally at proposed in the APL grazing plant and in earlier LMSC concepts.

This approach can be realized fairly easily for ship shapes through a rearrangement of interior spaces to allow an unobstructed passage above the Cold Water Pipe.

Top loading of the CWP is more complicated in the case of the LMSC spar and requires substantial changes to the design of the spar.

Figure 5.1 shows a spar concept modified to allow loading the CWP from the top. The diameter of the central core is increased from 36m to 59m. A trunked opening large enough for passage of the CPW is provided on the centerline. The increase in the weight of the structural concrete due to the revised spar dimensions has been estimated at 30,000 tons per platform. The resultant cost increase for an OTEC park was estimated to be in the order of $100,000,000 after allowing for savings through elimination of the submersible barge and reduction in deployment time.

Top loading of the CWP is impractical in the case of the MR&S spar, short of a quasi total redesign of the spar.

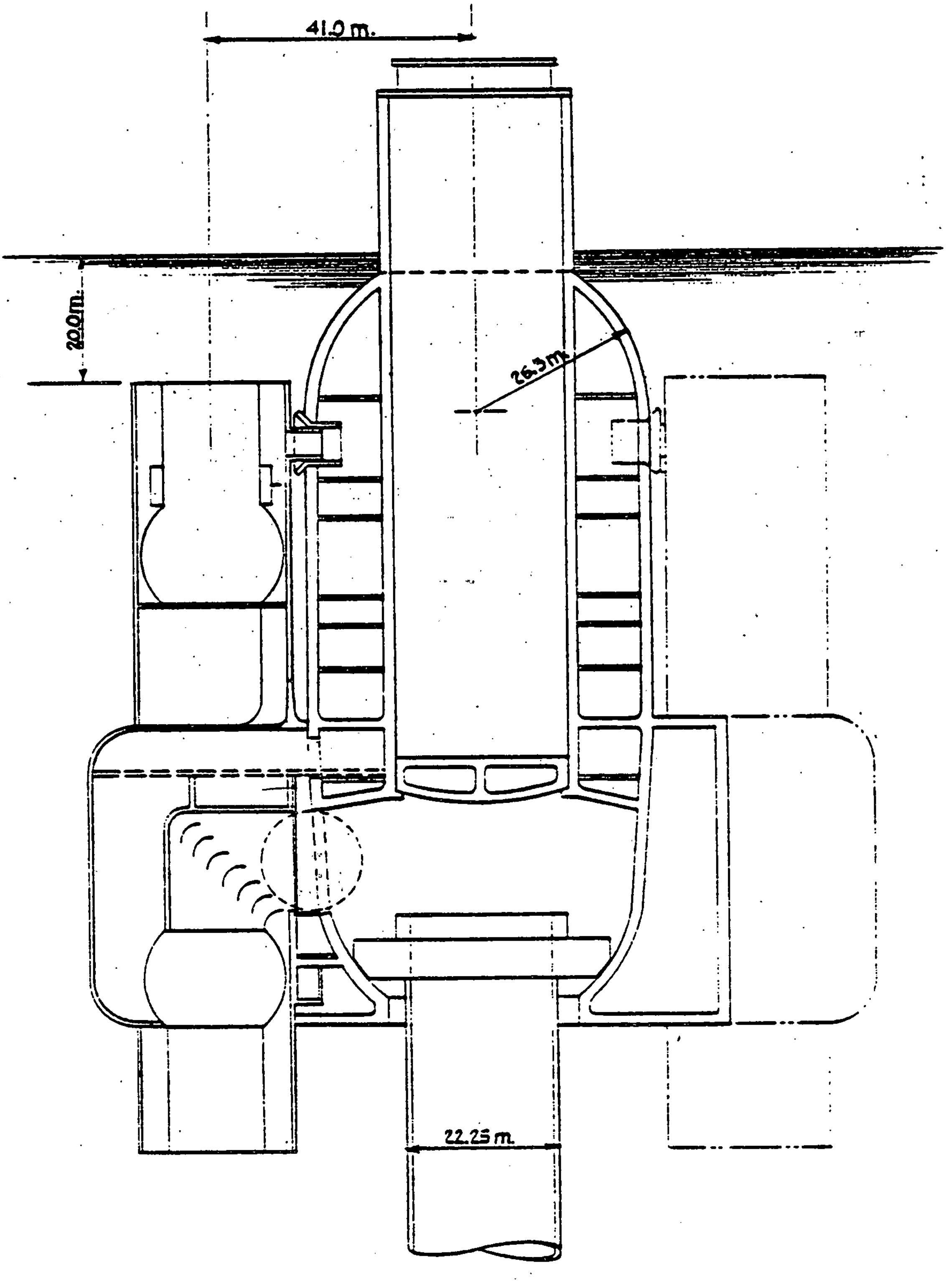
## 5.5 EFFECT OF CENTRALIZED OPERATION THROUGH A DACS

LMSC suggests that the OTEC platforms should be unmanned and that they should be remotely controlled by a DACS in a hotel barge. The same concept was also studied by MR&S who abandonned it on the grounds that it would meet with resistance on the part of the utility companies.

The unmanned operation concept has the advantage that it requires less operating personnel and reduced capital investments for personnel accommodation.

Savings in annual operating costs would be in the order of $28m. Of this figure $26m would be in personnel costs and the balance would be in the cost of operating the hotel barge. Savings in capital investment would be in the order of $42m for the eight unit hotel park.

These are very worthwhile savings provided that the DACS concept can operate with a level of reliability acceptable to its future operators. This has not yet been demonstrated. The concept, if feasible, is equally applicable to all the platforms, and does not impact on the ranking of the platforms.



SPAR-SHAPED PLATFORM WITH EXTERNAL POWER UNITS 400 MWe (NET)

## 5.6 MOTIONS

Table 2.2.10 gives the calculated motions for the Tampa site. While these estimates do not allow for the damping effect of the moorings and are consequently believed to be conservative it can be seen that they are quite substantial for the shipshaped platforms, particularly in beam seas. Moreover, weathervaning will not necessarily reduce these motions as the platform will align itself with the current and the waves could conceivably act at right angle to the current.

The LMSC ship shaped platform, has a relatively small angle of deck submergence because of its limited freeboard. Consequently, in an environment with severe wave heights the main deck and the turbo generators could quite easily be submerged and the seawater inlets could emerge above waterlevel and draw air instead of water. This effect can be mitigated by increasing the depth and consequently the freeboard and also by proper design of the various water inlet. While these would add to the cost of the LMSC shipshaped platform, it has been assumed that the increases in structural cost discussed in Section 2.6.3 (a) in connection with an increase in strength modulus, would be adequate to satisfy also the requirement for increased freeboard.

Even with this improved freeboard, however, LMSC shipshaped platform will find its main source of application in benign environments, and would require further substantial modifications in order to be used in sites with very large wave heights.

## 5.7 SITE SENSITIVITY

The conclusions on this report apply to a site off Tampa, on the West Coast of Florida. Alternative sites under consideration by DOE are New Orleans and Puerto Rico and it was considered of interest to examine the potential effect on major platform systems of designing for these alternative sites.

The environmental characteristics at the three sites are as follows:

| | Puerto Rico | New Orleans | W. Coast Florida |
|---|---|---|---|
| Current Velocity (Extreme) (Kts) | 2.76 | 2.49 | 5 |
| Wind (Knots) | 92.8 | 100.3 | 113.8 |
| Sig. Wave Height (ft) | 44.2 | 58.1 | 45.8 |

The platforms are impacted by site conditions in the following areas:

1. Motions
2. CWP
3. Sea Water System
4. Structure
5. Station Keeping

### 1. Motions

Platform motions are impacted by wave height and energy. The effect of platform motions on the ship shaped platforms is discussed in Section 5.6. The effect of increased wave heights on the spar shaped platform is not expected to constitute a problem. Assuming that considerations of freeboard discussed in 5.6 are satisfied, the increased motions associated with increased wave heights will impact on the CWP design. This is discussed in the following subsection.

### 2. Cold Water Pipe

Wave induced motions have a direct influence on CWP stresses and thicknesses. CWP costs may be expected to increase, particularly for ship shaped platforms with increase in wave heights. The cost increase is not expected to be major, within the order of magnitudes which characterize this project. Engineering studies are however, required to quantify this increase.

### 3. Seawater Systems

The effect of site selection on seawater systems is believed to be quite small, this effect will not be further considered.

## 4. Structure

The principal effect of a change in extreme wave height, on the structural design of the spar, will be to increase the dynamic pressure head acting on the hull envelope. In the case of a passage from Tampa to New Orleans this will result in a cost increase in the order of 6%.

A more complex situation exists for the ship shapes. The loads on ships in a seaway are normally calculated by balancing the ship on a so called "standard wave", in which the wave height is a function of ships length. Using this standard approach the variations in wave height with deployment height would have no effect on the loads for which the structure would be designed.

It is reasonable to assume that some increase in wave load occurs with increasing severity of weather conditions. In order to properly quantify this effect the ship shaped platform would have to be mathematically balanced on irregular waves in a sea spectrum corresponding to conditions at the deployment site. Computer programs exist which are capable of calculating bending moments in such conditions. These programs have shown a good level of correlation between calculated and measured stresses and have an important role to play in the structural design of the platforms. Cost considerations however prevent their use in the present case.

Bending moment calculations carried out for the engineering studies in Section 2.6 show that the bending moments increased by about 10% with a 20% increase in waveheight and that the costs of the concrete structure increased by approximately 3%. Utilizing these very gross approximations the cost of the structures for the ship shaped platforms may be expected to increase by about 5% in passing from Tampa to New Orleans. Engineering analysis is however, required to obtain reliable figures.

No cost adjustment is required in passing from Tampa to Puerto Rico as the waveheights are virtually the same.

## 5. Station Keeping

Table 2.3.5 shows that mooring costs are lower for the spars than for the ships.

The station keeping costs bear a close relationship to mooring loads which in turn are a function of site conditions. These loads are lower for the spars than for the ships. In more benign environmental conditions, the mooring loads are reduced for all concepts and the system costs are correspondingly lower. This effect is particularly significant for the LMSC ship shaped fixed moor designs. The cost differential for the station keeping system, for an eight unit OTEC park at Tampa is $329m, whereas in New Orleans, with sharply reduced current velocities, the cost differential is reduced to $120m. For Puerto Rico this difference amounts to $160m.

## 5.8 IMPACT OF SENSITIVITY STUDIES ON PLATFORM RANKING

Section 4 has shown that the LMSC spar is the most cost effective concept, followed by the LMSC ship. In order to assess the impact of the sensitivity studies in Section 5, on the relative ranking of these concepts, the data in Table 4.5 should be corrected to allow for the factors discussed in Sections 5.2 through 5.7. Some of these effects cannot be quantified at this stage through lack of sufficient data, however the overall effect can be assessed by correcting the park acquisition costs to allow for CWP deployment from the top of the LMSC spar, and modifying station keeping and structural costs to reflect site changes to New Orleans and Puerto Rico.

This is shown in Table 5.1 for the two LMSC platforms.

| | New Orleans | | Puerto Rico | |
|---|---|---|---|---|
| | LMSC (Ship) | LMSC (Spar) | LMSC (Ship) | LMSC (Spar) |
| Park Acquisition Cost | 2890 | 2820 | 2911 | 2791 |
| Capital Investment Costs (Annualized @ 0.134) | 387 | 378 | 390 | 374 |
| Annual Operating Costs | 129 | 129 | 129 | 129 |
| TOTAL | 516 | 507 | 519 | 503 |
| Power Generated | 3267 | 3316 | 3267 | 3316 |
| Cost/MWe/Year | 0.1579 | 0.1529 | 0.1589 | 0.1517 |
| Ranking | 1.03 | 1 | 1.05 | 1 |

The cost differential between the two platforms has been reduced from 11% to 3% for New Orleans and 5% for Puerto Rico. This differential is well within the limits of accuracy of a study like the present one. Consequently, the ship shaped concept is considered to be a viable candidate for sites with benign environmental conditions.

# 6. SUMMARY OF CONCLUSIONS

1. The LMSC spar concept is the preferred concept for a commercial OTEC platform.
2. The LMSC spar concept should be modified to allow deployment of the CWP from the platform top.
3. The cost of an eight unit OTEC park, off the West Coast of Florida and utilizing this concept is estimated at $2918 millions.
4. The cost of the LMSC spar is $880 per kilowatt, excluding costs of Power Systems and Energy Transfer Systems.
5. The LMSC ship shape platform is a viable alternative in benign environmental conditions.

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TECHNICAL REPORT
7968-1

# Calculated CWP Seakeeping Loads For Four Candidate OTEC Platforms

by

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April 1979

Prepared Under
Value Engineering Purchase Order No. 57875

# INTRODUCTION

This report describes a study carried out by HYDRONAUTICS, Incorporated for Value Engineering and John J. McMullen under Value Engineering Purchase Order 57875. This study was designed to evaluate wave induced bending stresses in CWP's proposed for use with four commercial size OTEC platform designs currently being evaluated by McMullen. The results are to be used as one basis for determining the CWP wall thickness and weights required for each of these four candidate OTEC platforms.

This report describes the platform/CWP designs considered, the methods used in the analysis and the calculated results.

It should be noted that this study was restricted to seaway induced CWP bending stresses. Current induced stresses and other possible CWP loads and failure modes were not considered. Only one wave spectrum, the DOE defined hurricane spectrum for a proposed OTEC site off the West Coast of Florida, was considered. This spectrum is a Bretschneider two-parameter spectrum with a significant wave height of 45.8 feet and a period of maximum energy of 13.67 seconds.

## PLATFORM/CWP DESIGNS CONSIDERED

Data for four candidate platforms and associated CWP's, as provided by McMullen, are given in Tables 1 and 2. The details of platform geometry were obtained from drawings produced by Lockheed, Gibbs and Cox and Rosenblatt and provided by McMullen.

The geometry of the two ship platforms were complicated by the presence of a large number (10 for the Lockheed design, 16 for the Gibbs and Cox design) cold and warm water discharge pipes. These discharge pipes, because of their large diameters (up to 78 feet) and lengths (up to 400 feet) were considered likely to have a large effect on platform motions and CWP loads and were therefore considered in some detail in the analysis.

The geometry of the Lockheed spar is rather complex, the design consisting of a central cylindrical member surrounded by eight external modules. This design was somewhat idealized in the analysis, the external modules being treated as circular cylinders and all small external components being neglected.

The cold water pipes were all assumed to be made of light weight concrete, with joints of finite stiffness located at about 112 foot spacing. The CWP was specified to be attached to the platform through an attachment which provided no pitch or roll (angular) restraint but which provided full restraint in heave. For each platform, various CWP wall thicknesses were considered to determine the wall thickness required to achieve an acceptable maximum CWP bending stress.

## METHOD OF ANALYSIS

The methods used to calculate the seaway response of the various platform/CWP designs are described in detail in Reference 1. These methods consider the coupled, linear response of a rigid platform and a flexible CWP to regular and random, long-crested (uni-directional) waves. The non-linear (quadratic) CWP damping is treated by a method of equivalent linearization.

The methods can consider a wide range of CWP, platform and CWP/platform attachment geometries, including multiple joints of finite or zero stiffness in the CWP. The methods, as developed and described in Reference 1, do not include treatment of large appendages or discharge pipes such as used in the Lockheed and Gibbs and Cox ships. The platform program XOTEC (Reference 1) was therefore modified to include the effect of the discharge pipes which were expected to be large, particularly for beam seas.

The calculation of platform, CWP and discharge pipe hydrodynamic forces is described below.

### Platform Hydrodynamics

The platform hydrodynamic forces (wave exciting forces, added mass and damping) were estimated using methods appropriate to each platform.

The hydrodynamic forces acting on the two ship hulls were calculated using strip theory and the Frank close fit method, as described in Reference 2.

The hydrodynamic forces acting on the two spar platforms were calculated using methods such as described in Reference 3 and a body of available calculated results for various spar-type platforms. The Rosenblatt spar was treated as two right circular cylinder segments. The Lockheed spar was treated as 10 right circular cylinder segments plus a circular plate. This approach for the spars was validated by comparing calculated motions for the

Lockheed spar with recent model test data for this spar, Reference 4. Figure 1 indicates the good agreement between calculated and measured spar motions and hence confirms the general accuracy of the predicted hydrodynamic forces.

## CWP Hydrodynamics

The CWP hydrodynamic characteristics (wave exciting force, added mass and damping) were based on the results summarized in Reference 1. The added mass and quadratic damping coefficients were taken to be 1.0 and 1.3, respectively. An equivalent linearized damping coefficient based on this quadratic damping coefficient and an assumed amplitude of motion or velocity was used. The calculations were repeated or the results corrected when assumed and corrected amplitude did not match.

Current loads on the CWP and possible interactions between current and wave velocity fields were not considered.

## Discharge Pipe Hydrodynamics

The discharge pipe hydrodynamic characteristics were calculated using the same methods used for the CWP. The same added mass and damping coefficients (1.0 and 1.3) were used. The equivalent linearized damping coefficient was based on an estimated amplitude of lateral motion of 10 feet. The water within the discharge pipes was assumed to act as part of the platform mass.

The close longitudinal and lateral spacing of the discharge pipes for both the Lockheed and Gibbs and Cox ships will result in significant interactions and reductions in added mass and damping. It was estimated that the total effective added mass, damping and wave exciting force for all discharge pipes would be about one half of the sum of the values for all individual pipes and this value was used in all calculations.

## SELECTION OF CWP WALL THICKNESS

Calculations were made for two or more CWP wall thicknesses for each platform so that the appropriate wall thickness could be selected. The thicknesses chosen were based on values specified initially by McMullen and on initial calculations.

The allowable maximum bending stress specified by McMullen was 2250 psi. This stress was assumed to correspond to the maximum stress expected at any point on the CWP during a long duration hurricane of the specified energy spectrum. It was estimated that the maximum stress occurring during such a hurricane might, when uncertainties in spectral shape were considered, approach four times the largest rms stress and it was proposed that the wall thickness selected be that value yielding a maximum rms stress of 542 psi (2250/4). The resulting wall thicknesses for each platform are:

| | | |
|---|---|---|
| Lockheed Spar | 1.75 | Feet |
| Rosenblatt Spar | 1.15 | Feet |
| Lockheed Ship | 1.8 | Feet |
| Gibbs and Cox Ship | 1.0 | Feet |

## DISCUSSION OF RESULTS

A summary of calculated CWP maximum stresses is given in Table 3. A summary of calculated platform C.G. motions is given, for 1.5 foot wall thickness CWP's, in Table 4; platform motions generally do not vary significantly with CWP wall thickness. Calculated wave induced bending stresses are given, for the four platforms, in Figures 2-5. Figures 6 and 7 show variations of bending stress along the CWP for spar and ship platforms, respectively.

Figure 2 indicates that the assumed maximum stress of four times the rms stress equals the allowable stress of 2250 psi with a CWP wall thickness of about 1.75 feet for the Lockheed spar. Figure 3 indicates that assumed maximum and allowable stresses for the Rosenblatt spar are equal for a CWP wall thickness of about 1.15 feet. The much smaller wall thickness for the Rosenblatt spar was felt to be due to the larger diameter (101 feet versus 73 feet). An additional calculation was made for the Rosenblatt spar with a 73 foot I.D., one foot wall thickness CWP; this produced a maximum rms stress of 1380 psi or expected maximum stress of 5520 psi, far greater than the allowable stress. This large increase in stress was due both to the decreased diameter and to the fact that with the smaller diameter the CWP fifth natural modal frequency and the frequency for maximum wave energy (0.44 and 0.46 radians per second, respectively) were nearly equal, maximizing CWP responses and stresses.

Due to the short time available for this study, it was only possible to make calculations for one case for the Lockheed ship with discharge pipes, as shown in Figure 4. All calculations shown in Figure 5 are for the ship platform with discharge pipes. The Figure 4 comparison case, with a two feet CWP wall thickness, indicates that maximum stresses in head and beam seas are very similar with and without discharge pipes. There is some evidence that this similarity may be the result of the specific CWP geometry considered; further investigation of the influence of the discharge pipes is needed.

Figure 4 indicates the assumed maximum and allowable stresses for the Lockheed ship in head seas are equal for a CWP wall thickness of about 1.85 feet. In beam seas a wall thickness of perhaps 2.2 feet will be required. It is generally assumed that ship-type platforms must be kept generally aligned with the direction of maximum wave energy. It is estimated that with reasonable control of ship heading, an appropriate wall thickness would be about 2.0 feet.

Table 1 and Figure 5 indicates the rather complex situation with the Gibbs and Cox ship. The bending stresses are significantly higher in head seas than in beam seas, and the stresses are somewhat larger with a 2.0 foot CWP wall thickness than with a 1.5 foot wall thickness. Time did not permit additional calculations for a one foot CWP wall thickness, which is estimated to be approximately the wall thickness for which maximum and allowable stresses will be equal in beam seas. In head seas a wall thickness greater than two feet will be required.

The unusual results for the Gibbs and Cox ship appear to be due to the unusual geometry of the ship hull and discharge pipes and the resulting matching of the ship and CWP natural frequencies and wave peak energy frequency. Further study of this platform and the effect of the discharge pipes is clearly needed.

## CONCLUSIONS

Based on the very limited study, several conclusions seem worthy of note; including:

1. The CWP wall thicknesses indicated for the spar platforms are less than those indicated for the ship platforms, a result that is not surprising in view of the smaller motions and deeper draft of the spars.
2. The stiffness of the CWP's considered is determined primarily by the joint stiffness and CWP length, and hence CWP bending stresses of these CWP's will generally increase rapidly with decreasing CWP diameter.
3. For all platforms, except the Gibbs and Cox ship, CWP stress is generally inversely proportional to CWP wall thickness.
4. The predicted results for the Gibbs and Cox ship, particularly the large stresses in head seas compared with beam seas, are surprising and warrant further study. These results appear to be due primarily to the 16 large discharge pipes used.

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## TABLE 1 PLATFORM CHARACTERISTICS

| Platform Characteristics | Lockheed Ship | Gibbs and Cox Ship | Lockheed Spar | Rosenblatt Spar |
|---|---|---|---|---|
| Displacement - L. T. | 254,000 | 310,000 | 251,000 | 808,000 |
| Length (Diameter) Ft. | 689 | 620 | 33 | 119.25 |
| Beam (Diameter ) Ft. | 190 | 300 | 33 | 119.25 |
| Draft - Feet | 92 | 45 | 366 | 697 |
| KG - Ft. | 53.5 | 68 | 134.5 | 293 |
| KB- Ft. | 48 | 23.5 | 146.6 | 325 |
| Gyradius - Roll - Ft. | 61.2 | 105 | 268 | 420 |
| Gyradius - Pitch - Ft. | 172.2 | 155 | 268 | 420 |
| GM - Roll - Ft. | 23.6 | 84 | 12.1 | 32 |
| GM - Pitch - Ft. | 767.5 | 505.5 | 12.1 | 32 |

## TABLE 2 CWP CHARACTERISTICS

| CWP Characteristic | Lockheed Ship | Gibbs and Cox Ship | Lockheed Spar | Rosenblatt Spar |
|---|---|---|---|---|
| Inside Diameter - Ft. | 73 | 100 | 73 | 101 |
| Length - Ft. | 2947 | 2955 | 2721 | 2339 |
| Nominal Wall Thickness - Ft. | 1.5 | 1.0 | 1.5 | 1.0 |

Concrete Density -85 pounds per cubic foot

Concrete Modulus of Elasticity -3 x $10^6$ psi

Joint Stiffness -9.5 x $10^{10}$ pound-feet per radian

## TABLE 3

## TABULATION OF MAXIMUM CALCULATED STRESSES

| Platform | CWP Wall Thickness-Ft. | Maximum Stress - PSI | |
|---|---|---|---|
| | | RMS | 4 RMS |
| Lockheed Spar | 1.0 | 1050 | 4200 |
| | 1.5 | 730 | 2930 |
| | 2.0 | 400 | 1590 |
| Rosenblatt Spar | 1.0 | 630 | 2520 |
| | 1.5 | 430 | 1720 |
| | 1.0 (ID = 73ft) | 1380 | 5520 |
| Lockheed Ship No Discharge Pipes | 1.5 (head) | 770 | 3090 |
| | 1.5 (beam) | 1400 | 5600 |
| | 2.0 (head) | 480 | 1920 |
| | 2.0 (beam) | 780 | 3110 |
| Lockheed Ship With Discharge Pipes | 2.0 (head) | 500 | 2000 |
| | 2.0 (beam) | 830 | 3320 |
| Gibbs & Cox With Discharge Pipes | 1.5 (head) | 1020 | 4100 |
| | 1.5 (beam) | 490 | 1940 |
| | 2.0 (head) | 1120 | 4480 |
| | 2.0 (beam) | 540 | 2160 |

## TABLE 4

## TABULATION OF CALCULATED PLATFORM MOTIONS AT C.G. FOR 1.5 FOOT CWP WALL THICKNESS

| Motion | RMS MOTION AMPLITUDE, FEET OR DEGREES | | | |
|---|---|---|---|---|
| | Lockheed Spar | Rosenblatt Spar | Lockheed Ship | G & C SHP |
| HEAD SEAS | | | | |
| Surge-Ft. | 2.7 | 1.8 | 3.8 | 1.3 |
| Heave-Ft. | 2.3 | | 5.2 | 4.8 |
| Pitch-Deg. | 0.2 | 0.7 | 2.3 | 1.8 |
| BEAM SEAS | | | | |
| Sway-Ft. | - | - | 6.5 | 3.6 |
| Heave-Ft. | - | - | 13.4 | 8.7 |
| Roll-Deg. | - | - | 7.7 | 2.7 |

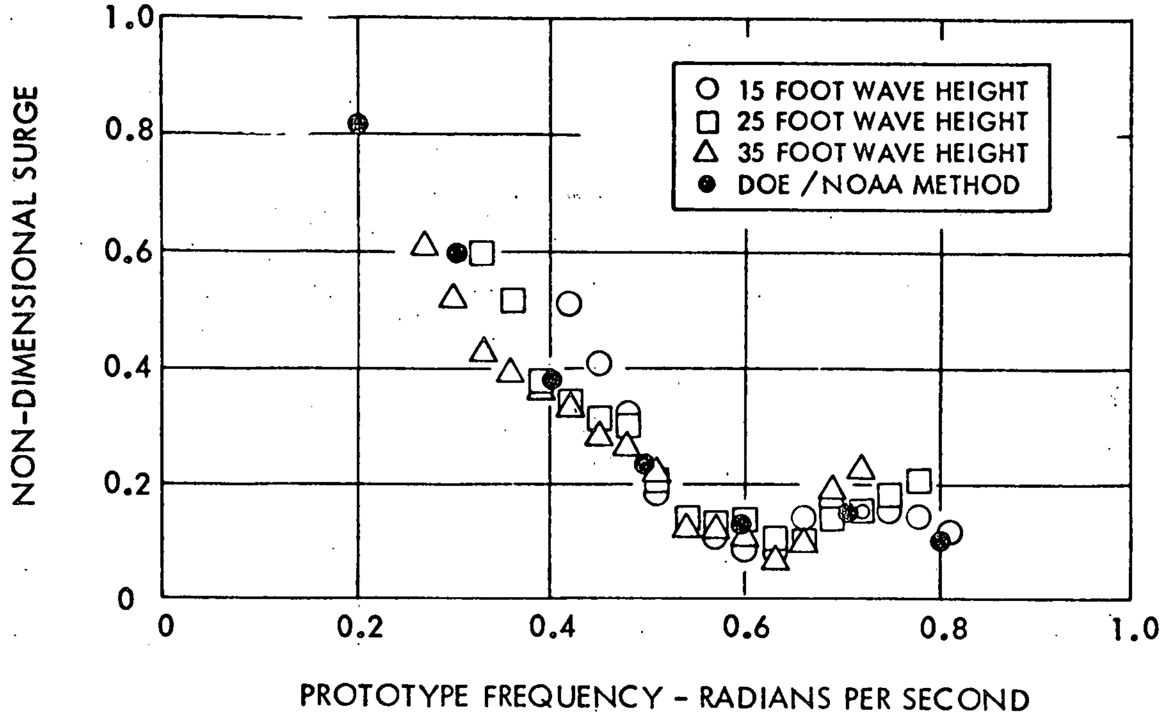


FIGURE Ia - COMPARISON OF CALCULATED AND MEASURED SURGE - SPAR ALONE

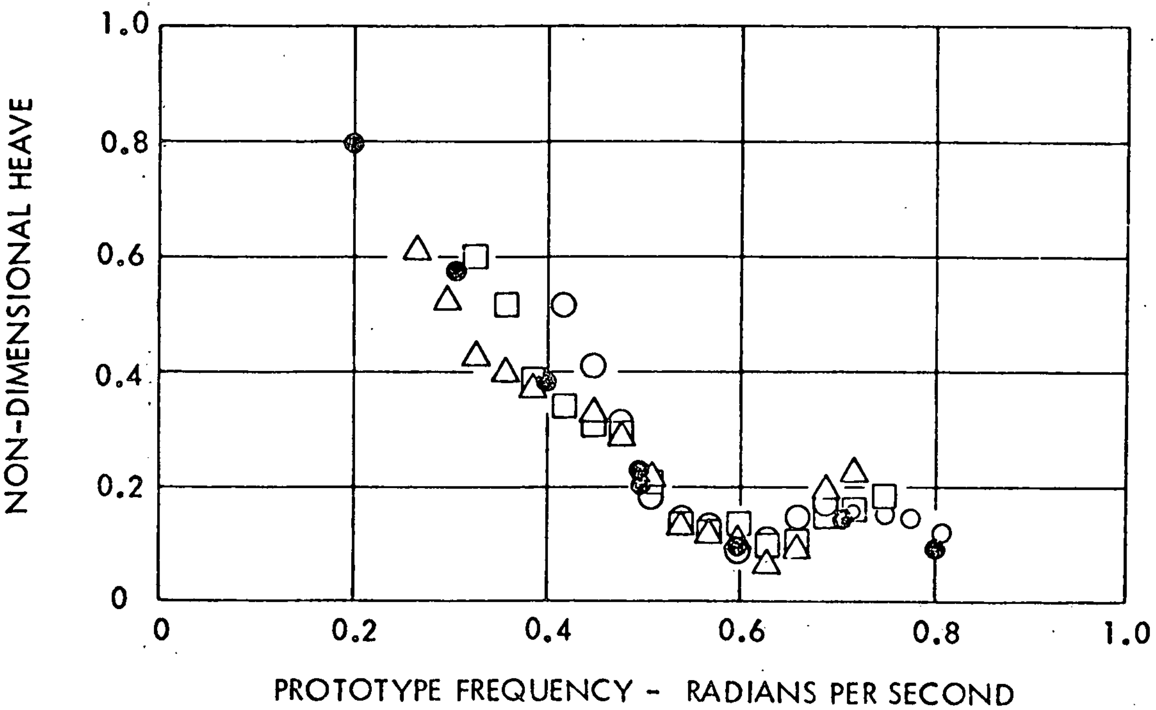


FIGURE Ib - COMPARISON OF CALCULATED AND MEASURED HEAVE - SPAR ALONE

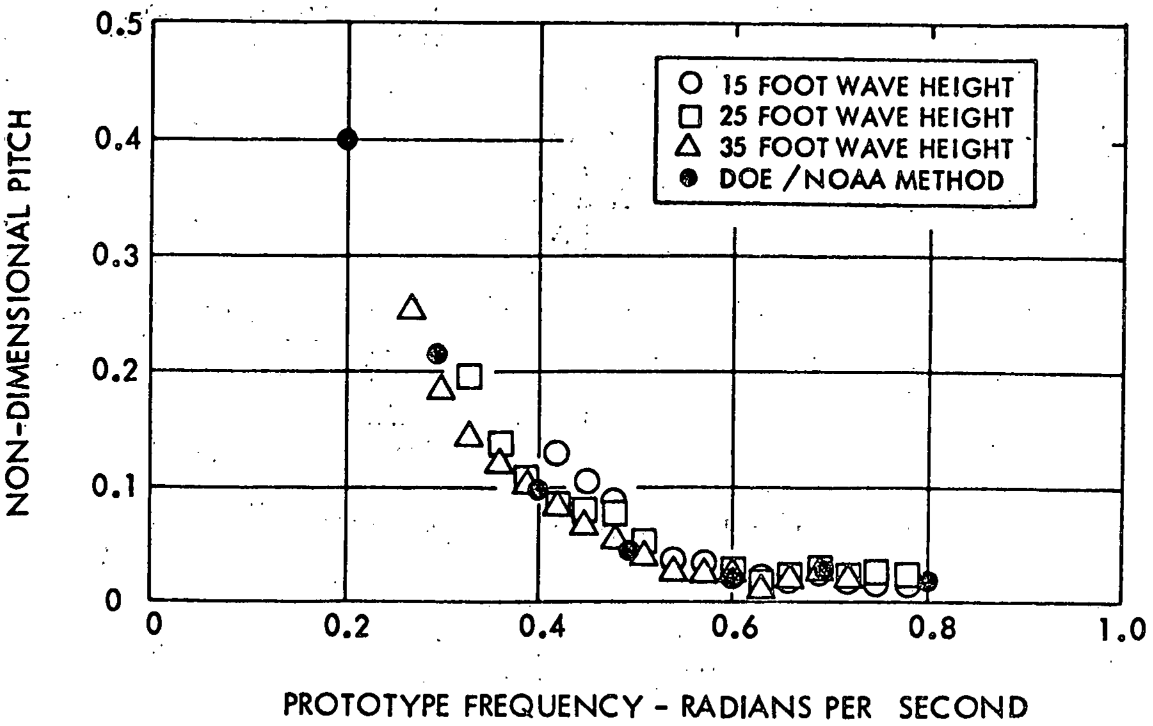


FIGURE Ic - COMPARISON OF CALCULATED AND MEASURED PITCH - SPAR ALONE

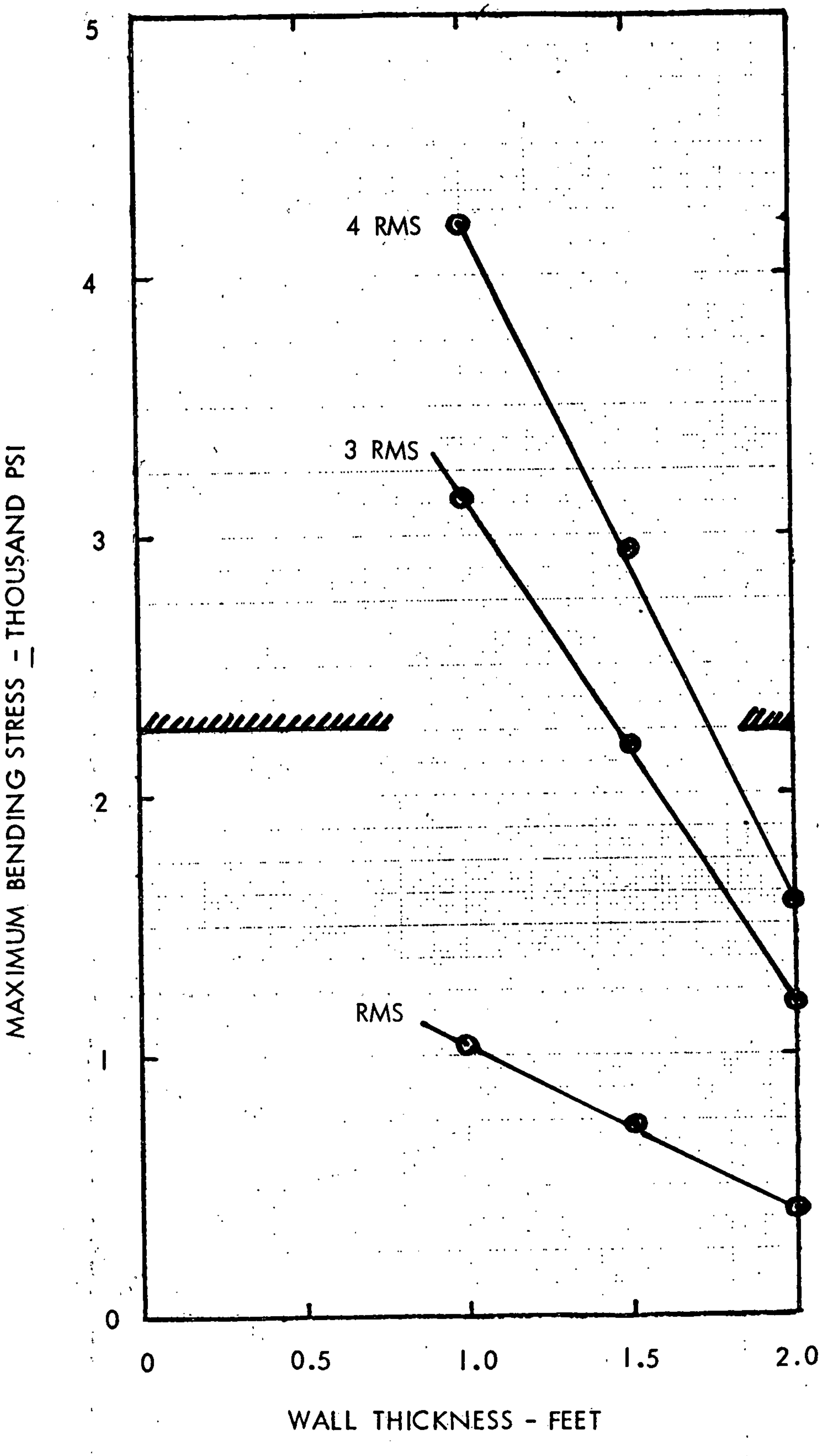


FIGURE - 2 - CALCULATED MAXIMUM WAVE INDUCED BENDING STRESSES - LOCKHEED SPAR

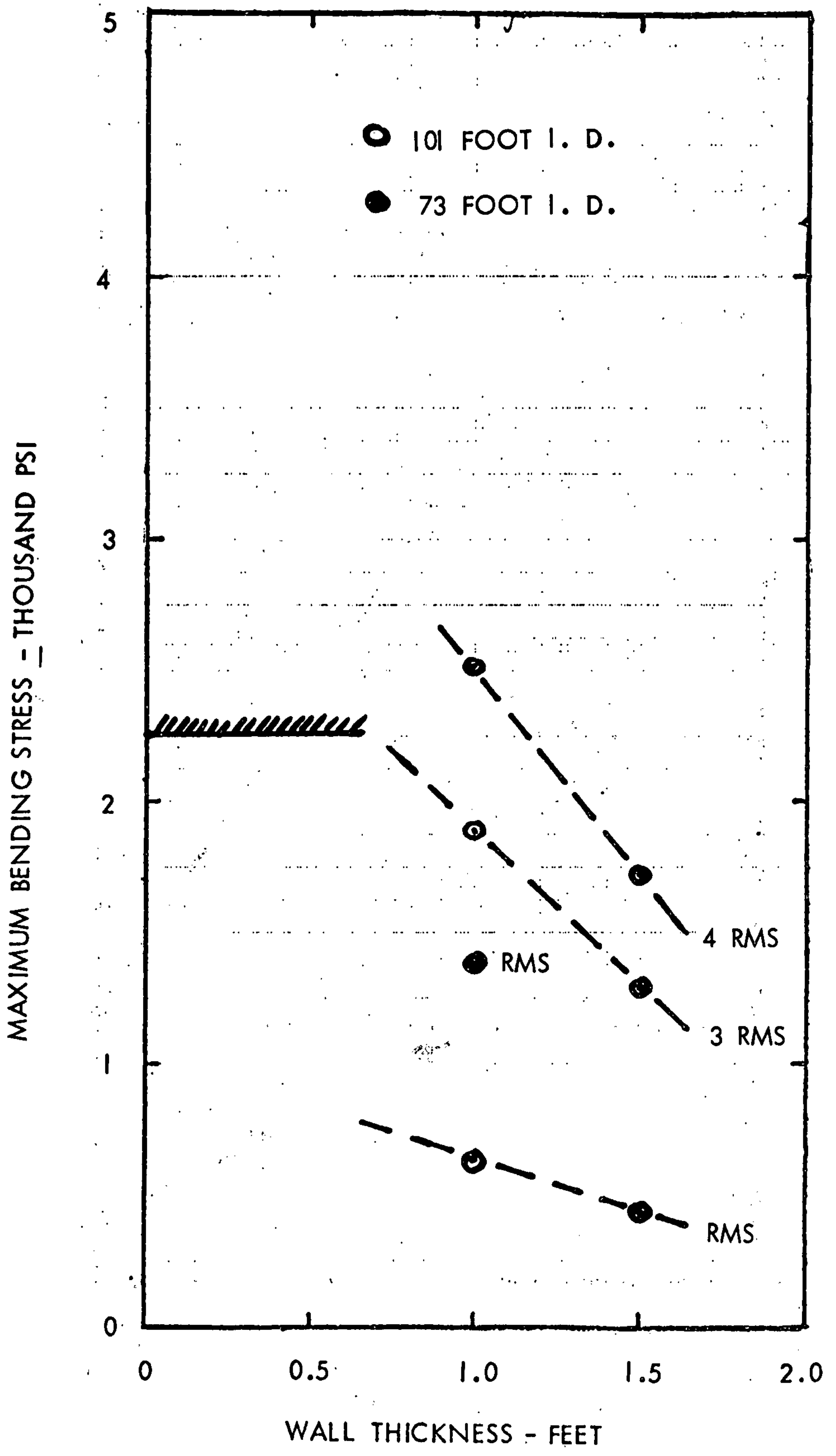


FIGURE - 3 - CALCULATED MAXIMUM WAVE INDUCED BENDING STRESSES - ROSENBLATT SPAR

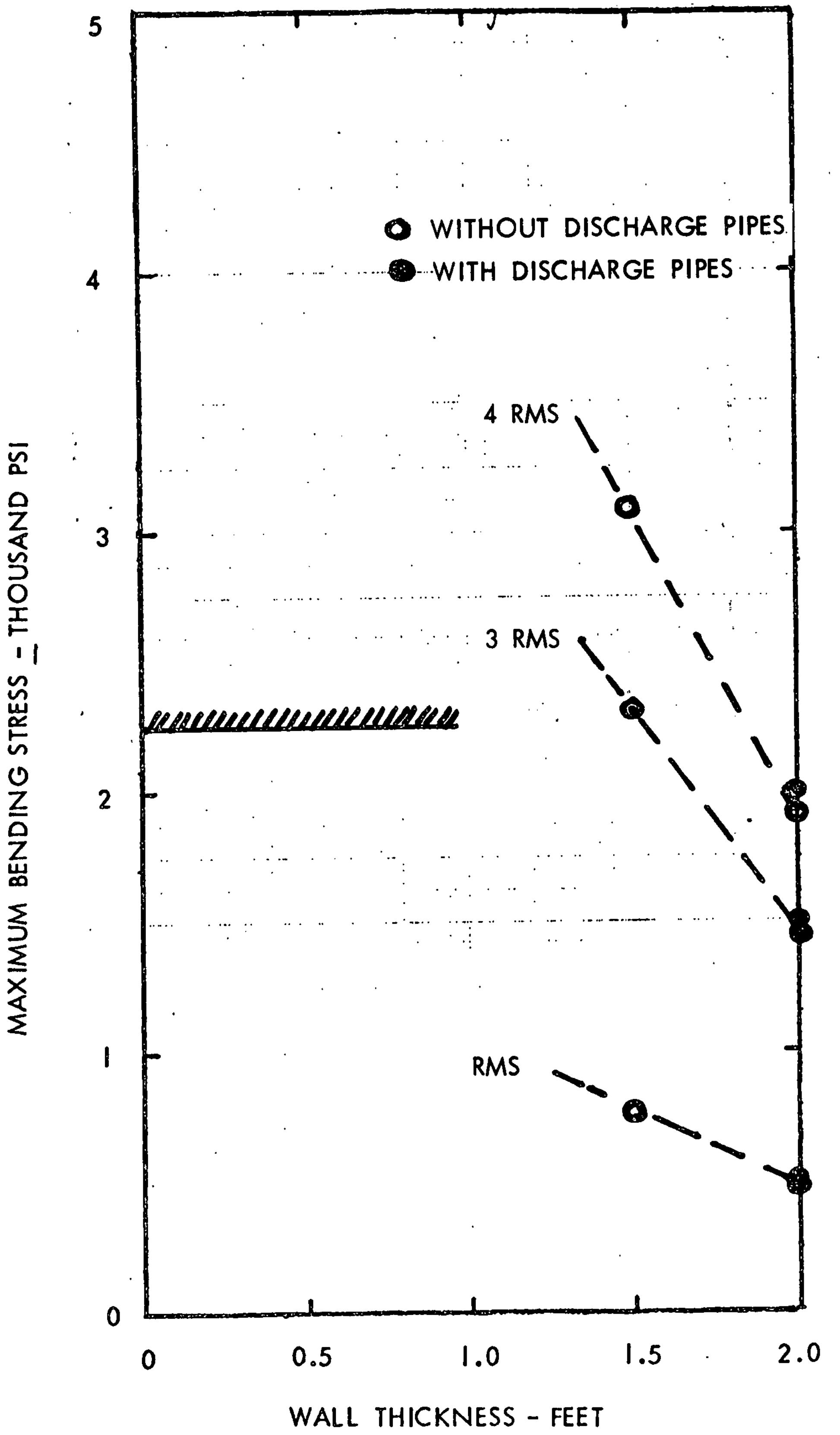


FIGURE - 4 - CALCULATED MAXIMUM WAVE INDUCED BENDING STRESSES - LOCKHEED SHIP

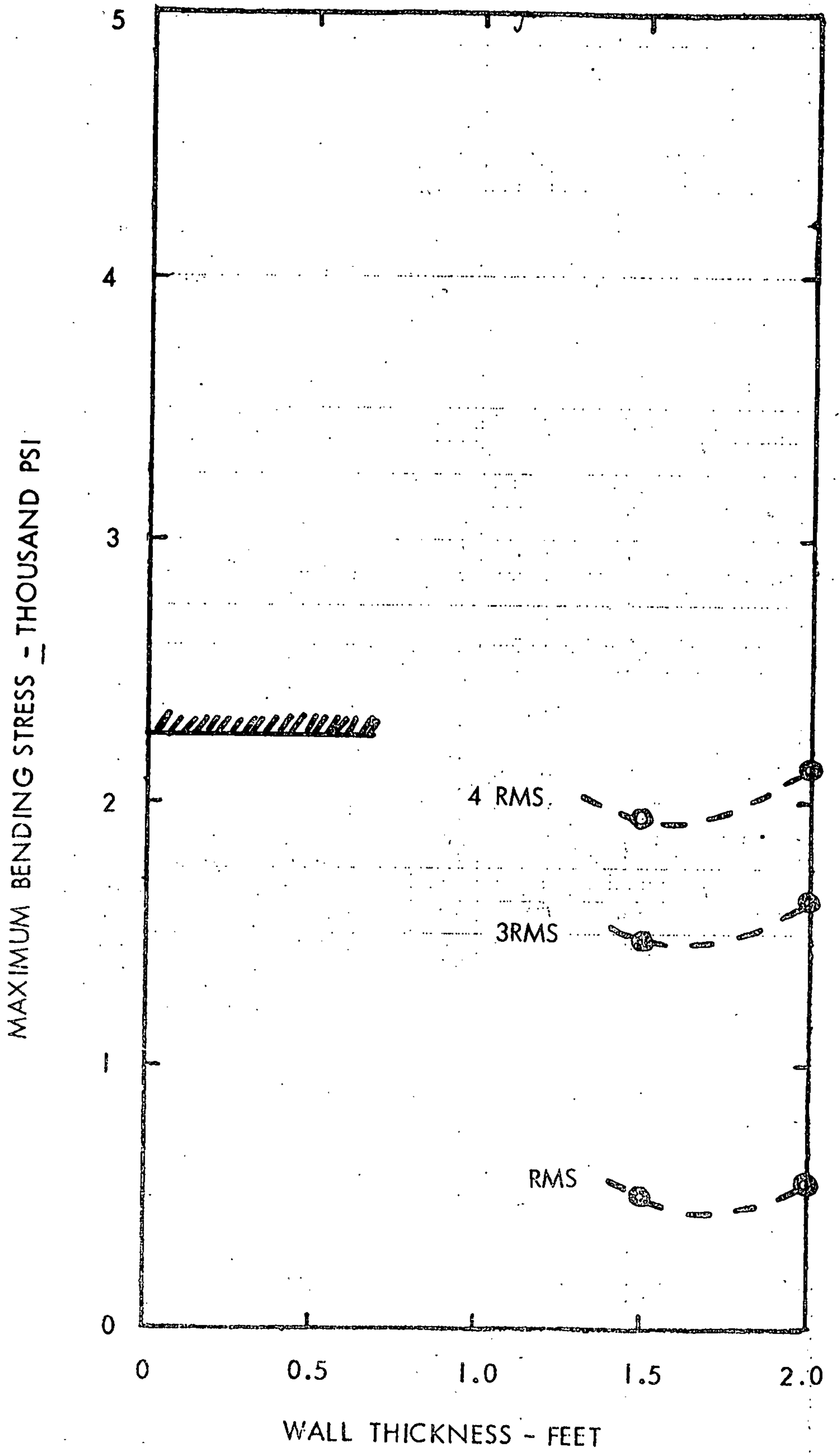


FIGURE - 5 - CALCULATED MAXIMUM WAVE INDUCED BENDING STRESSES - GIBBS AND COX SHIP

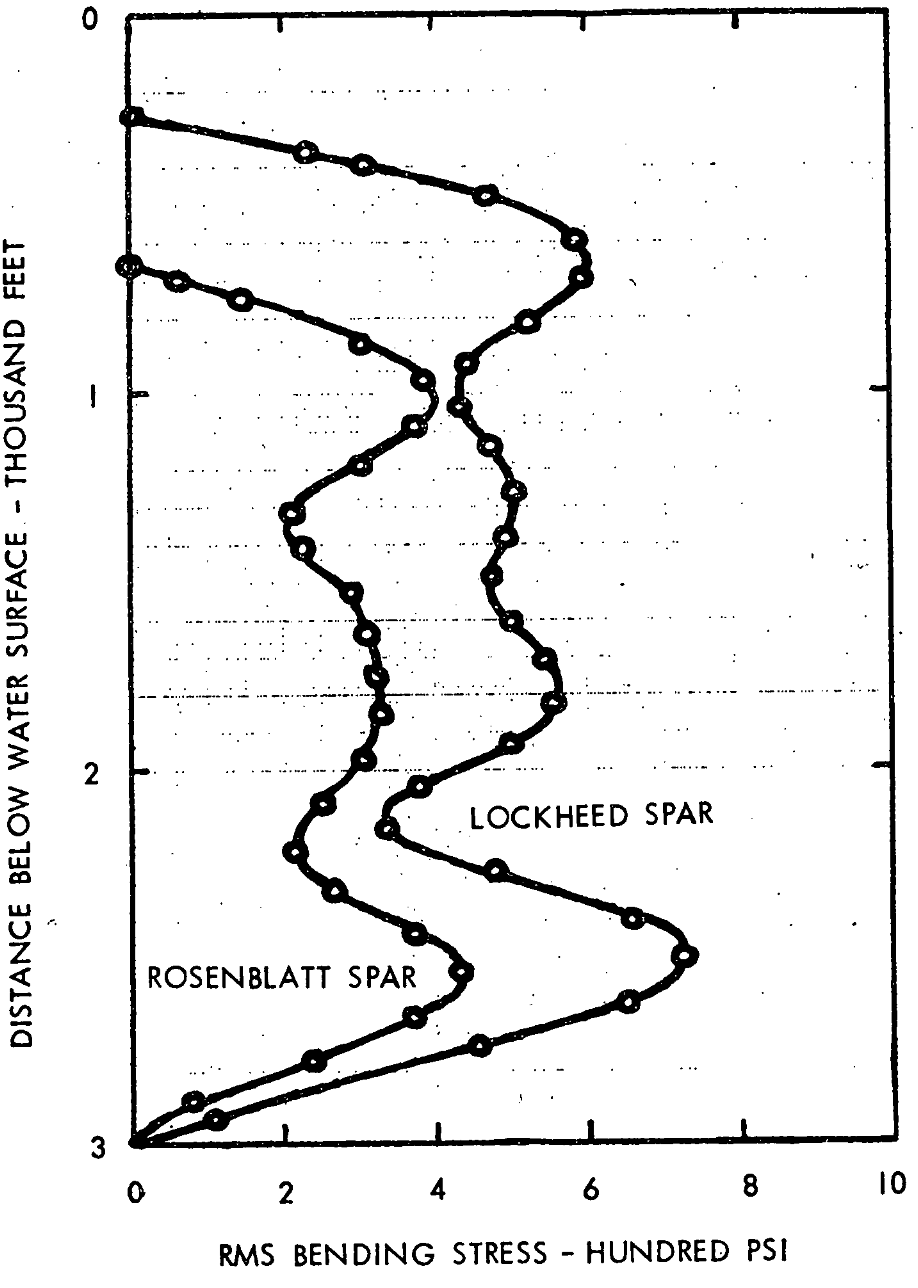


FIGURE -6- CALCULATED VARIATION OF BENDING STRESS WITH DEPTH - 1.5 FOOT CWP WALL THICKNESS

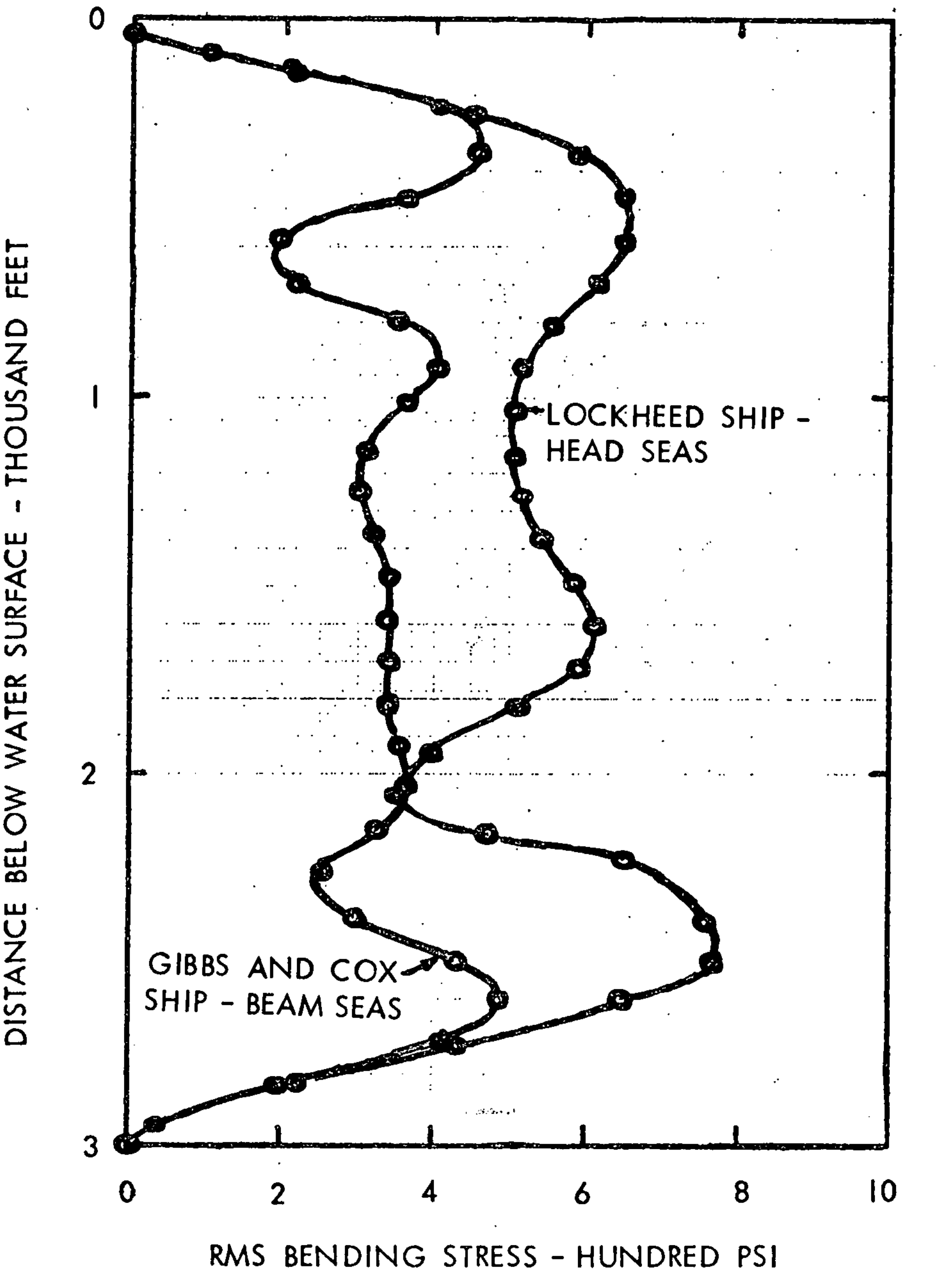


FIGURE - 7 - CALCULATED VARIATION OF BENDING STRESS WITH DEPTH - 1.5 FOOT CWP WALL THICKNESS

# APPENDIX B

# OCEAN THERMAL ENERGY CONVERSION
TOP LEVEL SPECIFICATION

# TABLE OF CONTENTS

2. MISSION DEFINITION

3. GENERAL REQUIREMENTS

4. HULL STRUCTURE

5. POSITION CONTROL SYSTEM

TABLE OF CONTENTS (CONTINUED)

## 1. INTRODUCTION

The intent of this document is to present system performance and design requirements which shall govern the design and construction of an Ocean Thermal Energy Conversion (OTEC) Commercial Plant for the U.S. Department of Energy (DOE).

This document covers the Ocean System portion of the OTEC plant. The Power System and the transmission system are not covered by this specification. Basic interfaces are addressed, however.

Two (2) hull forms have been specified by DOE for the Ocean System, a submerged spar and a ship shape, configuration. This TLS is applicable to both hull forms unless otherwise specifically noted.

## 2. MISSION DEFINITION

### 2.1 Primary Mission

The OTEC Commercial Plant shall be capable of generating 400 MWe of net electric power and shall transmit the power thus generated to shoreside electrical grids by cable. The Plant shall demonstrate the technical feasibility of the Ocean, Power and Transmission Systems and shall demonstrate that the plant can generate and transmit electrical power to shoreside grids at a cost and with a reliability which is competitive with existing generating concepts.

### 2.2 Contingent Tasks

The Plant shall be capable of satisfying the following contingent tasks:

- Training of plant operating personnel.
- Research and development related to ocean thermal energy conversion.
- Test and evaluation of developmental equipment related to power generation and transmission to the extent that such equipment can be installed, checked out and operated without degrading overall plant reliability, and that such installation can be accomplished on site.
- Oceanographic and hydrographic research including data gathering, sample analysis and other activities which require limited personnel and specialized equipment.

As contingent tasks, the above shall be accomplished without degrading the primary mission of the Plant in any way.

### 2.3 Platform Life

The OTEC Commercial Plant and all of its related subsystems shall have a life of 40 years, measured from the date of deployment. The ability to extend this life by repair and replacement shall be considered as an optional feature, but not as a primary design requirement.

### 2.4 Availability

The goal for overall OTEC Commercial Plant availability is 90 percent over a 40 year life, including considerations of plant down time for maintenance and repair, and shutdown during extreme environmental events. The plant shall be able to operate in sea state corresponding to those expected at the deployment site 95 percent of the time over a typical 40 year span.

## 2.5 Location of Sites

The OTEC plant shall be designed for optimum efficiency for the selected site conditions. Four locations have been identified as potential sites for an OTEC Plant: Keahole Point, Hawaii; Punta Tuna, Puerto Rico; New Orleans, Louisiana; West Coast of Florida:

Table 1 summarizes the environmental characteristics of the above sites.

## 2.6 Maintenance

The Ocean System will remain on site throughout its useful life and will not return to drydock for maintenance and repair except in the event of major damage.

## 2.7 Operation

The OTEC Commercial Plant shall be operated by rotating crews similar to the concepts now in use with offshore platforms. The Plant shall function 24 hours a day, with crews rotating in 12 hour shifts. Maintenance and the operation of functions such as provisioning, administration, shops, etc., shall be during a single shift, with reduced crews operating the Power System, Seawater System and essential platform functions during the other shift.

## 2.8 Logistics

Platform operation shall be supported by a shoreside installation which shall provide facilities for maintenance and repair, loading piers for supply vessels, storage capabilities for spares and docking facilities for detachable power modules.

Maintenance crews will be based on the shoreside facility. Operating crews will be based on the platforms.

## TABLE 1

## SUMMARY OF SITE ENVIRONMENTAL CHARACTERISTICS

| SITE | HAWAII | PUERTO RICO | NEW ORLEANS | W.COAST FLORIDA |
|---|---|---|---|---|
| Water Depth, Ft. | 3150 | 4000 | 4650 | 4592 |
| Depth for 36$^{o}$ ΔT: | | | | |
| Max. ft. | 3280 | 2790 | 4650(*) | 4592(**) |
| Min. ft. | 1560 | 2050 | 1560 | 1476 |
| Current Velocities: | | | | |
| Extrme, Kts. | 2.18 | 2.76 | 2.49 | 5.0 |
| Normal, Kts. | 1.13 | 1.21 | 1.17 | 2.5 |
| 100 Yr Return Period: | | | | |
| Max. Wind, Kts. | 65.7 | 92.8 | 100.3 | 113.8 |
| Gusts, Kts. | 95.2 | 134.6 | 145.4 | 165.0 |
| Sign. Wave Ht. Ft. | 35.9 | 44.2 | 58.1 | 45.8 |
| Avg. Monthly Exceedances: | | | | |
| 20 kt wind | 1.09 | 3.37 | 26.42 | 12.86 |
| 32 kt wind | 0.01 | 0.16 | 2.20 | 0.97 |
| 44 kt wind | 0.01 | - | 0.26 | 0.10 |
| 11 ft-sig. wave ht. | 1.71 | 0.15 | 2.02 | 9.84 |
| 16 ft sig. wave ht. | 0.51 | 0.05 | 0.46 | 0.13 |
| 19 ft sig. wave ht. | 0.31 | 0.02 | 0.24 | 0.03 |

(*) 36$^{o}$F ΔT not achieved during January, February, March, April

(**) 36$^{o}$F ΔT not achieved during January, February, March

# 3. GENERAL REQUIREMENTS

## 3.1 Platform Configurations

The platform configurations listed below shall be considered for the OTEC Commercial Plants:

1. Ship shape
2. Spar

The descriptions in Sections 3.1.1 and 3.1.2 are presented as indicative of arrangements studied by DOE and believed to be suitable for this application. They are shown for guidance only and may be modified by the contractor as required to achieve the platform's mission, to maximize cost benefits or to enhance the platforms reliability and suitability.

### 3.1.1 Spar

The platform consists of a central watertight core, a base construction and eight detachable power modules, arranged outside the platform.

The core contains the power conditioning equipment, the platform support services, outfit and furnishings. A trunked opening at the centerline of the core allows shipping and deployment of the cold water pipe.

The base construction is attached to the bottom of the core; it provides support for the cold water pipes and serves as a manifold for the distribution of cold water to the power modules. The construction also provides a connection for the lower end of the power modules.

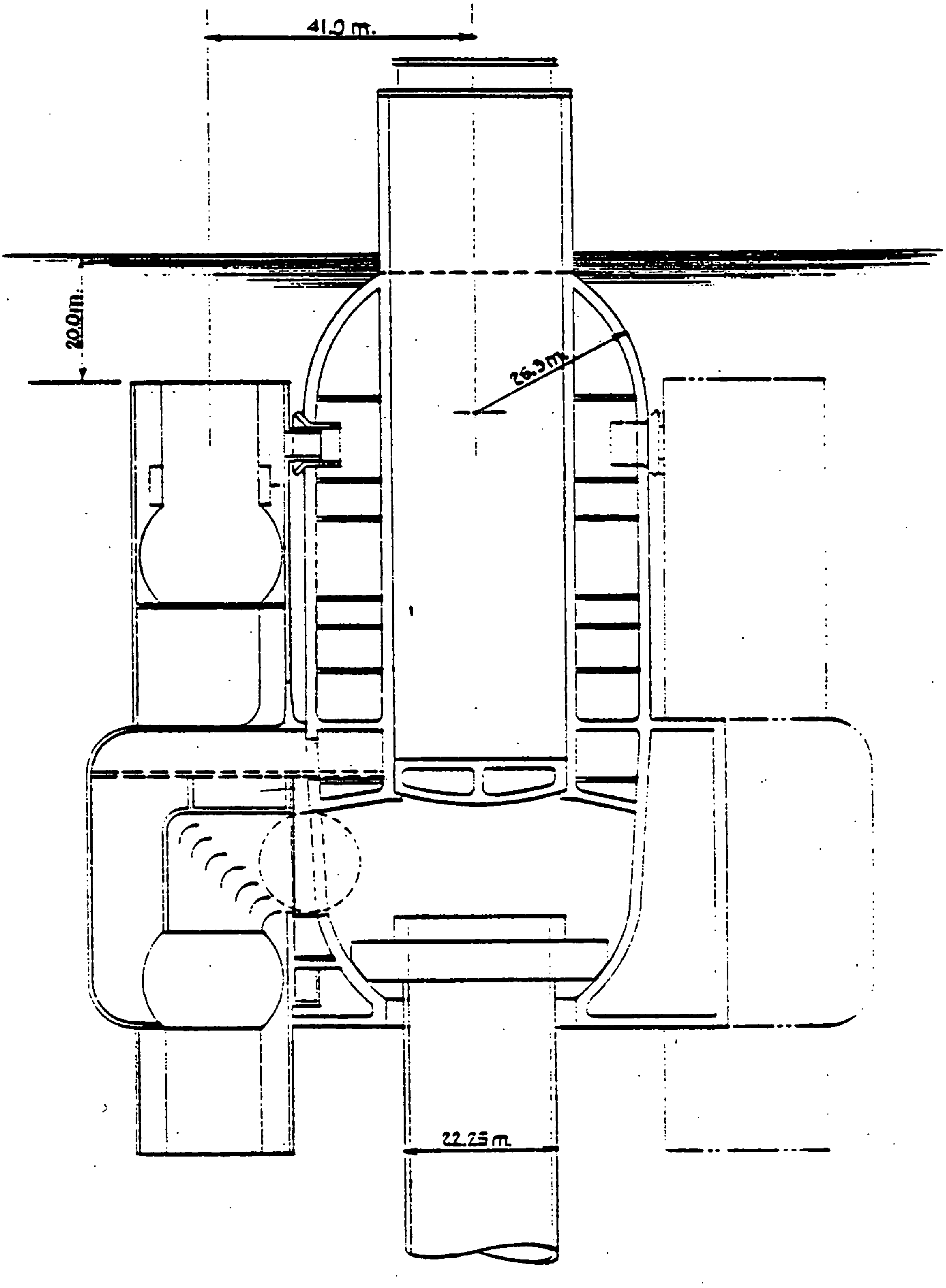
The power modules contain the seawater pumps, heat exchangers, piping, turbine generators and ammonia valves and pumps. Each power module has a generating capacity of 50 MWe.

The central core, the base construction and the power modules are totally submerged. The centerline trunk, in the core, is led above the waterline. A platform and deckhouse with accommodation for the crew is arranged on top of the trunk sufficiently high to provide protection against the seas.

Figure 1 shows a conceptual arrangement of the spar.

### 3.1.2 Ship Shape

The platform consists of a central displacement hull, T shaped in cross section and wall sided throughout.



SPAR-SHAPED PLATFORM WITH
EXTERNAL POWER UNITS
400 MWe (NET)

FIGURE 1

External heat exchangers buoyant in construction and detachable for repair or major maintenance are arranged on both sides of the hull. The evaporators located at the ends of the vessel take suction directly from the surrounding water and discharge into warm water plenums and down through discharge pipes. The condensers take water from a cold water plenum and discharge outboard and down through discharge pipes.

The turbine and generators are located in enclosures on the main deck.

The space between the Second and Main Decks is utilized for ammonia storage, electrical transmission and switchgear, electrical distribution equipment, auxiliary machinery, chlorinators and nitrogen and $CO_2$ storage. Wing wall spaces outboard of the main hull will be used for piping and cable runs. Ballast tanks are located at the ends of the vessel and between the warm and cold water plenums, forward and aft. The midship outboard tank spaces will be utilized for diesel fuel or ballast, as required.

Figure 2 shows a conceptual arrangement of the ship shape.

## 3.2 Construction

The Ocean System shall be fabricated at existing or modified U.S. facilities or in a new facility located on U.S. territory. The hull and major systems may be constructed as a unit or as a series of modules to be joined afloat, depending on the size and configuration of the platform, and economic considerations. Construction of eight (8) identical platforms is envisioned for a 3200 KW Energy Park.

## 3.3 Deployment

The platforms shall be deployed to the operating site by tugs, and shall be designed so as to be capable of being towed.

## 3.4 Licenses and Regulations

The OTEC Commercial Plant shall meet all regulations and satisfy all licensing requirements currently applicable to offshore platforms and power plants of similar size and capacity. Where the scope of such regulations does not address the OTEC Ocean Systems, their intent shall be met pending modification to the regulations. Applicable regulatory bodies and their areas of responsibility include but are not limited to the following:

- American Bureau of Shipping (ABS)
- United States Coast Guard (USCG)
- United States Public Health Service (USPHS)
- Federal Communications Commission (FCC)
- ASHRAE Standard 26-63 (ANSI B 59.1)
- Federal Aviation Authority (FAA), "Helicopter Design Guide".
- Standard Specification for Merchant Ship Construction, U.S. Department of Commerce, Maritime Administration
- Hydraulic Institute Standards
- Occupational Safety and Health Administration (OSHA)

## 3.5 Technology Limits

The OTEC Commercial Plant shall reflect the use of state-of-the-art technology as existing at the time that a construction contract is signed. Systems which are judged to exceed the state-of-the-art shall be redesigned and modified to obtain compliance with this requirement.

## 3.6 Safety

The design, construction and operation of the Plant shall reflect considerations of safety throughout. All applicable safety codes and standards shall be implemented, including OSHA, Coast Guard, and National Fire Protection Association. Special attention shall be directed towards the potential safety hazards associated with ammonia vapor.

## 3.7 Stability

Subdivision and stability shall be adequate to ensure survival of the platform after any of the following events:

1. Flooding of any two compartments.
2. Damage penetration in accordance with USCG criteria but with vertical extent of damage not exceeding the depth of the largest ship liable to collide with the platforms.
3. Side damage to an extent established by a collision analysis, based on probable collision energy levels and on the capability of the structure to absorb these levels.
4. Damage scenarios such as loss of CWP, mooring or other contingencies.

Survival shall mean that adequate buoyancy and stability remains to permit repairs to be carried out on site or to make possible the removal of the platform to a repair location.

## 3.8 Noise and Vibration

Noise and vibration producing equipment shall be resiliently mounted or isolated to minimize degradation of working and living conditions in nearby manned compartments. Special attention shall be directed towards noise reduction in living, recreation, and control spaces.

## 3.9 Motions

Maximum permissible motions shall be established on the basis of a motions analysis and shall meet the following criteria:

### 3.9.1 Motion Limits for Equipment Operability

At this time, no definitive motion limits have been identified for operability or survivability of the Power System or Seawater System.

Good design practice for rotating machinery suggests that accelerations normal to the axis of rotation be limited to 0.5 "g" while accelerations parallel to the axis of rotation be limited to 0.25 "G" unless special provisions are incorporated in the design of bearing and shafting. Moreover the maximum motions shall be checked to ensure that performance deterioration or mechanical damage does not result from such factors as emergence of sea water inlets or insufficient clearance of CWP/platform interface, or similar.

### 3.2.9 Motion Limits for Riser Cable

The locus of limiting motions (including both hull response to waves and positionkeeping watchcircle) shall not exceed limits to be established by the cable manufacturers based on cable mechanical strength limitations.

### 3.9.3 Motion Limits for Personnel Comfort

In order to ensure personnel comfort and performance, platform accelerations in way of living or working areas shall not exceed the tolerable motion spectrum in SNAME Technical Research Bulletin 1-32 when deployed in the environment defined in Table 1. These limiting motions shall not be exceeded over 95 percent of the life of the system.

## 4. HULL STRUCTURE

### 4.1 General

The platform structure shall be designed to withstand the overall and local loads imposed during construction, deployment and operation at the specified operating site. Design loads and safety factors shall reflect the intent of American Bureau of Shipping and U.S. Coast Guard regulations applicable to offshore platforms. If concrete or other materials are used which do not exhibit a well-defined yield point or for which properties vary, special consideration shall be given to these areas when developing safety factors.

### 4.2 Materials

The primary structure of the OTEC platform shall be steel, reinforced concrete or a composite of these materials. For the purposes of this study, "steel" includes all commercial grades of mild and high tensile or notch tough steel defined in the applicable Rules of the American Bureau of Shipping. "Reinforced concrete" includes combinations of cement, sand, aggregate, water, additives, and reinforcing bars currently used on large offshore structures.

### 4.3 Design Loads

In addition to the applicable ABS and USCG structural criteria, the following shall be used for guidance.

Norske Veritas Rules for Offshore Vessels
American Concrete Institute
Federation Internationale de la Precontrainte (FIT)

Overall hull design of the ship shall reflect the worst of the following conditions:

a) Static balance on a wave equal to the ship's length and depth in accordance with ABS rules.

b) Maximum bending moment resulting in irregular waves for a sea spectrum corresponding to the 100 year return period at the selected site.

c) Transitional conditions during construction transportation, maintenance or as a result of selected damage conditions to the platform or its components.

## 5. POSITION CONTROL SYSTEM

A position control system shall be provided which is capable of limiting the movement of the platform as defined below.

### 5.1 Operational Mode Requirements

The Position Control System shall limit platform lateral motions to those which, in combination with wave-induced motions, do not exceed the limits for cable mechanical strength during the design life of the system.

### 5.2 Survival Mode Requirements

The excursions of the platform up to the limits of the 100 year critical event shall not exceed the following:

- That required to prevent grounding of the CWP.
- That required to prevent collision with adjacent OTEC platforms in an energy park, or other fixed obstructions.

### 5.3 Design Loads

Design loads shall be established on the basis of a load analysis, including dynamic effects and considering combinations of angles of attack for all the load components to obtain maximum loads resulting from the following:

Wind and Current Load on the Platform
Current Load on the CWP
Wave Drift Load
Mooring Lines Spring Load due to Platform Motions

### 5.4 Configuration

It is intended that a fixed type, multipoint moor static positioning system be provided. Weathervaning may be considered as an alternative for the ship shape, in which case the contractor must demonstrate that the equipment is fully reliable and operative in the extreme conditions described above and does not involve the use of components beyond the present state of the art.

The fixed system shall consist of single or multiple anchors and mooring lines. The weathervaning system shall also include a buoy, swivel connection and stern thrusters for heading control.

Winches may be used for tension control if considered necessary however no reliance shall be placed on power driven equipment in the survival condition.

## 5.5 Anchor

### Type

Deadweight anchors shall be employed. The anchors shall be of concrete and shall be suitable for a life of 40 years.

### Holding Power

The anchors shall not move when subjected to a pull equal to the breaking strength of the mooring line. For this condition the cable angle above horizontal shall be the natural catenary resulting from the above line pull.

## 5.6 Lines

### Type

Mooring lines may be wire rope, synthetic rope, hollow links, chain or a combination of these. State-of-the-art materials and diameters shall be used unless it is shown that they are impractical and inadequate for the task.

### Life

Consideration shall be given to obtaining maximum line life and materials selected with due regard to their life in the ocean environment. Replacement shall be accomplished with no impact on plant operations.

### Protection

The mooring lines shall be adequately protected against abrasion, impact from the platform and workboats, and electrolytic action.

### Winches and Controls

A system of constant tension winches and appropriate controls may be provided for each line, capable of holding the line without slipping or yielding up to its breaking strength. State-of-the-art equipment, including fairleads, etc, shall be used if standard mooring lines are used.

## 5.7 Thrust Requirements

A thruster will be required for heading control if weathervaning is proposed. The system shall provide sufficient thrust to withstand wind and wave drift loads on the platform assuming that the platform will be aligned to minimize drag. Thrust calculations shall reflect a 10 percent power margin.

## 5.8 Use of Power System Discharges

It is not acceptable to vector the discharges from the Seawater System for either normal or survival operations due to the additional loading imposed on the pumps in achieving high enough velocities for thrusting purposes, and the possibility of Power System shutdown during extreme weather conditions or because of mechanical failure.

## 5.9 Control System

A control system shall be provided for the weathervaning concept. A control system shall also be provided for the fixed concept in the event that tension winches are provided. The systems shall automatically track the position of the platform relative to the riser cable buoy and adjust thrust as required to maintain the platform within an envelope of acceptable motions. The system shall sound appropriate alarms when this envelope has been exceeded.

Manual backup shall be provided for all critical automatic operations.

## 6. ACCOMMODATIONS

### 6.1 Crew Complement

Accommodation shall be provided on the platforms for a crew as follows:

| | | TYPE ACCOMMODATIONS | | |
|---|---|---|---|---|
| RATING | NO. | SUITE | SINGLE | DOUBLE |
| MASTER (AB) | 1 | 1 | | |
| DECKHAND (AB) | 2 | | | 1 |
| DECKHAND (SEAMAN) | 2 | | | 1 |
| DECK SUBTOTAL | 5 | | | 2 |
| PLANT SUPERINTENDENT | 1 | 1 | | |
| SHIFT SUPERVISORS | 3 | | 3 | |
| CONTROL ROOM | 10 | | | 5 |
| ROVING WATCH | 6 | | | 3 |
| OPERATING SUBTOTAL | 20 | | 3 | 8 |
| MECHANICAL FOREMAN | 1 | | 1 | |
| MECHANICS | 4 | | | 2 |
| ELECTRICAL FOREMAN | 1 | | 1 | |
| ELECTRICIANS | 4 | | | 2 |
| INSTRUMENTATION FOREMAN | 1 | | 1 | |
| INSTRUMENTATION SPECIALISTS | 4 | | | 2 |
| COOK | 2 | | | 1 |
| JANITOR MESSMEN | 6 | | | 3 |
| CLERICAL | 2 | | | 1 |
| MAINTENANCE SUBTOTAL | 25 | | | |
| SPARE CABINS | 2 | | 2 | |
| FOR TRANSIENT PERSONNEL | 6 | | | 3 |
| SUBTOTAL | 8 | | 2 | 3 |
| TOTAL | 58 | 2 | 8 | 24 |

## 6.2 Public Rooms

A dining room shall be provided to accommodate a minimum of one half of the total accommodations per sitting.

A separate recreational facility shall be provided, divided into a "quite" and "noisy" area. This facility may be used for crew training.

A small private lounge shall be provided for use by the senior supervisory staff.

## 6.3 Furnishing

Cabins and public spaces shall be fitted out generally in accordance with the requirements of MarAd's Standard Specification for Merchant Ship Construction.

Furniture shall be of steel or aluminum. Hardware shall be stainless steel or brass.

## 6.4 Medical

A dispensary shall be provided suitable for treating illness and minor injuries. An isolation ward with private facility shall be provided in accordance with U.S. Coast Guard regulations. Provision shall be made for the rapid transfer of seriously ill or injured personnel to shore based hospitals via helicopter. Dental facilities are not required.

Emergency medical equipment shall be provided in all living, working and control spaces, located in damage control lockers.

## 6.5 Offices

A centralized office complex shall be provided for the normal administration of platform and payload operations. Combined training and conference facilities shall also be provided.

## 6.6 Sanitary Spaces

Each stateroom shall have its own sanitary facility consisting of toilet, washbasin and shower. A bath shall be provided for the hospital.

All fixtures and accessories shall be of high grade marine type, exposed surfaces shall be of stainless steel or chrome plated.

## 6.7 Commissary

A centralized galley complex shall serve all messing areas, and shall be in close proximity to food stowage areas to facilitate transfer of supplies. The galley shall be designed to serve up to one-half the accommodations at one sitting.

Marine type equipment, in accordance with MarAd Standard Specification shall be fitted.

Steward service shall be provided for supervisory staff; remaining personnel shall have cafeteria style messing.

## 6.8 Laundry

A laundry shall be provided capable of handling all soiled clothes and linen generated by embarked personnel. Shoreside laundering shall be utilized for table clothes, linen, bedclothes and similar.

## 6.9 Stowage

Provision shall be made for the stowage of galley and stewards stores, baggage, medical supplies and other portable and consumable gear associated with personnel support. Galley stores and other consumables shall be based upon a 30 day resupply for chill, frozen and dry stores.

## 6.10 Joinerwork

Joiner lining will be used to conceal metal bulkhead in living spaces and over insulation. Joiner bulkheads may also be used in accommodation if desired.

All joinerwork shall be fire resisting, and in accordance with MarAd's Standard Specification for Merchant Ships Construction.

## 7. OUTFIT

### 7.1 Boats and Rafts

Boats, rafts and other lifesaving appliances shall be provided for all personnel in accordance with U.S. Coast Guard requirements. One power driven rescue boat with suitable stowage and handling equipment shall be provided.

### 7.2 Damage Control

Systems shall be provided to detect water leakage, smoke, ammonia vapor and other potential hazards and to sound alarms both localy and in the Central Control Station. Portable damage control equipment shall be located in lockers throughout the platform to combat such hazards, including oxygen breathing apparatus in all spaces containing ammonia transfer or storage.

### 7.3 Shops

A central workshop shall be provided to permit normal maintenance and repair to both platform and payload electrical and mechanical equipment. A separate electronics shop shall be provided to service navigation, communication and test equipment.

### 7.4 Test Facilities and Laboratories

A permanent laboratory shall be provided suitable for conducting all tests, analysis, data processing and performance monitoring of OTEC Ocean System and environmental parameters as specified by DOE. Provision shall also be made for the temporary topside stowage of up to four 8'x8'x20' vans containing special test, monitoring equipment and supplemental accommodations for technical personnel.

### 7.5 Spare-Parts Stowage

Stowage shall be provided for spare parts and miscellaneous equipment associated with the Seawater, Position Control and Support Systems, based on a 30 day resupply cycle.

### 7.6 Helicopter Facilities

Aircraft landing facilities shall be provided for day/night operation of helicopters of up to 50,000 pounds gross takeoff weight. These facilities shall include a landing pad with suitable visual landing aids, navigation transponders and tiedown facilities. A helicopter control station with 360 degree visibility and voice communications to both the helicopter and firefighting crews shall be provided. Aircraft hangaring, maintenance and repair capabilities are not required, though the platform shall be capable of emergency refueling aircraft and of providing firefighting and emergency services in way of the landing area. Provision shall be made for the transfer of air cargo from the landing zone to stowage areas.

### 7.7 Facilities for Supply Boats

Facilities shall be provided for the day/night mooring of offshore supply boats and the transfer of personnel and cargo from these boats in conditions up to Sea State 3.

### 7.8 Material Handling

Monorails, conveyors, and other appliances shall be provided as required for the safe transfer of supplies, spare parts and equipment throughout the platform. Overhead cranes shall be provided in way of turbogenerator sets, pumps and other rotating equipment to permit removal or laydown of major components for servicing.

Provision shall be made for moving heavy loads through trailers, straddle carrier, fork lift or similar equipment.

### 7.9 Cranes

Cranes capable of lifting up to 50 tons at an outreach of 50 ft shall service the boat mooring areas. If practical the cranes shall be designed to plumb the machinery removal paths.

### 7.10 Hoists and Elevators

Hoists and elevators in numbers and sizes to be determined shall be provided for personnel access and for equipment transfer.

### 7.11 Insulation

Fire insulation shall be provided to suit USCG requirements for fire control.

Thermal insulation shall be provided where required for crew comfort, to reduce heat load in air conditioned spaces or to protect personnel from hot metallic contact.

Accoustic insulation will be provided to limit noise to acceptable levels in living spaces and control centers.

### 7.12 Paint

Exposed surfaces in living spaces shall be painted generally in accordance with construction practice on offshore vessels.

Metallic surfaces, shall be protected by high performance painting system.

# 8. MAIN POWER CYCLE SEA WATER SYSTEMS

## 8.1 General

Cold water and hot water circulating systems shall be provided as the heat sink and source, respectively, for the power generation cycle. The sea water systems shall consist of circulating pumps, valves, strainers, piping and other fittings as required to circulate water through the power cycle condensers and evaporators.

The sea water systems shall be configured into eight separate systems as required to support the eight 50 MW power generation system modules. Each 50 MW sea water system shall be capable of operating independently from the other systems and with any number of systems not operating. Common suction and discharge plenums may be utilized to suit the platform arrangement; however, use of common plenums shall not preclude independent operation as specified above or maintenance of some systems with others operating.

## 8.2 Cold Water System

### 8.2.1 Cold Water Pipe

A single cold water pipe shall be provided to supply cold water to all condensers via a system of plenums and pumps as defined below.

The length of the CWP shall be selected on the basis of a desired temperature differential between cold and warm water inlets of 40°F. CWP length shall be optimized based on the trade-off between CWP weight and cost, plant efficiency, pumping efficiency and other factors, reflecting the temperature profile for the site. Heat gain by the cold water should be minimized.

The CWP shall be circular in cross-section and of constant inside diameter. The diameter shall be selected on the basis of trade-offs of CWP cost versus hydraulics and pumping costs.

Lightweight concrete, steel, fiber reinforced plastics or complaint wall materials may be used for the CWP provided that these materials are suitable for continuous exposure to salt water for the life of the system at an operating depth of about 3000 feet, and have demonstrated their capability to survive in such an environment with no maintenance after deployment. Stress levels will be established on the basis of a reliability analysis considering both load levels and frequency of occurrence.

Both fixed and hinged or compliant connections of the CWP to the hull are to be considered. In addition intermediate hinges or other forms of pipe flexibility are to be considered for non complaint materials. The design of such flexible connections shall reflect the anticipated 40 year cyclic loading anticipated for the combination of hull, CWP and site characteristics, and shall not fail due to fatigue.

The design of the CWP shall reflect no maintenance after deployment except for the possible removal of biofouling and other marine growth if weight buildup, drag or hydraulic losses become excessive. The Ocean System design should reflect consideration of such fouling, particularly in terms of increased drag and displacement.

The CWP shall be designed to be installed in sections from the top of the platform with the platform waterborne.

A large mesh screen or grating shall be provided at the lower end of the CWP to prevent ingestion of large marine life. The size of this mesh shall reflect the anticipated marine life at the depth of the CWP inlet and the size distribution. The mesh or grating size shall be small enough to prevent passage of fish large enough to damage the cold water pump.

### 8.2.2 Sea Water Pumps

A minimum of one cold water pump shall serve each 50 MW condenser and one warm water pump shall serve each 50 MW evaporator. The cold water pumps shall take suction from the common cold water plenum and discharge separately through their respective condensers and separate overboard discharges. The warm water pumps shall take suction from independent screened suction pipes and discharge through their respective evaporators and overboard discharges.

Alternatively, the cold and warm water pumps may be located on the discharge site of their respective heat exchangers if an arrangement advantage can be demonstrated and suction losses are not excessive.

Each 50 MW cold water circulating system shall have a nominal capacity of 6000 cfs at the necessary system head.

If multiple pumps are utilized for a single system, they shall be arranged to operate in parallel. It is not required that multiple pumps be capable of being isolated from one another for maintenance on one pump while the other is operating.

Pumps shall be of a state-of-the-art design and constant speed A.C. electric motor drive. If practicable, motor drivers shall be located in accessible watertight compartments outside of the flow stream. Submersible motors may be utilized where dictated by platform arrangement considerations and if of proven reliability in service.

Pumps may be horizontal or vertical, to suit the arrangement. Right angle drive arrangement shall be avoided. Direct drive arrangements are preferred but reduction gear drives will be considered where significant cost and/or arrangement benefits can be demonstrated.

Pump materials shall be corrosion resistant and selected on the basis of design optimization studies.

Pump efficiency shall be optimum at steady rated power operation.

### 8.2.3 Sea Water Piping

Sea water circulating systems shall be designed for minimum pressure drop characteristic consistent with platform arrangement considerations. Piping configuration shall be carefully studied to minimize losses; guide vanes shall be utilized at sharp bends. Diffusers shall be used in lieu of abrupt area changes. Diffuser lengths shall be optimized based on pressure loss vs. hull volume increase.

Warm water inlets shall be located as close to the surface as possible but sufficiently below the surface to preclude emersion in the most critical sea state under which operation is required.

All sea water inlets shall be fitted with appropriate screens or gratings to prevent ingestion of large foreign objects. Mesh size shall consider the trade-off between pressure drop and risk of foreign object damage. Inlet velocity at screens shall be less than 1.5 fps to prevent trapping of fish against the screen.

All sea water inlets shall be located to minimize re-ingestion of process water with corresponding reduction in cycle efficiency.

## 9. SUPPORT SYSTEMS

### 9.1 General

Platform support systems shall be provided as required for mechanical/electrical requirements, environmental control, personnel support, life-saving, platform support, material handling and navigation/communication. All such systems shall meet the requriements of the applicable regulatory agencies, including the American Bureau of Shipping and U.S. Coast Guard. All equipment shall be of commercial marine type.

The requirements set forth in this Section are based upon the assumption that the platform Support Systems are essentially self-sufficient, requiring only resupply of consumables which cannot be generated onboard. As indicated in Section 2, the platform is to be deployed in an Energy Park consisting of eight-400 MW Commercial Plants, which opens up the option of using shoreside facilities and platform/shore transfer for many Support System functions such as processing sewage and other liquid or solid pollutants, producing make-up compressed gases and fresh water, etc. Another basic option which should be traded-off with the self-sufficient platform concept is the concept of a central hotel platform for each OTEC park which would contain all personnel accommodations. These options shall be traded off against the cost and benefit of self-contained capability in the selection of Support Systems.

### 9.2 Platform Service Power and Lighting System

Electric power for platform services including hotel loads, power cycle auxiliaries and platform service auxiliaries shall be provided, via suitable transformers, from the main power cycle output. A minimum of two independent auxiliary engine driven generators shall be capable of powering essential loads during emergencies or when the main power cycle is not operating.

Power cycle start-up power requirements shall be met by an independent service boat or barge capable of serving any platform in the park or other parks.

Lighting for interior and exterior spaces of the platform shall be provided in accordance with criterion of the illuminating engineering society publication entitled "Recommended Practice for Marine Lighting".

### 9.3 Fluid and Gas Systems

Provision shall be made for the distribution, storage and replenishment or generation of all necessary fluids to support Plant operations. This shall include, but not be limited to, compressed air, nitrogen, ammonia, salt water, chlorine, fresh/distilled water, diesel oil, lubricating oil, hydraulic oil, firefighting and sewage. Such systems shall reflect current practice in the design and operation of offshore platforms. All systems shall include redundant pumps, compressors and other vital equipment where prone to failure.

### 9.3.1 Compressed Gas

A compressed air system shall supply diesel or turbine start-up, platform service and control air.

A nitrogen system shall be provided for inerting all ammonia piping. The sub-system shall be sized to provide a complete purging of an average of one module per month.

### 9.3.2 Bilge and Ballast

A bilge system shall be provided to drain all spaces below the waterline which are not tanks or voids. Bilge water shall be properly filtered or otherwise treated to remove pollutants before being discharged overboard. USCG criteria shall be followed in sizing of bilge lines and pumps.

A ballast system shall be provided to permit controlled flooding and dewatering of specified tanks for the purposes of maintaining proper draft, trim and stability. The stowage of fuel oil or other liquids in ballast tanks is not permitted.

### 9.3.3 Fuel Oil Transfer and Stowage

A fuel oil transfer and stowage system shall be provided to supply fuel to Auxiliary Electrical Service auxiliary boilers if installed, and other fuel-fired equipment. Storage for 60 days' supply shall be provided. Facilities shall be provided for the transfer of fuel oil from resupply vessels at a pressure and pumping rate appropriate to start-of-the-art in offshore fuel transfer.

### 9.3.4 Fire Detection and Extinguishing

Fire extinguishing systems shall consist of firemain, portable $CO_2$, AFF and HALON 1301 or $CO_2$ as defined below, in accordance with U.S. Coast Guard requirements. Fire detection capability shall include the ability to detect smoke and infrared (IR) radiation in appropriate spaces and to sound appropriate alarms.

A horizontal loop-type firemain shall be provided to supply seawater to fire stations located throughout the platform such that water can be directed to any area within or on the platform from two hoses simultaneously at a minimum pressure of 100 PSI. A minimum of 4 electrically driven firepumps shall be provided, located at the four quarters of the platform, with cross-connections such that any pump can feed any fire station.

Portable $CO_2$ fire extinguishers shall be provided throughout the platform in accordance with applicable U.S. Coast Guard requirements.

A system for manual spraying with AFF or other foam-type smothering agents approved by U.S. Coast Guard shall be provided in way of the helicopter landing area.

A HALON 1301 or $CO_2$ fixed flooding system shall be provided for all machinery spaces, platform control spaces and other spaces containing high-value equipment which would be damaged by water. The system shall be manually activated, with activation alarms both locally and in the Central Control Station.

### 9.3.5 Lubrication and Nydraulic

Lubrication systems including pumps, filters, transfer piping, fittings and storage tanks for 60 days' supply of each oil shall be provided to service turbogenerators, pumps, thrusters and other systems. The system shall be suitable for supplying clean lube oil to equipment with attached auxiliaries and for transferring dirty oil to storage tanks for processing. Hydraulic system(s) shall be provided to supply properly filtered hydraulic fluid to those equipments requiring same, at the specific pressure.

### 9.3.6 Fresh Water

Fresh water systems shall be provided for diesel engine cooling, (if required) generator cooling, washdown, auxiliary boiler feed and domestic use, including drinking, cooking, washing, showers and sanitary flushing. Cooling systems shall be independent from domestic water systems.

Hot fresh water shall be supplied to the galley, laundry, sanitary facilities and other services using either waste heat, oil-fired or electric heaters.

Domestic water systems shall comply with applicable U.S. Public Health Service (USPHS) regulations.

Fresh water shall be provided by a minimum of two distilling plants, each capable of satisfying normal daily demands, including 60 gallons per man per day and cooling system makeup. Alternatively, water may be supplied by tank vessels.

Potable water tanks shall be provided with a capacity equivalent to 120 gallons per accommodation if distillers are installed. If external resupply is used, the tanks shall be sized to suite the resupply cycle.

### 9.3.7 Pollution Control

Pollution control subsystems shall be provided to eliminate the discharge of liquid or solid pollutants into the environment. Such systems shall include collecting tanks, filters, incinerators, chemical treatment and other systems as required to effectively treat or transfer oily bilge water, sanitary system discharge, galley wastes, chemical waste, trash and other polluting substances. These systems shall prevent discharge of pollutants in accordance with applicable U.S. Coast Guard and Environmental Protection Agency regulation. Where such requirements are not met by onboard processing, provision shall be made for transfer to shoreside facilities.

### 9.3.8 Aircraft Fuel

Provision shall be made for emergency refueling of helicopters, including a storage tank, hoses, pumps, controls and filtration equipment. Air craft fuel system shall be in accordance with USCG requirements.

### 9.3.9 Refrigeration

A refrigeration system shall be provided to support the air conditioning and food storage systems.

## 9.4 Environmental Control Sub System

Heating, ventilation and air conditioning (HVAC) systems shall be provided as specified below for all platform spaces based upon the environmental extremes for the selected site.

### 9.4.1 Heating System

Portable electric heaters shall be provided for living, working and control spaces to insure a minimum temperature of 65°F.

### 9.4.2 Ventilation

All non-air conditioned spaces shall be ventilated in accordance with U.S. Coast Guard 46 CFR Subchapter ) Section 151.50-32 (d). Compartments containing ammonia tanks, evaporation, pumps, piping and turbines shall contain high-volume exhaust fans with natural supplies to exhaust ammonia fumes in the event of leakage. These fans shall have automatic shutdown capability in the event of fire.

### 9.4.3 Air Conditioning

All living, recreation, messing, working, medical and control spaces shall be air conditioned in accordance with SNAME T & R Bulletin No. 4-7. Working spaces are those in which personnel are permanently stationed and exclude operational spaces served by a roving watch.

## 9.5 Navigation and Communication

### 9.5.1 Radio

A suite of two way voice communications equipment shall be provided which is in accordance with current practice for large offshore platforms, and shall provide the ability to communicate with other Plants, shore facilities, helicopters, supply boats and nearby shipping traffic.

### 9.5.2 Radar

A radar system with a range of up to 20 nautical miles shall be provided capable of detecting and tracking both low air and surface targets.

### 9.5.3 Interior Communications

Telephone and announcing systems shall be provided to permit communications between all platform compartments. Television monitoring shall be provided for the helicopter pad, boat landing position, power plant machinery rooms and other key operation, with monitors in the Central Control Station. General, fire, flooding and $NH_3$ leakage alarms shall be provided.

### 9.5.4 Position Sensing

The capability shall be provided to sense platform position with ±50 feet relative to the riser cable buoy.

### 9.5.5 Lights

Navigation lights shall be provided in accordance with international standards. Additional high-intensity lighting shall be provided as an aid to nearby shipping.

Helicopter night flight operating lights shall be in accordance with the latest edition of "Visual Landing Aids General Service Bulletin No. 9-2".

### 9.5.6 Weather Monitoring

Facilities shall be provided to monitor weather conditions, both via communication with the U.S. Weather Service and by on-board observation of wind and sea conditions.

### 9.5.7 Exploration Aids

Facilities shall be provided for monitoring sea conditions (wave height and length, wind, etc.), ocean thermal profiles, current strength and other factors vital to Plant operation.

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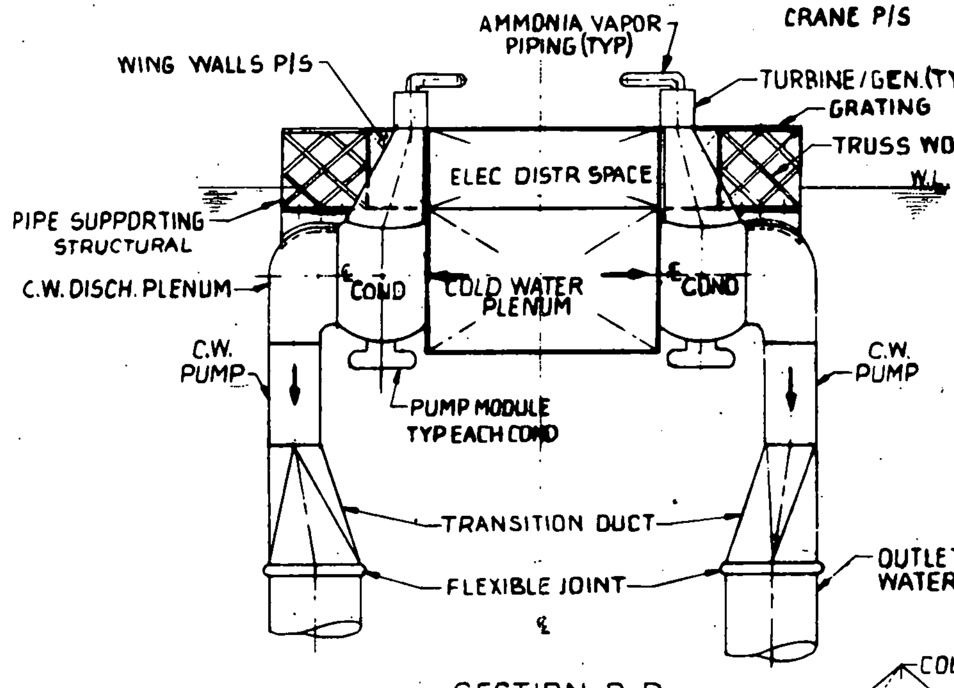
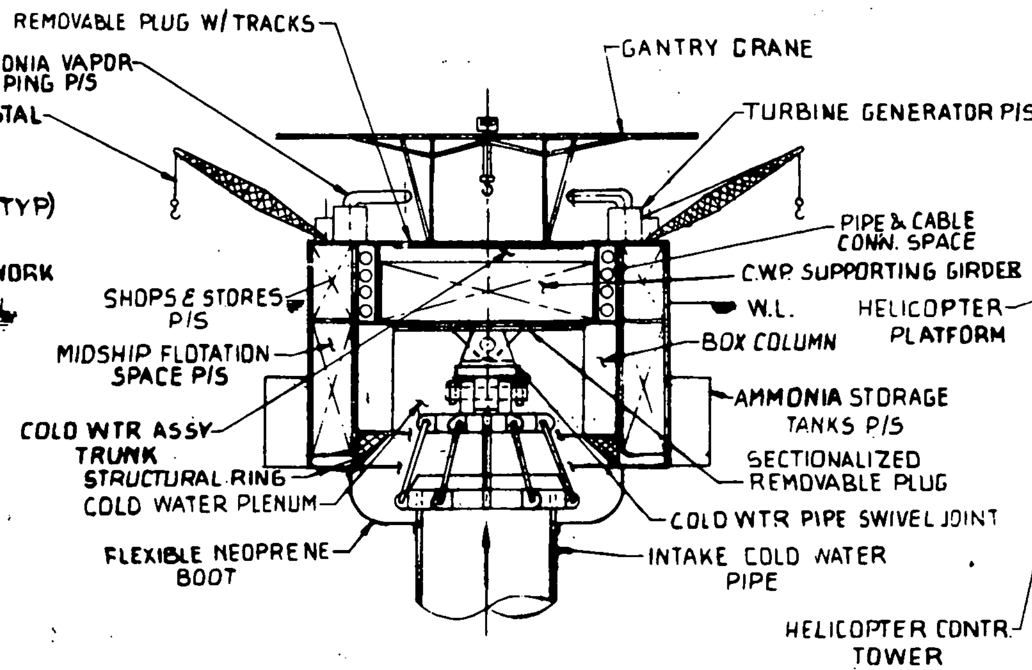
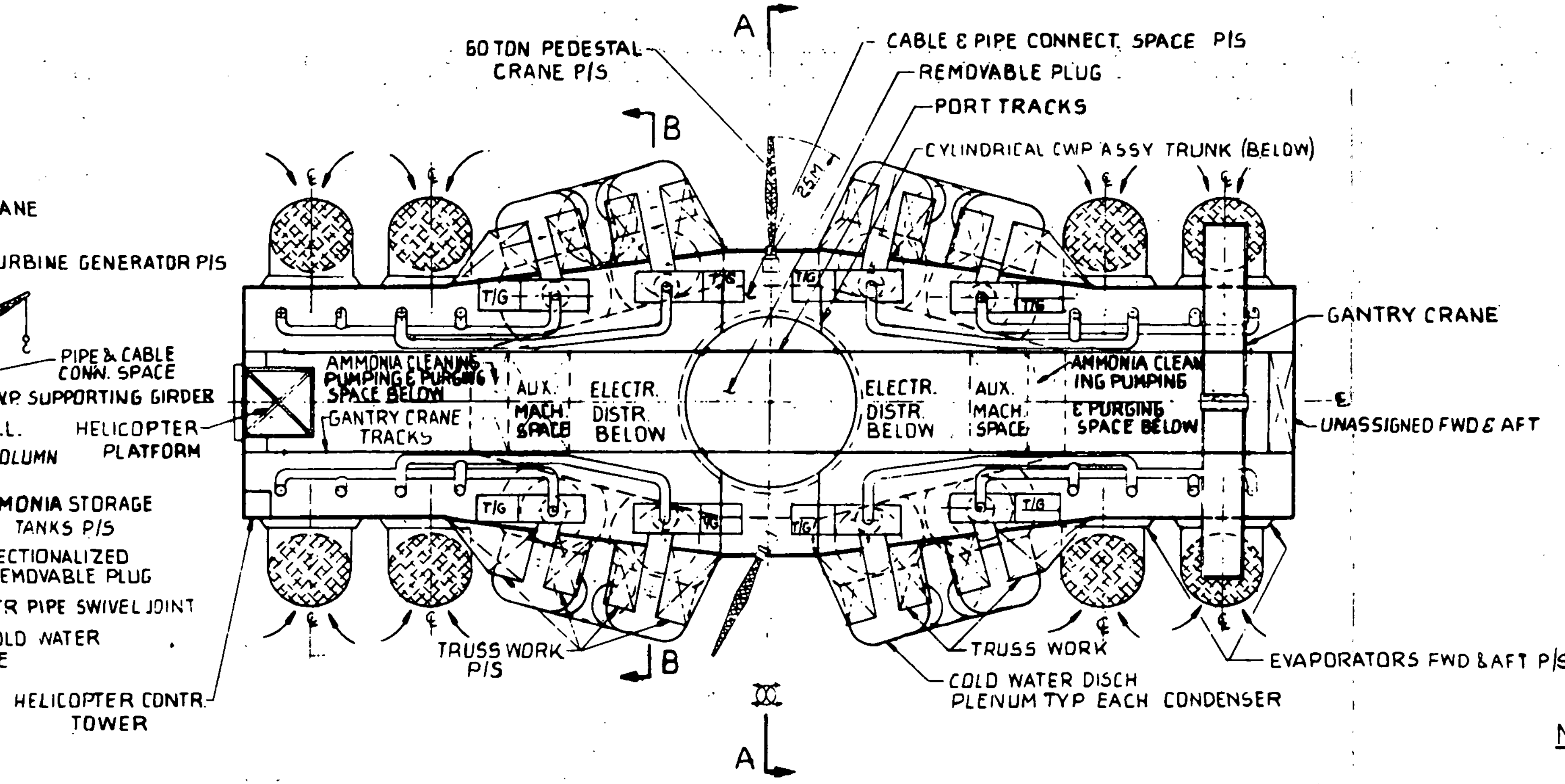


SECTION B-B



MIDSHIP SECTION A-A



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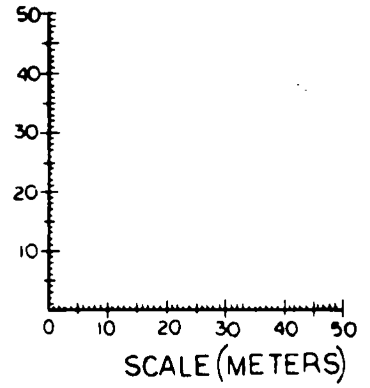

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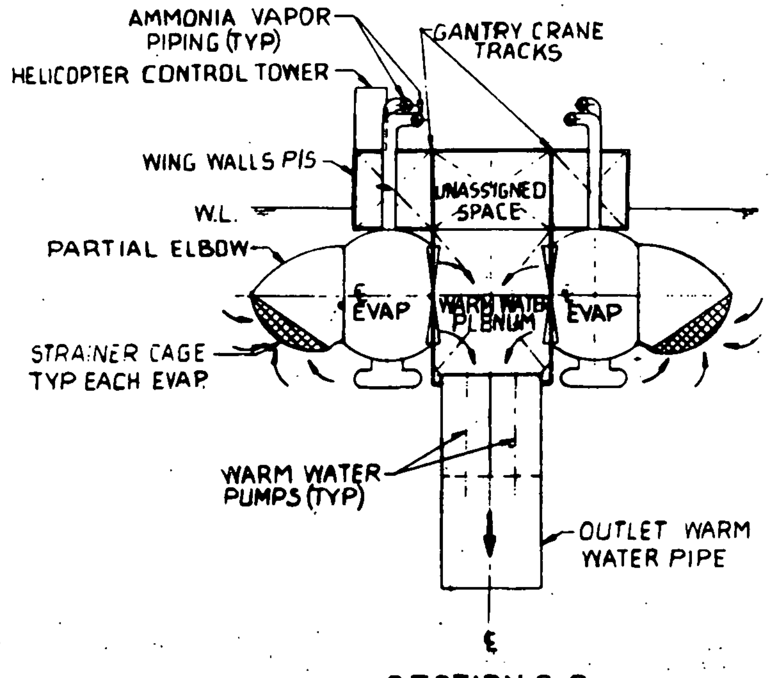

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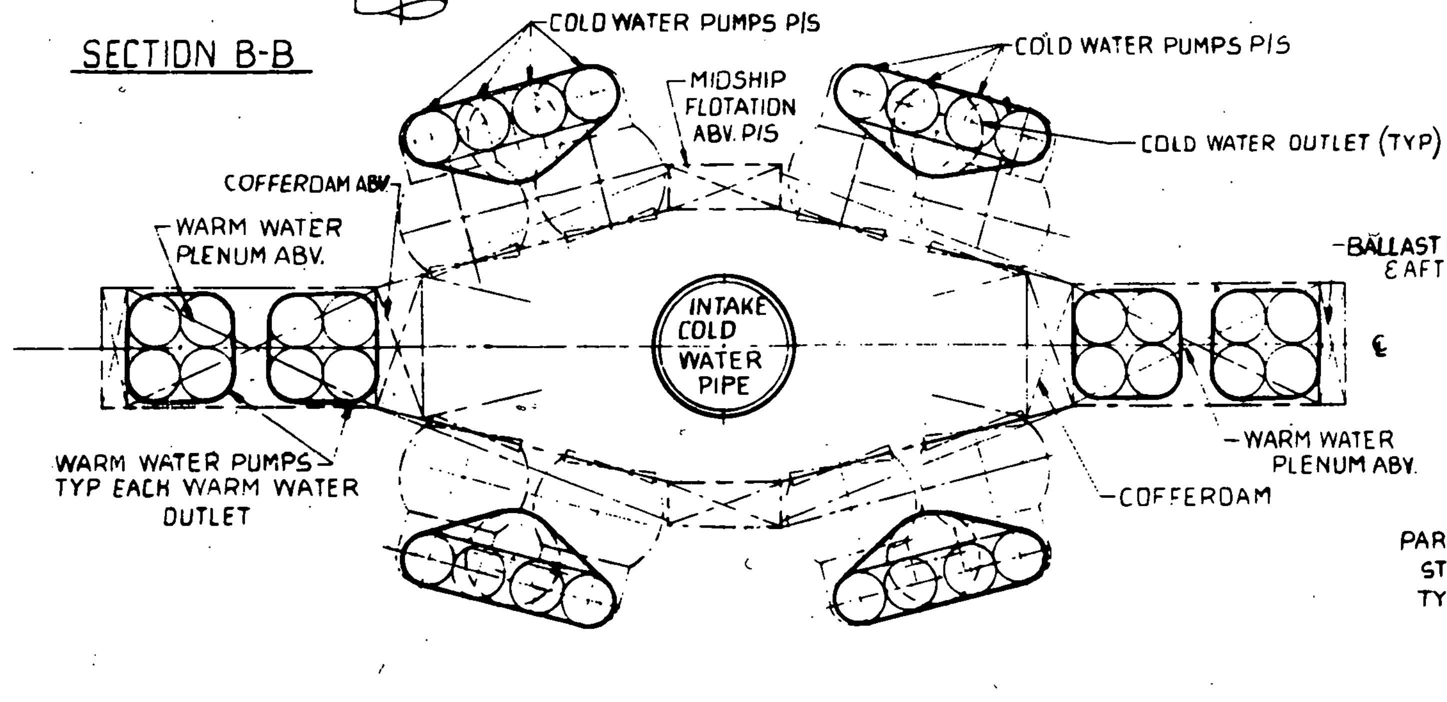

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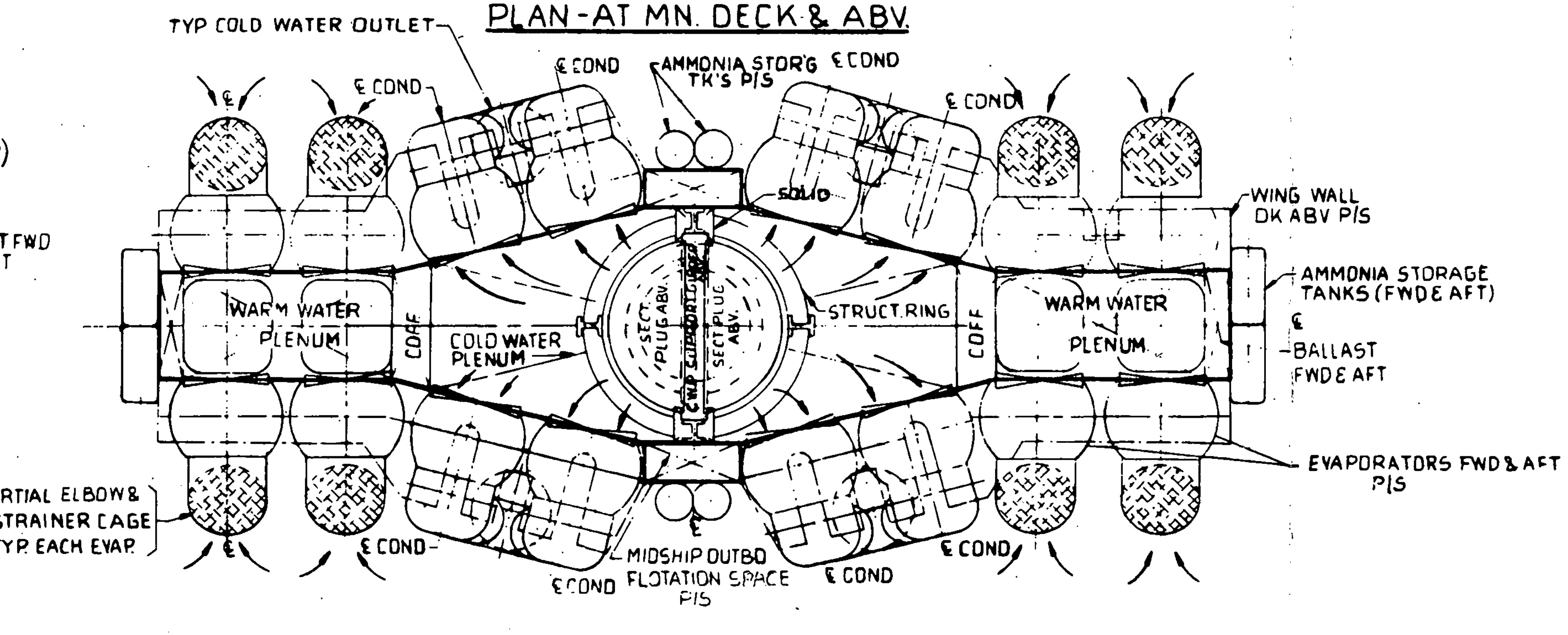

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NOTE

THIS OTEC PLATFORM CONCEPT HAS BEEN DEVELOPED FROM LOCKHEED MISSILE & SPACE COMPANY DWG NO.501-1010-1

| NO. | TITLE | DWG. NO. |
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REFERENCES

**JOHN J. McMULLEN ASSOCIATES, INC.**
NAVAL ARCHITECTS, MARINE ENGINEERS
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ONE WORLD TRADE CENTER, SUITE 3047 NEW YORK, N.Y. 10048

OTEC PLATFORM
CONCRETE SHIP 400MWe (NET)
GENERAL ARRANGEMENT PLANS & SECTIONS

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|---|---|---|---|
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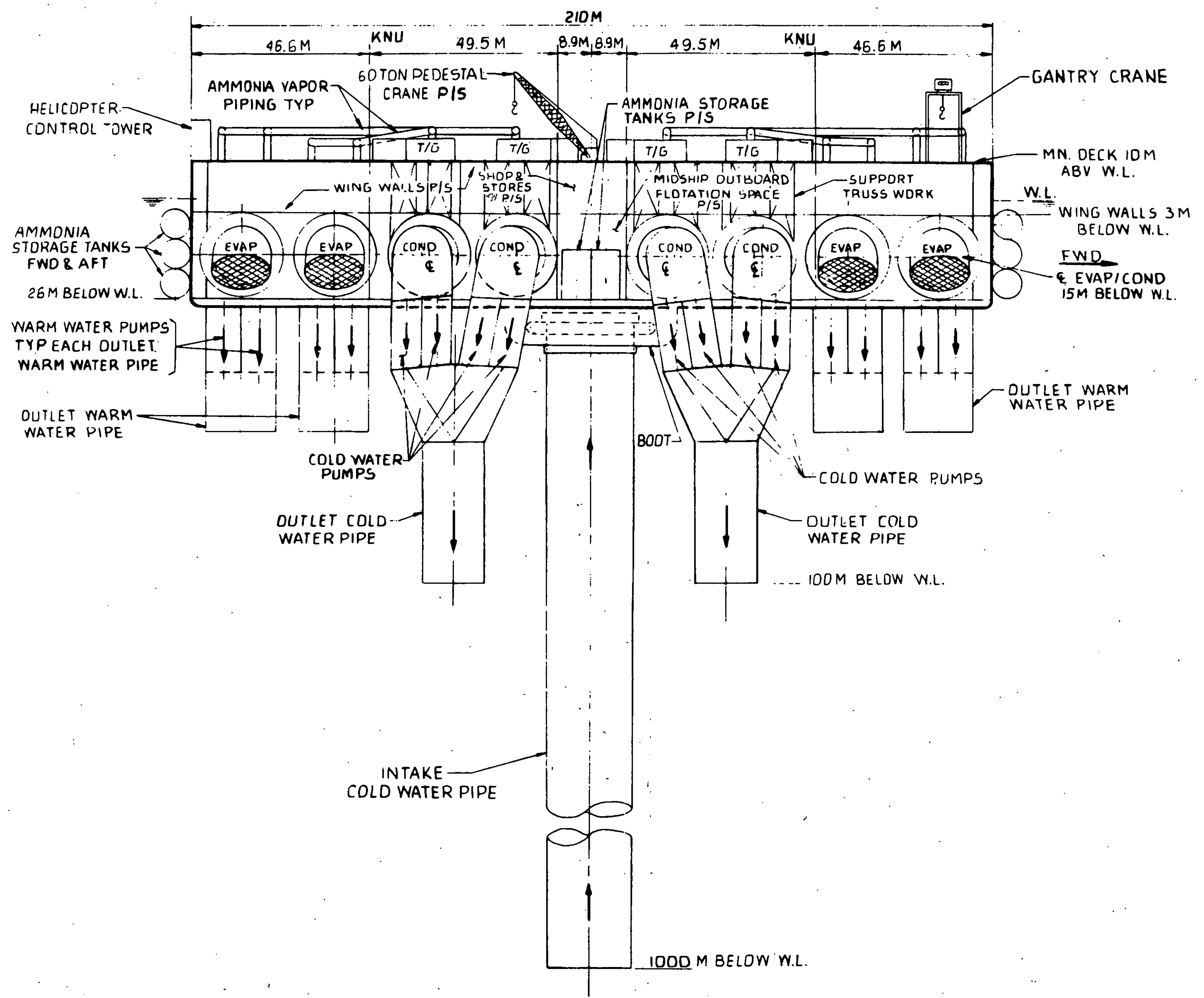
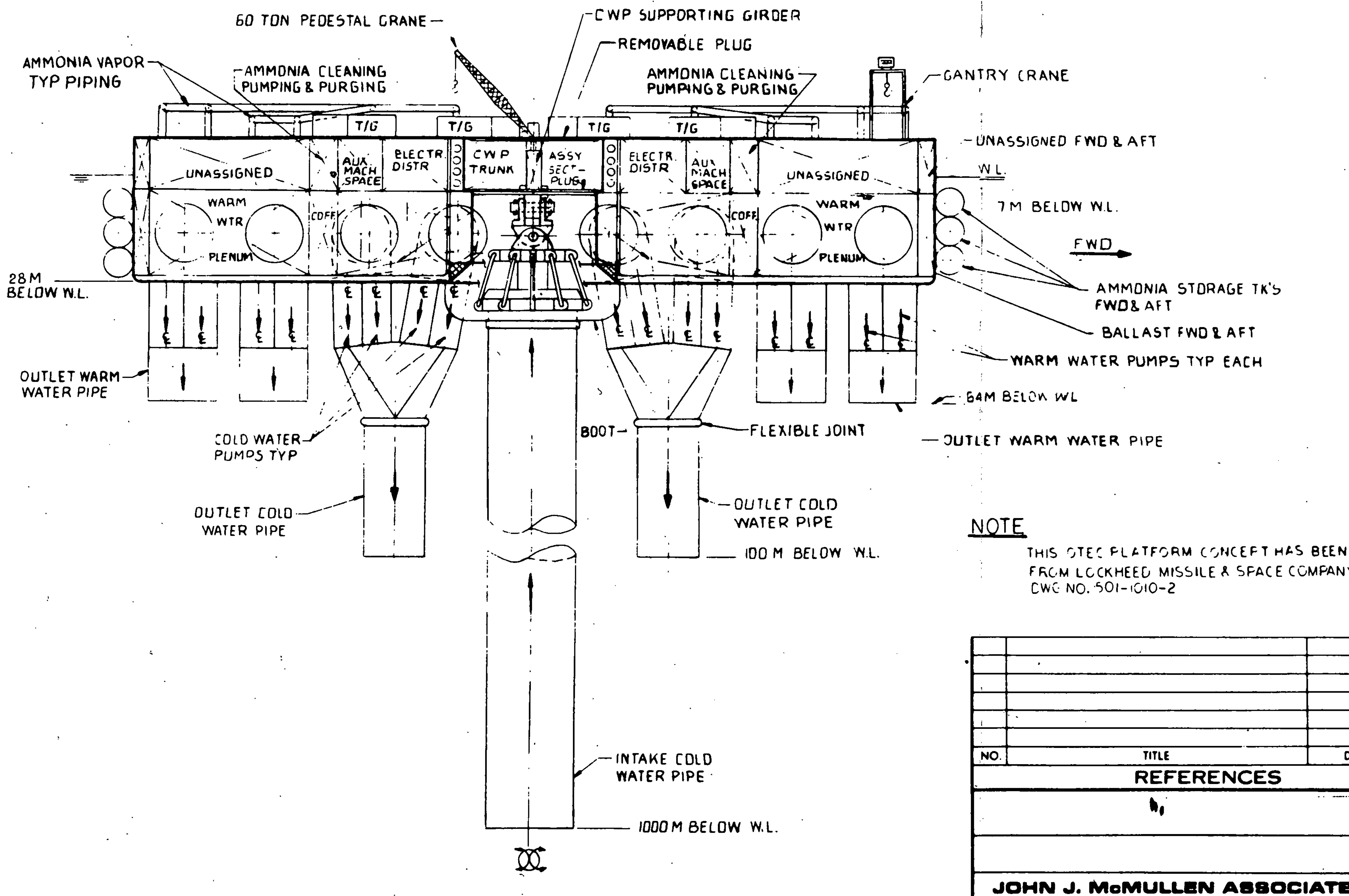


OUTBOARD PROFILE



INBOARD PROFILE

NOTE

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REFERENCES

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ONE WORLD TRADE CENTER, SUITE 3047 NEW YORK, N.Y 10048

OTEC PLATFORM
CONCRETE SHIP 400MWe(NET)
GENERAL ARRANGEMENT-ELEVATIONS

**DWG NO.** 2817M-S40-1-1
**ALT.** C
SH. 2 OF 2
SCALE 1:750
CHECKED E.K.
APPROVED
DRAWN BY E.Z.
APPROVED
DATE 06/29/79.