MODULAR OTEC PLATFORMS: SKSS DESIGNS

Final Report, Volume 1. Executive Summary

MASTER

February 29, 1980

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FINAL REPORT

VOLUME I

EXECUTIVE SUMMARY

MODULAR OTEC PLATFORMS

SKSS DESIGNS

Prepared For

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ABSTRACT

One of the possible options for generating electrical energy from ocean thermal gradients requires the use of a floating off-shore platform. The platform would contain all OTEC (Ocean Thermal Energy Conversion) systems and power cycle components and consist of the hull, seawater, station-keeping, platform service, and mission support subsystems. It would be stationed at one of the designated OTEC sites, and would transmit the generated electricity to the shore power networks by means of an electrical transmission cable.

The objective of the present study is to investigate the station-keeping subsystem (SKSS) requirements and develop preliminary SKSS designs for the two Modular Experiment Plant (MEP) candidates of 10/40 MW_e capacity for deployment at a specific site.

The two MEP hull candidates are a Barge type platform and a Spar shaped hull with external heat exchangers. The specific site assigned for this study is Puerto Rico.

The preliminary SKSS designs are developed for both platforms as follows:

- o An 8-leg spread catenary mooring system for the Spar.
- o A 12-leg spread catenary mooring system for the Barge.

Applicability of these designs to larger capacity commercial OTEC platforms are also investigated.

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The Contracting Officer's Technical Representative was Mr. David Price, Office of Ocean Engineering, NOAA.

The MR&S project team assigned to the study consisted of:

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The studies were periodically reviewed and guided by Mr. Naresh M. Maniar, Vice President.

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SECTION 1.0

INTRODUCTION

The energy contained in the thermal gradients of tropical oceans can be converted to electrical energy by means of the OTEC (Ocean Thermal Energy Conversion) process. The OTEC Plant to house the systems of the conversion process may be a land-based installation, a bottom-fixed shallow water platform, or an offshore floating platform. In the latter type of platforms, the complete OTEC system, consisting of the hull, seawater, station-keeping, platform service, and mission support sub-systems, would have to be stationed at a designated deployment site for the duration of its specified service life.

The design of suitable station-keeping subsystems (SKSS) for the U.S. Department of Energy's (DoE) planned Modular Experiment Platforms (MEP) of 10 to 40 Megawatt electrical (MW_e) capacity is the major objective of the present study.

The basic assignments for the study were contained in the following six tasks as delineated by the government:

1. Basic Design Requirements
2. Conceptual Designs
3. Preliminary Design for Modular Experiment SKSS
4. Development and Testing Recommendations
5. Cost-Time Analyses
6. Commercial Plant Recommendations

The performance of tasks 1 and 2 actually constituted the first phase of the study during which all possible design approaches and SKSS concepts were considered, the most suitable ones established, and conceptual designs developed and presented to the government.

The second phase of the study, covering tasks 3 through 6, was performed for state-of-the-art catenary SKSS concepts, as selected by the government, for both modular experiment platforms.

The study was performed by M. Rosenblatt & Son, Inc., as prime contractor, for the Department of Commerce (DoC), National Oceanic and Atmospheric Administration. Detailed results are presented in [1], [2] and [3];* an oral presentation was made to the DoC/DoE and the OTEC community on January 9, 1980.

This volume presents an executive summary of the findings and a synopsis of major technical investigations as well as the overall conclusions and recommendations.

In Section 3.0, the conceptual design and evaluation studies performed during the first phase of the project are summarized. Section 4.0 contains a brief compilation of preliminary design studies accomplished in the second phase and points to some of the salient results obtained. It also discusses alternative designs for the assigned SKSS concepts, their cost estimates, deployment and replacement scenarios, and the analysis of performance and reliability.

Sensitivity of the SKSS designs and their costs to varying such parameters as water depth, pretension level, maximum line tension, environmental conditions, etc. are summarized in Section 5.0; the development and testing requirements and recommendation are given in Section 6.0.

The basic conclusions and recommendations for the complete study are compiled in Section 2.0.

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

SECTION 2.0

CONCLUSIONS AND RECOMMENDATIONS

State-of-the-art catenary mooring systems for both the Spar and the Barge 10/40 MW_e Modular OTEC platforms have been designed. It has also been established that it is possible to manufacture, install, deploy at site, and operate these mooring systems by the projected date of third quarter, 1984.

In arriving at the preliminary SKSS designs, all possible SKSS concepts (including catenary moorings, tension-leg moorings, and turret-mooring) have been considered in the first phase of the study. Conceptual design studies showed that from the standpoint of technical and economic feasibility, spread catenary moorings are preferable for both platforms if a state-of-the-art system is desired.

The SKSS analytical investigations performed in arriving at the preliminary designs included quasi-static drag calculation for both platforms, including the contribution of cold water pipe to total drag, and static catenary solutions for the screening of concepts. The evaluation of the selected mooring array was accomplished by employing a dynamic time domain simulation computer program in addition to the static programs.

The resulting Spar SKSS design has the following characteristics:

- o 8-point spread Catenary Mooring
- o Two Segment Mooring Legs:
 - 5" Nominal diameter Polyethylene Jacketed Wire Rope
 - 4 1/8" diameter, API-2F quality chain
- o Passive winch systems or hydraulic line pullers.
- o High holding power drag embedment anchors.
- o Computer aided manual control system
- o Performance:
 - Pretension : 420 KIPS (20% of Breaking Strength)
 - Excursion radius at operating condition : 447 ft. (8.6% depth)
 - Most loaded line tension at survival condition : 870 KIPS
- o Estimated cost in \$ million (1980 dollars):

- Initial installation :	20.8 (w/winch)	16.8 (w/line pullers)
- Average Annual* :	2.128 (")	1.797 (" ")
- Present Value* :	21.87 (")	18.5 (" ")

The characteristics for the Barge SKSS design are:

- o 12-point spread Catenary Mooring
- o Two segment Mooring Legs:
 - 5 1/2" Nominal diameter Polyethylene Jacketed Wire Rope
 - 4 1/2" diameter, API-2F quality chain
- o Passive winch systems or hydraulic line pullers
- o High holding power drag embedment anchors
- o Computer aided manual control system

* See "Glossary" for definitions and Section 4.2 of Volume III for Calculation procedures.

- o Performance:
 - Pretension : 513 KIPS (20% of Breaking Strength)
 - Excursion radius at operating condition : 480 ft.(9.2% depth)
 - Most loaded line tension at survival condition : 1260 KIPS
- o Estimated costs in \$ million (1980 dollars):
 - Initial installation : 35.2 (winches) 27.9 (Line Pullers)
 - Average Annual : 3.588(") 2.854(" ")
 - Present Value 36.88(") 29.33 (" ")

Following overall conclusions may be drawn from the findings of this study and may be used as guidelines in any future SKSS designs:

- o Use of two segmented mooring lines, consisting of wire rope and chain, give overall advantages from the viewpoints of cost, maintenance and performance for deep water moorings.
- o The seabed mooring line should use high quality chain; chain meeting API-2F specifications is recommended.
- o Polyethylene jacketed wire rope is recommended for use as the upper segment of the mooring legs. Despite the higher initial costs, the jacketed wire rope provides better life cycle costs due to its longer service life.
- o The slowly varying wave drift forces do not result in excessive increases in line tensions (for the limited time runs made).
- o Time histories of line tensions obtained from dynamic analyses, show that the maximum tensions are only 20 to 30% higher than the mean tensions obtained by static analysis.
- o It may be suggested that future SKSS designs employ static analyses and simply increase the calculated line tensions by an appropriate factor. The results of this study indicate that the factor to be used could be 1.3, again for the limited duration runs.
- o According to information supplied by its manufacturer, based upon tests performed on bridge cables in a "salt water--air" environment, the jacketed wire rope can be expected to provide a 30-year service life.
- o The thirty year service life also appears feasible for other SKSS components such as the Chain, anchors, winches, etc.
- o Desirable factors of safety (in terms of line tension to wire rope breaking strength ratio) of 3 for the design operational sea state and of 2 for the design extreme sea state, are feasible with the herein proposed line components.
- o Drag embedment type anchors of high holding power to weight ratio (such as those manufactured by Bruce, Stevin, etc.), are good candidates for Modular OTEC platform SKSS. Some development of high holding power drag anchors for commercial OTEC platforms may be necessary.

- o Pretensioning of mooring lines can be accomplished by mooring winches or hydraulic line pullers. Spacewise and costwise, line pullers present important advantages. According to its manufacturer, the line puller will be capable of handling jacketed wire rope without any problems.
- o A fully automated tensioning system is not recommended, due to its high cost, development time and questionable reliability. A computer-aided control system with manual line tension adjustment is recommended for use with mooring winches or line pullers.
- o If an active tensioning system is used, the performance of SKSS can be improved by slacking off or taking up of appropriate mooring legs. For the Puerto Rico site studied in this project, by heaving the windward mooring cables, significant reductions are possible in the most loaded line tensions and in excursion radii. This effect could also be accomplished by a passive winch system, but the adjustments would be slow due to limited winch capacity.
- o The overall SKSS costs increase almost linearly with the number of mooring legs. Increasing the number of legs causes reductions in excursion radius--but only up to a certain number. For the case in this study, the Modular OTEC Barge platform, 14 legs is the critical point. Beyond this number, the reduction in excursion becomes insignificant, while costs keep increasing greatly.
- o A parametric study conducted on SKSS cost sensitivity reveals that:
 - Wire rope costs affect SKSS costs greatly. For the case in question, a 50% increase in wire rope costs brings about a 25% increase in SKSS costs.
 - Changes in winch and chain costs have a smaller, but still considerable, effect on SKSS costs. A 50% increase in the costs of these components causes a 10% increase in the overall cost.
 - Changes in the costs of other SKSS components do not affect the overall SKSS cost to any considerable extent.
- o Increasing water depths require the use of larger size mooring components and, therefore, cause increased SKSS costs. The depth of water wherein the SKSS is to be deployed will be governed by ocean bottom conditions and cold water pipe grounding limitations.
- o If, in any future SKSS design, galvanized wire rope should be used as the upper segment of mooring lines, the entire wire rope segment would have to be replaced every eight years. Additionally, the splash zone portions of the wire rope should be visually inspected every six months.
- o It is estimated, on the basis of a simple calculation which was done by scaling up the Modular plant SKSS to Commercial plant sizes, that the total combined drag forces for the commercial plant will be approximately twice those for the Modular plant. If this is indeed the case, it will be possible to develop state-of-the-art multi-leg mooring systems for the Commercial plants as

well--at least for the specified environmental conditions at the Puerto Rico site.

- o Even in this case, a Commercial OTEC Barge platform to be deployed at the Puerto Rico site would require 20 legs, using 7" diameter wire rope and 5" diameter "super" chain, of LJUSNE or equivalent manufacture.

The following recommendations are made for further development of Modular plant SKSS designs:

- o A bottom survey at the designated OTEC site to establish bathymetry, bottom slope, and bottom soil characteristics for use in detail designs.
- o Scale model tests of Platform/CWP/SKSS combination.
- o Development and testing of high holding power anchors for deployment at the designated site.
- o Investigation of cable terminations for the proposed Jacketed wire rope legs.
- o Development and testing of proposed alternative line tensioning equipment (hydraulic line pullers).

Additionally, it would be beneficial, even though not absolutely necessary, to improve the SKSS analytical models for future design efforts as follows:

- o Modify static analysis program to permit quick and inexpensive optimization of mooring leg catenaries.
- o Modify dynamic time domain simulation program to include effects of hydrodynamic cable loadings and oblique environmental loads.

SECTION 3.0

CONCEPTUAL DESIGNS

3.1 General

The basic guidelines for the conceptual design investigations, as set forth by the government, are summarized in Exhibit 1.

The scope of the first phase studies under these guidelines was to accomplish the following:

- o Establish design environmental conditions.
- o Establish design criteria.
- o Develop methodology to assess SKSS reliability and performance.
- o Develop methodology to optimize mooring design.
- o Prepare two SKSS conceptual designs for each of the two platforms, using the criteria and methodology developed, complete with life cycle costs, deployment and replacement scenarios.
- o Identify interface of SKSS with other OTEC subsystems.
- o Determine applicability of modular plant conceptual SKSS designs to commercial plant SKSS.

3.2 Design Process

3.2.1 Criteria

The design environmental conditions at the Puerto Rico site, in terms of bottom data (soil mechanics, bottom slope, etc.) and surface data (wind, waves, current) were developed on the basis of existing information in [4], [5], [6] and [7]. Extrapolation of the existing data was made where necessary and tabulations were prepared describing the wave periods, wind speeds, and current speed distributions versus depth for 13 significant wave heights ranging from 2 to 50 ft. Exhibit 2 shows such a tabulation for a sample environmental state.

In establishing the design criteria for SKSS components, all possible materials including steel, synthetic fibers, rubber and elastomers were considered. Stress criteria were established for the design operational and design extreme sea states. Essentially, factors of safety of 3 and 2 were used for the operating and survival conditions, respectively.

OTEC
10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

Conceptual Designs

BASIC REQUIREMENTS

- DESIGN OPERATIONAL SEA STATE:
 - 25' SIGNIFICANT WAVE HEIGHT
 - 40 KNOT WIND SPEED
- SURVIVAL SEA STATE:
 - 45' SIGNIFICANT WAVE
 - 94 KNOT WIND
- SERVICE LIFE : 10 YEARS
- DEPLOYMENT SITE = PUERTO RICO
- PLATFORM HULLS :
 - PILOT PLANTSHIP (BARGE) BY APL/JHU
 - SPAR WITH EXTERNAL HX BY GIBBS & COX
- EXCURSION LIMIT AT OPERATIONAL SEA STATE
 - 10 % OF WATER DEPTH

EXHIBIT 1

A. H. GLENN AND ASSOCIATES

SAMPLE ENVIRONMENTAL STATE

DATA SHEET

ENVIRONMENTAL WAVE, WIND, CURRENT STATE: APPROXIMATELY
17°57'N, 65°52'W, OFFSHORE PUNTA TUNA, PUERTO RICO,
APPROXIMATE CHART DEPTH 1200 METERS, E WAVE DIRECTION¹

Significant Wave Height, H_s	15.0 Ft.
Significant Wave Period, T_s	8.5 Secs.
Wind Speed ¹	27. Knots
Still Water Depth, d	1200. Meters

Distribution of Wave Periods

Percentage of Waves in Period Group

0 - 2.4 Secs.	0.9
2.5 - 4.4	6.9
4.5 - 6.4	20.3
6.5 - 8.4	35.6
8.5 - 10.4	26.3
10.5 - 12.4	7.5
12.5 - 14.4	1.5
14.5 - 16.4	0.5
16.5 - 18.4	0.3
18.5 Plus	0.2

Current Speed Versus Depth, Meters

0	94	Cm/Sec
100	68	
200	62	
300	52	
400	44	
500	37	
600	32	
700	29	
800	27	
900	25	
1000	24	

Probability of Exceedance of Environmental State

0.564 Percent

Note: ¹Direction from which waves move or wind blows.

EXHIBIT 2

The approaches to be used in assessing the SKSS reliability and performance and in optimizing the mooring designs were combined into one methodology which is summarized in Exhibit 3.

The generic SKSS concepts considered for the initial screening process were:

- o Spread catenary mooring
- o Tension leg mooring
- o Rotary (Turret) mooring

Despite the fact that it offers a distinct advantage for the barge platform by enabling it to weatherwane into the direction of environmental loading, the turret mooring concept was abandoned early in the study due to excessive costs, space problems, and specifically due to the need to use a slip ring type mechanism to provide passage of electrical riser cable from the barge.

Using the remaining two generic mooring concepts, i.e., the spread catenary and the tension leg mooring, a matrix of SKSS designs was prepared. Each design in the matrix was then evaluated for its:

- o Performance and reliability
- o Cost and time schedules
- o Ease of deployment/replacement procedures
- o Interface with hull/cold waterpipe/riser cable

The SKSS designs evaluated included:

- o Multi-leg spread catenary moorings for both the spar and the barge.
- o Vertical and inclined multi-leg tension moorings for the spar.

A complete range of available or development stage candidates for mooring line segments were considered including:

- o wire rope
- o chain
- o nylon hawsers
- o kevlar rope
- o hollow cylindrical links
- o solid bar links
- o tension rods

All possible candidates for other components of the mooring arrays, such as anchors, fairleads, winches, etc., were also considered and screened.

3.3.2 SKSS Analyses

Quasi-static drag calculations were made for both platforms at a range of seven environmental conditions from 2 ft. to 45 ft. significant wave heights and the associated wind and current speeds. Calculations included the determination of wind drag and current drag as well as an estimation of the slowly varying wave drift forces. Mean wave drift forces. Mean wave drift forces were calculated for both the beam sea and the head sea conditions for the barge. The values for average wave drift forces were multiplied by a factor of three to obtain the extreme loads to be used in designs.* Exhibit 4 summarizes the calculated loadings for both platforms (in beam seas for the barge).

For the conceptual designs, a straightforward static analysis procedure was used in the estimation of SKSS loads and stresses. A computer program (CALMS),** developed by Exxon [8], was used to analyze the mooring leg catenaries consisting of composite lines sometimes with riser buoys and clump weights.

* Later on in the project, during preliminary design studies, dynamic analyses of SKSS response showed that the extreme wave drift forces do exceed the mean value by a factor of slightly greater than 3. However, this does not affect the line tension response by the same ratio. Actual time histories of line tensions reveal that the maximum line tension is only greater than the mean value, by approximately 20 to 30%. (See Volume III, Table 6, page 3-29).

** See Volume II for a discussion for CALMS' limitations.

Loading on OTEC Barge in Beam Seas vs. Sea State

<u>Environmental State</u>	<u>H_s (ft.)</u>	<u>F_{wind} (LT)</u>	<u>F_{current} (LT)</u>	<u>F* drift (LT)</u>	<u>Total (LT)</u>	<u>Total (KIPS)</u>
1	2	1.47	193.59	4.08	199.14	446.07
3	6	4.25	202.85	54.6	261.7	586.21
4	8	5.88	206.77	102.3	314.95	705.49
6	15	10.72	226.41	354.6	591.74	1325.5
8	25	23.51	253.04	802.17	1078.72	2416.2
10	35	93.93	379.51	1259.1	1732.54	3880.8
12	45	129.91	467.11	2256.9	2853.92	6392.7

Loading on 40 MW OTEC Spar vs. Sea State

<u>Environmental State</u>	<u>H_s (ft.)</u>	<u>F_{wind} (LT)</u>	<u>F_{current} (LT)</u>	<u>F* drift (LT)</u>	<u>Total (LT)</u>	<u>Total (KIPS)</u>
1	2	0.83	209.35	0.57	210.75	472.08
3	6	2.36	217.28	4.08	223.72	501.13
4	8	3.24	220.52	6.09	229.85	514.86
6	15	5.93	238.13	11.49	255.55	572.4
8	25	12.99	268.90	18.75	300.64	573.4
10	35	52.0	298.95	27.57	478.52	1071.8
12	45	71.78	492.43	32.97	597.18	1337.6

* The man drift forces

by a factor of 3 to obtain maximums.

EXHIBIT 4

This program computes anchor line tensions, suspended line lengths, anchor loads, and the total horizontal restoring force as functions of assumed horizontal offsets (or excursions).

Exhibits 5 and 6 present the characteristics of catenary mooring systems resulting from conceptual designs, respectively for the Spar and the Barge platforms.

The analyses for tension leg type mooring concepts were made by considering inclined legs to form a catenary and calculating the excursion resulting from static loads. Vertical tension moorings were treated similarly but since the leg inclination angles were small they were considered to be straight.

3.3 Conclusions

At the completion of all investigations for conceptual designs, the following conclusions were reached:

1. The two best SKSS designs, satisfying the excursion limitations and providing adequate factors of safety, for the Spar platform were:
 - o 8 leg spread catenary mooring with wire rope/chain legs
 - o 3 leg vertical tension mooring
2. For the barge platform, the two best SKSS designs that satisfy the excursion and total restoring force requirements were:
 - o Single buoy mooring with support arm
 - o Four-leg spread catenary with solid bar link mooring lines.
3. The SKSS concepts recommendable for use as baseline designs in the next phase of the study were:
 - o 8 leg spread catenary with wire rope/chain lines for the Spar platform (Exhibit 7).
 - o Single buoy mooring with support arm for the barge platform (Exhibit 8).

OTEC

10/40 MW_o MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SUMMARY OF DESIGN CYCLES

Final Concept Design SPAR

WATER DEPTH AT SITE = 5470'

MOORING LEGS = 8

LEG SIZE / TYPE: 5" GALVANIZED WIRE ROPE

4" API-2F CHAIN*

CLUMP WEIGHT / RISER BUOY: 200 KIPS / 50 KIPS

PRETENSION = 19% OF BREAKING STRENGTH

UNDESIRABLE FEATURES

- ° CLUMP WEIGHTS & RISER
- ° BUOYS ARE REQUIRED

DESIRABLE FEATURES

- ° STATE OF ART COMPONENTS
- ° 1 LEG FAILURE IS ACCEPTABLE

** HIGH QUALITY CHAIN COMPLYING WITH REQUIREMENTS OF AMERICAN PETROLEUM INSTITUTE SPECIFICATIONS, API-2F, (REFERENCE 12). PREVIOUS DESIGNATIONS FOR SIMILAR QUALITY CHAIN WAS "OIL RIG QUALITY-ORQ".

EXHIBIT 5

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

BARGE FINAL CONCEPT DESIGN

WATER DEPTH AT SITE = 5470'

MOORING LEGS = 4

LEG SIZE/TYPE: 920 # FT. SOLID BAR LINK

PRETENSION: 30% OF BREAKING STRENGTH

UNDESIRABLE FEATURES

- o PIN JOINT CONNECTIONS ARE CRITICAL
- o NOT STATE OF ART (NOT PREVIOUSLY DEPLOYED)
- o COST IS VERY HIGH
- o DEPLOYMENT IS DIFFICULT

DESIRABLE FEATURES

- o COST IS SUPERIOR TO SBL FOR THIS MAGNITUDE OF RESTORING FORCE

EXHIBIT 6

JOYWAY Modular Experiment
SPAR Platform
SINSS Conceptual Design
S. Lag. Wire / Chatty Gateway
Offshore Location

40 MWe Modular Experiment
BARGE Platform
SKSS Conceptual Design
Tension Buoy Mooring

4. The applicability of these conceptual SKSS designs to larger commercial plants was found to be as follows:
 - o The 8 leg spread catenary concept does not appear to be applicable for commercial Spar platforms. The adoption of larger number of legs and use of hollow cylindrical links or solid bar links as leg components may be necessary.
 - o Single buoy mooring concept for the commercial Barge platforms may be applicable but with a larger number of tension legs and with increased leg scantlings. Otherwise, a multi-leg catenary (more than eight) with solid bar links may have to be adopted.
5. The initial acquisition costs for the recommended SKSS designs were estimated to be approximately:
 - o \$19 million for the Spar 8-leg wire/chain catenary mooring system.
 - o \$51 million for the Barge single buoy mooring system.
6. It was considered possible to meet the scheduled deployment date of mid-1984 for the Spar SKSS. Considerable development was found to be necessary for the Barge SKSS.

3.4 Overview

The results of conceptual design studies were presented to DoC/DoE on April 25, 1979 and the recommended baseline Spar SKSS concept to be used in the preliminary design stage was approved by the government.

For the Barge platform, the recommended single buoy mooring concept was considered to be not quite state-of-the-art specifically with respect to the necessary development of an electrical slip ring for transmission of 40 MW_e power.

The baseline SKSS concept assigned for the Barge platform to be used in the preliminary design studies was also a multi-point spread catenary mooring system with state-of-the-art mooring components (Exhibit 9).

SECTION 4.0

PRELIMINARY DESIGNS

4.1 General

The basic NOAA/DoE requirements for the SKSS preliminary designs are summarized in Exhibit 10. As it will be noted, an important reduction was made in the environmental conditions for the operating and survival sea states as compared to those specified for the conceptual design phase. The operational sea state was reduced from 25 ft. significant wave height to 20.1 ft., and the survival sea state from 45 ft. to 35.9 ft. This reduction was based on the most recent revision of the design wind, wave and current criteria for the Puerto Rico site by Bretschneider [9].

Another major change in the requirements was the expected design life of the OTEC SKSS which was increased to 30 years from the 10 years specified for the conceptual design phase.

4.2 Design Assumptions

Following basic assumptions were made during development of preliminary designs in order to simplify an otherwise very complex calculation procedure:

- o Using the available bathymetry charts and bottom data, the most suitable site for SKSS deployment was sought; after considering three sites with 4,000 ft., 5,200 ft., and 6,000 ft., water depth off the Southeast coast of Puerto Rico, the intermediate depth site was judged to be the best.

- o It was assumed, based on limited data available, that the largest and most frequent non-hurricane loads come from Northeast to Southeast.

- o Hurricanes were considered to have almost equal probability of occurrence from any direction.

- o The effect of Puerto Rico land mass in reducing the severity of weather from the north and northwest was neglected.*

* This effect was later considered in the parametric sensitivity analysis studies.

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

Preliminary Designs

- BASIC NOAA/DOE REQUIREMENTS
 - STATE-OF-THE-ART CATENARY MOORINGS FOR :
 - 40 MW_E MODULAR EXP - SPAR (GIBBS & COX)
 - 40 MW_E MODULAR EXP - BARGE (APL/JHU)
 - DESIGN LIFE EXPECTANCY = 30 YEARS
 - DESIGN SEA STATES :
 - OPERATIONAL : 20 FT SIGNIFICANT WAVE
(3 YEAR RETURN PERIOD)
 - SURVIVAL : 35 FT SIGNIFICANT WAVE
(100 YEAR STORM)
 - ALLOWABLE EXCURSION :
 - 10 % OF WATER DEPTH @ DOSS
 - DEPLOYMENT SITE :
 - PUNTA TUNA (PUERTO RICO)

EXHIBIT 10

- o External wind, wave and current loads for the most probable hurricane were considered to be coplanar and concurrent for the SKSS analyses.*
- o In developing life cycle costs for SKSS alternative designs, following assumptions were made:
 - Calculations for 1980 dollars
 - Interest rate : 9%
 - Resale and scrapping costs neglected

4.3 Technical Approach

In general, the design approach used in the concept evaluation stage was repeated. However, much more detailed investigations including revised drag calculations, quasi-static catenary calculations and dynamic analyses of SKSS response in the time domain were carried out.

The platform drag calculations, revised for the new operating and survival sea states, resulted in total drag values as shown in Exhibit 11. A sample plot of the quasi-static drag forces for varying significant wave heights for the Barge platform in beam seas is shown in Exhibit 12.

In obtaining the catenary solutions, Exxon's CALMS [8], Ultramarine's STAMOR [10] computer programs, and programmable desk calculators were employed. The solutions obtained from the static programs were used as input into a time domain computer program [11] together with the platform geometry, SKSS characteristics and hydrodynamic coefficients. The program computes the time history of vessel responses and provides as output:

- o Time history of platform excursion, wind-current-wave drift forces, individual line tensions, and the total SKSS restoring force.
- o Statistics of response including histograms of excursion and line tension crest and trough amplitudes and the corresponding empirical versus Rayleigh probability distributions.

* However, the effect of non-coplanar environment was also studied; See Section 5.0.

Loading on the OTEC Barge in Beam Seas vs. Sea State

<u>Condition</u>	<u>H_s (FT.)</u>	<u>F Wind (KIPS)</u>	<u>F Current (KIPS)</u>	<u>F Avg. Drift (KIPS)</u>	<u>Total Mean (KIPS)</u>
Survival	35	317.5	1073	865.1	2256
Operating	20	47.95	647.1	403.8	1099

Loading on the OTEC Spar vs. Sea State

<u>Condition</u>	<u>H_s (FT.)</u>	<u>F Wind (KIPS)</u>	<u>F Current (KIPS)</u>	<u>F Avg. Drive (KIPS)</u>	<u>Total Mean (KIPS)</u>
Survival	35	117.7	733.3	79.88	931
Operating	20	17.77	514.6	36.86	569

EXHIBIT 11

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

QUASI-STATIC DRAG COMPONENTS

The most significant result obtained from time domain analyses was that, for the duration of runs (2000 seconds), the maximum line tension and excursion values were not much larger than the mean values. This may make it possible to employ, in future SKSS designs, only a static analysis using mean values adequate for design and then applying a multiplication factor, e.g. 1.3.*.

Exhibits 13 and 14 are plots showing probability density functions for the Barge sway and Spar surge motions as computed and comparing them to exponential and Rayleigh distributions, respectively. Accordingly, the estimation of extreme values for Barge and Spar responses, these theoretical distributions were employed. Exhibit 15 summarizes the extreme values for excursion radii and most loaded line tensions for both platforms.

The extreme values calculated in this manner were used in determining if the specific SKSS design meets the extreme failure criteria; the time histories of responses did not indicate any resonance phenomena for the duration of runs.

In meeting the fatigue failure criteria, the stress range was calculated directly from the time domain output for the total number of cycles involved, and was found to be extremely small for both platforms even in the survival condition.**

It was concluded that the finalized SKSS designs meet both the extreme load and fatigue failure criteria.

4.4 Design Iterations

Starting with the catenary mooring systems of final concept design stage presented in Section 3.2.2 (Exhibits 5 and 6) and taking into consideration the changes in major requirements for the preliminary design stage, a number of design cycles were performed for both platforms.

* See Section 3.2.4 of Volume III for a complete discussion of the effects of mooring cable hydrodynamic loading and vortex shedding phenomena, and section 3.3.3 of this volume for an explanation of the multiplication factor of 1.3.

** See section 3.2.6 of Volume III for further details.

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

BARGE SWAY MOTION

EXHIBIT 13

OTEC

10/40 MW₆ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SPAR SURGE MOTION

EXHIBIT 14

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

CONDITION	<u>EXCURSION RADIUS (FT.)</u>			<u>MOST LOADED LINE TENSION (KIPS)</u>		
	MEAN	RMS	EXTREME VALUE	MEAN	RMS	EXTREME VALUE
<u>SPAR</u>						
OPERATING **	398	6.77	437	665	5.95	699
SURVIVAL **	592	8.34	635	862	9.36	910
<u>BARGE</u>						
OPERATING **	502	20.3	619	798	18.71	934
SURVIVAL **	846	23	935	1223	38.2	1545
SURVIVAL ***	755	46.3	1098	1062	53.2	1651

** WITH COPLANAR ENVIRONMENTAL LOADS

*** WITH ASSUMED NON-COPLANAR ENVIRONMENTAL LOADS

EXTREME VALUE RESULTS

EXHIBIT 15

The aforementioned three iterations constituted the first design cycle for the Spar. In the second cycle, a baseline design was established. The basic characteristics of this design are summarized in Exhibit 16.

The Barge platform's SKSS iterations included consideration of a 16-point catenary with 7" wire rope/6" chain and a 12-point catenary with 5½" wire rope/5 1/8" chain. Exhibit 17 shows the characteristics of the baseline design which resulted from the 2nd cycle.

Both baseline designs use the following SKSS components:

- o Two segment mooring legs.
- o Galvanized wire rope
- o ABS Grade 3 chain
- o Drag anchors of high holding power.
- o Passive winch system with manual controls.

4.5 Alternatives to Baseline Designs

The performance and reliability of the baseline designs may be altered, and in some cases improved, by substituting alternative SKSS components. Major alternatives are:

- o Polyethylene jacketed wire rope in lieu of galvanized.
- o Oil rig quality "ORQ", or as it is presently referred to "API-2F", chain [12] in lieu of Grade 3.
- o Deadweight anchors instead of drag anchors.
- o Active winch systems with automatic controls in place of passive systems.
- o Hydraulic line pullers instead of tensioning winches.

Exhibit 18 lists all possible combinations of SKSS components using these alternatives for the Barge platform. The alternatives for the Spar platform are the same except for scantlings of components.

As it can be seen, five distinct alternative SKSS designs are possible as variations of the baseline design. A sixth alternative, not shown in Exhibit 18 but later included in cost comparisons of

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SPAR - CYCLE 2

WATER DEPTH AT SITE = 4900'

OF MOORING LEGS = 8

LEG SIZE/TYPE: 5" GALVANIZED WIRE ROPE

4 1/2" GRADE 3 CHAIN

PRETENSION: 19% OF BREAKING STRENGTH

UNDESIRABLE FEATURES

- o GALVANIZED WIRE ROPE
REQUIRES PERIODIC
REPLACEMENT AND
MAINTENANCE

DESIRABLE FEATURES

- o ALL COMPONENTS ARE
STATE OF ART AND
EXCEPT FOR ANCHORS
ARE AVAILABLE IN U.S.
- o CHAIN UPPER END CAN
BE RAISED TO SURFACE

EXHIBIT 16

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

BARGE - CYCLE 2

WATER DEPTH AT SITE = 4900'

OF MOORING LEGS = 12

LEG SIZE/TYPE: 5 1/2" DIA. GALVANIZED WIRE ROPE
5 1/8" CHAIN

PRETENSION: 17% OF THE BREAKING STRENGTH

UNDESIRABLE FEATURES

- EXCURSION OF 502' IS SOMEWHAT HIGH

DESIRABLE FEATURES

- LINE SIZE IS VERY CLOSE TO OPTIMUM
- COMPONENTS ARE AVAILABLE IN U.S.

EXHIBIT 17

OTEC

10/40 MW₀ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SKSS COMPONENT	BARGE ALTERNATIVES				
	A	B	C	D	E
WIRE ROPE	5 1/2" DIA. CALV. IWRC	5 1/2" DIA. POLYETH. JACKET IWRC	5 1/2" DIA. GALV. IWRC	5 1/2" DIA. GALV. IWRC	5 1/2" DIA. GALV. IWRC
CHAIN	5 1/8" GR 3	4 1/2" ORQ	5 1/8" GR 3	5 1/8" GR 3	5 1/8" GR 3
ANCHOR	BRUCE FABRI. PICK ANCHOR	BRUCE PICK ANCHOR	BRUCE PICK ANCHOR	DEADWEIGHT WITH SKIRTS	BRUCE PICK ANCHOR
WINCH	INTERCON WINCH PASSIVE	INTERCON WINCH PASSIVE	INTERCON WINCH ACTIVE	INTERCON WINCH PASSIVE	LINE PULLER PASSIVE
WINCH CONTROLS	MANUAL	MANUAL	AUTOMATIC	MANUAL	MANUAL

BARGE ALTERNATIVE SKSS DESIGNS

EXHIBIT 18

Section 4.9, utilize jacketed wire rope and ORQ chain in combination with drag anchors and hydraulic line pullers with manual control.

4.6 Reliability and Performance Analysis

In comparing the performance and reliability of the alternative designs and selecting the most promising ones, the "system worth" is used as a measure of merit.

System worth is made up of two basic components: system cost and system effectiveness. The cost estimates are included in section 4.9 for all alternative designs and the life cycle costs presented therein are used directly in this evaluation.

The system effectiveness is determined by considering three parameters: reliability, performance, and the effect of "burden variables". Reliability is assessed in terms of the system's capability to withstand failure under extreme loads and fatigue loads by considering the design factor of safety and the expected fatigue life.

The excursion radius at the operating condition is used as a measure of performance. Each alternative SKSS design is evaluated on the basis of the degree to which it meets the excursion requirements.

"Burden Variables" are such factors as the weight - space requirements, development - construction - deployment times and relative complexities of the systems.

All of these factors are evaluated by means of quantitative (and when necessary qualitative) considerations and grades assigned to each category of system effectiveness. Each category is then assigned a weighting factor to reflect the relative importance of that category in SKSS design:

Reliability = 50 %

Performance = 40 %

Burden Variables = 10 %

By the use of a decision matrix in which the individual grades for different alternative designs are first normalized and then multiplied by the weighting factors, an overall value for system effectiveness is obtained.

Exhibit 19 is a sample decision matrix for the Barge platform's alternative SKSS designs and shows the development of a measure of merit for system effectiveness. In Exhibit 20, the effectiveness values developed in this manner for all alternative SKSS designs of both platforms and the life cycle costs in terms of "Average Annual Costs" from Section 4.9 are listed.

It can be seen that the lowest cost and highest effectiveness are obtainable with Alternative B which uses jacketed wire rope and ORQ chain with high holding power drag anchors, passive winches, and manual controls. Further reduction in costs is possible when hydraulic line pullers are used in lieu of tensioning winches, (see section 4.9).

4.7 Description of Preliminary SKSS designs

Preliminary design drawings, deployment scenarios, and maintenance/replacement scenarios are developed for the baseline SKSS designs corresponding to Alternative B. Due to potential cost savings and simplicity in arrangement possible through the use of hydraulic line pullers in place of tensioning winches, the alternative line puller arrangements are also included on the Spar and Barge SKSS drawings. A complete set of drawings is appended in Volume 3 of this report [2].

The Barge and Spar platform SKSS descriptions for the baseline designs are summarized in Exhibits 21 and 22. Exhibits 23 and 24 are artist's conceptions of the respective mooring designs. The principal design characteristics of the mooring systems are summarized in Exhibit 25.

4.8 Deployment and Replacement Scenarios

Deployment scenarios are presented in detail in the preliminary design drawings included in Volume 3. The equipment required for the deployment of Barge platform SKSS are listed in Exhibit 26. Exhibit 27 depicts the first stage of the deployment process, again for the Barge. The scenario for the Spar platform SKSS is essentially the same with minor changes only.

The scenario for maintenance and replacement of SKSS components is summarized in Exhibit 28.

DECISION MATRIX - BARGE

CATEGORY	EVALUATION FACTORS	ALTERNATIVE SKSS DESIGNS				
		A	B	C	D	E
BURDEN VARIABLES (Weight: 10%)	Hull Interface - Weight	5	5	3	5	7
	Hull Interface - Space					
	Development Time	5	5	3	5	4
	Construction Time					
	System Complexity	10	10	7	7	7
	Average for Burden Variables	6.7	6.7	4.3	5.7	6
PERFORMANCE (Weight: 40%)	Excursion at Oper. Cond.	5	5.9	8.9	5	5
	Excursion at Survival Cond.	1	1.1	4.3	1	1
	Average for Performance	3	3.5	6.1	3	3
RELIABILITY (Weight: 50%)	F.S. at Intact Survival	5.3	5.1	6.3	5.3	5.3
	F.S. at Damaged Survival	3.8	3.8	4.5	3.8	3.8
	Fatigue Life	2.5	10	2.5	2.5	2.5
	Average for Reliability	3.9	6.3	4.4	3.9	3.9
Measure of Merit for System Effectiveness		0.17	0.24	0.24	0.17	0.17
Rank Based on System Effectiveness		2	1	1	2	2
SKSS Average Annual Cost in \$K		4100.9	3588.3	4344.2	5938.2	3702.4

OTEC

10/40 MW_g MODULAR PLATFORM STATION KEEPING SUBSYSTEMS

<u>ALTERNATIVE</u>	<u>S P A R</u>		<u>B A R G E</u>	
	<u>EFFECTIVENESS</u>	<u>COST \$K</u>	<u>EFFECTIVENESS</u>	<u>COST \$K</u>
A	0.19	2514.2	0.17	4100.9
B	0.22	2128.3	0.2 ^L	3588.3
C	0.22	2620.2	0.17	4344.2
D	0.19	3665.2	0.17	5938.2
E	0.19	2289.4	0.17	3702.4

SYSTEM WORTH EVALUATION

O T E C

10/40 MW₆ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

DESCRIPTION OF SKSS COMPONENTS

NUMBER OF MOORING LEGS 12

WIRE ROPE

5 1/2 NOMINAL DIAMETER
6 1/2 OD WITH JACKET
8 X 37 1WRC UNIT LAY
MONITOR AA STEEL
BREAKING STRENGTH = 2,567 KIPS

WIRE ROPE ROPE LENGTHS

(LINES 1,2,11,12) = 5,000'
(LINES 3,4,9,10) = 4,500'
(LINES 5,6,7,8) = 5,500'

POLYETHYLENE JACKET

HIGH DENSITY POLYETHYLENE - ASTM
D 1248 TYPE III, CATEGORY 5,
CLASS C, GRADE J4, PRESSURE
EXTRUDED

CHAIN

4 1/2' API SPEC 2F STUD
LINK CHAIN
BREAKING STRENGTH: 2508 KIPS

CHAIN LENGTHS

(LINES 1,2,11,12) = 5,000'
(LINES 3,4,9,10) = 5,500'
(LINES 5,6,7,8) = 5,550'

ANCHORS

HIGH HOLDING POWER DRAG
EMBEDMENT TYPE. POSSIBLE
ALTERNATIVES INCLUDE BRUCE
FABRICATED PICK, STEVMUD AND
HOOKMUD ANCHORS.

HOLDING FORCE REQ'D: 997 KIPS
WEIGHT OF ANCHOR: 50 KIPS

RECOMMENDED SKSS CHARACTERISTICS FOR THE BARGE PLATFORM

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

WINCHES

RATED FOR 1,000 KIP - PULL
AT STALL (SIZED FOR PASSIVE
SYSTEM).

WITH GE-581 GENERAL ELECTRIC
TRACTION GENERATORS FOR THE
D.C. MOTOR.

CONTROL SYSTEM

- o COMPUTER WITH 16 BIT WORD,
16K BITS OF STORAGE
CAPACITY
- o PRINTER - SILENTPRINTER
700 TYPE

PRIME MOVER GENERATOR SET

CAT D-399 DIESEL ENGINE RATED
AT 1,200 HP DRIVING A GENERAL
ELECTRIC MODEL 581 GENERATOR,
4 UNITS

PERFORMANCE CHARACTERISTICS

PRETENSION - 513 KIPS
EXCURSION RADIUS :
AT OPERATING CONDITION 480'
AT SURVIVAL CONDITION 813'
MOST LOADED LINE TENSION:
AT OPERATING CONDITION 858 KIPS
AT SURVIVAL CONDITION 1,260 KIPS
EXTREME LINE TENSION; 1,506 KIPS
EXTREME HOLDING FORCE; 997 KIPS

BARGE SKSS - Cont'd

OTEC

10/40 MW₆ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

DESCRIPTION OF SKSS COMPONENTS

NUMBER OF MOORING LEGS = 8

WIRE ROPE

5" NOMINAL DIAMETER

6" OD WITH JACKET

8 X 37 1WRC UNIT LAY

MONITOR AA STEEL

BREAKING STRENGTH = 2,156 KIPS

WIRE ROPE ROPE LENGTHS

(LINES 1,2,3,7,8) = 5,000'

(LINES 4,5,6) = 5,700'

POLYETHYLENE JACKET

HIGH DENSITY POLYETHYLENE - ASTM
D 1248 TYPE III, CATEGORY 5,
CLASS C, GRADE J4,
PRESSURE EXTRUDED

CHAIN

4 - 1/8" API SPEC 2F
STUD LINK CHAIN
BREAKING STRENGTH - 2,063 KIPS

CHAIN LENGTHS

(LINES 1,2,3,7,8) = 5,000'

(LINES 4,5,6) = 5,360'

RECOMMENDED SKSS CHARACTERISTICS FOR THE SPAR PLATFORM

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

ANCHORS

HIGH HOLDING POWER DRAG EMBEDMENT
TYPE. POSSIBLE ALTERNATIVES
INCLUDE BRUCE FABRICATED PICK,
STEVEMUD AND HOOKMUD ANCHORS.
HOLDING FORCE REQ'D : 553 KIPS
WEIGHT OF ANCHOR : 28 KIPS

WINCHES

RATED FOR 1,000 KIP -
PULL AT STALL
(SIZED FOR PASSIVE SYSTEM)
WITH GE-581 GENERAL ELECTRIC
TRACTION GENERATORS FOR THE
D.C. MOTOR.

PRIME MOVER GENERATOR SET

CAT D-399 DIESEL ENGINE
RATED AT 1,200 HP DRIVING A
GENERAL ELECTRIC MODEL 581
GENERATOR, 2 UNITS

CONTROL SYSTEM

- o COMPUTER WITH 16 BIT WORD,
16K BITS OF STORAGE
CAPACITY
- o PRINTER -
SILENTPRINTER 700 TYPE

PERFORMANCE CHARACTERISTICS

	OPERATING CONDITION	SURVIVAL CONDITION
PRETENSION - 420 KIPS	---	---
EXCURSION RADIUS	447'	622'
MOST LOADED LINE TENSION	690 KIPS	870 KIPS
EXTREME 9LINE TENSION/HOLDING FORCE) : 923/553 KIPS		

SPAR SKSS - Cont'd

EXHIBIT 22-B

CIV

SKSS - Preliminary Design
For 10/40 MWe
Modular BARGE Platform

MR&S

SKSS - Preliminary Design
For 10/40 MWe
Modular SPAR Platform

MR&S

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

PRINCIPAL DESIGN CHARACTERISTICS

- o 10% OF THE DEPTH ALLOWABLE EXCURSION IS MET, ALTHOUGH IN SOME CASES EXTREME EXCURSIONS EXCEED THIS LIMIT. IF A MARGINAL REDUCTION IN WATCH CIRCLE RADIUS IS REQUIRED, THEN A SEMI-ACTIVE OR FULLY ACTIVE SYSTEM WOULD BE THE MOST ECONOMICAL SOLUTION.
- o ACCEPTABLE FACTORS OF SAFETY ARE MAINTAINED IN THE OPERATIONAL AND SURVIVAL CONDS., (3 FOR OP., 2 FOR SURV.)
- o ONE LEG FAILURE IS ACCEPTABLE FOR BOTH PLATFORMS ALTHOUGH FOR THE BARGE IT IS RECOMMENDED THAT SOME LINE SCOPE ADJUSTMENT BE MADE TO INCREASE THE FACTOR OF SAFETY OVER THE MEAN LEVEL.
- o ALL SYSTEM COMPONENTS ARE REGARDED AS STATE OF THE ART.
- o MOST COMPONENTS CAN BE PURCHASED FROM U.S. MANUFACTURERS WITH THE EXCEPTION OF HIGH HOLDING POWER ANCHORS.
- o ALL MAJOR COMPONENTS ARE EXPECTED TO HAVE A 30 YEAR LIFE; HOWEVER, PERIODIC INSPECTION MUST BE CONDUCTED TO CONFIRM THIS FOR WIRE ROPE AND CHAIN.
- o INTERFERENCE WITH OTHER PLATFORM SUBSYSTEMS HAS BEEN MINIMIZED AS MUCH AS POSSIBLE.

EXHIBIT 25

OTEC

10/40 MW₀ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

EQUIPMENT REQUIRED FOR SKSS DEPLOYMENT

1. ONE 500 TON CRANE BARGE HAVING A LOW CAPACITY WILDCAT OR HIGH CAPACITY BRAKE, AND A 6" WIRE ROPE LINE PULLER; FOUNDATION ON DECK FOR PLACING WIRE REELS.
2. ONE 2,200 DWT. CAPACITY BARGE WITH ALL THE WIRE ROPE AND REELS ON BOARD.
3. ONE 3,000 HP TOWING TUG.
4. FOUR 1,900 DWT. DECK BARGES WITH TIERS.
5. A 3,000 HP TOWING TUG.
6. ONE 5,000 HP TUG WITH 250,000 LB. TOWING WINCH, AND 20,000 FEET OF TWO-INCH SUPER HTS CROWN LINE ON A MOUNTED STOWAGE REEL.
7. ONE 400 L.T. DECK BARGE.
8. THREE 5,000 HP TUGS.
9. TWO 1,500 HP TUGS.
10. CHAIN AND WIRE STOPPERS, SLINGS, MARKER BUOYS, PELICAN HOOKS, ETC.
11. COMPLETE COMMUNICATIONS GEAR (WALKIE-TALKIE SPECIAL BAND RADIOS, ETC.), FOR COORDINATING THE ACTIVITIES.

EXHIBIT 26

OTEC
10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

PLAN VIEW

PROFILE A-A

① DEPLOYING ANCHOR & CHAIN WITH DEPLOYMENT BARGE
& TUG WITH CROWN LINE

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

MAINTENANCE / REPLACEMENT

- WINCHES, ANCHORS, SEABED CHAIN AND JACKETED WIRE ROPE ARE EXPECTED TO HAVE A 30 YEAR LIFE.
- CONSIDERATION FOR POSSIBLE REPLACEMENT OF UPPER SEGMENT OF JACKETED WIRE ROPE IS CONSIDERED IN SENSITIVITY ANALYSIS.
- IF GALVANIZED WIRE ROPE IS USED (WITHOUT JACKET):
 - THE ENTIRE GALVANIZED WIRE ROPE SEGMENT IS EXPECTED TO BE REPLACED EVERY EIGHT YEARS. A LINE CHASER IS USED TO BRING THE WIRE ROPE/CHAIN CONNECTION TO THE SURFACE. THE RECOVERY PROCEDURE IS THE REVERSE OF THE DEPLOYMENT PROCEDURE.
 - A VISUAL INSPECTION OF THE UPPER SEGMENT OF THE GALVANIZED WIRE ROPE SHOULD BE MADE EVERY 6 MONTHS.
 - THE LOWER CABLE SEGMENTS SHOULD BE INSPECTED EVERY 4 YEARS USING AN RCV.

4.9 Cost/Time Analyses

The basic guidelines and assumptions used in estimating SKSS costs are summarized in Exhibit 29. In calculating the initial acquisition costs, the format shown in Exhibit 30 is used in which the cost items are listed in compliance with DoE's "Work Breakdown Structure" [13].

For each of the five alternative SKSS designs presented in Section 4.5, and in addition for a variation of alternative B using hydraulic line pullers instead of winches, the initial acquisition costs, annual operating costs, and replacement costs over the expected SKSS design life are estimated. Shown in Exhibit 30 is a sample cost estimate for the Spar SKSS design Alternative A which uses galvanized wire rope and Grade 3 chain mooring lines.*

Life cycle costs are developed in terms of average annual costs and present values in accordance with a procedure described in [14] and excerpted in Section 4.2 of Volume III, (Reference 2).

The resulting SKSS cost estimates are listed in Exhibits 31 and 32 for the Barge and Spar platforms respectively.

In view of the fact that all SKSS components for the recommended baseline preliminary designs are state-of-the-art and either available off-the-shelf or procurable within reasonable lead times, it is projected that the systems can be deployed and made operational in the third quarter of 1984 which is the original target date for the Modular Experiment Platform deployment as foreseen in the DoE's program plan [5].

A time schedule showing the various phases of SKSS development is shown in Exhibit 33.

*Note that Grade 3 chain was used only as a design iteration, and is not recommended for use in deep water moorings.

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SKSS COSTS

- o SKSS COSTS ARE DETERMINED IN TERMS OF AVERAGE ANNUAL COST AND PRESENT VALUE
- o ASSUMED INTEREST RATE IS 9%
- o SCRAPPING AND RESALE COSTS ARE NEGLECTED
- o REPLACEMENT OF GALVANIZED WIRE ROPE IS ANTICIPATED EVERY EIGHT YEARS
- o CHAIN AND JACKETED WIRE ROPE IS EXPECTED TO HAVE A 30 YEAR LIFE
- o A 12.5% CONTINGENCY COST IS APPLIED TO THE DEPLOYMENT COST ESTIMATE TO ALLOW FOR:
 - POSSIBILITY OF LOSS OF FAVORABLE WEATHER WINDOW WITH RESULTING DOWNTIME DURING DEPLOYMENT
 - POSSIBILITY OF HAVING TO TRANSPORT SERVICE EQUIPMENT FROM PORTS OTHER THAN NEW ORLEANS RESULTING IN HIGHER TRANSPORTATION COSTS

BREAKDOWN OF SPAR SKSS COSTS

WORK BREAKDOWN STRUCTURE	COST - \$ x 10 ³
3.1.2.1.1 INITIAL COSTS, P	
a. SKSS COMPONENTS	
Anchors	
Drag	170
DWT	
Mooring Legs	
Wire	4,091
Chain	5,154
Terminations	211
Shackles, Chain Links	152
Deck Equipment	
Winches	4,800
D.C. Motors	320
Diesel Generators	336
Fairleads	552
Hawse Pipes	189
Control System	228
SUBTOTAL, SKSS COMPONENTS	16,204
b. DEPLOYMENT/INSTALLATION	2,124
c. CONTRACT AND DETAIL DESIGN	810
TOTAL, P	19,138
3.1.2.1.2 ANNUAL OPERATING COST, Y	
a. ROUTINE MAINTENANCE	81
b. OPERATING PERSONNEL	160
TOTAL, Y	241
3.1.2.1.3 REPLACEMENT COSTS, T _N	
a. WIRE SEGMENTS	4,091
b. INSTALLATION	706
TOTAL, T _N	4,797

OTEC

 10/40 MW₀ MODULAR PLATFORM
 STATION KEEPING SUBSYSTEMS

SKSS ALTERNATIVE	COSTS: \$ X 10 ⁻³		
	INITIAL	AVERAGE ANNUAL	PRESENT VALUE
A. 5½" GALVANIZED WR 5 1/8" GRADE 3 CHN MANUAL WINCH CONTROL BRUCE ANCHOR	32,096	4,100	42,147
B. 5½" JACK. WR 4½" ORQ CHN MANUAL WINCH CONTROL BRUCE ANCHOR	35,234	3,588	36,879
C. 5½" GALV. WR 5 1/8" GR. 3 CHN AUTOMATIC WINCH CONTROL BRUCE ANCHOR	34,597	4,344	44,648
D. 5½" GALV. WR 5 1/8" GR. 3 CHN MANUAL WINCH CONTROL DWT ANCHOR	50,979	5,938	61,030
E. 5½" GALV. WR 5 1/8" GR. 3 CHN MANUAL LINE PULLER CONTROL BRUCE ANCHOR	24,549	3,367	34,600
F. 5½" JACK. WR 4½" ORQ CHN MANUAL LINE PULLER CONTROL BRUCE ANCHOR	27,686	2,854	29,330

COST ESTIMATES

BARGE ALTERNATIVE SKSS DESIGNS

OTEC

 10/40 MW₀ MODULAR PLATFORM
 STATION KEEPING SUBSYSTEMS

SKSS ALTERNATIVE	COSTS: \$ X 10 ⁻³		
	INITIAL	AVERAGE ANNUAL	PRESENT VALUE
A. 5" GALVANIZED WR 4½" GRADE 3 CHN MANUAL WINCH CONTROL BRUCE ANCHOR	19,318	2,514	25,840
B. 5" JACK. WR 4 1/8" ORQ CHN MANUAL WINCH CONTROL BRUCE ANCHOR	20,807	2,128	21,873
C. 5" GALV. WR 4½" GR. 3 CHN AUTOMATIC WINCH CONTROL BRUCE ANCHOR	20,228	2,620	26,929
D. 5" GALV. WR 4½" GR. 3 CHN MANUAL WINCH CONTROL DWT ANCHOR	30,968	3,665	37,669
E. 5" GALV. WR 4½" GR. 3 CHN MANUAL LINE PULLER CONTROL BRUCE ANCHOR	15,157	2,127	21,859
F. 5" JACK. WR 4½" ORQ CHN MANUAL LINE PULLER CONTROL BRUCE ANCHOR	16,824	1,797	18,468

COST ESTIMATES

SPAR ALTERNATIVE SKSS DESIGNS

OTEC
10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

TIME SCHEDULE

SECTION 5.0

PARAMETRIC SENSITIVITY ANALYSES

Certain assumptions and choices had to be made in developing the baseline preliminary designs. In order to analyze the effect of changes in these assumptions and choices on the SKSS costs and performance, sensitivity studies are conducted by varying some of the parameters. Using the Barge SKSS with 12 leg catenary mooring array as the base design, the sensitivities of following parameters are investigated:

- o Allowable excursion
- o Changing line tension
- o Changing environmental loads' direction and magnitudes
- o Number of mooring legs
- o Water depth at site
- o Cost assumptions

Exhibits 34 thru 41 present the results of these parametric studies.

As it can be seen in Exhibit 34, the excursion (watch circle radius) is controlled by the amount of pretension applied on mooring legs. In general, the higher the pretension, the lower the resulting excursion; however, SKSS costs are expected to increase with increasing pretension levels.

By changing the pretension levels of individual mooring lines relative to each other, the performance and reliability of the SKSS can be improved. This is summarized in Exhibit 35 where the line numbers refer to the numbering system for the Barge SKSS shown in Exhibit 36. It is obvious that by slacking off and/or taking up appropriate lines, the excursion performance and the most loaded line tension can be greatly improved in comparison to the base design.

In Exhibit 37, the impact on system costs of SKSS responses for a number of assumed variations in the direction and magnitude of environmental loads are summarized.

Four variations are analyzed:

1. Full environmental load from the south
(baseline design)
2. Full environmental load from the north.

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

OTEC BARGE INTERMEDIATE SITE

SENSITIVITY ANALYSIS VARIATION IN PRETENSION

EXHIBIT 34

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

OTEC BARGE INTERMEDIATE SITE

Condition	Excursion Ft.	Most Loaded Line Tension KIPS	Change from the Reference Condition	
			Excursion Ft.	Most Loaded Line Tension KIPS
I Slack Line 7 - 200 ft.				
Operational	568	794	+48	- 30
Survival	890	1150	+30	-155
II Slack Line 7 - 200 ft.; Lines 1, 2, 3, 11, 12 - 1000 ft.				
Operational	460	710	-60	-115
Survival	860	1110	0.0	-195
III Slack Lines 1, 2, 3, 11, 12 - 1000 ft.				
Operational	425	723	-95.0	-102
Survival	825	1220	-35.0	- 85
IV Take Up Lines 6 & 8 - 100 ft.				
Operational	330	795	-190	- 30
Survival	640	1225	-220	- 80
V Take Up Lines 6 & 8 - 100 ft.; Slack Lines 1, 2, 3, 11, 12 - 1000 ft.				
Operational	212	685	-308	-140
Survival	575	1100	-285	-205
REFERENCE CONDITION (no line scope change) (Baseline Design)				
Operational	520	825	None	None
Survival	860	1305	"	"

**VARYING WATCH CIRCLE
RADIUS AND MOST LOADED
LINE TENSION BY
VARYING MOORING LINE SCOPE**

OTEC
10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

BARGE MOORING MAP

OTEC

10/40 MW₀ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

OTEC BARGE INTERMEDIATE SITE

Load and Direction	Lines	Wire	Chain	Operation		Survival		Cost \$ x 10 ⁻³
				e ft.	Tmax KIPS	e ft.	Tmax KIPS	
1) From South Operational = 1150 KIPS Survival = 2313 KIPS	1 2 11 12 3 4 9 10 5 6 7 8	5" 5 1/2" "	4 5/8" 5 1/8" "	500	826	840.0	1270	32,530
2) From North Same as (1)	1 2 11 12 3 4 9 10 5 6 7 8	5" 5 1/2" "	4 5/8" 5 1/8" "	540	680	922	1080	32,530
3) Operational = 706 KIPS Survival = 1477 KIPS Current from East and Wind and Waves from South	1 2 11 12 3 4 9 10 5 6 7 8	4 1/2" " "	4.0" " "	507.0	505.0	865.0	820.0	26,158
4) Operational = 690 KIPS Survival = 1388 KIPS 40% Reduction for N.W. Loads	1 2 11 12 3 4 9 10 5 6 7 8	3 3/4" 5 1/2" "	4.0" 5 1/8" "	400.0	473.0	712.0	670.0	30.751

e = Excursion Tmax = Most Loaded Line Tension

VARIATION IN DIRECTION AND MAGNITUDE OF ENVIRONMENTAL LOADS

3. Non-coplanar loads - current from the east, wind and waves from the south.
4. 40% reduction in loads from the northwest (effect of the Puerto Rican land mass).

As seen, the best improvement in performance can be obtained with variation 4 above, if indeed a 40% reduction in loads can be expected, as assumed. Variation 3, with the assumed non-coplanar loads, gives considerably smaller line tensions, and, therefore, reduced costs, with only a very small increase in watch circle radius.

By increasing the number of legs, some improvement is obtained in the excursion performance up to about 14 legs. Beyond that, the reduction in excursion is insignificant, while the SKSS costs increase drastically. This is demonstrated in Exhibit 38.

The sensitivity of OTEC SKSS costs to increasing water depth is analyzed for the baseline Spar platform mooring design. As it can be seen in Exhibit 39, costs increase almost linearly with increased water depth at site.

The sensitivity of SKSS system costs to variations in the costs of individual components such as wire rope, chain and winches is presented in Exhibit 40. Effects of variation in anchor costs and in the assumed interest rate are summarized in Exhibit 41. Also shown in Exhibit 41 are the cost changes due to introduction of upper segment mooring cable replacement after fifteen years and scheduling of a major inspection of mooring cables every four years.

It is clear that changes in wire rope costs drastically influence the overall SKSS cost; for a 50% increase in wire rope cost, the system cost increases by 23%. Chain and winch cost increases of 50%, introduce system cost increases of over 10%.

All of the other parameters have very insignificant effects on the total SKSS cost.

OTEC
10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SENSITIVITY ANALYSIS
VARIATION IN NUMBER OF LINES

EXHIBIT 38

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

SENSITIVITY ANALYSIS

OTEC SPAR (8 pt moor)
ALL EXCURSIONS APPROXIMATELY
10% OF DEPTH AT SITE

VARIATION IN WATER DEPTH

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

PARAMETER	INITIAL COST P	ANN. OPER COST Y	REPL. COST TN	PRESENT VALUE PV	AVERAGE ANN. COST AAC	% CHANGE
BASE DESIGN	35,235	160	--	36,879	3,588	--
50% INCREASE IN WIRE ROPE COST	43,624	160	--	45,268	4,404	+ 23
50% DECREASE IN WIRE ROPE COST	28,846	160	--	28,490	2,772	- 23
50% INCREASE IN CHAIN COST	39,409	160	--	41,053	3,994	+ 11
50% DECREASE IN CHAIN COST	31,061	160	--	32,705	3,182	- 11
50% INCREASE IN WINCH COST	40,187	160	--	41,831	4,070	+ 13
50% DECREASE IN WINCH COST	30,283	160	--	31,927	3,106	- 13

COST SENSITIVITY ANALYSIS

EXHIBIT 40

OTEC

10/40 MW_e MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

PARAMETER	INITIAL COST	ANN. OPER COST Y	REPL. COST TN	PRESENT VALUE PV	AVERAGE ANN. COST AAC	% CHANGE IN PV
BASE DESIGN	35,235	160	--	36,879	3588	--
50% INCREASE IN ANCHOR COST	35,474	160	--	37,118	3612	+ .7
50% DECREASE IN ANCHOR COST	34,995	160	--	36,639	3565	- .7
50% INCREASE IN INTEREST RATE	35,235	160	--	36,393	5026	- 1.3
50% DECREASE IN INTEREST RATE	35,235	160	--	37,841	2323	+ 2.6
REPLACE UPPER SEGMENTS AFTER 15 YRS.	35,235	160	4744	39,181	3715	+ 3.5
MAJOR IN- SPECTION EVERY 4 YRS.	35,235	160	756	38,551	3751	+ 4.5

COST SENSITIVITY ANALYSIS

EXHIBIT 41

SECTION 6.0

DEVELOPMENT AND TESTING RECOMMENDATIONS

Before attempting a final SKSS design for OTEC modular Platforms, it is considered necessary to verify some of the simplifying assumptions made in the development of preliminary designs.

The type of tests foreseen are:

- o Model basin tests of Platform/Cold Water Pipe/SKSS combination.
- o Oceanographic data surveys at site.
- o SKSS component tests.

Additionally, a need is recognized to improve the analytical models to be used in the static and dynamic analyses of SKSS responses.

Model basin tests could be performed with 1/50 to 1/100 scale models. Simulation of the hull/cold water pipe coupling effects and of the mooring systems spring constants would have to be accomplished. Tests could be run at the operational and survival sea states with corresponding winds, currents, and irregular waves. For each sea state the six motion components, mooring line tensions, and wave drift forces could be measured.

Exhibit 42 summarizes budgetary cost estimates for above described model basin tests from two European facilities. The costs, in U.S. dollars, range from \$130,000 to \$165,000. It is estimated that roughly the same extent of tests could cost less if performed in the United States.

Oceanographic data surveys should cover:

- o bathymetric surveys to define bottom contours.
- o geotechnical surveys to determine soil conditions at site.

The cost of such a survey was quoted by one prospective surveyor to range from \$60,000 to \$200,000 depending on the extent and duration of surveys.*

It would be desirable to have complete wave spectra records specifically for severe sea states for long term analysis of SKSS responses.

* \$60,000 for the first phase only of a two-phase survey, \$200,000 for combined phases 1 and 2.
See Section 6.2.3 of Volume III for more detail.

OTEC

10/40 MW₀ MODULAR PLATFORM
STATION KEEPING SUBSYSTEMS

	DSRL DANISH KRONE $\times 10^{-3}$	NSMB H. FLORIN $\times 10^{-3}$
MODEL MANUFACTURE	143	53
TEST SET-UP & SIMULATION	149	56
TESTS FOR :		
6 MOTION COMPONENTS		
LINE TENSIONS		
WAVE DRIFT FORCES	240	160
HYDRODYNAMIC COEFF	45	32
ANALYSIS & REPORTING	90	30
TOTAL	667 (~\$ 133,000)	331 (\$ 165,000)

BUDGETARY MODEL BASIN TEST COSTS BY TWO EUROPEAN SHIP MODEL BASINS

However, such an undertaking is costwise prohibitive and therefore not recommended. Designing mooring systems with existing data and hindcasting techniques is possible. Additional data would have been useful for designing with lower factors of safety.

Similarly, from a cost and scheduling standpoint, any extensive testing of critical SKSS components does not appear appropriate at this time. However, full scale anchor tests, chain and wire rope tests and winch performance tests in accordance with American Petroleum Institute specifications are recommended.

In order to perform quick and economical analyses of future SKSS designs, it is recommended that a more refined quasi-static SKSS model be developed, capable of handling variable anchor depths, irregular bottom slope, non-zero slope at the anchor, and multi-segment cables. Existing static analysis programs are not capable of doing all of these.

Even though not required for any near future SKSS designs, the improvement of the existing time domain simulation program to account for current variations by depth, hydrodynamic loading on mooring cables, and oblique environmental loadings would be beneficial. The cost of such an analytical model development is estimated to be \$100,000 to \$150,000.

SECTION 7.0

COMMERCIAL PLANT RECOMMENDATIONS

Commercial OTEC plants will be much larger in physical size and in electrical power generating capacity as compared to the Modular Experiment OTEC plants. The objective of this section of the report is to investigate the applicability of Modular Plant SKSS designs to commercial size platforms.

Basic differences are:

Power Generation	: 400 MW _e vs. 40 MW _e
Design Life	: 40 years vs. 30 years
Operating Sea State	: 10 year return period vs. 3 year
Commercial SPAR dimensions	: 493' H, 190' W, 331' d, Displ. 246,000 LT
Commerical BARGE dimensions	: 689' LoA, 190' B, 112' D, Displ. 258,000 LT

(Both taken from Reference 16)

The differences in the sizes and environmental conditions for the commercial plants bring about increased total platform drag forces. Simple calculations performed by scaling up the parameters for modular plant SKSS to commercial plant sizes indicate that the drag forces will be approximately twice the forces calculated for the modular plants. Specifically, the total platform drag load for the Barge platform in beam seas is calculated to be 4816 KIPS, and that for the Spar platform, 2225 KIPS, both for the extreme sea state - or the survival conditions.

Using these drag loads and following a quasi-static analysis approach with the same factor of safety and excursion requirements as those for the modular plant, it was found that for both platforms, use of state-of-the-art wire rope and chain components may provide adequate catenary mooring designs.

The resulting designs are summarized in Exhibit 43. As it can be seen, the Commercial Spar SKSS requires 12 mooring legs of 7" wire rope and 5" AP1-2F chain segments. The initial installation costs of such a mooring system is estimated to be approximately \$33 million.

The Commercial Barge SKSS requires 20 mooring legs of 7" wire rope and 5" "Ljusne" super chain segments as one alternative. The estimated cost of this SKSS design is \$62.8 million. Another alternative for the

COMMERCIAL PLANT SKSS DESCRIPTION

	<u>SPAR</u>	<u>BARGE</u>	<u>BARGE</u>
Water Depth Under Platform	5200'	5200'	5200'
Total Drag Force	2225 KIPS	4816 KIPS	4816 KIPS
Number of Mooring Legs	12	20	8
Line Size/Type	7" dia./wire rope 5" dia./API-2F chain	7" Dia./wire rope 5" Dia./Super chain	8½" Bruce D Link Chain
Mooring Line Pretension	720 KIPS	720 KIPS	2639 KIPS
Pretension as % of B.S.	20%	20%	29%
Line Breaking Strength	3600 KIPS	3600 KIPS	9,200 KIPS
Approximate Line Length	10,000'	10,500'	10,500'
Survival Condition Excursion	562'	710'	880'
Survival Condition Line Tension	1400 KIPS	1714 KIPS	4600 KIPS

EXHIBIT 43

Commercial Barge is an 8-point mooring with single segment, $8\frac{1}{2}$ " Bruce D-Link chain legs. The cost of this SKSS design is estimated to be \$87.5 million.

For both the Commercial Spar and the Barge SKSS, the use of hydraulic line pullers is assumed in developing cost estimates.

It appears from these investigations that state-of-the-art wire/chain mooring designs are feasible for commercial plants and that they still cost less than using D-Link chains, or equivalent, with a smaller number of legs.

The problem with the large number of legs is one of successfully interfacing them with other platform subsystems. Should it be found that the number of legs must be reduced, then the use or development of higher strength chains or hollow cylindrical links and/or solid bar links may be necessary.

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GLOSSARY

Active System -	An SKSS control system with sufficient dynamic heave capacity to take up mooring line scope in the survival environmental state.
Burden Variables -	SKSS design parameters which are best compared on a qualitative basis.
CALMS -	A computer program developed by Exxon Production and Research Company, which computes the restoring force and line tensions of a mooring array.
Clump Weight -	A large weight attached to, or combined with, the seabed line to reduce the uplift angle at the anchor for a given line scope.
Composite Catenary -	A catenary formed by joining two or more line segments of different material properties.
Crown Line -	A line attached to the anchor to stabilize the anchor as it is lowered to assist in anchor embedment.
Davenport Wind Spectrum -	A probability density function which is used in the mathematical model for the description of wind gust velocity over time.
Decision Matrix -	A matrix of alternative concepts versus measures of merit which is used to systematically determine the optimum alternative.
Design Extreme Value -	An extreme value used for design, which incorporates a risk parameter to reduce the probability of failure.

Extreme Value - This is the most probable extreme value of a response which is computed if no risk parameter is considered.

Heave Capacity - The line pull a winch can achieve while hauling in a line under load.

Hollow Cylindrical Link - A mooring line made up of watertight cylinders pinned together.

Mooring Array - Refers to the number and orientation of the mooring legs of the SKSS.

Operating Environmental State - A sea state defined by wind, wave and current direction and magnitude, with a 3-year return period.

Passive System - An SKSS control system, with insufficient dynamic heave capacity to take up line scope in the survival environmental state. Pretension adjustments are made in more benign sea states.

Pretension - The line tension computed for a mooring leg when no wind, wave or current loads are applied to the platform.

Quasi-Static Analysis - Essentially a static analysis where line tensions are adjusted for expected platform excursion about a mean position.

Riser Buoy - A buoy attached to a mooring leg for the purpose of reducing the angle at the fairlead relative to the horizontal.

Risk Parameter - A design parameter used in the calculation of the design extreme value of a response for the purpose of obtaining a desired risk level or probability of failure.

Seabed Line The segment of a mooring line which lies on the ocean bottom.

Solid Bar Link - A mooring line made up of links of built-up plate sections which are joined by pin connections.

STAMOR	A computer program developed by Ultramine Inc. which computes the restoring force and line tensions of a mooring array.
Strumming -	Mooring cable vibration which results from vortex shedding.
Survival Environmental - State	A sea state defined by wind, wave and current direction and magnitude, with a 100-year return period.
System Effectiveness -	A measure of the relative effectiveness and performance of an alternative SKSS on the basis of selected measures of merit.
System Worth -	A measure of the total relative value of an SKSS, based on SKSS system effectiveness and cost.
Vortex Shedding -	The generation of vortices behind a bluff body in subsonic flow which can lead to periodic pressure variation on the body.
Wave Drift Forces -	Forces due to waves acting on a floating body associated with the scattered wave system, including the diffraction of oncoming waves and radiated waves due to the motion of the body.
Average Annual - Cost (AAC)	The average cost per year, in 1980 dollars, of purchasing, installing, deploying and maintaining the SKSS and its components throughout the designated service lifetime. The cost of borrowing money, in terms of a given interest rate, is included but no allowance is made for inflation.
Present Value (PV)	The total cost, under the same guidelines as for AAC, which would have to be laid out now to purchase, install, deploy and maintain the SKSS and its components throughout the service life period.