ENVIRONMENTAL IMPACT REPORT

PROJECTED OTEC DEVELOPMENT FOR THE TERRITORY OF GUAM

GCMP

GUAM COASTAL MANAGEMENT PROGRAM

BUREAU OF PLANNING
GOVERNMENT OF GUAM
AGANA, GUAM

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BUREAU OF PLANNING

OCTOBER, 1979

DAMES & MOORE PROJECT NO. 03074-056-11

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1.0 INTRODUCTION

1.1 Coastal Energy Impact Program and Study Objectives

This study was conducted under the authority of the U. S. Coastal Energy Impact Program (CEIP). The program was created by amendments to the Coastal Zone Management Act of 1972, (CZMA), and signed into law on July 29, 1976. Subsequent implementing regulations include those of January 15, 1979 (CFR Part 931).

The purpose of the CEIP is to study and plan for any economic, social, or environmental consequence that is likely to occur as a result of siting, constructing, or expanding energy facilities within the coastal zone (see Sec. 308 c of CZMA).

The objective of this study, as authorized by the Guam Bureau of Planning on June 5, 1979, is to assess the economic, social and environmental consequences of constructing and operating an Ocean Thermal Energy Conversion (OTEC) plant on Guam. Both a small-scale, land-based plant and a large-scale, sea-based plant were to be considered.

The study relied on existing work on Guam, and on the general OTEC literature. No new field work was undertaken. As the first examination of general environmental impacts of OTEC on Guam, the study was to focus on anticipated impacts and identification of mitigation measures, as well as the present gaps in the data that prohibit a complete examination of OTEC impacts. This will assist the Guam Bureau of Planning's Coastal Management Program in further developing its energy facility planning process and, specifically, in evaluating the applicability of OTEC technology as an alternative energy source for Guam.

1.2 Definition of Ocean Thermal Energy Conversion

1.2.1 The OTEC Concept

Approximately one million kilocalories per square yard per year of solar radiation fall on the earth's surface. The oceans store immense quantities of this incident solar energy in the form of heat. Stored thermal energy can be converted to electrical energy, in a heat engine, by utilizing the warm surface waters as a heat source and the cold deeper waters as a heat sink. Because of the high-entropy nature of this stored energy and the low efficiency of the heat engine, maximum achievable efficiencies of an Ocean Thermal Energy Conversion plant are only approximately four to ten percent (Cohen, 1974). This means that very large quantities of water must be moved to extract usable amounts of energy. However, the amount of available energy is nearly limitless.

In basic concept, a closed cycle heat engine will use the heat difference (dT) of approximately 40^{o} Farenheit (F) of thermally stratified ocean waters and a working fluid capable of boiling and condensing within the ambient temperature ranges. Ammonia is presently considered the most satisfactory working fluid. The cycle begins with the warmer sea water heating the working fluid in a heat exchanger, and vaporizing the working fluid. The vapor then turns a turbine which generates electricity. The turbine exhausts the working gas into a second heat exchanger where the vapor is condensed by colder, deep sea water. The working fluid then returns, via pumps, to the beginning of the cycle. The process is shown schematically in Figure 1.

1.3 Discussion of the Potential or Need for OTEC on Guam

The need for OTEC on Guam stems from the Territory's complete dependence upon imported oil, and on the desire to replace existing oil-fired equipment with an alternate energy source.

Guam currently has an installed electrical generating capacity of about 274 Megawatts (MW), all of which relies upon imported oil. As imported oil becomes increasingly scarce and expensive, the cost of generating electricity will increase accordingly (Pinckert, 1978). Replacing some of this existing generation with an OTEC power plant would reduce Guam's dependence on imported fuel oil, and could reduce the trend in increasing costs of electricity. The amount of this replacement is, of course, dependent upon the size of

SCHEMATIC DIAGRAM OF CLOSED CYCLE POWER SYSTEM

REFERENCE: INTERSTATE ELECTRONICS CORP. 1978

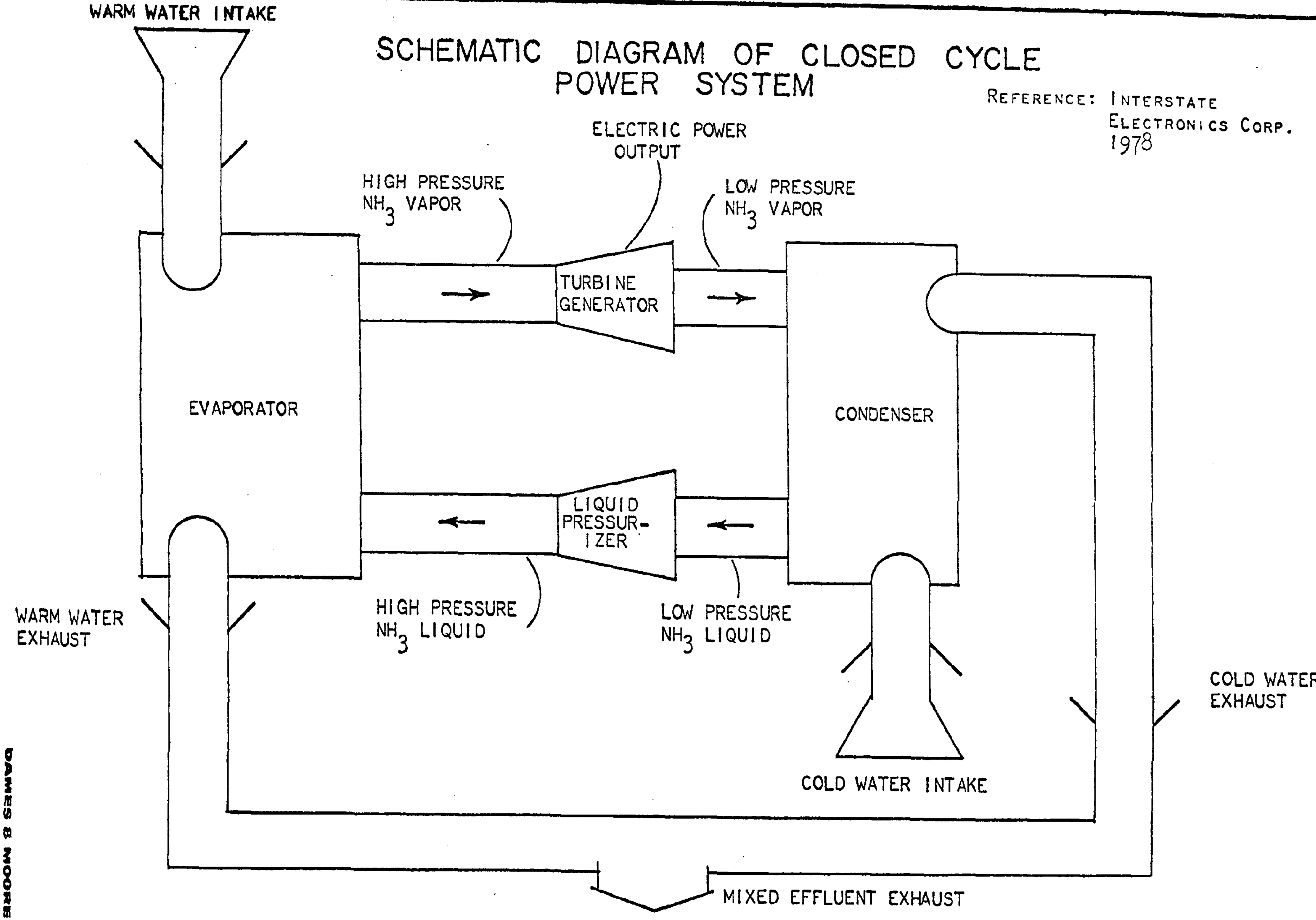

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FIGURE 1

the OTEC facility. A 10 MW shore-based facility (about 4 percent of the presently installed capacity), and a 100 MW ocean-based facility (about 36 percent of the presently installed capacity), were considered in this study. Based upon 1978 peak demand data, a 10 MW plant would provide about 7 percent of the peak demand; and a 100 MW plant would provide about 67 percent of the peak demand (Bureau of Planning, 1978). Taking the OTEC application to its maximum, and supplying 100 percent of Guam's power needs, is beyond the scope of this study.

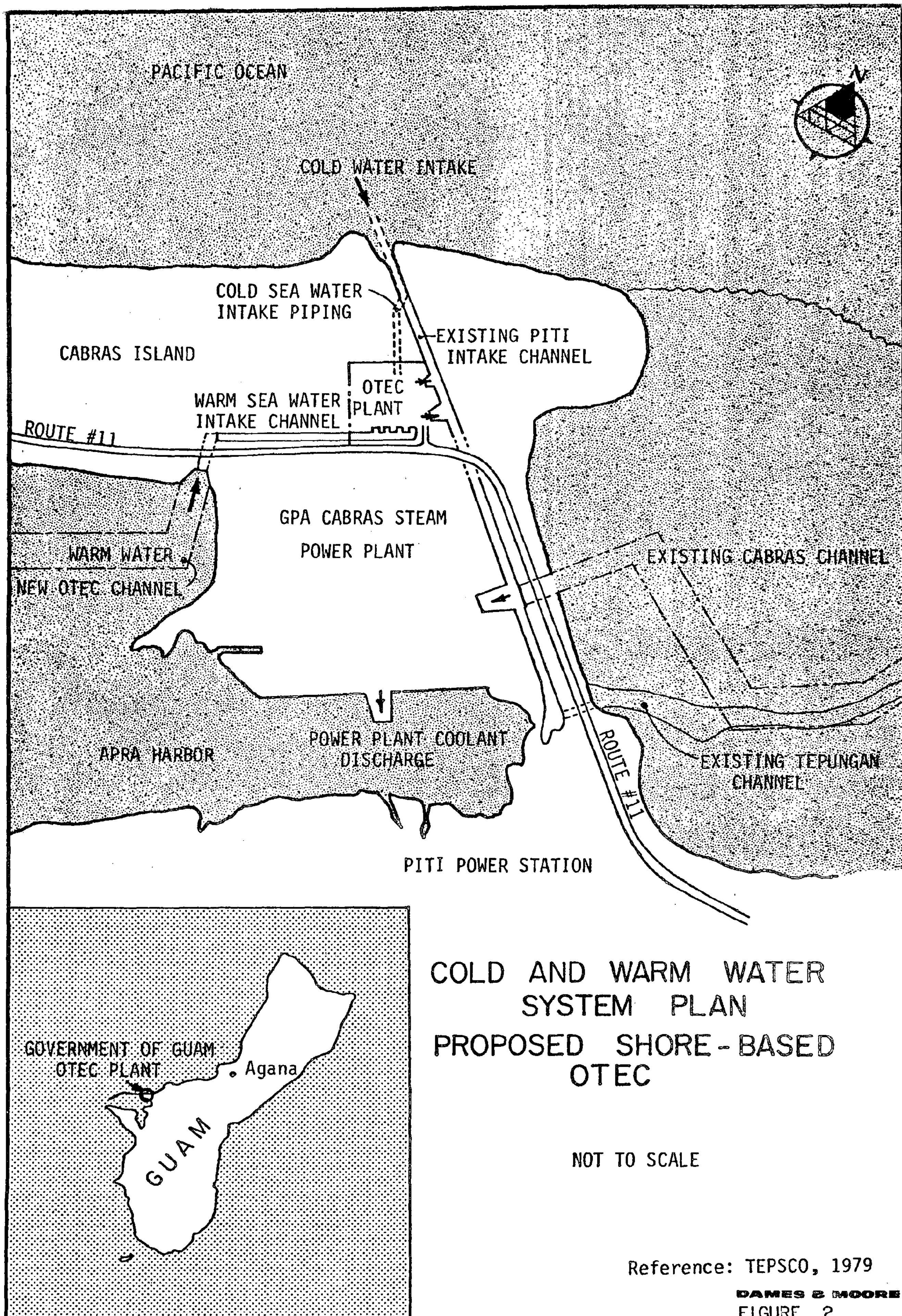
An OTEC power plant could also be utilized to provide additional capacity, as it is required to meet increasing demand. The Guam Power Authority (GPA) has developed electrical demand information since 1972. Previous analysis of this information indicates that a three percent growth rate is reasonable (Bureau of Planning, 1978). This analysis also suggests that additional generative capability of about 66 MW will be required in about 10 years. The shore-based OTEC alternative studied could provide 15 percent of this requirement, and the ocean-based OTEC system studied could exceed this requirement by 52 percent.

1.4 Description of Types of OTEC Facilities Applicable for Study on Guam

1.4.1 The Small Shore-Based Alternative

For this study, the 10 MW facility proposed in 1977 by Tokyo Electric Power Services Company, Limited (TEPSCO)* for Guam was used as a generic example. The proposed facility was to be located on Cabras Island adjacent to the existing Cabras power plant. This location has also been selected as the optimal site for a land-based facility in the Land-Use and Economic plan for Apra Harbor and Surrounding Areas, Port Authority of Guam (1979). The proposed location and layout is shown on Figure 2. The facility was to consist of four 2.5 MW units. Approximately 178 million gallons per day (mgd) of cold (about 40^{o} F) water was to be pumped from the 2,000-foot depth off the existing Piti and Cabras power plants' cooling water intake channel. The four steel intake pipes were to be 92 inches in diameter and about 6,000 feet in length. Approximately 202 mgd of warm (about 80^{o} F) water was to be drawn from the surface of Apra harbor. The mixed effluent,

*Note: The use of parts of the TEPSCO proposal in this report is for analytical purposes only and does not constitute an endorsement of this proposal by the Government of Guam.



COLD AND WARM WATER SYSTEM PLAN
PROPOSED SHORE-BASED OTEC

NOT TO SCALE

Reference: TEPSCO, 1979

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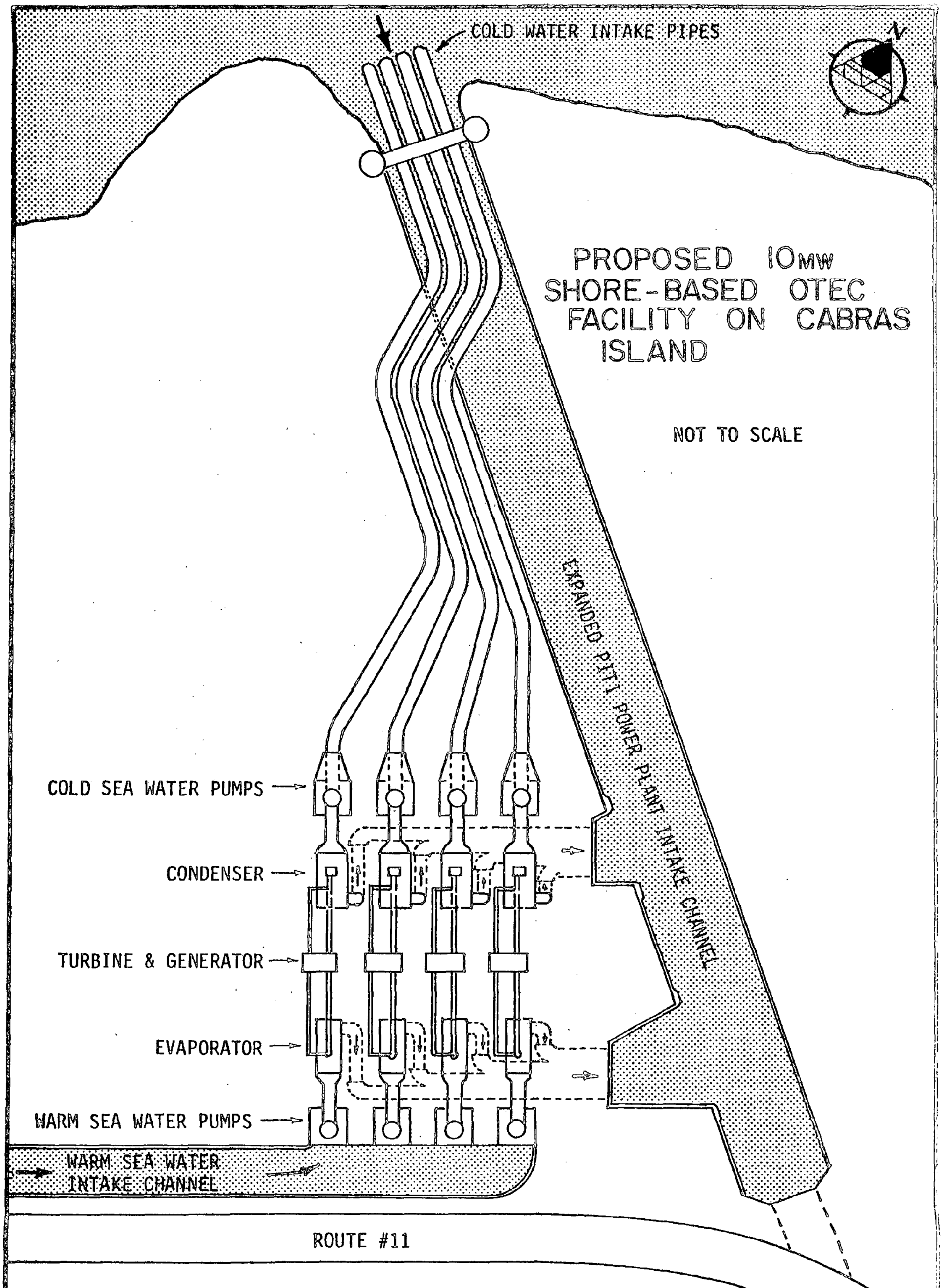
FIGURE 2

which would total about 380 mgd, was to be discharged in an expanded channel along the right of way of the existing Cabras /Piti power plants' intake channel. Presumably, this effluent would be utilized in the Cabras and Piti power plants and discharged into the existing outfall lagoon, shared by both plants, within Apra Harbor. Figure 3 depicts this flow pattern through the proposed plant.

This proposed plant would use ammonia as the working fluid, with a maximum feed capacity of 250 tons per hour. The evaporators and condensers were to be of horizontal tube construction, from an unspecified material. Aluminum and titanium are the most common materials under consideration, however, and aluminum was assumed to be used for this study. No surface area estimates of heat exchanger size were provided.

To prevent growth on the heat exchange surfaces (biofouling), which causes reduction in the thermal efficiency of the OTEC plants, a biocide (usually chlorine) is used. Mechanical scrubbers are also being considered. A description of the proposed plant did not address the biofouling problem. Screens across the cold and warm water intakes, to minimize the entrainment of marine life in the water cycles, were also not addressed in the proposal.

Construction cost for the shore-based facility was previously estimated at $32,180,000 in 1977 dollars. This



REFERENCE: TEPSCO, 1979

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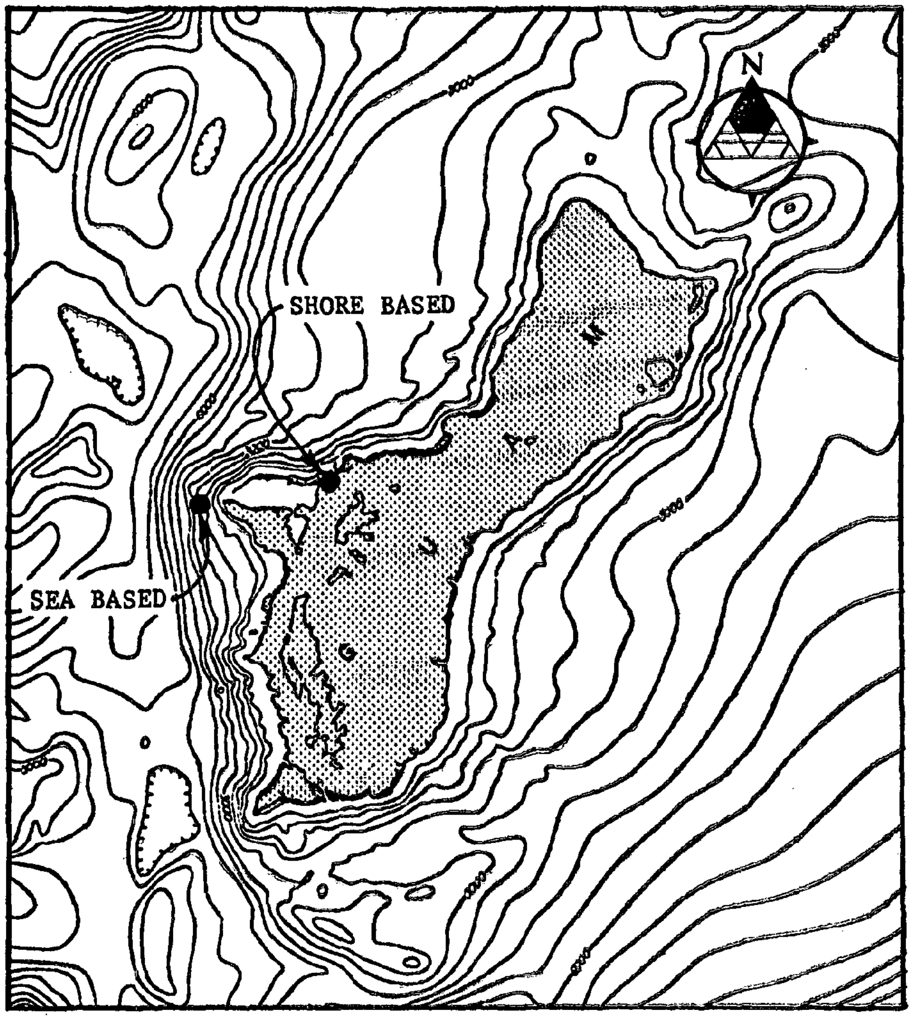
FIGURE 3

would result in an estimated generation cost of about 6.2¢/Kilowatt Hour (KWH).

1.4.2 The Large Sea-Based Facility

For this study, a generic description of a large, floating facility was developed. The OTEC facility could either be dynamically positioned, as proposed by TRW Systems Group; or moored with a single point mooring, as proposed by Lockheed Missiles and Space Company.

The OTEC facility would be positioned in 3,000 feet of water about 1½ miles off the Glass breakwater and the mouth of Apra Harbor. The location is shown on Figure 4. The plant would geneate a 100 MW of electricity from four 25 MW units. The units would share a common 2,000-foot deep cold water intake pipe (CWP) which would have a screened intake of ½-inch mesh size to minimize entrainment of marine life. Approximately 1,800 to 3,600 mgd (2,700 mgd, average) of cold (40^{o} F) water would be used as a coolant, and a like volume of warm (80^{o} F) surface water would be used on the heat side of the cycle, for a total average discharge of about 5,400 mgd. The four warm water intakes would be screened to minimize entrainment of marine life in the OTEC system. Discharge of the mixed effluent would take place in about 120 feet of water.



GUAM AND VICINITY

1 0 1 2 3 4 5 6 7 8 9 10
statute miles

Bathymetric chart of Guan and vicinity. Contour interval is 600 feet on both land and sea floor. (Reference: Emery, 1962)

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FIGURE 4

The offshore plant would utilize about 1,500 tons of ammonia as a working fluid (ERDA, 1977), with another 25 percent, or 375 tons, stored in reserve.

The evaporators and condensers would be tube/shell type, constructed of aluminium. An estimated total of approximately 10 million square feet of heat exchange surface would be required (ERDA, 1977).

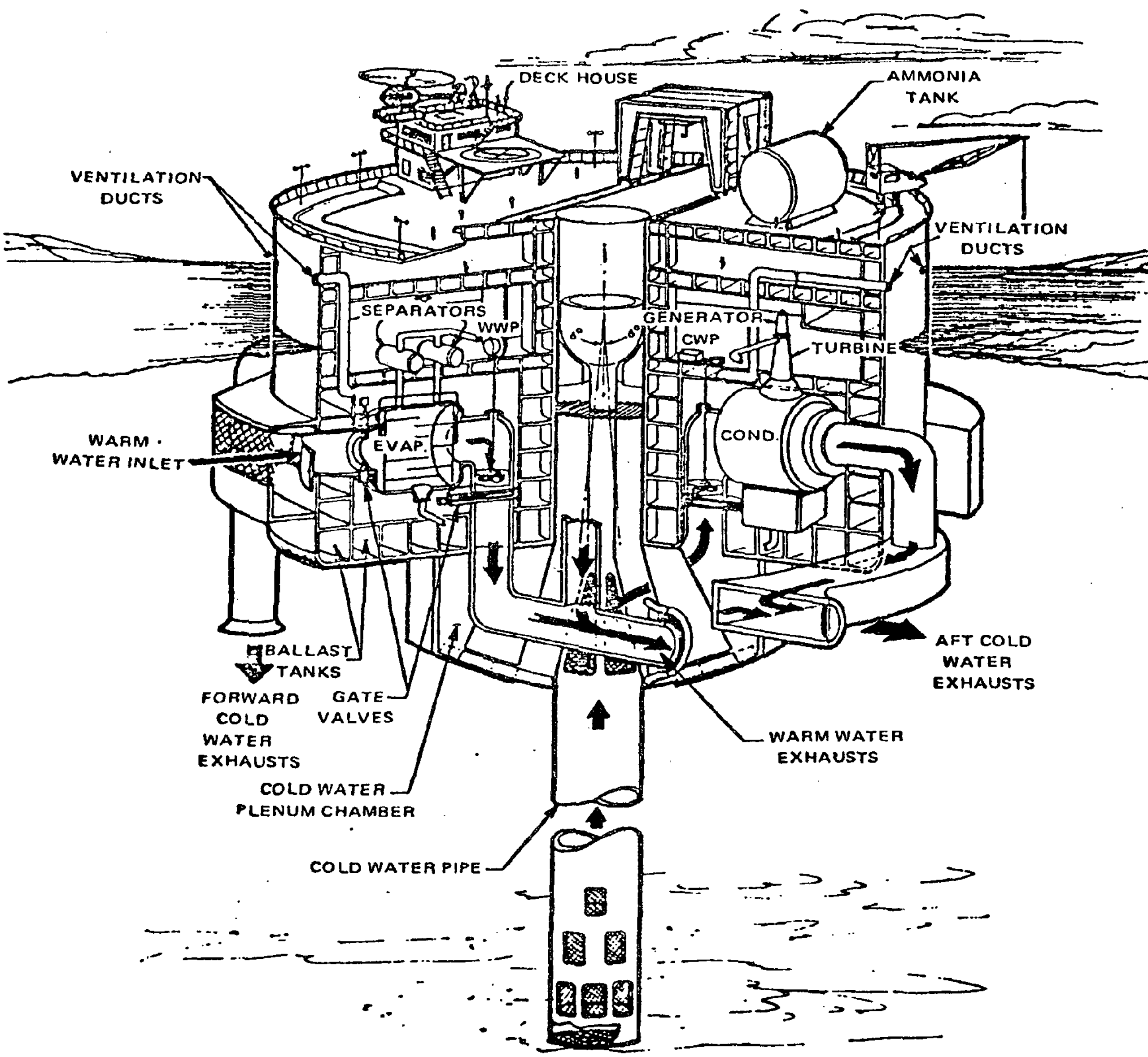
To prevent the growth of biological slimes on the seawater side of the heat exchangers, a biocide would be required. While several are currently under consideration in proof-of-concept plants (Dames & Moore, 1979), chlorine appears to be the most promising and is, therefore, used in the proposed 100 MW plant. Chlorine discharges would meet current EPA specifications of a 30-day average of not more than 0.2 parts per million for not more than two hours per day.

The OTEC equipment would be contained in a large vessel, commonly called a platform. The platform could be made from conventional marine steel or aluminum, although ferro-cement is also under consideration.

Construction costs, based upon current research estimates, would be about $235 million, based upon ERDA an estimated cost of $2,350 per kilowatt hour. This would result in a user cost of about 4.7¢ per KWH, excluding transmission costs.

The generated power could either be transmitted to shore, viable in underwater cable, or utilized at sea in an industrial process. As of August, 1979, a 50 Kilowatt OTEC test plant was generating electricity off the coast of Hawaii, proving the technological feasibility of the process.

Typical OTEC platforms of the type envisioned for this study are depicted in Figures 5 and 6.



OTEC – BASELINE SYSTEM CONFIGURATION

SOURCE: TRW Systems Group

CUTAWAY VIEW OF 100 MW SEA-BASED OTEC PLANT MODEL

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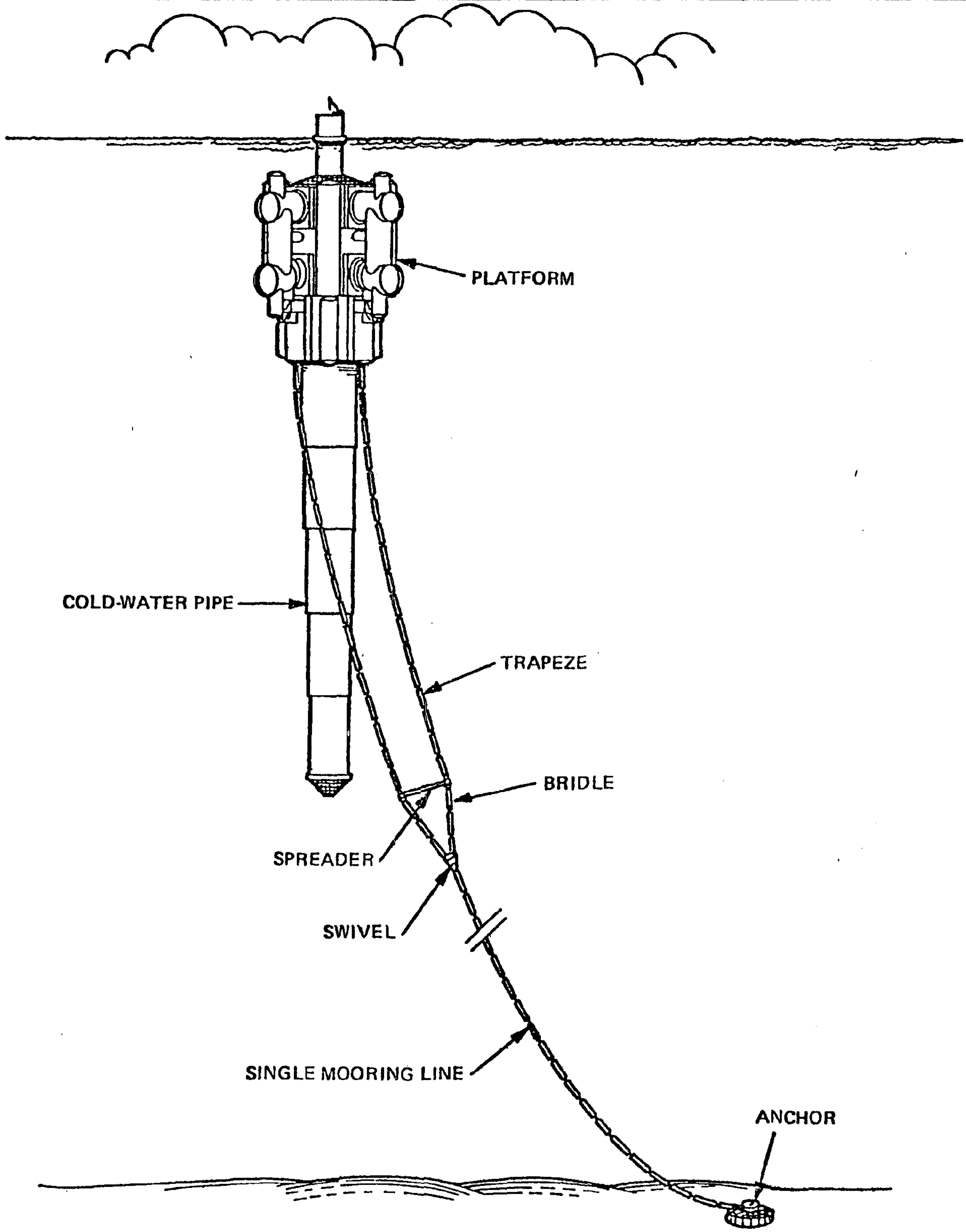
FIGURE 5



SOURCE: Lockheed Missles and Space Company

FULL VIEW OF LOCKHEED OTEC PLANT MODEL

DAMES & MOORE
FIGURE 6

2.0 ANTICIPATED LOCATIONS FOR OTEC FACILITIES

2.1 Land-Based

Of prime importance in locating a land-based OTEC facility is the proximity of cold, deep ocean water which can be pumped a short distance to the OTEC facility. Proximity is important to reduce pumping costs, and to reduce warming of the cold water prior to the condensing stage. A review of near-shore bathymetry (see Figure 4) shows that waters 3,000 feet deep occur close to shore in the vicinity of Cocos Island, and off the Glass Breakwater.

A land-based OTEC facility, of the size envisioned for Guam, ideally should be also near electrical switching gear to minimize electrical distribution switching system costs. Extensive, and expensive, switching for a 10 MW plant would add unnecessary increased costs. The major electrical switching center in Guam is associated with the Piti/Cabras power plants.

The requirements of proximity to deep water, and proximity to existing electrical switching gear, are both met reasonably well at the site of the proposed facility. Therefore, for this study, the site was determined adequate.

The proposed site is currently vacant, and is adjacent to heavy industrial use, consisting of the Piti and Cabras power plants and

Commercial Port activities. The Community Design Plan prepared for the area (Bureau of Planning, 1978), projects the proposed site to be in heavy industrial use in the year 2000. The site currently consists of scrub vegetation, predominantly Tangan-tangan, and has a small hill of about 30 feet in height of coralline origin in the center.

2.2 Sea-Based

The major consideration in siting a sea-based OTEC facility is the availability of a permanent cold water supply at a reasonable depth. Studies by the University of Guam Marine Laboratory (Lassuy, 1979) indicate that a persistent reservoir of cold water (dT of 35^{o}F) occurs in as little as 1,500 feet off the Glass Breakwater. The 1,500-foot depth occurs approximately six-tenths of a mile from the breakwater. A dT of 41^{o}F occurs at about the 2,000-foot depth in the same general vicinity.

A second consideration for a sea-based OTEC facility is the average wind and wave condition, or sea-state, for which a floating platform must be designed. During the January through May dry season, easterly tradewinds of about 15 miles per hour (mph) blow 90 percent of the time (Tracey, et al, 1959). In contrast, during the wet season, calms are frequent, with wind speed seldom exceeding 15 mph. Under these wave conditions, an OTEC platform could be designed for with ease. However, the wet season also includes the period of highest frequency of tropical storms and typhoons, with concurrent winds from 75 to 200 mph. The historic typhoon pattern indicates that chances are one in five that Guam will experience a typhoon in any particular year, (Tracey, et al, 1959). The sea-state produced under these more severe conditions would pose a serious design consideration to a sea-based OTEC facility, as the platform would be unable to avoid the storm or seek safe shelter, as in the case of normal shipping. Current OTEC systems (OTEC-1) are designed to withstand winds of about 100 mph. Prior to further consideration of a sea-based OTEC facility off Guam, detailed sea-state design studies, based upon expected typhoon frequencies and conditions, should be required. These studies would enable a determination to be made as to whether an ocean platform could be designed and economically built to withstand these events.

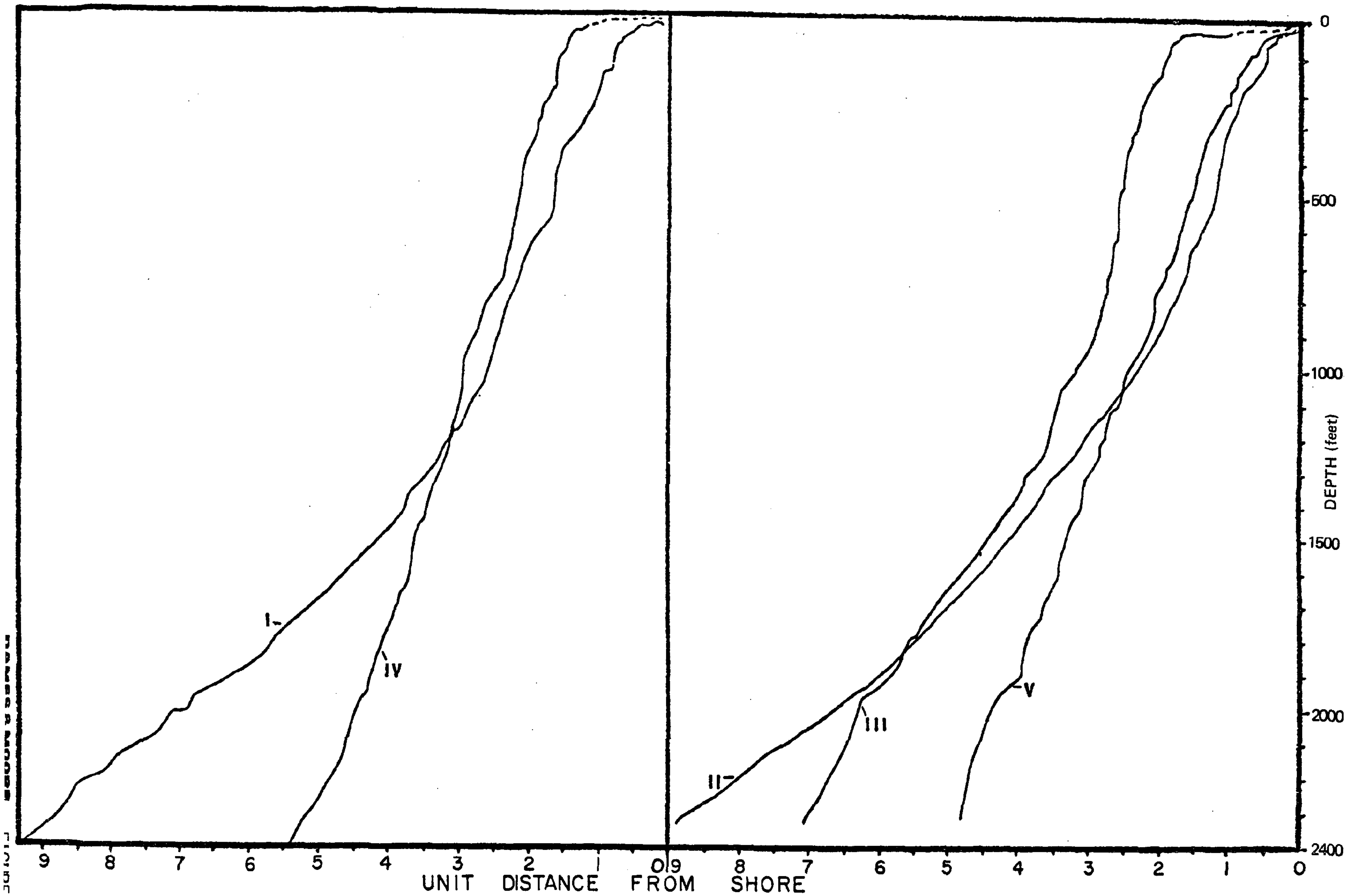
A third consideration for a sea-based OTEC facility is the proximity of the plant to the consumers of the electrical energy. U. S. Department of Energy estimates put electrical cable costs for a 100 MW plant on the order of a million dollars per mile. The proximity (less than a mile) of deep water to the electrical switching capabilities associated with the existing Piti/Cabras power plants makes the area offshore of Glass Breakwater favorable, from the standpoint of minimizing transmission cable and electrical switching costs. However, the transmission cable would be unnecessary, and proximity to land not a consideration, if the OTEC energy produced was utilized in an industrial process at sea (see Section 3.2.9).

Based upon the considerations of a persistent dT, seastate, and proximity to land to minimize transmission costs, the optimal Guam site appears to be offshore of the Glass Breakwater. In addition, the westward-moving North Pacific Equatorial Current, which flows past Guam at about ½-mile per hour, would probably carry an OTEC discharge away from shore at this site.

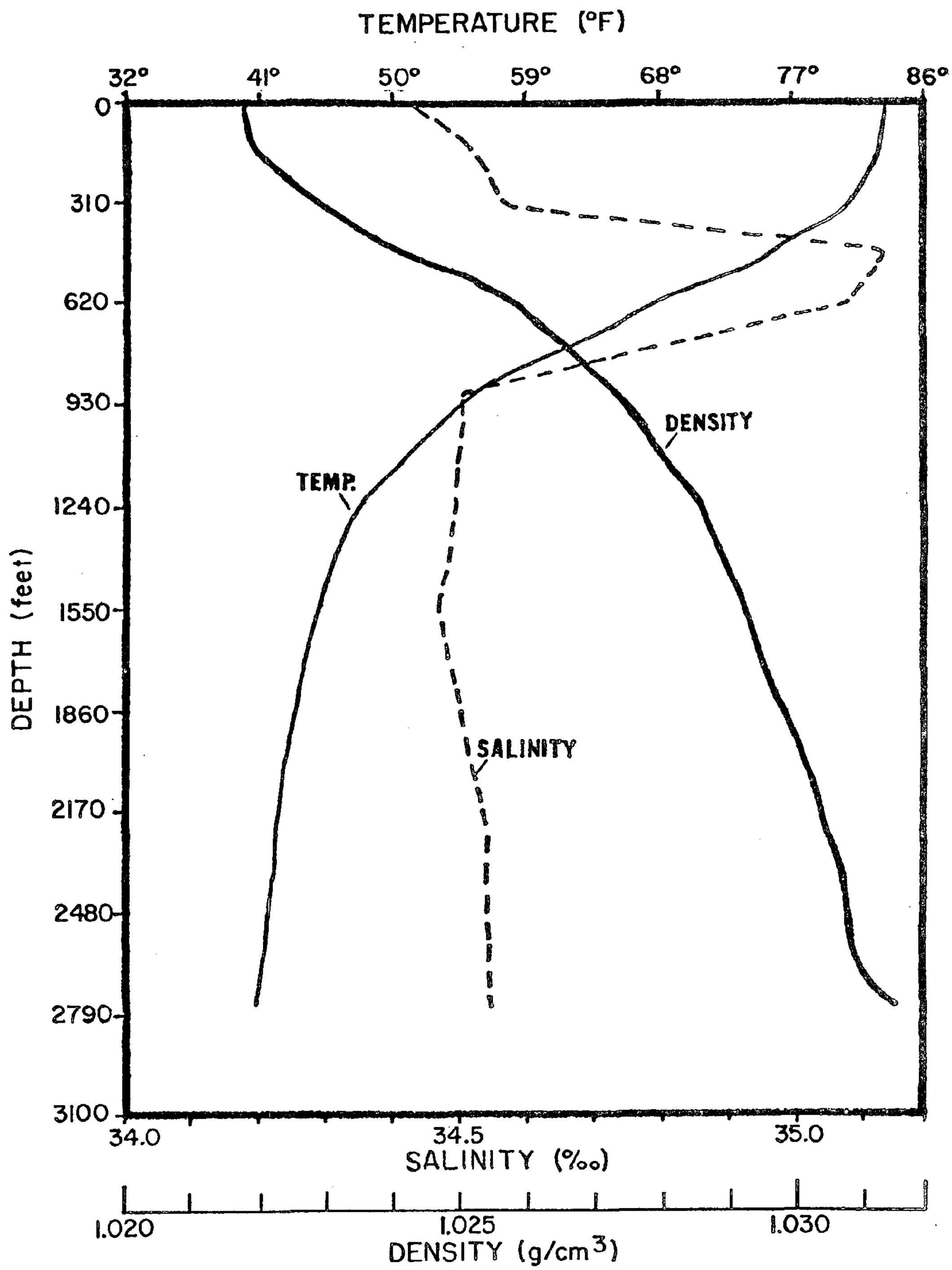
2.3 Aspects of the Marine Environment Common to Both Facilities

The University of Guam Marine Laboratory has studied the waters offshore of the Glass Breakwater for a potential OTEC facility (Lassuy, 1979). From their brief investigation, the area studied appears suitable for ocean thermal energy conversion. The information contained in this section is applicable to both a land-based and sea-based facility which would rely upon the waters off Glass Breakwater for the cold intake water.

Briefly, the area is characterized by steep slopes (26-52%) dropping quickly to 2,000-2,400 feet deep (Figure 7). Surface temperatures are generally above 80^{o} F, and begin to drop markedly below 300 feet. Salinity and density decrease slightly with the temperature change (Figure 8). At 1,500 feet, the temperature is about 45^{o}F; and at 2,800-3,000 feet, it is consistently about 41^{o}F (Figure 9). The nutrients, phosphorus and nitrogen, increase

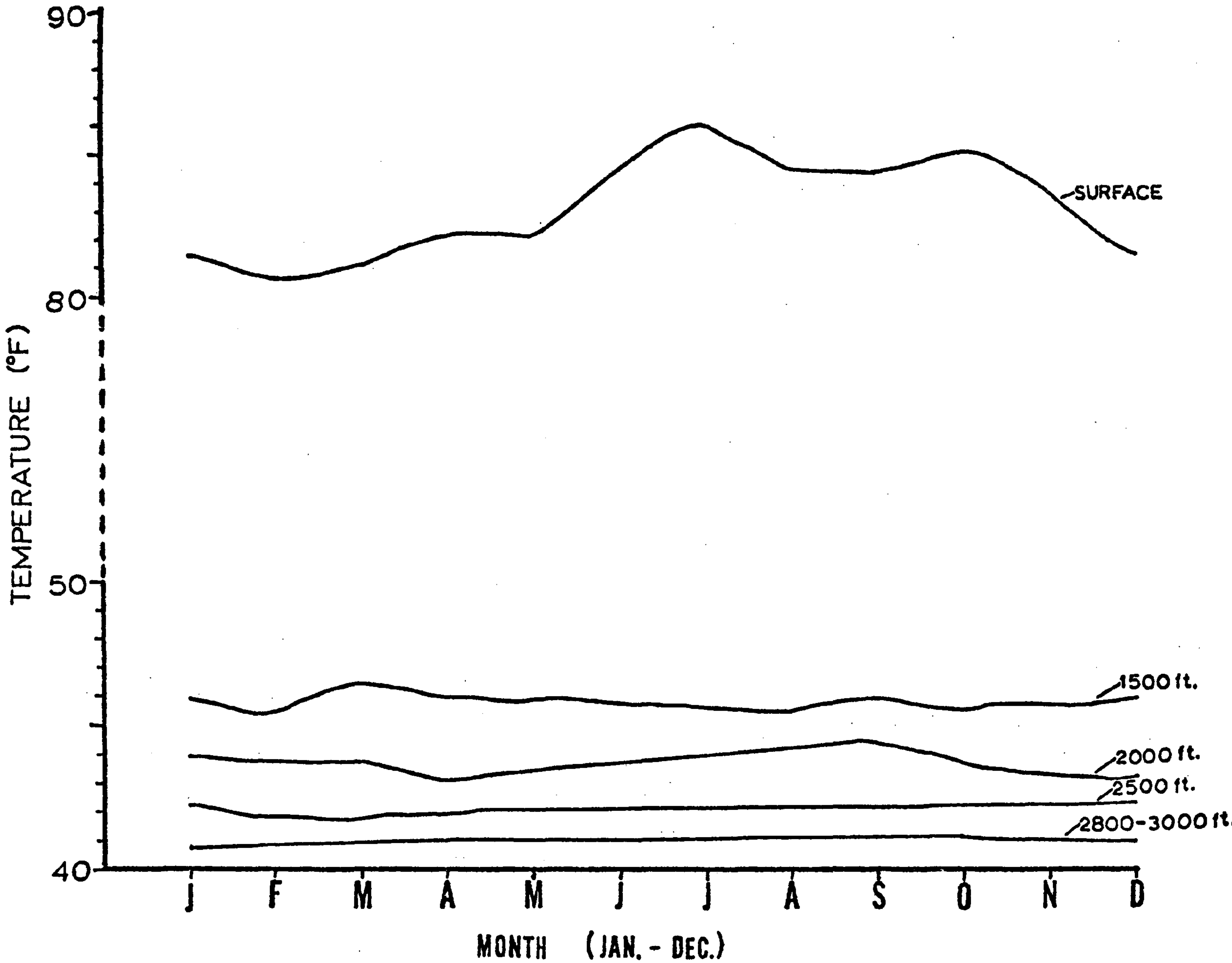


Fathometer profiles of the bottom at five sites in the vicinity of Cabras Island, Luminao Reef and Glass Breakwater, Guam. (Reference: Lassuy, 1979)



Mean temperature, salinity and density profiles in the vicinity of Cabras Island, Luminao Reef and Glass Breakwater, Guam (Feb., 1978 to Feb., 1979).

DAMES & MOORE
FIGURE 8



Mean monthly temperatures for surface, 1500, 2000, 2500 and 2800-3000 ft in the vicinity of Cabras Island, Luminao Reef and Glass Breakwater, Guam.

Reference: Lassuy, 1979

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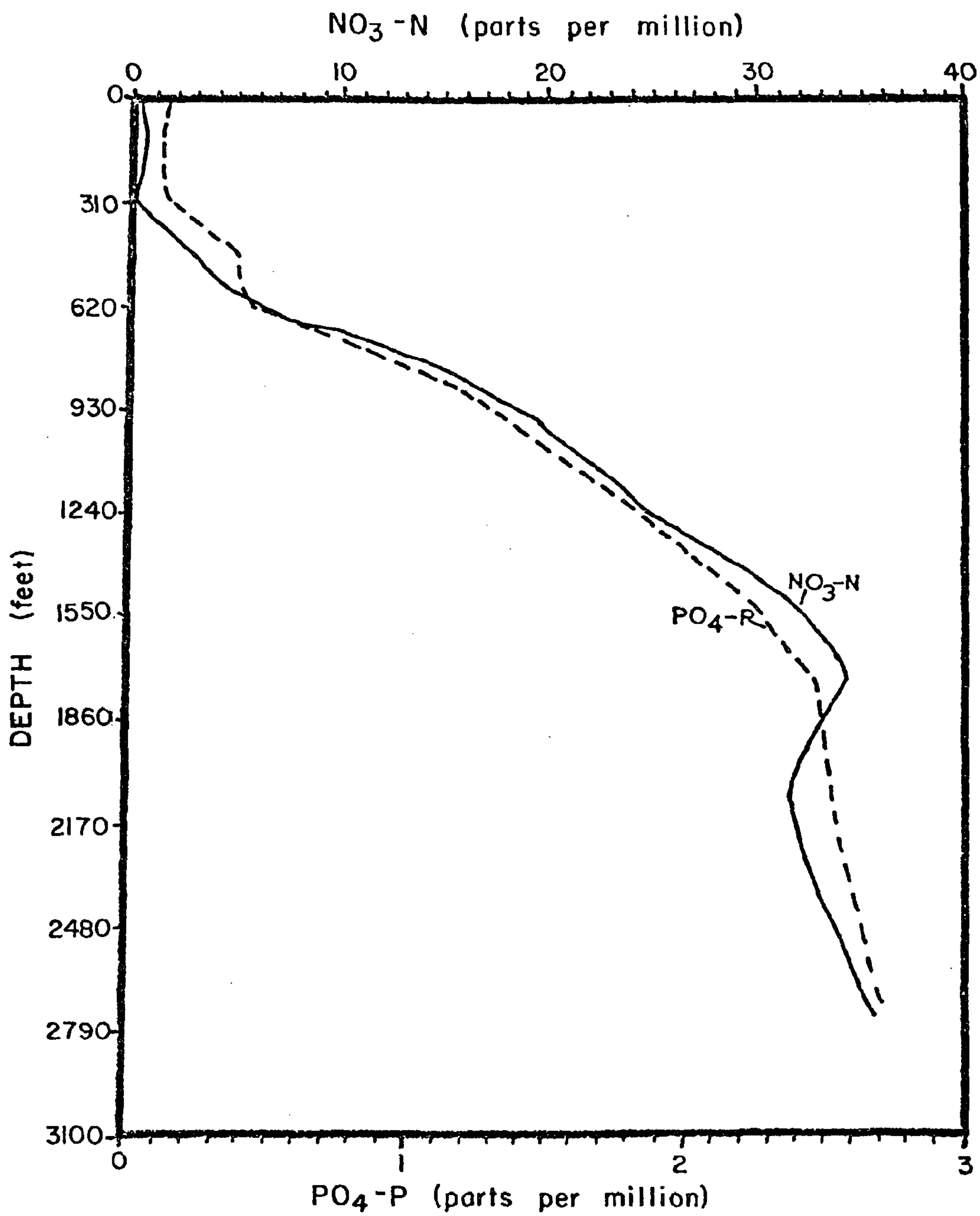
FIGURE 9

dramatically with depth. Phosphorus (PO_4-P) increases from about 0.2 to 2.7 parts per million, reaching concentrations fifteen times that of the surface concentration. Nitrogen (NO_3-N) increases from less than 1.0 to 35 parts per million, reaching concentrations 35 times that of the surface, at the 2,700-foot depth (Figure 10). Oxygen shows a reverse trend, with dissolved oxygen dropping from about 6.25 to about 2.5 parts per million from the surface to the 2,800-foot depth (Figure 11). These patterns are similar to those of other OTEC sites, notably Hawaii (Dames & Moore, 1979).

While no site-specific primary productivity (phytoplankton) studies have been done at different depths, the waters off Guam can be expected to follow tropical ocean trends for total biomass (productivity) as described by Nielsen (1963). This trend is for the largest amount of primary productivity (phytoplankton) to occur in the Photic zone, or zone in which light intensity is 99% of the incident surface radiation. This zone is about 300 feet deep in the tropical Pacific (Figure 12).

Zooplankton species that could be anticipated include Chaettosnatha, Euphasiacea, decopod crustacea, Pteropoda, as well as invertebrate larvae. Vertical distribution of zooplankton would parallel phytoplankton, with the majority living in the upper, mixed layer. The thermal and density changes form a barrier through which they are unable to pass. Other offshore marine biota include albacore and skipjack tuna, mahimahi, jack, swordfish, marlin, and



Mean nitrate-nitrogen (NO_3-N) and reactive phosphorous (PO_4-P) profiles from surface to 883 m (2900 ft) in the vicinity of Cabras Island, Luminao Reef and Glass Breakwater, Guam (Feb., 1978 - Feb., 1979).

Reference: Lassuy, 1979

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FIGURE 10

several species of sharks. The quantification of primary production with depth, and qualitative and quantitative plankton and neckton studies, are research areas which will require a thorough examination prior to further quantification of OTEC impact on Guam.

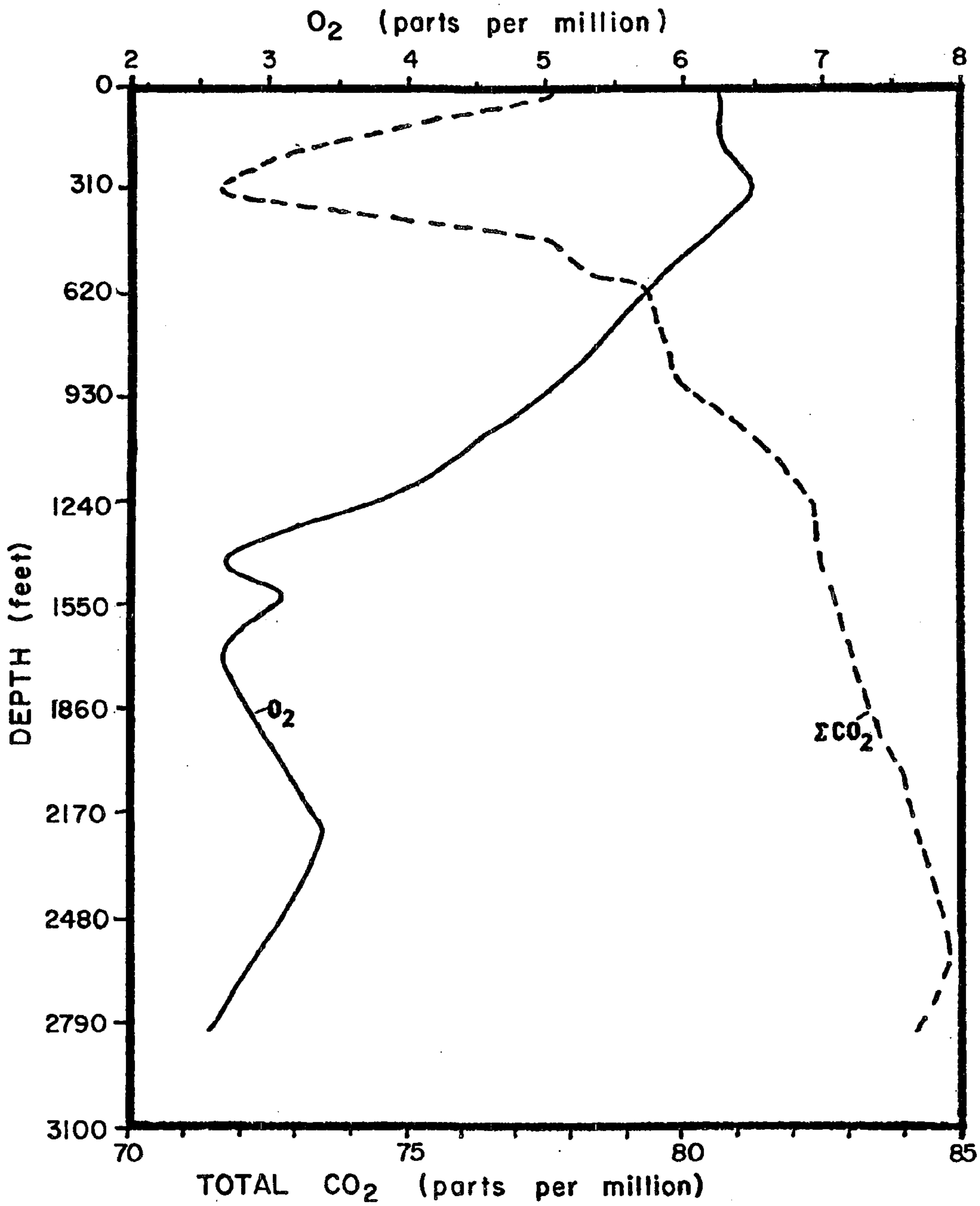
3.0 ANTICIPATED IMPACTS OF OTEC DEVELOPMENT

3.1 Environmental Impacts

To date, there have been no full-scale studies of environmental impacts of an OTEC facility. Most of the impacts described below come from engineering experience with shore-based power stations, and through extrapolation of existing data. The successful deployment and operation, in July, 1979, of the first sea-based 50 kilowatt (KW) OTEC plant off the coast of the Island of Hawaii began to quantify the magnitude of the impacts identified in this section.

3.1.1 Construction and Deployment Impacts

The environmental impacts of constructing a small, land-based OTEC plant on Cabras would include noise, traffic and, perhaps, dust (from site preparation). These impacts would be similar in magnitude to the construction of a conventional power plant of similar size. In addition, there would be marine impacts, such as sedimentation, pressure changes with resultant fish mortality, and noise from the enlarging of the intake and discharge channels and placing the cold water pipe (CWP). The benthic communities in these areas



Mean dissolved oxygen (O_2) and total carbon dioxide (CO_2) profiles from surface to 905 m (2970 ft) in the vicinity of Cabras Island, Luminao Reef and Glass Breakwater, Guam (Feb. 1978 - Feb., 1979).

Reference: Lassuy, 1979

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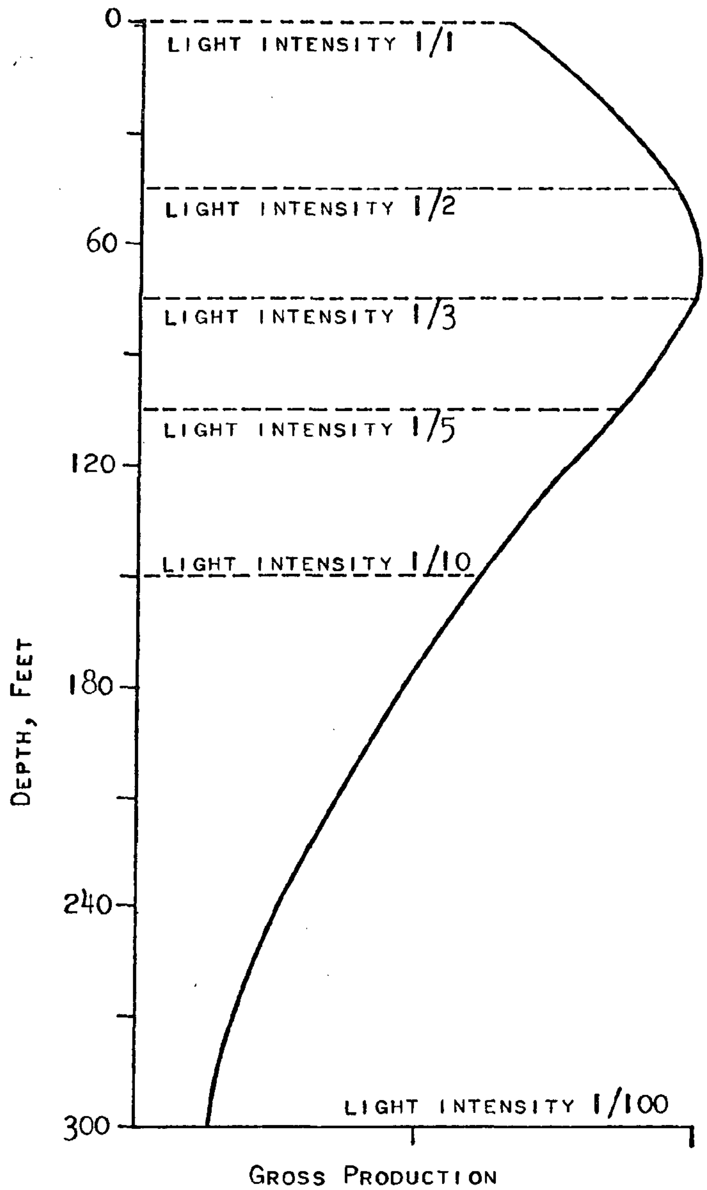
FIGURE 11



LIGHT INTENSITY AND GROSS PRODUCTION AT DIFFERENT DEPTHS IN TROPICAL OCEAN

GROSS PRODUCTIVITY WITH DEPTH

REFERENCE: NIELSEN, E. S., 1963

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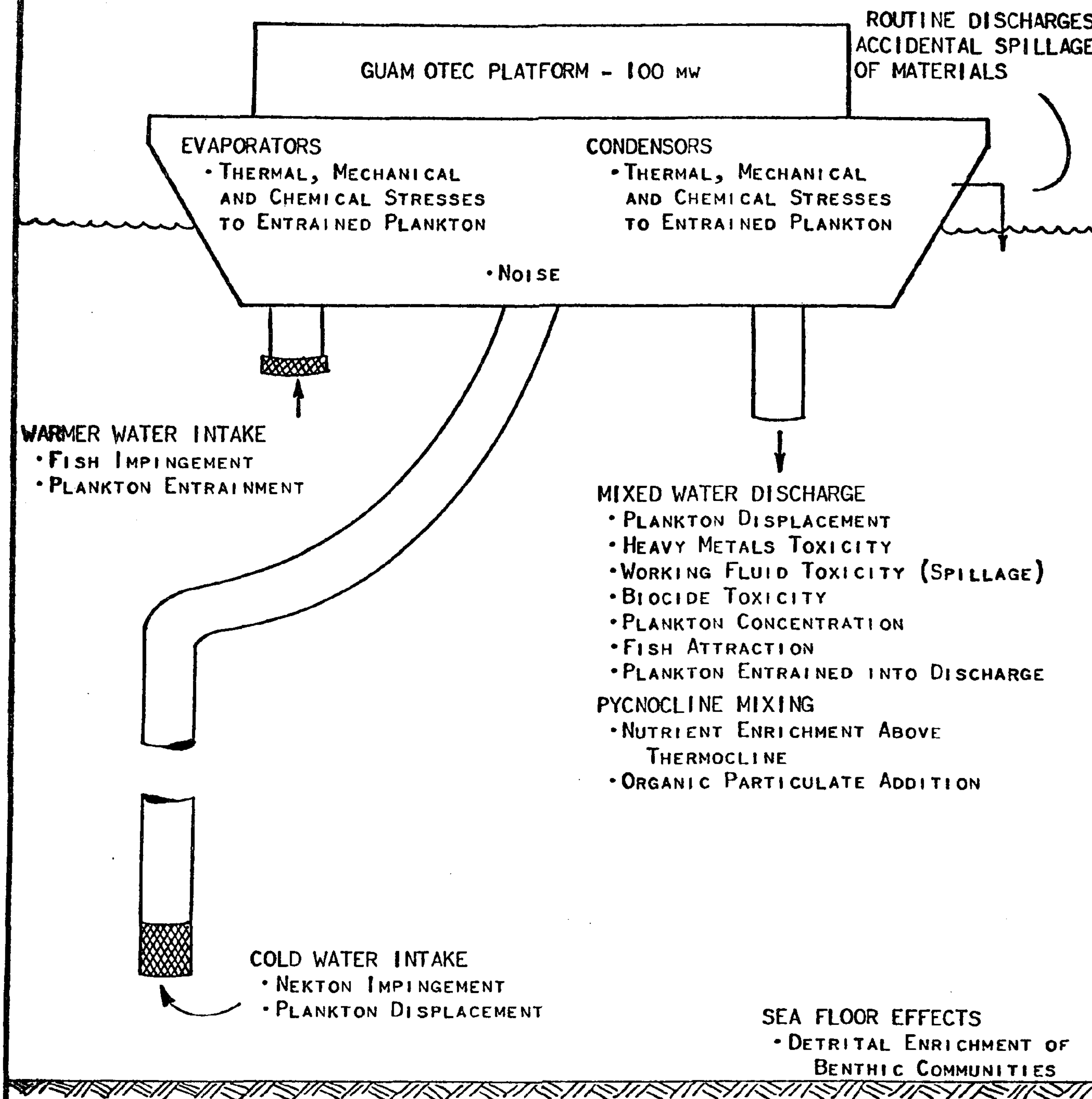
FIGURE 12

(predominantly corals), would be covered and destroyed. Prior to any construction, the benthic community along the final CWP alignment should be examined and identified. Special attention should be given to precious corals which might be found, at depth, in the corridor, as well as threatened or endangered species whose presence has not been currently detected.

The environmental impacts of constructing a large sea-based OTEC plant would be similar to any large construction project, and would include noise, traffic, and consumption of material and energy. It is unlikely that a platform could be constructed on Guam, as the existing marine construction capabilities are inadequate and would require considerable expansion, with the attendent environmental impacts of this expansion. If the OTEC platform was constructed elsewhere and towed to Guam, these construction impacts could be avoided on Guam. Towing and positioning the platform would create a minor navigational hazard, however.

3.1.2 Operational Impacts - Water Quality

The potential environmental effects associated with the operation of OTEC are shown in Figure 13, and are discussed in this section. A review of existing information indicates that the major impacts would probably be associated with the following:



OTEC ENVIRONMENTAL IMPACT SCHEMATIC
(OPERATIONAL IMPACTS)

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- o Toxicity effects (lethal and sublethal due to chemical changes)
- o Mixing effects
- o Intake/discharge mortality effects

However, studies of currents, winds, waves and the oceanographic conditions at the proposed sites are necessary to thoroughly quantify the magnitude of the anticipated impacts.

3.1.2.1 Toxic Effects

Biocides - Biocides must be introduced at times into the intake streams to reduce biological growth (bio-fouling) in the heating and cooling systems. These fluids, and the use of growth-resistant (anti-fouling) paints, are intended to be toxic to life forms whose presence could restrict the water flow, or compromise heat transfer in the heat exchangers. While chlorine addition will be limited to an allowable concentration of 1.67 pounds per million gallons for two hours per day, circulation of large volumes of water (approximately 388 or 5400 mgd, depending upon the plant selected) will result in large total discharges (approximately 635 or 9000 pounds) of chlorine per day.

In the smaller plant, the toxicity of chlorine to near-shore biological processes could result in imbalances due to reduction in the productivity of certain species, or a depressant effect on primary production. In the larger facility, the impacts could be serious and cumulative to pelagic plankton forms. Numerous studies have addressed chlorine toxicity, including research by Eppley and others (1975) which indicated irreversible photosynthetic inhibition at residual chlorine concentrations of about ten parts per billion. For the near-shore discharge from the shore-based facility, the effects of chronic low-level discharge in the marine communities of Apra Harbor need to be researched. For the ocean-based plant, the importance of possible changes in productivity will be dependent on plume dispersal conditions at the site, and will be offset, to some extent, by nutrient enrichment effects induced by convective mixing. Preliminary indications (UoG, 1979) are that biofouling may not be as extensive on Guam as on other proposed OTEC sites. If so, chlorine use could be reduced accordingly. University of Guam ongoing studies and U. S. Department of Energy studies on smaller OTEC plants are designed to further research biofouling and the impacts of chlorine control methods.

Working Fluid - The ammonia working fluid that is utilized in the closed cycle engine will be contained to the greatest extent possible. However, because the heat exchanger surfaces will be exposed to constant physical and chemical stresses, some leakage is possible, as are accidental spills. The environmental effects of such leaks will depend greatly on amounts leaked, and weather and sea conditions at the time of spill. The discharge of ammonia will affect both plankton and fish (Epifanio and Srana, 1975; O'Connors, 1975; Schwoenbel and Tillmanns, 1972). Such effects could include mortality and sublethal effects, such as reduced growth, reduced respiration, depressed reproduction, and other stresses. Stressed individuals would also become more susceptible to predation. Spilled ammonia would form ammonium hydroxide, which would dissociate into ammonium and hydroxyl ions, which would increase the pH of the receiving waters. The toxicity of ammonia is related to the amount of undissociated ammonium hydroxide. In the pH range of 7.5-8.5 common to Guam's offshore waters, ammonia would exist predominately in the ammonium ion form, thus minimizing toxicity.

In the event that the ammonia spill was entirely subsurface, about 90 percent would go into solution (EPA, 1977). An increase in ammonia concentrations of this magnitude could have dramatic detrimental effects on marine life. The impacts would be a function of ammonia dispersal, as well as the richness of the communities affected.

The proposed land-based facility could be surrounded by berms to contain, or direct, the flow of the ammonia to the safest and least damaging location. The amount would be small, but contact with the rich coral communities on the seaward side of Cabras Island, or the upper reaches of Apra Harbor, would probably result in nearly total destruction of marine life.

The proposed sea-based facility would be located such that prevailing trade winds and currents would convey the spill seaward, thus isolating its impact on the pelagic environment. Near-total kills of organisms could be anticipated, until dilution reached levels of about 5 to 10 times that found in nature. However, spilled ammonia might threaten Luminao Reef in the event of winds other than normal trades existing during the accident.

Synergistic Effects of Chlorine and Ammonia - Since the possibility of ammonia leaking into chlorinated sea water exists, the synergistic effect should be considered. If ammonia nitrogen levels are sufficiently high in chlorinated sea water, monochloramines may be formed. Monochloramines are persistent, have high chronic toxicity to many marine organisms, and are thus undesirable. The formation of monochloramines is dependent on the chlorine dose, pH, and amount of ammonia. Monochloramines appear to form more easily when the ammonia nitrogen level is at least one part per million. Since ambient levels of ammonia at tropical sites are generally one part per million or less, a concentration of about 0.6 parts per million or about 3,360 pounds (eight one hundredths of one percent of the total sea-based OTEC reservoir) from leaked ammonia would be necessary to produce the critical concentration. The formation of monochloramines is receiving continued research in the U.S.A., and much more should be known over the years during which a Guam OTEC plant would be planned.

Metallic Ions - Losses from the piping, pumps and heat exchanger surfaces of an OTEC plant, as envisioned in this study, will represent a continuing low-level source of aluminum. The erosion/corrosion rate for aluminum under OTEC conditions is estimated at 0.1 mil per year. While the erosion rate may be small, the extremely large surface areas anticipated on an OTEC plant (100,000 $Ft.^2$ for shore-based, and 10 million $Ft.^2$ for sea-based) will result in substantial total amounts of ionic aluminum being discharged. Aluminum is ubiquitous, and very little is known of its toxicity to marine organisms. Previous studies (Pulley, 1950) found that shrimp and mullet could endure concentrations of about 10 parts per million for more than two days. However, little information has been gathered on the metal's effect on plankton and its possible bio-accumulation. While the problem of bio-accumulation and food chain magnification is a potentially important issue and deserves careful studies, the low-discharge concentrations anticipated minimize the potential of bio-accumulation.

In addition to metals from heat exchangers, OTEC systems are anticipated to use protective coatings to retard growth on CWP; and, in the case of a sea-based OTEC Platform, anti-fouling paints. These paint coatings generally consist of salts of heavy metals (primarily copper, mercury, zinc) and arsenic, all of which are toxic to marine life. The metals slowly diffuse out of the paint matrix. The effects of these metals will be similar to those of any large marine vessel, and are not considered significant impacts.

3.1.2.2 Mixing Effects

Nutrients - Another environmental concern, with respect to OTEC operation, is that of nutrient enrichment of euphotic waters in the vicinity of the effluent discharge. Pumping of cold, nutrient-rich water from depth and discharging into the sun-lit upper layers may stimulate increases in local primary production. Characteristically, the near surface waters off Guam are oligotrophic, supporting low amounts of phytoplankton production despite availability of abundant solar energy for photosynthesis. Phytoplankton production in the area is probably nitrate-limited (Lassuy, 1979). This limited productivity occurs because no mechanism exists for mixing of nutrient-rich deeper water across the pycnocline and into the sun-lit upper strata, where the nutrients would stimulate more vigorous primary production. The OTEC systems will create artificial upwelling conditions, thus promoting eutrophication of local waters.

For the small, shore-based facility, this water with increased nutrients will be discharged and flow through the existing Piti and Cabras power plants and then into the outfall lagoon, which leads to Apra Harbor. This discharge will be the equivalent of a cold river of nutrient-rich water, equivalent in volume to a flow about 1.4 times the average flow of the combined effluents of the Piti and Cabras power plants. The increase in nutrients in the backwaters of the harbor, where mixing is normally slow, will result in stimulation of primary productivity. Depending upon the species stimulated, this productivity may, or may not, be transferred up the food chain and result in increases in fish species. Prior to final design of a shore-based OTEC plant, culturing experiments using phytoplankton presently found in upper Apra Harbor, with nutrient levels raised to those expected from the 2,000- to 3,000-foot deep intake waters (see Figure 10), need to be undertaken.

For the ocean-based OTEC system, depending on operating properties and site conditions, significant thermohaline mixing of discharge waters through the pycnocline and into deeper waters might occur. Displacement of plankton, micronekton and nekton organisms from their normal locations in the water column, and possible interference with vertical migration patterns and behavior, are anticipated potential impacts.

For a 100 MW OTEC plant discharging approximately 5,400 mgd, nutrient impacts should be considered in light of near-field (up to 1,000 feet from the platform) and far-field (greater than 1,000 feet from the platform).

In the near-field, rapid initial mixing can be induced by proper selection of discharge port configuration and size. The discharge plume could be oriented to sink to the limit of the photic zone in less than an hour, thus minimizing the exposure of phytoplankton to the elevated nutrient conditions. In addition, in the near-field the discharge plume should remain intact and, thus, minimize the availability of nutrient-rich water to phytoplankton not entrained and carried beyond the photic zone. The discharged water will contain increased levels of nitrogen and, to a lesser extent, silicates (Interstate Electronics Corporation, 1978). The elevated silicate concentrations will probably favor diatoms, which require silicates, over dinoflagellate and coccolithophore plankton.

In the far-field, the colder and denser plume will continue to expand and sink to depths of lower light levels and higher nutrient levels, eventually stabilizing at a point where densities are equal. This level would probably be in excess of 300 feet. At this point, nutrients in the plume may be up to twice that of ambient levels, but light should limit increased primary production. However, there is some concern (Lassuy, 1979) that deep currents will drive the dispersed plume up onto Luminao Reef, under other than trade conditions. This phenomenon, of potentially serious impact, is receiving continued study at the University of Guam.

Natural Toxicity - There is some evidence that natural levels of micro-constituents in deep ocean waters inhibit phytoplankton growth (Barber, 1973). While no information is available to indicate this may occur at the proposed site, should this happen it will offset, to some degree, the enrichment effects described earlier. Present research at the University of Hawaii is directed towards further defining this phenomenon (Caperon, 1979). Natural toxicity will require continued study and definition to determine its effect on OTEC impacts.

Entrainment and Impingement - Entrainment refers to the incorporation of smaller pelagic organisms (plankton and micronekton) into the condensor or evaporator water flow. Impingement refers to the physical blockage of larger organisms from joining this entrainment through placement of barrier screens on the intake ports. Entrainment effects will be among the more important aspects of OTEC operation, from an environmental standpoint. Organisms entrained into OTEC heat exchangers will experience a variety of stresses, including thermal stresses (inside the heat exchangers, and as the discharge water equilibrates with ambient receiving water), mechanical stresses (turbulence, abrasion and pressure changes), chemical stresses (biocides, corrosion products), and ecological stresses (altered light and trophic conditions attending vertical water mass displacement). Organisms in discharge receiving waters will also be subjected to some of these adversities. These stresses will manifest lethal and sublethal effects which may bear upon the population dynamics of certain species, but may be well below detectability in the case of some species. Studies at coastal generating stations with heat exchangers in operation indicate that pump entrainment effects (mechanical or hydraulic stresses) may account for a significant portion of total plankton mortalities (e.g., see Carpenter and others, 1974). The 40°F thermal changes over approximately ten seconds, which may characterize OTEC entrainment conditions, would be relatively benign by comparison to the more radical temperature changes normally associated with heat exchangers in coastal generating stations. The pumping systems used to circulate sea water through the OTEC plants may impose mechanical stresses similar to those in coastal power plants.

Implications of evaporator (upper ocean levels) entrainment may be more important than for condensor (deep water) entrainment, since early life history stages of most species of pelagic fish of commercial resource value reside the upper (mixed) ocean layer. Although they normally comprise only a small portion of the zooplankton community from a numerical standpoint, their numbers may figure importantly in maintenance of stable, reproducing populations. This would be especially true in the land-based facility which would be obtaining warm water from Apra Harbor.

Impingement effects are significant concerns at many coastal power plants, where traveling screens and trash racks account for high levels of mortality among fishes attracted to and drawn into intake structures. Velocity caps, improved well screen designs with a mesh size of about ½-inch, effective barriers and fish return systems are mitigating these effects in many locations. Similar technological innovation should be incorporated into both the shore-based and sea-based OTEC final designs.

<u>Temperature Impacts</u> - In the case of the ocean-based OTEC system, the mixed effluent will be discharged at 100 feet and gradually sink, as noted previously. However, in the proposed shore-based OTEC system, the discharge is to be put into the existing Cabras/Piti power station intake channel. The mixed

effluent would be cooler (possibly 20^{o}F cooler) than the presently used cooling water, which is currently drawn from the surface waters off Cabras Island. The cooler water will affect the efficiency of cooling loops within the existing power plants. This technological impact deserves consideration in the final design of the proposed shore-based plant. If the OTEC effluent water temperature was raised about 10^{o}F by its subsequent use in the Piti and Cabras plants, the resultant discharge would still be about 10^{o}F cooler than normal ambient temperature of the receiving Apra Harbor waters. These waters currently receive nearly 265 mgd of water 10^{o}F warmer than "normal" from the Piti and Cabras power plants. The depressing effects of temperature reduction could offset partially the nutrient enhancement effect described earlier, and deserves study as OTEC designs proceed.

Fish Attraction - The sea-based OTEC platform would constitute an artificial habitat and will, thus, attract fish populations. Numerous investigators have recorded high pelagic fish densities (tuna, wahoo and mahi mahi) adjacent to artificial and natural floating objects. Reasons hypothesized for this phenomenon have been the presence of shade, presence of epibiotic food sources and shelter from predators, among others. The OTEC platform will provide all of these characteristics. The fish attraction aspect of the platform cannot presently be quantified, but could be of importance to commercial and sport fishing. Studies to be performed at the Mini-OTEC platform off Hawaii should begin to quantify this impact.

Benthic Enrichment - Benthic enrichment might also occur in the vicinity of the OTEC plant, due to increases in detrital fallout resulting from increases in productivity in the surrounding water column. This impact will be of greater significance in the shore-based facility than the sea-based facility, due to the reduced mixing in upper Apra Harbor. Benthic enrichment of the sea-based facility is expected to be minor. Studies of the phenomena would present a true research opportunity for Guam-based scientists.

Operational Waste Discharges - A sea-based OTEC platform would produce minor waste discharges from cleaning of the system, lubricants, and wash-down waters. These should be insignificant and minor, and every effort should be made to minimize them through properly designed housekeeping procedures in the final design of an OTEC system. Both the sea-based and land-based OTEC facilities should provide for collection and proper disposal of liquid wastes, such as sewage, wash-down water and used lubricants, to island-based facilities.

3.1.3 Operational Impacts - Air Quality

The major air quality impact associated with either a shore-based or sea-based OTEC plant is the accidental release of the ammonia working fluid. This could occur for several reasons. A vehicle collision with the land-based plant, or a ship collision with the sea-based plant, could damage the working fluid containment system. Human error or accident might also cause a release of the working fluid, as might an act of terrorism. Proper design and operational procedures can minimize these events. The hazards of this release are discussed in Section 3.3.4.

The possibility of a typhoon damaging either of the proposed OTEC plants and causing a release of the working fluid must also be considered. Both the shore-based and the sea-based OTEC facilities are considered "fixed", from the standpoint of being unable to avoid typhoons. In spite of design modifications that might minimize damage and reduce the possibility of ammonia release, storm damage is probably the largest threat to the ammonia working fluid piping system of either OTEC alternative.

U. S. Coast Guard studies indicate that approximately 60 percent of a major ammonia spill would go into solution, with the remaining 40 percent vaporizing to be dispersed in the atmosphere. Atmospheric dispersion would be a function of winds and atmospheric stability.

The proposed sea-based facility is located such that prevailing trade winds would convey the spill seaward, thus minimizing impact on Guam.

3.1.4 Visual Impact

3.1.4.1 Land-based Alternative

The proposed land-based facility would be similar in external appearance to a warehouse, like those at the Guam Commercial Port facilities. The visual appearance would be more pleasing than the Cabras or Piti power plants, and there would be no exhaust stacks or emissions associated with the OTEC operation. The four large, cold water pipes would be below grade in the intake channel and, therefore, not particularly obtrusive on the landscape. From the shore near Piti Village, the OTEC plant would appear as an additional 2 to 3-story building, depending on the heat exchanger design.

3.1.4.2 Sea-based Alternative

A large sea-based OTEC facility, as depicted in Figure 5, moored up to 1½ miles to sea, would be visible from the western shoreline of Guam. The extent to which it could be seen from the north or south would be dependent upon the final location selected. The platform would probably project 50 to 100 feet above the surface and would be lit at night. The presence of the platform would, thus, be noticeable both day and night. It would have the cross-sectional appearance of a large freighter or warship, both of which are common visitors to Apra Harbor. There would be no emission, or other exhaust, associated with the platform. This visual impact is not considered significant.

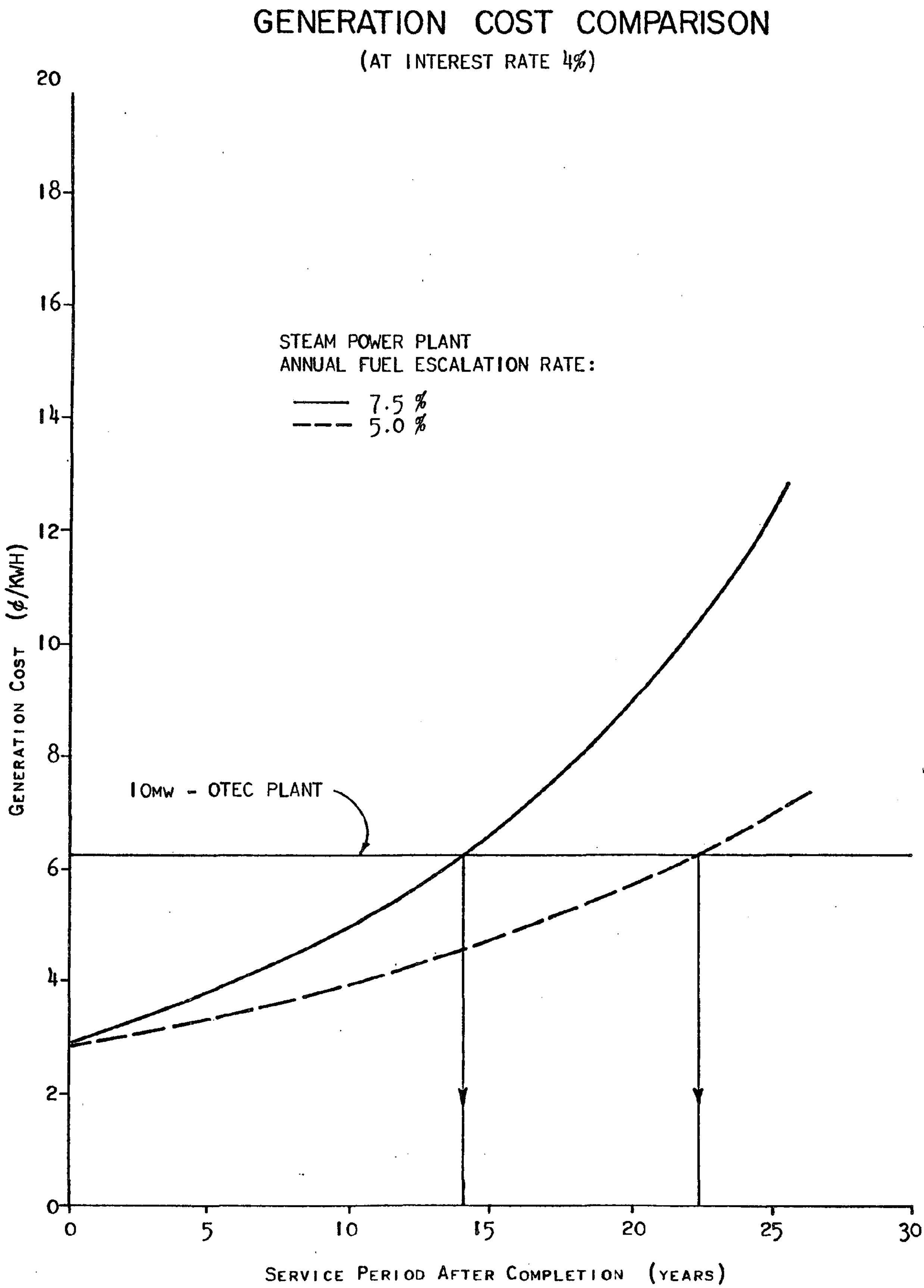
3.2 Economic Impacts

The economic impacts of OTEC implementation on Guam will be a function of the alternative plant selected and the institutional operating arrangements. Numerous scenarios are possible. However, because OTEC is envisioned as an extension of Guam Power Authority's (GPA) generating capability, this study assumes the GPA would operate the OTEC facility selected. GPA OTEC operation would be controlled by the Guam Public Utilities Commission (PUC).

TEPSCO (1977) prepared a comparison of generation costs for the proposed OTEC plant and the steam power plant. Fuel escalation rates of 7.5 percent and 5 percent, considerably less than those experienced in 1979, were provided. This simplified comparison is presented in Figure 14. The comparison demonstrates the effect OTEC might have on continuing increases in generation costs.

3.2.1 Employment

3.2.1.1 Land-based Alternative - The construction of a 10 MW shore plant, at an estimated construction cost of 32 million dollars, would provide a significant boost to Guam's construction industry during the construction period. A 32 million dollar project would be about one-quarter of Guam's record year's construction business (1974), and about one-half of a typical year's activities (Dames & Moore, 1978). This increase in construction would have positive economic impact, but might contribute to the existing immigrant labor problem as additional alien labor would probably be required to meet the added labor demand. The skills required for OTEC component assembly might also require additional skilled labor that could be committed to other projects. This would mean an additional number of technically skilled people might also have to be imported, above the estimated 5,500 alien



REFERENCE: TEPSCO, 1979

DAMES & MOORE

FIGURE 14

contract workers currently on Guam. These increased labor demands would create increased community demands on housing, and other facilities, for the workers and their families.

As there are no commercial OTEC facilities in operation, no data exists on the number of operators required for an OTEC power plant. However, estimates based upon anticipated designs indicate approximately the same(± 15%) number of persons as required for a steam-power plant would be required for an OTEC plant. This estimate is based on maintenance requirements of the generators, heating and cooling systems, electrical switching gear, and items not associated with the power sources (e.g., an OTEC-powered turbine, or a diesel-powered turbine).

<u>3.2.1.2 Sea-Based Alternative</u> - Construction of a large sea-based plant would require a ship drydock, and a construction facility currently not available on Guam. Because the cost of constructing these facilities would be a large percentage of the cost of a sea-based OTEC plant, it is likely that a sea-based OTEC plant would be built in a shipyard at a location other than Guam, and then towed to its final location. Therefore, the

construction impact on Guam of this alternative would be minimal.

The operation of a large, offshore power plant would require an estimated crew of 50 operators. The need to service this crew with provisions would create more jobs in the community (estimated 10-15) in the form of surface vessel or helicopter service companies.

It is likely that some of the skills required for maintenance of the sea-based facility are not currently available within GPA. These additional, skilled operators would have to be hired from somewhere other than Guam. However, in numbers of employees, for the same reasons expressed in Section 3.2.1.1, no major change in actual number of operators is anticipated. Operating experience with Mini-OTEC (50 KW) and OTEC-1 (100 MW) will begin to define these manpower needs more closely.

3.2.2 Government Revenues

Government revenues would be obtained indirectly from an OTEC plant in the construction phase, or in the positioning phase of a large sea-based plant, by the extra income spent in the community and taxed. The construction of a 32 million dollar plant would generate significant spending in the

Territory which would be captured by existing government means. GPA, an independent government agency, would obtain revenue from selling the power generated. The amount of revenue would be set by the PUC, and would be a function of the cost of money (the interest rate at which GPA would borrow money), and the users' rates allowed by the PUC. A full evaluation of the economics of OTEC is to be undertaken by other investigators.

3.2.3. Private Sector Profits

The private sector on Guam is in the position to reap the most immediate benefits from OTEC implementation. The increase in the construction industry, and subsequent demands on service industries, would be significant. Using a multiplier of 2.8 dollars created for every dollar spent, and a 10 percent profit margin, construction of the small plant would create profits of nearly 9 million dollars during the construction phase.

The costs of positioning an ocean-based plant would not be large. However, servicing and the complement of approximately 50 operators would require equipment and personnel, and could cost about a million dollars a year. Using the same profit margin of 10 percent, the platform servicing company could net $100,000 annually. If the 2.8 multiplier is applied to the servicing company operation, and additional $280,000 in profits is possible. In addition, the shipping of raw materials and replacement equipment into Guam would generate a significant amount of revenue. Even if 1 percent of the 235 million dollar facility were replaced each year, the amount of material flowing through Guam would generate significant business.

3.2.4 Military Support

In discussions with the U. S. Navy (Toves, 1979), their position, in regards to OTEC and other alternative means of electricity generation, is that their requirements dictate that electrical power be available at all times. For this reason, the Navy requires some generator units to be "warm and spinning" in readiness. Concern was expressed over the currently unproven reliability of OTEC-generated power to meet these readiness requirements. GPA officials also share this concern, and would not move to install an OTEC facility until the reliability of OTEC technology has been proven (Becher, 1979). With this assurance, the stated Navy position is that the U. S. Navy on Guam desires to divest itself of all utility operations and would purchase power from GPA, regardless of the method of generation.

Additional research and operating experience must be completed to convince the U. S. Navy of the reliability of

OTEC. However, since even a 100 MW sea-based plant would be less than half of GPA's generating capacity, it appears the guarantee of firm, available power could be made from oil-fired generators concomitant with the generation of electricity by OTEC, or other means.

3.2.5 Related Industry Support

The possible requirements of the construction industry and offshore supplier were discussed in Section 3.2.3. Industry support would be required in the shipping and handling of OTEC components. Of particular significance is the shipping and handling of the ammonia working fluid. Large amounts of ammonia would be required to initially charge the system, and additional amounts would be required on an on-going basis. Guam currently has no facility which would handle the large amounts of ammonia required. A new facility, designed with the toxicity of ammonia as a critical requirement, would be necessary. Crews specifically trained in handling the ammonia would also be required, creating new jobs.

A similar situation would exist in regards to the chlorine requirements for OTEC. Chlorine could be shipped as a gas, or in the powdered hypochlorite form. In either case, the amounts required for a 10 MW or 100 MW facility will be relatively large. The exact amounts will begin to be determined by the extent of biofouling, and the effectiveness of chlorine as a biocide, on the State of Hawaii Sea Coast Test Facility, Mini-OTEC, and OTEC-1. The required chlorine, which is a hazardous cargo under Federal regulations, must be handled and stored with care equal to that of ammonia. This will require new, special facilities and crews, and will create new jobs as well.

3.2.6 Effects on Tourist Industry

The generation of electrical power via OTEC will have no effect on Guam's existing $100 million-a-year tourist industry, as visitors to Guam are generally isolated from the current means of electricity generation, and would remain isolated from either of the proposed systems. The usual island tours, and other activities, would probably continue to avoid the Piti/Cabras industrial area.

However, the presence of an OTEC facility on Guam may well attract additional visitors, as it has in Hawaii. Engineers, scientists, and others, would be attracted to an OTEC facility, much like they are attracted to nuclear-powered and municipal solid waste-fired plants in the United States. Interest in design, performance, and environmental and economic impacts would draw a new type of visitor to Guam. Not large in number compared to traditional Guam market areas, these visitors will be influential and genuinely interested in not only the Guam OTEC project, but the natural and social environment on Guam. Such visitors could play a major role in promoting Guam, from a visitor's standpoint.

3.2.7 Effects on Fishing Industry

3.2.7.1 Fish Attraction to Sea-Based Plant

The attraction of fish to floating objects has been discussed in Section 3.1.2. Fish attraction to OTEC is being studied in Hawaii in 1979 with regard to the 50 kilowatt Mini-OTEC facility there. However, the attraction phenomena is so well documented that it is highly probable higher order predacious fish will be attracted to an OTEC facility. This will increase the density of fish, and increase commercial and sport fishing in the area of the platform. Such an increase will provide an economic boost to Guam's fledgling fishing industry, which landed less than a thousand pounds of fresh fish per day in 1978. This was 36 percent of all fish products consumed on Guam. The boost will be in the form of increased requirements for vessels, equipment and supplies, and more fishermen/boat operators to take advantage of the increased fish population. The question of species mix, or which desirable species will be predominantly attracted, must await further study to determine the magnitude of this beneficial impact.

3.2.7.2 Hazards To Fishing

A sea-based facility with an underwater power cable to shore could be designed to minimize the exposure of the cable to shipping and fishing activities. However, long-line fishing and deep trawling would probably be restricted in the cable corridor from the platform to the island. Also, fishing and other activities would be restricted to activities which are safe and prudent, from a marine navigational standpoint.

The intake CWP for a land-based OTEC is not anticipated to obstruct navigation or fishing because it will probably be anchored to the bottom and coral reef. This would be analogous in construction technique to a large sewage treatment plant outfall structure; but, because of the relatively large size of the OTEC pipe, the environmental impacts would be correspondingly greater.

The outfall structure for a sea-based OTEC platform is not envisioned as extending beyond the perimeter of the platform (see Figure 5). Therefore, no hazard to navigation, or adverse effects on fishing, are anticipated.

The outfall structure for a land-based structure would be both into the cooling water intake channel for the Piti and Cabras power stations, and then into the discharge lagoon of Apra Harbor. In neither case are the discharge structures envisioned as presenting navigational hazards. However, possible navigational effects on outfall designs should be considered in the further design of any OTEC facility selected for Guam.

3.2.7.3 Mariculture Potential for Shore-based OTEC Facility

Guam's stable temperature regime and relatively constant photoperiod afford ideal conditions for mariculture. The use of OTEC effluent for mariculture depends upon the metal and ammonia content being sufficiently low, and on the ability to divert the effluent from the ponds for the two hours per day when chlorination might take place. These requirements are necessary at any life stage of the organism selected.

Milkfish, mullet, oysters, mussels and penaeid shrimp appear to be suitable (Bur. Plan., 1977), and could be raised in facilities designed to control effluent temperatures to those tolerable to the selected organism. Conceivably, the effluent could be run through a tower to pick up heat and oxygen from the atmosphere and give up chlorine, prior to its use for mariculture, if necessary.

The selection of the organism to be cultured will depend predominantly on the economics of management and operation, as well as the market demand and price. Oysters, penaeid shrimp and milkfish have been cultured successfully in Hawaii. Prawns have been cultured on Guam. There appear few technological barriers to the culture of these organisms on Guam (Bur. Plan., 1977); but new species of oysters might need to be introduced, and a source of milkfish fry (other than the Philippines) would be required. Estimates of production range from 3,000 pounds per acre per year for milkfish, to 40,000 pounds per acre per year for oysters (Bur. Plan., 1978). The areas of nutrient requirements and deep water chemistry need examination prior to an economic study and final organism selection. In addition, land requirements adjacent to the proposed site would appear to limit the extent of mariculture.

3.2.8 Relationship to Overall Commercial Port Development

The proposed land-based OTEC location would not interfere with Commercial Port operations, other than to utilize land that could be used for port expansion. Such port expansion would be inefficient due to the OTEC site's distant location from shipping activities.

However, the development of the sea-based OTEC service capability, as previously discussed, would probably require Commercial Port facilities. Similarly, the large ammonia and chlorine storage facilities, and their pipelines, would require a shore-side location to facilitate transfer of these chemicals to the offshore facility, presumably by tanker vessels. One possibility is to locate these facilities adjacent to the existing fuel pier.

The use of a portion of the cold water discharge from a shore-based OTEC plant for operating air conditioners or freezer-chillers could provide additional benefits to the Commercial Port operation. Using essentially the OTEC concept to run an ammonia-powered heat pump to power chillers, the Commercial Port area could be provided with extensive refrigeration/air conditioning, with cold water already "paid for" by the OTEC power plant. Excess water, several times in excess of existing Cabras and Piti power plant needs, would be available from the OTEC plant. The possibility of utilizing inexpensive cooling would enhance Guam's position as a trans-shipment facility for frozen fish, as is outlined in the Land-Use and Economic Plan for Cabras Island and Surrounding Areas. The use of cool OTEC effluent would also reduce the growth in electrical energy required for an equal amount of air conditioning obtained by conventional electro-mechanized chilling units. Additional thermodynamic studies on the efficiency of water-cooled chillers need to be undertaken, utilizing the 2.2 mgd excess flow of OTEC water (about 10^{o}F cooler than ambient), and typical water-cooled chiller thermal characteristics to quantify the amount of cooling available and its estimated construction cost.

Another potential use of the OTEC effluent would be as thaw water or process water in any fish processing facilities developed in the Commercial Port area.

3.2.9 Industrial Applications of OTEC at Sea

Because of the high cost of underwater transmission cable (1 million dollars per mile, minimum), it may be more desirable to utilize the OTEC resource off Guam for industrial applications. While this would mean GPA would not be able to use the power generated by a sea-based OTEC plant, industrial processes at sea could provide employment and reduce land use conflicts on Guam due to noxious or bothersome industrial development.

The offshore industry could exist on board an expanded OTEC platform. Appropriate industries are those that have some, or all, of the following characteristics:

- Require large amounts of electricity
- Generate noise
- Generate thermal effluents that require large amounts of cooling water
- Generate discharges that are high in biological wastes or suspended solids
- Generate air emissions
- Are high in unit value, to maintain marketability in spite of the more expensive production costs that occur in the marine environment

Suggested candidates are:

Manganese nodule processing
Ammonia-based fertilizer production
Electrolytic chlorine production
Electrolytic hydrogen extraction from sea water
Aluminum refinery
Sulphur smelter

All of these processes are subject to fluctuations in market conditions, which will undoubtedly change prior to the completion and use of an OTEC facility on Guam. Presently, some probably would be uneconomic at sea (aluminum, sulphur), and some are uneconomic even at less expensive facilities on land (manganese nodules). However, with increasing demand and scarcity of minerals becoming more common, these processes will become increasingly attractive, if associated with OTEC power generation. Each candidate industry would also have its own environmental aspects which would have to be defined and evaluated.

3.3 Social Impacts

3.3.1 Community Identification and Development

The Guam Bureau of Planning has developed a Community

Design Plan (CDP) for each of the communities on Guam. These plans provide the basis for consideration and implementation of future zoning designations. The CDPs were developed with a significant amount of community and government input, and serve as a pictorial representation of community perceptions and goals (Bur. Plan., 1978). Discussion with community leaders (Salas, 1979), and a review of community attitudes (Bur. Plan., 1977), indicate that Cabras Island is projected to be in heavy industrial use until the year 2000, and presumably beyond. Areas of adjacent Piti Village have been designated low and medium density residential, as well as commercial.

The Cabras Island site envisioned for the land-based OTEC facility is not within Piti Village, and would have minimal operational impact in the village. However, the construction of a large project (of any type) on Cabras Island will temporarily increase traffic, noise, vehicular emissions along Marine Drive, and affect the village. In addition, the extra money pumped into Guam's economy would spur development of the commercial areas of Guam, which include those within Piti.

3.3.2 Recreation

As previously mentioned, recreational fishing will be enhanced, either by a land-based or sea-based OTEC project. Recreational fishing, diving access, and other shore-side activities, will be restricted in the area of the CWP for a land-based plant. No other recreational impacts have been identified in a previous study of planning for impacts of energy facility expansion (Bur. Plan., 1978), nor are any anticipated.

3.3.3 Cultural Tradition

There are no known cultural or historic landmarks in the areas proposed for OTEC projects. However, traditional subsistence fishing takes place in the area along the Apra Harbor cooling basin, and these activities might be enhanced by the increased nutrients of the land-based OTEC discharge.

3.3.4 Public Safety

The increased handling of ammonia and chlorine on Guam, due to increased OTEC requirements, will pose greater hazards to the public than currently exist with the limited use of these chemicals on Guam. The properties of ammonia and chlorine, and their health-related aspects have been described by others (I.E.C., 1978), and follow:

Anhydrous Ammonia

Incompatible with mercury, halogens, calcium hypochlorite, hydrogen fluoride.

Physical state at normal atmospheric pressure: gas.

Solubility: very high, greater than 50 g/100 ml H_2O.

Boiling point: -28°F.

Vapor density: 0.6 units (Ratio of vapor or gas to equal volume of air).

Ignition temperature: 1204°F.

Flammability limits: (percent volume in air)

Minimum concentration which explosion cannot occur - 16%

Maximum concentration which explosion cannot occur - 25%

Hazard Ratings

Health: Short exposures could cause serious temporary or residual injury, even if promptly treated.

Flammability: Must be pre-heated before ignition can occur.

Type of Hazard: Flammable material. Gas or vapor rapidly toxic, or extremely irritating, on exposure for a short time, or in low concentration.

Life Hazard: Primary skin irritant, can cause severe eruptions or burns. Respiratory threshold limit value (TLV) 50 parts per million.

Precautions: Keep away from heat, sparks, open flame; avoid spilling, contacting skin, eyes, clothing. May require gloves, goggles, apron, etc. Use adequate ventilation, avoid breathing fumes, mists, gasses or vapors. Personal respiratory protection may be required.

Fire Extinguishing Method: Water spray.

Ammonia, in high concentrations, is an irritating and corrosive compound that can damage the eyes, mucous membranes and skin, and, on inhalation, inhibit respiration. Upon removal from an ammonia atmosphere, an exposed individual usually recovers in a few days; in extreme cases, eye damage can be permanent. Severe lung exposures can be fatal.

<u>Chlorine</u>

Incompatible with ammonia, acetylene, butadiene, benzene and other petroleum fractions, hydrogen, sodium carbides, turpentine, and finely divided powdered metals.

Physical state at normal atmospheric pressure: gas.

Solubility: Fairly high, nearly 5 g/100 ml H_2O.

Boiling point: -30°F.

Vapor density: 2.5 units.

Type of hazard: Gas or vapor highly toxic, or extremely irritating, on exposure for short time or in low concentrations. Oxidizing material: contact with other combustible may cause fire. Irritant, sensitizer, corrosive, causes skin irritation or burn.

Hazard rating: Short exposure could cause serious temporary, or residual, injury even if promptly treated. Not flammable.

Reactivity: Normally stable except in combination with certain other materials or at elevated temperatures and pressures.

Life hazard: Primary skin irritants can cause burns and skin eruptions. The respiratory TLV 1 part per million.

Precautions to take: Do not handle unless safety precautions are understood. Use adequate ventilation, avoid breathing fumes, mists, gasses, or vapors. Personal respiratory protection may be required. Avoid contact with acids, combustibles, and moisture.

Chlorine is a product carried in large tonnages and is fairly typical of the more hazardous gas cargoes. When sufficient concentration of chlorine gas is present, it will irritate the mucous membranes, the respiratory system, and the skin. Large amounts cause irritation of the eyes, coughing, and labored breathing. Symptoms of exposure to high concentrations are gagging and vomiting, followed by difficult breathing. In extreme cases, the difficulty of breathing may result in death by suffocation. Liquid chlorine in contact with the eyes or skin will cause local irritation and/or burns.

A summary of the sources of ammonia and chlorine, as well as other potential hazards inherent in an OTEC facility and their mitigation, follows in Table 1.

OTEC-1 BULK CARGO HAZARD IDENTIFICATION

AGENT	SOURCE	PHYSICAL STATE	HANDLING PROCEDURES	CREW HAZARD LEVEL	OTEC I HAZARD LEVEL	TYPE OF HAZARD	NEUTRALIZING AGENT	HAZARD MAINTENANCE	COMMENTS
ANHYDROUS AMMONIA NH_3	1	1,2	1,2,3	1,2	3	1,2,3	Water	1,2,3,4,5,6	Protective clothing and Breathing Equipment may be required
CARBON DIOXIDE CO_2	3	2	6	3	4	4	Air Circulation	1	Breathing equipment may be required. Diver hazard.
CHLORINE Cl	3	1,2	1,2,3,5,6	1-2	3	3,7	Ventilation	1,2,3,4,5,6	Protective clothing and breathing equipment may be required.
DIESEL FUEL	4	1	2,3	3	3	1,5	Containment Boom-Absorbents	3,4,5,6	Spill Hazard
ELECTRICAL CONNECTIONS	2,3	--	3	1	4	6	Insulation	2,3,4,5	Protective Clothing and Devices Required
LUBRICATING OILS	3	1	2,3	3-4	3	1	Containment Boom-Absorbents	3,4,5,6	Spill Hazard
OXYGEN	5	1,2,4	1,2,3,6	1	1-2	2	Ventilation	1,2,4,5,6	Supports combustion

SOURCE	PHYSICAL STATE	HANDLING PROCEDURE	CREW HAZARD LEVEL	OTEC 1 HAZARD LEVEL	TYPE OF HAZARD	HAZARD LEVEL MAINTENANCE
1. Working Fluid	1. Liquid	1. Containment	1. High	1. High	1. Flammable	1. Circulation
2. Process Product	2. Gas	2. Storage	2. Medium	2. Medium	2. Oxidant	2. Sensor Monitoring
3. Process Requirement	3. Solid	3. Transfer	3. Low	3. Low	3. Toxic/Irritant	3. Visual Monitoring
4. Fuel	4. Cryogen	4. Shipment	4. None	4. None	4. Sufficant	4. Special Precaution
5. Support Requirement		5. Controlled Application			5. Explosive	5. Personnel Training
		6. Ventilation			6. Shock	6. Containment
					7. Corrosive	

NOTE: Other hazardous materials such as acetylene, paints and thinners, etc. will be carried aboard; however, they have not been listed above due to their being carried in minimal quantities and their hazards should be readily discernible.

POTENTIAL HAZARDS SUMMARY - OTEC

Reference: I.E.C., 1978

DAMES & MOORE
TABLE I

4.0 EXISTING LAND-USE AND ENVIRONMENTAL CONTROLS APPLICABLE TO OTEC DEVELOPMENT

4.1 Land-Use Districting and Coastal Zone Management Policies

The two proposed OTEC facilities have been evaluated in view of the eighteen policies of the Guam Coastal Management Program (GCMP), (Bur. Plan., Vol. 1, undated). These policies also provide specific recommendations on how the objectives of each policy statement can be achieved. The following tabulation delineates the impacts of OTEC development on the Guam Coastal Management Program's policies.

Coastal Management Program Policies	OTEC Impact
1. More effective administration of natural resource related laws, programs, and policies shall be achieved through: o Revision of unclear and out-dated laws and regulations. o Improved coordination among local agencies. o Improved coordination between territorial and federal agencies. o Educational and training programs for local government personnel, and refinement of supporting technical data.	Will require improvements in all four identified areas for successful implementation.

2. Shore Area Development

Only those uses shall be located within the Seashore Reserve which:	a) CWP for land-based facility will impact coastal aesthetics.
o Enhance, are compatible with, or do not generally detract from the surrounding coastal area's aesthetic and environmental quality and beach accessibility.	b) Sea-based OTEC impact depends on shoreline location and, therefore, no other site feasible.
o Can demonstrate dependence on such a location and the lack of feasible alternative sites.	

3. Urban Development

Uses permitted only within Commercial, Multi-Family, Industrial and Resort-Hotel zones; and uses requiring high levels of support facilities shall be concentrated within urban districts, as outlined on the Land-Use Districting Map.	Land-based OTEC to conform, as siting is within industrial area.

4. Rural Development

Rural districts shall be designated in which only low density residential and agricultural uses will be acceptable. Minimum lot size for these uses should be ½-acre until adequate infrastructure, including functional sewering, is provided.	Not applicable.

5. Major Facility Siting

In evaluating the consistency of proposed major facilities with the goals, policies and standards of the Comprehensive Development & CMP, the Territory shall recognize the national interest in the siting of such facilities, including those associated with electric power production and transmission, petroleum refining and transmission, port and air installations, solid waste disposal, sewage treatment and major reservoir sites.	Land-based OTEC will comply with Coastal Management & Community Design Plans. National interest in area of research and development of OTEC should receive consideration.

6. Hazardous Areas

Identified hazardous lands, including flood-plains, erosion-prone areas, air installation crash and sound zones and major fault lines, shall be developed only to the extent that such development does not pose unreasonable risks to the health, safety, or welfare of the people of Guam, and complies with land-use regulations.	Land-based OTEC would require protection from erosion, and storm and tsunami inundation.

7. Housing

The government shall encourage efficient design of residential areas, restrict such development in areas highly susceptible to natural and man-made hazards, and recognize the limitations of the island's resources to support historical patterns of residential development.	Not applicable

8. Transportation

The Territory shall develop an efficient and safe transportation system while limiting adverse environmental impacts on primary aquifers, beaches, estuaries, and other coastal resources.	Not applicable

9. Erosion and Siltation

Development shall be limited in areas of 15 percent, or greater, slopes by requiring strict compliance with erosion, sedimentation and land-use district guidelines, as well as other related land-use standards for such areas.	Not applicable, as land-based OTEC would be on slope less than 15 percent.

10. Conservation of Natural Resources - Overall Policy

The value of Guam's natural resources as recreational areas, critical marine and wildlife habitats, the major source of drinking water, and the foundation of the island's economy, shall be protected through policies and programs affecting such resources.

OTEC implementation would utilize valuable resource for betterment of island economy. Proper design would be necessary to protect other critical resources.

11. Air Quality

All activities and uses shall comply with all air pollution regulations and all appropriate federal quality standards in order to ensure the maintenance of Guam's relatively high air quality.

Air pollution would be reduced if OTEC plant replaced an oil-fired facility.

12. Water Quality

Safe drinking water shall be assured and aquatic recreation sites shall be protected through the regulation of uses and discharges that pose a pollution threat to Guam's waters, particularly in estuarine, reef and aquifer areas.

Benefit versus "threat" of OTEC discharges needs to be determined by future study. Although it is highly probable net benefit from discharge will result.

13. Fragile Areas

Development in the following types of fragile areas shall be regulated to protect their unique character: historic and archaelogic sites, wildlife habitats, pristine marine and terrestrial communities, limestone forests, and mangrove stands and other wetlands.

Danger of thermal plume from sea-based facility affecting Luminao Reef needs further study. Affects of nutrient addition, depressed temperature of effluent and mixing within Apra Harbor require further study for land-based facility.

14. Living Marine Resources	
All living resources within the territorial waters on Guam, particularly corals and fish, shall be protected from over-harvesting and, in the case of marine mammals, from any taking whatsoever.	Not applicable.
15. Visual Quality	
Preservation and enhancement of, and respect for, the island's scenic resources shall be encouraged through increased enforcement of, and compliance with, sign, litter, zoning, subdivision, building and related land-use laws; visually objectionable uses shall be located to the maximum extent practicable so as not to degrade significantly views from scenic overlooks, highways and trails.	Land-based OTEC could be designed to minimize incursion of view from roadway. Displacement of larger power plants by a sea-based OTEC plant would improve visual quality in Piti/Asan area.
16. Recreational Area	
The government of Guam shall encourage development of varied types of recreation facilities located and maintained as to be compatible with the surrounding environment and land uses; adequately serve community centers and urban areas, and protect beaches and such passive recreational areas as wildlife and marine conservation areas, scenic overlooks, parks and historic sites.	CWP for land-based OTEC would limit access to shore along proposed channel.
17. Public Access	
The public's right of unrestricted access shall be ensured to all non-federally-owned beach areas and all Territorial recreation areas, parks, scenic overlooks, designated conservation areas and other public lands; and agreements shall be encouraged with the owners of private and federal property for the provision of reasonable access to, and use of, resources of public nature located on such land.	Security fencing around CWP and discharge pipes for a land-based facility would restrict public access.

18. Agricultural Lands

Critical agricultural lands shall be preserved and maintained for agricultural use.	Not applicable.

4.2 Synopsis of Environmental Regulations and OTEC Requirements

The OTEC technology, due to its limited research application, has yet to be considered fully by regulation agencies. However, Territorial and Federal regulations governing construction and discharge of effluent have been identified. The following table provides a synopsis of these regulations and their applicability to OTEC.

Environmental Regulation	Sea-Based OTEC Requirement	Land-Based OTEC Requirement
Seashore Protection Act	N/A	Permit for construction
GEPA - Water Quality Standards	Permit required for dT of -15 to 20 degrees of farenheit, chlorine discharge would meet existing U.S. & GEPA standards. Long-term effects of trace aluminum and trace ammonia impacts and subsequent permit conditions also a consideration. Nutrient addition also may vary from ambient. Environmental study and assessment of discharge impact probably required	Permit required for dT of -15 to 20 degrees of farenheit, chlorine discharge would meet existing U.S. & GEPA standards. Long-term effects of trace aluminum and trace ammonia impacts and subsequent permit conditions also a consideration. Nutrient addition also may vary from ambient. Environmental study and assessment of discharge impact probably required
GEPA - Air Quality Standards	N/A	N/A
GEPA - Land Grading Permit	N/A	Permit, as significant site preparation anticipated

GEPA - Blasting Permit	N/A	Permit for site preparation as blasting anticipated above and below water for CWP
GEPA - Proposed hazardous waste regulations	Permits possibly required for transporting, storage and disposal of chlorine, ammonia and other wastes to be defined as hazardous.	Permits possible required for transporting, storage and disposal of chlorine, ammonia and other wastes to be defined as hazardous.
DPW - Flood Hazards	N/A	Design must consider storm, tsunami hazards
DLM - Submerged Lands Permit	Permit for placement of electric power transmission cable	Permit for placement of CWP and discharge structure
COE - 404 Permit	Permit to anchor platform and to provide access for electric power transmission cable	Permit and Environmental assessment for CWP and discharge structure
U.S. Coast Guard	Construction inspection of platform and approval by USCG and American Bureau of Shipping	N/A
	Emergency spill control plan required for ammonia and any petroleum products on the platform	Emergency spill control plan approval
U.S. EPA	Hazardous substance control plan for ammonia	Hazardous substance control plan for ammonia
U.S. Dep't of Defense	Permit only if platform outside of territorial sea (12 miles)	N/A
U.S. Dep't. of Labor	OSHA standards will apply	OSHA standards will apply

5.0 MITIGATION STRATEGIES FOR ANTICIPATED ADVERSE IMPACTS

5.1 Suggested Regulatory Authority Needed to Augment Existing Controls for Siting, Land-Use or Pollution Control

5.1.1 Introduction

As OTEC has received regulatory agency attention from primarily an experimental standpoint, there is no real, legal regime directly applicable to a commercial OTEC plant. While existing local regulatory controls appear adequate, administrative interpretation of these controls as they apply to OTEC will be required.

5.1.2 Power Regulations

As long as the OTEC facility is located within the 12-mile "territorial waters" limit, international legal control should not be significant. However, an OTEC facility in U. S. territorial waters would be subject to U. S. law, as well as the regulatory laws of Guam. Other investigators (Bathen, 1975) have summarized the conflicts in state and federal laws governing OTEC. A few of the potential conflicts follow.

The Submerged Lands Act, which conveys to Guam title and ownership of the shoreline, reserves for the federal government the right to regulate the "production of power" in the submerged lands of the U. S. and its territories. Thus, the territorial government's authority to regulate OTEC development under the Submerged Lands Act appears limited, and federal permission (via the Secretary of the Interior) could be required. Also, the United States Code (16 USC 797(e)) authorized the Federal Power Commission to license power projects in any bodies of water over which Congress has jurisdiction. This would appear to apply to a sea-based OTEC plant, and could add an additional permit requirement to the commercial use of OTEC for power generation. Similarly, in the Outer Continental Shelf Lands Act, Congress specifically stated:

> "The Constitution and the laws and civil and political jurisdiction of the United States are extended to...all artificial islands and fixed structures which may be erected (on the outer continental shelf)...as if (this) were an area of exclusive Federal jurisdiction located within a state: ..."

This would appear to indicate exclusive Federal jurisdiction aboard structures such as a sea-based OTEC platform. This issue, and the jurisdictional issues stated above, will probably be decided administratively with the coincidental operation of the first commercial, sea-based OTEC platform.

5.2 Methods to Mitigate or Minimize Adverse Impacts

5.2.1 General

Ocean Thermal Energy Conversion in actuality should be considered a mitigation measure for Guam's traditional generation of electricity using an oil-fired power plant. OTEC will greatly reduce the air emission problems, reduce noise, and slow the rapid increase in electricity costs caused by increasing oil prices. The reduction in oil use will reduce the risk from oil spills. OTEC is not without adverse environmental characteristics, but utilization of these OTEC characteristics offers potential benefits to Guam.

5.2.2 Construction Impacts

The construction impacts of a land-based OTEC can be mitigated by appropriate erosion controls at the land site, and with judicious route selection of the CWP. Interference with existing power plant cooling could be minimized by phasing cooling and effluent channel construction. The visual effect of the completed plant could be enhanced through landscaping and appropriate architectural design. In effect, the exterior of the facility could be made park-like, enhancing the view along Guam Highway Route 11.

The sea-based OTEC platform construction impacts are not anticipated to affect Guam (see Section 3.1.1).

5.2.3 Operation Impacts

The primary impacts that can be minimized are the depressed temperature and the elevated nutrients.

5.2.3.1 Temperature Mitigation - Shore-Based OTEC

Even after the OTEC effluent temperature difference has been reduced by use in the Cabras and Piti power plants for cooling, the resultant discharge probably would be 10-15^{o}F cooler than the ambient conditions of the Apra Harbor receiving waters. Use of some of the cool water in chiller units for the Commercial Port would add additional heat and further mitigate the impact of discharge. The amount of this heat would probably be minor, however.

Construction of a warming structure, such as a tower or raceway, would elevate the temperature; but the size of the structure required for the 380 mgd flow would make this difficult, due to added costs and space requirements. Another alternative is to return the effluent via a discharge pipe down over Luminao Reef to the 300- to 500-foot depth. This would also be expensive.

5.2.3.2 Temperature Mitigation - Sea-Based OTEC

The most feasible method of mitigation of the temperature impacts of a sea-based OTEC plant is to discharge the mixed effluent (see Figure 1) at the depth where ambient temperature equals the discharge temperature. This would involve an additional pipe to handle the mixed volume of water to the 300- to 500-foot depth.

5.2.3.3 Nutrient Mitigation - Shore-Based OTEC

The appropriate mitigation of the effects of discharging elevated nutrient concentrations from a shore-based OTEC facility is to utilize the nutrients in a mariculture scheme. The nutrients would be incorporated into the selected organism and harvested, reducing the nutrients discharged into Apra Harbor. At the planned discharge rate of 380 mgd, about 13,000 pounds of nitrogen and 1,000 pounds of phosphorous would be available per day for mariculture nutrients. While not all would be utilized in a mariculture, and additional contaminants (e.g., solids) would be added to the effluent, nutrient impact would be reduced.

Alternatively, phytoplankton could be raised in an impoundment and continuously harvested for use in mariculture or livestock feed at locations throughout Guam.

5.2.3.4 Nutrient Mitigation - Sea-Based OTEC

Due to the increased dispersion characteristics of the open ocean, nutrient impacts of a sea-based plant will not be as severe as those from a shore-based plant. Plume dispersal and behavior could minimize these impacts (see Section 3.1.2.2). However, if the eutrophication of the waters surrounding a sea-based plant is determined objectionable, the impact could be greatly mitigated if discharge of the nutrient-rich water took place below the photic zone.

5.3 Other Recommendations

The following recommendations are of a procedural nature to facilitate Guam's evaluation of OTEC development and utilization of this technology. These are in addition to recommendations made in previous sections.

1. Place the responsibility for collecting and disseminating OTEC information, and coordinating research and development efforts, under one agency. The Guam Energy Office, with its interest in alternative energy development and its programmatic relationship to the U.S. Department of Energy, appears the most appropriate Government of Guam entity. In addition, any inference of "vested interests" in the status quo would

be eliminated by the designation of the Energy Office as the lead Government of Guam agency.

2. Develop more public awareness of OTEC through an educational effort coordinated by the Guam Energy Office. This would involve presentations to schools and special interest groups, as well as to the public through various media.

3. Provide funding to government and private engineers and scientists to duplicate relevant OTEC research carried out elsewhere. Conduct more benthic research of near-shore reef communities which would be affected by thermal discharge, especially of Luminao Reef due to its close proximity, shallow depths and value as a pristine marine community. Research on biofouling, pelagic wave climate, water chemistry, and biological productivity at various depths needs to be accomplished to compare Guam conditions to those receiving publicity elsewhere.

4. Continue to conduct economic studies to provide a comparison of alternative OTEC construction costs and operating expenses with traditional power plant costs and operating expenses. A computerized economic model, which can be modified with changing labor and material costs, oil costs, financing costs, etc., seems most appropriate.

5. Increase contact with OTEC investigators and program managers to increase Guam's awareness of technological changes. This should be accomplished by having Guam's Power Authority, Guam Natural Energy Institute, University of Guam Marine Laboratory investigators, and others, attend appropriate meetings and conferences; and by contracting with others to provide evaluation of programs in specifically identified areas. (Heat exchanger and underwater electrical transmission are two examples.)

6. Continue to bring the natural and economic conditions on Guam to the attention of Federal agencies funding OTEC projects, to attract appropriate developmental work to Guam.

APPENDICES

APPENDIX A.1 - SELECTED BIBLIOGRAPHY

A.1 SELECTED BIBLIOGRAPHY

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