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Oceanic Engineering Operations
Interstate Electronics Corporation
Anaheim, California 1980

to

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ABSTRACT

Ocean Thermal Energy Conversion (OTEC) employs the temperature differential between warm surface and cold deep ocean water to produce electric power. OTEC plants will operate in tropical and subtropical waters that exceed 500m in depth. The organisms inhabiting these ocean areas have adapted to a stable, pristine environment. The operation of an OTEC plant may disturb this environment, which could result in potentially serious environmental impacts on the biota. The impacts include, among others, the entrainment of plankton and the impingement of organisms on the intake screens.

The assessment of these issues requires a thorough characterization of both the site and the plant engineering and is an integral part of the OTEC program. Interstate Electronics, as part of the OTEC Environmental Assessment Program, examined the historical data from the candidate OTEC resource areas and preliminarily assessed the effects of OTEC impingement and entrainment. The results of these investigations are presented. Additionally, suggestions to complete the OTEC site characterization are given when the available information is insufficient to assess the effects of an OTEC plant.

INTRODUCTION

Ocean Thermal Energy Conversion (OTEC) employs the temperature differential between warm surface and cold deep ocean water to produce electric power via either a gas or a steam turbine. The greater probability of achieving OTEC performance goals with a closed-cycle system has led to its selection as the baseline power system for initial demonstration. In the closed-cycle OTEC system (Figure 1), the warm water is pumped through an evaporator containing a working fluid (e.g., ammonia), and the vaporized working fluid drives a gas turbine which provides power. Having passed through the turbine, the vapor is condensed by colder water drawn from 500m to 1,000m and is pumped to the evaporator for reuse. No conventional fuel is used: the enclosed working fluid is evaporated and condensed repeatedly by the warm surface and cold deep ocean water.

The geographical regions where OTEC plants may operate is limited by the temperature differential available between surface and deep ocean waters. OTEC operation requires a minimal temperature difference between the warm surface waters and cold deep waters of approximately 20°C, hence the resource area is confined to the tropical-subtropical oceans located between 30° north and south of the equator (Figure 2). Water depth, current velocity structure, and the local economic climate are also important considerations in selecting OTEC sites. The U.S. Department of Energy is focusing its attention on three regions of the OTEC resource area for demonstration and commercialization: the eastern Gulf of Mexico, the Hawaiian Islands, and Puerto Rico.

The organisms inhabiting the OTEC resource area are oceanic in nature and have adapted to a stable, pristine environment. The installation and operation of an OTEC plant may disturb this environment and result in potentially serious environmental impacts. The impacts considered include, among others, the entrainment of plankton and the impingement of organisms on the intake screens. The assessment of these issues requires a thorough characterization of both the biota and the intake engineering. The Oceanic Engineering Operations (OEO) of Interstate Electronics Corporation has

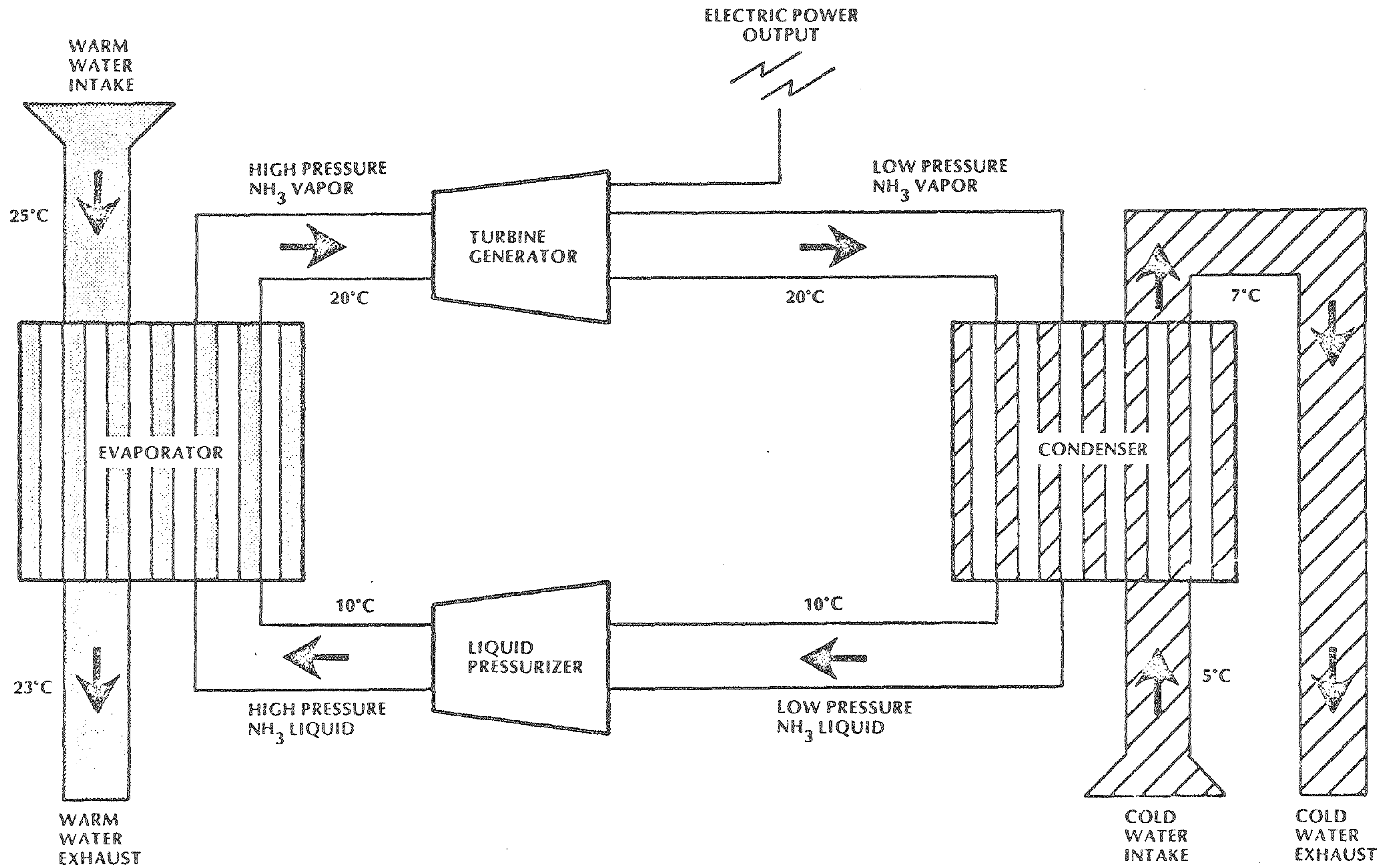

Figure 1. Schematic Diagram of Closed Cycle OTEC System (1)

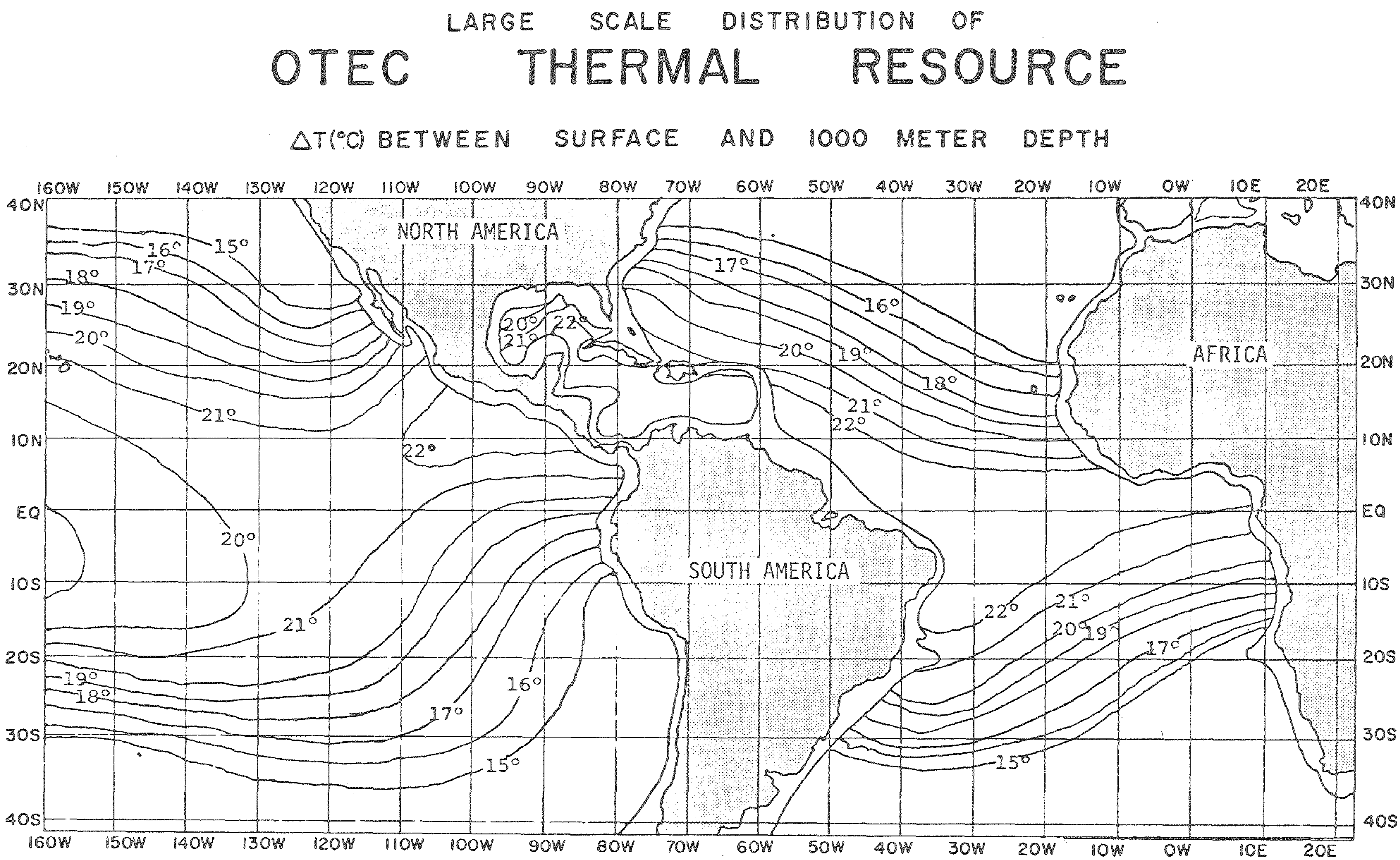

Figure 2. OTEC Resource Area

LARGE SCALE DISTRIBUTION OF

OTEC THERMAL RESOURCE

ΔT(°C) BETWEEN SURFACE AND 1000 METER DEPTH

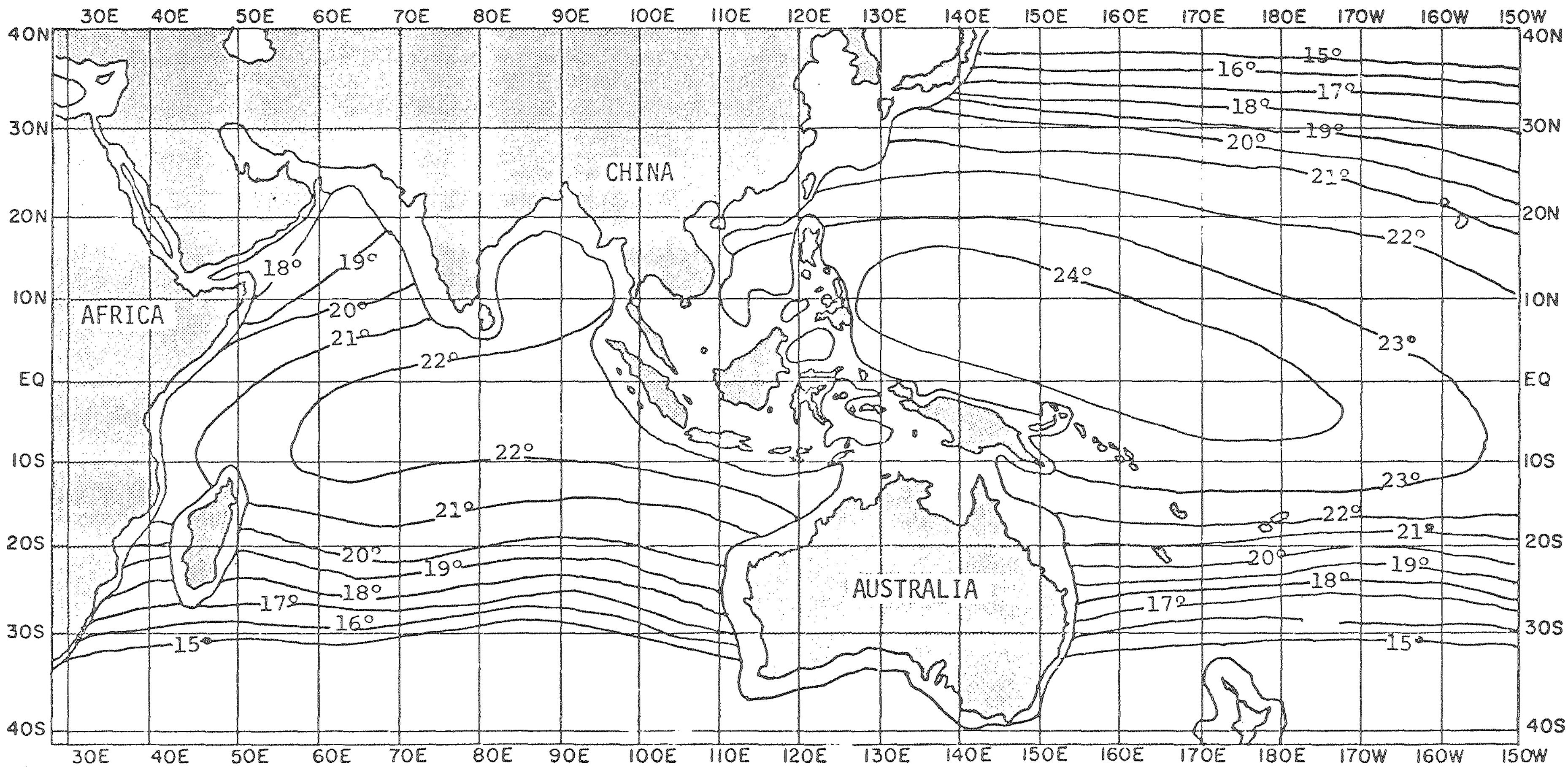

Figure 2. OTEC Resource Area (continued)

prepared an OTEC-1 Environmental Impact Assessment (1) and the Programmatic Environmental Impact Assessment (2) for the Department of Energy. In these assessments, OEO examined the historical data for several potential OTEC resource areas and candidate intake designs.

INTAKE SCREENS

The OTEC concept provides a unique screening situation. OTEC plants utilize large volumes of water per unit of power produced as compared to conventional power plants. For instance, a 400-MW OTEC plant would pump 222 million m^3 day^{-1} while a similar sized nuclear power plant (San Onofre, California) uses 2 million m^3 day^{-1}. Generally, conventional power plants have vertical traveling screens at their intakes. The screen tops are out of the water and can be serviced and cleaned. The warm water and cold water intakes of an OTEC plant will be located between 5m to 25m and 1,000m depths, respectively; too deep for normal screen operation. Therefore, sumps have been proposed that provide an air-water interface where conventional screening can be used.

One of the designs considered for OTEC-1, to be deployed off Hawaii in 1980, has a velocity cap covering the bottom of the warm water intake which produces a horizontal flow field. The horizontal flow field is more readily sensed by fish than vertical flows and may be avoided (3). The OTEC-1 cold water intake at 640m has a bar screen with openings of approximately 2.5 cm by 76.2 cm. Static "L" shaped screens having openings of 1.6 mm by 76 mm are used at the warm water and cold water sumps.

Several studies investigated the screening requirements of large scale OTEC plants and estimates of over 8,000 m^2 screen surface area may be required for a 400-MW plant (3, 4, 5). Presently, both static and traveling screens are under consideration. The most economical traveling screen has been estimated at 3m wide with total cost minimized (including initial cost, head loss, and operational maintenance cost) at an intake velocity of 46 cm sec^{-1} (3).

ENTRAINMENT

The entrainment rate is related to the vertical location of the warm and cold water intakes as well as the vertical distribution of the plankton. A 400-MW OTEC plant will have its warm water intake in the upper 25m and its cold water intake at 900-1,000m.

Marine organisms small enough to pass through the screens of an OTEC plant will be withdrawn with the seawater flowing through the heat exchangers. Entrained organisms at the warm water intake will be subjected to chlorine and the physical abuse (acceleration, impaction, shear forces, and abrasion) associated with passage through the plant. At the cold water intake, entrained organisms will be exposed to these conditions plus a temperature and pressure change of approximately 20°C and 100 atmospheres, respectively. Mortality rates at both intakes may be nearly 100 percent. Organisms that survive will be exposed to an altered environment and increased predation. The relevant biological information for the phytoplankton and zooplankton in the eastern Gulf of Mexico, Hawaii, and Puerto Rico is presented and daily entrainment rates are estimated.

Phytoplankton

The vertical distribution of phytoplankton biomass in OTEC resource regions is characteristically low at the surface with a subsurface maximum near the thermocline or nutricline. Generally, the surface chlorophyll _a_ values ranged from 0.05 - 0.26 mg chlorophyll _a_ m^{-3}, while the subsurface maxima (from 60m to 125m) ranged from 0.12 - 0.39 mg chlorophyll _a_ m^{-3} (1, 2).

The net carbon fixation by phytoplankton in Hawaiian waters is between 53 and 84 mg C m^{-2} day^{-1} (9). Offshore prpoductivity measurements for the Caribbean Islands is about 100 mg C m^{-2} day^{-1} (6). The maximum primary production in Hawaiian waters occurs at depth, near the chlorophyll _a_ maximum (8, 10).

By estimating an average chlorophyll _a_ concentration of 0.1 mg m^{-3} at the surface, and ssuming biomass reported as chlorophyll _a_ is converted to biomass carbon by multiplying by 100 (7), the daily phytoplankton entrainment rate for a 400-MW OTEC plant is about 12 kg C. Since the primary production in surrounding waters will be about 80 mg C m^{-2} day^{-1}, the entrained biomass is comparable to that produced daily in about 15 km^2. Therefore, OTEC will affect a small area localized around the plant. Also, the majority of the phytoplankton productivity and biomass occurs near the bottom of the photic zone and away from the intake, thus the phytoplankton will not be seriously affected by OTEC-1 operation. In fact, biomass may increase downstream due to the discharge of nutrient-rich deep waters into the surface layers.

Zooplankton

Vertical distribution data for oceanic zooplankton is scarce for the OTEC resource regions. Zooplankton biomass in the upper 150m of Hawaiian waters range from 0.5 to 0.8 mg C m^{-3} (11, 12, 13, 14) while the eastern Gulf of Mexico has reported concentrations of 0.1 to 3.1 mg C m^{-3} (15) and 1.75 to 6.9 mg C m^{-3} (16). Zooplankton vertically migrate to the surface at night. The night biomass in the upper 150m of Hawaiian waters is about 1.3 to 1.7 times the day biomass (11). The night:day biomass ratio was reported as 2.3 in the eastern Gulf of Mexico (15). Average biomass concentrations of about 0.25 mg C m^{-3} occur in depths greater than 300m in both regions (12, 15). At 1,000m depth, concentrations range from 10 to 30 percent of the surface values (2).

By assuming a surface biomass of 1.75 mg C m^{-3} and a night:day biomass ratio of 1.5, the warm water intake entrainment rate for a 400-MW OTEC plant can be estimated at 310 kg C day^{-1}. With an average zooplankton biomass of 0.25 mg C m^{-3} at 1,000m, the cold water intake entrainment rate is estimated to be 26 kg C day^{-1}. Since the daily entrained biomass by a 400-MW OTEC plant is comparable to the zooplankton biomass in the upper 150m of a 1.3 km area, the effect will be localized and will not impact the zooplankton populations in the oceanic basins in which these plants operate. However, the deployment of several plants within an oceanic region may result in regional ecosystem impacts and seriously disrupt the zooplankton population.

Meroplankton

One critical biological implication of OTEC plants is their operation in proximity to shore and the entrainment effects on the nearshore larvae. The existence of a larval population near the spawning site around the islands is vital for adult population existence.

Estimates of meroplankton (planktonic eggs and a larvae of nearshore invertebrates and fish) abundance are speculative because larval abundance varies according to species dominance, seasonal spawning patterns and several other factors and generalizations can be legitimately made. However, large OTEC plants could impact the nearshore populations in localized areas. Further studies will be required to assess the impact of OTEC operation on the meroplankton.

IMPINGEMENT

Impingement of organisms will be one of the most visible effects of OTEC operation on the marine environment. Impingement is both an environmental issue and a plant operational concern, since maintenance costs are associated with intake screen cleaning and plant downtime. *A priori* impingement rate estimates are difficult to make and depend on intake location and velocity, ambient current velocity, time of day, and the size, feeding activity, and swimming abilities of the populations. In addition, marine organism behavior also will play a role in impingement rates.

Several studies have documented that epipelagic fish congregate around offshore structures seeking protection and food (19, 20). Lights may also attract marine organisms. However, the actual number of organisms attracted is impossible to predict and will depend on several factors including plant distance offshore, water depth, type of intake structure design, water clarity and the availability of attractable organisms in the area.

The avoidance capabilities of oceanic organisms differ not only between species, but perhaps also by time of day. It is suggested that vertically migrating species of mesopelagic fish are less capable of escape than the inactive resting daytime fishes at depth (21).

No quantitative attraction numbers are available which will aid in the prediction of OTEC impingement rates. Subsequently, impingement rates are computed from the ambient concentration and intake flow rate, with no consideration given to attraction or avoidance behavior.

The only quantitative information on oceanic organisms which may be impinged on OTEC screens is from midwater trawl data. Although the intake velocities for OTEC plants (between 50-100 cm sec^{-1}) are less than the towing speeds of midwater trawls (100 to 200 cm sec^{-1}); similar kinds and quantities of organisms caught may be impinged. This is thought to occur primarily due to the overriding significance of volume to impingement, rather than velocity of the withdrawn waters (22, 23). Hence, organisms affected by impingement include small epipelagic fish, mesopelagic fish, macroplanktonic crustaceans (penaeid and caridean shrimps, mysids, large euphausids), and cephalopods.

Gelatinous organisms, such as coelenterates, salps and ctenophores, will also be impinged. All of these organisms are collectively called micronekton.

Micronekton play important roles in the oceanic ecosystem, acting as an important intermediate step in the food chain between the zooplankton and many commercially important fish, such as tunas, marlin and swordfish (17). In addition, the micronekton inhabit the mesopelagic during the day and vertically migrate to the epipelagic at night to feed. By so doing, they serve as an important step in a ladder that brings the energy produced in the photic zone to the organisms living in the deeper regions of the ocean.

Few tropical-subtropical studies have used opening-closing midwater trawls to systematically collect stratified samples of micronekton. The majority of the studies conducted report results from night collections or numerical abundance. Data for diel vertical distribution indicate the upper 400m of a 1,200m water column off Oahu had an average of 0.82 mg m^{-3} biomass during the day and 6.26 mg m^{-3} biomass at night, on a wet weight basis (18). Between 400m and 1,200m, the biomass averaged 5.80 mg m^{-3} during the day and 3.05 mg m^{-3} at night.

Then, the warm water intake screen will impinge about 420 kg daily while the cold water intake will impinge approximately 460 kg per day. This daily impingement rate is comparable to the micronekton population in the upper 1,000m of a 0.2 km^2 area. Thus, impingement by a 40-MW OTEC plant may reduce the micronekton population in a localized area downstream of the plant. The ecological impact of this loss is probably insignificant when the replacement ability of the micronekton population in the surrounding oceanic region and the migration abilities of the nektonic organisms that prey on the micronekton are considered.

CONCLUSION

Ocean Thermal Energy Conversion (OTEC) plants will produce electrical power by redistributing large volumes of surface and deep ocean waters. Presently very little is known about the best available technology that can be used to minimize impingement or entrainment rates. Further site specific data are required to fully assess these impacts. These studies include:

1. Seasonal estimates of vertical distribution and abundance of marine organisms.
2. Extent of vertical redistribution of biota.
3. Further field impact data examining both plant and environmental conditions in an attempt to correlate impingement and entrainment rates with physical, biological, and plant operation conditions.

In general, the impingement and entrainment by offshore 400-MW OTEC plant is small, primarily due to the localized affect of the disturbance and the large size of ocean basins in which these plants will operate. As a note of caution, plants in nearshore regions will entrain large amounts of meroplankton; potentially affecting nearshore populations. Multiple plants, on the otherhand, may significantly affect the surrounding oceanic region.

ACKNOWLEDGEMENT

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