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ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM AT POTENTIAL OTEC SITES

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ENVIRONMENTAL MONITORING AND ASSESSMENT PROGRAM AT POTENTIAL OTEC SITES

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Abstract

Ecologically sound operations of projected Ocean Thermal Energy Conversion (OTEC) plants can be insured by careful attention to the marine environment during the design phase. This requires quality information from regions of potential OTEC interest, coordinated with required assessment studies to insure legal compliance. Currently, preliminary or actual surveys and laboratory studies are being conducted in the waters of Puerto Rico, the Gulf of Mexico, Hawaii, and Guam for potential moored or seacoast OTEC plants and in the equatorial South Atlantic for proposed plant-ship operations to provide such benchmark and baseline data. These data plus existing archival information can be used to model effects of OTEC operations based on projected design schemes. Four major areas of concerns (1) redistribution of oceanic properties, (2) chemical pollution, (3) structural effects, and (4) socio-legal-economic; and 11 key issues associated with OTEC deployment and operation have been identified. In general mitigating strategies can be used to alleviate many deleterious environmental effects of operational problems as biostimulation, outgassing, etc. Various assessment research studies on toxicity, biocide releases, etc., are under way or are planned to investigate areas where no clear mitigating strategy is available. Data from the monitoring and assessment programs is being integrated into a series of environmental compliance documents including a comprehensive programmatic environmental impact assessment.

Purpose

The goals of this paper are to present a logical stragety for the evaluation and eventual monitoring at Ocean Thermal Energy Conversion (OTEC) sites or regions so that

- o the effects of an OTEC plant on the environment, and
- o the influence of the environment on OTEC operations can be assessed.

This should result in information which can be used by engineers, designers, and planners to insure practical, safe, and efficient operations of any OTEC plant and provide sufficient justification for operational permits for OTEC plants from the involved regulatory agencies.

Environmental Concerns

The four major classes of environmental concerns and the key issues in these classes associated with OTEC deployment and operation are:

- o redistribution of oceanic properties (ocean water mixing, impingement/entrainment, climatic/thermal)
- o chemical pollution (biocides, working fluid leaks, corrosion)
- o structural effects (artificial reef, nesting/migration)
- o socio-legal-economic (worker safety, enviro-maritime law, secondary economic impacts).

The potential changes in the oceanographic properties of sea water due to OTEC pumping operations are a major environmental concern. Because large amounts of cold deep water and warm shallow water will be pumped to the heat exchangers, likely at some third depth; parameters such as temperature, salinity, density, dissolved oxygen, nutrients, carbonates, particulates, etc. will be modified by mixing with ambient ocean water in the vicinity of the eventual discharge. Discharges in the photic zone may cause biostimulation due to the increased nutrient contribution from the deep waters, with potential changes in either the size, relative abundance or species composition with respect to the resident marine population resulting in secondary effects on the food web. Displacement of sea water also could have toxic effects on ambient species by the introduction of trace chemical substances such as trace metals, organic decay products, etc., from other depths. Certain species, particularly those with low mobility, will be harmed by impingement/entrainment in the pumping system either by contact with the screens and walls of the pipe-heater exchanger system or by the pressure and temperature changes encountered in transit of the system from intake to discharge. Surface discharges may produce climatic effects by alteration of the air-surface-water-temperature ratio. Such an alteration, at sufficient scale such as in an OTEC park, could affect the microclimate by modification of locally generated winds and currents. Long-term operation of a large number of OTEC plants could result in reduced available heat due to the thermal extraction. Surface discharges also could enhance the release of CO_2 and other gases dissolved in cold deep waters with potential climatic effects for large scale operations. This is particularly true for open cycle systems where gases even normally dissolved in the surface ocean, must be separated from vaporized sea water so that gas bubbles do not impede plant efficiency. Such gases will be vented into the atmosphere potentially modifying the local microclimate as discussed above. However, subsurface discharges below the surface mixed layer in the pycnocline could mitigate all or most of the potential problems associated with surface discharges.

Chemical pollution could result as functions of various OTEC plant operations and maintenance procedures. Of major concern are biocides proposed to keep the system components clean of biological growth. There are alternative ways (various mechanical systems) to clean heat exchanger systems, but these may not clean surfaces to the extent necessary for efficient operation. The major problem with biocides is the levels of concentration needed to impede biological growth in the system which unquestionably will affect organisms in the vicinity of the discharge. Furthermore, if chlorine is used as a biocide and ammonia as a working fluid, accidental combinations of these chemicals can produce compounds even more toxic to ambient organisms than the separate chemicals. Leaks of the working fluid of a closed cycle system also will pollute ambient ocean water. The effects and chemical fate of proposed working fluid leaks into sea water are not well understood. Ammonia, for example, is a nutrient in proper amounts and could stimulate marine growth complicating the biofouling problem. However, the excessive doses associated with a major leak are toxic to both marine and human life. Chemical pollution also will be produced by the corrosive effect of sea water passing through the heat exchanger system. Corrosion would produce metallic ions, and scale particles which could have direct toxic effects or long-term effects through incorporation of corrosion products into the particulate food supply of marine organisms through the process of bioaccumulation.

The physical presence in the ocean of a structure the size of an OTEC system itself has an impact on the ocean. The structure of whatever configuration will become an attractive habitat for a wide range of organisms based on experience from artificial reefs. The long-term effects of the structure on the environment will depend on the types, size, and abundance of the organisms attracted to or attached to the structure and this will modify the local population. Regional effects on populations might occur by either interference with, or modification of, nesting habits or migration pathways.

The first three major classes of concerns chiefly dealt with impacts on marine life. However, there are human consequences of OTEC operations which are grouped here as socio-legal-economic issues. Worker safety is of prime concern regulated by the Occupational Health and Safety Administration (OSHA) and the Coast Guard for strictly marine occupational concerns. Potential work hazards are the chemicals used or produced by the OTEC system such as ammonia or chlorine, foul weather during marine operations, collision and systems accidents. Because of the novelty of OTEC operations standard safety procedures will be augmented by procedures unique to OTEC. The siting of OTEC facilities either in international waters or where the downstream effects of OTEC operations might intrude into international waters, will raise the issues of international rights and responsibilities and responsibilities beyond those treated by conventional maritime law and treaties. At present the law of the sea is in a state of flux so that the resolution of potential international issues may be complicated and time-consuming. Probably multilateral agreements or treaties among concerned parties, as is done for fishing rights, may be the interim solution of potential legal problems which may impede OTEC operations. Finally, the construction and operations of an OTEC facility may affect existing social and institutional structures. New jobs will be created and shore-based "boomtown" growth may occur with its associated impacts on housing, education, sanitation, etc. The electrical energy produced by OTEC plants may be transmitted to consumers either by AC or DC transmission lines. The cable needed to transmit this power could have impacts on marine ecosystems at the sea bed and at the shoreline. DC transmission will require two converter facilities, one at sea and one on shore, causing land use problems. If OTEC systems are used to produce energy-intensive products, they will produce air/water emissions typical of those produced in similar land-based industries.

The present and projected status of the resolution of these issues is listed in Table 1. Detailed discussion of these issues is found in the 1978 Environmental Development Plan (EDP) for OTEC.

Present Program

Monitoring

The monitoring strategies are designed for shipboard operations, manned platforms as well as instrumented buoys (Table 2). This program is to be integrated with those proposed by OTEC groups for bio-fouling and corrosion, and by NOAA for synoptic oceanographic parameters. An additional goal is to develop a packaged monitoring program which can be mobilized rapidly to aid in site selection for larger OTEC platforms (Fig. 1). Data collection and monitoring strategies will be done in view of compliance with NEPA and EPA, Corps of Engineers, Coast Guard, etc. regulations.

Specifically the program initiated pre-operational studies in four areas (Fig. 2).

- o Hawaii - one site off the Kona coast (OTEC-1 site);
- o Puerto Rico - one site near Punta Tuna;
- o Gulf of Mexico - regional survey using two station locations: (1) west of Tampa, (2) south of Biloxi;
- o South Atlantic - regional survey, 5-10°S, 20-30°W and affected zone.

In the areas considered for the sea coast or moored OTEC option - Hawaii, Gulf of Mexico, and Puerto Rico - a program has been initiated to take background data before placement of any operating OTEC system in these areas. This is required to insure that baseline information is available to evaluate the effects of OTEC on the ambient environment and to provide environmental data useful in the design of the operating system. At this time, only attractive thermal regions are known with any certainty. It is premature, therefore, to pick exact sites for potential OTEC plants until knowledge of other important environmental siting factors is obtained. Accordingly, for the initial studies each thermal region is divided into subregions in which it is expected that the basic environmental conditions relating to OTEC are spatially homogeneous, although likely to vary seasonally.

Table 1 Issues, required research, and projects

Issues	Required Research	Status of Projects		
		Completed	Current	Planned
Ocean Water Mixing	-Develop computer model to predict the impact of OTEC operations on oceanographic characteristics	2	3	3
	-Establish baseline oceanographic data at potential OTEC test sites	3	2	7
	-Characterize changes in oceanographic characteristics resulting from OTEC test operations	2	2	1
	-Determine impacts of oceanographic changes on site-specific marine ecosystems		4	2
Impingement/Entrainment	-Search existing literature to determine extent of impact at similar ocean water pumping operations		2	1
	-Monitor impacts at OTEC testing sites and define factors responsible for attraction of organisms		2	1
Climatic/Thermal	-Develop computer models to predict impacts of OTEC operation on micro- and macroclimate	2	2	1
	-Characterize site-specific climatic impacts resulting from OTEC test module operations	1	2	1
	-Determine potential increase in levels of atmospheric CO_2 resulting from OTEC operations			1
	-Determine potential microclimate effects of degassing during open cycle OTEC operations			
Biocides	-Survey existing literature to determine impacts of biocides on marine species		2	1
	-Monitor, sample, and characterize biocide discharges during OTEC testing operations		2	1
	-Conduct laboratory tests to determine the effects of varying levels of biocide use on marine ecosystems		2	1
Working Fluid Leaks	-Survey existing literature to characterize impacts of various levels of potential working fluid leaks on marine ecosystems		2	1
	-Monitor, sample, and characterize the extent of working fluid leaks during OTEC operations		2	1
Corrosion	-Survey existing literature to determine effects on marine species of metallic element compounds discharged from heat exchangers constructed of various metals		2	1
	-During OTEC testing operations, monitor, sample, and characterize metallic elements discharged and dispersed into ambient ocean water, and determine the impacts of these discharges on indigenous marine species		1	2
Artificial Reef Nesting/Migration	-Define factors responsible for attraction of organisms		3	1
Worker Safety	-Develop worker safety programs for OTEC facilities using input from land-based facilities using/producing the same chemicals		1	1
	-Develop a warning system for OTEC facilities to prevent collisions with other ocean vessels		1	1
Enviro-maritime Law	-Conduct survey of international law of the sea applicable to OTEC operations; update biennially	1		1
	-Conduct in-depth study of potential legal/institutional issues involving the particular site(s) chosen for OTEC operations			
Secondary Economic Impacts	-Assess the secondary impacts (e.g., land use, air/water emissions, solid wastes) associated with construction of OTEC plants		1	1
	-Assess the socioeconomic impacts of OTEC development	1	1	1
	-Assess the ecological and secondary impacts of electricity transmission			
	-Survey existing literature to characterize air/water emissions expected to be encountered in the production of chemicals at OTEC plants; develop applicable control technologies			1

Table 2 Proposed ecological monitoring strategies

		Time Schedule
STEP I	Pre-OTEC site occupation studies; background sampling of significant ecological and chemical parameters in conjunction with a literature review to define preoperational environmental conditions. Sampling from survey ships or from fixed moorings. Sampling frequency bi-monthly initially for one year, further sampling frequency to be determined by experience.	Initiated FY 78 in Hawaii, Puerto Rico, Gulf of Mexico, South Atlantic
STEP II	Non-interference with Platform Operations	Initiated FY 79 Platform
	No permanent work space on platform	
	Sampling equipment self-contained and transported to and from site	
	Sampling frequency a function of operations schedule	
	All analyses done on beach	
STEP III	Limited interference with platform operations	Plan FY 79
	Limited permanent work space on platform	RFP late FY 79 or Early FY 80
	Sampling equipment and some analytical equipment on site	Operational FY 80
	Most analyses done on beach	
STEP IV	Limited interference with platform operations (crane operations, etc.)	Plan FY 79-80 (experience from Phase I and II)
	Permanent work space in container/vans	
	Power/water from platform but with backup systems	RFP late FY 80
	Operations Van (sensor packages on buoy) A. Wet Lab - sample preparation - gross equipment repairs B. Dry Lab - instruments/analyses/electronic repairs C. Dry Lab II - data reduction/storage/remote monitors	Operational FY 81 (first unit) Additional units as required
	Storage Van (not applicable to buoy) A. Wet Storage - nets, over the side gear B. Dry Storage - equipment, paper C. Sample Storage - refrigerator	
	Real-time operations with rotating permanent technicians	
	Essentially all analyses and data processing done on site	

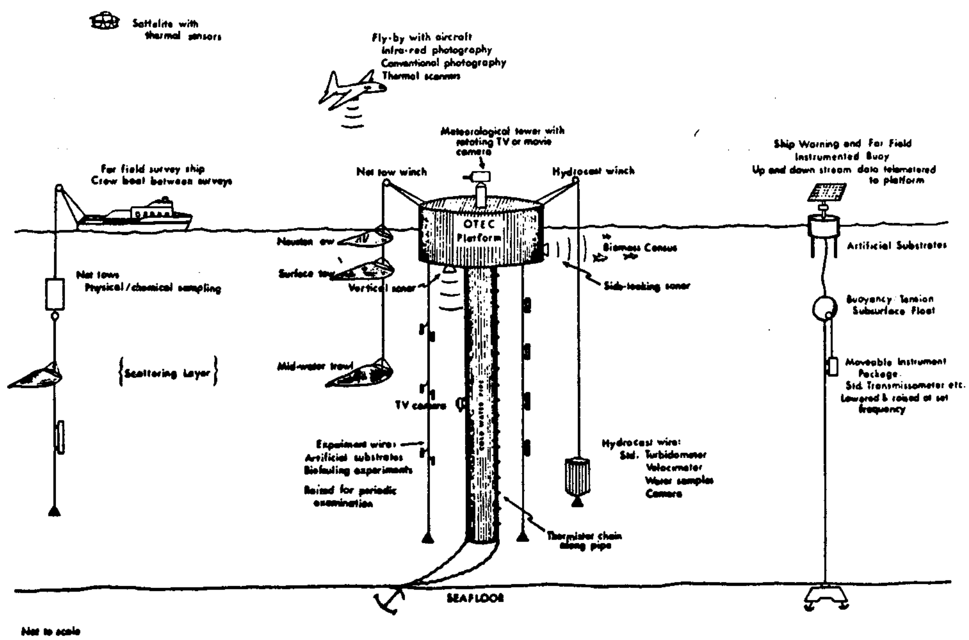

Figure 1.

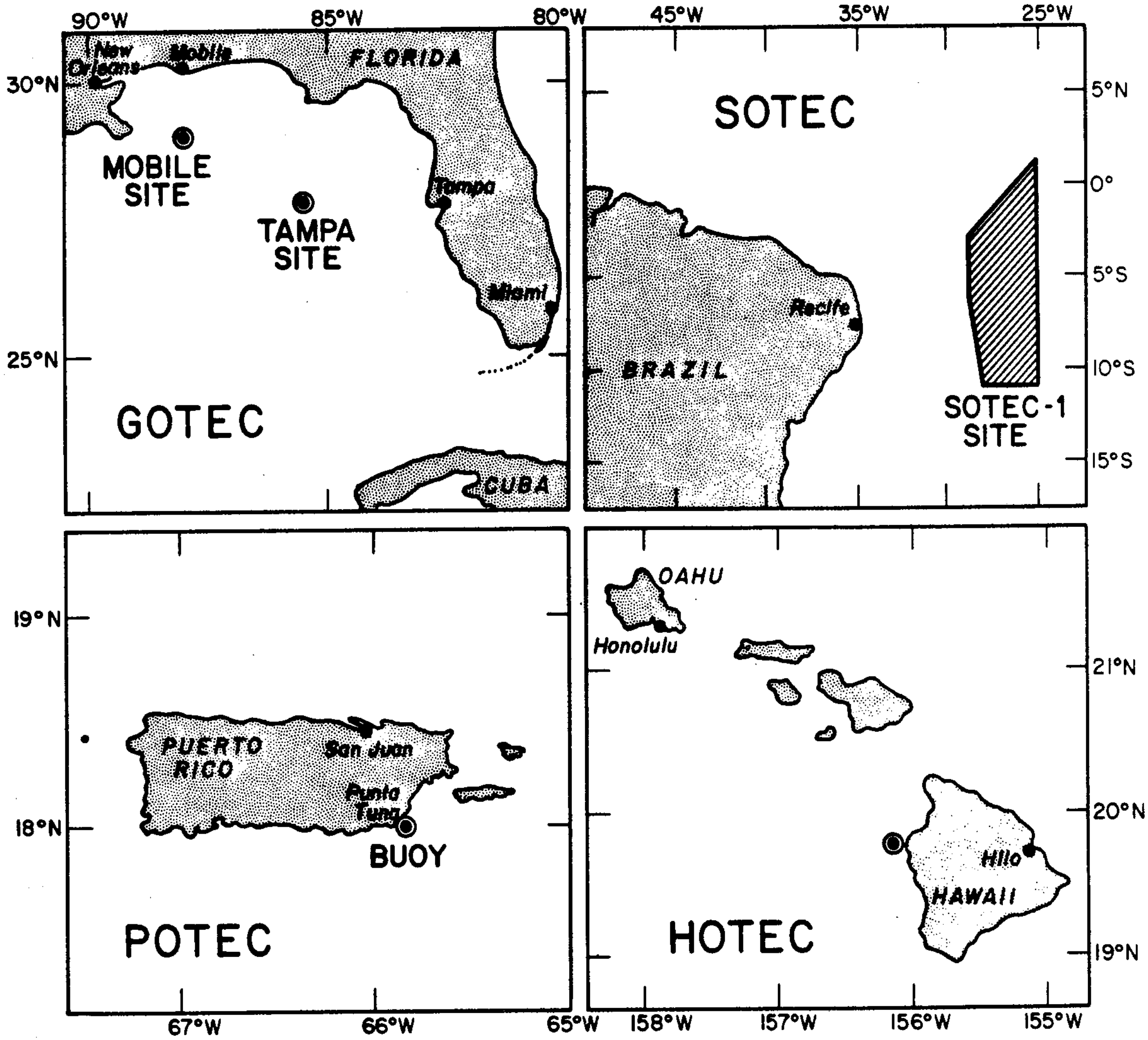

Figure 2.

XBL 795-1393

To characterize each subregion a reconnaissance benchmark is located. A benchmark is defined as a specific location, typical of a subregion, where serial data are taken and to which historical data may be referred. Because of the lack of serial, long-term records of any kind in attractive thermal regions, we believe that the benchmark approach is more valuable in the long term than initiating broad regional surveys where variations in measurements may be attributed to site as well as time variability. Where substantial subregional variability is found, the benchmarks will be used as starting points for potential regional surveys. The intent of taking measurements at benchmarks is to provide data, at a specific location, which will form the basis, in conjunction with previously obtained data from the area, for defining longer term and more comprehensive environmental surveys required for the siting and permitting OTEC plants in the designated thermal regions. Station operations at the reconnaissance benchmark sites are given in Tables 3 and 4. In addition to this station operation at each benchmark, a current meter array will be deployed to complement current profiler runs during station operations, except in Hawaii due to the loss of the Holoholo. A current meter array is planned at the Hawaii benchmark prior to the deployment of OTEC-1. Satellite data, when available, will be used to assist the interpretation of data from the arrays. Because of costs and reliability factors, measurements for the initial surveys will be mainly from survey ships rather than from instrumented buoys. The survey ship will occupy each benchmark site bi-monthly for a minimum of three days with augmented sampling every four months. Sampling at each station occupation is designed to give, at a minimum, day-night variations as well as bi-monthly variations for the biologically significant parameters. Parameters sampled bi-monthly are thought to have variations which may be detected at that frequency. Parameters sampled every four months are thought: (1) to have less variation annually; or (2) to have potential but unresolved significance to OTEC. The augmented sampling every four months also is done to develop optimal measurement and sampling techniques for parameters which may become routine during future site occupations. Upon completion of the initial study (actually, during the surveys) the sampling frequencies and choice of parameters will be re-examined. Results from augmented samplings, from serial samplings, and historical data reviews will be used to design subsequent site data collections. In progress comparison of data from the various OTEC sites is given in other papers at this conference. Status of these sites is shown in Table 5.

Table 3

Station operation	
Profiler	Vertical profiles of horizontal currents
Hydrocast	Discrete samples at depth of: a. temperature b. salinity c. dissolved oxygen d. nutrients e. phytoplankton
STD	Vertical profiles of salinity, temperature
Net tows	Biological samples
XBT	Vertical profiles of temperature to 750 m
Current meter arrays	Discrete measurements of horizontal water currents at depth
Transmissometer	Vertical profiles of light transmittance

Class of Stations	
PRIMARY Occupied in locations of prime OTEC interest - sampling frequency to ascertain diurnal changes	3-DAY DURATION 2 Deep Hydrocasts 2 Shallow Hydrocasts 2 Oblique Net Tows 4 Current Profilers 12 XBT 4 STD
CURRENT PROFILER Occupied to determine spatial variability of current regime	2-1/2 HOUR DURATION 1 Current Profile

Table 4 Ecological/chemical parameters

Parameter	Station operation	Station Frequency	Sampling Frequency
Temperature	hydrocast	bi-monthly	all hydrocasts
Temperature	STD, XBT	bi-monthly	4 STD, 12 XBT
Salinity	hydrocast	bi-monthly	all hydrocasts
Salinity	STD	bi-monthly	4 STD
Water Currents	current meter	continuous	one/30 min
	profiler	bi-monthly	4
Light transmittance	transmissometer	bi-monthly	2 traces/cruise
Dissolved oxygen	hydrocast	bi-monthly	2 casts
Orthophosphate	hydrocast	bi-monthly	2 casts
Total phosphate	hydrocast	every 4 months	2 casts
Silicate	hydrocast	bi-monthly	2 casts
Nitrate	hydrocast	bi-monthly	2 casts
Ammonia	hydrocast	every 4 months	2 casts
Urea	hydrocast	every 4 months	2 casts
Total nitrogen	hydrocast	every 4 months	2 casts
Alkalinity	hydrocast	yearly	2 casts
Trace metals	hydrocast	yearly	1 cast
Chlorophyll/phaeophytin	hydrocast	bi-monthly	2 shallow casts
ATP	hydrocast	every 4 months	2 shallow casts
Phytoplankton census	hydrocast	bi-monthly	1 shallow cast
^{14}C uptake	hydrocast	every 4 months	1 cast
POC	hydrocast	yearly	1 cast
DOC	hydrocast	yearly	1 cast
Zooplankton census	net tow	bi-monthly	6 tows

Assessment

Complementary to the monitoring program are a series of studies to ascertain those effects of potential OTEC operations that are not site-dependent but are generic to OTEC. Also included in such studies are the legal compliance activities (Sands et al., 1979) and model studies (Ditmars this volume) which are discussed in detail in this symposium. Initial studies on toxicity to organisms of various OTEC operations are under way at the Gulf Coast Research Laboratory. The toxicities of aluminum (heat exchanger material), ammonia (working fluid), and chlorine (biocide) are being investigated by bioassays of mullet (fish), copepods (zooplankton). Biostimulation studies using ^{14}C uptake techniques investigating the potential for artificial upwelling effects due to redistribution of nutrients have been started in conjunction with nitrogen fixation studies. Entrainment/impingement, artificial reef, and chlorine studies are being done through DOE's Office of Health and Environmental Research (OHER).

Table 5 OTEC-ERA number of visits/site (July 1977 - May 1979)

Site/Region	Measurements Physical	Chemical	Biological
Mobile	8	6	6
Tampa	-	5	5
South Atlantic	2	2	2
Puerto Rico	5	5	5
Hawaii	2	2	2

Afterword

As the initial OTEC test module contract has just been let (September, 1978) it is too early to determine if the environmental strategies advocated here need to be augmented or modified greatly. Unquestionably strong interactions among environmental groups, regulatory agencies, designers, engineers, and DOE will be required to insure the success of the OTEC environmental program in attaining the goal of ecological compatibility and economical viability for OTEC systems.

To insure continuity among stated DOE program positions and interim reports of this nature, portions of existing documents such as the OTEC Program Summary (1976 and 1977), the OTEC Environmental Development Plan (1977 and 1978), and DOE Assessment Seminar (November meeting) have been quoted here exactly or with minor modifications.

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