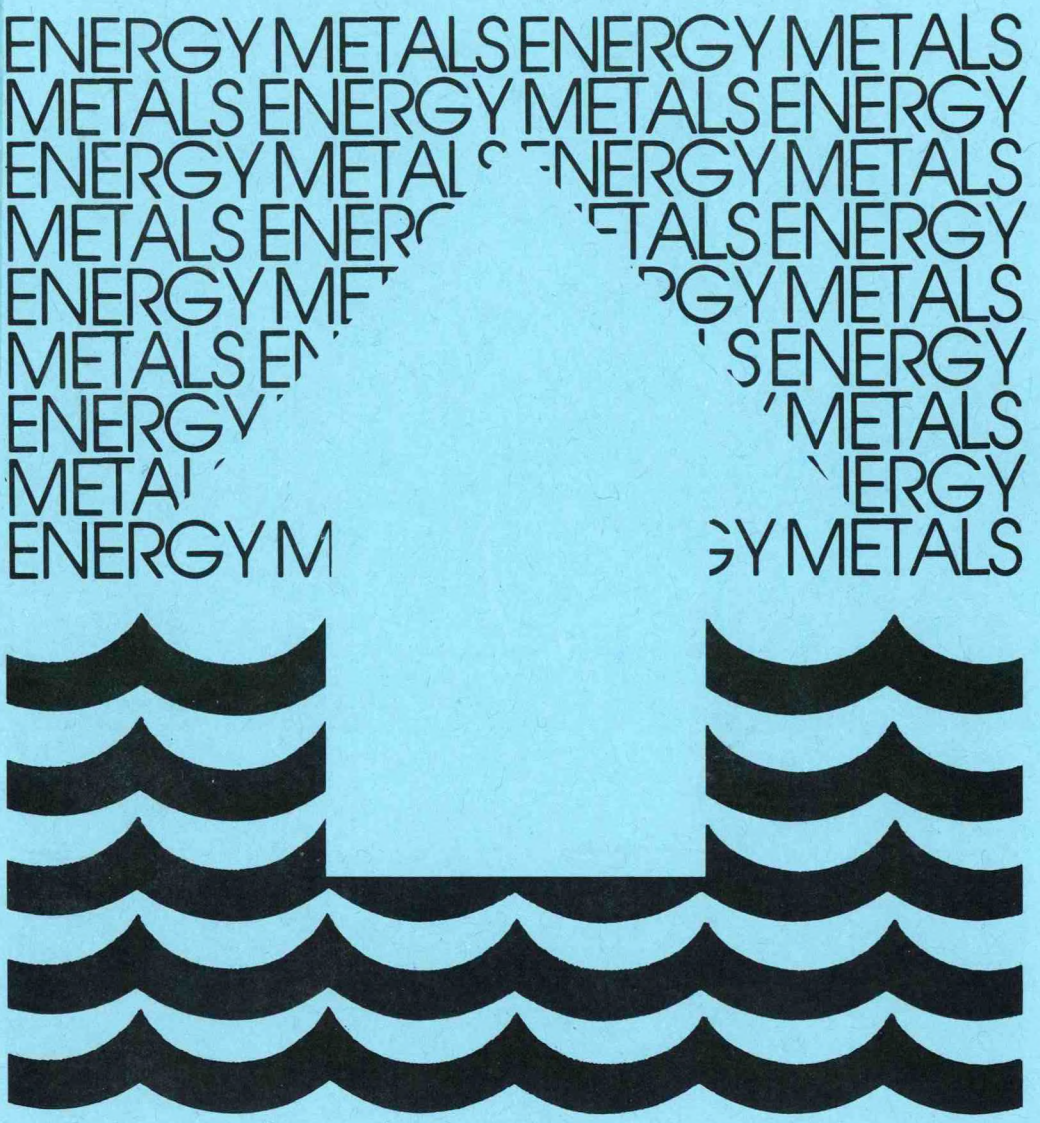

Ocean Thermal Energy Conversion

Report To Congress: Fiscal Year 1984

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

March 1985

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Washington, D.C. 20230

THE DEPUTY ADMINISTRATOR

APR 3 1985

Honorable George Bush
President of the Senate
Washington, D.C. 20510

Dear Mr. President:

I am pleased to submit the Ocean Thermal Energy Conversion Report of the National Oceanic and Atmospheric Administration (NOAA) to the Congress for fiscal year 1984 pursuant to Section 405 of the Ocean Thermal Energy Conversion Act of 1980 (P.L. 96-320).

Sincerely,

Anthony J. Calio

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Enclosure

UNITED STATES DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
Washington, D.C. 20230

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Honorable Thomas P. O'Neill, Jr.
Speaker of the House of Representatives
Washington, D.C. 20510

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Ocean Thermal Energy Conversion

Report To Congress: Fiscal Year 1984

Prepared by:
National Ocean Service
Office of Ocean and Coastal Resource Management
Ocean Minerals and Energy Division
2001 Wisconsin Avenue, N.W.
Washington, D.C. 20235

March 1985

U. S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
Anthony J. Calio, Deputy Administrator

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EXECUTIVE SUMMARY

Ocean thermal energy conversion (OTEC) activities conducted by the National Oceanic and Atmospheric Administration (NOAA) during fiscal year 1984 are described in this report to the Congress. The agency focus for fiscal year 1984 has been on preapplication consultation with potential applicants, ocean engineering and technical assistance to the Department of Energy (DOE), revision of regulations for OTEC licensing, and analysis of the environmental impacts associated with an OTEC facility.

NOAA has provided ocean engineering and technical management assistance to the DOE OTEC program since 1976. The DOE OTEC program effort is focused primarily on a proof-of-concept experiment to demonstrate the technical and economic feasibilities of OTEC electric power generation from a relatively large scale, 40-megawatt electric pilot plant. During fiscal year 1984, NOAA continued to support the DOE OTEC proof-of-concept experiment.

Early work on the development of the OTEC concept emphasized construction of OTEC plants on floating platforms. NOAA supported this concept by developing ocean engineering technology for platforms, cold water pipes, seawater systems, anchors, moorings, foundation systems, and for subsystem integration. However, in more recent years, interest in shelf-mounted systems has increased. The initiation of the DOE study to design a 40-MWe shelf-mounted pilot plant has underscored this shift of research emphasis. In fiscal year 1984, NOAA supported this transition by completing projects in direct support of floating platform development and by focusing on projects that expand the technology base applicable to the shelf-mounted OTEC plants. Principal activities of NOAA's Ocean Engineering Technology Development Program in fiscal year 1984 included small-scale hydrodynamic tests of shelf-mounted platforms and cold water pipes, and a large-scale slopemounted cold water pipe experiment in Hawaii. These experiments and tests were used to collect data which will be used by designers of future shelf-mounted OTEC plants.

During fiscal year 1984, NOAA also undertook two reviews of the OTEC licensing regulations (15 CFR Part 981) to ensure that the regulations did not hinder the development and commercialization of OTEC technology. First, NOAA conducted a periodic review as required by Section 117 of the OTEC Act. The review was initiated by inviting interested persons to submit written or oral comments on the existing regulations. To insure ample opportunity for public comment, the review period was held open until August 1983. Second, the Office of Management and Budget conducted a review of the OTEC regulations from October 1983 to March 1984 in accordance with the Paperwork Reduction Act. OMB requested that NOAA review the

information required by each applicant to determine if such provisions could be clarified and refined to reduce the paperwork burden on an applicant for an OTEC license. As part of this review, NOAA sent a letter to relevant Federal agencies asking that they review the OTEC information requirements and specify the information each agency still considered necessary to carry out its statutory responsibilities in relation to processing an OTEC license application. NOAA subsequently drafted proposed revisions to the existing OTEC regulations incorporating comments received during these reviews and including revisions to the OTEC Act passed by Congress in 1984 (P.L. 98-623).

The OTEC Act of 1980 also calls for the initiation of a program to assess the effects on the environment of OTEC facilities and plantships. In support of this program, during fiscal year 1984, NOAA continued research activities emphasizing information needs related to the licensing of an OTEC operation. Activities included further research on the regional influence of an OTEC operation, defining the area within which the thermal plume of one OTEC operation might be expected to impinge so as to degrade the thermal gradient used by another OTEC operation, and research related to the potential effect of OTEC operations on fisheries.

Chapter I

INTRODUCTION

General

The Ocean Thermal Energy Conversion Act of 1980 as amended (42 U.S.C. 9101, et. seq., P.L. 96-320, amended by P.L. 98-623), known as the OTEC Act, was passed by Congress to facilitate OTEC development by establishing a more certain and stable legal regime for development of OTEC facilities located in U.S. territorial waters or connected to the United States by pipeline or cable. The law also applies to all OTEC plantships owned or operated by U.S. citizens and all OTEC facilities or plantships documented under U.S. law. The Act requires that one must obtain a license from the National Oceanic and Atmospheric Administration (NOAA) in order to own, construct, or operate such a facility or plantship. The OTEC Act of 1980 and the implementing regulations provide the framework for resolving many of the uncertainties which otherwise would have presented serious barriers to the development of a commercial OTEC industry.

The OTEC Act is an important early step in encouraging the U.S. commercial development of an OTEC industry. NOAA, in its role as the Federal agency responsible for OTEC licensing, has made further efforts to assist OTEC development by drafting implementing regulations which streamline the licensing process. NOAA has developed a procedure for preapplication consultations with likely applicants which assist in implementing a one-stop licensing process for all relevant Federal permits. The Act requires NOAA to make a license determination on an OTEC application within one year of submittal to the agency. NOAA also provides ocean engineering and technical assistance to the Department of Energy's OTEC development program. NOAA, by virtue of its expertise in oceanic and marine sciences, has been called on to support the DOE OTEC development program since 1976.

Purpose and Organization of Report

This report is prepared in response to Section 405 of the OTEC Act. It provides a description of the OTEC related activities conducted by NOAA during fiscal year 1984. Chapter I of this report provides background information on the provisions of the OTEC Act of 1980, and a general description of OTEC concepts and potential. Descriptions of NOAA ocean engineering and technology activities are the basis for chapter II. Regulatory and licensing activities are outlined in chapter III. The supporting NOAA environmental investigations are described in chapter IV.

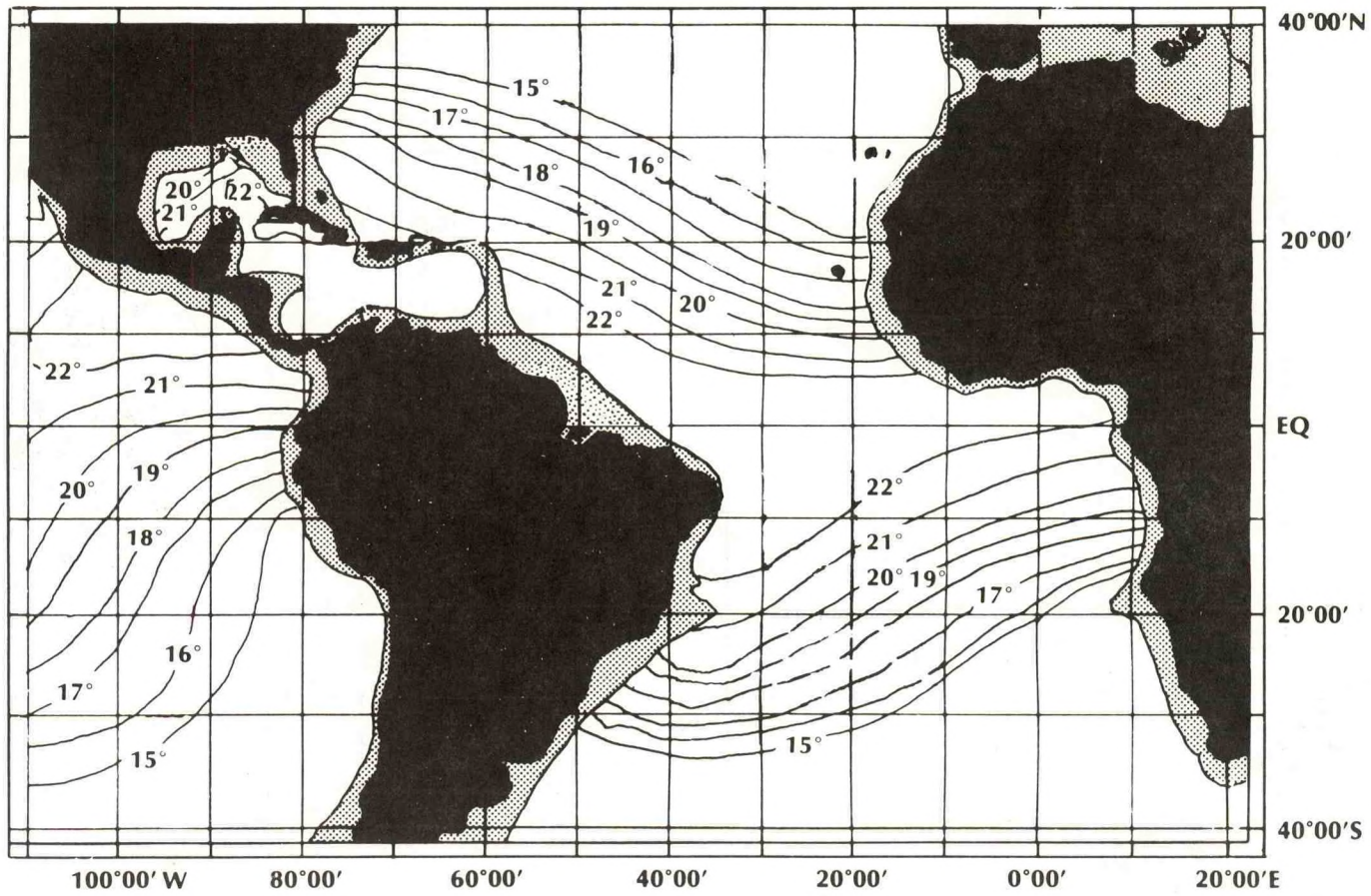
Ocean Thermal Energy Conversion Background

For more than a century it has been known that a heat engine can be powered by the temperature difference between cold water of the deep sea and relatively warm water near the sea-surface. This principle was first described in 1881 by a French physicist, Jacques d'Arsonval. A French engineer, Georges Claude, attempted to apply these concepts in 1929 when he constructed a land-based facility on the coast of Matanzas Bay, Cuba. His early attempts validated the OTEC theories, but the plant itself was a commercial failure. Even today, although OTEC has been experimentally demonstrated to be a sound technology, many design and economic uncertainties remain. They must be resolved before an OTEC-based industry can flourish. Lending institutions are reluctant to commit resources to commercial OTEC plants until there is a reasonable promise of economic success based on successful commercial-scale demonstrations under working conditions that approximate commercial operations. Once the practicability of a commercial OTEC venture has been demonstrated, companies are likely to pursue the significant potential which has been identified for development of domestic commercial facilities and for the export of OTEC technology.

Present OTEC designs involve standard technology and materials currently known to industry; however, they have not been fully tested under long-term working conditions and at commercial scale. Envisaged are either partially submerged, ocean-based platforms; stationary, near-shore platforms; or plantships designed to drift or "graze" warm oceanic waters using the generated electrical power to produce energy-intensive products. The technique for the generation of energy by OTEC methods can be applied most economically in tropical or subtropical areas where the temperature difference between the ocean surface waters and deep waters (500-1000 meters) is at least 20°C (See figures 1 and 2). The two thermodynamic techniques that appear the most economically sound and technically feasible in the foreseeable future are the closed and open cycle systems.

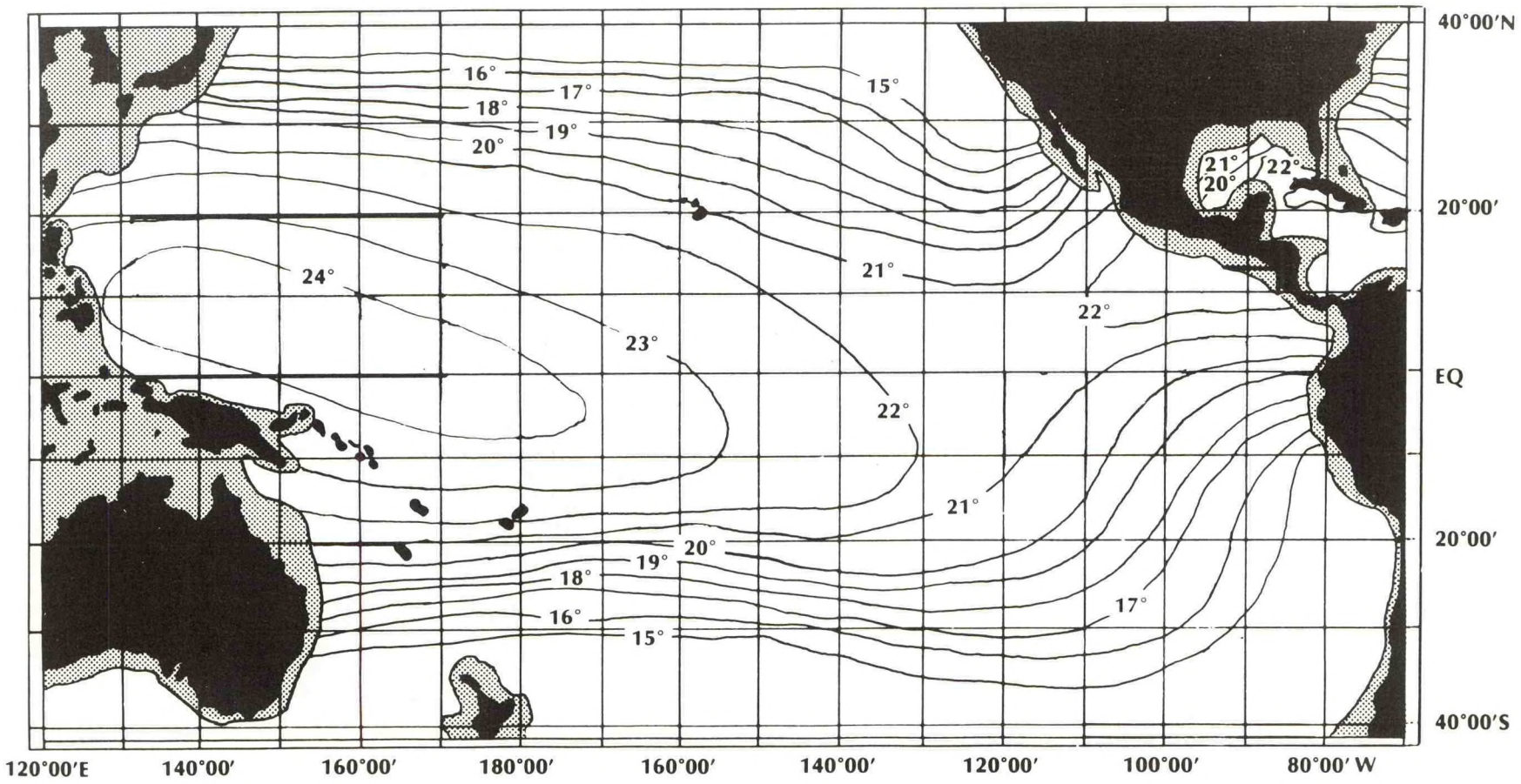
The closed cycle technique uses a working fluid that has a low boiling temperature such as ammonia or Freon™ (See figure 3). This fluid is heated and vaporized in a heat exchanger by the warm surface waters. The vapor drives a turbine which powers an electric generator. After passing through the turbine, the working fluid vapor is condensed to a liquid in another heat exchanger by exposure to cold water drawn from the deep ocean. The working fluid is then pumped back through the warm water heat exchanger, and the cycle is repeated.

In the open cycle system, seawater itself is the working fluid. Warm surface seawater is pumped into a flash evaporator in which the pressure is reduced to the point where the warm seawater boils at ordinary ambient temperature. This produces steam that drives a low-pressure turbine to generate electricity. After leaving the turbine, the steam is cooled and condensed by exposure to cold, deep water in a heat exchanger. The open cycle technique has the advantage that the dissolved salts do not accompany the surface water when it forms steam, and a valuable byproduct, fresh water, is produced when this steam condenses.



*Contours indicate temperature differential (°C) between surface and 1000 m depth

Figure 1. The OTEC Thermal Resource Area (Atlantic)



*Contours indicate temperature differential (°C) between surface and 1000 m depth

Figure 2. The OTEC Thermal Resource Area (Pacific)

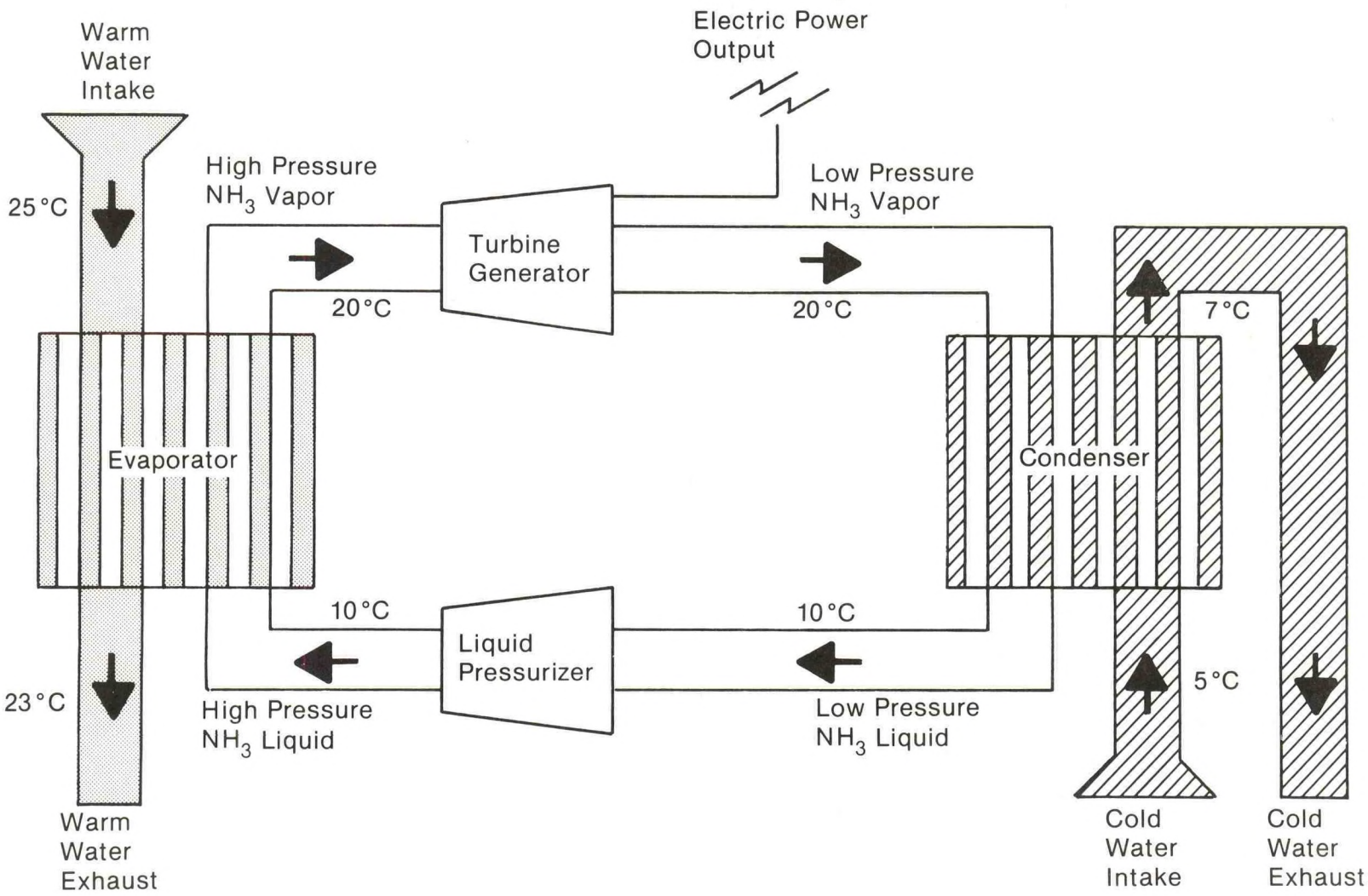


Figure 3. Schematic Diagram of a Closed-Cycle Power System

Chapter II

OTEC OCEAN ENGINEERING RESEARCH AND TECHNOLOGY DEVELOPMENT

NOAA has provided ocean engineering support to the Department of Energy's (DOE) OTEC Program since 1976. The NOAA program has focused mainly on the critical research necessary to design, install, and maintain OTEC ocean structures. Up until 1981, floating OTEC concepts received more attention than shelf-mounted or land-based systems. After 1981, DOE's changing emphasis to shelf-mounted and land-based systems was reflected in the NOAA research program.

Three major projects were undertaken by NOAA in fiscal year 1984: 1) a small-scale shelf-mounted OTEC platform test was conducted by CBI Industries, Inc.; 2) a small-scale slope-mounted cold water pipe test was conducted; and 3) a large-scale (eight-foot diameter, eighty foot long fiber glass-reinforced plastic pipe) test was started off Kahe Point, Hawaii. A summary of each project follows.

Small-Scale Shelf-Mounted Platform Tests

Current conceptual designs for shelf-mounted OTEC platforms utilize a large power production module containing heat exchangers, pumps, and associated equipment, primarily mounted below the waterline on a multilegged offshore structure. In contrast to these designs, conventional offshore jacket structures (e.g., oil drilling platforms) are relatively unaffected by waves because of their open structure below the surface. A platform model test was conducted at CBI Industries, Inc. to investigate the effect of wave blockage by subsurface power plants on total platform forces. The test results form a data base for comparisons with current state-of-the-art analytical tools and future mathematical models as they are developed.

The model was constructed using a scaling factor of 26 to 1 (prototype to model). Five different power modules were mounted in sequence over the platform frame. Each model configuration was exposed to a variety of waves, and wave and current combinations. The forces and overturning moments were measured in the various model configurations and compared to the numerical results of three-dimensional linear diffraction theory. The results indicated that the forces and overturning moments were dependent upon the type and size of platform blockage, and that the experimental data correlated reasonably well with theory.

Small-Scale Shelf-Mounted Cold Water Pipe Tests

Current concepts for shelf-mounted OTEC cold water pipes suffer from a lack of a data base from which pipe design, fabrication, and installation can be accomplished. NOAA conducted small-scale cold water pipe tests to provide information to aid in the design and evaluation of designs for slope-mounted systems.

The hydrodynamic loads on a slope-mounted cold water pipe are a function of wave height and period, wave angle of attack, the pipe's distance above the seafloor, the slope of the seafloor, and the effect of ocean current coupling. During 800 test runs at CBI Industries, Inc., these parameters were varied to obtain data under all conditions presently assumed for potential OTEC sites. Final data reduction and analysis are planned for fiscal year 1985 and will establish the functional relationships between the waves and currents, and the resulting forces and foundation loads. These relationships will be used by cold water pipe designers to establish design parameters for large pipes where site environmental conditions are already known.

Phase III Slope-Mounted Cold Water Pipe Experiment

In April 1984, NOAA and a team of contractors completed the deployment off Kahe Point, Hawaii, of a section of test pipe, 8 feet in diameter and 80-feet long. The deployment followed an 8-month design and fabrication effort and marked the beginning of a 12-month data collection effort to provide the OTEC cold water pipe designer with information critical to the design of large-scale OTEC pipes. The major objectives of the experiment are to:

- o Measure hydrodynamic loads on a slope-mounted cold water pipe;
- o Measure environmental conditions and correlate with pipe loads; and
- o Calibrate analytical models for use in large-scale cold water pipe design.

An objective of secondary importance is the investigation of large-diameter pipe joining and installation techniques on the steep slopes.

The test pipe is mounted on a 40-degree slope, and instrumented to measure forces induced by waves and currents. Dynamic water velocity, pressure, and wave period and height are also measured. All the data is transmitted to a laboratory-housed data acquisition system which telemeters the data to Honolulu for final reduction and processing.

There has been very little data collected using a test pipe as large as the one deployed at Kahe Point. Because of the uncertainty in applying hydrodynamic theories to large pipes, the data will be extremely useful in identifying the most applicable theory. Comparisons will be made between theoretically predicted forces and the forces actually measured during the experiment. Adjustments to theoretical parameters will be made to fit the theory to actual conditions.

Data from the small-scale cold water pipe test at CBI Industries, Inc. will be used to complement the larger scale data being collected at Kahe Point. Although the small-scale data possess a larger uncertainty in its applicability to full-scale conditions, comparison of data from both tests

will help reduce the uncertainty. The small-scale tests will cover a much broader range of environmental forcing conditions than those expected during the experiment at Kahe Point. By using both data sets, force predictions can be made for all potential OTEC sites.

Preview of Fiscal Year 1985 Activities

NOAA will phase out of the Department of Energy OTEC Ocean Engineering Program in fiscal year 1985. Ongoing projects, such as the large-scale slope-mounted cold water pipe experiment, will be completed before the phase out.

Emphasis in the Department of Energy's OTEC program is changing from larger (40-100 megawatt) plants to small (1-10 megawatt) installations. This change in emphasis implies that the data collected during NOAA tests, such as the slope-mounted cold water pipe experiment at Kahe Point, can be considered full-scale data for pipes 8-12 feet in diameter.

Chapter III

OTEC LICENSING RELATED ACTIVITIES

The OTEC Act established Federal jurisdiction over ocean thermal energy conversion facilities located in U.S. territorial waters, or connected by pipeline or cable to United States territory, or plantships owned or operated by U.S. citizens. The OTEC Act calls for a unified licensing process among all Federal agencies (except Coast Guard inspections and approvals) involved in licensing a facility or plantship. The system is administered by NOAA.

Review of OTEC Licensing Regulations

NOAA published final regulations implementing the OTEC Act in the Federal Register on July 31, 1981 (46 FR 39388-38420). During 1984, NOAA undertook two reviews of the OTEC license procedures. First, NOAA initiated a periodic review as required by Section 117 of the Act beginning with a notice in the Federal Register on May 11, 1983 (48 FR 21154-21156). This review sought public comments on whether the OTEC regulations impede development and commercialization of the OTEC technology and should be revised.

A second review of the regulations was conducted by NOAA at the request of the Office of Management and Budget in accordance with the Paperwork Reduction Act. OMB requested that NOAA review the information requirements for each applicant to determine if such provisions could be clarified and refined so as to reduce the paperwork burden on an applicant for an OTEC license. On May 11, 1984, NOAA sent a letter to all relevant Federal agencies requesting comments on the OTEC regulations. The Federal agencies were asked to specify information requirements each applicant would need to provide to their respective agency in processing a license request. In response to these agency comments and comments received from the public, NOAA has drafted proposed revisions to the existing regulations. NOAA plans to publish the proposed regulations for public comment in 1985. The regulations will also incorporate amendments to the OTEC Act passed by Congress late in 1984.

Preapplication Consultation and Federal/State Coordination

Preapplication consultations are intended to facilitate overall OTEC development by identifying potential problems for particular OTEC projects, thus enabling managers to plan and adjust design features if necessary during early development stages. Preapplication consultation also fosters early dialogue between NOAA and potential OTEC license applicants. It can save applicants from wasting effort, time, and money in gathering information that NOAA may not need. Spokespersons for the evolving OTEC industry have endorsed the preapplication consultation concept. A preapplication conference is an important step in enabling NOAA subsequently to meet the 356 day statutory review process outlined in the Act. During 1984, preapplication meetings have been held with Ocean Thermal Corporation (OTC).

OTC began intermittent preapplication consultations with NOAA in July 1982 on a proposed 40-MWe OTEC pilot plant intended eventually for commercial operation. OTC was one of two corporations that originally received cost-sharing contracts in 1980 from DOE for the conceptual design of a 40-MWe OTEC pilot plant. In fiscal year 1983, OTC was selected by DOE to begin the preliminary design phase of the 40-MWe pilot plant. OTC now has decided to proceed with a commercial venture since DOE is ending its participation in the project. In September 1984, OTC submitted a letter of intent to file a formal license application with NOAA.

OTC plans to construct a 40-MWe ocean thermal energy facility near shore in shallow water at Kahe Point, Oahu, Hawaii. The warm water intake for the OTEC plant will be connected to the thermal discharge of the Hawaiian Electric 600 MWe fossil-fuel plant, thereby boosting the thermal resources above that available from the ocean alone. NOAA has held two preapplication consultations during fiscal year 1984 with the Ocean Thermal Corporation and two Federal/State briefings on the proposal:

On April 6, 1984, NOAA met with OTC and TRW to review the OTEC license process.

On July 26, 1984, NOAA met with OTC and representatives from the National Marine Fisheries Service to review potential impacts of construction and operation of a facility on marine habitat.

On August 16, 1984, NOAA conducted an interagency briefing for all Federal agencies potentially involved in the licensing process for an OTEC facility at Kahe Point, Hawaii. This meeting included a technical briefing on the construction and operation of the proposed facility, the potential environmental impacts of the facility, the permitting process and other procedures required by each federal agency represented at the meeting.

On August 28 and 29, 1984, NOAA and OTC conducted a preapplication briefing in Honolulu, Hawaii, for all State and local agencies involved in the permit process for an OTEC facility at Kahe Point.

Study on Export Potential

New OTEC related NOAA responsibilities are contained in the provisions of section 408 of Title VI of Public Law 98-623, which amended the OTEC Act of 1980 (Public Law 96-320). The amendment directs that the Administrator of NOAA develop and submit a report to Congress on the export potential of ocean thermal energy conversion (OTEC) components, facilities and plantships manufactured by U.S. industry. The amendment explicitly indicates that the report will detail the steps the U.S. Government is taking and plans to take in order to promote and advance the export potential of the U.S. OTEC industry. The report also is to include the views of selected Federal agencies who have a vested interest in the subject, and to recommend appropriate actions for promoting and enhancing the U.S. OTEC potential. During 1985, NOAA will be developing the export potential study.

Chapter IV

ENVIRONMENTAL ASPECTS

During fiscal year 1984, environmental research within NOAA's OTEC licensing office continued to focus on the determination of regional influence of OTEC operations and on the potential effects on fisheries. As noted in the reports to Congress in fiscal years 1981-83, this emphasis is consistent with priorities identified in NOAA's OTEC Environmental Effects Assessment Program Plan for fiscal years 1981-85. However, because of the intent of Ocean Thermal Corporation to apply for a license to build, own, and operate a 40-MWe OTEC plant at Kahe Point, Oahu, Hawaii, part of the research program has centered on this area.

Regional Influence Model

The regional influence model, started by Argonne National Laboratory in fiscal year 1983, was completed in fiscal year 1984. The final report of this study is still undergoing a peer review which is near completion. The purpose of the model is to delineate the area within which the operation of an OTEC plant would influence the operation of another plant, and to better define changes in the physical-chemical characteristics of the nearby waters that could result in environmental effects.

The model was first applied to a "base case", that of a 40-MWe OTEC plant sited in deep water off a hypothetical coast. A mixed-discharge effluent is released into the upper ocean, and then the velocity and temperature distributions of the effluent plume are examined for two conditions of simulated coastal currents. The plant effluent was also modeled to contain a "dye" to indicate the fate of constituents such as biocides or nutrients. The model was applied under similar conditions to: (1) an 80-MWe OTEC plant located on a coastal margin to examine the effects of doubling the capacity; (2) two 40-MWe OTEC plants sited near each other to examine interference effects; (3) a 40-MWe plant located further offshore; and (4) the case of a near-bottom discharge on a slope. The objective was to define how simple changes in the base condition might affect the regional influence caused by the discharge. The influence of the intake was estimated to be insignificant.

Based upon the receipt of notice from OTC to file an application for an OTEC license for Kahe Point, the NOAA OTEC Office decided in late 1984 to extend the Argonne study to a site-specific situation--that of an OTEC plant at Kahe Point. The study was initiated and is soon to be completed. In addition to providing more information on the operation of the model, it will provide information necessary to the licensing and related environmental impact statement process.

Fishery Effects

During fiscal year 1984, fishery effects research was performed in several areas. Of the new studies, two examined the effects of "cold shock", and one examined the vertical distribution of fish eggs and larvae. The results of these studies are presently in preparation. A synthesis of the potential impact of OTEC operation on fisheries, initiated in fiscal

year 1983, was completed in fiscal year 1984 and sent out for comment. The report on this study is presently near publication.

The rationale for the "cold shock" studies derived from the fact that when the eggs, larvae, and juveniles of fish entrained with warm OTEC waters are mixed with the cold water prior to discharge, there will be a sudden "cold shock" of about 10 C° imposed on them. Also, when mixed effluents are discharged to the ocean, fish entrained by the diluting plume will be subject to some degree of cold shock. Although work has been performed on "heat shock" due to thermal discharges from conventional and nuclear power plants, a review of the literature showed no reported work on the effects of cold shock on the early life history stages of tropical fish.

Two efforts were initiated in fiscal year 1984 on the effects of cold shock, one by the National Marine Fisheries Service (NMFS), Southeast Fisheries Center Beaufort Laboratory and one by NMFS's Southwest Fisheries Center-Honolulu Laboratory. The Beaufort Laboratory study is being performed on the juvenile stage of a Caribbean fish species. The Honolulu Laboratory study is being performed on eggs, larvae, and juvenile fish of several Hawaiian species. The results of both studies are due soon.

The study on the vertical distribution of fish eggs and larvae was initiated because, for potential OTEC sites in tropical waters, there is almost no quantitative information available on the distribution of early life stages of fish. This information is needed in order to determine the potential number of fish that will be subjected to impingement and primary and secondary entrainment. The development of such an understanding may allow plant modifications to be made that will minimize the environmental impact of plant operations.

To initiate the vertical distribution study, a ship-of-opportunity was utilized in fiscal year 1984 to sample fish eggs and larvae in the water column offshore of Puerto Rico and St. Croix. A report is being prepared that should be available in March, 1985. A similar study is underway for Kahe Point during fiscal year 1985.

The effort to assess potential fisheries effects focused on two regions-the Caribbean and the North Pacific--because these are areas where U.S. OTEC interests have the greatest potential for development. The study also emphasized the nearshore application of OTEC more than the open ocean case because of the greater potential for environmental impact associated with the nearshore application. The study concluded that the potential risk to fisheries is low and thus development can proceed with an early, small-scale, OTEC project. Due to the lack of a suitable precedent, however, there will remain some level of uncertainty regarding these initial conclusions until a pilot plant can be monitored for some period of time.

Biological Impact of OTEC Generated Sound

During fiscal year 1984, NOAA initiated a study to assess the potential impacts of underwater sound generated from OTEC activities on selected biological species at the proposed OTEC site at Kahe Point, Oahu, Hawaii. The possible impact of OTEC operations on the Navy Fleet Operational Readiness Accuracy Check Site (FORACS) range located near the proposed OTEC site is also being investigated. This study is being conducted under the provisons of an interagency agreement between NOAA's Ocean Minerals and Energy Division, Office of Ocean and Coastal Resource Management (OCRM), National Ocean Service (NOS) and the Department of the Navy, Naval Ocean Systems Center (NOSC). This study will be completed in fiscal year 1985 and the result will include an acoustic model and a report on observed effects of OTEC-like sounds on selected biological species.