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IMO/FAO/UNESCO/WMO/WHO/IAEA/UN/UNEP
JOINT GROUP OF EXPERTS ON THE SCIENTIFIC ASPECTS
OF MARINE POLLUTION
- GESAMP -

REPORTS AND STUDIES

No. 20

MARINE POLLUTION IMPLICATIONS OF OCEAN ENERGY DEVELOPMENT

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NOTES

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Definition of Marine Pollution by GESAMP

"POLLUTION MEANS THE INTRODUCTION BY MAN, DIRECTLY OR INDIRECTLY, OF SUBSTANCES OR ENERGY INTO THE MARINE ENVIRONMENT (INCLUDING ESTUARIES) RESULTING IN SUCH DELETERIOUS EFFECTS AS HARM TO LIVING RESOURCES, HAZARDS TO HUMAN HEALTH, HINDRANCE TO MARINE ACTIVITIES INCLUDING FISHING, IMPAIRMENT OF QUALITY FOR USE OF SEA WATER AND REDUCTION OF AMENITIES."

* * *

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MARINE POLLUTION IMPLICATIONS OF OCEAN ENERGY DEVELOPMENT

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MARINE POLLUTION IMPLICATIONS OF OCEAN ENERGY EXPLOITATION

1. INTRODUCTION

1. The Working Group met for its second meeting at FAO headquarters, Rome, from 25 to 29 October 1982. The first meeting of the subgroup of the Working Group took place at UNESCO headquarters, Paris, from 29 June to 2 July 1981. A meeting of United States OTEC experts was organized on 11 June 1981 which resulted in the primary working paper of the first meeting.

2. The Working Group wishes to thank the FAO Technical Secretary and the staff of FAO, as well as the staff at UNESCO for providing excellent facilities and assistance in all aspects of its work.

3. The following experts participated:

Washington, D.C., 11 June 1981: Messrs. L. Lewis, E. Myers, P. Wilde, J. Ditmars, D. Evans and L. Neuman (Technical Secretary, United Nations).

Paris, 29 June-2 July 1981: Messrs. R. Gerard, P. Marchand, and B. J. van der Pot.

Rome, 25-29 October 1982: Messrs. E. Myers (Chairman), G. Kullenberg, A. Jernelov, E. Gomez, L. Neuman (Technical Secretary, United Nations) and H. Naeve (Technical Secretary, FAO).

1.1 Terms of reference

4. The terms of reference are set out in the report of the eleventh session of GESAMP, paragraph 12.3, viz:

(a) To review the current literature and results of ongoing research and describe marine pollution implications of the exploitation of the major sources of unconventional ocean energy with special reference to coastal areas and multiple-use concepts, particularly in developing countries;

(b) To discuss long-term environmental impacts to be expected from extensive ocean energy exploitation at the global level.

5. The preliminary report presented to the Group at its twelfth session focused upon OTEC and was used as the basis for the sections of the present report dealing with this technology. The other technologies examined resulted from inter-sessional work according to the criteria described below.

1.2 Technologies considered

6. The oceans possess a number of characteristics that are representative of kinetic or potential forms of renewable energy: temperature gradients, biomass, waves, tides, currents, winds and salinity gradients. The feasibility of technologies that would tap such forms of energy was considered in 1979 and 1980 by the Technical Panel on Ocean Energy of the United Nations Conference on New and Renewable Sources of Energy (United Nations, 1981). As further noted in 1.3.1 (Commercial Applicability) the panel concluded that ocean thermal energy conversion

(OTEC), marine biomass, waves and tides offered the most promise for commercial application by the year 2000.

1.2.1 Ocean Thermal Energy Conversion (OTEC)

7. OTEC utilizes the temperature difference between warm surface waters and cold deep waters to drive a heat engine that produces power. The closed-cycle OTEC process (fig. 1) employs a working fluid (e.g., ammonia, Freon) upon which work is performed by warm, surface water pumped to an evaporator to produce a vapor that turns a gas turbine which, in turn, drives an electrical generator (Abelson, 1978). After exiting the turbine, the gaseous working fluid is condensed through a heat exchanger by the temperature of cold deep waters, that are pumped to near the surface through a long cold water pipe, and the cycle is repeated. The open-cycle process (Lewandowski et al, 1980) is quite similar, with the exception that seawater is the working fluid. Warm seawater, after being deaerated, is flash evaporated to produce a steam vapor that drives the turbine. After being recondensed by cold waters, the condensate can be used for fresh water.

8. The OTEC process is very dependent upon the availability of a suitable thermal resource, defined as the temperature difference (ΔT) between the warm, sea surface water and the underlying cold deep water (Allender et al., 1978). The needed operational temperature differential is about 20°C (36°F) or greater (Gritton et al., 1980; Ditmars and Paddock, 1979); however, due to seasonal variations, this value is not always available in many coastal waters. Figure 2 shows the distribution of the thermal resource between the sea surface and the 1000 m depth on a global basis. Note that the resource is generally confined to a band 20° in latitude, north and south of the equator; also, the broad continental shelves in many oceanic areas prevent the cold, deep water from approaching the coastal areas. Given a suitable thermal resource, an OTEC plant must pump relatively large volumes of both cold and warm water in order to develop net power (see para. 31).

9. Developing countries located within the 40° latitudal band have the best thermal resource for OTEC. These include coastal countries located in the western and central east Atlantic, Indian and Pacific Oceans. Estimates of the thermal resource for countries in these regions have been made and are shown in table 1.

10. Several types of OTEC platforms have been designed to a conceptual level. These include a moored or grazing barge (George et al., 1979, 1981); a spar-shaped vessel (Gibbs and Cox, Inc., 1980); and a fixed-tower (General Electric Co., 1983) or a land-based (or artificial island; Ocean Thermal Corporation, 1983) plant along a coast with a narrow continental shelf. Probably, the unique feature of any of these systems is the attached cold water pipe (CWP) which must be approximately 10 m in diameter for a 40 MWe commercial OTEC plant and extend to a depth of about 1000 m. It has no parallel in offshore construction; therefore, both time and frequency domains of the dynamic response of the CWP to normal and extreme currents and waves must be modelled and tested (Johns Hopkins University, 1980; McGuiness, 1981).

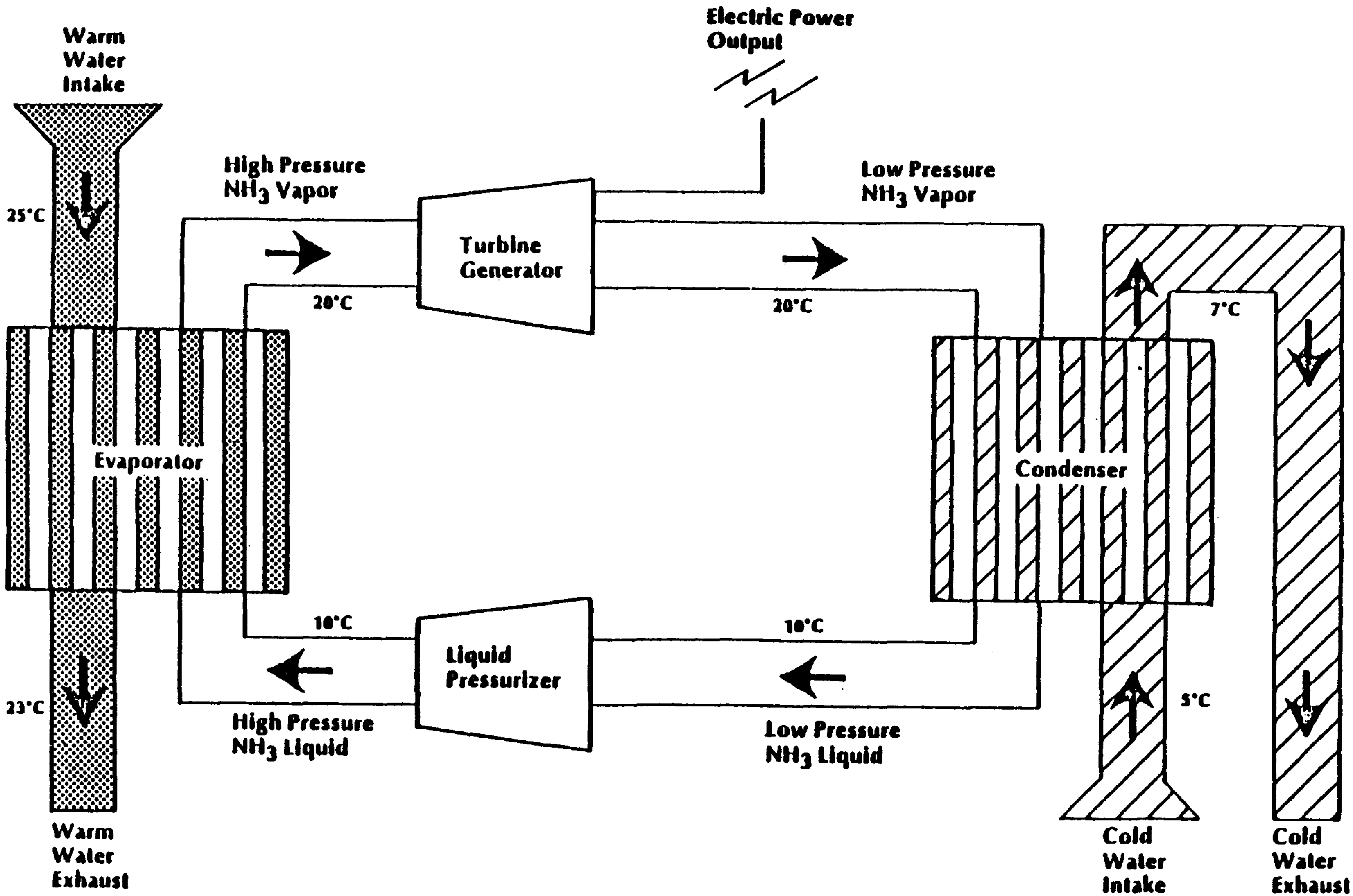

Figure 1. Schematic Diagram of a Closed-Cycle Power System
Source: Adapted from DOE, 1979

Figure 2

Large-Scale Distribution of
OTEC Thermal Resource
ΔT(°C) Between Surface and 1,000 Meter Depth

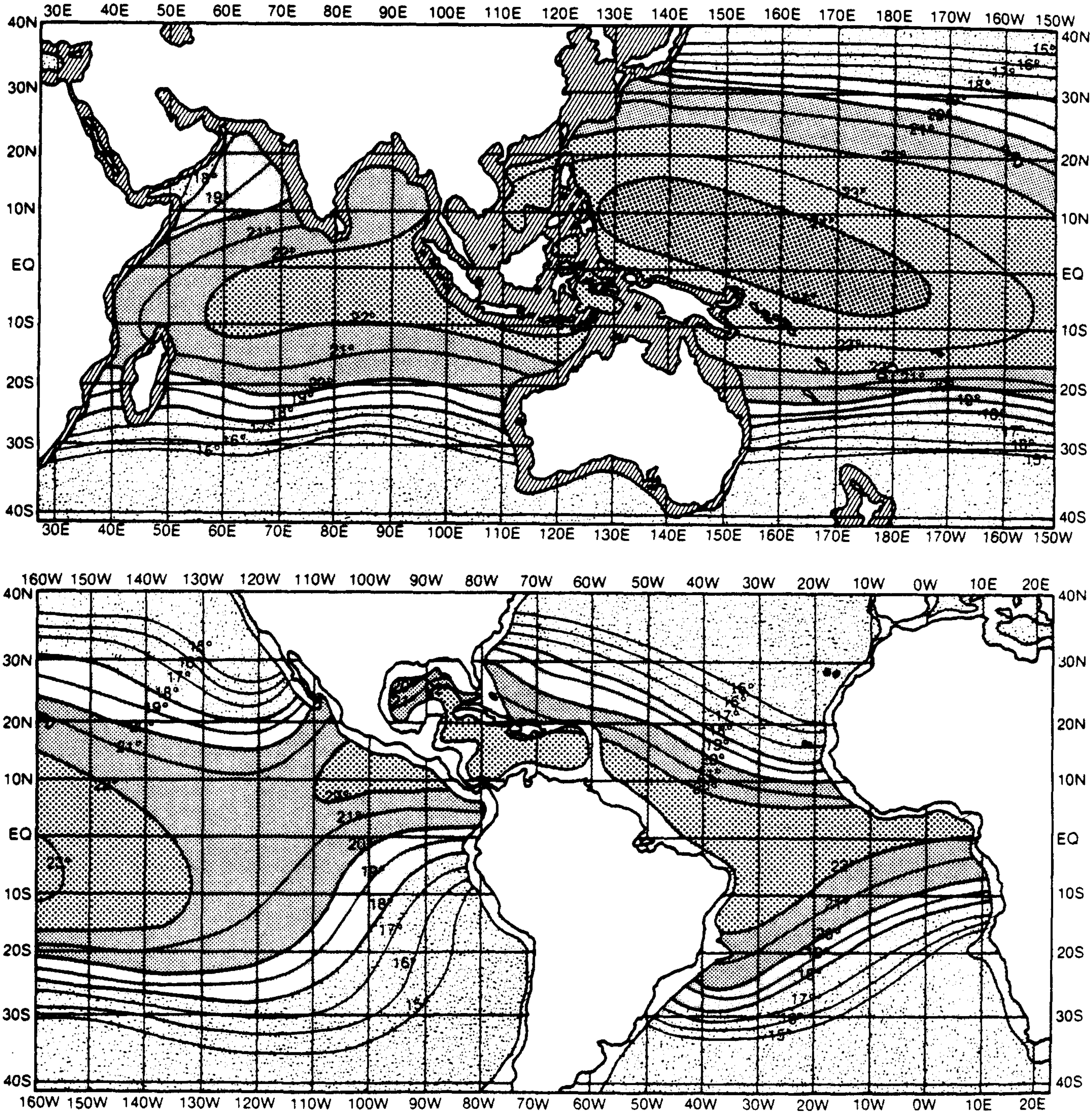

Table 1. Developing countries with adequate ocean thermal resources

Country/area	Latitude	Longitude	Delta T(°C) between 0-1,000 m	Distance from resource to shore (km)
Africa				
Angola	6°S-18°S	11°E-14°E	18-22	65
Benin	6°N	3°E-4°E	22-24	25
Congo	4°S-5°S	11°E-12°E	20-22	50
Gabon	2°N-4°S	9°E-11°E	20-22	15
Ghana	5°N-6°N	3°W-1°E	22-24	25
Guinea	9°N-11°N	14°W-15°W	20-22	80
Guinea-Bissau	11°N-13°N	15°W-17°W	18-19	50
Ivory Coast	5°N	3°W-8°W	22-24	30
Kenya	2°S-5°S	34°E-41°E	20-21	25
Liberia	5°N-17°N	8°W-12°W	22-24	65
Madagascar	10°S-25°S	45°E-50°E	18-21	65
Mozambique	10°S-25°S	35°E-40°E	18-21	25
Nigeria	4°N-6°N	4°E-9°E	22-24	30
Rio Muni	2°N-3°N	10°E	20-22	30
Sao Tome and Principe	0°N-2°N	7°E-9°E	22	1-10
Senegal	13°N-17°N	16°W-17°W	18	50
Sierra Leone	7°N-9°N	12°W-14°W	20-22	100
Somalia	10°N-2°S	41°E-50°E	18-20	25
Togo	6°N	2°E-3°E	22-24	50
United Republic of Cameroon	3°N-4°N	9°E-10°E	22-24	30
United Republic of Tanzania	5°S-10°S	35°E-40°E	20-22	25
Zaire	5°S-6°S	12°E	20-22	50

Table 1 (continued)

Country/area	Latitude	Longitude	Delta T(°C) between 0-1,000 m	Distance from resource to shore (km)
<u>Latin America</u>				
Bahamas	25°N	77°W-79°W	20-22	15
Barbados	13°N	58°W-60°W	22	1-10
Belize	16°N-17°N	87°W-88°W	22	50
Brazil	4°N-32°S	35°W-55°W	20-24	75
Colombia	2°N-12°N	63°W-79°W	20-22	50
Costa Rica	8°N-12°N	83°W-85°W	21-22	50
Cuba	20°N-23°N	75°W-85°W	22-24	1
Dominica	15°N-16°N	61°W-62°W	22	1-10
Dominican Republic	18°N-20°N	68°W-72°W	21-24	1
Ecuador	2°N-4°S	81°W-79°W	18-20	50
El Salvador	13°N-14°N	87°W-90°W	22	65
French Guiana	4°N-5°N	50°W-52°W	22-24	130
Grenada	13°N	61°W-62°W	27	1-10
Guatemala	14°N-17°N	88°W-94°W	22	65
Guyana	5°N-8°N	58°W-60°W	22-24	130
Haiti	18°N-20°N	72°W-75°W	21-24	1
Honduras	14°N-16°N	83°W-88°W	22	65
Jamaica	18°N-19°N	76°W-78°W	22	1-10
Lesser Antilles	12°N-18°N	61°W-65°W	22-24	1
Mexico	17°N-22°N	104°W-108°W	20-22	32
Nicaragua	11°N-14°N	84°W-86°W	22	65
Panama	8°N-9°N	76°W-83°W	21-22	50
Saint Lucia	13°N-14°N	61°W-62°W	22	1-10
Saint Vincent and the Grenadines	13°N-14°N	61°W-62°W	22	1-10
Suriname	4°N-5°N	52°W-58°W	22-24	130
Trinidad and Tobago	11°N	61°W	22-24	10
Venezuela	8°N-12°N	60°W-73°W	22-24	50
United States Virgin Islands	18°N	65°W	21-24	1

Table 1 (continued)

Country/area	Latitude	Longitude	Delta T(°C) between 0-1,000 m	Distance from resource to shore (km)
Indian and Pacific Oceans				
American Samoa	12°S	165°W	22-23	75
Australia	10°S-40°S	115°E-155°E	18-22	100
Burma	5°N-30°N	95°E-100°E	20-22	75
China	21°N-40°N	108°E-122°E	21-22	50
Comoros	1°N-3°N	43°E-45°E	20-25	1-10
Cook Islands	18°S-22°S	155°E-165°E	21-22	1-10
Fiji	15°S-20°S	175°E-180°E	22-23	1-10
Guam	13°N	145°E	24	1
India	10°N-25°N	70°E-90°E	18-22	65
Indonesia	5°S-10°S	95°E-127°E	22-24	50
Kiribati (Gilbert)	5°S-5°N	172°E-178°E	23-24	1-10
Maldives	2°N-8°N	72°E-74°E	22	1-10
Mauritius	20°S-21°S	57°E-58°E	20-21	1-10
New Caledonia	20°S-22°S	165°E-168°E	20-21	1-10
Papua New Guinea	0°-11°S	131°E-151°E	22-24	30
Pacific Islands (Trust Territory)	15°N-20°S	135°E-150°W	22-24	1
Philippines	18°N-5°N	120°E-127°E	22-24	1
Samoa	10°S-16°S	168°W-175°W	22-23	1-10
Seychelles	1°S-7°S	53°E-57°E	21-22	1
Solomon Islands	4°S-12°S	155°E-165°E	23-24	1-10
Sri Lanka	6°N-10°N	80°E-82°E	20-21	30
Thailand	5°N-10°N	96°E-100°E	20-22	75
Vanuatu	11°S-20°S	160°E-170°E	22-23	1-10
Viet Nam	12°N-23°N	105°E-108°E	22-24	65

1.2.2 Marine biomass

11. The basic concept of the marine biomass system is to utilize macro-algae to capture and store solar energy through photosynthesis (Tompkins, 1982; Ritschard et al., 1981). Photosynthesis is dependent upon the availability of carbon dioxide and nutrients, which are in plentiful supply in deep, cold ocean waters and also in some surface layers of the ocean. To complete the process, the stored energy must be released in a usable form. Current thought focuses on the conversion of the stored photosynthetic energy to methane through an anaerobic digestion process (Tompkins, 1982).

1.2.3 Wave energy

12. The energy contained in the ocean's waves is vast, particularly in those areas beyond 30°N and 30°S characterized by vigorous wave climates (United Nations, 1981). Wave energy converters can be principally classified as follows: (1) devices which employ the vertical rise and fall of waves to activate air or water operated turbines; that is, those devices which utilize the pressure field caused by the vertical wave motion; (2) devices which rely on the rolling, pitching or heaving motion of the waves to utilize, for example, the rocking motion of cams on the sea which activate turbines; and (3) devices which focus the energy in waves by refraction or diffraction (U.S. Department of Energy, 1980). To date, the most technically advanced of these are those that utilize the vertical wave motion to activate air operated turbines by extracting energy from resonance (within an internal chamber) created by the motion of the waves.

13. The principle behind wave focusing techniques is to concentrate wave energy at one location, making it more convenient to convert. One proposed focusing-type method, known as surge funneling, produces energy by channeling shoaling waves into a storage basin and using the hydraulic head developed to run a turbine. A related passive wave energy concept, proposed for application on Mauritius, is to build up the fringing coral reef so as to allow waves to top this wall and create a hydraulic head within the reef (Bott and Lawrence). This head would be utilized to drive a turbine placed at the outlet.

1.2.4 Tidal energy

14. Tidal energy has the unique status of being established on a commercial scale, albeit at only one plant located at La Rance, France (United Nations, 1981). The 240 MWe French plant has been operating for more than 15 years and has proved the reliability of using the hydraulic head created by ocean tides to drive a generator. The Technical Panel on Ocean Energy identified some 40 sites throughout the world that would have the characteristics suitable for developing a capacity of over 200 MWe: favourable geographical location, in order to minimize engineering work; an average tide of 5-12 meters; the possibility of linkage to a power grid, in order to allow the variable output of the plant to be accommodated; and favourable socio-economic and ecological conditions.

1.3 Restrictions of report

15. Several restrictions or boundary conditions were imposed on or adopted by the Working Group. Of critical importance was the sparcity of data and studies on potential ocean energy impacts and the absence or unavailability of investigations on existing installations or pilot plants which operated recently. Although OTEC

demonstration plants have operated on several occasions over periods of months, no detailed studies of environmental effects were conducted and any other information on other ocean energy installations is not readily available.

16. Furthermore, although some predictive studies of large plants in the open ocean have been conducted, little or no attention has been paid to the smaller installations (1-15 MWe) currently contemplated or planned for early commercial stages. As a result this report has sought to extrapolate from current information in order to identify environmental concerns and indicate where planning is most important.

17. The following sections indicate concerns which served to focus the report on areas of more immediate interest. Studies which the Working Group recommends to answer primary research needs are presented in the final section.

1.3.1. Commercial applicability

18. In accordance with its terms of reference, the Working Group elected to restrict its attention to the major sources of unconventional ocean energy which could reach widespread commercial application by the year 2000. After considering the conclusions of the Technical Panel on Ocean Energy of the United Nations Conference on New and Renewable Sources of Energy which was held in Nairobi from 10 to 21 August 1981 (United Nations, 1981), the Working Group examined OTEC, biomass, wave and tidal energy. Energy from ocean currents and salinity gradients was excluded from consideration.

19. Although it was recognized that wave energy might not reach extensive commercial application before the year 2000, it was noted that several pilot projects in developing countries were receiving serious attention and possible funding. As a result, it was decided to include a preliminary discussion of wave energy, emphasizing guidelines and basic considerations.

20. Tidal energy is the only proven form of ocean energy currently being exploited on a commercial scale. The major facility is the French tidal plant at La Rance, which produces about 240 MWe (United Nations, 1981). In its discussion of tidal energy, the Technical Panel on Ocean Energy noted that, besides the high cost of investment, the major constraint hampering the development of tidal plants in some locations is potential harm to the environment.

21. Biomass energy technologies have undergone recent advances which may favour their commercialization (Tompkins, 1982). In addition, the large amount of nutrient-rich water which could result from OTEC plant operation could accelerate the development of biomass energy production (United Nations, 1981). For these reasons and the fact that biomass may be a less technologically sophisticated system better adapted to developing countries, it was included in the study.

1.3.2 Normal operating conditions

22. The Working Group has also restricted its attention to normal operating conditions for the energy alternatives considered. Thus, the marine pollution implications of these energy alternatives are limited to those that would develop under normal, everyday operating conditions. This does not imply that accidental catastrophic incidents should be belittled; to the contrary, catastrophic accidents could pose major environmental threats to both marine and human life as briefly

mentioned in the next section. However, to adequately treat such possibilities would require a definition of detail (e.g., working fluid, site location and its relation to areas of biological significance and population centres) that is beyond the scope or purpose of this effort.

1.3.3 Other considerations

23. As noted in the above section, catastrophic events cannot be fully excluded in examining the full environmental implications of ocean energy development. For any potential application of an ocean energy technology, a careful examination should be made of risks and probabilities connected to possible catastrophic events. In this report only some such hazards will be mentioned.

24. In connection with OTEC, catastrophic events could occur leading to a sudden release of operating chemicals (e.g., ammonia, Freon) (National Oceanic and Atmospheric Administration, 1981). For instance, for a closed-cycle 10 MWe system using ammonia as the working fluid, the total inventory of ammonia (including surge and leakage losses) would be in the range of about 230,000-300,000 litres with approximately half in the power system loop and half in storage (Davis, 1983). Because of its thermodynamic and physical properties, the volume of Freon, if used, would be three to four times that of ammonia volume. In the case of an ammonia leakage, the effects could be acute and short-term. The most unfavourable circumstance would be a sudden release from a large installation near a population centre on a calm day, creating a toxic cloud that could pose a serious threat to nearby population centres. In the case of a Freon leakage, a concern would be the long-term effects on the ozone layer and thereby on global increases in transmitted ultra-violet (UV) radiation.

25. In connection with wave energy utilizing wave-focusing techniques, a critical high-wave zone could be created which could affect ship traffic and safety.

2. OCEAN THERMAL ENERGY CONVERSION (OTEC)

2.1 State of development

26. Ocean thermal energy conversion (OTEC) is a technology which is on the threshold of commercial application. Because the best thermal resource is found in tropical oceans, developing countries are expected to be its principal users (United Nations, 1981).

27. Of all solar-based energy systems, OTEC is particularly attractive because it supplies continuous, baseload power day or night, rain or shine, summer or winter. The source of the power derives from the temperature differences between the warmer ocean surface waters which both collect and store vast quantities of solar energy, and the colder waters at depths of about 1,000 m which are produced over long time periods and continuously replenished.

28. Although considerable interest has been generated in the potential of OTEC, several misconceptions exist regarding its availability, cost and efficacy. OTEC plants do not involve high technology systems as do nuclear plants, giving developing countries an opportunity to participate in the construction phase as well as in operation and maintenance. Furthermore, OTEC technology for land-based or shelf-mounted plants up to 50 MWe is essentially available today.

29. At this writing, OTEC activities are under way in a number of locations and by a number of different entities:

United States: After supporting the conceptual design of two pilot plants in Hawaii, the U. S. Department of Energy (DOE) is supporting the preliminary design of one 40 MWe pilot plant at Kahe Point, Oahu, Hawaii. Also, a private concern has contracted with the Government of the United States Territory of Guam to build a commercial 48 MWe land-based OTEC facility.

France: The French Government National Centre for the Exploitation of the Oceans (CNEXO) is undertaking design studies and site work preparatory to building a land-based 5 MWe prototype open cycle plant in Tahiti in 1986-1988. The plant will have multi-purpose applications for aquaculture, refrigeration, and freshwater production in addition to electricity.

Japan: Private Japanese companies have designed, built and operated a land-based 100 KWe (0.1 MWe) pilot plant for the Government of Nauru in the Pacific Ocean. Current plans call for proceeding to a 2.5 MWe plant at the same site to be operational by 1986. The Japanese Government is also sponsoring OTEC research and development activities.

Sweden: A number of private companies have agreed to form the Swedish OTEC Group for the purpose of building OTEC plants principally in developing countries. Initial activities are taking place in the Caribbean Sea (e.g., a 10 MWe plant is presently being designed for Jamaica).

The Netherlands: The activities of several private Dutch companies have focused upon Curacao in the Netherlands Antilles with the objective of building a 10 MWe land-based plant for electricity.