OCEAN THERMAL ENERGY CONVERSION (OTEC)

by

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Ocean thermal energy conversion (OTEC) is a power generation concept which utilizes the thermal difference present between surface and deep ocean waters in the tropics. Of all the solar energy options, OTEC is unique in its ability to produce huge chunks of electric power, virtually uninterrupted, day and night throughout the year. These characteristics of OTEC have a number of ramifications:

1. OTEC does not require a man-made energy storage system. The ocean itself provides the storage.

2. OTEC could be of interest to utilities because power plants rated at hundreds of megawatts can be base-loaded and integrated with the national grid.

3. The commercial demonstration of OTEC requires huge sums of money and the only source for funds at present is the Federal Government.

A schematic of an OTEC cycle is depicted in Figure 1. Warm surface water is pumped through an evaporatoe to produce ammonia (or other suitable substance) vapor. Cold water is pumped from the deep to keep a condenser cool and thus create a low pressure in the condenser. The difference in pressure between the evaporator and condenser causes the vapor to rush to the condenser and in so doing drives a turbo-generator. The condensed ammonia is pressurized by the pump before it is fed into the evaporator to close the cycle.

A key issue in OTEC design and cost is the heat exchanger (evaporator/condenser). Early studies by researchers at universities and industry have concluded that with cost effective heat exchangers, OTEC can be economically viable. Accordingly, in Fall 1976, ERDA initiated an aggressive development program focused on heat exchangers with the intent that in Fall 1977 a programatic decision will be made to chart the future course of the program. Figure 2 illustrates the parallel activities currently underway to achieve the program goals stated.

In 1977, five heat exchangers rated at 3.2 M Btu/h will be tested at a newly constructed facility at Argonne National Laboratory. Cleaning methods to remove marine fouling will be evaluated in the summer of 1977. ERDA is in the process now of negotiating a contract with TRW, Inc., of Los Angeles to build a 1 MW_e evaporator and condenser for testing at sea. For this purpose, the Hughes Mining Barge (HMB) a companion vessel to the famous Glomar Explorer has been acquired by ERDA. The HMB is being modified and equipped so that it can serve as a test platform for the 1 MW_e heat exchangers.

Figure 3 shows ERDA's schedule for OTEC requests for proposals from industry which has been issued. Proposals are now being evaluated in the following areas: power system development, hull shape selection, underwater electric cable design, and many others.

Figure 4 summarizes the major findings of two major independent studies conducted in 1974-75. Figure 5 illustrates the series of hardware development culminating in a 25 MH_e or larger module. Figure 6 shows three shell and tube heat exchanger (evaporator) concepts which ERDA is actively pursuing. Two condenser concepts, a horizontal and vertical, shell and tube are also being studied. In addition, various shell-less heat exchangers now at the bench scale stage are being investigated. Enhancements of heat transfer on the shell and the water-side are being pursued. Questions of manufacturability of large units, choice of material, and the effect of the ocean environment on OTEC components are underway as illustrated in Figure 7. In Figure 8 a schematic is shown of the accelerated core test facility being readied at Argonne for Fall 1977. This is a heat exchanger test loop to simulate actual OTEC conditions.

In conjunction with heat transfer, the other critical items are biofouling of heat transfer surfaces and corrosion of metal exposed to seawater. Figures 9 and 10 illustrate the scope of this effort.

The logic behind the use of the HMB as an Early Ocean Test Platform (EOTP) is depicted in Figures 11 and 12.

Before the availability of the ocean thermal resource for U.S. exploitation and the possible missions for OTEC is discussed, it will be instructive to recapitulate the progress of the technology to date and to discuss the pending problems. The cold water pipe necessary to transport the deep ocean water to the condenser is a huge conduit. Its length will range between 2000 to 4000 ft and the diameter, for a 100 MW_e plant, approximately 50 ft. The early baseline designs of industry employing state-of-the-art technology indicated the need for platforms the size of a football field and a few stories high. Such structures are being built today for the North Sea oil and gas technology. However, a hull/platform 130 ft in diameter and 100 ft deep is a major engineering challenge.

The OTEC sites available to the U.S. are the Gulf of Mexico, New Orleans, Key West, Brownsville, Hawaii, Puerto Rico, Virgin Islands, and various atoles in the Pacific. For most of these sites, direct electric transmission using underwater high-voltage dc cable is contemplated. Once the power is brought to shore, it can be integrated with the existing grid. Most likely, the presence of cheap OTEC power would stimulate the industrial growth of the region. For plants located in the open seas, where high temperature difference can be identified, OTEC power could be used to produce various chemicals and energy intensive products: ammonia and aluminum refining. Of tremendous potential to the U.S. is the creation of an OTEC industry to manufacture OTEC plants in the U.S. for export to many nations possessing a good thermal resource.

Present projection of OTEC cost is about $1700/kW using corrosion resisting titanium heat exchangers. The use of aluminum would drop the cost to $1250/kW and with various improvements in the technology the cost might be dropped below $1000/kW for near U.S. site and even lower for open-sea, equatorial sites. To this cost we must add the transmission and the chemical conversion cost as applicable. In summary, ERDA is looking seriously at the ocean thermal energy conversion concept as a solar resource of tremendous economic potential to the U.S. and the rest of the world. The impact of OTEC cannot be near-term, nor can the technology be proven overnight. However, ERDA is vigorously pursuing the concept and has evolved a rational and orderly plan for the exploitation of this renewable, pollution-free, and hopefully economic resource.

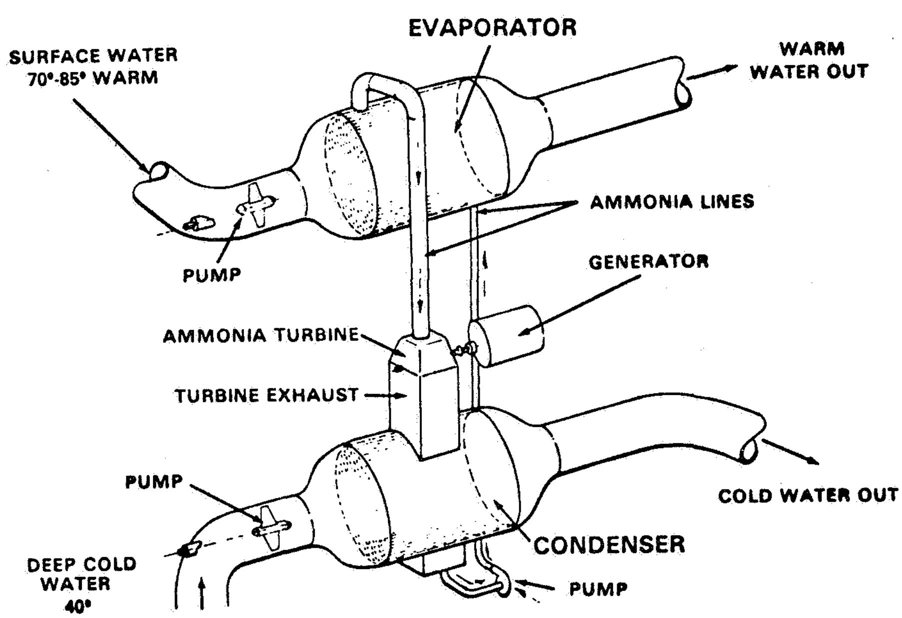

Figure 1. Schematic of an OTEC power cycle.

- CONCLUSION ....

  FOR BEST RISK/REWARD BALANCE CONCENTRATE ON HEAT EXCHANGER

- HEAT EXCHANGER DEVELOPMENT SCHEDULE

ACTIVITY	TIME FRAME
– ACCELERATED CORE TESTS	1977 AND 1978
– CLEANING TESTS	1977 AND 1978
– 1 MW_e HEAT EXCHANGER COMPONENT OCEAN TEST	1979
– 5 MW_e PILOT PLANT TEST	1980
– DEMONSTRATION TEST	1984

- PROGRAMMATIC DECISIONS 1977, 1978, 1979

Figure 2. Developmental summary of parallel activities currently underway to achieve OTEC program goals.

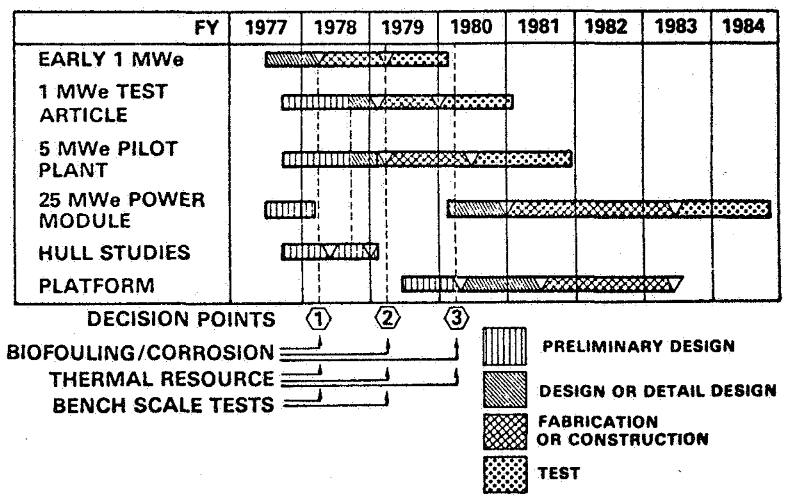

Figure 3. Test article development schedule.

- **MODULAR CONSTRUCTION**
  - 25 MW MODULAR
  - REDUNDANCY FOR MAINTENANCE
- **HEAT EXCHANGERS ARE CRITICAL COMPONENTS**
  - DETERMINE EFFICIENCY
  - REQUIRE 55% OF COST
  - 50% COST REDUCTION - NEAR CERTAINTY

Figure 4. Engineering evaluation studies by TRW/Lockheed.

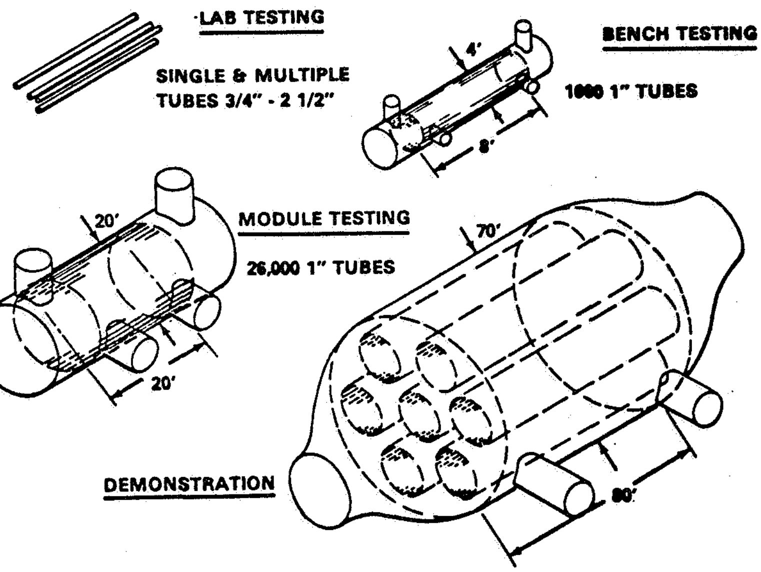

Figure 5. Heat exchanger test elements.

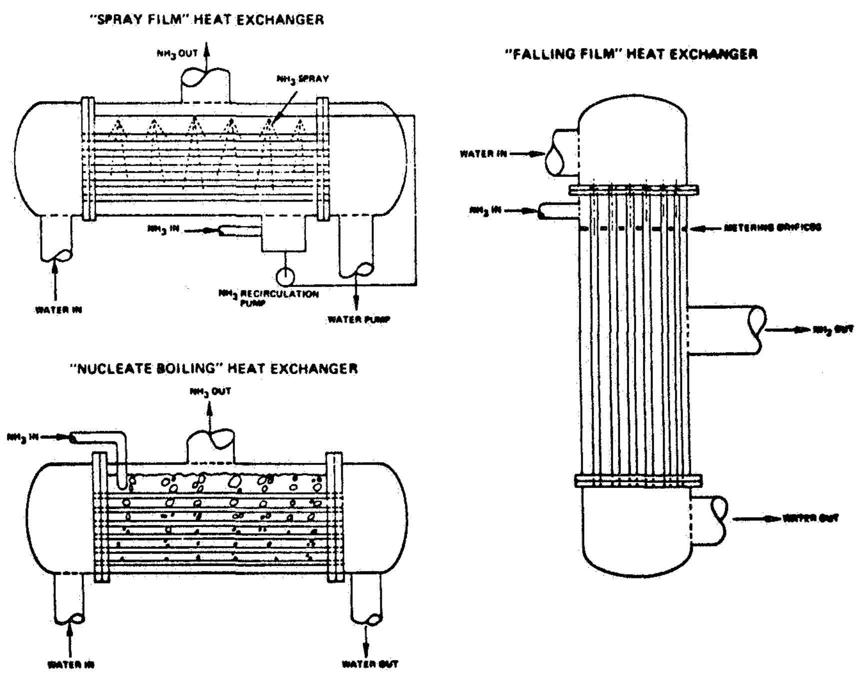

Figure 6. Three shell and tube heat exchanger (evaporator) concept which ERDA is actively pursuing.

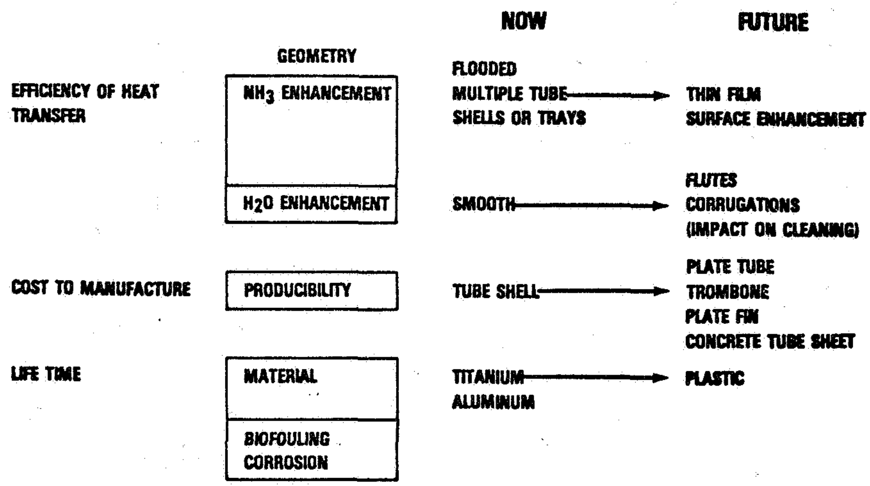

Figure 7. Critical issues — heat exchange.

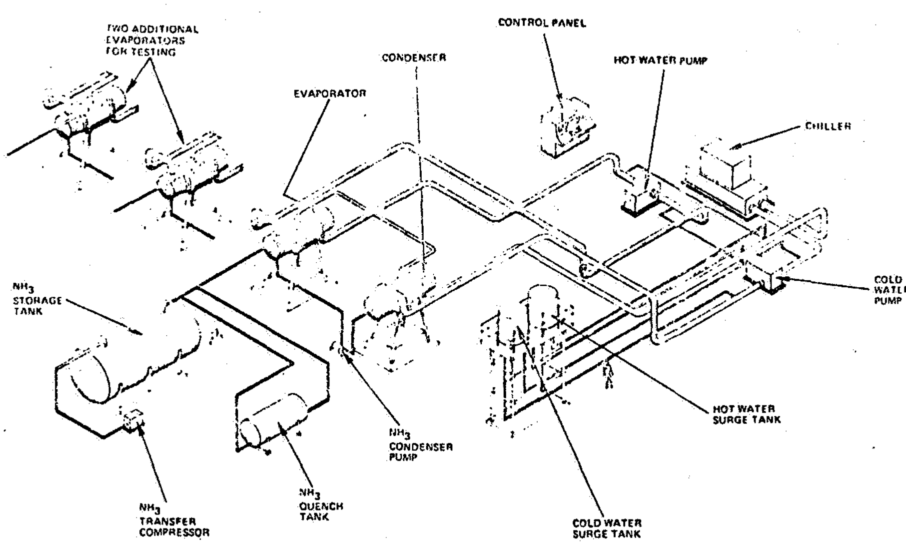

Figure 8. Accelerated core test facility — component layout.

- CAN WE QUALIFY ALUMINUM AS AN ENGINEERING MATERIAL?
- CAN WE CLEAN ENHANCED SURFACES?
- CAN WE CLEAN PLATE TYPE HEAT ESCHANGERS?

Figure 9. Biofouling and corrosion-critical issues.

PROJECT	COMPLETION DATE	ANTICIPATED RESULTS
SITE STUDIES – BIOFOULING, CORROSION, AND OCEAN DATA		
• SITE 1 – HAWAII (WARM WATER)	10/77	BIOFOULING RATE DATA
• SITE 2 – ST. CROIX, V.I. (WARM AND COLD WATER)	9/78	BIOFOULING RATE DATA
• SITE 3 – GULF OF MEXICO (WARM WATER)	9/78	BIOFOULING RATE DATA
PREVENTION AND CONTROL OF FOULING ON HEAT EXCHANGER TUBES	9/77	DATA FROM THREE MECHANICAL AND TWO CHEMICAL TESTS
	9/78	• DATA FROM MULTITUBE TEST OF CLEANING METHODS • SELECTION OF METHOD
CORROSION STUDIES ON ALUMINUM AND TITANIUM	9/78	• DATA FROM PITTING AND CORROSION FATIGUE TESTS • ALLOY SELECTION
COLD-WATER CALCAREOUS DEPOSIT EVALUATION	9/78	• COLD-WATER TESTS • SELECTION OF PROPER CLEANING METHOD
HULL PROTECTION AND CLEANING	9/77	SELECTION OF CLEANING METHOD FOR PLATFORM

Figure 10. Biofouling and corrosion projects.

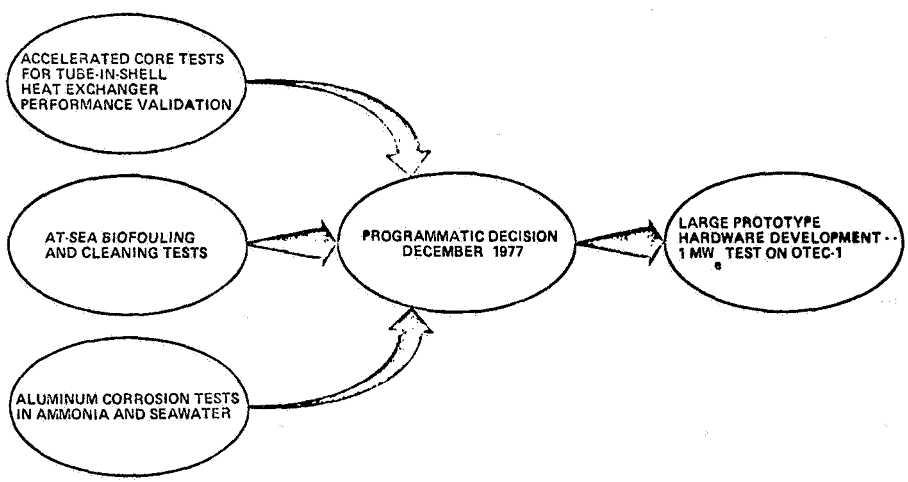

Figure 11. Heat exchanger and development program.

- TEST PROGRAM ACCELERATION
- EARLY ACQUISITION OF OPERATIONAL DATA
- TEST LOCATION MOBILITY
- COST/RISK/BENEFIT ADVANTAGES
- OPERATIONAL FLEXIBILITY
- AVOIDANCE OF LAND ACQUISITION PROBLEMS
- ENVIRONMENTAL IMPACT CONCERNS MINIMIZED
- FAVORABLE PROGRAM VISIBILITY

Figure 12. EOTP-1 concept attributes.