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OTEC PLATFORM CONFIGURATION AND
INTEGRATION STUDY -
FINAL REPORT
VOLUME 3
PROJECT PLAN

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FOREWORD

The OTEC Platform Configuration and Integration Study was performed by Lockheed Missiles & Space Company, Incorporated, under DOE Contract EG-77-C-01-4063. Supporting Lockheed in this work were six subcontractors: Bechtel Corporation; Earl & Wright Consulting Engineers; Hydronautics, Incorporated; Morris Guralnick Associates, Incorporated; Tuned Sphere International, Incorporated; and T. Y. Lin International.

The final report is comprised of four separately bound volumes, as follows:

Volume 0 EXECUTIVE SUMMARY

Volume 1 SYSTEMS ENGINEERING AND INTEGRATION

describes the systems integration and evaluation of six OTEC platform configurations and recommendations for the most satisfactory configuration for an OTEC commercial plant

Volume 2 TECHNICAL CONCEPT

describes the conceptual designs of two platform configurations for a 400-MW(e) (net) commercial plant

Volume 3 PROJECT PLAN

presents the project plan for an OTEC demonstration plant

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Section 1
OTEC DEMONSTRATION PLAN

The objective of the OTEC technology demonstration program is to provide sufficient practical experience with large scale OTEC systems to allow prospective users to evaluate realistically the technical and economic characteristics of OTEC technology. Of course, this must be done at as low a cost to DOE as possible. The demonstration program must thus fulfill two requirements: it must be realistic and it must be economical. The demonstration program can be conceived of as being comprised of two elements; the object of the demonstration itself, in this case an OTEC platform carrying a power system of some given output, and a set of demonstration activities intended to familiarize potential OTEC users with the performance of the demonstration plant. The twin requirements of realism and economy impact both elements of the demonstration plan. However, since the cost of the demonstration plant itself will be the major cost component of the program, it is the one most affected by the desirability of minimizing overall cost, and is discussed here at greater length than the operational demonstration proper. The first section of this chapter discusses the characteristics which are desired in the demonstration plant, while the second comments on the demonstration activities for that plant. For the purposes of the discussion, it is assumed that the primary OTEC mission is to supply electricity to shore, this being the mission of the platforms considered in this study. However, many of the observations presented here are equally applicable to grazing plantships. In preparing this plan, LMSC has drawn on its relationship with various members of the prospective OTEC user consortium, a group of industrial companies and utilities interested in OTEC development which LMSC has organized as part of its commercialization activities. In addition, the early history of the federal nuclear power program has been researched and lessons drawn from it have been applied in formulating this OTEC technology demonstration plan.

1.1 DEMONSTRATION PLANT

Three interrelated issues of paramount importance must be addressed in determining the proper configuration of a demonstration plant. The first of these is the cost of the plant (which it would be desirable to keep as low as possible), the second is the scale (output) of the plant, and the third is the state of development of the technology it employs. At this point, it is desirable to embark on a short methodological excursion to discuss the relationship among the last two variables.

The cost of producing any good is in general a function of the scale of the production facility and of the degree of maturity of the production process. In the case here discussed, the good that is produced is electricity and the technology that is used is OTEC. Capital costs are the main determinant of OTEC electricity costs, since operating and maintenance costs are of only secondary importance in OTEC plants. The capital cost of OTEC plants can be expressed conceptually as a function of scale and of technological maturity,

$$$/KW(e) = F (\text{Scale, Technological Maturity})$$

where F is assumed to be a declining function of its arguments, so that increases in either scale or technological maturity result in decreases in cost per kilowatt. Of course, the two variables, scale and technological maturity, are interrelated; at any point in time the level of technological maturity determines the scale, i.e., the maximum (or conceivably minimum) output attainable by commercial plants. A successful demonstration program would be one that provided sufficient information for prospective users to project with a high degree of confidence the technical and economic performance of commercial OTEC plants, although these plants would presumably be of greater output and employ somewhat different technology than the demonstration plant itself.

An illustration of the relationship between demonstration and first generation

commercial plants can perhaps be drawn from the history of the nuclear power program. After a series of small-scale (roughly 10 MW(e) each) experimental and demonstration plants, four large scale demonstration plants were built with joint government-industry funding. These averaged 85 MW(e) in output and cost the equivalent of 1400 \$/KW(e) in 1977 dollars. By contrast, the first three privately owned nuclear power plants, built, although only slightly later in date than the large demonstration plants, has an average output of approximately 250 MW(e) and cost only 680 \$/KW(e) (also in 1977 dollars). It should be stressed that the decrease in cost between demonstration and first generation commercial plants reflects both economics of scale and technological improvements, Ref 1. The situation is depicted in Figure 1-1, which shows the conceptual relationship between cost per kilowatt and scale and technological maturity. While the demonstration plant in itself need not lie in the area of commercial viability it must be sufficiently large and sufficiently advanced technologically that commercial viability can be projected for follow-on, first generation commercial plants. On the basis of nuclear power program experience, it appears that demonstration plants could cost roughly twice as much per kilowatt as the first generation commercial plants are expected to cost. Given the economics of scale of OTEC systems found by LMSC in the course of both the Power System Development study and the platform study reported upon here, this suggests that the capacity of OTEC demonstration platforms and individual power systems should be approximately one-third that of planned, first-generation commercial units.

Defining the likely output of OTEC commercial plants is complicated by the existence of two distinct potential American markets for these units. The first such market comprises Hawaii, Puerto Rico, and U.S. island possessions. These island sites are characterized by high costs of alternative (mainly oil-fueled) electricity generation, and requirements for comparatively small individual plant generation capacity, with the possible exception of Puerto Rico. Consequently, these sites appear well suited to the introduction of small (up to approximately 100 MW(e)) OTEC plants, as they would fit well into the electrical grid on the islands and the relatively high electricity costs would in

Figure 1-1
 $\$/KWe = F(\text{Scale, Technological Maturity})$

many cases still be below those of oil-fired generation. The second market to be considered is that for baseload electricity generation in the southeastern states, and would be served by OTEC plants located in the Gulf of Mexico. These plants would have to meet much more stringent criteria for cost-effectiveness than those plants serving island locations, as they would be in direct competition with large (roughly 1000 MW(e)) nuclear and coal-fired power plants. Consequently, OTEC plants operating in this area are likely to be as large as technology allows in order to capture maximum economies of scale. Information from consortium members suggests that plant outputs of up to 400 MW(e) should be considered for first generation units operating in this market area.

It seems natural to aim an early OTEC demonstration at potential customers in the first market discussed above, as the comparatively small plant outputs required in island applications would minimize both the technology development required and the cost of the demonstration itself. In addition, successful demonstration of OTEC plants in this market may reduce or obviate the need for demonstration of larger plants for use in the Gulf of Mexico. In this context, it is interesting to note that a majority of prospective users consulted feel that a demonstration plant with an output of roughly 25 MW(e) would provide sufficient risk reduction for them to consider commercial applications in the 100 to 300 MW(e) output range. This information agrees with utility behavior observed at the beginning of the nuclear power program. Well conducted, comparatively small-scale tests and demonstrations were sufficient to ensure widespread industrial participation in later, large-scale demonstration, and to motivate some companies to perform initial studies which eventually lead to first-generation commercial plants.

As mentioned above, OTEC plants used for commercial electricity supply to island locations are likely to have individual outputs somewhat under 100 MW(e), and a demonstration plant should be able to deliver roughly one third of the output of a commercial unit. This suggests that the output of the demonstration plant should be of the order of 25 MW(e). This output could be provided by a single power system, or by two or more autonomous power modules. Given

the economics of scale apparent in OTEC power systems, it seems desirable to use power modules with individual outputs greater than 10 MW(e); hence, a 25 MW(e) demonstration should use at most two power modules. Should it be strictly necessary to minimize the cost of the demonstration program, it would be possible to equip a platform sized for roughly 25 MW(e) with a single power system delivering half this output; however, the resulting power system demonstration would perhaps be less than persuasive. Should this course be followed, it is recommended that the demonstration platform be designed to accommodate two alternative power system configurations, one consisting of two half-size power modules (one such module not being installed) and the other of a single, full-size power system. Thus, if the initial demonstration fails to provide sufficient power system data, a second demonstration using a full-scale power system could be carried out with minimal adverse cost and schedule impact.

A more promising course of action would appear to be to design the demonstration platform for an output of approximately 50 MWe, using two 25 MWe power systems. This approach would provide a demonstration of nearly full-scale platform and power systems for island applications, simplifying the projection of first-generation commercial plant economics. In addition, a platform sized for a 50 MWe output would be much closer to a full commercial plant, and consequently it would have a much better chance of being purchased by a commercial user after the end of the demonstration program than would one capable of only 25 MWe. Alternately, should it be desirable to retain the demonstration platform as a test facility after the end of the demonstration program itself, the greater size and capability of the platform would enhance program flexibility by allowing simultaneous testing and development of two, large-scale power system concepts. Adoption of a demonstration platform which is sized for a 50 MWe output would enhance program flexibility in another and perhaps more important way. Such a platform, and the power system(s) it would carry, would be perhaps sufficiently large to obviate the need for a separate demonstration plant for the southeastern U.S. OTEC market. Such a second demonstration program might be required should the first program fail to provide suffi-

cient data to project the technical and economic performance of OTEC plants supplying electricity to the continental U.S. Consequently, LMSC recommends that the first OTEC demonstration plant for the electricity supply mission be designed for an output of approximately 50 MWe, and use at least one 25 MWe power system. The size of the demonstration plantship should of course be similarly dictated by the economies of scale of chemical processing and by the needs of potential users of plantship.

Should a follow-on demonstration be required for OTEC plants supplying electricity to the Mexican Gulf region, an argument similar to that presented above suggests that their output should range from 100 to 200 MWe, using individual power systems with outputs ranging from 25 to 50 MWe. It should perhaps be emphasized that adoption of a 50 MWe demonstration plant for the island application bids fair to eliminate the need for such a second, and costlier, demonstration program. Should such a program prove necessary, it seems likely that the earlier demonstration of a fairly large OTEC plant would increase user interest and might lead to their substantial participation, possibly including financial commitment, in this larger demonstration program.

It is of paramount importance that as much of the technology used in the demonstration plant should be transferable to first generation commercial units. It is not a major part of the demonstration mission to advance the state of technology by itself; thus, unproved or speculative concepts should not be included in the demonstration plant. In this context, the demonstration plant should be regarded properly as a prototype commercial unit rather than an experimental facility.

With the exception of the transmission riser cable, none of the major components of an OTEC plant appear to pose fundamental design problems requiring major advances in the state of the art. However, the physical size of many of these components is significantly beyond current practice, and conceivably may give rise to doubts on the part of some prospective users concerning component constructability and operability. Such questions should be dispelled in the

course of the demonstration program. Consequently, it is recommended that as many of the demonstration plant components as possible should be similar to those which would be used in first generation commercial plants. The advantages inherent in modular design should be exploited to the fullest to minimize the extent of technological projection required to evaluate the results of the demonstration. For example, on the assumption that first generation commercial power systems will have outputs of approximately 50 MWe each, adoption of a 25 MWe power system for the demonstration plant would allow full scale seawater pumps to be used in the demonstration if their number were halved. This appears to be a desirable means of reducing technological uncertainty, i.e., of demonstrating the degree of technological maturity already achieved at the time of demonstration. A similar comment can be made regarding turbines, the cold water pipe and associated screens, and position control components (thrusters, anchors, mooring lines, links, etc.).

A majority of prospective users has indicated that the technology and economics of power transmission and /or utilization requires demonstration. Therefore, it is strongly recommended that cable connection to shore, preferably to an utility grid, be included as part of the demonstration program for electric applications, and on-board product processing be included in demonstrations of OTEC chemical processing plantships.

1.2 DEMONSTRATION ACTIVITY

Once a demonstration plant is built and deployed the objective of the remainder of the demonstration program is to operate the plant in a manner as similar as possible to the operation of a commercial plant, while recording all data required for technical and economic evaluations and providing opportunity for potential users to familiarize themselves with the operation and performance of the plant. The demonstration period should be long enough for a wide range of operational situations to arise. This is particularly important in the case of OTEC, as plant performance will be a function of seasonal temperature variations. A large majority of prospective users indicated that a demonstration period of up to three years duration would be required for a credible demonstration.

The desirability of operating the plant in as much of a production mode as possible gives rise to some interesting questions concerning the proper crew of the plant. It is desirable to involve utility personnel in the actual operation of the plant, since the utilities are the major potential users of first generation OTEC power plants. This was indeed the practice in nuclear power demonstration projects. However, land-oriented utility personnel may find difficulty in adjusting to the living and working conditions onboard sea-based OTEC plants. This suggests that either offshore oil workers or personnel belonging to the maritime trades may constitute more promising labor pools among which to recruit OTEC plant operating personnel. Maritime personnel appear particularly attractive, as many of them have relevant experience in the continuous operation and maintenance of at-sea power machinery. Several utilities consulted indicated that they have had successful experience in employing former maritime and naval personnel, particularly in nuclear power plants. It appears that use of former maritime or naval personnel would provide a labor force well suited to OTEC operations, while enhancing the credibility of the demonstration and fostering industry participation in the demonstration program. It is self-evident that such participation is essential to the success

of the OTEC demonstration program and indeed to that of all OTEC commercialization activities. This applies both to participation by utilities for the electrical mission of OTEC and to participation by chemical manufacturers for the plantship applications.

It would be most desirable for prospective users to be involved in the operation of the plant, perhaps as subcontractors. As a minimum, they should be consulted in developing testing and data collection programs, and their representatives should have observer status on board the demonstration plant. As a secondary point, it may be noted in this context that it may be found desirable to house observers and non-operating personnel on a hotel ship moored near the OTEC demonstration plant. This arrangement would avoid distorting the design and cost of the plant in order to accommodate a large hotel load which would not be required in a commercial plant but would be essential to the success of the demonstration program.

In the preceding section, it was found desirable to make the demonstration plant as similar to a commercial plant as possible in order to minimize the required technology projection into commercial configurations. The same spirit should influence the planning of all demonstration activities. The demonstration plant should be operated, in so far as possible, as a commercial plant, and it should be perceived to be so operated by potential users. An ideal arrangement would perhaps be for the demonstration unit to be operated by a utility or group of utilities, which would use the power produced by the plant in their own grid. Possibly, the federal government could be paid by the contracting utility (or utilities) the amount by which the value of the electricity delivered exceeded the operating cost of the demonstration plant. This arrangement would seem to ensure maximum credibility for a demonstration of OTEC-generated electricity supply to a commercial grid. A similar arrangement could perhaps be used in product-oriented technology demonstrations.

1.3 SUMMARY

The LMSC recommendations for the demonstration plant and program are summarized as follows.

1. The first demonstration power system should be sized for approximately 25 MWe net output.
2. The first demonstration platform should be sized for roughly 50 MWe net output.
3. If a second demonstration proves necessary for large scale commercial plants, power systems should be sized for 25-50 MWe and the platform for 100-200 MWe net output.
4. Modular design should be exploited to use as many full-scale components as possible (seawater pumps, screens, thrusters, mooring components, etc.).
5. Demonstration plant technology should be well proven and directly transferable to commercial plants.
6. Energy transfer by electrical transmission or on-board chemical processing should be included in the demonstration.
7. Duration of the demonstration exercise should be about three years.
8. The manner of operating of the demonstration plant should be as similar as possible to that of a commercial plant.
9. Prospective users should be closely involved in plant operations and data collection, if possible as contractors.

REFERENCE

- 1 P. Mullenbach, "Civilian Nuclear Power", Twentieth Century Fund, New York, 1963.