APPROVED ~~AS REVISED BY LETTER DATED 5-11-92~~
by the Board of Directors of
The Metropolitan Water District
of Southern California
at its meeting held

MAY 12 1992

EXECUTIVE SECRETARY

39625

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MWD
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

March 24, 1992

To: Board of Directors (Ad Hoc Committee on Energy & Desalination--Action)
(Engineering & Operations Committee--Action)
(Finance & Insurance Committee--Action)

From: General Manager

Subject: Revision No. 2 to Appropriation No. 604 to Increase Funding by $2.15 Million to a Total of $2.8 Million to Finance Estimated Preliminary Engineering and Design Costs, through Fiscal Year 1992/93, for the 5-MGD Demonstration Plant for the Seawater Desalination Program

Report

In November of 1991, the Board approved Revision No. 1 to Appropriation No. 604 for $150,000 to a total of $650,000, to provide interim funds for the Desalination Study pending Board determination of possible deferrals to the Capital Program. With the decision made to retain the 5-MGD Demonstration Plant in the current Capital Program, this additional funding request of $2.15 million will provide funding for continued preliminary engineering, including test unit construction and operations, and final design through Fiscal Year 1992/93. It is still estimated that the cost of the design and development work for the 5-MGD Demonstration Plant with an advanced distillation process for the desalting of seawater will be approximately $5.5 million. The 5-MGD Demonstration Plant Program cost is estimated to be $30 million.

This action is exempt from the provisions of the California Environmental Quality Act because it involves studies for possible future actions which your Board has not yet approved.

Attached are copies of the October 16, 1991 Board letter with its expanded report, and the revised Board letter dated November 18, 1991. A peer review report on the conceptual design is also attached. The report was prepared by five independent highly regarded desalination experts. These documents provide full details of the work to be undertaken.

Board Committee Assignments

This letter was referred for action to:

The Ad Hoc Committee on Energy and Desalination because of its charge to report matters of significance concerning

Metropolitan's energy supplies and desalination technology to the Engineering and Operations Committee, pursuant to Administrative Code Section 2570(b);

The Engineering and Operations Committee because of its jurisdiction over the operation, protection, and maintenance of the plants and facilities required for the production, exchange, sale, storage, treatment, and delivery of water and power, pursuant to Administrative Code Section 2431 (c); and

The Finance and Insurance Committee because of its jurisdiction to authorize the appropriation of funds, pursuant to Administrative Code Section 2441(d).

Recommendations

AD HOC COMMITTEE ON ENERGY AND DESALINATION AND ENGINEERING AND OPERATIONS COMMITTEE FOR ACTION.

It is recommended that the General Manager be authorized to initiate Environmental and Water Quality Studies, Test Unit Development and Operation, Preliminary Engineering, and Final Design for a 5-MGD Desalination Demonstration Plant.

FINANCE AND INSURANCE COMMITTEE FOR ACTION.

It is recommended that the Board authorize an increase of $2.15 million to a total of $2.8 million from the 1991 Revenue Bond Construction Fund to Appropriation No. 604 for Estimated Costs of Environmental and Water Quality Studies, Test Unit Operation, Preliminary Engineering, and Final Design through June 30, 1993.

Carl Boronkay

CN/rdl/atr
(boardapr/apr-604)

Attachment A--Financial Statement
Attachment B--10-16-91 Board letter with expended report.
Attachment C--11-18-91 Revised Board letter
Attachment D--Peer Review Report

Attachment A

FINANCIAL STATEMENT

(Program No. 5-6040-71)

The estimated costs for the continued development of a 5-MGD Seawater Desalination Demonstration Plant are shown below. The initial costs were accumulated under the Study authorized by Appropriation No. 604 in July 1990, and also under Revision No. 1 to said appropriation dated November 18, 1991.

	Study	Revision No. 1	Revision No. 2
Labor			
Preliminary Design and Studies	$ 85,681	$ 125,000	$ 870,000
Materials & Supplies	10,000	40,000	160,000
Incidental Expenses	19,825	20,000	70,000
Professional Services	340,000	390,000	930,000
Operating Equipment	176	176	75,000
Administrative Overhead	44,318	64,700	452,000
Contingencies		10,124	243,000
TOTAL:	$ 500,000	650,000	$ 2,800,000

Attachment A (contd)

FINANCIAL STATEMENT

Estimated Funds Required:

Initial Study and Revision No. 1	$ 650,000
Revision No. 2	2,150,000
TOTAL:	$ 2,800,000

Source of Funds: 1991 Revenue Bond Construction Fund
Class Two: Projects directly related to the supply of water, but not necessarily of an urgent nature.

Projected Expenditures of Funds:

Through 1990/91	$ 109,800
Through 1991/92	890,200
Through 1992/93	1,800,000
TOTAL:	$ 2,800,000

Project Benefits: The project will demonstrate designs, materials and operational methods which, on a large scale plant, could be expected to yield lower costs.

MWD
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

October 16, 1991

To: Board of Directors (Ad Hoc Committee on Energy & Desalination--Action)
(Engineering & Operations Committee--Action)
(Finance & Insurance Committee--Action)

From: General Manager

Subject: Revision No. 1 to Appropriation No. 604 to Increase Funding to $2 million to Finance Estimated Preliminary Design and Study Costs for the Remainder of the Fiscal Year for the Seawater Desalination Program

Report

In July of 1990, the Board approved Appropriation No. 604 in the amount of $500,000 to finance the estimated costs for a planning study to define the work necessary to ultimately construct and operate a seawater desalination plant, based on current and proven processes, and to incorporate features and methods applicable to future large plants. The report also indicated that the important output of the plant will be information gained on true costs.

The efforts undertaken as part of the planning study have included the development of a conceptual design of an advanced seawater distillation process, seawater quality studies, site investigations, and an implementation plan. Several features are incorporated in the conceptual design that will provide a more efficient process and a substantial reduction in capital costs. These benefits can be realized by developing each design feature and incorporating them in the demonstration plant.

The design features of this multi-effect distillation process include the adoption of the vertical-tube-evaporator concept, the use of aluminum tubing, higher-temperature operation, stacking the "effects" in a vertical configuration, utilizing up to 30 "effects" instead of the 15 in use today (made possible by higher temperature), and the use of a concrete vessel (silo or tower).

These features have been researched by federal agencies and reviewed by several independent desalination experts engaged by Metropolitan. The development of these design features will require a detailed engineering design of the 5-million-gallon-per-day (MGD) demonstration plant in conjunction with the operation of a 2000-gallon-per-day desalination test unit, and a model testing program. The estimated costs for funding the development work and design of a 5-MGD seawater demonstration plant with an advanced distillation process are approximately $5.5 million.

The demonstration plant is intended to produce five million gallons per day of distilled water and demonstrate: (1) advanced desalination technology, (2) power-plant integration, (3) product water quality, (4) product water distribution, (5) energy use, (6) environmental impacts and institutional issues, and, importantly, (7) true costs for seawater desalination. It is anticipated these costs will serve as a "benchmark" against which all other water-source costs will be measured.

The requested funding will finance a 2000-gallon-per-day test unit, model testing, water-quality studies, and planning and environmental studies. Measured test results from the 2000-gallon-per-day test unit will provide verification of conceptual design features prior to the final design of the demonstration plant in 1992/93. It is estimated, from current studies, that the 5-MGD demonstration plant program will cost $30 million.

Approval of funding for studies is exempt from California Environmental Quality Act.

Board Committee Assignments

This letter was referred for action to:

The Ad Hoc Committee on Energy and Desalination because of its charge to report matters of significance concerning Metropolitan's energy supplies and desalination technology to the Engineering and Operations Committee, pursuant to Administrative Code Section 2570;

The Engineering and Operations Committee because of its jurisdiction over the operation, protection, and maintenance of the plants and facilities required for the production, exchange, sale, storage, treatment, and delivery of water and power, pursuant to Administrative Code Section 2431 (c); and

The Finance and Insurance Committee because of its jurisdiction to authorize the appropriation of funds, pursuant to Administrative Code Section 2441.

Recommendations

ENGINEERING AND OPERATIONS COMMITTEE FOR ACTION.

It is recommended that the General Manager be authorized to initiate Environmental and Water Quality Studies, Test Unit Development and Operation and Preliminary Engineering for a 5-MGD Desalination Demonstration Plant. (Ad Hoc Committee on Energy and Desalination, and Engineering and Operations Committee--Action.)

FINANCE AND INSURANCE COMMITTEE FOR ACTION.

It is recommended that the Board authorize an increase of $1.5 million to a total of $2 million from the 1991 Construction Fund to Appropriation No. 604 for Estimated Costs of Environmental and Water Quality Studies, Test Unit Operation, and Preliminary Engineering, through June 30, 1992.

RWBalcerzak
for Carl Boronkay

DWD/br
(604-ba)

Attachment "A"--Fiscal Statement
Attachment "B"--"Report" (expanded)

Attachment "A"

FINANCIAL STATEMENT (Program No. 5-6040-71)

The estimated costs for the continued development of a 5-MGD Seawater Desalination Pilot Plant are shown below. The initial costs were accumulated under the Study authorized by Appropriation No. 604 in July 1990.

	Study	Revision No. 1
Labor		
Preliminary Design and Studies	$ 85,681	$ 536,000
Materials & Supplies	10,000	160,000
Incidental Expenses	19,825	70,000
Professional Services	340,000	630,000
Operating Equipment	176	75,000
Administrative Overhead	44,318	279,000
Contingencies		250,000
TOTAL:	$ 500,000	$ 2,000,000

Attachment "A" (cont.)

Estimated funds required

Initial (study)		$ 500,000
Revision No. 1		1,500,000
	Total:	$ 2,000,000

Source of funds: 1991 Construction Fund

Class Two: Projects directly related to the supply of water, but not necessarily of an urgent nature.

Projected Expenditure of Funds:

Through 1990/91		$ 109,800
Through December 1991		390,200
Through June 1992		1,500,000
	Total:	$ 2,000,000

1991/92 Capital Program

Estimated Program Cost	$ 500,000 (study)
Program Estimated Fiscal Year 1991/92	$ 321,800

Project Benefits: The project will demonstrate designs, manufacturing techniques and materials specifically chosen to yield lower costs in large-unit sizes.

Attachment "B"
Appropriation No. 604

Report on Desalination Pilot Plant Planning Study

October 16, 1991

Summary

In July of 1990, the Board approved Appropriation No. 604 in the amount of $500,000 to finance the estimated costs for a planning study to "define the work necessary to ultimately construct and operate a seawater desalination plant."

The report suggested that the "advanced" plant should be "based on current and proven processes . . ." yet incorporate features and methods applicable to future large plants. It further stated, ". . . the important output of the plant will be information gained on true costs . . . ."

Staff has investigated the several processes that represent the "state-of-the-art" today. We have concluded that the scaled-up plant in which Metropolitan would be interested should include features that are not present in most production plants today, but which do lend themselves to modification, afford the greatest economy of scale, for the large desalting plants we envision.

The efforts undertaken as part of the planning study have included the development of a conceptual design of an advanced seawater distillation process, seawater quality studies, site investigations, and an implementation plan. Several features are incorporated in the conceptual design that will provide a more efficient process and a substantial reduction in capital costs. These benefits can be realized by developing each design feature and incorporating them in the demonstration plant.

The design features of this Multi-Effect-Distillation process includes the adoption of the vertical-tube-evaporator concept with "fluted" tubes, the use of aluminum tubing, higher-temperature operation, stacking the "effects" in a vertical configuration, utilizing up to 30 "effects" instead of the 15 in use today (made possible by higher temperature), and the use of a concrete vessel (silo or tower).

These features have been researched by federal agencies and reviewed by several independent desalination experts engaged by Metropolitan. The development of these design features will require a detailed engineering design of the 5-MGD demonstration plant in conjunction with the operation of a 2000-gallon-per-day desalination test unit, and a model testing program. The estimated costs for funding the development work and final design of a 5-MGD seawater demonstration plant with an advanced distillation process is approximately $5.5 million.

The demonstration plant is intended to produce 5-MGD five million gallons per day of potable water and demonstrate: (1) advanced desalination technology, (2) power-plant integration, (3) product water quality, (4) product water distribution, (5) energy use, (6) environmental impacts and institutional issues, and, importantly, (7) true costs for water desalination. It is anticipated these costs will serve as a "benchmark" against which all other water-source costs will be measured.

It is estimated, from current studies, that the 5-MGD demonstration plant program will cost $30 million.

Report

Original Charge

Metropolitan's Board of Directors approved Appropriation No. 604, in the amount of $500,000 to finance the estimated costs for a planning study for the construction and operation of a demonstration scale seawater desalination plant. The action was considered to be the appropriate next step following recent seawater desalination feasibility studies. The planning study was directed to emphasize seawater evaporator technology driven by steam purchased from an existing coastal power station.

It was estimated that a design and site would be available for construction in two years. The design would be of an advanced desalination plant based on currently available processes modified to take advantage of those features which could result in cost savings when "scaled up" in size to large-capacity. It was also anticipated Metropolitan's continued efforts to undertake the construction and operation of a seawater desalination demonstration plant would motivate manufacturers of desalination equipment to develop larger capacity desalination equipment. It was believed that potential "economies of scale," from desalination plants designed for large-capacity, could provide significant water production cost savings compared to currently available desalination units which are sized and designed for a generally much smaller demand.

Investigations by Staff

1. Previous Studies: Metropolitan has, over the years, periodically reviewed developments in the state-of-the-art of seawater desalination technology. In 1988, Metropolitan, in cooperation with the United States Department of Energy, engaged General Atomics to study the viability of coupling a seawater desalination plant with a new generation (high temperature gas cooled) nuclear power plant. In 1989, Metropolitan engaged the Bechtel Corporation to study a similar installation to be operated in conjunction with a fossil fuel power plant. Each of these studies were based on currently available seawater evaporator-type desalination technology. Based on the information provided in these studies, the staff has determined water production cost estimates of $1,100 per acre-foot not including water distribution costs.

2. Most recently, in cooperation with the San Diego County Water Authority, Metropolitan participated in a feasibility study of a 50-MGD desalination plant to be driven by a new gas turbine/steam power plant to be located at one of San Diego Gas and Electric's existing power plant sites. The selected alternative design was a "hybrid," a combination of membrane and distillation technology. It is estimated the hybrid design will provide a slight savings in water production costs compared to using a single type of desalination technology; however, the added complexity of operating two different types of technology in one plant may outweigh the gain in overall energy efficiency. Estimated water production costs for the hybrid design were $1,100 per acre-foot.

3. Desalination Technology: Worldwide, the majority of fresh water produced from seawater by desalination technology uses a distillation process called Multi-Stage-Flash (MSF). This process is driven by steam from a boiler or a power plant. The heat energy evaporates a fraction of seawater in each of a series of "flash" chambers. On the other hand, the seawater evaporator technology used as a design basis in each of Metropolitan's previous studies is Multi-Effect-Distillation (MED). MED uses heat energy similar to the MSF process, but by using a more efficient method of heat transfer, the MED process is more energy efficient than the MSF process. The largest single MED unit currently operating is 5-MGD and the process is used predominately in the Mediterranean-Caribbean. The process was developed in laboratories and pilot plants by the U.S. Office of Saline Water and The Office of Water Research and Technology.

Another distillation type of desalination process currently available is Vapor Compression. This process uses a heat transfer method similar to the MED process and acquires heat energy provided by a compressor. This technology is limited to capacities of 700,000 gallons per day.

Reverse osmosis is a membrane type of desalination technology. Seawater, pumped to very high pressures, is forced through the membrane which acts as a salt filter. This process requires extensive pretreatment facilities, but the actual reverse osmosis process itself is contained within a series of pressure vessels. Reverse osmosis is predominately used to desalinate brackish waters because costs increase significantly with increasing feed water salinity.

All of the desalination processes currently available are land intensive and require a very large site. MED processes are currently equivalent to reverse osmosis processes in terms of water production costs. However, it is believed MED can be more energy efficient if units are designed for larger capacities, and total water production costs can benefit from the economies of scale.

4. Site Investigations: Three power utilities operate a total of 12 power stations along the coastline in Metropolitan's service area. Each of the power utilities is planning to repower several of these power plants. This will provide higher fuel efficiency and reduced air emissions. The reconfigured power plants could operate at higher capacities the majority of the time (be base loaded) and thereby be suitable for coupling to a desalination plant.

5. Potential Development: The development of seawater desalination technology has not progressed significantly since 1980.

Several design features for very large-capacity MED plants that have been studied and tested include the use of vertical tube evaporators, fluted tubes, and the use of concrete. The vertical tube evaporator is widely used commercially but not in desalination. Most desalination units have used horizontal tubes.

The vertical tube evaporator (VTE) allows the use of "fluted" tubes which significantly enhance the heat transfer process.

The use of concrete as a material for the vacuum vessel has been studied, but has not been widely demonstrated. Construction costs for large-capacity plants can be reduced by using concrete instead of carbon steel for the actual vacuum vessels.

Development of Process Concept

A team of engineering consultants, each with extensive seawater desalination experience, was engaged to produce a conceptual design of a large-capacity plant. The conceptual design features innovative concepts from previous research and pilot testing conducted by federal agencies in the 1960's and 1970's. The conceptual design of a large-capacity seawater desalination plant provides the guideline for demonstrating seawater desalination as a possible future water supply in Southern California. The conceptual design features the following improvements:

1. High Temperature Operation: The ability to operate a seawater evaporative process at high temperatures (230°F) increases the amount of water produced per pound of steam consumed. High temperature steam is more expensive than low temperature steam that is used for existing MED, yet total unit cost of water should not increase.

2. Vertical-Tube-Evaporation Process: The vertical-tube-evaporator process allows for the use of fluted tubes that provide for better heat transfer. Vertical tube evaporators are extensively used in industry. The process was used in seawater desalination, yet failed due to the use of improper materials and a lack of brine chemistry control.

3. Aluminum: Aluminum tubing is significantly less costly than traditional copper-based materials presently used for seawater distillation, yet still provides a good heat transfer capability. Cost savings for the materials of construction benefit most from the economies of scale for building large scale plants. The use of aluminum for structural members as well as tube bundle construction will reduce the likelihood of corrosion caused by dissimilar metal effects.

4. Stacking the Effects: Stacking one vacuum vessel on top of another allows for a more efficient method for transferring fluids. "Stacking" will also reduce site area requirements.

5. Concrete: Stacking the effects generates a configuration that makes viable a tower-like structure to contain the tube bundles for the numerous effects. Concrete, in this configuration, appears to be an acceptable substitute for the more expensive carbon steel that is traditionally used for vacuum vessel construction.

A copy of the conceptual design process description is attached.

Benefits of Advanced Seawater Evaporator Desalination

The features of the advanced seawater evaporator have been selected to mesh advantageously with the retrofitting of an existing coastal power plant. The concept of incorporating the construction of a seawater desalination plant with a power plant reconfiguration project has the following advantages:

1. Design Integration: Power plant reconfiguration plans can be optimized to include a seawater desalination plant and provide construction and operating cost savings.

2. Site Availability: Power plant reconfiguration work can include the removal of existing boilers/structures to provide space for a high-capacity seawater desalination plant.

3. Energy Costs: A combined (dual purpose) plant provides benefits to each, and the opportunity to optimize energy costs.

4. Enhanced Performance: The capital cost per unit of capacity of the advanced seawater evaporator is estimated to be only one-half of the capital costs of currently available desalination processes. The increased heat transfer capabilities of the advanced seawater evaporator provides for a highly energy efficient water production.

Advanced Seawater Evaporator Development

The planning study has identified the tasks to be undertaken in order to develop the advanced seawater evaporator design for construction of the demonstration plant. The development work will require engineering design work, independent design review, model testing and a small test unit. An independent review of the conceptual design was recently completed by three separate desalination experts engaged by Metropolitan. A summary of their comments is included in this report.

The Engineering staff has identified the following procedure to develop and verify the suitability of the conceptual design. The goal is to complete a preliminary detailed design of the advanced seawater evaporator for implementation in a demonstration plant.

Conceptual and Preliminary Design Work

- Conceptual Design
- Preliminary Review of Conceptual Design
- Conceptual Design Draft Report
- Final Review of Draft Report
- Final Conceptual Design Report
- Preliminary Design of Demonstration Plant

Development Work

- Design and Construction of 2,000-gallon-per-day Test Unit
- Testing and Operation of Test Unit
- Laboratory Tests of Materials
- Model Testing

The completion of the above tasks will provide the information required to verify the conceptual design before conducting final design of the demonstration plant. The estimated cost for the development tasks is $2 million.

Development of the advanced seawater evaporator will "Cap" previous research and pilot testing and provide an important "benchmark" in the development of seawater desalination technology.

Demonstration Plant Project Planning

The planning study has identified the tasks to be undertaken to design, build and operate a seawater desalination plant. Site investigations, process studies--along with discussions with power utilities and state regulators--indicate that there is a lack of information available to plan, design and regulate large-capacity seawater desalination plants. The demonstration project will be required to demonstrate the following items:

1. Water Quality: The California Department of Health Services has issued a preliminary draft outlining a protocol for regulating seawater desalination plants. The Department is currently requiring seawater desalination plants to conform to the Surface Water Treatment Rule. The demonstration project will be required to demonstrate the distillation process as an alternative treatment process and will provide water quality data to support revisions to seawater desalination product water regulations.

2. Water Distribution: A demonstration plant capacity of 5-MGD will require local agency purchases or other uses of the product water. Product water distribution for large-capacity plants will require extensive modifications and

additions to the existing distribution system. The demonstration plant will be required to establish planning and coordinating criteria with product-water customers for large-capacity plants.

3. Environmental Impacts: Seawater evaporators will have some impact on the environment and the demonstration plant will be required to provide meaningful information on potential impacts. The increased use of fossil fuel required to supply steam to the seawater evaporation and the resultant air emissions shall be measured. Distillation plants produce air emissions from evaporated seawater constituents that are noncondensable. Seawater desalination plants dispose concentrated seawater for return to the ocean. The demonstration plant will provide information on desalination plant discharge constituents and potential environmental impacts. Environmental requirements in California require extensive planning and possible extra mitigation costs. It is postulated the actual effects on the environment are minimal; however, there is a need to demonstrate desalination technology and its environmental impacts before building large-capacity plants.

Project planning for a seawater desalination demonstration plant will require a series of environmental studies, facility plans, interagency negotiations and water quality studies. These planning efforts will be required for any type of desalination process. An implementation plan has been developed that incorporates a 2,000-gallon-per-day test unit, a 5-MGD demonstration plant and the appropriate planning efforts for building a large-capacity plant.

Demonstration Plant Cost Estimates

The cost estimates for the seawater desalination demonstration plant have been broken down into a planning and development phase, a final design phase and a construction phase. Monies appropriated to date have essentially contributed to the development of a conceptual "advanced" design. The next phase of the effort, through approximately the end of the fiscal year, will see construction and operation of the test unit, some model testing, continued development of water quality studies, environmental studies, and some preliminary design work.

It is anticipated information developed from the operation of the test unit will generate the opportunity for a go/no go decision (in the summer or early fall of 1992) to proceed with the final design of the 5-MGD demonstration plant. That will require further funding, to a total of approximately $5.5 million for completion of the final design, to award of a construction contract. It is currently estimated the 5-MGD demonstration plant will cost $30 million to design and build.

As a comparison, the Santa Barbara 5-MGD desalination plant costs approximately $30 million. The Marin County 5-MGD desalination plant including modifications to the distribution system is estimated at $65 million. The cost estimates shown are used to identify the potential savings in water production costs from a large-capacity plant as a result of a successful development and demonstration of the advanced seawater evaporator:

	Advanced Seawater Evaporator	Existing Desalination Technology
Planning, Development & Engineering	$ 5.5 million	$ 3.5 million
Demonstration Plant	$ 25 million	$ 25 million
Demonstration Plant Water Costs	$ 1,500/AF	$ 2,000/AF
Full Scale Desalination Plant Costs	$ 200 million	$ 400 million
Full Scale Desalination Plant Water Costs	$ 850	$ 1,100

DWC/rdl
(ba:604-att.b)

A SEA-WATER EVAPORATOR DESIGN FOR SOUTHERN CALIFORNIA

The Metropolitan Water District is investigating many possible sources to meet projected needs for large-scale additions to water supply in Southern California. Some of these alternates will be useful, but each new increment of supply is more costly than the last. The Pacific Ocean looms as the ultimate, inexhaustible source. Cost and reliability are the factors that will determine when desalting the sea will become the economic choice.

The commercially available desalination technology has evolved in parts of the world where small units sited close to special purpose needs are the norm. Such currently available plants are not only very costly, but they are ill-suited to the needs of Southern California. This region needs water in very large increments for general use over a large area. Nevertheless, proven elements of this technology exist which can be modified and scaled up to the unit size needed. The result could lead to much lower costs.

The modifications involved are derived from the extensive evaporator development program at the Oak Ridge National Laboratory in the 1962-74 period. This work, sponsored by the Office of Saline Water and the Atomic Energy Commission, included both laboratory and large-scale field tests . Research at Berkeley and UCLA in the University of California also contributed. By adapting these results to the special conditions of Southern California, making use of new materials, and employing operating experience and field results available in recent years, we have developed a specific process, conceptual design, and plant arrangement to meet the needs of the Metropolitan Water District. This conceptual design is described below.

FACTORS AND LIMITS GOVERNING DESIGN

A plant design must meet several important criteria to fit the needs of the Southern California region. These include large unit size, energy efficiency, space efficiency, reliability, environmental impact, and cost. These criteria all interact extensively.

1. Size. The Metropolitan Water District now delivers as much as three billion gallons a day of imported water to its municipal members. Over the next 20 years the increase in demand is expected to exceed the available new sources by more than a billion gallons a day. Desalination is not likely to supply all this need, but clearly large units are indicated, up to 100 million gallons per day, whenever their costs reach a reasonable range. Large units also will be more efficient in space and energy use, and will achieve a lower cost through the economies of scale.

Size has another important aspect because, in Southern California, putting the fresh water on the beach is not enough. The water must be piped inland, blended with other water supplies, and added to the existing gravity delivery system to reach the millions of individual users. The economies of scale for pipeline construction dictate that we produce as much water as possible at any one site, in order to hold down distribution cost.

2. Energy Cost and Efficiency. Energy costs in the region are high, and are expected to go much higher. It is important that a desalination plant built today remain competitive in the future when fuel costs rise. Accordingly, the process must be based on the lowest cost source of energy obtainable. For a distillation process this means using secondhand steam that has first been used to generate electricity. Thus we are constrained to locate any proposed water plant at a coastal power station. Southern California has about fourteen such stations, and the coastline is in such demand that it is unlikely that any new ones will be built. Some of these stations are planning to repower with modern gas-turbine combined cycle units. The reduced energy costs from associating a desalination plant with such a project can be a compelling factor in the selection of a process and a plant site. It is such a situation that governs the present design.

The design optimum in a desalting plant occurs when the capital cost of an incremental gain in energy efficiency is equal to the capitalized cost of the energy saved. Such optima are usually quite flat, so that in a water-short region it is preferable to build efficiency on the high side of the optimum, to gain the maximum output from the project. This strategy also protects against fuel cost increases.

For a process based on thermal instead of electric energy, the optimum efficiency is affected primarily by the cost of heat transfer surface. The process described herein uses low-cost aluminum heating surface, a relatively new and very successful development of the past ten years. Studies show that with aluminum tubing the highest attainable thermal efficiencies are still cost effective, even for the secondhand steam from a turbine. The design efficiency is therefore set by the limit of technical performance.

3. Space Efficiency. The coastal power stations in California were originally built in sparsely settled regions, but now they are all crowded by dense urban surrounds. At most sites there is very little land available for water plant construction. An important criterion, therefore, is to arrange the chosen process to fit on the least possible land area.

4. Reliability. Reliability of the water plant is a key issue, since improving technology always involves some uncertainty. For this reason, the MWD will operate several small test evaporators to measure key performance and materials issues, culminating in the construction and operation of a large demonstration or pilot plant representing a full-scale sector of the large plant. These tests will verify

the most important design features. In addition, MWD will insure that the plant is built and operated as designed by using advanced quality-control measures during construction and by thoroughly training the operators.

5. Environmental Effect. The environmental and ecological impact of the water plant will be closely watched in California. The noise level and external appearance of the plant will be of considerable concern. The plant's emissions will also be reviewed, but in most locations these are usually viewed as benign.

6. Cost. The cost of water resulting from the plant is the basic figure of merit for the design, provided the other criteria are also met. The lower the cost, the sooner desalination can become a part of the region's water supply.

PROJECT TIMING

The utility plans to begin operation of the first combined cycle plant in early 1999. The date for commitment to join a water unit to this program is early 1996. We believe that such a commitment to an advanced process requires that the pilot or demonstration plant shall have operated for over a year by that point, meaning completion by mid 1994. Thus the pilot plant design must be essentially complete by the end of 1992, and the full scale design must be far enough along to reflect its features in the pilot unit.

POWER COMPANY SUPPLY PARAMETERS

1. Low Pressure Steam Supply: 1.17 million pounds per hour at 24 psia saturated. Cost about $ 1.65 per million Btu.

2. High Pressure Steam Supply: As needed for ejectors from plant auxiliary supply. Cost about $ 3.00 per million Btu.

3. Sea Water Intake Supply: As needed up to 150 million pounds per hour from existing intake system. Temperature varies over the year from 56 to 67 F, averaging 61 F. (Not chlorinated)

4. Electric Power Supply: 440 v power at 7 cents/kWhr

5. Land available: About 5 acres of plant site land close to steam turbine, plus parking and administrative space. (It is assumed that the control room will be closely associated with the power station control room.) About 10 acres are available nearby for distilled water storage and treatment tanks.

6. Waste brine discharge: Existing condenser outflow channel available. Final mixture must meet discharge regulations for temperature, quantity and content.

7. Location and soil conditions: The location is about 300 yards from the open ocean beach, with a major highway between the plant site and the water. The soil is firm beach sand to a depth of at least 300 feet. The water table stands about 10-15 feet below grade.

PROCESS SELECTION

1. Brief Description. The process chosen is a once-through, forward feed vertical tube evaporator using 2" fluted aluminum alloy tubes in 30 effects. Vertical tube feed-heater bundles operate in the vapor space of each effect, and the condensed product is flashed to equilibrium with each effect in turn. The top brine temperature is 230 F, and the last effect boiling temperature is just under 100 F. The expected performance ratio of the plant is 24, with a production of about 80 mgd of distilled water. Total sea water intake is about 120 mgd, and brine blowdown is about 40 mgd, with a concentration of 3x seawater. This flow sheet is illustrated schematically in Fig. 1.

2. Vertical Layout. The process is arranged in two vertical stacks, each with 15 effects one above the other. The plant is housed in a vertical concrete cylinder about 110 feet in diameter and 230 feet above grade, extending another 80 feet below grade. The cylindrical silo has a concentric internal silo about 60 feet in diameter, with 12 or more radial walls connecting the two cylindrical walls. (See Fig. 2 & Fig. 3) The annular space between these cylinders is the evaporator region, designed for an internal working pressure range of 10 psi gage to full vacuum. Each vertical stack of 15 effects occupies half of the annular space, with heavy walls and piping ducts separating the two halves.

Each effect is made up of twelve pie-shaped sectors at one level. A pressure-tight floor of concrete or metal supports the tube bundles and separates the fluids of each effect from those above and below. The maximum pressure difference between adjacent effects is 1.5 psi vapor pressure plus 1 psi water load. There is no lateral pressure difference around the half-annulus. The pressure floors are spaced about 20 feet apart--twice the height of the tube bundles, to allow room for retubing. The central cylinder is open to the atmosphere, and is used for some of the pumps and piping, service access, elevators, storage, etc. The remainder of the pumps are located outside the silo, in vertical caissons or wells extending from grade down to the common basemat level of the structure.

3. Tube Bundle. The individual effect tube bundles, representing one twelfth of the effect surface, have 2" thick aluminum alloy tube sheets and about 3200 fluted tubes 2" in diameter and 10 feet long. The bundle is wedge-shaped, with the

length 15.6 feet, the narrow end 7 feet wide and the wide end 11 feet wide. Thus overall shipping dimensions are 10'x 11'x 16'. Though all bundles at each level operate in parallel, each is individually shrouded, baffled and vented, so that the steam path though the bundle is fully controlled.

As shown in Fig. 4 and Fig. 5, the bundle is divided by an internal baffle, and fed with steam from both ends. This arrangement insures sufficient area for demister installation in the lower effects. We propose to fabricate, assemble and test the bundles in a dedicated shop facility, and ship them to the plant site. The pilot plant will use a single bundle of the full-scale design for each of its effects.

4. Feed Heater Bundles. The feed heaters will consist of 3/4" aluminum tubes, smooth on the inside and possibly fluted on the outside. These will be mounted in vertical bundles hung in the steam-flow vapor space adjacent to the outer end of the effect bundles. To reduce the brine side pressure drop and the number of brine seals, it is proposed to make these assemblies up to 100 feet high, passing through several effects with an elastomer seal and/or metal baffle at each pressure floor. Only distilled water and vapor will be present at these points. An alternative arrangement would have a water box at each effect level.

5. Brine Distribution The non-deaerated feed water is screened, passed through the final condenser and then pumped in series through all 30 effects. At the top effect a distribution header meters equal flows to each of the twelve tube bundles. A closed pan attached to the upper tube sheet receives the feed and distributes it to the individual tubes, either by means of a perforated plate or through a nozzle inserted in each tube. One option is to maintain a free surface in this upper pan, with a pressure-controlled vent line and vent condenser. Since the pressure at this point will be above atmospheric, much of the non-condensable gas in the feed can be removed conveniently at this point.

6. Brine Flow Within Effect. At the entrance to each tube the hot brine experiences a pressure drop, because it enters a zone whose pressure is controlled by the condensing temperature of the next effect below. The brine flashes and foams as it passes down the tube, and about 2-3 percent of its mass is evaporated by the heat passing through the fluted tube. At the top effect the vapor produced has a volume 30 times that of the remaining brine, and this ratio exceeds 1000:1 at the lower effects. The result is that the foaming, boiling brine is accelerated rapidly down the tube by the expanding vapor, producing in effect a wiped film evaporator action. The mixture falls into a separation pan whose bottom is formed by the upper tube sheet of the next effect below. The brine collects in the pan and passes through nozzles into the tubes below.

7. Vapor Flow Within Effect. The vapor separates by gravity from the brine, and leaves the pan through windows at the outer and inner ends that are screened with de-entrainment separators. Here it enters a region between the end of the tube

bundle and the outer or inner wall of the silo. This chamber, bounded on top and bottom by the pressure floors, forms the duct that leads the vapor to the steam aperture of the effect below. The feed heater bundles are hung in this space and take up about 1/10 of the space. Flashdown of product also occurs here. Lateral ports in the separating radial walls insure that the same pressure prevails at all bundles of a given level.

The vapor entering the bundle is guided by baffles and steam lanes that preserve a *relatively constant velocity as the volume shrinks. This carefully designed path* leads to a vent point where the non-condensable gases and the remaining vapor are vented to an external line. For the effects operating above atmospheric pressure, this line leads to a condenser and thence to atmosphere. For vacuum effects the vent gases are cascaded to a pre-condenser, steam ejector and after-condenser.

8. Product Flow Within the Effect. The first effect produces no product, the steam condensate being all returned to the power station. For other effects, the *vapor condensed on the fluted tubes is funneled rapidly down the flutes to the* lower tube sheet, where it flows across the sheet to a receiving box along one side of the bundle. The receiving box contains an elongated U-trap to pass distilled water into the effect below while still maintaining a pressure seal between effects. The condensate from the feed-heater tubes also flows to the box. As the product *drips or flows to the floor below, it flashes to equilibrium with the pressure there,* releasing vapor that enters the tube bundle to increase the boiling rate in the tubes.

The volume of product accumulates from effect to effect, and in the lower effects amounts to more than the volume of the brine in the tubes. In these stages the product flash-down region of the vapor space is increased in size.

9. The Concrete Silo Structure. The use of concrete for evaporator shells has *been studied for a long time, culminating with a pilot-plant project that was* operated in Japan for several years with favorable results. In this work, concrete was shown to be quite resistant to salt brine, provided the reinforcing bar had sufficient cover. Distilled water has an erosive effect on some types of concrete, caused by leaching of the cement binder. It is believed that both salt penetration and distillate leaching can be essentially eliminated by using a mix containing almost no uncombined water and several modern additives, including very fine silica "fume". MWD is doing intensive study and testing of such mixes.

Air inleakage can be essentially eliminated by minimizing construction joints and properly designing those that are necessary. Penetrations and access ports require special attention against leakage. The economic advantage of concrete over steel for evaporator shells increases with the size of the unit. Continuous-pour slip-casting is advantageous and cost-effective if the structure has vertical sides and is over 100 feet high. It is ideally suited for placing the structure planned here.

10. Use of Aluminum Heat-transfer Surface. Aluminum tubing has been studied for use in sea-water evaporators for many years, because of its obvious cost advantages. These tests included extensive loop testing at the Oak Ridge National Laboratory and the aluminum-tubed pilot plant of the Office of Saline Water, built at the Wrightsville Beach test site and operated by the Reynolds Metals Company. This work showed that aluminum in sea water was very vulnerable to contact with heavy metal impurities, especially copper and iron. Special traps were built to remove these materials. Once the tubing was protected from such exposure, especially from rust specks derived from the steel shell of the pilot plant, corrosion performance was satisfactory up to 240 F.

A major commercial development of aluminum-tubed evaporators using the horizontal spray-film multiple effect process has been very successful in the last ten years. Over twenty such plants have been built, mostly quite small. These plants achieved mechanical simplicity by using backward mixed feed, which in turn limited the scale-free operating temperature to about 170 F. The aluminum tubing was protected from heavy metals by passing incoming sea water through a scrap-aluminum filter bed. The low operating temperature also served to help protect the aluminum.

The Reynolds Metals Company has performed a comprehensive assessment of all previous work on aluminum in hot sea water, including their own extensive laboratory tests. Their assessment includes detailed investigation of the types of failure observed, identifies the metallurgical causes, and relates these to the alloy composition and to the experimental environment. The report concludes that if certain precautions in assembly and operation are rigorously observed, aluminum will perform very satisfactorily in a sea water evaporator up to 240 F.

From the metallurgical data, the company has developed a new alloy with a slightly different manganese content from the standard #5052 now used. They believe this minor change will offer a worth-while improvement in corrosion resistance. They are prepared to produce extruded 2" fluted tubes at a cost estimated somewhere in the range of 50 cents a linear foot, which is about $1 per square foot.

11. Brine Chemistry and Scale Control. The use of forward feed at a top brine temperature of 230 F will permit sulfate scale to be completely avoided. As the brine becomes more concentrated it is also cooled, staying just outside the anhydrite solubility curve. Carbonate scale will be controlled by the widely used polymeric additives. Deaeration of the feed before heating is not required, since aluminum does not require a reducing environment. The existing sea water intake is not chlorinated, and we do not propose to chlorinate the feed to protect the condenser, because of the potential for creating volatile halomethanes. The condenser and feed system will be designed for complete drainage upon shutdown. Ozone or hydrogen peroxide dosing might be used if biofouling becomes a problem.

A biodegradable detergent may also be added to the feed to promote foaming flow while boiling and thus increase heat transfer rates. If this is done, most of the additive will be recovered from the waste brine by a froth flotation separator. The incoming sea water will be filtered through a heavy ion trap filled with scrap aluminum. Steam from the power station will pass through a similar trap.

12. Heat Transfer. We have collected extensive test data from single and multiple fluted tube measurements to define a curve of overall heat transfer coefficients for preliminary design. This curve includes allowances for bundle size, aging loss, and 10% tube losses, and allows no credit for foaming flow. It will be corrected if necessary before final design, from the ongoing test results. The effect values range from over 2000 in British units for the top effect, to about 800 for the bottom, using the "rubber band" circumference for the reference area. The feed heater values range from 550 to 750.

13. Instrumentation and Control. A detailed instrumentation and control plan is not yet available, pending completion of a dynamic flow stability analysis. However, the objective will be to provide automatic sequencing of controls for normal start up and shutdown, and a multitude of sensors capable of detecting any leaks, salt contamination, or changes in temperature, pressure or liquid level. Since the associated power plant will normally be run base loaded, there is no provision for part-load operation, except the trimming needed as the sea water temperature changes over the season.

14. Product Post-Treatment. Distilled water post-treatment facilities or blending facilities will be needed at the plant site, but they cannot be specified until later, pending exploration of several methods of blending. It is possible that an RO unit will be operated in parallel with the evaporator to produce blending water.

R. Philip Hammond, Team Leader
David M. Eissenberg
Dieter K. Emmerman
John E. Jones, Jr.
Hugo H. Sephton

August 23, 1991

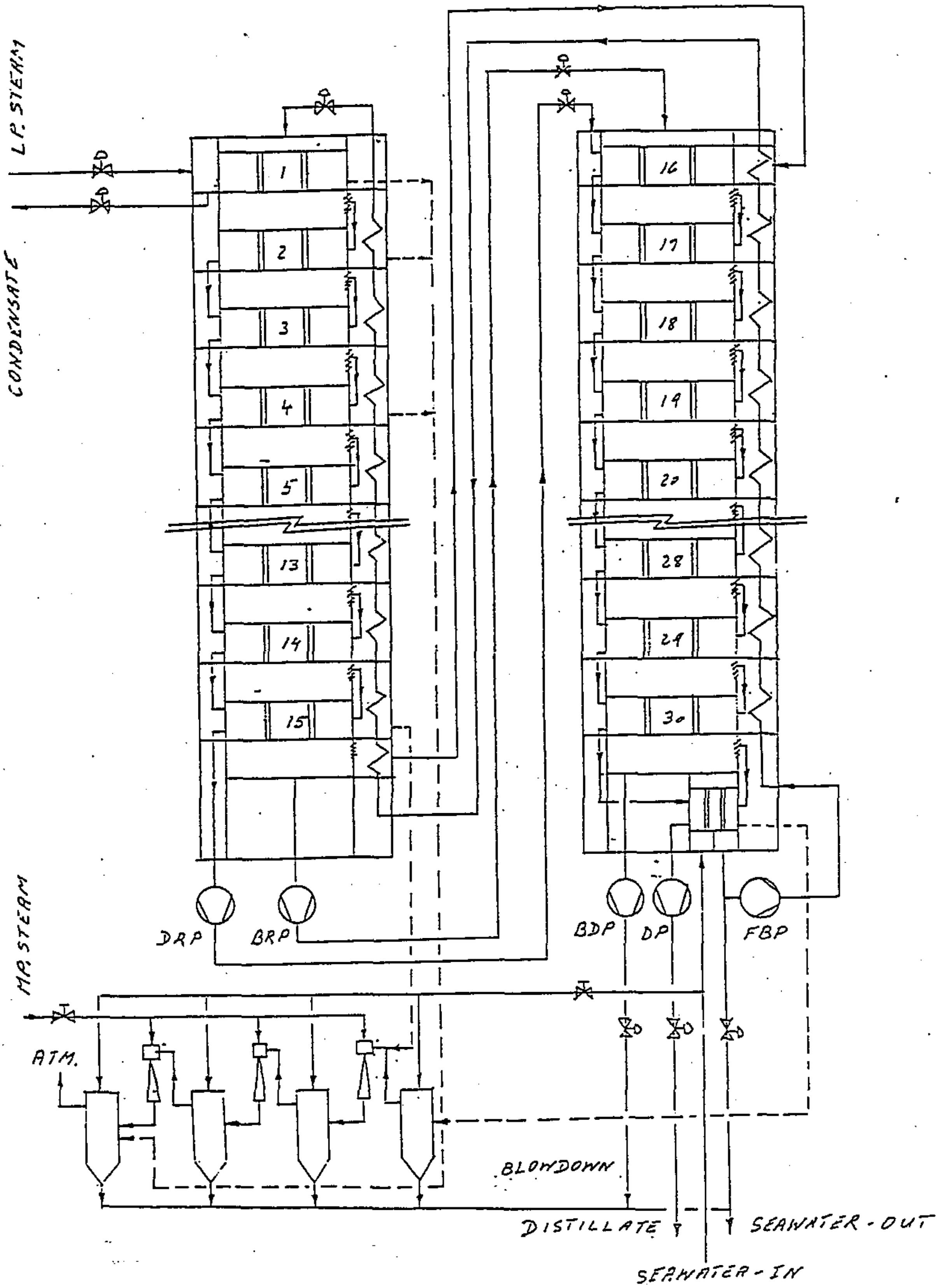

FIG. 1 PROCESS FLOW SHEET

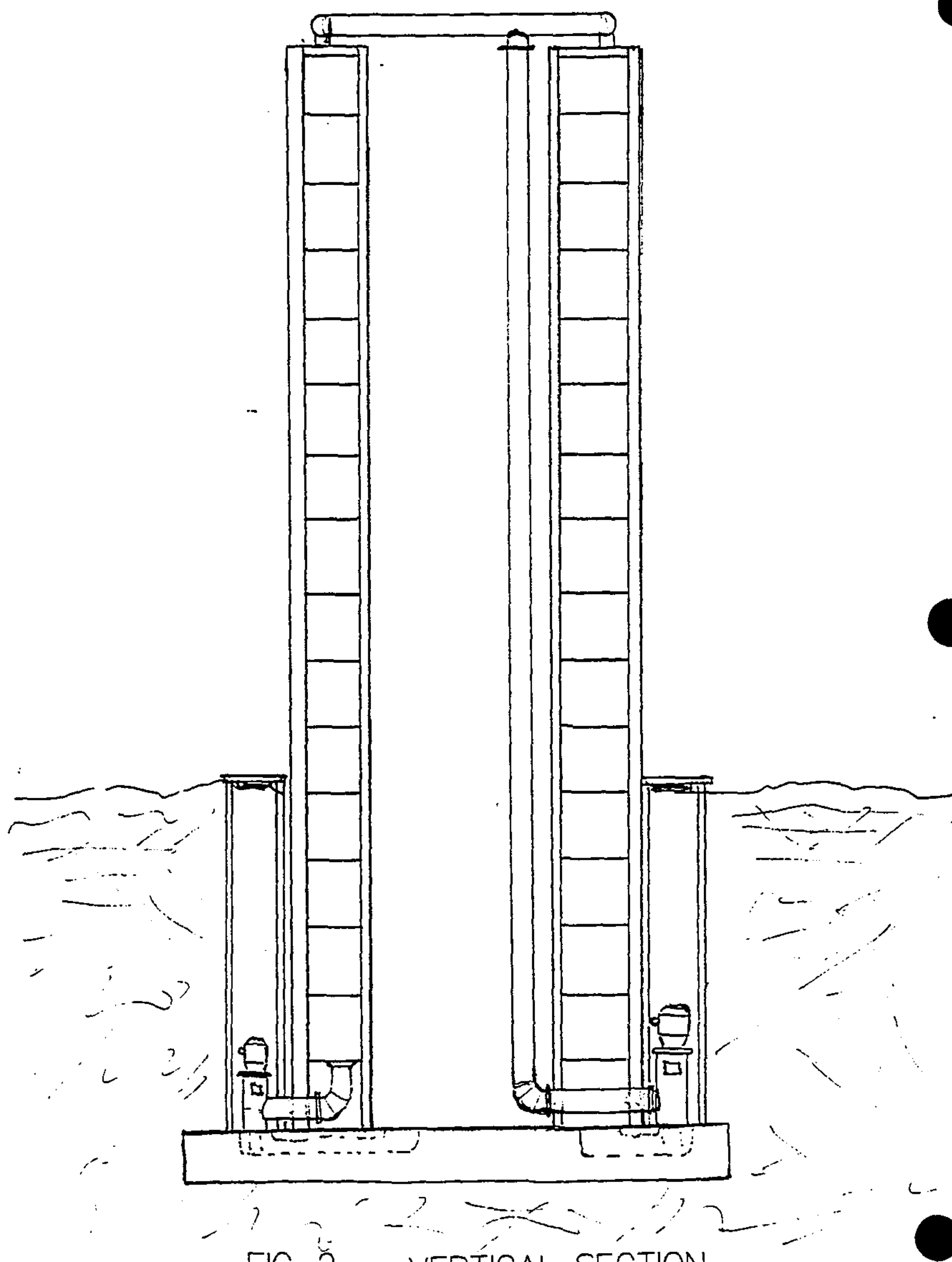

FIG. 2 VERTICAL SECTION

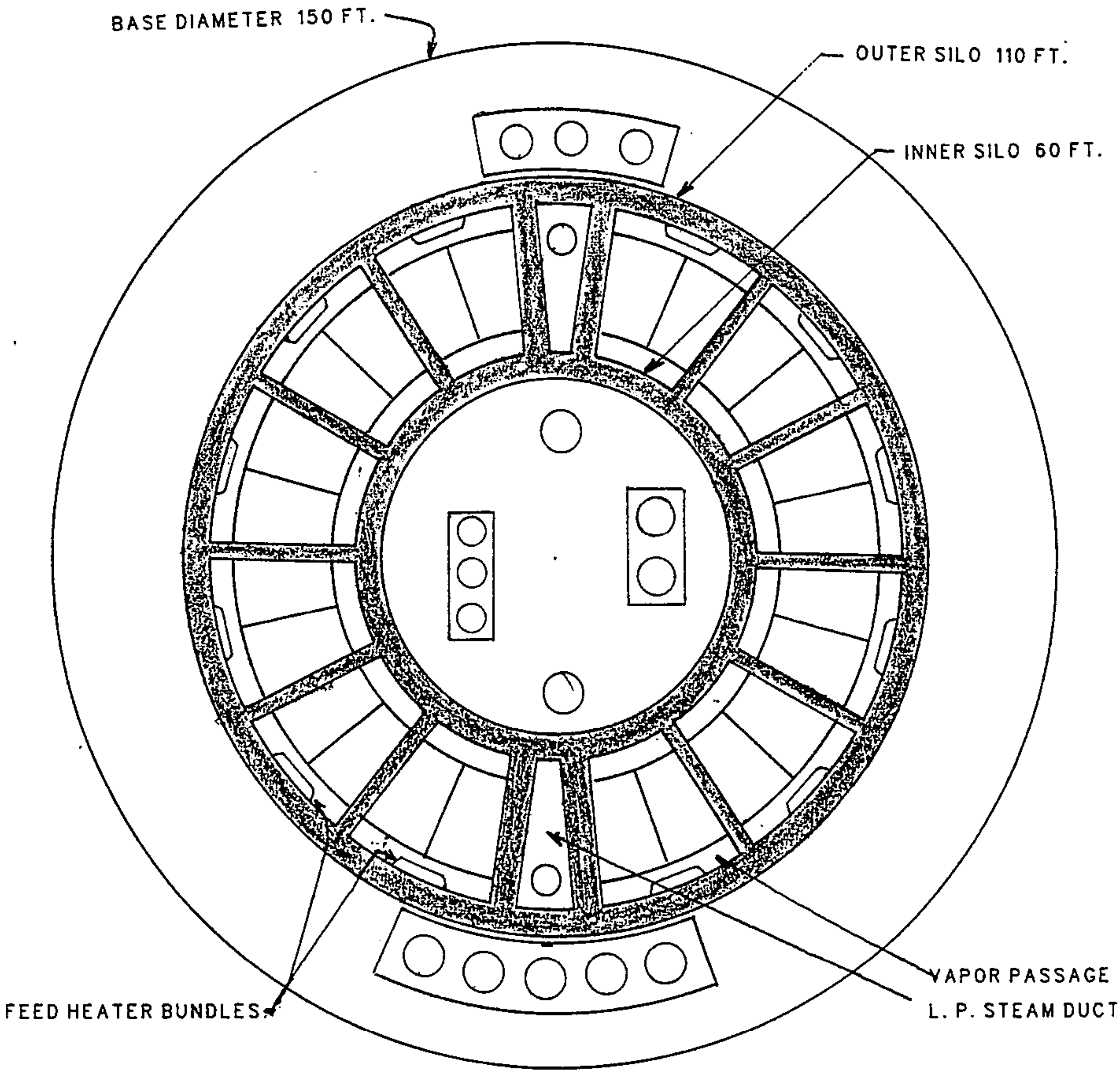

FIG. 3 CROSS SECTION OF SILO

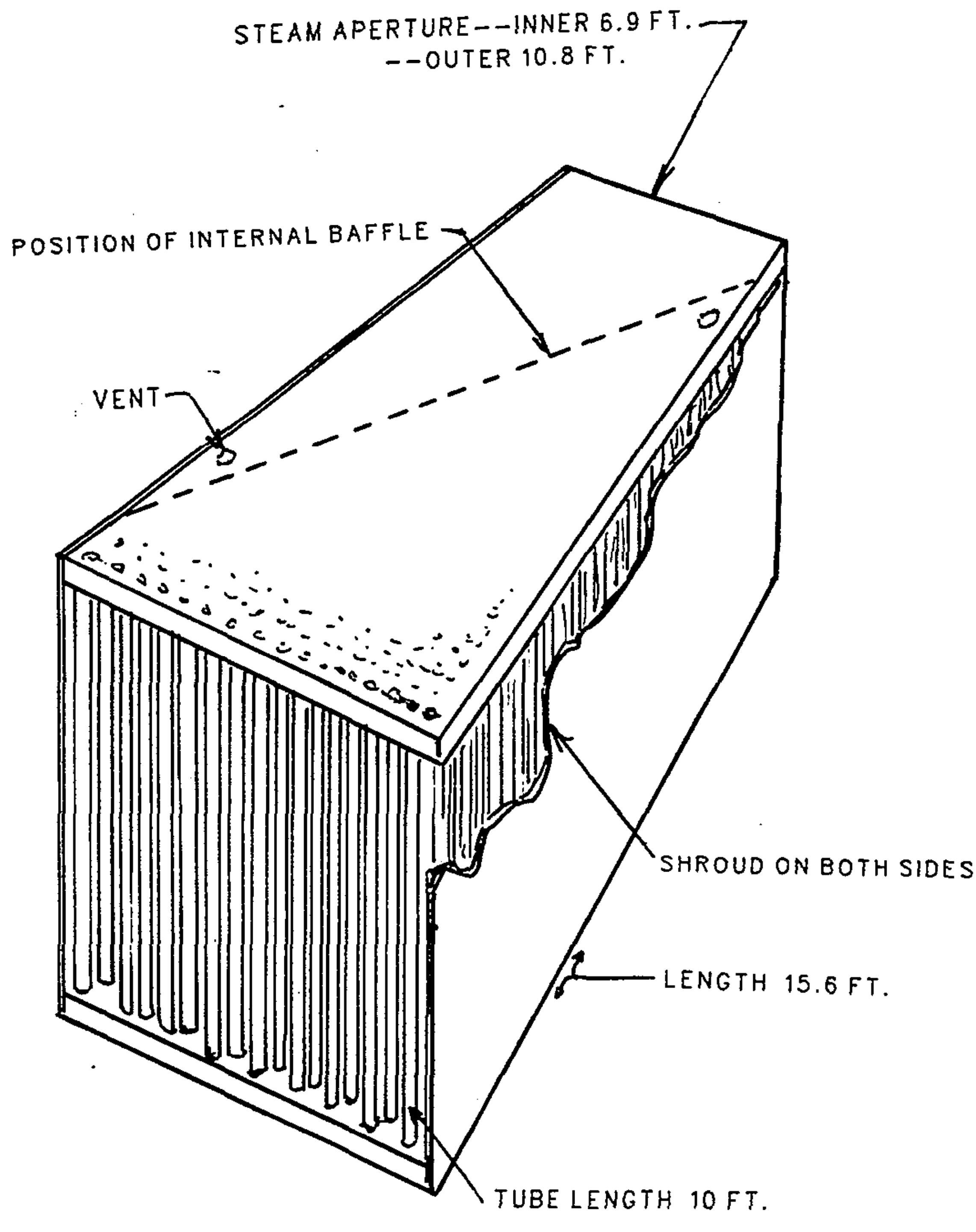

FIG. 4 DOUBLE ENDED BUNDLE

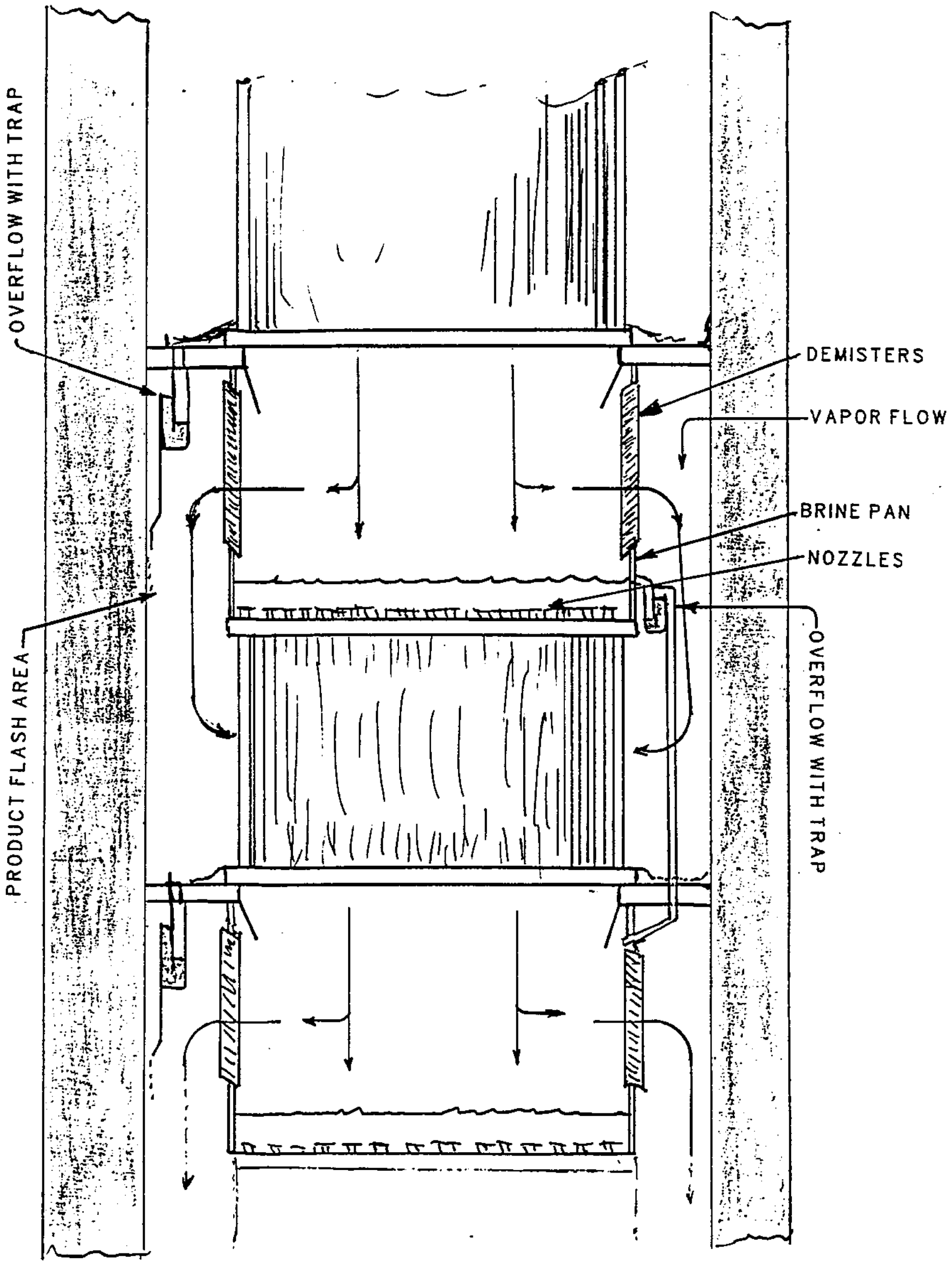

FIG. 5 EFFECT INSTALLATION

TECHNICAL REVIEW OF ADVANCED SEAWATER EVAPORATOR CONCEPT DESIGN

A technical review of the preliminary concept design was conducted by independent consultants engaged by Metropolitan. Each consultant is recognized as an eminent seawater desalination expert.

Seawater Desalination Consultants

Ferris Standiford: A former professor of chemical engineering. Presently, Mr. Standiford is a partner with, and successor to, the renowned W. L. Badger of Badger Associates, a chemical process firm and a worldwide designer of chemical process equipment. For over 40 years, Mr. Standiford's specialty has been vertical-tube evaporators, having designed and supervised the vertical-tube demonstration plant of the Office of Saline Water, Freeport, Texas. (He's acknowledged as preeminent in this field.)

Jack Laughlin: A design and process engineer, specializing in seawater evaporation. He joined the firm of Stearns-Rogers at the time they were building the first Virgin Islands vertical-tube evaporator, and later placed in charge of operating this and other seawater plants. Currently, Mr. Laughlin is active in managing and planning desalination projects, and has many years of experience in design and process engineering.

Gordon Leitner: A former official of the AquaChem Corporation at the time they were building evaporator test units for the Office of Saline Water. Mr. Leitner gained vast experience in seawater evaporators, having participated in that project. He later became president of AquaChem and continued in desalination as an independent consultant. His specialty has become "economic optimization of desalination projects."

Preliminary Concept Design Review

Each of the three reviewers stated that the process design is unique, in that it combines (for the first time) a number of features and advantages which had been proven separately. Each reviewer was convinced that the concept was practical and would function as designed.

Recommendations:

The following design parameters were identified by the reviewers for modifications or improvements:

Scale Control: Each reviewer agreed that the brine conditions would not produce plant-destructive scale. Brine chemistry conditions were identified to be on the margin of carbonate-scale formation. The test unit will indicate the presence of scale, and each expert recommended various methods of pretreatment to reduce this formation.

Heat Transfer: Two reviewers identified the thermodynamic advantage of venting the main-tube bundles into the feed heaters. Each reviewer had a different estimate of the heat-transfer coefficients to be expected in the test unit. The testing program will establish these factors prior to final design.

Biofouling: Marine growth can be expected in the seawater condensers. The use of reverse-flow (thermal shock), chlorine, or other biocide chemicals will prevent excessive marine growth.

Aluminum: All reviewers stated that aluminum could be used successfully when operated with certain precautions. Each reviewer stated that the feed heaters and condensers were the most vulnerable to scale formation and erosion. Experience from operating the test unit will indicate the appropriate design versions to be made in order to increase material reliability

Concrete: All believed that concrete was the correct choice for this size shell. One reviewer noted that silicate leached from concrete had formed a coating on aluminum in a system he had previously operated. The lack of recirculated fluids (once-through operation) and high-temperature-concentrated brine will prevent silicate leaching, and should be verified in the test program.

Brine Distribution: All reviewers recommended a perforated plate-type of brine distributor to the use of nozzles. One reviewer suggested a special kind of nozzle may provide better distribution and should be model-tested. Each reviewer confirmed that the brine distribution plate should be model-tested as part of the development work.

Technical Details: Each reviewer offered useful technical comments on construction, instrumentation, and operation.

Attachment C

8-6 Revised

MWD
METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

November 18, 1991

To: Board of Directors (Ad Hoc Committee on Energy & Desalination--Action)
(Engineering & Operations Committee--Action)
(Finance & Insurance Committee--Action)

From: General Manager

Subject: Revision No. 1 to Appropriation No. 604 to Increase Funding by $150,000 to a total of $650,000 to Finance Estimated Preliminary Engineering Study and Design Costs for the Seawater Desalination Program

Report

On November 18, 1991, the Joint Meeting of the Engineering and Operations Committee and the Ad Hoc Committee on Energy and Desalination recommended that Revision No. 1 to Appropriation No. 604 to increase funding by $1.5 million, to a total of $2 million, be revised to increase funding by $150,000, to a total of $650,000. The $150,000 increase will provide short-term funding for continuation of preliminary engineering studies and design work for a 5-million-gallon-per-day (MGD) desalination demonstration plant while your Board is reviewing possible deferrals to the Capital Projects Program.

Revised Recommendations

ENGINEERING AND OPERATIONS COMMITTEE FOR ACTION.

It is recommended that the General Manager be authorized to continue preliminary engineering studies and design work for a 5-MGD desalination demonstration plant. (Ad Hoc Committee on Energy and Desalination and Engineering and Operations Committee--Action.)

FINANCE AND INSURANCE COMMITTEE FOR ACTION.

It is recommended that the Board authorize an increase of $150,000 to a total of $650,000 from the 1991 Construction Fund to Appropriation No. 604 for estimated costs to continue preliminary engineering studies and design work for a 5-MGD desalination demonstration plant.

for Carl Boronkay

PCA/as
(604-ba2)

A PEER REVIEW OF

THE METROPOLITAN WATER DISTRICT'S

SEAWATER DESALINATION CONCEPTUAL DESIGN

March 26, 1992

CONSENSUS REPORT

PEER REVIEW COMMITTEE

Ferris Standiford, P.E.

Gordon F. Leitner, P.E.
Leitner & Associates, Inc.

O. J. Morin, P.E.
Black & Veatch

Ernest O. Kartinen, Jr., P.E.
Boyle Engineering Corporation

Thomas D. Wolfe, R.E.A.
HPD, Incorporated

INTRODUCTION

BY

David W. Dean, P.E.
Metropolitan Water District

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Table 1 — Cost of Water Estimates

Appendix A — Individual Comments

Appendix B — Metropolitan Water District's Seawater Desalination Conceptual Design

INTRODUCTION

Metropolitan has recently completed a planning study to design, build, and operate a seawater desalination demonstration plant. Previous studies show that currently available desalination technologies will require modifications in order to be applied to large-scale (50-100 million-gallon-per-day (MGD) capacity) projects in California. The planning study indicates that the development of an advanced multi-effect-distillation process will provide a substantial reduction in the capital cost of building a large-scale seawater desalination plant. As part of the planning study, a conceptual design was made based on previous research and testing conducted by federal agencies. The design is a multi-effect-distillation process consisting of 30 special alloy aluminum, vertical-tube bundles, stacked in a concrete vacuum vessel tower. The use of aluminum, concrete, and the stacking configuration will provide a large savings in material and construction costs compared with currently available membrane-type and distillation-type desalination processes. A detailed description of the conceptual design is shown in Appendix B.

Metropolitan has engaged five individual desalination experts to provide an independent peer review of the conceptual design. The review will provide Metropolitan with the criteria required to evaluate undertaking the development and design of a demonstration plant.

PURPOSE

To provide an independent peer review of Metropolitan's conceptual design and proposed demonstration of an advanced large-scale, multi-effect-distillation seawater desalination plant.

The review will be presented as a consensus report from the five desalination experts, supplemented with each expert's individual comments.

The technical review will include:

- Materials of construction;
- Fabrication, assembly, and construction;
- Potential improvements; and
- Design development recommendations.

BACKGROUND

In July of 1990, Metropolitan's Board approved the amount of $500,000 to finance the estimated costs for a planning study to define the work necessary to ultimately construct and operate a seawater desalination demonstration plant. The plant would demonstrate current and proven processes, and would incorporate features and methods applicable to future large-scale plants (50-100 MGD). It was also indicated that the important results of the project would be information gained on the true costs of desalting seawater.

The efforts undertaken as part of the planning study have included the development of a conceptual design of an advanced seawater distillation process, seawater quality studies, site investigations, and an implementation plan. Previous seawater desalination feasibility studies have been conducted using currently available membrane technology, distillation technology, and a combination of the two. These studies have shown the design, performance, capital costs, and operating costs for large-scale plants. A review of these studies shows that each type of technology will require several modifications in order to build large-scale projects in California.

The planning study focused on the advantages of building a large-scale desalination facility at an existing coastal power plant. Existing coastal power plants are industrial facilities located on the coastline and are equipped with seawater intakes and outfalls. Other advantages of locating a desalination plant at an existing coastal power plant include the availability of low-grade steam energy and the opportunity to combine desalination plant construction with plans by the power utilities to rehabilitate/ repower these power plants. A joint partnership between a power utility and Metropolitan to reconfigure an existing power plant in conjunction with building a large-scale desalination plant provides a variety of opportunities to design the plant to maximize energy efficiency and to reduce total construction costs. A successful demonstration project will provide Metropolitan and the power utilities with a proven design and actual cost information to support a large-scale seawater desalination system.

Several features are incorporated in the conceptual design that will provide a more energy-efficient process and a substantial reduction in capital costs. Freshwater is produced by distilling seawater in a series of evaporators or effects. The design features of this multi-effect-distillation process include the adoption of the vertical-tube-evaporator concept, the use of aluminum tubing, higher-temperature operation, stacking the effects in a vertical configuration, utilizing up to 30 effects instead of the usual 15 in use today (made possible by higher temperature), and the use of a concrete vacuum vessel (silo or tower). These benefits can be realized by developing each design feature and incorporating them in the demonstration plant.

Many of these features have been researched and tested by federal agencies as well as in other commercial applications. The first phase of the demonstration project is the development of these design features. This will require a detailed engineering design of a 5 MGD demonstration plant in conjunction with the operation of a 2000 gallon-per-day desalination test unit and a model testing program.

The second phase of the demonstration project includes the final design, construction, and two-year operation of a 5 MGD desalination plant. The demonstration plant is intended to produce five million gallons per day of distilled water and demonstrate: (1) advanced desalination technology, (2) power-plant integration, (3) product water quality, (4) product water distribution, (5) energy use, (6) environmental impacts and institutional issues; and, importantly, (7) true costs for seawater desalination. It is anticipated that these costs will serve as a benchmark against which other future water-source costs will be measured.

A successful development and demonstration of the desalination process described in the conceptual design will provide a large savings in actual capital costs and represents a major stride in seawater desalination technology. The peer review will evaluate the technical viability of the conceptual design, the design development process and verify the potential economic benefits.

David W. Dean
Desalination Project Engineer
Metropolitan Water District

(othr:consensus.dd)

39625

A PEER REVIEW OF

THE METROPOLITAN WATER DISTRICT'S

SEAWATER DESALINATION CONCEPTUAL DESIGN

March 26, 1992

A CONSENSUS REPORT

By______________________
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Ernest O. Kartinen, Jr., P.E.
Boyle Engineering Corporation

AND

____
Thomas D. Wolfe, R.E.A.
HPD, Incorporated

PEER REVIEW COMMITTEE REPORT OF THE METROPOLITAN WATER DISTRICT'S SEAWATER DESALINATION CONCERPTUAL DESIGN

PREFACE

The Peer Review Committee, individually and jointly, reviewed Metropolitan's conceptual design and finds that the concept as presented is basically sound. The process and economic detail developed appear reasonable given the level of detail design accomplished to date.

The Committee believes that while several process considerations need resolution through further design study and testing, some improvements to the proposed design can also be achieved. These items can be resolved during the proposed test program and demonstration plant design program scheduled later this year. The Committee also believes that the approach used for the conceptual design is technically feasible and will provide water costs significantly below conventional approaches.

The Committee recommends that Metropolitan proceed with the testing, engineering, and demonstration phases of the project on schedule.

1. SUMMARY AND CONCLUSIONS

Upon review of the conceptual design, the Committee concludes that:

a. The use of the multi-effect-distillation process for this facility offers the best state-of-the-art technology available for seawater desalination systems;

b. The conceptual design will consume less energy than other seawater distillation systems;

c. Utilizing the vertical tube arrangement, and the concept of stacking the effects will result in technical and economic advantages;

d. Some of the design, fabrication, and construction details must be demonstrated by further testing;

e. The materials of construction and the proposed fabrication and construction procedures will lead to a significant capital cost advantage over existing designs; and

f. The cost of water from this conceptual design will be lower than any present day seawater desalination process.

2. RECOMMENDATIONS

The Committee recommends the following actions:

a. Proceed with the testing and design phase of the demonstration project;

b. Continue work on design of the feed heaters;

c. Proceed with the investigations of the location and design of the entrainment separators. This design detail could reduce the overall tower height;

d. Proceed with the design investigation for the addition of a deaerator system;

e. Investigate the use of the tapered forward feed concept;

f. Examine in more detail the tube sheet thickness, the tube to tube sheet joint arrangement, and the evaporator tube bundle design;

g. Investigate the benefits of revising the conceptual design to allow for replacement of evaporator tube bundles while the plant is in operation;

h. Investigate concepts to reduce the concrete tower wall thickness and prevent corrosion of the concrete surfaces;

i. Determine optimum tube profile to employ in the design of the evaporator tube bundles;

j. Investigate pretreatment and posttreatment requirements; and

k. Investigate tube-cleaning procedures to be employed.

3. TECHNICAL DISCUSSIONS

3.1 Process Selection

The economics of the conceptual design are greatly dependent on the cost of motive steam to drive the evaporation process. Steam supply at the proposed facility at a reasonable cost is made possible by the ability to work with the power utility to optimize the power plant boiler and turbine combination to the needs of the seawater desalination plant.

The multiple effect falling film evaporator currently proposed is the proper selection for a plant to desalt seawater on a large-scale capacity at the given costs for energy for this particular site on the Southern California coastline. This process shows significant economic benefits through increased scale of plant capacity. The process permits building the plant as one or more towers of stacked effects (the number of effects depends primarily on energy costs and other site restrictions) that minimize land area requirements and site preparation costs. The use of doubly fluted tubes, inexpensive aluminum materials for heat transfer and building the vacuum vessel as a concrete tower, makes it economically attractive to design the plant for much higher efficiencies of energy utilization than conventional designs. Not only does the process selected permit maximum water production from the limited available energy supply at each power plant site (as low pressure turbine exhaust steam), but the process also helps insulate future water costs from increases in fuel costs. The use of concrete for the vacuum vessel also represents a substantial economic benefit for high capacity plants as proposed here and shows the promise for an exceptionally long plant life.

The seawater desalination conceptual design that serves as the basis of the present analysis utilizes no new elements with regard to the desalination process:

- The multiple effect falling film evaporator was selected for the first of the U.S. government's seawater desalting demonstration plants. It was built in Freeport, Texas, and operated throughout the remaining life of the government's program which ended in 1975.

- Fluted tubes, which reduce the heat transfer surface required, and thus costs, have been proven in service at Freeport, Texas, and in a number of other falling film seawater evaporators.

- Aluminum materials of construction, that are less expensive than conventional copper alloys, has been proven successful in a number of desalting plants, provided certain design and operational precautions are observed.

- The stacking of evaporator tube bundles in a vertical tower has been examined in the past, and found economically attractive at plant capacities of only one-tenth of that proposed in the conceptual design. The economic benefits increase markedly with the capacity of the plant.

The process selected permits for a large number of design options. The Committee believes that the conceptual design incorporates a reasonable selection from these options, but possibly not the very best options. It is for this reason that further design and test work should be undertaken. The Committee has examined and identified areas where improvements in cost, operability, and reliability can be achieved. Process details should be designed with regard to feed seawater pretreatment and product water posttreatment requirements.

3.2 Materials

3.2.1 Concrete Towers

The Committee agrees that the use of vertical reinforced concrete towers as the evaporator vessels offer significant advantages over other alternatives, that is:

a. Increased water production capacity per given land area; and

b. Reduced capital costs per plant capacity.

The estimated capital cost for the towers is quite high and represents over 30 percent of the total desired capital costs for plant and equipment. Some areas were suggested by the Committee for reducing this cost component; however, the capital cost as estimated in the conceptual design is acceptable at this stage of the project.

The Committee recommends that further study of the concrete tower design be pursued, including an investigation of the potential effects of distilled water and steam vapor on the concrete surface.

The necessity of increasing the number of concrete towers from two to three or four due to site considerations will increase costs and the increased cost factor should be included when evaluating special site considerations.

3.2.2 Aluminum for Heat Transfer Sections and Evaporator Internals

There is an increasing amount of commercial experience indicating that aluminum is an acceptable material for seawater distilling plants at temperatures up to 170°F. There is test experience which most favorably suggests that aluminum will be suitable in evaporator tubes and for evaporator internals.

The Committee is concerned about the use of aluminum in the feed heater tubes, especially with aerated seawater. The performance of aluminum feed heater tubes at higher temperatures requires demonstration.

The Committee recommends a deaerator for the seawater feed. The addition of a deaerator will help to improve the life of the aluminum feed heater tubes. Further investigation is recommended to be conducted within the scope of the proposed test program.

3.2.3 Pump Materials

Stainless steel for pump impellers and shafts and Ni-resist material for the pump casings would be suitable; however, there has been some poor experience with Ni-resist material castings made in the U.S.. Further study of acceptable pump material compatible with aluminum is warranted.

3.3 Fabrication and Construction

The proposed project is unique in that a desalting plant of the design proposed has not yet been constructed. Each of the components, in and of themselves, is not new from the standpoint of never having been done before. The major task with respect to fabrication and construction is to design each of the components so that the plant is both easily constructable and maintainable. These goals can only be achieved by careful engineering, construction, and operation.

Topics specifically discussed by the Committee included the design of the feed heater tubing, evaporator tube bundle and the concrete vacuum vessel towers.

3.3.1 Feed Heaters

Primary design improvements to the feed heaters include the possibility of using a "tapered feed" concept, tube plate spacing, and the seals between adjacent effects to maintain the pressure differences.

3.3.2 Evaporator Tube Bundles

A major consideration is whether or not to design the bundles to allow for in-place replacement of individual tubes. The Committee's consensus is that in-place replacement is not necessary. Provisions should be made so that individual tubes that do fail are accessible for plugging (removal from service).

Achieving uniform flow distribution through the many tubes in an evaporator tube bundle was discussed by the Committee. With the exception of the "lateral feed" flow to the top effect, an uneven flow distribution through the tubes can be avoided by feeding downward through perforated plates of the same dimensions as the tube sheets. In any event, even flow distribution was seen as easily solved but will require careful attention to design details.

The tube sheets are proposed to be two inches thick. The need for such thick tube sheets was discussed and it was concluded that thinner tube sheets should be considered.

Fastening of the tubes to the tube sheets requires further study. The consensus is that welding of the tubes to the tube sheets would probably be the best fastening method. This will also allow for the use of thinner (less than two inches) tube sheets.

Since it is planned to fabricate the evaporator tube bundles offsite, transport them to the site, and "load" and "unload" the bundles from the top of the concrete tower, it is extremely important that the bundles be designed to accommodate the handling procedures to be employed during construction. The evaporator tube bundles must retain structural integrity without distorting. The bundles must also be designed so that they can be easily positioned in the tower and sealed.

3.3.3 Construction

Construction of the tower by slip-forming is probably the least expensive means of construction. Slip-forming is the most effective method for constant dimension structures; that is, unchanging diameters and wall thickness.

It is essential to design the concrete towers to allow for ready installation and removal of feed heater tubes and evaporator tube bundles. The design of the concrete towers and evaporator tube bundles and feed heater tube assemblies needs to be carefully coordinated.

It is planned that each effect will be divided into segments. Consideration during design should be given to constructing the plant so that a problem in one segment of an effect will not require shutdown of the entire plant in order to solve the problem.

3.4 Potential Improvements

Potential improvements to the basic design concept were discussed by the Committee. It was agreed that the program should investigate tapered forward feed as an alternative to introducting all the preheated feed to the first effect. This is considered by the Committee to be a potentially significant improvement to the process.

The use of aluminum-clad thermal insulation on the inside faces of the effect chambers could result in the reduction of the concrete tower wall thickness included in the conceptual design for its insulating effect. There is reasonable assurance that the wall thickness required for structural integrity is less than currently proposed with concomitant cost reductions.

Design of the structure for enabling the repair or maintenance of a single vertical section is a desirable improvement. If this capability could be achieved, it would allow maintenance to take place on a single vertical section, while the balance of the plant remains in operation.

The Committee recommends that several entrainment separator designs, modifications to vapor shrouds, and locations for the entrainment separators be reviewed as potential improvements to the conceptual design.

3.5 Design and Development Recommendations

The potential exists for making significant improvements to Metropolitan's conceptual design; however, some technical details will require confirmation and resolution before final design of the demonstration plant can be completed. A twin effort involving test work and additional engineering design can accomplish both tasks.

3.5.1 Testing Activities

A 9-12 month test program involving small test units is proposed. Testing should seek to establish firm design values for the following parameters:

- Heat transfer coefficients over the operating temperature range.
- Brine flow rates for optimum performance over the operating range.
- Distribution plate design.
- Characteristics of vapor flashing through the distribution plate on liquid distribution to the next effect.
- Optimum tube flute geometry for maximum heat transfer.
- Measures needed to avoid corrosion and scaling in the feed heaters at the upper brine temperatures.
- Scale inhibitor dosing requirements and effectiveness.
- Measures needed to avoid corrosion and scaling in the evaporator tube bundles.

- Tube-cleaning procedures for scale removal.

- Effects of hot condensate/distilled water and steam on the proposed concrete materials.

- Effectiveness of deaeration for corrosion control.

Many design issues are economic trade offs between operating and capital costs; however, more engineering is required to evaluate these tradeoffs. Additional preliminary design is required to quantify and/or improve on the following items:

- Feed heater design details:

  - Number of passes required
  - Leakage control
  - Tapering per effect
  - Vapor side baffling
  - Tube/tubesheet sealing method
  - Materials of construction

- Evaporator tube bundle design details:

  - Vapor side pressure drops
  - Tube to tubesheet joints
  - Optimize vapor space area (minimizes containment structure volume)
  - One-piece installation and replacement

- Technical and economic impact of modifying the concrete vacuum vessel towers and piping systems to allow for sectional retubing without complete system shutdown.

- Design of the brine distribution plate:

    - Type, offset plate
    - Provisions for removal or tilt-up to allow tube access

- Revise heat and material balance to optimize the use of low temperature seawater available.

- Tradeoff/optimize seawater conversion ratio against production and pumping costs.

4. ECONOMICS

4.1 Construction Costs

The construction cost estimated in Metropolitan's conceptual design indicates that the total initial cost of the unit will be approximately $160,000,000. On a unit-cost basis, this is $2.03 gallons per day (GPD) unit capacity. This compares very favorably with present day unit cost for conventional multi-effect-distillation units at $6 to $7 GPD. The breakdown of capital costs is estimated in Table 1, along with an independent analysis of these costs. Review of this information shows that when the direct costs are compared, the correlation is quite close.

The major capital cost items are the construction of the concrete towers and the cost to fabricate the evaporator tube bundles. These items are shown as a percentage of the total direct costs:

Item	Percent of Total
Concrete Towers	34
Evaporator Tube Bundles and Feed Heaters	35

These two items make up over 60 percent of the total cost. A plant of this particular design has never before been constructed, and it will be important to verify the cost assumptions made for the design and fabrication of these items.

The capital costs for these items emphasizes the importance of carrying out a thorough testing and demonstration program.

4.2 Water Cost

The water costs are also shown in Table 1. A review of this information shows the cost advantage offered by Metropolitan's conceptual design. The total cost of water is approximately $500-$525 per acre-foot (AF). at the plant boundary. Posttreatment costs are not included. This estimate compares with present day water cost estimates ranging from $1,000 to $1,500 AF.

The main cost factors are the capital costs, energy costs steam, and electric energy costs which make up approximately 34, 29 and 19 percent, respectively, of the total water costs. The largest water cost component for Metropolitan's conceptual design and any desalination system is the cost for the initial capital investment. Currently available desalination processes have a capital cost component of about 50 to 60 percent of the total. Thus, Metropolitan's conceptual design shows a potential for significant improvement in seawater desalination total water costs.

TABLE 1

COST OF WATER ESTIMATES

(Dollars in Thousands)

	Independent Review	Metropolitan's Conceptual Design
Capacity, MGD	80	78
Construction Period, Months	36	36
Load Factor, %	0.85	0.85
DIRECT CAPITAL COSTS		
Installed Equipment Cost	$ 92,477	$ 89,032
Civil Works	17,950	14,675
TOTAL DIRECT CAPITAL COST	**$ 110,427**	**$ 103,707**
INDIRECT CAPITAL COSTS		
Interest During Construction	$ 26,503	$ 9,069
Work Capital (5% Dc) Parts	5,521	223
Markup		19,764
Contingency + A&E	27,607	25,302
TOTAL INDIRECT COSTS	**$ 59,631**	**$ 54,358**
TOTAL CAPITAL COST	$ 170,058	$158,065
CAPITAL COST, $GPD	2.14	2.03
OPERATING COST (ANNUAL)		
Load Factor	0.85	0.85
Fixed Charge Interest Rate	0.07	0.07
Operating & Maintenance	2,625	1,993
Repair Parts, 1.5% Equipment	1,387	569
Chemicals	2,180	4270.5
Electric Power @ $0.07/kwh	8,524	7,972
Low Pressure Steam @ $1.65/1000		
Low Pressure Steam @ $1.45/1000	12,697	9,110
High Pressure Steam @ $3.00/MBTU	1,499	incl
Replace 1/2 aluminum every 5 years	1,826	569
Fixed charge, 30 years	13,577	12,619
TOTAL ANNUAL COSTS	**$ 44,315**	**$ 37,103**
WATER COST AT PLANT		
$/1000 Gallon	$1.80	$1.56
$/Acre-Foot	$585	$509

(table:desal.dwd)

APPENDIX A

INDIVIDUAL COMMENTS

(To be submitted by mail at a later date)

APPENDIX B

METROPOLITAN WATER DISTRICT
SEAWATER DESALINATION
CONCEPTUAL DESIGN

INTRODUCTION FOR REVIEWERS

This summary report describes the present version of MWD's 80 Mgd conceptual design and indicates the constraints that have guided it. The details of the internal arrangement of the silo, tube-bundle support, and piping layout are incomplete, and we have not yet chosen a method of joining fluted tubes to tubesheets.

We would like your comments on overall feasibility and on any specific details, bearing in mind that most aspects of the system will be tested and demonstrated in our test units and in the pilot plant operation. The pilot plant will be a complete 5-6 MGD 30 effect plant, using a full size tubing bundle in each of its effects. In the large plant there will be 12 bundles per effect.

In our view the principal uncertainties in the process are the brine chemistry and the use of aluminum at high temperature. We plan now to use aerated sea water in the final condenser and in the feed heaters, with standard anti-scale additives. We may also use a foaming additive.

Aluminum has been very successful at low temperature, and worked well up to 240 F in the Wrightsville Beach pilot plant once the causes of failure were understood and removed. The incentives for trying to make aluminum work at this higher temperature are great, but copper alloys remain as a backup. Aluminum would be cost-effective even if it had to be completely replaced every five years.

Low temperature differences are well proven in the commercial low-temperature MED process. Some units operate with 15 effects in the temperature span between 160 F and 100 F, or an average of 3.75 degrees per effect, including boiling point elevation. The addition of 15 more effects at the high temperature end from 160 F to 230 F should be easier, since heat transfer and vapor density are both higher there.

The vertical arrangement of effects is unusual, but greatly simplifies the interstage flow and reduces the number of pumps. The use of concrete on this scale is certainly novel, but very cost effective. We propose to use a special mix with fly ash, silica fume and other additives, having the minimum possible level of uncombined elements and water. Subject to our tests, it will be used uncoated in contact with water vapor or brine. We will minimize contact between concrete and product water within the plant by using aluminum pressure floors between effects and aluminum shrouds on the bundles. The entire internal support system for the effect bundles is to be made of aluminum structural shapes.

Operating 30 effects in series could conceivably result in dynamic imbalance or surging. Although unlikely, this possibility will be studied by computer modeling and checked in the pilot plant.

A SEA-WATER EVAPORATOR DESIGN FOR SOUTHERN CALIFORNIA

The Metropolitan Water District is investigating many possible sources to meet projected needs for large-scale additions to water supply in Southern California. Some of these alternates will be useful and cost-effective, but generally each new increment of supply is more costly than the last. The Pacific Ocean looms as the ultimate, inexhaustible source. Cost and reliability are the factors that will determine when desalting the sea will become the economic choice.

The commercially available desalination technology has evolved in parts of the world where small units sited close to special purpose needs are the norm. Such currently available plants are not only very costly, they are ill-suited to the needs of Southern California. This region needs water in very large increments for general use over a large area and at much lower cost. Although the plants as they now exist are unsuitable, our investigation shows that proven elements of this technology can be selected, combined and modified to fit MWD's special needs. Preliminary indications are that the modified process will also meet the target of substantially lower cost.

The process modifications involved are derived from several sources, especially the extensive evaporator development program at the Oak Ridge National Laboratory in the 1962-74 period. This work, sponsored by the Office of Saline Water and the Atomic Energy Commission, included both laboratory and large-scale field tests. Research at Berkeley and UCLA in the University of California also contributed. We have adapted these results to the special conditions of Southern California, making use of newly available materials, and employing operating experience and field results acquired in recent years. The result is a specific process, conceptual design, and plant arrangement to meet the expected needs of the Metropolitan Water District. This conceptual design is described below.

FACTORS AND LIMITS GOVERNING DESIGN

A plant design must meet several important criteria to fit the needs of the Southern California region. These include large unit size, high energy efficiency, space efficiency, reliability, environmental impact, and cost. These criteria all interact extensively.

1. <u>Size.</u> The Metropolitan Water District now delivers as much as three billion gallons a day of imported water to its municipal members. Over the next 20 years the increase in demand is expected to exceed the available new sources by more than a billion gallons a day. Desalination is not likely to supply all this need, but clearly large units are indicated, up to 100 million gallons per day, whenever their costs reach a reasonable range. Large units also will be more efficient in space and

energy use, and will achieve a lower cost through the economies of scale. Size has another important aspect because, in Southern California, putting the fresh water on the beach is not enough. The water must be piped inland, blended with other water supplies, and added to the existing gravity delivery system to reach the millions of individual users. To hold down this distribution cost, the economics of pipeline construction dictate that we produce as much water as possible at any one site.

2. Energy Cost and Efficiency. Energy costs in the region are high, and are expected to go much higher. It is important that a desalination plant built today remain competitive in the future when fuel costs rise. Accordingly, the process chosen must use the lowest cost source of energy obtainable. For a distillation process this means using secondhand steam that has first been used to generate electricity. Thus we are constrained to locate any proposed water plant at a coastal power station. Southern California has about fourteen such stations, and the coastline is in such demand that it is unlikely that any new ones will be built.

Some of these stations are planning to repower with modern gas-turbine combined cycle units. The reduced energy costs from associating a desalination plant with such a project can be a compelling factor in the selection of a process and a plant site. Of the possible coupling methods, use of exhaust steam from a back-pressure turbine provides the least costly source of energy. Other arrangements such as using bleed steam, vapor recompression, etc., cannot compete. The prospect of participation in a repowering project is truly a unique opportunity. It is such a situation that governs the present design.

The design optimum in a desalting plant occurs when the capital cost of an incremental gain in energy efficiency is equal to the capitalized cost of the energy saved. Such optima are usually quite flat, so that in a water-short region it is preferable to build efficiency on the high side of the optimum, to gain the maximum output from the project. This strategy also protects against fuel cost increases.

For a process based on thermal instead of electric energy, the optimum efficiency is affected primarily by the cost of heat transfer surface. The process described herein uses low-cost aluminum heating surface, a technology brought to technical success and commercial use during the past ten years. Studies show that with aluminum tubing the highest attainable thermal efficiencies are still cost effective, even for the secondhand steam from a turbine. The design efficiency is therefore set not by cost but by the limit of technical performance.

3. Space Efficiency. The coastal power stations in California were originally built in sparsely settled regions, but now they are all crowded by dense urban surrounds. At most sites there is very little land available for water plant construction. An important criterion, therefore, is to arrange the chosen process to fit on the least possible land area.

4. Reliability. Reliability of the water plant is a key issue, since nominally low cost water can rapidly become less so when a plant must be shut down for extended periods. Even though the basic process has been proven reliable, any new plant or plant arrangement will have to be tested. This will be accomplished by operating several small test evaporators to measure key performance and materials issues, followed by the construction and operation of a large demonstration or pilot plant representing a full-scale sector of the large plant. These tests will verify all major design features and permit a rigorous proof of operability before the large unit is undertaken. In addition, MWD will insure that the plant is built and operated as designed by using advanced quality-control measures during construction and by thoroughly training the operators.

5. Environmental Effect. The environmental and ecological impact of the water plant will be closely watched in California. The noise level and external appearance of the plant will be of considerable concern. The plant's emissions will also be reviewed, but in most locations these are usually viewed as benign.

6. Cost. The cost of water resulting from the plant is the basic figure of merit for the design, provided the other criteria are also met. The lower the cost, the sooner desalination can become a part of the region's water supply. Using standard engineering estimating practice, we have developed preliminary indications of the cost of constructing and operating a plant of this design. As we expected, a major cost improvement was obtained by scaling up an established process by ten-fold, rearranging it to simplify and streamline the flow of fluid, and using a more compact heat-exchanger surface. Compared to existing designs, the quantities of concrete, metal, and other materials required per unit of output are much reduced.

The cost indications now available are not conclusive, but they provide a powerful incentive to continue with the design approach chosen, so that a valid cost and performance perspective can be developed and verified at the pilot plant stage. It should be noted that similar economies of scale and plant rearrangement have also been explored for reverse osmosis processes, the other leading sea-water desalination technology. In this case, however, the inherent modular nature of RO was found to limit severely the economic advantage of scale-up.

PROJECT TIMING

In MWD's service area, one utility plans to begin operation of a new large combined cycle plant in early 1999. The site for this unit is very favorable for desalination for several reasons: it is a favorable location in MWD's system, a right of way for product water transport already exists, and sea intake and outfall capacity are more than adequate for the plant. The date for commitment to join a water unit to this program is early 1996. We believe that such a commitment using an advanced process requires that the pilot or demonstration plant shall have operated for over a year by that point, meaning completion by mid 1994. Thus the pilot plant design must be essentially complete by the end of 1992, and the full scale design must be far enough along to reflect its features in the pilot unit.

POWER COMPANY SUPPLY PARAMETERS

1. Turbine Exhaust Steam Supply: 1.17 million pounds per hour at 24 psia saturated. Cost about $ 1.45 per 1000 pounds.

2. High Pressure Steam Supply: As needed for ejectors from plant auxiliary supply. Cost about $ 3.00 per 1000 pounds.

3. Sea Water Intake Supply: As needed up to 150 million pounds per hour from existing intake system. Temperature varies over the year from 56 to 67 F, averaging 61 F. (Not chlorinated)

4. Electric Power Supply: 440 v power at 7 cents/kWhr

5. Land available: About 5 acres of plant site land close to steam turbine, plus parking and administrative space. (It is assumed that the control room will be closely associated with the power station control room.) About 10 acres are available nearby for distilled water storage and treatment tanks.

6. Waste brine discharge: Existing condenser outflow channel available, to be blended with condenser flow from existing conventional power plant. Final mixture must meet discharge regulations for temperature, quantity and content.

7. Location and soil condition: The location is about 300 yards from the open ocean beach, near a major highway. The soil is firm beach sand to a depth of at least 300 feet. The water table stands about 10-15 feet below grade.

PROCESS SELECTION

1. Brief Description. The process chosen is a once-through, forward feed vertical tube evaporator using 2" fluted aluminum alloy tubes in 30 effects. Vertical tube feed-heater bundles serve as vent condensers to the main bundles, with the combination designed for streamlined, tapered path flow at nearly constant velocity. The condensed product from each effect is flashed to equilibrium with each following effect in turn. The top brine temperature is 230 F, and the last effect boiling temperature is just under 100 F. The expected performance ratio of the plant is 24, with a production of about 80 mgd of distilled water. Total sea water intake is about 120 mgd, and brine blowdown is about 40 mgd, with a concentration of 3x seawater. This flow sheet is illustrated schematically in Fig. 1.

2. Vertical Layout. The process is arranged in two vertical stacks, each with 15 effects one above the other. The plant is housed in a vertical concrete cylinder about 110 feet in diameter and 230 feet above grade, extending another 80 feet below grade. The cylindrical ~~silo~~ has a concentric internal silo about 60 feet in diameter, with 12 or more radial walls connecting the two cylindrical walls. (See Fig. 2 & Fig. 3) The annular space between these cylinders is the evaporator region, designed for an internal working pressure range of 10 psi gage to full vacuum. Each vertical stack of 15 effects occupies half of the annular space, with heavy walls and piping ducts separating the two halves.

Each effect is made up of twelve pie-shaped sectors at one level. A pressure-tight floor of concrete or aluminum metal supports the tube bundles and separates the fluids of each effect from those above and below. The maximum pressure difference between adjacent effects is 1.5 psi vapor pressure plus 1 psi water load. There is no lateral pressure difference around the half-annulus. The pressure floors are spaced about 20 feet apart--twice the height of the tube bundles, to allow room for retubing. (A more compact version is also proposed--see below.) The central cylinder is open to the atmosphere, and is used for some of the pumps and piping, service access, elevators, storage, etc. The remainder of the pumps are located outside the silo, in vertical caissons or wells extending from grade down to the common basemat level of the structure. An alternative, more convenient but also more expensive, is to use two silos--one for each 15 effect stack.

3. Tube Bundle. The design approach for the effect tubes is to establish a bundle size that can be conveniently assembled by semi-automated means in a factory "clean-room" environment. The bundles will be tested and shipped to the plant site for installation by a crane operating from the top of the silo. The original plan was to leave sufficient vertical space between effects so that individual tubes could be removed and replaced. We are considering a more compact arrangement that leaves room only for access to inspect and plug tubes. We would design for rapid "unstacking" of any vertical array with the crane for replacement of entire bundles when needed. The silos could be about 50 feet shorter with this scheme.

In the original plan the individual effect tube bundles, representing one twelfth of the effect surface, have 2" thick aluminum alloy tube sheets and about 3200 fluted tubes 2" in diameter and 10 feet long. The bundle is wedge-shaped, with the length 15.6 feet, the narrow end 7 feet wide and the wide end 11 feet wide. Thus overall shipping dimensions are 10'x 11'x 16'. Though all bundles at each level operate in parallel, each is individually shrouded, baffled and vented, so that the steam path though the bundle is fully controlled.

As shown in Fig. 4 and Fig. 5, the bundle is divided by an internal baffle, and fed with steam from both ends. This arrangement insures sufficient area for demister installation in the lower effects. We propose to fabricate, assemble and test the bundles in a dedicated shop facility, and ship them to the plant site. The pilot plant will use a single bundle of the full-scale design for each of its effects. The actual shape of the bundles, and their layout within each effect, is still subject to change, but the overall process parameters, vent rates, vapor velocities, etc., are well established and well within conservative design rules.

4. Feed Heater Bundles. The feed heaters will consist of 3/4" or 5/8" aluminum tubes, smooth on the inside and possibly fluted on the outside. These will be mounted in shrouded vertical bundles hung in the steam-flow vapor space and ducted to the discharge end of the effect bundles. To reduce the brine side pressure drop and the number of brine seals, it is proposed to make these assemblies up to 100 feet high, passing through several effects with an elastomer seal and/or metal baffle at each pressure floor. Only distilled water and vapor will be present at these points. An alternative arrangement would have a water box at each effect level. The shrouding is to be arranged so that a leak of high-pressure brine from a feed-heater tube can be readily isolated within a small bundle, without contaminating the product flow from the rest of the plant. This will give considerable flexibility in scheduling shut-downs to plug tubes.

5. Brine Distribution The non-deaerated feed water is screened, passed through the final condenser and then pumped to the top of the plant to flow in series through all 30 effects. At the top effect a distribution header meters equal flows to each of the twelve tube bundles. A closed pan attached to the upper tube sheet receives the feed and distributes it to the individual tubes, either by means of a perforated plate or through a nozzle inserted in each tube. One option is to maintain a free surface in this upper pan, with a pressure-controlled vent line and vent condenser. Since the pressure at this point will be above atmospheric, much of the non-condensable gas in the feed can be removed conveniently at this point.

6. Brine Flow Within Effect. At the entrance to each tube the hot brine experiences a pressure drop, because it enters a zone whose pressure is controlled by the condensing temperature of the next effect below. The brine flashes and foams as it passes down the tube, and about 2-3 percent of its mass is evaporated by the heat passing through the fluted tube. At the top effect the vapor produced has a volume 30 times that of the remaining brine; at the lower effects this ratio becomes 1000:1. The result is that the foaming, boiling brine is accelerated rapidly down the tube by the expanding vapor, producing in effect a wiped film evaporator action. The mixture falls into a separation pan whose bottom is formed by the upper tube sheet of the next effect below. The brine collects in the pan and passes through nozzles into the tubes below. A major efficiency of the vertical stacking arrangement is that the brine collecting pan is also the distributing pan. Piping, transport and redistribution to the next effect are eliminated. The orifices in the nozzles or distribution plate are sized to permit the pan to drain dry on pump shutdown and to establish a working liquid level of 12-18 inches at full flow. Overflow is prevented by a U-trapped bypass to the next effect.

7. Vapor Flow Within Effect. The vapor separates by gravity from the brine, and leaves the pan through windows at the outer and inner ends that are screened with de-entrainment separators. Here it enters a region between the end of the tube bundle and the outer or ~~inner~~ wall of the silo. This chamber, bounded on top and bottom by the pressure floors, forms the duct that leads the vapor to the steam inlet of the effect below. The feed heater bundles are hung in this space and take up about 1/10 of the space. Flashdown of product also occurs here. Lateral ports in the separating radial walls insure that the same pressure prevails at all bundles of a given level.

The vapor from the effect above mixes with vapor flashed from the product and enters the bundle guided by baffles and steam lanes that preserve a relatively constant velocity as the volume shrinks. This carefully designed path leads to a vent point within the feed heater bundle, where the non-condensable gases and the remaining vapor are vented to an external line. For the effects operating above atmospheric pressure, this line leads to a condenser and from there to atmosphere. For vacuum effects the vent gases are cascaded to a pre-condenser, steam ejector and after-condenser.

8. Product Flow Within the Effect. The first effect produces no product, the steam condensate being all returned to the power station. For other effects, the vapor condensed on the fluted tubes is funneled rapidly down the flutes to the lower tube sheet, where it flows across the sheet to a receiving box along one side of the bundle. The receiving box contains an elongated U-trap to pass distilled water into the effect below while still maintaining a pressure seal between effects. The condensate from the feed-heater tubes also flows to the effect below. As the product drips or flows to the floor, it flashes to equilibrium with the pressure there, releasing vapor that enters the tube bundle to increase the boiling rate in the tubes.

The volume of product accumulates from effect to effect, and in the lower effects amounts to more than the volume of the brine in the tubes. In these stages the product flash-down region of the vapor space is increased in size.

9. The Concrete Silo Structure. The use of concrete for evaporator shells has been studied for a long time, culminating with a pilot-plant project that was operated in Japan for several years with favorable results. In this work, concrete was shown to be quite resistant to salt brine, provided the reinforcing bar had sufficient cover. Distilled water has an erosive effect on some types of concrete, caused by leaching of the cement binder. It is believed that both salt penetration and distillate leaching can be essentially eliminated by using a mix containing almost no uncombined water and several modern additives, including very fine silica "fume". MWD is doing intensive study and testing of such mixes.

Air inleakage can be essentially eliminated by minimizing construction joints and properly designing those that are necessary. Penetrations and access ports require special attention against leakage. The economic advantage of concrete over steel for evaporator shells increases with the size of the unit. Continuous-pour slip-forming is advantageous and cost-effective if the structure has vertical sides and is over 100 feet high. It is ideally suited for placing the structure planned here.

Much of the connective piping required by the process can be formed in place within the concrete structure. The low-pressure steam lines conducting exhaust steam to the top of the first effect, and process vapor to the top of the 15th effect, can be simple vertical channels in the concrete, possibly with an internal lining or insulation. Brine and product wells can be formed in the concrete basemat to receive and manifold the multiple large pumps required.

10. Use of Aluminum Heat-transfer Surface. Aluminum tubing has been studied for use in sea-water evaporators for many years, because of its obvious cost advantages. These tests included extensive loop testing at the Oak Ridge National Laboratory and the aluminum-tubed pilot plant of the Office of Saline Water, built at the Wrightsville Beach test site and operated by the Reynolds Metals Company. This work showed that aluminum in sea water was very vulnerable to contact with heavy metal impurities, especially copper and iron. Special traps were built to remove these materials. Once the tubing was protected from such exposure, especially from rust specks derived from the steel shell of the pilot plant, corrosion performance was satisfactory up to 240 F.

An Israeli company has been very successful in the last ten years with major commercial development of aluminum-tubed evaporators using the horizontal spray-film multiple effect process . Over twenty such plants have been built, mostly quite small. These plants achieved mechanical simplicity by using backward mixed feed, which in turn limited the scale-free operating temperature to about 170 F. The aluminum tubing was protected from heavy metals by passing incoming sea water through a scrap-aluminum filter bed. The low operating temperature also served to help protect the aluminum.

The Reynolds Metals Company has performed a comprehensive assessment of all previous work on aluminum in hot sea water, including their own extensive laboratory tests. Their assessment includes detailed investigation of the types of failure observed, identifies the metallurgical causes, and relates these to the alloy composition and to the experimental environment. The report concludes that if certain precautions in assembly and operation are rigorously observed, aluminum will perform very satisfactorily in a sea water evaporator up to 240 F.

From the metallurgical data, the company has developed a new alloy with a slightly different manganese content from the standard #5052 now used. They believe this minor change will offer a worth-while improvement in corrosion resistance. They are prepared to produce extruded 2" fluted tubes at a cost they estimated to be somewhere in the range of 50 cents a linear foot, which is about $1 per square foot. (We are using $1.50 per square foot in current estimates.)

11. Brine Chemistry and Scale Control. The use of forward feed at a top brine temperature of 230 F will permit sulfate scale to be completely avoided. As the brine becomes more concentrated it is also cooled, staying just outside the anhydrite solubility curve. Indications are that carbonate scale can be controlled by the widely used polymeric additives. If extensive testing does not confirm this prediction, some sulfuric acid addition will be used. Deaeration of the feed before heating is not required, since aluminum does not require a reducing environment.

The existing sea water intake is not chlorinated, and we do not propose to chlorinate the feed to protect the condenser, because of the potential for creating volatile halomethanes. Biofouling control by the well-proven thermal shock method would be satisfactory, but we have not yet studied its applicability to our system. Ozone or hydrogen peroxide dosing might be used if biofouling becomes a problem in the test and pilot units. The condenser and feed system will be designed for complete drainage upon shutdown, since stagnant brine often causes problems.

A biodegradable detergent may also be added to the feed to promote foaming flow while boiling and thus increase heat transfer rates. If this is done, most of the additive will be recovered from the waste brine by a froth flotation separator. The incoming sea water will be filtered through a heavy ion trap filled with scrap aluminum. Steam from the power station will pass through a similar trap.

12. Heat Transfer. We have collected extensive test data from single and multiple fluted tube measurements made in several laboratories to define a curve of overall heat transfer coefficients for preliminary design. This curve includes allowances for bundle size, aging loss, and 10% tube losses, and allows no credit for foaming flow. It will be corrected if necessary before final design, from the ongoing test results. The effect values range from about 2000 in British units for the top effect, to about 800 for the bottom, using the "rubber band" circumference for the reference area. The feed heater values range from 550 to 750.

13. Instrumentation and Control. A detailed instrumentation and control plan is not yet available, pending completion of a dynamic flow stability analysis. However, the objective will be to provide automatic sequencing of controls for normal start up and shutdown, and a multitude of sensors capable of detecting any leaks, salt contamination, or changes in temperature, pressure or liquid level. Bypass valves will be provided to isolate the product stream from any one brine heater unit. Since the associated power plant will normally be run base loaded, there is no provision for part-load operation, except the trimming needed as the sea water temperature changes over the season.

14. Product Post-Treatment. Some type of distilled water post-treatment facilities or blending facilities will be needed at the plant site, but they cannot be specified until later, pending exploration of several methods of blending. It is possible that an RO unit will be operated in parallel with the evaporator to produce blending water.

R. Philip Hammond, Team Leader
David M. Eissenberg
Dieter K. Emmerman
John E. Jones, Jr.
Hugo H. Sephton

August 23, 1991
Revised Jan. 30, 1992

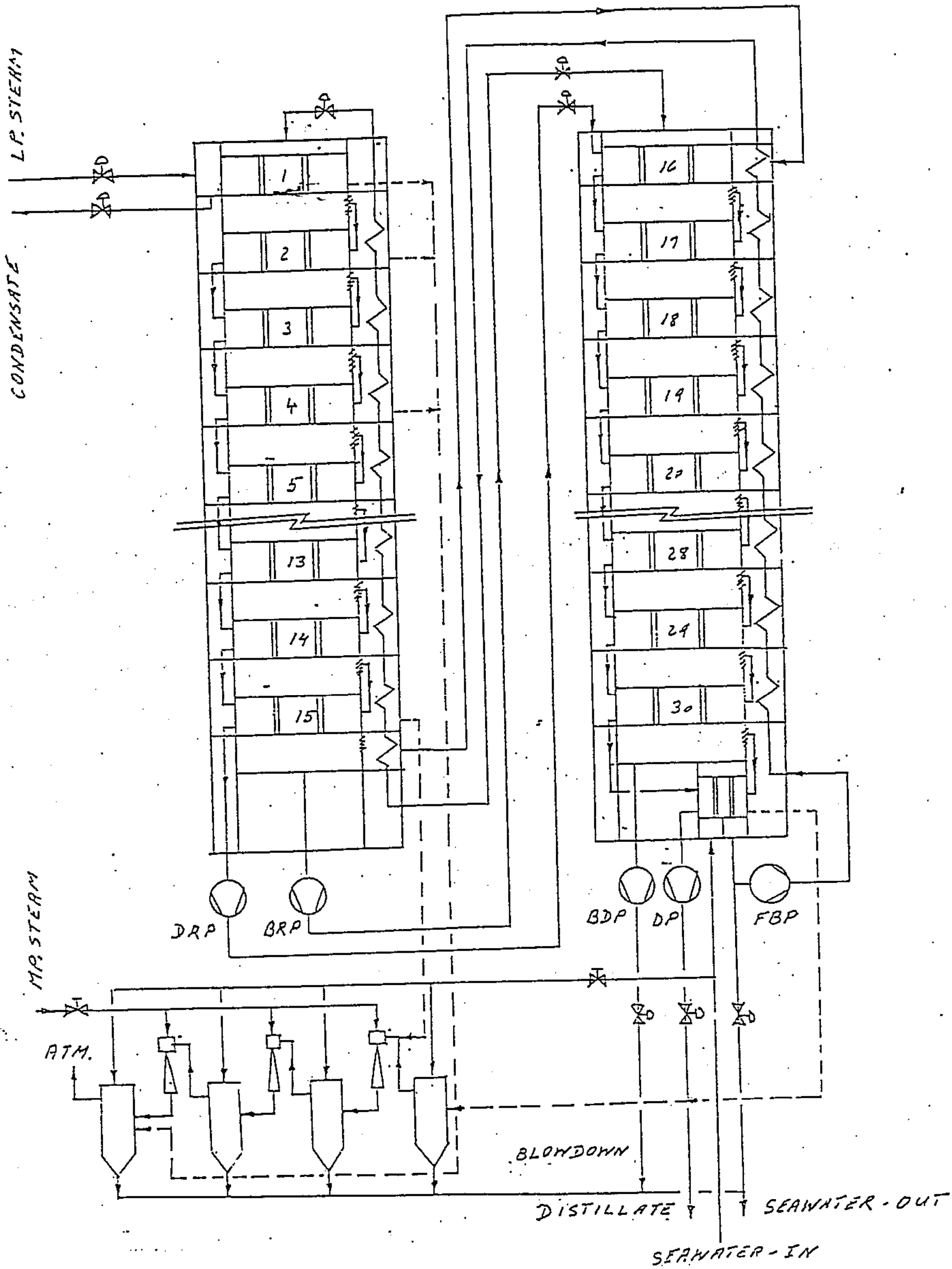


FIG. 1 PROCESS FLOW SHEET

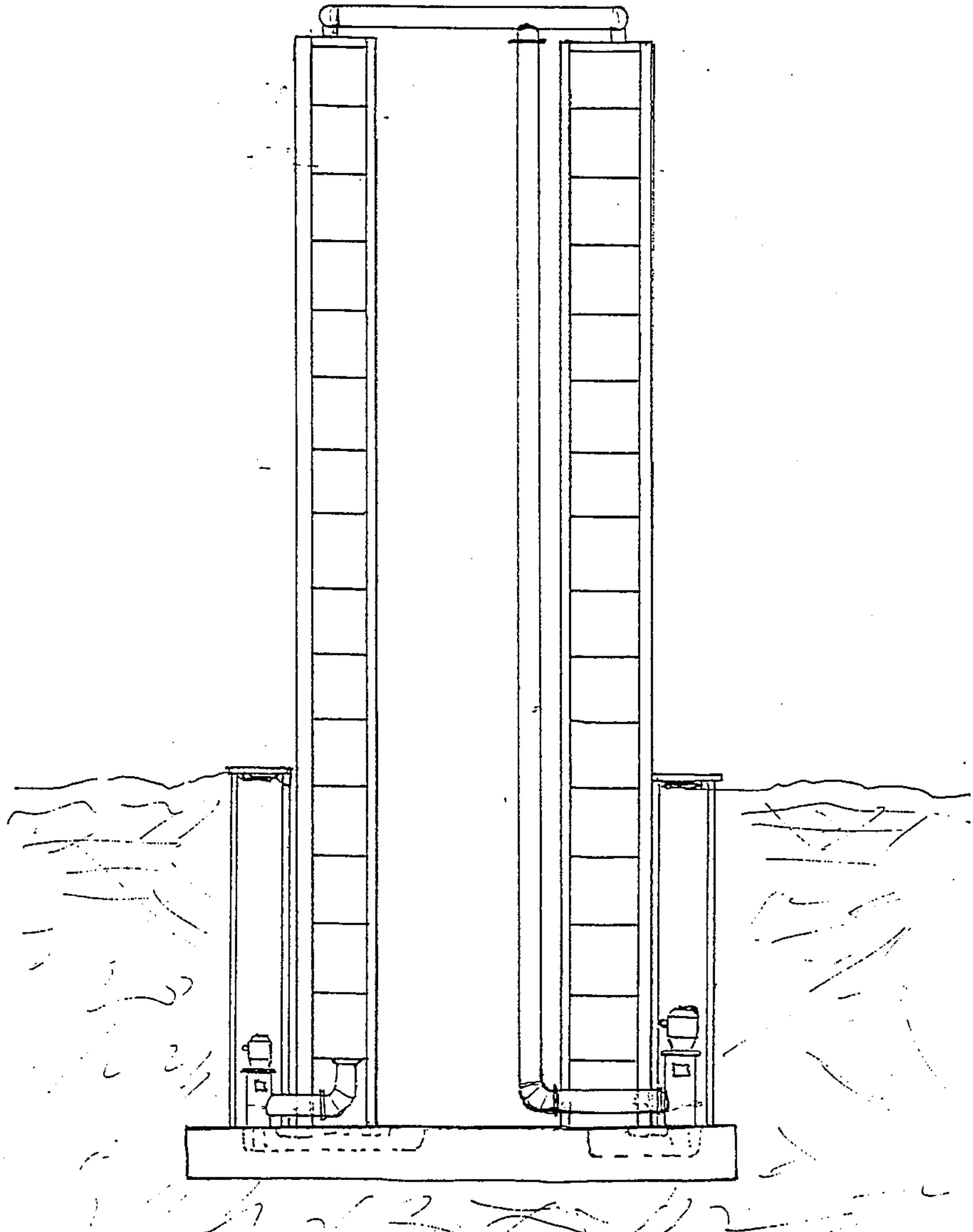


FIG. 2 VERTICAL SECTION

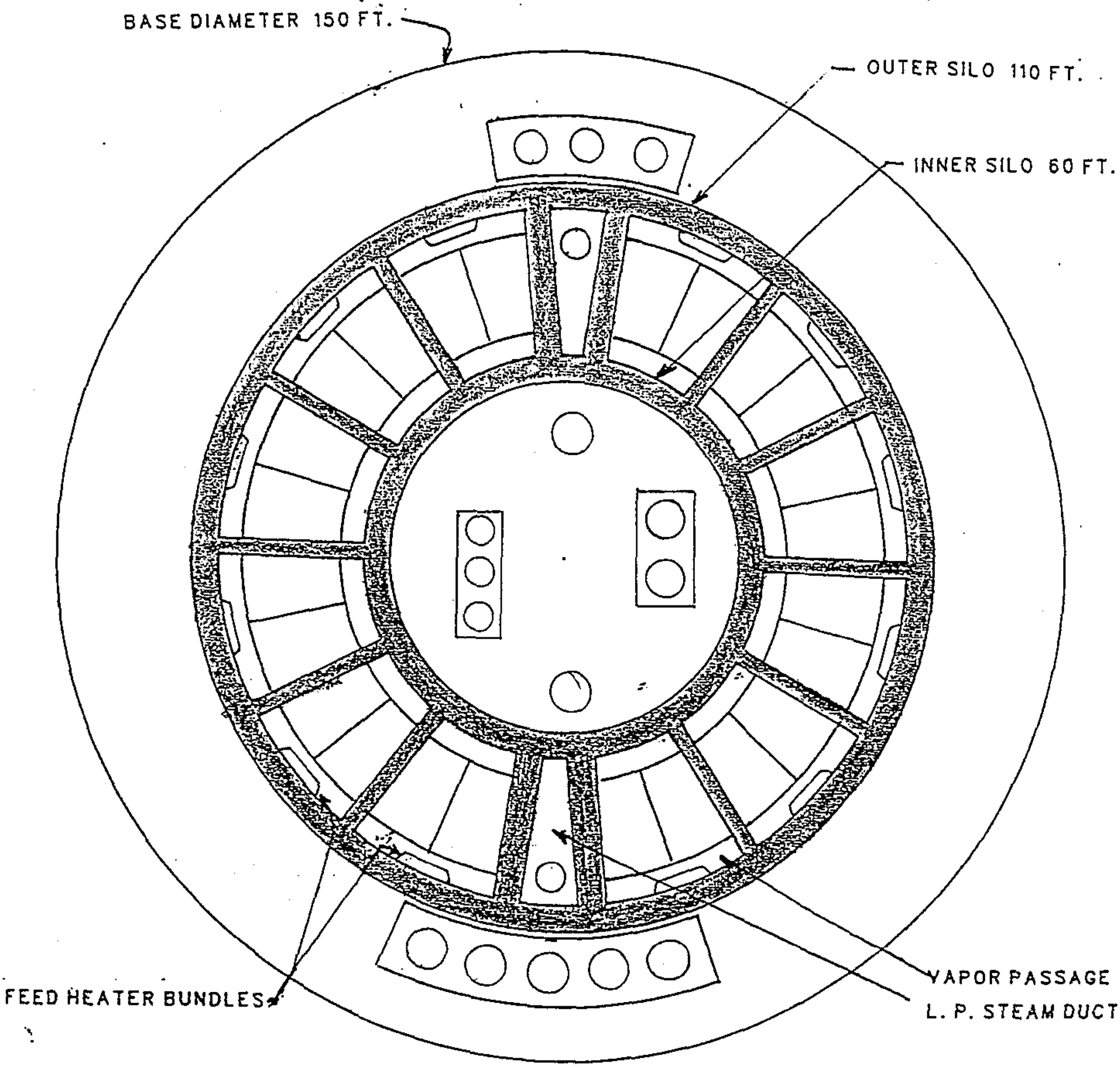


FIG. 3 CROSS SECTION OF SILO

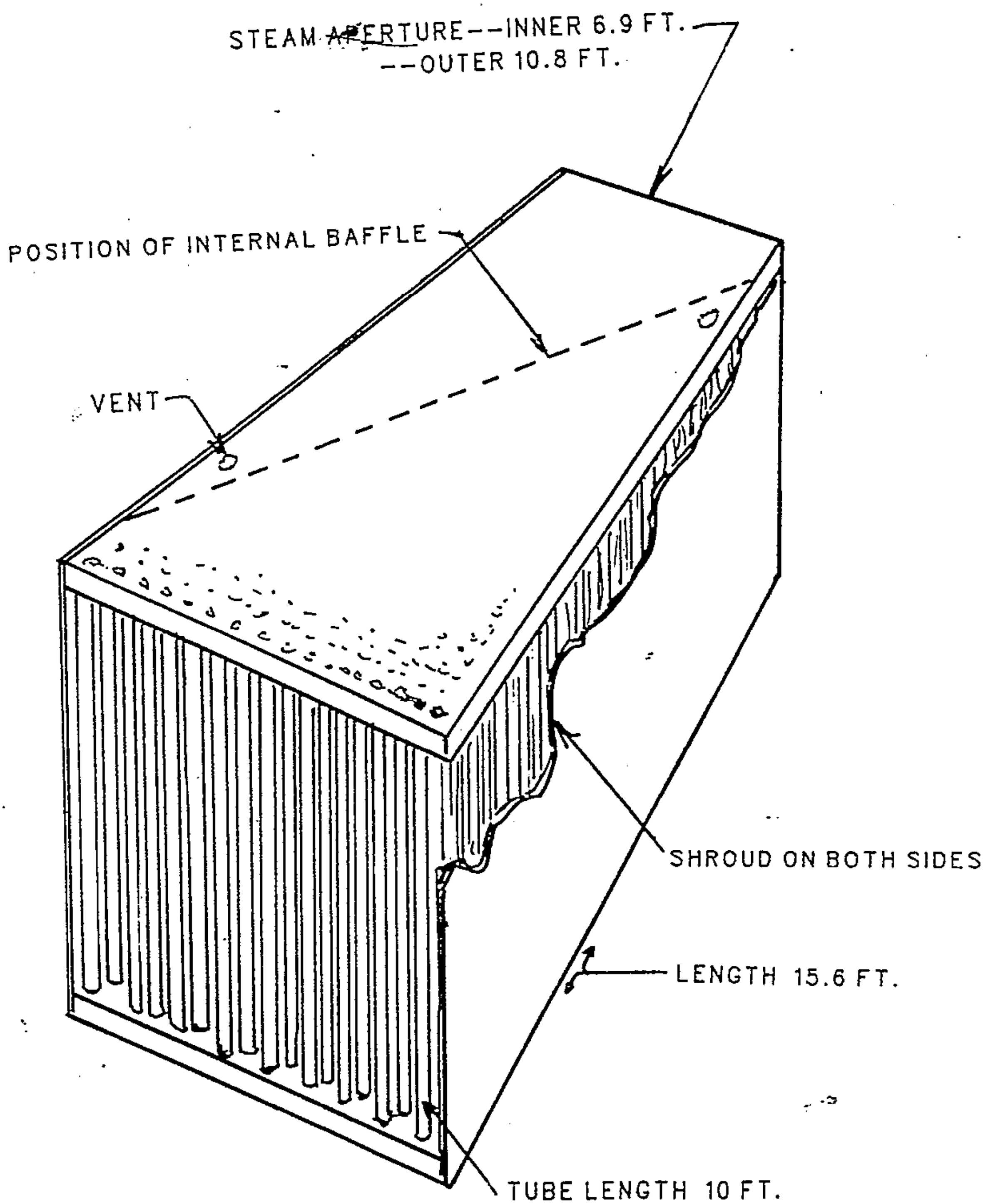


FIG. 4 DOUBLE ENDED BUNDLE

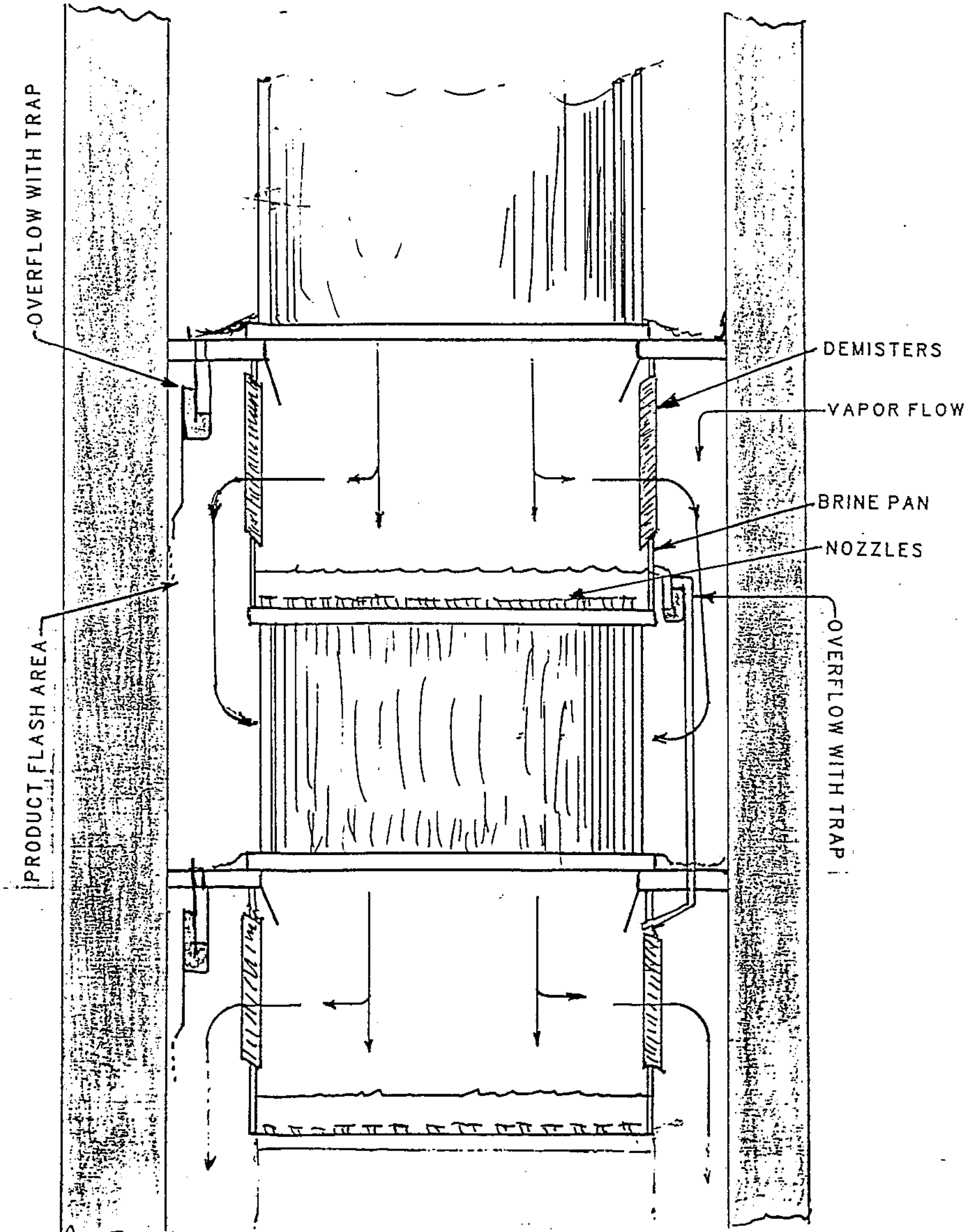


FIG. 5 EFFECT INSTALLATION

Preliminary Construction Cost Estimate.

Dual Silo, Aluminum Tubes, Plant capacity 78 MGD)

1	Concrete Silos (39,209 yds)	31,367,000
2	Foundation (15,846 yds)	7,131,000
3	Effect Tubes (1.199 M tubes)	8,993,000
4	Feedheater Tubes	1,971,000
5	Final Condenser Tubes	671,000
6	Tubesheets (1500 ft^2/effect)	8,060,000
7	Waterboxes	117,000
8	Distributors	505,000
9	Demisters	869,000
10	Fabrication	6,960,000
11	Ejector System	800,000
12	Pumps & Motors	6,830,000
13	Chemical Dosing System	200,000
14	Inst. & Controls, Control Valves	2,500,000
15	Deaerator	0
16	Piping & Valves	2,000,000
17	MCC & Switchgear	2,500,000
18	Electric & Instrument Cable	400,000
19	Platforms & Stairs	800,000
20	Crane	750,000
21	Misc. (paint, hardware, gaskets)	400,000
22	Subtotal: Materials	83,824,000
23	Freight @1.5% on 22-(1->5)	505,000
24	Insurance @ 0.6% x 22	502,000
25	Spare Parts @ 0.5% on 22-1,2,19	223,000
26	Engineering @ 7% on 22	5,868,000
27	Civil Works @ 9% on 22	7,544,000
28	Installation @ 25% on 22-1,2)	11,332,000
29	Subtotal	25,974,000
30	Total	109,798,000
31	Markup @ 18% on 30	19,764,000
32	Plant Cost	129,562,000
33	Interest During Construction @ 7%	9,069,000
34	Contingency 15%	19,434,000
35	Total Project	158,065,000
36	Specific Cost $/gpd	$2.03

TENTATIVE WATER PLANT OPERATING COST

Basis: Metropolitan Water District cost parameters
and expected energy costs.

Capital charge rate	8.0 %
Period, I :	30 y, 7%
Operating hrs	7450 /y (310 days) (85%)
Cost of power	$ .07 /kwh
Cost of fuel	$ 2.25 / M Btu
Cost of steam	$ 0.93 / 1000 # (24 psia)
Capacity charge	$ 0.52 / 1000 #

30 Effect Plant
78 MGD

	$ / kgal	$ / aft	
Capital cost	0.52	170	
Chemicals	0.15	49	
Spare parts	0.02	7	
O & M	0.07	23	
Retubing allowance	0.02	7	
Pumping power	0.28	91	
Steam *	0.32	104	
Capacity charge *	0.18	58	
Water cost	1.56	509	at plant
Treatment and conveyance (assumed)	0.46	150	
Total	2.02	659	

* Based on back-pressure steam from combined cycle gas turbine unit at existing site, no charges included for access to land or seawater intake, no condenser credit, no off-peak credit.

Version 2 of: TENTATIVE WATER PLANT OPERATING COST

Basis: Using Black & Veatch Cost parameters
and MWD energy cost projections

Capital charge rate	10.0 %, instead of 8%
Period, I :	20 y, 8%, " 30y, 7%
Operating hrs	7450 /y (310 days) (85%)
Cost of power	$ .07 /kwh
Cost of fuel	$ 2.25 / M Btu ok
Cost of steam	$ 0.93 / 1000 # (24 psia) extra Suel
Capacity charge	$ 0.52 / 1000 #

$1000/KW @ 30 yrs @ 7%

Huntington Repower Cap/KW

30 Effect Plant
78 MGD

	$ / kgal	$ / aft
Capital cost	0.65	212
Chemicals	0.15	49
Spare parts	0.02	7
O & M	0.07	23
Retubing allowance	0.02	7
Pumping power	0.28	91
Steam *	0.32	104
Capacity charge *	0.18	58
Water cost	1.69	551 at plant
Treatment and conveyance (assumed)	0.46	150
Total	2.15	701

* Based on back-pressure steam from combined cycle gas turbine unit at existing site, no charges included for access to land or seawater intake, no condenser credit, no off-peak credit.

39625

128 Wendover Circle
Oak Ridge, Tennessee 37830
February 6, 1992

Dr. R. Phillip Hammond
Post Office Box 1735
Santa Monica, California 90406

Dear Phil:

Conceptual Design Report - Chapter V. Aluminum Performance in Seawater Evaporators

Attached is my first draft of Chapter V of our Conceptual Design Report. As you recall, it is intended to fit within your overall outline as shown in Attachment 1.

I welcome comments from everyone—I would especially request that Jack Snodgrass and the Design Team provide any corrections, additions, comments, suggestions, and/or additional references they may find helpful. If MWD or Design Team members have additional information on IDE or Sidam plant operation I would be pleased to incorporate it.

Sincerely yours,

John E. Jones Jr.

JEJ:sbw

Attachment

cc/att: David Dean, MWD
David Eissenberg
Dieter Emmerman
Chet Holtyn, Reynolds Metals
Chuck Nichols, MWD
Hugo Sephton
Jack Snodgrass, Reynolds Metals

OUTLINE

CONCEPTUAL DESIGN REPORT

CHAPTER V. ALUMINUM PERFORMANCE IN SEAWATER EVAPORATORS

I. INTRODUCTION

II. ECONOMIC INCENTIVE

III. CORROSION PERFORMANCE OF ALUMINUM

- A. Historic Data and Experience
  1. Aluminum Association Desalting Test Plant
  2. Reynolds/OSW Corrosion Tests and Pilot Plant
  3. Israel Desalination Engineering, Ltd.
- B. Effects of Various Parameters on Aluminum Performance
  1. Alloy Composition
  2. pH
  3. Temperature
  4. Feed Treatment
  5. Velocity of Flow
  6. Deaeration
  7. Cold Work
  8. Crevices
  9. Galvanic Couples
  10. Surface Condition

IV. RECOMMENDED APPROACH TO THE USE OF ALUMINUM

- A. Alloy Selection
- B. Heat Transfer Tube Configuration
- C. General Design Guidelines
- D. Test and Validation

V. SUMMARY

CHAPTER V. ALUMINUM PERFORMANCE IN SEAWATER EVAPORATORS

I. INTRODUCTION

The strong interest in economic, large-scale desalination of seawater which emerged in the United States in the 1960s led to extensive exploration of alternate processes and materials. Among the alternatives explored was the use of aluminum alloys.

By that time aluminum had been successfully used in seawater applications such as pipelines, structures, and seagoing ships so the potential for compatible use of aluminum alloys in seawater was established. Considering the fact that aluminum is otherwise a very suitable material in view of its good thermal conductivity, light weight, adequate strength, and lower cost, it was an obvious candidate material for evaluation and testing.

II. ECONOMIC INCENTIVE

If desalination is to be implemented on a large scale the need for lower cost heat transfer material for use in evaporators is obvious. The traditional materials for such application have been copper-based alloys (copper nickel, aluminum, brass, etc.) or even more expensive titanium and stainless steels.

For smooth tubes such as those employed in an MSF or HTME plant the cost advantage for aluminum alloys over copper alloys would be in the range of a factor of 2.5 to 3. This is a very significant advantage and is the primary reason which stimulated Israeli Desalination Engineering, LTD., to develop the very successful horizontal, aluminum tubes Multi Effect Distillation (MED) concept.

However, for the doubly fluted tubes utilized in the Vertical Tube Evaporator concept, the economic advantage of aluminum alloy tubes is even greater. The reason for this additional economic advantage is the fact that aluminum can be readily extruded to shape at high speed while copper-based alloys cannot. Doubly fluted tubes from copper-based alloys are typically produced as round tubes and subsequently swaged to produce the fluted configuration.

Based on Reynolds current estimate of approximately $1.60/lb for finished fluted tubes delivered to California, the present test profile (.734 lb/ft) would cost $1.17 per foot of length or approximately $2.22 per square foot of heat transfer surface based on the nominal tube size. However the present test profile includes a thicker wall than necessary for the large-scale prototype plant to accommodate the possibility that the flutes might be machined off to make the tube sheet joint in the test unit. Based on promising results in alternate joining techniques, this thickness can readily be reduced to yield a tube cost on the order of $0.90 per foot of length or $1.71 per square foot of heat transfer surface based on the nominal tube size. For comparison, Dieter Emmerman has projected comparable delivered cost for copper-based alloy double fluted tubes to be in the order of $12 per square foot of heat transfer surface based on the nominal tube size. Therefore, when fabrication cost of double fluted tubes is included, the economic advantage of aluminum alloy heat transfer surface is about a factor of 7 times more favorable than that for copper alloy heat transfer surface.

Perhaps it should be noted here that Reynolds Metals has recently reaffirmed their earlier cost projection of $1.55 to $1.65 per pound for double-fluted aluminum alloy tubes delivered to California. However, MWD should recognize that the demand for aluminum is currently at a low ebb and this cost may increase moderately in the next few years as the demand for aluminum rebounds.

Reynolds has volunteered that they are willing to negotiate a fixed price with MWD based on current cost projections for a large quantity of tubing for the MWD Pilot Plant and guarantee that price for two years (or perhaps a little longer). This option seems worth considering, if it does not otherwise conflict with MWD procurement policies.

III. CORROSION PERFORMANCE OF ALUMINUM

A. Historic Data and Experience

A review of the use of aluminum in desalination reveals data and experience beginning in the late 1940s and continuing to today. The heaviest concentration of research and experimental activity occurred during the late 1960s and early 1970s within the Department of Interior's Office of Saline Water program. Since 1973 here has been little continuing research activity on aluminum in the United States but the use of aluminum in some commercial desalination plants, for example, the Israeli IDE horizontal Multi Effect Distillation plant, has provided encouraging results and some additional data.

"A Review Paper — Aluminum in Desalination" by Ailor[1] provides a good summary of the early research literature along with 71 references for the reader who wishes to delve into the history of aluminum use in desalination in more detail. A second general reference is "Application of Aluminum Alloys in Evaporative Desalination" by Bonewitz et al.[2].

1. Aluminum Association Desalting Test Plant[2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17]

The Aluminum Association sponsored the construction and operation of a 3000 gpd flash distillation unit at the OSW Materials Test Center at Freeport, Texas. The facility was operated by Dow Chemical Company and began operation on August 22, 1969. The facility was operated for 38 months with an on-stream availability greater than 99%. A schematic flowsheet of the plant is shown in Figure 1 with operating parameters. The plant was designed and operated to provide engineering information to facilitate the selection of aluminum materials in desalting plants. Aluminum alloys 3003, alclad 3003, 5052, 6063, 5050, and 1200 were tested in the form of 3/4 in OD x .049 in wall thickness tubes for use in heat transfer. Aluminum Alloy 5054 plate was used and Alloy 6061 was also used for plate as well as for pipe and structures. Tests were conducted for temperatures from 110 to 250°F and at flow rates of 2.5, 5, and 10 ft/sec. General conclusions from the 38 month test programs are:

a. Initial pitting was observed in freshly exposed tubes in the Heat Reject (E-21) and Heat Recovery (E-22) exchangers. These pits became inactive after the initial test period and no further pit growth was observed during the 38 months of operation. Because these tubes were the first to contact incoming treated seawater this pitting may be attributable to the scavenging of heavy metal ions. After the initial conditioning process which provides an inherent protective oxide film, no further pitting or pit growth was observed.

b. Except for this initial pitting in the front end of heat reject/heat recovery exchangers, all heat exchanger tube alloys performed well.

c. During two periods of operation the brine heater, which operated at

Flow chart of the Aluminum Association desalting test plant

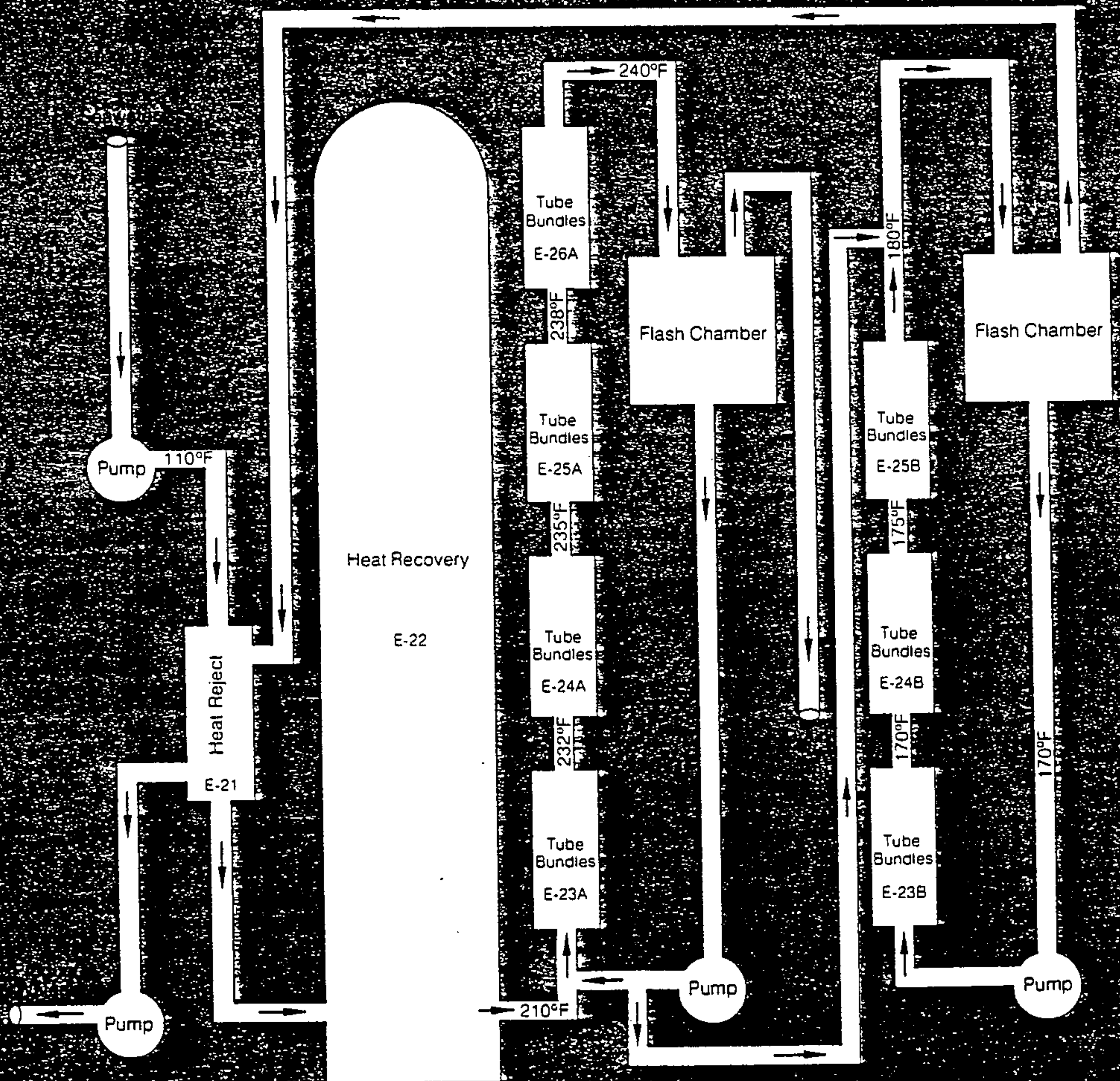


Figure 1

temperatures ranging from 240 to 250°F, formed some anhydride scale due, in one case, to low velocity (2.5 ft/sec flow) at 250°F and, in the other case, due to misoperation resulting in inadvertent overheating. Pitting and corrosion occurred under this scale.

d. No significant corrosion occurred on any of the process equipment (piping, tube sheets, flanges, tanks, etc.).

2. Reynolds/OSW Corrosion Tests and Pilot Plant[17,18,19,20,21,22,23,24]

During the period 1968 through 1973 Reynolds Metals, under contract to OSW, conducted both laboratory and pilot plant tests of aluminum alloys for desalination.

Early in the pilot plant operation, it became evident that laboratory corrosion testing of aluminum alloys at elevated temperatures in saline solutions would be useful in understanding the performance of aluminum alloys in the pilot plant. Extensive laboratory tests were conducted on aluminum alloys 1100, 1235, 3003, 3004, 5050, 5052, 6061, and 6063 over approximately a four-year period at temperatures up to 300°F. The best performers among the conventional alloys were Alloy 3004 and Alloy 5050. These are aluminum manganese magnesium and aluminum magnesium alloys respectively.

As a result of this effort Reynolds developed and conducted preliminary tests on three new alloys specifically formulated for application in desalination. These are aluminum manganese magnesium alloys which represent somewhat of a hybrid between Alloy 3004 and Alloy 5050. They are designated RX510, RX511, and RX512. Reynolds recommends the use of Alloy RX512 for heat transfer tubing in seawater desalination at temperatures up to 250°F.

For the most promising alloys Reynolds achieved an average laboratory corrosion rate of approximately 1 mill/year in two-week tests at 250°F. The instantaneous corrosion rate at the end of the test was typically less than the average by a factor of 1/3 to 1/10 which reflects the fact that aluminum corrosion rates decline markedly after the buildup of a protective aluminum oxide layer.

The Reynolds/OSW Pilot Plant operated intermittently over a period of about 4-1/2 years through February 1973 (see Figure 2). It was initially designed and operated as a 26 stage, 50,000 gpd MSF plant with a maximum brine temperature of 250°F. The plant was designed with aluminum tubes and a steel shell. Three small VTE effects were added to the plant in the summer of 1970 to increase the capacity to 54,000 gpd. The VTE effects were designed to operate in conjunction with and draw feed from Stages 6, 8, and 10 of the MSF plant. The VTE effects operated at temperatures up to 220°F with acid feed treatment and 190°F with phosphate feed treatment. Finally, a single horizontal tube effect was added to the plant.

The original plant tested aluminum Alloys 3003, 3004 clad, 5052, and 6061. Subsequent tests included Alloys 1235, 3004, 5050, and 6063.

Conclusions from the Reynolds/OSW Pilot Plant are encouraging and generally consistent with results from the Freeport Test Facility. Aluminum Alloy 3004 showed the most stable behavior for heat transfer surface. Aluminum Alloy 5052 provided satisfactory performance below 190°F. Alloy 5050 was substituted for Alloy 5052 in the later phases of operation because it was expected to show superior performance. Alloy 6063 tubes were used in the VTE effects because of availability and fabricability and performed satisfactorily. Alloy 6061 is suitable for external structures and piping.

The steel shells created additional problems in this system because steel corrosion products deposited on aluminum heat transfer surface in certain areas promoting corrosion and pitting or contributed to galvanic corrosion due to proximity to the aluminum heat transfer tubes. While the problems derived from the use of a steel shell were mitigated by design modifications, it is apparent that the use of a steel shell or steel structures in combination with aluminum heat transfer tubing is undesirable.

On occasion construction debris and silt caused blockage or partial blockage of tubes which led to corrosion. The corrosion was arrested when the

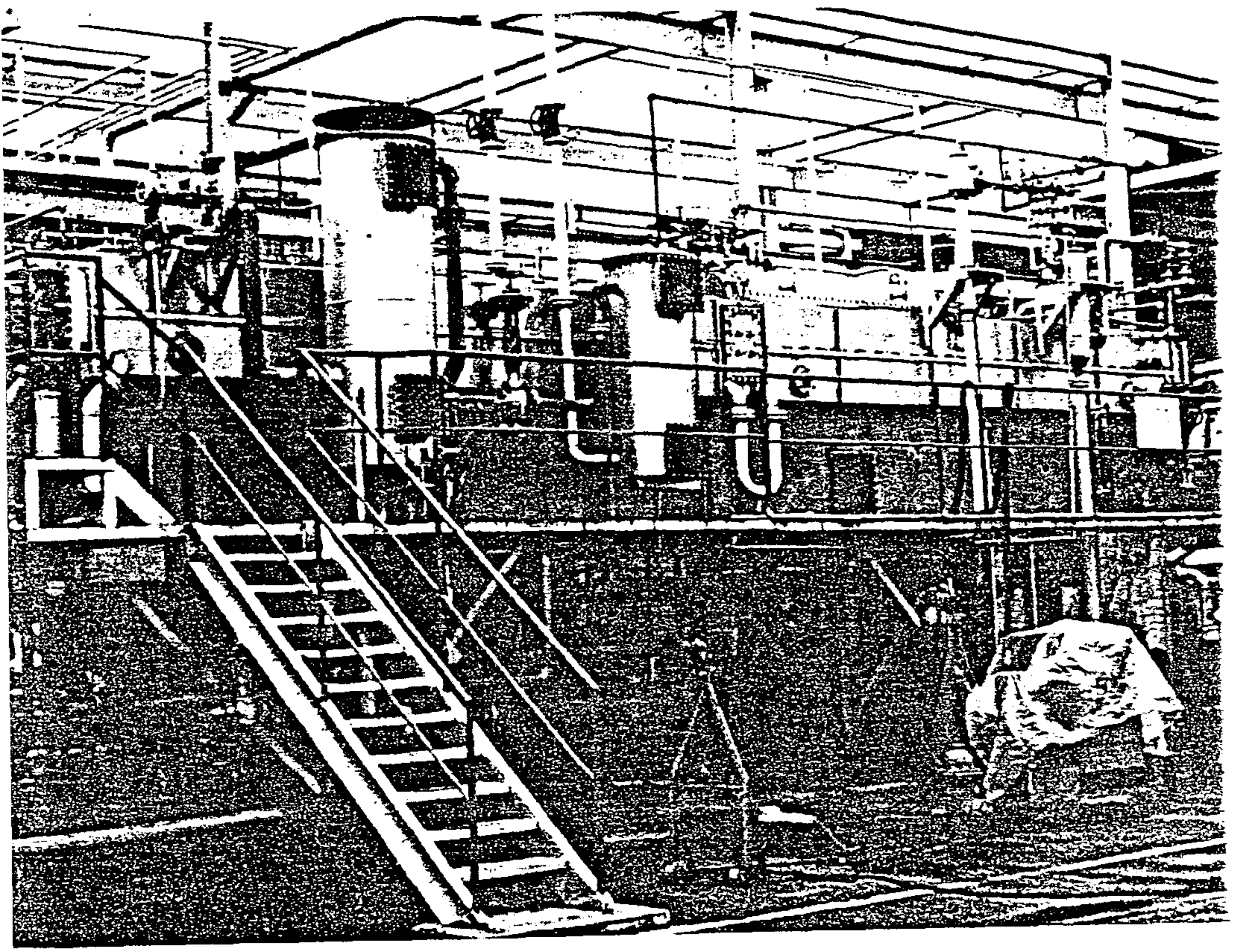


Figure 2
Reynolds/OSW Pilot Plant

blockage was removed.

Similar problems were encountered in the VTE when silt and debris clogged the suction piping to the pump feeding the VTE effects. Other problems were encountered with feed to the VTE because of low brine level in the MSF stage from which feed was being drawn. Also, the ceramic spray nozzles in the VTE effects were found to break easily and had to be replaced.

These problems led to calcium sulfate scale formation in the VTE on two occasions. Apparently, the flow problems led to recycle of the brine in the VTE leading to an increase in brine concentration resulting in the scale.

Once these problems were corrected, no significant corrosion was noted either inside or outside the vertical tubes during 16 months of operation. Overall conclusions from the Reynolds/OSW Pilot Plant regarding the use of aluminum in desalination are:

- for vessel construction, Alloy 3004 performed well at temperatures up to 250°
- doughnut sacrificial anodes proved effective in eliminating corrosion of aluminum piping at dissimilar metal joints
- aluminum structures, railing, and walkways required no maintenance and performed well

A summary of the alloys which proved most reliable for various application include:

Application	Aluminum Alloy
Vessels	3004
Pipe	6061-T6
Pipe fittings	6061-T6, 3003F
Heat transfer tubing	3004, 3003, 5052 below 190°F
Structural shapes	6061-T6, 6063-T6
Tread plate	6061-T6
Pedestrian grating	6063-T6

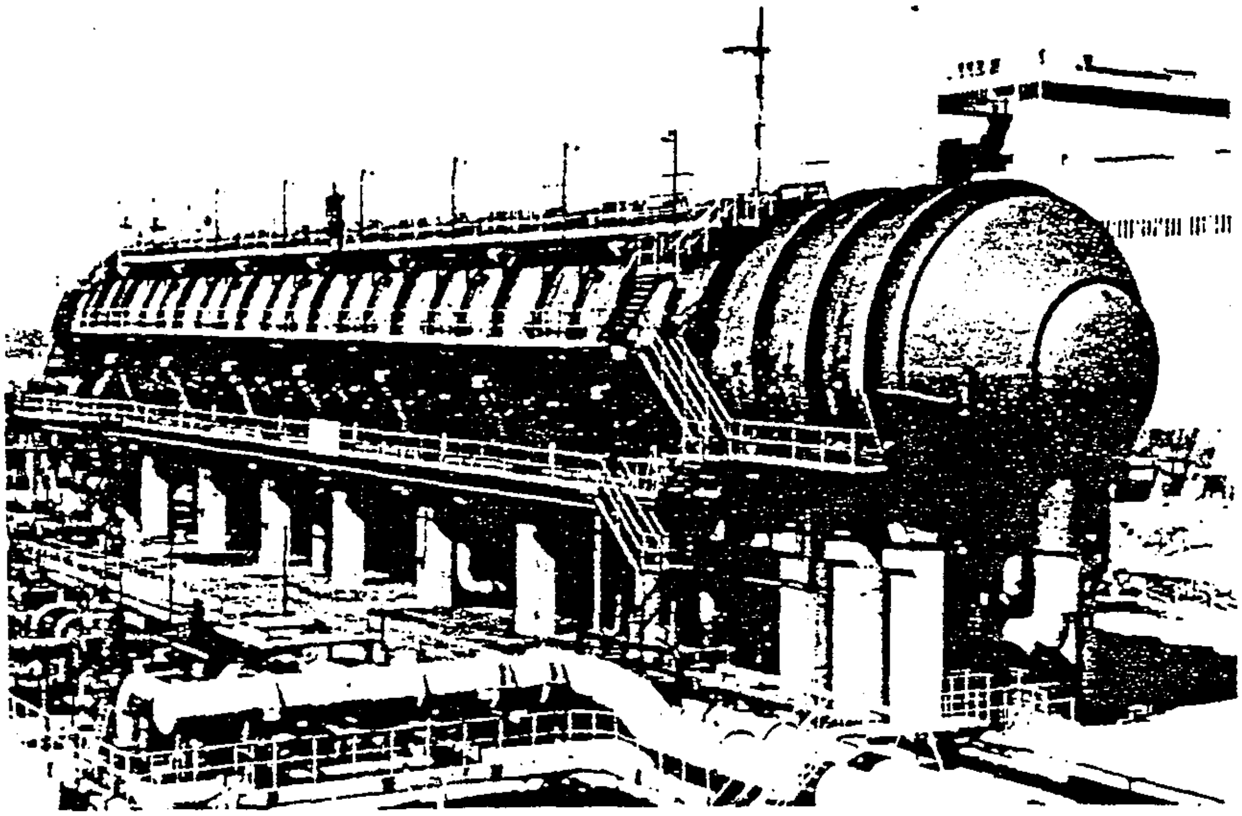
The following recommendations are arrived at avoiding or preventing problems with the use of aluminum.

- Avoid heavy metal ions in solution—particularly copper and mercury. Use traps or scavengers to remove heavy metal ions in incoming streams if needed.
- Eliminate dissimilar metals by using all aluminum where economically and practically feasible. When necessary, place dissimilar metal joints where the least corrosion will occur and use sacrificial anodes to protect the aluminum.
- Avoid very low flow or stagnant areas—particularly in aerated seawater.
- Avoid very low pH (below 4.5) or very high pH (above 9.0) solutions in contact with aluminum.

3. Israel Desalination Engineering, Ltd. (IDE)[25]

The low-temperature, horizontal aluminum tubes Multi Effect Distillation (MED) concept is marketed principally by IDE. There have been a large number of moderate-sized plants placed in operation over the last 15 years, particularly in the Caribbean. Sidam (French) also markets the MED concept but prefers to use more conservative materials such as titanium and copper nickel alloys.

The IDE plants are fully developed and operate well by all accounts. This was accomplished over a period of years. The one MGD plant at Eliat, Israel, completed in 1974, served as the first prototype. Beginning in 1975 the U.S. and Israel signed a joint 10-year agreement to build and test a large-scale demonstration plant at Ashdod, Israel. This was originally intended to be a 10 MGD plant but was reduced to approximately 5 MGD during the program (see Figure 3). The total expenditure on this program was $31 million (half from the U.S.). Several years of high-quality engineering development during this program allowed IDE to resolve any engineering problems and produce a smoothly operating plant.



The 4.6 Million-Gallon-Per-Day
Multieffect Low-Temperature Distillation Plant
at Ashdod, Israel
Developed and Operated Under the
Joint United States-Israel Desalination Project

Figure 3

The major disadvantages of the MED concept relative to VTE are (a) the horizontal tube configuration cannot take advantage of enhanced heat transfer performance achievable with vertical fluted tubes and (b) the MED concept utilizes brine spray over the outside of a horizontal tube bundle; therefore, if scaling conditions occur with this configuration the outside of the tubes are inaccessible for inspection or cleaning. To minimize the risk of scale the MED concept operates at a maximum brine temperature of 170°F or less limiting the performance ratio which can be achieved.

Specific data on performance of the IDE plants is proprietary. However, general information on replacement histories for nine MED evaporators located in the U.S. Virgin Islands, Curacao, the Cayman Island, and Bonaive has been obtained.[26] The Virgin Islands plants were started up during the period 1981 to present. The other plants were started up during the period of 1987-1988. All had aluminum tubing in both the evaporators and the heat rejection condensers, and all operated at a "low" first effect feedwater temperature of about 160°F.

According to IDE, evaporatory tube replacement was required only in the Cayman Island plant. Failure of the evaporator in the Cayman Island plant was caused by scaling of the evaporator tubes which was irreversible because the tubes could not be cleaned. The scaling resulted from unforeseen well water chemistry in the incoming brine.

Condenser tube replacement was required in the Cayman Island plant because of the same unforeseen well water chemistry problem. Condenser tube replacement was also required in each of the Virgin Islands plants. According to IDE, the replacement of aluminum tubing with titanium tubing was required in the Virgin Islands plants because of sand entering the feedwater intake and eroding the condenser tubes.

While not all of this experience is generic to the VTE concept (for example, the evaporatory scaling experienced in the Cayman Island plant would not require tube replacement in a VTE) it does help to highlight the fact that the most vulnerable areas in the VTE plant are (a) the condenser where sand or silt can cause erosion problems or unusual water chemistry (for example heavy metal ions in the intake) can cause corrosion problems, (b) the feed heater where unusual feed brine chemistry could cause corrosion and/or pitting, and (c) the first effect of the evaporator where problems in process steam and/or brine chemistry could result in pitting or excessive corrosion of the aluminum tubing. These are areas of the plant which merit special attention during the design/development phase of the program.

B. Effects of Various Parameters on Aluminum Performance

1. Alloy Composition

Alloy composition is quite important to the performance of aluminum in desalination. For heat transfer surface and areas where aluminum alloys are most vulnerable to pitting and corrosion, research indicates the aluminum manganese (for example, Alloy 3003), aluminum manganese magnesium (for example, Alloy 3004), and aluminum magnesium (for example, Alloy 5050) alloys perform best. Advanced alloys developed by Reynolds specifically for application in desalination (for example, RX512) are also in this family of alloys. However, laboratory tests indicate that aluminum magnesium alloys which have a high magnesium content (above 2.5 to 3%) have a greater potential for grain boundary precipitation in combination with high temperature and cold working. This can contribute to accelerated corrosion attack and therefore precludes the use of some high magnesium alloys in desalination which are otherwise very suitable for use in seawater.

For thicker sections such as piping and structural shapes the standard structural materials (for example, Alloy 6061-T6) are quite acceptable.

2. pH

The effect of pH on corrosion and pitting can be quite significant by itself when the pH exceeds 8.0 to 9.0 on the high side or drops below 4.5 on the low side. Even within these limits pH in combination with oxygen content can have an important influence on corrosion and pitting.

In general, very high pH (above 8 or 9) prevents pitting but tends to remove the natural aluminum oxide protective coating on the surface of the aluminum leading to modestly higher rates of general corrosion attack and scaling. On the other hand, very low pH (below 4.5) tends to contribute to increased tendency for pitting, especially in the presence of excess oxygen or in low velocity or stagnant regions.

The optimum pH appears to be about 6.0 in combination with low free oxygen content (see Figure 4).

The susceptibility to pitting from heavy metal ions is reduced as pH increases.

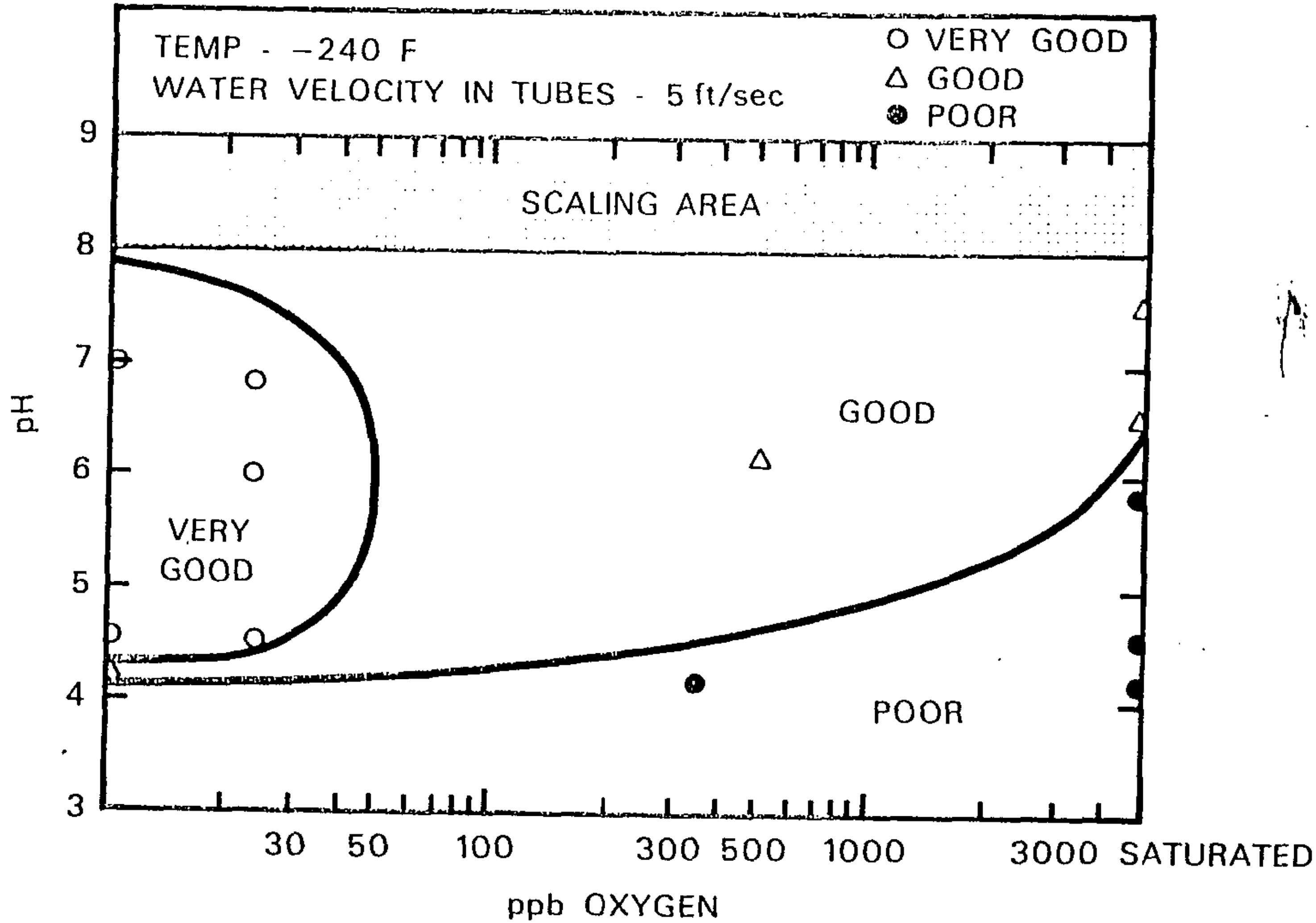
3. <u>Temperature</u>

Higher temperature up to 250°F has a moderate accelerating effect on corrosion or pitting attack on aluminum alloys as it does on copper-based alloys. However, the effect of elevated temperature does not preclude the use of aluminum alloys in desalination as was once presumed. The most important consequence of elevated temperature is that it tends to accelerate the negative effects of anhydride scale, galvanic couples, or heavy metals on aluminum corrosion and pitting.

Temperature cycling (such as repeated start-up and shutdown) does not appear to be any more of a concern than the first start-up and shutdown.

4. <u>Feed Treatment</u>

Both the Aluminum Association Desalting Test Plant and the first eight stages (and first two VTE effects) of the Reynolds/OSW Pilot Plant operated with acid feed treatment. The low temperature (<190°F) stages (Stage 9 through 26) of the Reynolds/OSW Pilot Plant used a "threshold chemical" feed treatment (originally Darex 40S was used and later Calgon PD-8 was used).



EFFECT OF pH AND OXYGEN CONTENT OF SEA WATER ON PITTING OF ALUMINUM ALLOY TUBES FROM FREEPORT PLANT ENVIRONMENTAL SIDE UNIT

Figure 4

The IDE plants proportedly use polyphosphate feed treatment. It is proposed that the MWD Pilot Plant will use a feed treatment system based on polymeric additives.

Essentially all of the high-temperature performance data on aluminum alloys is based on acid feed treatment. Low-temperature performance data is based on both acid feed treatment and polyphosphate feed treatment. Both apparently worked adequately.

In the Reynolds/OSW Pilot Plant the polyphosphate-treated section of the plant was described as having a "muck layer." While this did not contribute to aluminum corrosion attack, it may be of some concern relative to heat transfer performance of a VTE plant.

Aluminum does not appear to be highly sensitive to feed treatment in so far as corrosion behavior is concerned. The choice of feed treatment can probably be based on other cost and performance factors.

5. Velocity of Flow

Tests at 2-1/2, 5, and 10 ft/sec in the Aluminum Association Desalting Test Plant indicate that very low velocity flow ($\leq$2.5 ft/sec) or stagnant regions can contribute to increased corrosion attack where solids could collect on the aluminum surface in concentrated brine. High velocities up to 10 ft/sec had no detrimental effect. In general, brine flow velocity in the feed heater is recommended to be in the range of 5 to 6 ft/sec.

6. Deaeration

Unlike copper-based alloys, aluminum can operate quite satisfactorily with high levels of dissolved oxygen; so deaeration of the incoming brine feed is not necessary prior to entering the feed heater.

If heavy metal ions are present, however, free oxygen can accelerate pitting attack. For example, copper ions up to a concentration of 40 ppb in deoxygenated seawater does not appear to cause aluminum to pit. However, 20 ppb copper in the chloride form in combination with 90 ppb oxygen caused severe attack.

Therefore it is especially important to strip heavy metal ions out of the feed by means of a heavy metal trap or scavengers if the brine feed is not to be deaerated prior to the feed heater.

7. Cold Work

There is some indication that cold worked aluminum alloys with high (2.5 to 5%) magnesium content experience grain boundary precipitation of the magnesium at higher temperatures. These precipitates are undesirable because they can lead to intergranular attack. For example, Alloy 5052 (2.5% ± 0.3 magnesium) formed grain boundary precipitates when cold worked and sensitized at 190 to 225°F for up to 1000 hours.

There is no evidence of other detrimental effects of cold working although it would seem prudent to minimize cold working to the extent possible in the heat transfer surfaces.

8. Crevices

Crevices such as sometimes occur between the tube and tube sheet or baffles plates contribute to an increase in corrosion either through galvanic couples or through concentration of solids. In general, one should strive to eliminate or avoid such crevices throughout the plant.

9. Galvanic Couples

Galvanic couples can have a severe effect leading to localized corrosion and pitting, to the extent possible, dissimilar metals should be eliminated by using all aluminums where feasible. When dissimilar metal joints are required they should be located in a zone with low corrosion potential and should include a sacrificial anode to protect the aluminum. The negative consequences of galvanic couples are enhanced by high temperature and increased brine concentration.

10. Surface Condition

The corrosion resistance of aluminum is derived from the oxide film formed on its surface. In principle, corrosion resistance could be enhanced by improving the existing oxide film or removing the existing oxide film followed by the controlled growth of a more perfect oxide film. Laboratory tests have been conducted to explore this possibility.

Results indicate that improved oxide film can be grown on aluminum alloy surfaces with a practical treatment. For Alloy 6063-T6 such a treatment would include a 2-to-3 hour etch with 0.5% NaOH + 1.0% NaF, a distilled water flush, a 1-hour oxide growth with emersion in 205°F distilled water, and a 15-minute seawater flush. Boehmite, the most protective form of oxide, is promoted by such treatment. Boehmite forms rapidly at temperatures greater than 180°F in water.

If such treatments are considered desirable, evaluation of the treatment for each alloy should be made before applying any such treatment in a plant. Evidence from field testing of aluminum in desalination does not indicate that such surface treatment is necessary.

IV. RECOMMENDED APPROACH TO THE USE OF ALUMINUM

A. Alloy Selection

Application	Aluminum Alloy
Heat transfer tubing	3004, RX512
Vessels	3004
Pipe and structures	6061-T6

B. Heat Transfer Tube Configuration

The present prototype tube for test has a profile as illustrated in Figure 5. The tube weighs 0.73 lb per foot with an outside fluted perimeter of 8.052 inches and an inside fluted perimeter of 7.577 inches. If it is not necessary to machine off the outside flutes to make the tube-to-tube sheet joint, the thickness and therefore the weight of the tube can very likely be reduced significantly for the pilot plant.

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Co.	Co. Reynolds Metals
Dept.	Phone #
Fax # 213 451-0164	Fax # 804-281-3026

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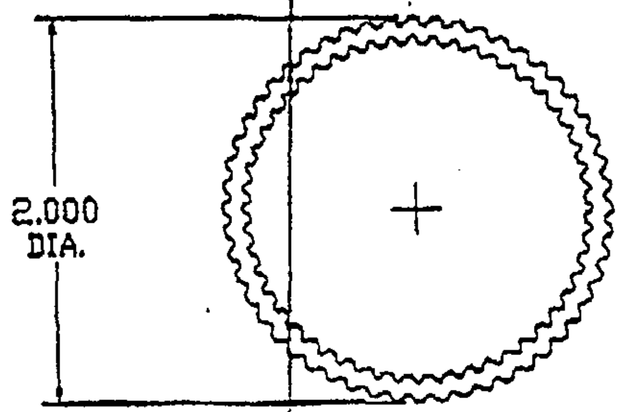
To John Jones	From C. Holtyn
Co. Oak Ridge	Co. Reynolds Metals
Dept.	Phone #
Fax # 615-574-8216	Fax # 804-281-3520



John,
PER OUR TELCON.
WE HAVE INCREASED
the depth of the
I.D. FLUTES. The
OVER ALL THICKNESS
REMAINS the SAME.
PENDING
• TUBE SHEET / TUBE JOINT DESIGN
• EXTRUSION TRIALS AT EL CAMPO
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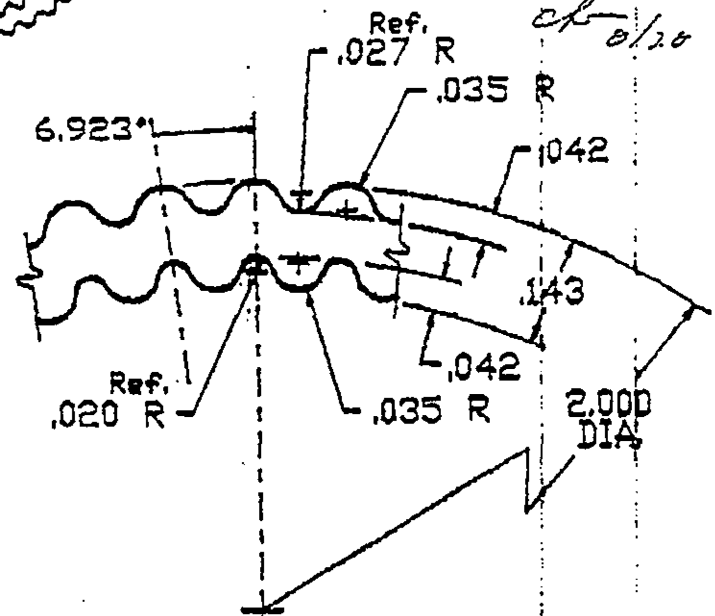

CODE	A	BT	CT	M	S		

This drawing represents the interpretation by El Campo Aluminum of the section requested by its customer. El Campo Aluminum will manufacture extrusions in accordance with this drawing. The customer should thoroughly check it against its own design criteria. El Campo Aluminum makes no warranty of fitness for a particular purpose with regard to extrusions produced to this drawing. Its only warranty being that set forth in its sales order acknowledgment form.

---- TYPICAL WALL THICKNESS EXCEPT NOTED | BREAK SHARP CORNERS ---- R. EXCEPT NOTED

SHAPE DATA

EST. AREA	.612	FACTOR	21
EST. WEIGHT	.734	CIRCLE SIZE	2.000
EST. PERIM.	15.629	TYPE SECT	Holl. UL2

DATE	SYM.	REVISION	BY

EL CAMPO ALUMINUM COMPANY

RT. 3 | EL CAMPO, TEXAS

DRN	CKS	CHKD		SCALE	Full	DATE	8-28-91

STANDARD TOLERANCES EXCEPT AS NOTED

Fluted Tube

DIE NUMBER

TEMPER

Figure 5

C. General Design Guidelines

Avoid heavy metal ions in solution—particularly copper and mercury. Use traps and scavengers to remove heavy metal ions in the incoming streams (brine or steam) if needed.

Eliminate dissimilar metals by using all aluminum where economically and practically feasible. When necessary place dissimilar metal joints where the least corrosion will occur and use sacrificial anodes to protect the aluminum.

Avoid very low flow or stagnant areas, such as crevices—particularly in aerated seawater.

Avoid very low pH (below 5) or very high pH (above 8) solution in contact with aluminum.

Provide hard wire grounding of all electrical instrumentation—not through the structure. Instrument lines and equipment should be aluminum or stainless steel (316).

Avoid the use of caustics.

Acid cleaning of aluminum is acceptable if carefully controlled.

Control brine flow in feed heaters in the range of 5-to-6 feet per second.

Stainless steel pumps and valves should be used where aluminum is not suitable.

Details are important! Compatibility of packing materials, gaskets, elastomers, impellers, etc., must be considered carefully and tested if needed.

D. Test and Validation

The economic advantage for the use of aluminum in the MWD VTE plant is compelling and must be pursued to ensure the cost-effectiveness of large-scale seawater desalination in Southern California. While considerable experimental evidence indicates that aluminum can perform quite satisfactorily in this application, it also indicates aluminum performance is sensitive to corrosion and erosion if a proper operating environment is not maintained. The plant design must carefully consider the compatibility of every component with aluminum, the quality of incoming brine and steam must be evaluated carefully for compatibility with aluminum—brine intake should be monitored to ensure seawater quality does not deteriorate beyond established design parameters, and a feed treatment system must be provided which fully protects the evaporator, condenser, and brine heater tubing from corrosion and erosion.

The best assurance of success in achieving these requirements is a thorough test and evaluation program which can be carried out in two phases.

Phase 1 would focus on laboratory-scale component and system tests in support of the pilot plant design. This would include:

- Laboratory-scale validation tests of aluminum alloy corrosion performance.
- Test unit validation of aluminum heat transfer and corrosion performance
- Prototypic tests of alternatives for brine distribution to the tubes, steam flow, and distribution within a vertical tube bundle and feed heater bundle, feed heater bundle seals, intereffect product flow, etc.
- Analytical analysis and validation of dynamic stability, control requirements, etc.

Phase 2 would focus on performance testing and modification of the Pilot Plant to achieve a smoothly operating system with sufficient performance data to assure the successful design of an 80 MGD VTE plant. This will likely take a minimum of 2 to 3 years of operation of the Pilot Plant.

V. SUMMARY

Aluminum is suitable for use in seawater desalination at temperatures up to 250°F. However, care must be exercised to assure that a proper operating environment is maintained.

In the Vertical Tube Evaporator concept aluminum alloy heat transfer tubes have an economic advantage in the order of a factor of 7 compared with copper alloy tubes. This derives in part from the fact that double-fluted vertical tubes can be extruded at high speed using aluminum alloys. This economic advantage of aluminum must be pursued to ensure the cost-effectiveness of large-scale seawater desalination in Southern California.

The acceptable corrosion performance of aluminum in seawater desalination has been established through laboratory-scale and pilot plant demonstration in the U.S. and through commercial application of Israel Desalination Engineering's all-aluminum Multi Effect Distillation units. This experience base has led to a number of general design rules which, when combined with a thorough test and validation program of the selected aluminum alloys and design features, are the key to the successful use of aluminum.

39625

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Dave — FYI from RRH.

TITLE: A Sea Water Evaporator Design for Southern California

SUBTITLE: Report of the Evaporator Design Team, Metropolitan Water District of Southern California

CHAPTER X: Concrete Vacuum Vessels

The use of concrete for construction of large scale vacuum vessels has a long history, the latest being the J-6 Large Rocket Test Facility currently under construction at Arnold Air Force Base, Tennessee. One unit of this project is a chamber 250 feet in diameter and 100 feet high, capable of holding vacuum of 1/2 psia. This project utilized conventional cast-in-place construction with double waterstopped and keyed joints.

The influence of seawater on concrete has been under study since the 1940's, cumulating in a series of reports beginning in 1958. Studies of the use of concrete for desalination plants by the U.S. Department of the Interior resulted in a report published in 1968.

Based on the work done by the Office of Saline Water, the Agency of Industrial Science and Technology of Japan, beginning in 1969, sponsored research for the specific purpose of determining the suitability of using concrete as an Evaporator Shell Material. These studies produced a series of reports beginning in 1972, and the construction of a 26 million gallon per day pilot plant at the Chigasaki Test Facilities.

Tazawa et al, concluded in 1977 that concrete was an "excellent evaporator shell material for desalting plants", reflecting the favorable results from operation of the pilot plant.

The use of any material for the evaporator shell requires the materials to be compatible with the required temperature, pressure and corrosive environments present within and without the shell. The exterior environment is that of a coastal region within a seismic zone.

The environment within the shell varies with temperatures up to 250 F and negative pressures of 0.95 percent atmospheric. Seawater brine, distilled water, and their associated vapors, as well as steam, provide the corrosive materials. The shell material must resist the corrosive elements and elevated temperatures without excessive deterioration and maintain the negative pressures over the entire life span.

The exterior of the evaporator shell must withstand the corrosive coastal environment of salt laden air. In addition, the structure must conform to the seismic design requirements of Southern California.

The use of concrete as a shell material provides an attractive choice, due to its ability to provide an aethetically pleasing structure, ease of construction, reduced construction time and minimal maintenance requirements. Compatibility with the required interior and exterior environments has been studied at length and described in reports by Nojiri and Fuji. Compatibility with siesmic requirements is well documented by local building codes.

The studies of concrete subjected to conditions experienced in a desalination facility show that high quality concrete will resist hot brine corrosion with insignificant deterioration. Physical properties offer no major obstacles. Very low concrete permeability is required by the operating pressures and the density desirable for protection against corrosive materials. Such concrete has high compressive strength and low-shrinkage, providing a safety factor against the reduction in compressive strength and increase in creep that is normally experienced at elevated temperatures.

Thermal stresses and temperature distribution follow standard heat transfer theory and are easility determined by standard methods. The small, shallow cracks that may occur due to rapid heat up/cooldown are insignificant and do not adversely affect air tightness or durability. An air-permeability of 10^{-7} cm/sec is easily achieved with proper material selection. Major air leaks occur at construction joints and points of penetration. This problem can easily be taken care of by proper design and construction procedures.

Distilled water very aggressively attacks normal concrete by reacting with the calcium hydroxide, available as free lime, formed from the hydration of water and portland cement. Proper use of pozzolanic materials (i.e., flyash, silica fume) sharply reduces the available calcium hyroxide, thereby reducing the leaching of free lime to a negligible amount. This effectively eliminates attack on the concrete surface, assuring proper protection of the reinforcing steel within the concrete.

A concrete mixture of non-reactive aggregates, low alkali Portland cement, Class F flyash, silica fume, air entrainment and water-reducing admixtures is capable of providing a formed concrete with extremently low permeability characteristics. With a 2.5 to 3.0 inches of cover over the reinforcing steel and proper design of attachment points and joints, a durable shell requiring minimal maintenance can be achieved.

Concrete can be used for either a horizontal or vertical configuration. A horizontal shell, requiring considerable land area, would most likely be of standard cast-in-place construction, requiring many construction joints and the risk of leakage associated with joints. Partial post-tensioning may be used to reduce possible leakage. A vertical configuration, using minimum land area, can be continuously slipformed to reduce leakage associated with joints. A clean, aesthetically pleasing structure results.

Studies of the use of corrosion inhibiting admixtures, epoxy coating of reinforcing steel; cathodic protection and the use of coatings indicate the negative impacts outweigh any advantage. The use of conventional cast-in-place concrete would appear to be the most economical; however, the need for post-tensioning and/or expansive cements to reduce air leakage minimizes the advantage over a slip-formed structure.

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A EFFEC NUMBE	B BRINE CONC X SEA	C BP ELEV DEG F	D DEL T St:Br DEG F	E DEL P STEA DEG F	F OVRAL DEL T DEG F	G BRINE TEMP DEG F	H STEAM Q IN M #/HR	I STEAM TEMP DEG F	J FD HTR LOAD M #/HR	K EVAP M #/HR	L BRINE OUT M #/HR	M CUM PROD M #/HR	N BRINE FL DN M #/HR	O PROD FL DN M #/HR	P EFFE U BTU	Q EFFECT AREA M SQFT	R HTR U BTU	S HTR AREA M SQFT
TRM HTR									0.0000								719	0.0000
EF 1	1.00	1.03	2.90	0.10	4.03	230.00	1.1760	232.90	0.1412	1.0348	33.9652	0.0000	0.0000	0.0000	1845	0.1934	719	0.0399
EF2	1.03	1.06	2.90	0.10	4.06	225.97	1.0348	228.87	0.1421	0.8928	33.0724	1.0348	0.1370	0.0000	1845	0.1934	716	0.0402
EF3	1.06	1.08	2.50	0.10	3.68	221.91	1.0298	224.81	0.1289	0.9009	32.0345	2.0646	0.1342	0.0042	1844	0.1934	714	0.0416
EF4	1.09	1.10	2.53	0.10	3.73	218.22	1.0393	220.73	0.1306	0.9087	30.9916	3.0997	0.1180	0.0076	1843	0.1934	711	0.0418
EF5	1.12	1.13	2.55	0.10	3.78	214.49	1.0343	217.02	0.1323	0.9021	29.9715	4.1264	0.1156	0.0116	1841	0.1934	708	0.0421
EF6	1.15	1.15	2.53	0.10	3.79	210.72	1.0292	213.27	0.1326	0.8966	28.9593	5.1441	0.1133	0.0156	1841	0.1934	708	0.0423
EF7	1.19	1.18	2.52	0.10	3.80	206.93	1.0255	209.46	0.1330	0.8925	27.9536	6.1540	0.1097	0.0195	1838	0.1934	705	0.0427
EF8	1.22	1.21	2.51	0.10	3.82	203.13	1.0217	205.65	0.1337	0.8880	26.9559	7.1562	0.1062	0.0234	1835	0.1934	703	0.0430
EF9	1.26	1.24	2.50	0.10	3.84	199.31	1.0176	201.82	0.1345	0.8831	25.9666	8.1503	0.1030	0.0273	1829	0.1934	700	0.0434
EF10	1.31	1.27	2.50	0.10	3.87	195.46	1.0134	197.97	0.1354	0.8781	24.9855	9.1364	0.0998	0.0313	1829	0.1934	700	0.0436
EF11	1.35	1.30	2.48	0.10	3.89	191.60	1.0092	194.09	0.1360	0.8732	24.0126	10.1143	0.0966	0.0353	1823	0.1934	697	0.0441
EF12	1.40	1.34	2.48	0.10	3.91	187.71	1.0051	190.19	0.1370	0.8681	23.0478	11.0841	0.0933	0.0393	1814	0.1934	695	0.0445
EF13	1.45	1.37	2.48	0.10	3.95	183.80	1.0007	186.27	0.1382	0.8625	22.0920	12.0455	0.0902	0.0434	1800	0.1934	692	0.0449
EF14	1.50	1.41	2.48	0.10	3.99	179.85	0.9961	182.32	0.1396	0.8565	21.1453	12.9982	0.0872	0.0476	1782	0.1934	689	0.0453
EF15	1.56	1.45	2.49	0.10	4.04	175.86	0.9913	178.34	0.1413	0.8500	20.2081	13.9419	0.0844	0.0519	1782	0.1934	689	0.0455
EF16	1.62	1.49	2.47	0.10	4.06	171.82	0.9862	174.31	0.1421	0.8441	19.2797	14.8762	0.0816	0.0563	1756	0.1934	686	0.0460
EF17	1.69	1.54	2.49	0.10	4.12	167.76	0.9819	170.23	0.1443	0.8376	18.3605	15.8019	0.0783	0.0604	1723	0.1934	684	0.0464
EF18	1.76	1.59	2.51	0.10	4.20	163.63	0.9763	166.12	0.1470	0.8293	17.4530	16.7178	0.0757	0.0652	1682	0.1934	681	0.0468
EF19	1.83	1.64	2.55	0.10	4.29	159.43	0.9702	161.95	0.1500	0.8201	16.5571	17.6228	0.0733	0.0702	1636	0.1934	678	0.0471
EF20	1.91	1.69	2.59	0.10	4.38	155.15	0.9637	157.70	0.1534	0.8103	15.6735	18.5162	0.0710	0.0755	1636	0.1934	678	0.0473
EF21	2.00	1.75	2.56	0.20	4.51	150.77	0.9568	153.36	0.1577	0.7991	14.8034	19.3975	0.0687	0.0811	1585	0.1934	675	0.0485
EF22	2.10	1.80	2.61	0.20	4.61	146.26	0.9489	148.82	0.1614	0.7875	13.9472	20.2653	0.0667	0.0874	1531	0.1934	673	0.0488
EF23	2.20	1.87	2.66	0.20	4.73	141.65	0.9417	144.25	0.1654	0.7762	13.1043	21.1195	0.0643	0.0934	1471	0.1934	670	0.0492
EF24	2.32	1.93	2.73	0.20	4.86	136.92	0.9340	139.58	0.1702	0.7638	12.2762	21.9600	0.0619	0.0998	1405	0.1934	667	0.0494
EF25	2.44	2.00	2.81	0.20	5.01	132.06	0.9256	134.79	0.1755	0.7501	11.4641	22.7858	0.0597	0.1068	1336	0.1934	665	0.0496
EF26	2.57	2.08	2.90	0.20	5.18	127.05	0.9165	129.86	0.1812	0.7353	10.6692	23.5955	0.0575	0.1143	1265	0.1934	662	0.0499
EF27	2.72	2.15	3.00	0.30	5.46	121.87	0.9070	124.77	0.1910	0.7160	9.8957	24.3883	0.0552	0.1222	1191	0.1934	659	0.0505
EF28	2.88	2.23	3.11	0.30	5.64	116.41	0.8934	119.41	0.1975	0.6960	9.1445	25.1596	0.0540	0.1331	1112	0.1934	656	0.0507
EF29	3.06	2.32	3.24	0.30	5.85	110.77	0.8831	113.88	0.2048	0.6783	8.4122	25.9096	0.0516	0.1419	1027	0.1934	654	0.0508
EF30	3.25	2.40	3.41	0.40	6.22	104.92	0.8718	108.15	0.2176	0.6542	7.7064	26.6394	0.0492	0.1516	836	0.1934	648	0.0515
FINAL	3.46	LOAD	1.319			CONDEN	0.8551	RISE	24.43		PRODUCT	27.3429				CONDS	648	0.0119

U	V	W
USER INPUT	DATE	30-Sep-91
NO. OF EFFECTS	30	
TOP BRINE TEMP	230	DEG F
STEAM SUPPLY	1.176	M #/HR
FEED RATE	35	M #/HR
SEA TEMP	61	DEG F
INITIAL DEL T	2.90	
TRIM RISE	0	
RESULTS	OF RUN	
PRODUCTION	79.06	M GALLONS/
PERFORMANCE RA	23.25	
BRINE CONC.	3.46	X SEA
BRINE FLOW	7.71	M #/HR
PRODUCT FLOW	27.34	M #/HR
DISCHARGE TEMP	90.00	DEG F
BRINE OUT TEMP	104.92	
CONDENS RISE	24.43	
PROD COOLER RIS	9.78	
BRINE COOL RISE	3.28	
CONDENSER OUTL	98.49	DEG F
EFFECT AREA	5.80	M SQ FT
HEATER AREA	1.38	
CONDENSER AREA	0.01	
TOTAL AREA	7.19	M SQ FT
REGULAR FEED: NEWX30R2		
EFFECT TUBE LEN	10	FT
HEATER TUBE LEN	20	FT
NO. TUBES/EFFECT	38672	

X	Y	Z	AA	AB
90	820	710	745	645
100	920	713	836	648
105	1030	716	936	651
110	1130	719	1027	654
115	1223	722	1112	656
120	1310	725	1191	659
125	1392	728	1265	662
130	1470	731	1336	665
135	1545	734	1405	667
140	1618	737	1471	670
145	1684	740	1531	673
150	1744	743	1585	675
155	1800	746	1636	678
160	1850	749	1682	681
165	1895	752	1723	684
170	1932	755	1756	686
175	1960	758	1782	689
180	1980	761	1800	692
185	1995	764	1814	695
190	2005	767	1823	697
195	2012	770	1829	700
200	2018	773	1835	703
205	2022	776	1838	705
210	2025	779	1841	708
215	2027	782	1843	711
220	2028	785	1844	714
225	2029	788	1845	716
230	2030	791	1845	719
235	2030	794	1845	722
240	2030	797	1845	725

A EFFECT NUMBER	B BRINE CONC. X SEA	C BP ELEV DEG F	D DEL T St:Br DEG F	E DEL P STEAM DEG F	F OVRALL DEL T DEG F	G BRINE TEMP DEG F	H STEAM Q IN M #/HR	I STEAM TEMP DEG F	J FD HTR LOAD M #/HR
TRM HTR									0.1085
EF 1	1.00	1.03	2.80	0.10	3.93	230.00	1.1760	232.80	0.1519
EF2	1.03	1.05	2.80	0.10	3.95	226.07	0.9156	228.87	0.1523
EF3	1.05	1.07	2.34	0.10	3.51	222.11	0.9111	224.91	0.1348
EF4	1.07	1.08	2.39	0.10	3.57	218.61	0.9250	220.95	0.1369
EF5	1.10	1.10	2.43	0.10	3.63	215.03	0.9197	217.42	0.1390
EF6	1.12	1.12	2.41	0.10	3.63	211.40	0.9145	213.83	0.1387
EF7	1.15	1.14	2.41	0.10	3.65	207.76	0.9115	210.18	0.1388
EF8	1.18	1.16	2.41	0.10	3.66	204.12	0.9082	206.53	0.1392
EF9	1.21	1.18	2.40	0.10	3.68	200.45	0.9046	202.86	0.1396
EF10	1.24	1.20	2.40	0.10	3.70	196.77	0.9010	199.18	0.1398
EF11	1.27	1.22	2.40	0.10	3.72	193.08	0.8976	195.47	0.1403
EF12	1.30	1.24	2.40	0.10	3.74	189.36	0.8939	191.76	0.1409
EF13	1.34	1.26	2.40	0.10	3.77	185.62	0.8902	188.02	0.1416
EF14	1.38	1.29	2.39	0.10	3.78	181.85	0.8863	184.25	0.1418
EF15	1.42	1.31	2.41	0.10	3.82	178.07	0.8829	180.46	0.1428
EF16	1.29	1.16	2.42	0.10	3.68	174.25	0.8788	176.65	0.1374
EF17	1.31	1.17	2.47	0.10	3.74	170.56	0.9371	172.98	0.1392
EF18	1.34	1.18	2.66	0.10	3.94	166.83	0.9865	169.29	0.1465
EF19	1.37	1.20	2.86	0.10	4.16	162.88	1.0306	165.54	0.1541
EF20	1.40	1.21	3.07	0.10	4.38	158.72	1.0770	161.58	0.1618
EF21	1.44	1.22	3.30	0.20	4.72	154.35	1.1260	157.41	0.1741
EF22	1.48	1.24	3.55	0.20	4.99	149.63	1.1729	152.92	0.1834
EF23	1.52	1.25	3.83	0.20	5.28	144.64	1.2272	148.19	0.1938
EF24	1.57	1.27	4.17	0.20	5.65	139.35	1.2836	143.18	0.2065
EF25	1.62	1.29	4.57	0.20	6.06	133.71	1.3412	137.88	0.2209
EF26	1.68	1.31	5.01	0.20	6.52	127.65	1.4014	132.22	0.2369
EF27	1.75	1.33	5.52	0.30	7.15	121.13	1.4649	126.14	0.2587
EF28	1.82	1.34	6.10	0.30	7.74	113.98	1.5279	119.50	0.2792
EF29	1.91	1.36	7.35	0.30	9.01	106.24	1.5997	112.34	0.3235
EF30	2.00	1.37	8.27	0.40	10.05	97.23	1.6546	104.58	0.3591
FINAL	2.11	LOAD=	0.836			CONDENS	1.7335	RISE	34.77

K EVAP M #/HR	L BRINE OUT M #/HR	M CUM PROD M #/HR	N BRINE FL DN M #/HR	O PROD FL DN M #/HR	P EFFECT U BTU	Q EFFECT AREA M SQFT	R HTR U BTU	S HTR AREA M SQFT	T
							719	0.0344	
0.9156	36.0844	0.0000	0.0000	0.0000	1845	0.1697	719	0.0267	
0.7633	35.3212	0.9156	0.1478	0.0000	1845	0.1697	716	0.0269	
0.[illegible]62	34.3971	1.8266	0.1450	0.0038	1844	0.1697	714	0.0263	
0.7881	33.4641	2.7479	0.1250	0.0066	1843	0.1697	711	0.0266	
0.7807	32.5583	3.6610	0.1236	0.0101	1843	0.1697	711	0.0268	
0.7758	31.6589	4.5653	0.1220	0.0137	1841	0.1697	708	0.0270	
0.7727	30.7642	5.4631	0.1184	0.0171	1838	0.1697	705	0.0272	
0.7690	29.8768	6.3542	0.1152	0.0205	1835	0.1697	703	0.0274	
0.7650	28.9966	7.2384	0.1122	0.0239	1835	0.1697	703	0.0275	
0.7612	28.1233	8.1155	0.1092	0.0273	1829	0.1697	700	0.0277	
0.7573	27.2568	8.9859	0.1060	0.0306	1823	0.1697	697	0.0279	
0.7530	26.3977	9.8492	0.1031	0.0340	1814	0.1697	695	0.0282	
0.7486	25.5460	10.7054	0.1003	0.0374	1814	0.1697	695	0.0283	
0.7445	24.7012	11.5543	0.0975	0.0409	1800	0.1697	692	0.0285	
0.7401	38.4635	12.3963	0.0944	0.0442	1782	0.1697	689	0.0288	
0.7413	37.6278	13.2309	0.1481	0.0477	1756	0.1697	686	0.0281	
0.7979	36.6818	14.1203	0.1395	0.0490	1756	0.1697	686	0.0282	
0.8400	35.7023	15.0577	0.1377	0.0530	1723	0.1697	684	0.0287	
0.8765	34.6882	16.0353	0.1410	0.0595	1682	0.1697	681	0.0292	
0.9153	33.6318	17.0529	0.1441	0.0666	1636	0.1697	678	0.0296	
0.9519	32.5358	18.1123	0.1467	0.0744	1585	0.1697	675	0.0305	
0.9895	31.3997	19.2108	0.1527	0.0850	1531	0.1697	673	0.0310	
1.0334	30.2136	20.3530	0.1552	0.0950	1471	0.1697	670	0.0314	
1.0771	28.9812	21.5416	0.1578	0.1063	1405	0.1697	667	0.0319	
1.1203	27.7031	22.7766	0.1612	0.1198	1336	0.1697	665	0.0324	
1.1645	26.3774	24.0581	0.1648	0.1355	1265	0.1697	662	0.0329	
1.2062	25.0063	25.3875	0.1683	0.1535	1191	0.1697	659	0.0337	
1.2487	23.5893	26.7619	0.1742	0.1768	1027	0.1697	654	0.0343	
1.2762	22.1389	28.1848	0.1773	0.2011	936	0.1697	651	0.0349	
1.2954	20.6663	29.6383	0.1927	0.2453	745	0.1697	645	0.0358	
	PRODUCT=	31.1265	LMDT=	5.86303		CONDS=	645	0.4741	

U	V	W
USER INPUT	DATE	24-Mar-92

NO. OF EFFECTS	30	
TOP BRINE TEMP	230	DEG F
STEAM SUPPLY	1.176	M #/HR
FEED RATE (TOP)	37	M #/HR
(MID)	14.6	
SEA TEMP	61	DEG F
INITIAL DEL T	2.80	
TRIM RISE	2.81	

RESULTS OF RUN

PRODUCTION	90.00	M GALLONS/DAY
PERFORMANCE RATIO	26.47	
BRINE CONC.	2.11	X SEA
BRINE FLOW	20.67	M #/HR
PRODUCT FLOW	31.13	M #/HR
BRINE OUT TEMP	97.23	
CONDENSER RISE	34.77	
CONDENSER OUTLET	95.77	DEG F
PROD COOLER RISE	0.06	
BRINE COOL RISE	0.00	
FEED INLET TEMP	95.82	DEG F
EFFECT AREA	5.09	M SQ FT
HEATER AREA	0.92	
CONDENSER AREA	0.47	
TOTAL AREA	6.49	M SQ FT

SEMI-TAPER: ST3-392

EFFECT TUBE LENGT	10	FT
HEATER TUBE LENGT	20	FT
NO. TUBES/EFFECT	33949	
TUBE SHEET AREA	1286	SQ FT
NO. HTR TUBES	11655	

39625

SEAWATER DESALINATION STATUS REPORT

MEETING NOTES

THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

AD HOC COMMITTEE

ENERGY
AND
DESALINATION

MONDAY
FEBRUARY 10, 1992

SEAWATER DESALINATION STUDIES

• General Atomics, 1989	Nuclear Powered 100 mgd Distillation Plant	$300,000
• Bechtel, 1990	Fossil Fuel Powered 100 mgd Distillation & Existing Coastal Power 25 mgd Distillation Plant	$75,000
• Black & Veatch, 1991	New San Diego Power Plant 30 mgd Hybrid Distillation & Reverse Osmosis Plant	$50,000
• Bechtel, 1991	New Baja Power Plant 100 mgd Hybrid Distillation & Reverse Osmosis Plant	$100,000
• Black & Veatch, 1992	Repowered SDG & E South Bay Reverse Osmosis Plant	$30,000

SOURCES FOR STAFF STUDY OF DESALINATION OPTIONS

- Recent State-of-the-Art Studies
  - General Atomic 1988, Bechtel 1989, San Diego, Black & Veatch 1991
- Interviews with Major Vendors of all Processes
  - IDE, Sashakura, Swenson, Sidem, LA Water Treatment, Ionics
- Work with Outstanding Authorities in the Field

Design Reviewers	Design Team
	Dr. R.P. Hammond, Leader
- Watson	- Eissenberg
- Laughlin	- Emmerman
- Leitner	- Jones
- Standiford	- Sephton
	- Snodgrass
	- Rider

OPTIONAL SOURCES FOR WATER SUUPLY

Transport Item

- Alaska, Columbia Pipelines
- Towing Icebergs
- Towing Bags
- Ocean Thermal Energy
- Tankers
- Cloud Seeding

Desalination

- Solar Stills
- Multi-Stage Flash
- Multi-Effect Distillation
- Vapor Compression
- Freezing
- Electrodialysis
- Reverse Osmosis

APPLICATION OF DESALINATION TECHNOLOGY

- Reclaimed Water
  - Membrane Technology
- Groundwater Recovery
  - Membrane Technology
- Seawater Desalination
  - Distillation & Membrane Technology

FULL SCALE DESALINATION

- Large Scale Desalination is the Most Energy Efficient
- Large Scale Projects Will Have Greater Impacts on:
  - Coastal Environment
  - Water Distribution
  - Water Quality
  - Energy Use
  - Water Costs

DESALINATION PLANT CAPACITY TERMINOLOGY

1 Million Gallons per day = 1,120 AF/Year

If a Plant is 90% Available Then

$$\frac{\text{1 Million Gallons}}{\text{1 Day}} = \text{1000 AF/Year \&}$$

$$\frac{\text{100 Million Gallons}}{\text{1 Day}} = \text{100,000 AF/Year}$$

or

Say 8% of Existing Colorado River Supplies

CALIFORNIA SEAWATER DESALINATION

Projects		Capital Costs/GPD	Water Costs/AF
Bechtel	25 MGD MED	$4.75	$1,000
San Diego Black & Veatch	30 MGD MED	$5.61	$1,253
San Diego Black & Veatch	30 MGD RO	$4.48	$1,121
*Santa Barbara	5 MGD RO	$6.00	$2,000
Marin County	5 MGD RO	$8.00	$2,300
MWD	80 MGD MED	$2.50	$600 - $750

AUTHORIZED $500,000 SEAWATER DESALINATION DEMONSTRATION PLANT PLANNING STUDY, JULY 1990

Status	Item	Cost
100%	Background Research	$50,000
75%	Conceptual Design	$250,000
95%	Action Plan	$50,000
80%	Water Quality Survey	$50,000
5%	Permit Requirement Study	$50,000
	Miscellaneous	$150,000
	Total	$500,000
	Authorized Revision November, 1991	$150,000
	Total Budget	$650,000
	Commited Funds	$400,000
	Actual Costs December 31, 1991	$285,000

SEAWATER DESALINATION ENERGY NEEDS

- Large Amounts of Energy
  - High Quality Energy
    - Electrical
    - High Pressure Steam
  - Low Quality Energy
    - Low Pressure Steam

SEAWATER DESALINATION ENERGY NEEDS (cont.)

- Low Quality Energy is Provided by a Power Plant
- Local Power Utilities Plan to Repower Coastal Power Plants
  - Meet Increased Demand
  - Lower Heat Rate (Power/Fuel)
  - Reduce Air Emissions
- A Large Scale Seawater Desalination Plant Built in Conjunction with a Power Plant Repower Project will Provide Capital and Operating Cost Benefits.

SPACE EFFICIENCY

- Coastal Land is Scarce, Expensive and Restricted
- Some Power Stations May Have Only Some Sites Available
- Existing Processes Must be Adapted to Fit Needs of Large Capacity, Small Space, High Efficiency

INITIAL DETERMINATIONS FOR DEMONSTRATION PLANT STUDY

- Reverse Osmosis and Multiple Effect Distillation are only Processes Worthy of Consideration
- The Most Feasible Locations are at Existing Coastal Power Stations (12 in MWD Region)

  - Coastal Power Stations have:
    - Sea Intake and Outfalls
    - Discharge Permits
    - Industrial Zone on Coast
    - Turbine Exhaust Steam Energy

REVERSE OSMOSIS

- Well-Known and Proven Process
- Can be Located Anywhere
- Uses High Quality Energy - Electricity or High Pressure Steam
- Recent R & D Work has Improved Reliability not Efficiency
- Plant Layout can be Adapted to Vertical Stacking
- Existing RO Units are Industry Standard, Unlikely to Change, Regardless of Size of Plant
- Modified Process Feasible but Very Small Cost Advantage from Scale-up to Large Units

MULTI-EFFECT DISTILLATION PROCESS

- Well Known and Proven Process
- Uses Low Quality Exhaust Steam Energy from Power Turbine
- Limited to Locations at Power Plants
- Federal Agency Research and Pilot Plant Experience Supports Process Performance
- No R & D Work over Last 10 Years
- Vertical Tube Version of Process is Presently Used in Other Industries
- Large Units Practical, With Large Cost Benefit from Scale-Up

BOTH RO AND MED PROCESSES NEED MODIFICATION FOR MWD USE

- Available Units too Small
- Land Use too Large
- Energy Efficiency too Low
- Estimated Water Costs $1200/AF
- Existing Water Costs $2000 to $5000/AF

MWD MODIFICATION
VERTICAL STACKING CONCRETE SILO VESSEL

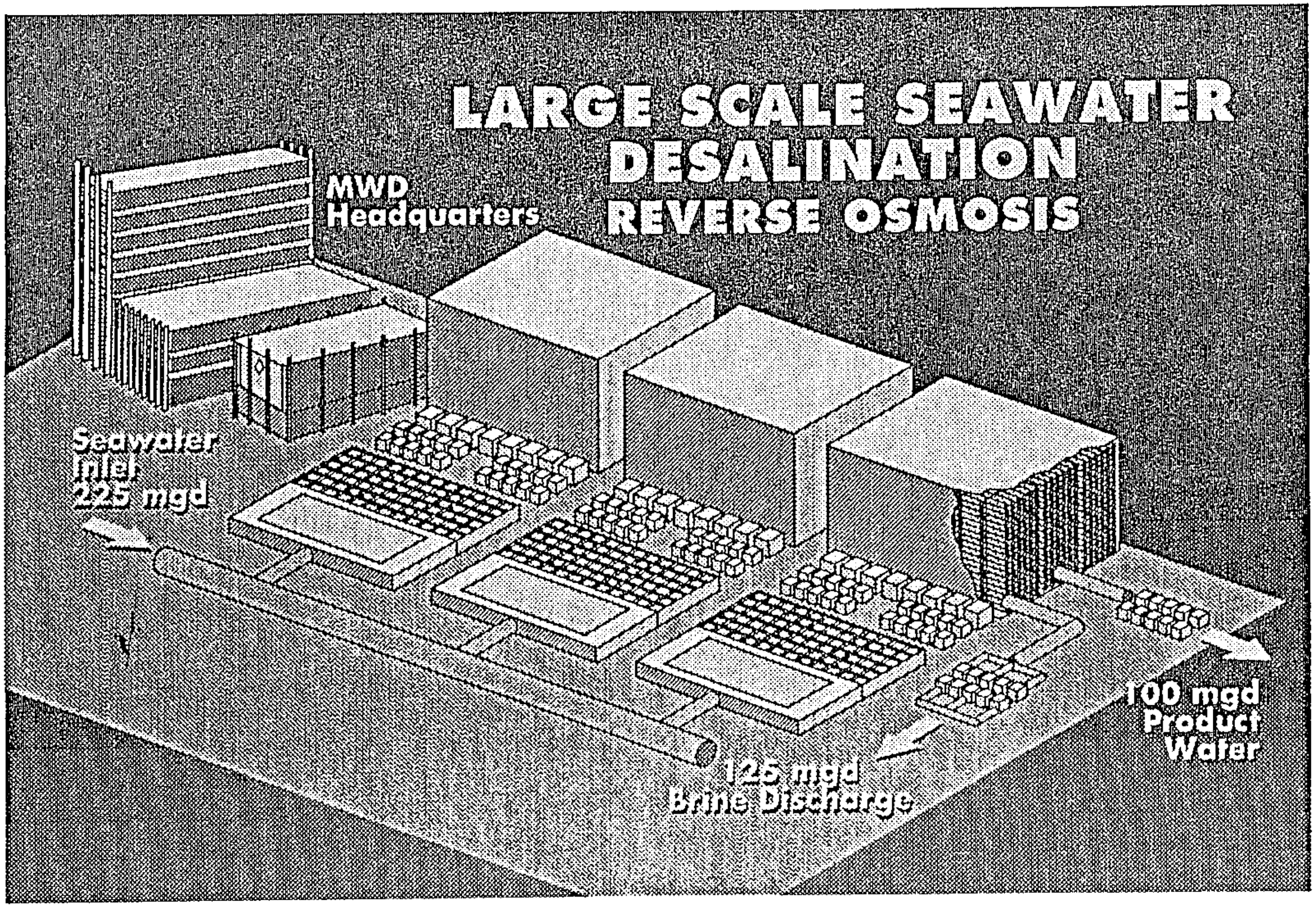
- Does Not Change the Physical Process
- Rearranges the Plumbing for Vertical Flow
- Fewer Pumps Needed
- More Compact Plant
- Requires Much Less Land
- Used in Other Industries
- MWD is Experienced in Large Concrete Structure Construction

CRITICAL DESIGN PARAMETERS

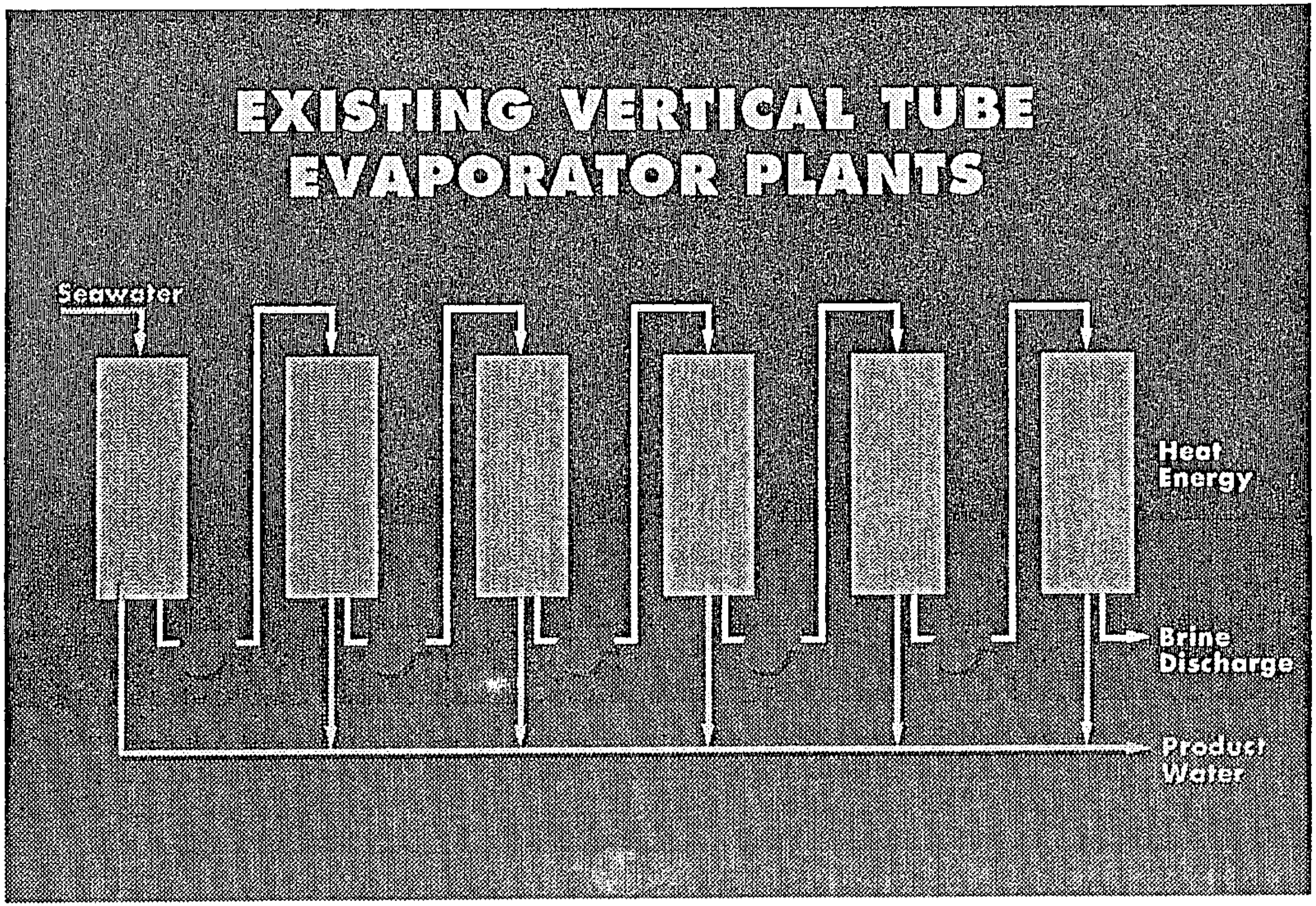
- Fluted Tubes
- High Temperature Operation
- Vertical Stacking
- Concrete Vessel

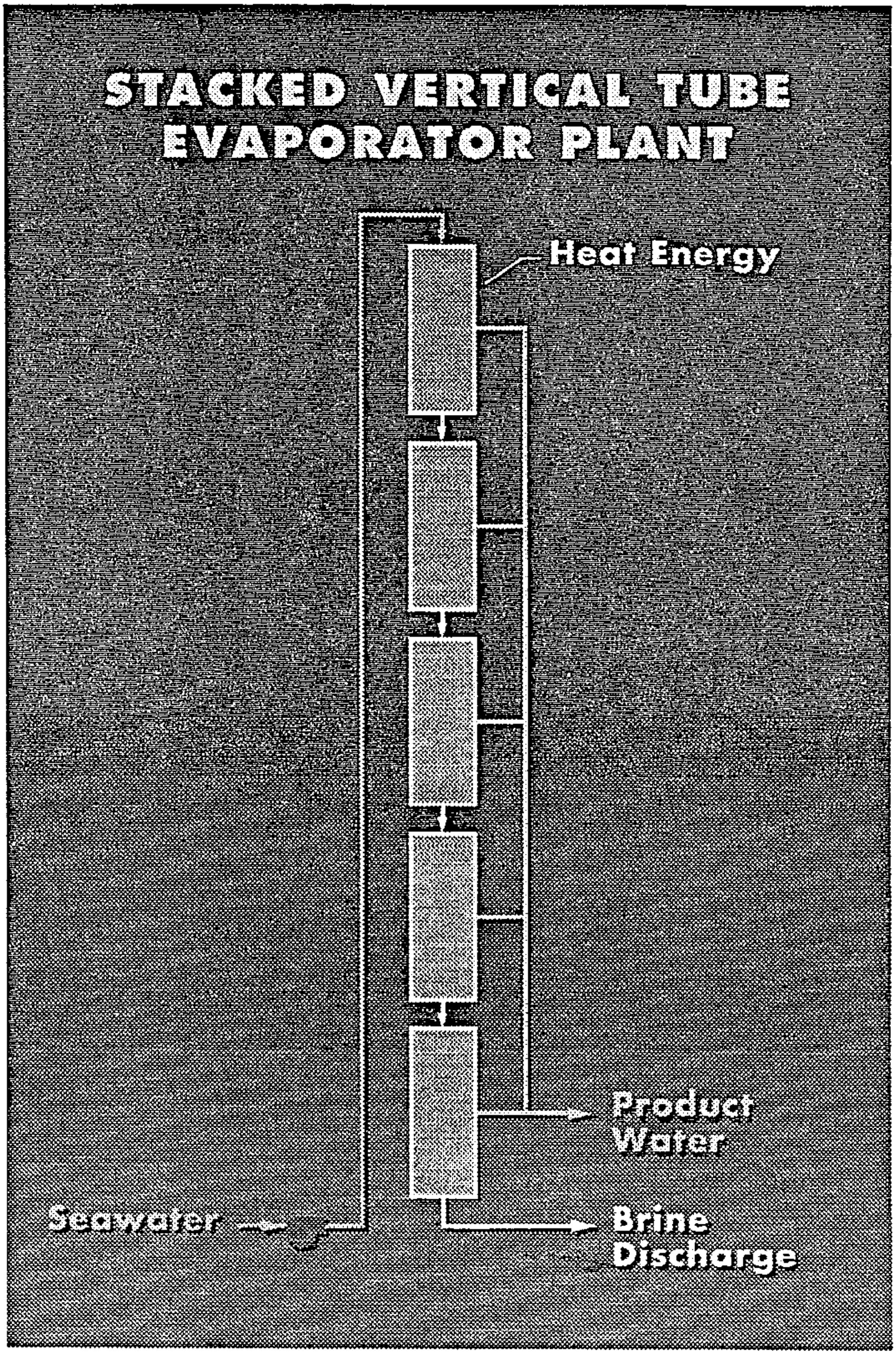
FLUTED TUBES

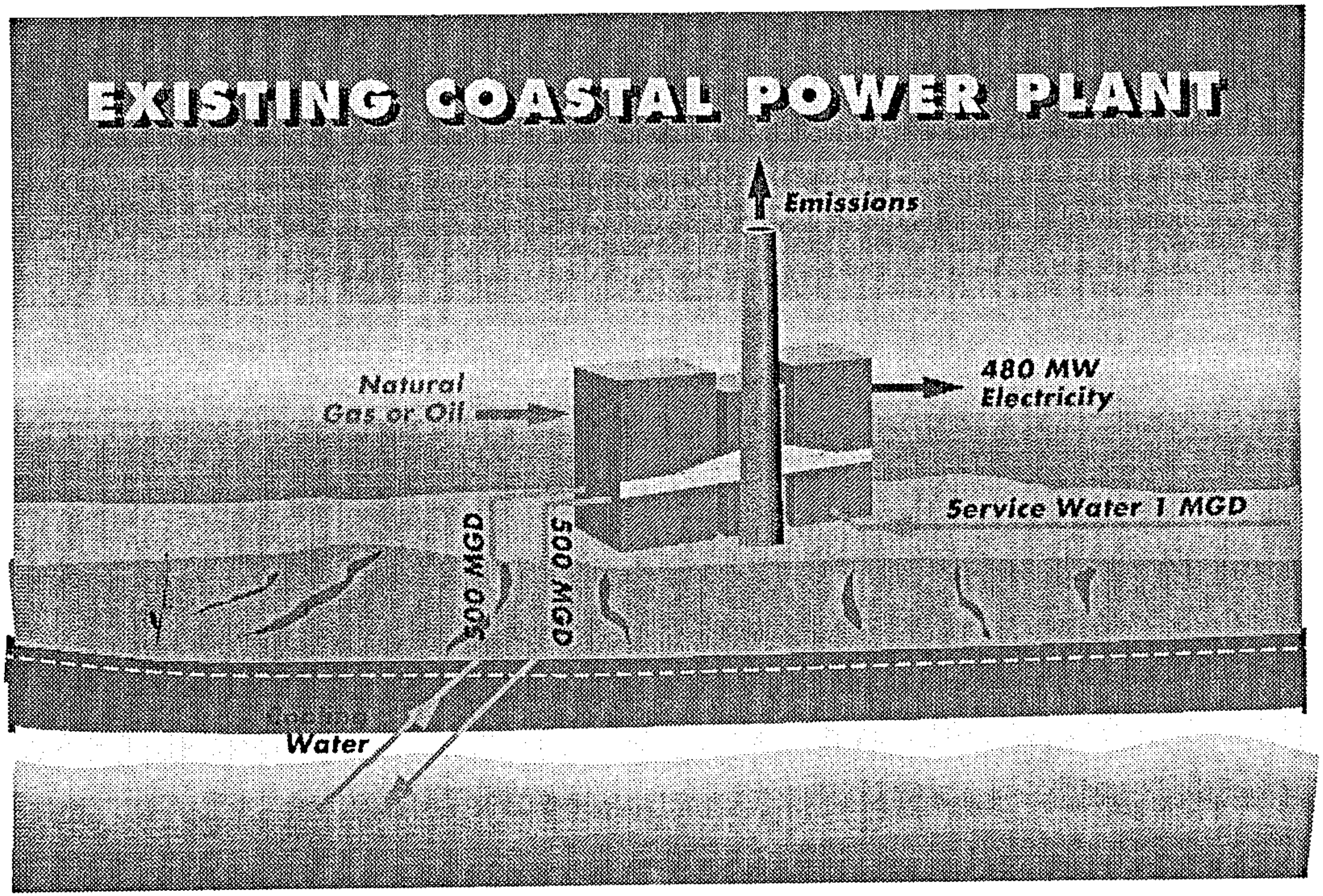
- Invented 30 Years Ago by Swiss Engineer
- Greatly Improved by Work at ORNL
- More Than Doubles Tube Efficiency
- Halves the Plant Volume Needed
- Commercially Available and Widely Used
- Not Usable in Horizontal Tube Evaporators



LARGE SCALE SEAWATER
DESALINATION
REVERSE OSMOSIS
MWD
Headquarters
Seawater
Inlet
225 mgd
100 mgd
Product
Water
125 mgd
Brine Discharge


EXISTING VERTICAL TUBE
EVAPORATOR PLANTS
Seawater
Heat Energy
Brine Discharge
Product Water


STACKED VERTICAL TUBE
EVAPORATOR PLANT
Heat Energy
Product
Water
Seawater
Brine
Discharge


EXISTING COASTAL POWER PLANT
Emissions
Natural
Gas or Oil
480 MW
Electricity
Service Water 1 MGD
500 MGD
500 MGD
Water

39625