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isn = 17121 ~~P583~~

THE SUN - - -

THE SEA - - -

and FRESH WATER - - -

SOLAR DISTILLATION TECHNOLOGY

The sun - the sea - and fresh water - solar distillation technology.
628.1672 Agency for International Development,
A265 Washington, D.C. Office of Engineers.
The sun - the sea - and fresh water - solar distillation technology. 1966.
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II.Title: Solar distillation technology.

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NOVEM

Department of State
AGENCY FOR INTERNATIONAL DEVELOPMENT
OFFICE OF ENGINEERING
Washington, D.C. 20523

A.I.D. HISTORICAL AND
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PN-AB[illegible]-163
73042

THE SUN - - -
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SOLAR DISTILLATION TECHNOLOGY

NOVEMBER 1966

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AGENCY FOR INTERNATIONAL DEVELOPMENT
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"In those lands (developing nations), there is an urgent need for water that is simply clean and pure enough for basic human needs—for drinking, for cooking, for washing and bathing . . . ."

PRESIDENT LYNDON B. JOHNSON
Summerville Dam Dedication
September 3, 1966

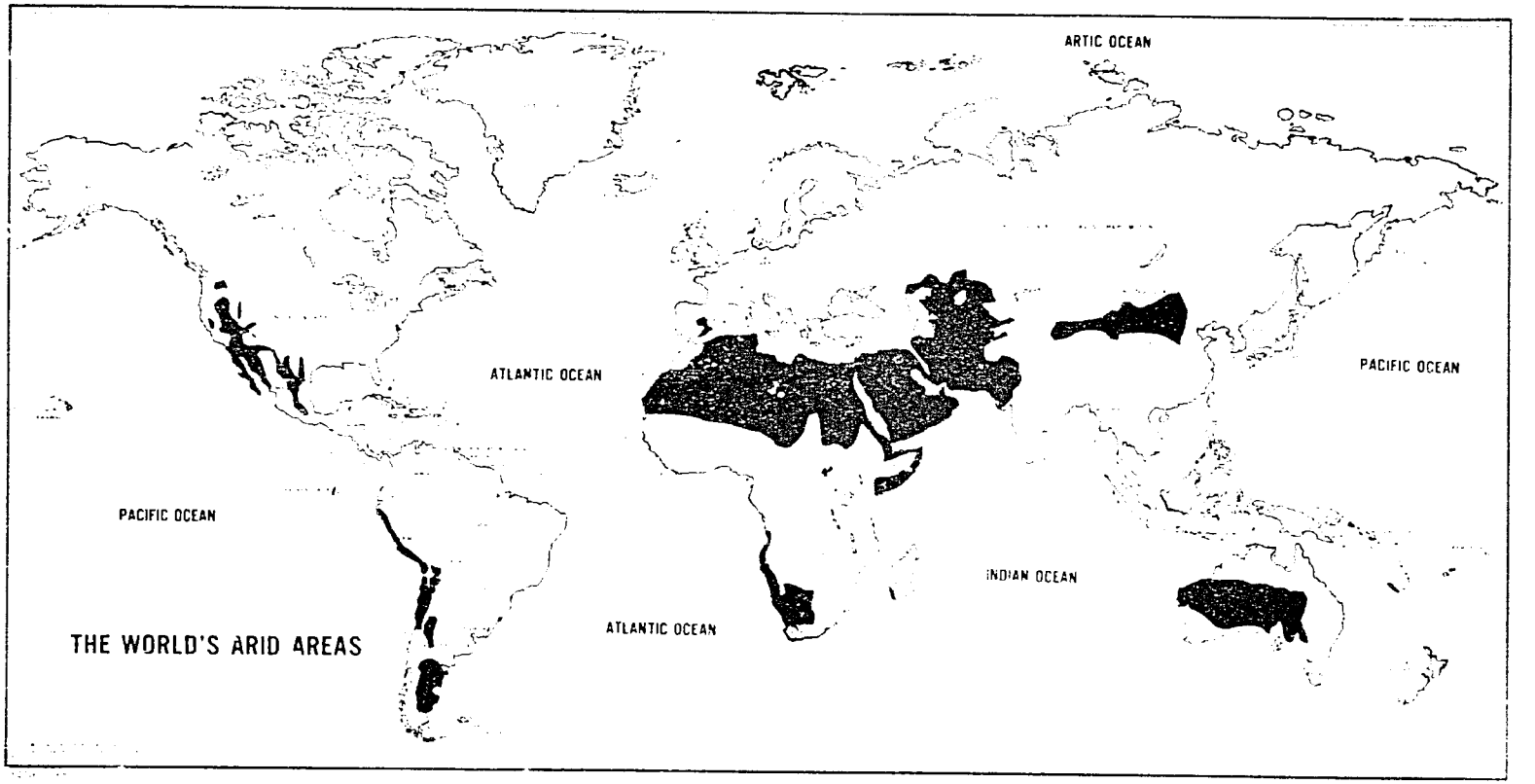
ARTIC OCEAN
ATLANTIC OCEAN
PACIFIC OCEAN
PACIFIC OCEAN
INDIAN OCEAN
ATLANTIC OCEAN
THE WORLD'S ARID AREAS

Figure 1.

THE SUN AT WORK

On the Isle of Patmos in the Aegean Sea one of the largest solar stills in the world will be built to produce fresh water for thirsty islanders. It is an example of using the sun's energy to produce fresh water from the sea at a reasonable cost. Actually, there is nothing complicated about solar stills; they are simple to design, easy to build, and usually trouble free to operate. They do not require expert engineers or technicians to run them. The most complicated piece of machinery is a water pump. Concrete, glass, and asphalt are the principal building materials, and these are abundant and inexpensive throughout most of the world.

Solar stills could work in the Arctic, if necessary, but their most likely application is between the latitudes of 10° N. and 50° N. (See map). In this wide belt lie many of the land masses of the world and also some of the most arid lands, sometimes fertile, bathed in an abundance of sunshine, yet lacking water for agriculture, industry, or human consumption. 1/ Fortunately, there are plentiful amounts of sea or underground brackish waters which can be made into fresh water. Concrete, glass, asphalt, sunshine, and seawater - these are the ingredients. They need only to be put together to produce water for man's need.

Solar stills are not new. A 6,000-gallon-per-day unit that produced water for many years was built in Chile about 1875. There was almost no other interest in them until Congress established the Office of Saline Water (OSW) in 1952. From then to 1964 that office invested nearly a million dollars in a solar still program which advanced the state of the art and stimulated worldwide interest. 2/ Now, the technology is quite well developed, but there is not enough experience with prototype or production plants to fully establish their role in the world's growing shortage of fresh water. In 1965 the OSW concluded its solar distillation program because the solar still does not appear to economically satisfy the large and ever increasing fresh water demands in the United States. This does not mean that solar stills should be abandoned. On the contrary, improvements in designs, materials, and operation will further reduce the water cost, and the solar still will become even more attractive to the developing nations.

Solar Energy

Solar stills are operated by energy directly from the sun, and the lure of this free energy has intrigued engineers for many years. When one considers the amount received by the earth, it is indeed a fanciful figure to dream about. Each year the earth's

---

1/ The map does not show the many thousands of islands where solar stills could supply fresh water.

2/ See Appendix II for OSW Bibliography.

surface receives about 25 X 10^{20} Btu's (British thermal units). This amount is 100,000 times more than the total energy produced yearly from oil, coal, and gas for the entire world! A part of this energy produces about 250 billion acre-feet of water as rainfall, most of which flows to the oceans. As an economic oddity, if a charge of $10 an acre-foot was made for this water, the annual income would be in the trillions of dollars. Although these are astounding figures, the average intensity of solar energy coming to the earth's surface is relatively low, being about 1,500 Btu's per square foot per day. In sunny locations it exceeds 2,000 Btu's, which is enough to vaporize about two pounds of water. In table I below are some maximum and minimum daily values of solar radiation for selected locations around the world. Surprisingly, our Southwest is among the sunniest places on earth.

Table I.

Selected Solar Radiation Data

(Btu/ft^2/day)

Location	Maximum	Minimum	Yearly Average
Algeria	2,400	1,460	2,000
Argentina	2,650	765	1,580
Australia	2,350	757	1,575
India (Poona)	2,690	1,430	1,980
Egypt	2,370	1,200	2,030
Caribbean Area	2,280	1,528	1,940
SW USA (El Paso, Texas)	2,730	1,200	2,030

The variation of solar energy received throughout a clear day is illustrated by the curve in figure 2. As expected, the amount is greatest at noon. The total energy received is equal to the area under the curve, or about 1,800 Btu's for this particular day.

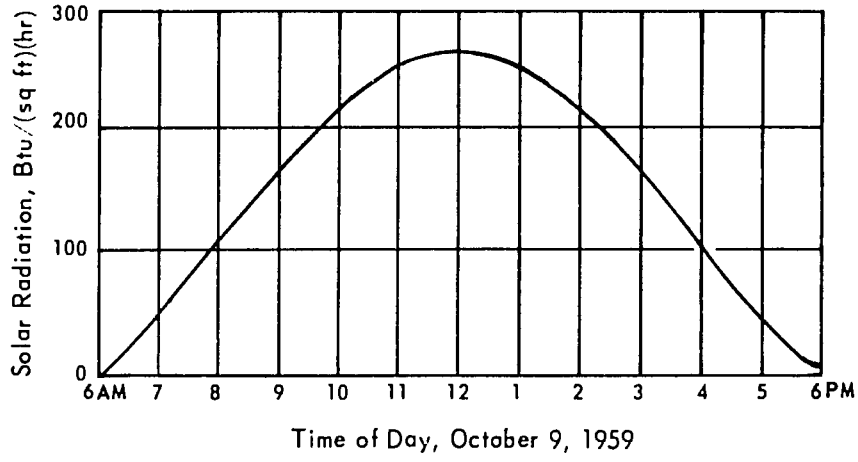

Figure 2. Solar Radiation for a clear day
Daytona Beach, Florida

Solar Still Design

The major appeal of the solar still is its simplicity. It is essentially a basin or box covered with a transparent material. The sketches in figure 3 show two principal types: the basin and the tilted wick types.

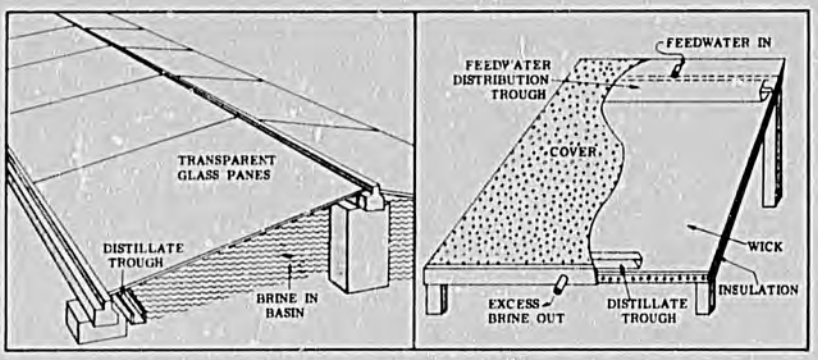

Figure 3. Basin and Wick Types Solar Stills

Solar energy passing through the cover heats up the brine or sea water in the basin; this causes the water to vaporize. The vapor then rises and condenses on the underside of the cover and runs down into distillate troughs. The wick type still, shown on the right, operates in the same manner except that the water evaporates from a wetted black wick. The wick type stills are tilted to collect the greatest amount of solar energy. For either type the cover may be glass or plastic. Much time and effort have been spent in developing low-cost plastics having specific properties for solar still construction. A desirable plastic is one which is cheap, relatively inert to solar radiation, and wettable. Although suitable plastics have been developed, they have some disadvantages. One disadvantage is that some plastic films become brittle and deteriorate from the sun's ultraviolet radiation. Consequently, the plastic films have to be replaced from time to time, but chemists have learned how to modify some plastics so that they will have a longer life. Another disadvantage is that the condensing water usually forms droplets on the surface of the plastic film. These droplets reflect a portion of the sun's rays back to the sky and they often drip back into the basin. Production is then reduced. If the plastic films were wettable, no loss would occur because the condensed fresh water would run off in a thin layer into the collecting trough. Now, it is possible to produce wettable films by chemical and mechanical means though at a greater cost. In spite of these disadvantages several large plastic solar stills have been built, but reports have revealed other problems. The thin films have been damaged by heavy rains, by other bad weather conditions, and by wildlife; in addition, the plastic gathered dust which was removed using fresh water from the still. Yet the outlook for the plastic covered solar stills is good because plastics provide opportunities to alter the designs and also to reduce the unit costs. The development and testing of new plastic stills continue under private sponsorship and recent reports indicate increased productivity and a reduction in material and construction costs. For the moment, however, the glass-covered stills appear to be the most reliable design. The OSW glass-covered test stills at Daytona Beach, Florida, have gone through hurricanes without excessive damage, and there is a report that glass solar energy collectors have withstood hailstorms of moderate severity. Thus, the rugged nature of these stills will insure a longer life and help to cut the costs for producing potable water.

The solar stills in figures 4 through 7 show the types which have been built and tested.

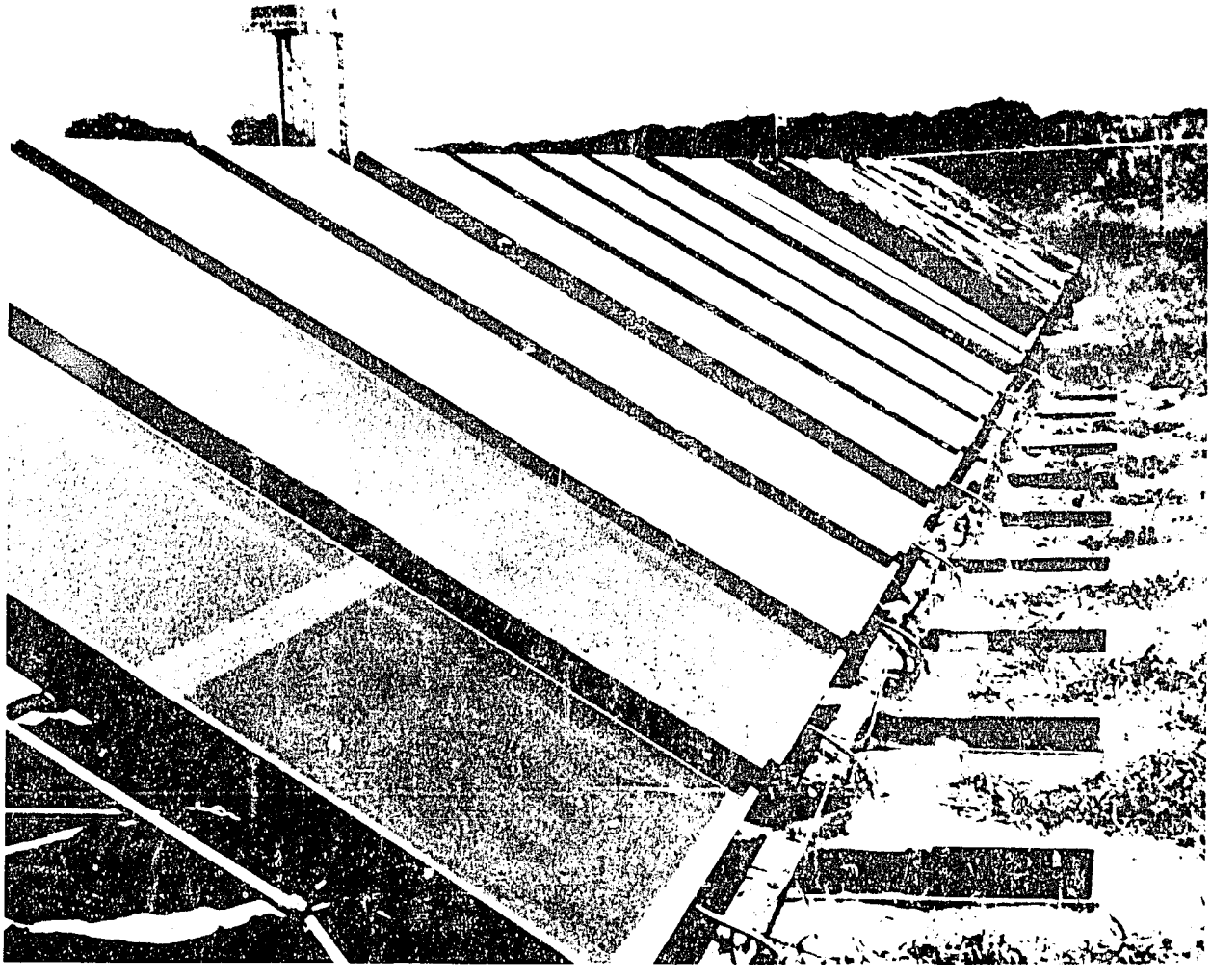

Figure 4. Tilted-Wick Still

This type of still can be prefabricated and installed on suitable supporting framework at the site. Water evaporates from a cloth wick and condenses on the underside of a transparent cover, which can be glass or plastic. These stills are tilted to increase interception of solar energy. Although productivity is high, wick life is short, and control of feedwater to the wick is difficult. Installed cost is estimated to be approximately $2 per square foot. This kind of still never advanced beyond the experimental stage, and it is not recommended for a prototype or production plant.

Figure 5. Inflated Plastic Still

This is one of the earliest inflated plastic stills, designed by DuPont and built by Battelle at the Office of Saline Water Research Station near Daytona Beach, Florida. Operation was generally satisfactory, but the installation cost was relatively high. This was the forerunner of later plastic still designs. Present designs, using low-cost plastics and simplifications in film retaining structure, can be built for an estimated $0.50 per square foot.

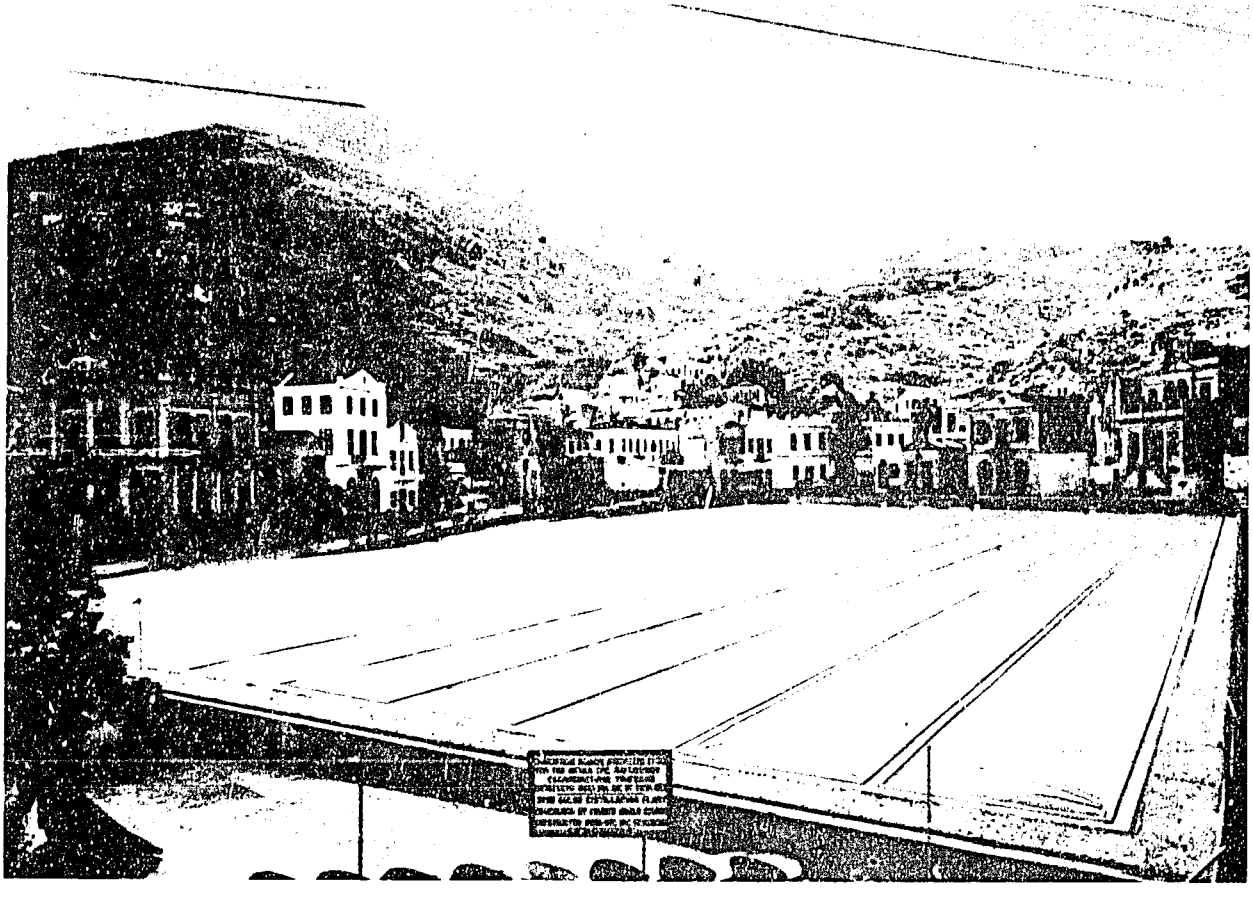

Figure 6. Inflated Plastic Still

This is a relatively new design of a plastic-covered, air-inflated still, installed on the island of Symi in Greece by the Church World Service to supply drinking water to a small village. As mentioned previously, dust and other debris settling on the outer surfaces of the plastic film have to be washed by some of the product water. Thus, some production is lost. Cost figures have not been published, but installed cost is thought to be about $1.50 per square foot.

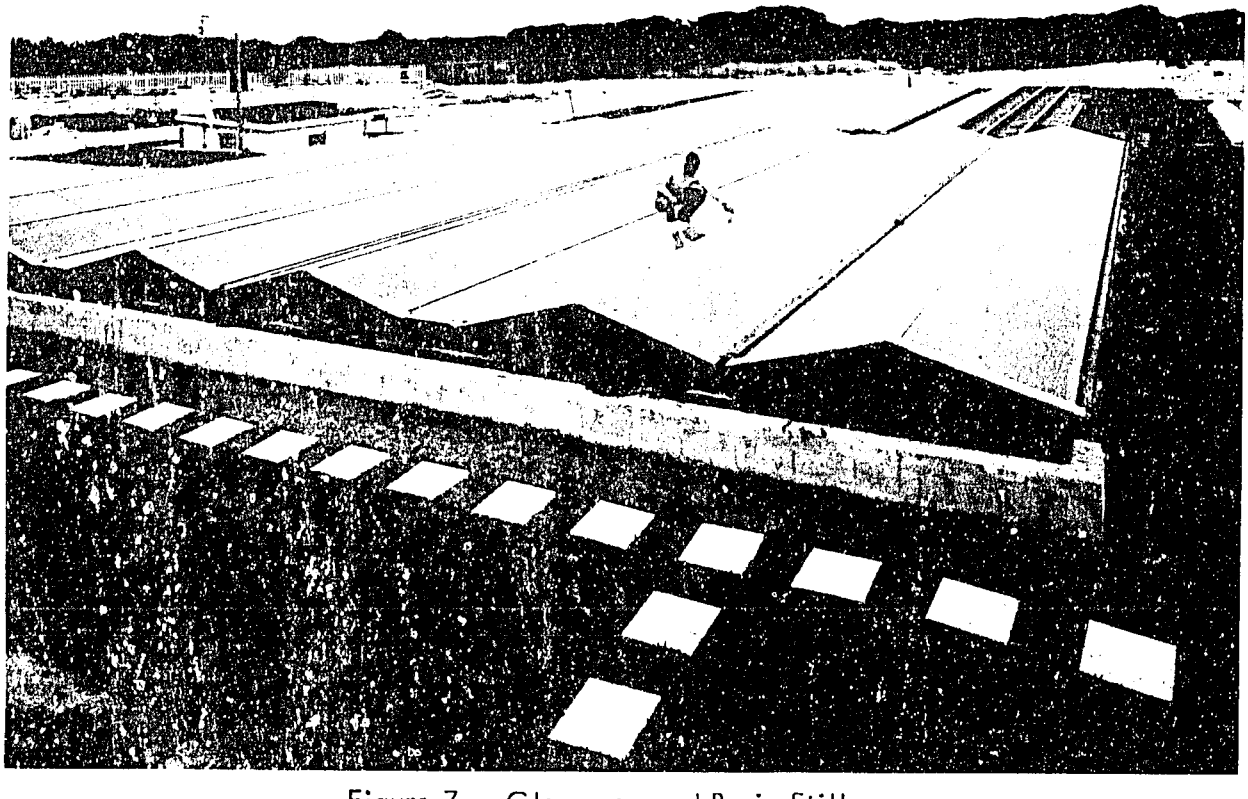

Figure 7. Glass-covered Basin Still

This still consists of a waterproof basin and a glass cover, with the glass supported by concrete beams and pedestals. This particular design was developed by Battelle engineers and Dr. George Löf at the Daytona Beach Solar Station. It is the most durable and most highly developed of the solar stills and can be expected to operate for many years with little maintenance or operating labor. Installed cost in large-sized plants is approximately $1 per square foot, although this will vary from country to country abroad.

The Cost of Water

Water is seldom free. In the early days of America there was an abundance of it at relatively little cost. When cities and towns grew up and central water systems were necessary, water costs began to mount. As the country developed, the business of supplying water became more complex and costly. Cities had to protect watersheds, build reservoirs, construct water treatment plants, and erect vast transportation and distribution systems. The real cost of water began to increase. Sometimes it was not passed on to consumer but appeared in the form of taxes or other levies. In the United States water has been looked upon as a commodity which should be plentiful and cost next to nothing. Even in our water-short areas, such as the western part of the nation, agricultural water has to be cheap. The farmer or rancher cannot afford to pay high costs for water and make a profit from his business. Good water at low costs is an incentive for industrial development. Municipal water must be potable and clean. Thus, each consumer has essentially the same requirement for water quality, and all would like it to be essentially free.

The cost of desalting water by a mechanical process is, in most cases, not competitive with the cost of water from a natural supply, but where the natural supply is limited or non-existent the cost is secondary. To offset a growing water shortage, Congress established the Office of Saline Water to develop economical methods for producing from sea or brackish waters potable water for municipal, industrial, and other uses. It was hoped that the cost could be reduced to supply agricultural needs, but the cost differential is still too great. Nevertheless, after some twelve years of concentrated effort the cost for desalting water has decreased until it is estimated to be between 35¢ to 40¢ per thousand gallons from the very large multistage flash distillation plants. 1/ This is equivalent to about $130 an acre-foot, which, as mentioned previously, is too high for agricultural uses. In California, agricultural water costs from $3.50 an acre-foot to as high as $25 an acre-foot.

What is the outlook for solar distillation? All water producing processes require energy, and for the other conversion methods the cost of energy accounts for a significant part of the overall water cost. Solar energy is free, but the equipment for capturing and using it is not. The distribution of water costs shown in Figure 8 clearly emphasizes the importance of energy cost on the one hand and the investment costs on the other for the two distillation processes. Note that nearly 80% of the water cost from a solar still is in the capital investment (amortization). The reason is that solar stills cover large areas in order to "capture" enough energy to produce fresh water. For example, a 25,000-gallon-per-day still covers from four to six acres of ground (175,000 to 260,000 ft.^{2}). A flash plant of equal capacity would fit into 2,500 ft.^{2}! Fortunately, solar stills are constructed from inexpensive materials - asphalt, cement, and glass - and can be erected in areas of low land cost so that the total investment is not prohibitive. Note also in figure 8 the relative labor costs for the two processes. Here, solar stills have a definite advantage - especially for a developing country - because highly trained technical personnel are not required to operate and maintain the equipment.

1/ Typical costs of desalted water from 50-mgd plants conceptual design studies. Cost of water from the 150-mgd Metropolitan Water District Plant (California) is estimated at 21¢/1,000g ($68/acre-foot).

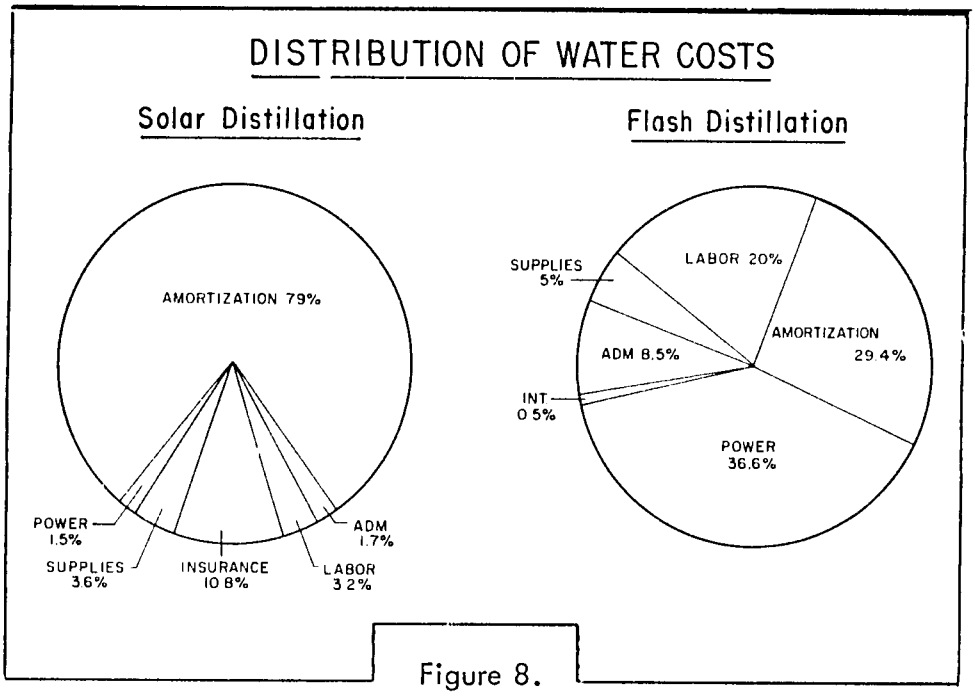

Figure 8.

The approximate construction costs for a basin type, glass-covered solar still are shown in Table II.

Table II.

Construction Costs for Typical Basin-Type Solar Still
(per 1,000 sq. ft. of area)

ITEM	MATERIALS* (Dollars)	LABOR (Man-Hours)
Layout, grading, compacting and soil sterilization	$ 10	20
Asphalt mat liner 1/	80	40
Concrete blocks	60	10
Precast concrete beams	190	25
Glass and asphaltic cement	210	25
Distillage trough materials	50	5
Miscellaneous piping and pumps	70	5
Storage tank	50	5
TOTALS	$720	135

*U.S. Prices

1/ Substitute materials may be used to seal the solar still basin; e.g., coated cement, jute or bamboo sealed with natural gum or tar.

In the column on the right are the man hours of labor needed for each phase of construction. These figures may be used to approximate construction costs abroad, but material and operating costs will vary from country to country. The actual cost of the water depends upon many factors. For purposes of comparison, a 25,000-gallon-per-day solar still in the United States would produce water for $2 to $3 per 1,000 gallons. The cost of water from a flash plant of equal capacity could cost upward of $3. per 1,000 gallons. For plants producing millions of gallons daily the flash process has a definite advantage. The OSW 1-million-gallon-per-day plant at San Diego, California produced water for approximately $1.20 per 1,000 gallons (OSW RPT 1964). It is uncertain where the breakeven point is, but it appears that solar stills are competitive in capacities of about 50,000 gallons per day except where there is a ready source of inexpensive fuel as in a gas or oil field. For plant sizes below this rating, solar stills become increasingly attractive because their cost per unit of capacity does not change appreciably whereas the cost per unit of capacity of a flash distiller rises sharply as the size is reduced. Although water at $2 to $3 per thousand gallons is more expensive than many U.S. municipal water supplies, there are countless communities in the world where people pay more than $3. Often this water is of very poor quality - brackish or polluted. Abundant supplies of pure water for domestic uses at a rate of 3 gallons for each cent will be enthusiastically accepted.

The relationship between the size of a solar still and its capacity depends upon its design and efficiency. As an approximation, the area/capacity ratio is 10:1 if the unit is glass-covered and well insulated. For example, a 25,000-gallon-per-day still would require about 250,000 ft.^{2}.

The glass-covered solar stills have other advantages, which can be seen from figure 7. This unit can serve as a catchment for rainfall. For every inch of rain, a 25,000-gallon-per-day still would collect about 160,000 gallons of water. 1/ Another way to increase production is by blending the product water with the feed. For sea water the increase is small, being on the order of 2%, but if a brackish water of 5,000 ppm 2/ salt is the feed to the still, blending would increase production by about 11%. The blended water would then have a salt concentration of 500 ppm, which is considered an upper limit by the U.S. Public Health Service. 3/ If World Health Organization (WHO) standards of 1,200 ppm are followed, the increase would be about 32%. The water from solar stills is not only free of salt, but it is also free of bacteria, or other disease producing organisms. Nevertheless, chlorination is recommended especially if the water is blended or stored.

Construction of a Solar Still

The construction of a 300 gallon-per-day glass-covered, basin-type solar still is shown on pages 14 through 29. This unit was built and tested by the Battelle Memorial Institute at the OSW Solar Test Station, Daytona Beach, Florida. Production or prototype units could be constructed using typical construction equipment available in most of the developing nations and also using local labor. Simplicity of operation and maintenance is evident from the design of the unit.

1/ In many arid areas the amount of rainfall may amount to several inches each year.
2/ ppm = parts per million. Sea water averages 35,500 ppm salt.
3/ In blending it is important to restrict the total concentration of chlorides to an acceptable level.

Solar Stills Today and Tomorrow

The Church World Service and anonymous donors have sponsored a program for building solar stills on several islands in the Aegean Sea. A 4,000-gallon-per-day unit was dedicated in 1964 on Symi, an island with a population of 3,000. Up to this time the people depended on the collection and storage of rainwater, a practice not uncommon in many places throughout the world. In 1965 the Church World Service also built solar stills on the islands of Salamis and Aegina. Another was scheduled for Santorini in 1966. (Table III). A parallel program of the Government of Greece will entail the construction of large stills on the islands of Kimolos, Nisyros, and Patmos in 1966 and 1967. Portugal, Spain, Australia, and Tunisia have started projects of their own with units in operation or under construction in the Cape Verde Islands (Portugal), Las Marinas and Tabarca (Spain), Northam and Coober Peedy (Australia), and Gafsa (Tunisia). Thus, the solar still has passed from the development stage through a private sponsor phase to government supported programs. An international program may emerge from President Johnson's recently announced "Water for Peace" plan to help solve international water problems. 1/ In this respect the Agency for International Development (A.I.D.) can lend technical assistance and perhaps some financial support.

A.I.D. is able to assist many of the developing arid nations in some of their water problems. Appendix A shows those nations with arid lands where solar stills might be used to produce a supply of potable water. Note that most of these countries produce cement, a basic construction material for the stills. Some of the nations also produce glass; however, where one material is lacking, it may be convenient to import it from a nearby country, again with the assistance of A.I.D. in the following way: The Office of the Controller, in a publication entitled "Status of Foreign Currency Funds" (3/31/66) shows currencies held by the United States throughout the world. These funds were generated by the sale of American commodities and they might be used for purchasing the required materials for export to an adjacent country where a solar still project is proposed. The recipient nation then should provide the land, labor, and locally available materials as part of the "self-help" effort.

Water is a simple substance and is the life blood of our present day civilization; no nation today can advance its economy without an ever-increasing supply. But water management and the economies of supply are complex and often controversial. If the natural supplies are short, desalination is a means for obtaining fresh water, and it may be practical under certain circumstances. The feasibility of desalination to provide large quantities of fresh water has been studied in depth for both the United States and certain countries abroad. In California, for example, desalting sea water may supplement existing water supplies; in New York it may "drought-proof" 2/ a protracted drought similar to the drought period of 1961-65; or in some Mid-east countries it may be the only alternate source of fresh water. Regardless of the situation there are many complex, interlocking factors which require evaluation before the true value of desalination can be assessed. On the other hand, the evaluation of the solar still as a water supply for an arid area is simple. For the first time, perhaps, the islanders on Symi, Aegina, and so on are not dependent upon rainfall. The solar still provides a reliable

1/ First International Symposium on Desalination, October 1965.

2/ Drought Proofing by Desalination, Johnson, Bruce; Paper to ASCE, Las Vegas, Nev., November 1966.

source of water diminished only during cloudy or rainy weather! Then, it becomes a catchment and the supply is assured. The solar still becomes more than just a means for obtaining water; it is an insurance against either a drought or no water at all. This asset may be difficult to relate in terms of dollars or cents; nevertheless it is real and should be considered in cost evaluation or feasibility studies.

Finally, the solar still may stimulate new enterprises, such as tourism, cottage industries, or hydroponics for food production. It may even make habitable many picturesque coastal areas. The solar still is no panacea, but within limitations it can provide a source of fresh water to help the economy in many developing nations.

Table III.

Large Solar Stills Today

Location		Capacity (gpd)	Type
GREECE	- Aegina	2,500	Plastic
	- Kimolos	~~10,000~~ 3,000	Glass
	- Nisyros	~~10,000~~ 3,000	Glass
	- Patmos	~~20,000~~ 10,000	Glass
	- Salamis	500	Plastic
	- Santorini	*	--
	- Symi	4,000	Plastic
AUSTRALIA	- Northam	330	Glass
	- Coober Pedy	3,500**	Glass
SPAIN	- Las Marinas	1,000	Glass
	- Tabarca	2,500	Glass
PORTUGAL	- Cape Verde (Santa Maria do Sal)	--	Plastic
TUNISIA	- Gafia	750	Glass

*Planned. **Yearly average, but production expected to be 6,500 gpd during summer.

Appendix A

LIST OF COUNTRIES BY DESERTS 1/

North American Desert
- USA 2/,3/
- Mexico 2/,3/

Atacama-Peruvian Desert
- Peru 2/
- Chile 2/

Monte-Patagonian Desert
- Argentina 2/,3/

Australian Desert
- Australia 2/,3/

Gobi Desert
- Mongolia
- China 2/

Takla-Makan Desert
- China 2/

Turkistan Desert
- USSR 2/,3/

Thar Desert
- India 2/,3/
- Pakistan 2/,3/

Iranian Desert
- Pakistan 2/,3/
- Afghanistan 2/
- Iran 2/,3/

Arabian Desert
- Bahrain
- Iraq 2/
- Israel 2/,3/
- Jordan 2/
- Kuwait
- Muscat & Oman
- Quatar

Arabian Desert (Cont'd)
- South Arabia
- Saudi Arabia 2/
- Syria (UAR) 2/
- Trucial Coast
- United Arab Republic (Egypt) 2/
- Yemen

Somali-Chalbi Desert
- Ethiopia (Eritrea) 2/
- French Somaliland
- Somalia
- Kenya 2/

Sahara Desert
- Algeria 2/
- Cameroon 2/
- Chad
- Libya
- Mali
- Mauritania
- Morocco 2/
- Niger
- Nigeria 2/
- Spanish Sahara
- Sudan 2/
- Tunisia 2/
- United Arab Republic 2/
- Upper Volta

Kalahari-Namib Desert
- Angola (Portugese W. Africa)
- Bechuanaland
- South Africa 2/,3/
- South West Africa

1/ Geography of Coastal Deserts, Meigs, Perevil, UNESCO No. 28 (1966

2/ Cement Producers - U.S. Dept. Interior, Bureau of Mines Mineral Yearbook (1964)

3/ Glass Producers - International Directory, Glass Industry (1966)

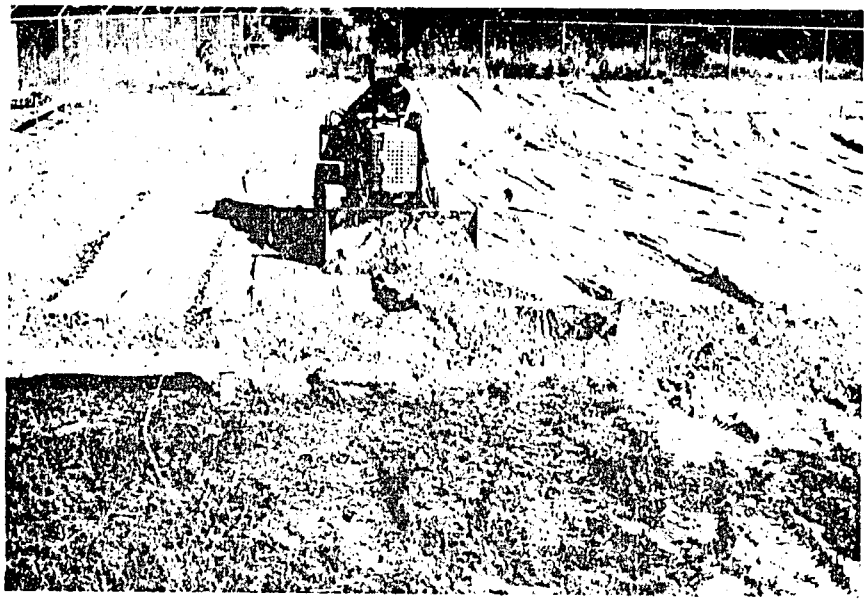

Figure A-1. The first step in the construction was rough grading by dozer.

Here the bottom of the basin is being scooped out and the perimeter dike is being formed roughly to shape.

Figure A-2. The dike was compacted with a small mechanical tamper.

For a large still this compaction could be done by a sheep's foot roller.

Figure A-3. The compacted dike was given its final shaping by hand.

For a large still this operation could be done with a mechanical grader.

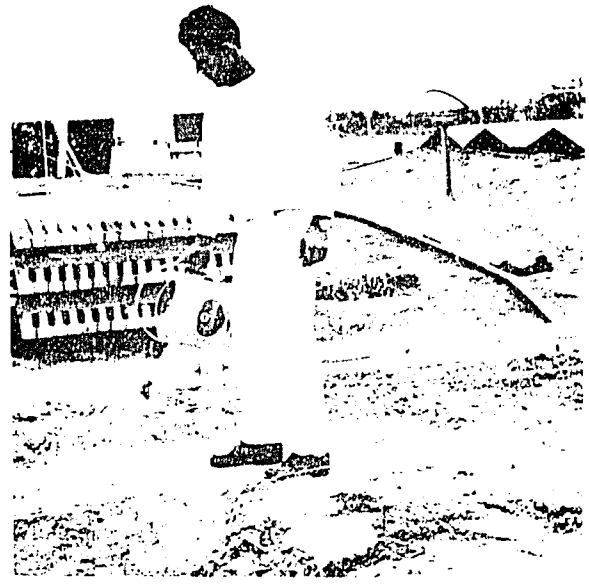

Figure A-4. A soil sterilizer was sprinkled on the prepared ground to prevent the growth of weeds which might puncture the basin liner.

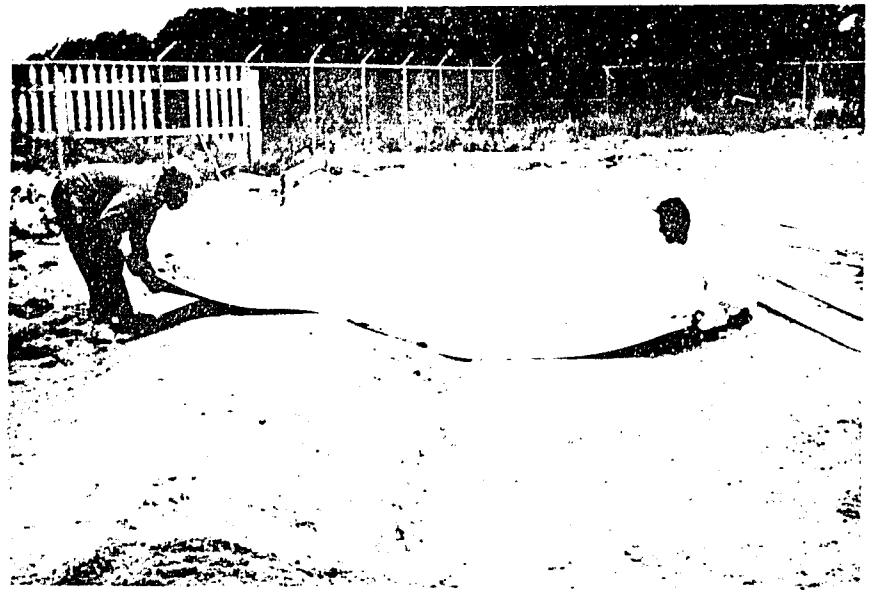

Figure A-5. The prefabricated asphaltic liner (1/4 inch thick) was placed in sections, starting at the periphery.

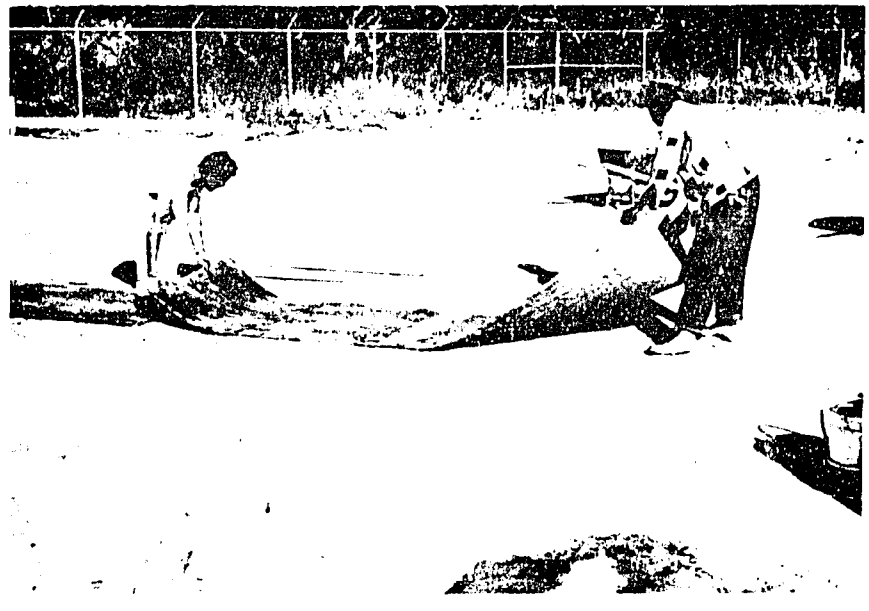

Figure A-6. After the asphaltic mats had been laid completely around the dike, the center sections were fitted into position.

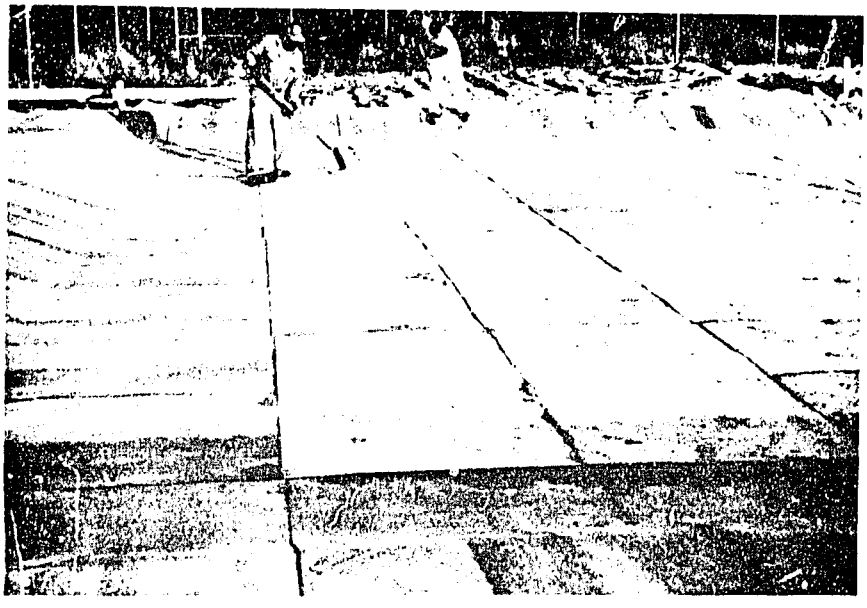

Figure A-7. When all mats were in place, excess mica and sand were swept away in preparation for the gusset cover strips.

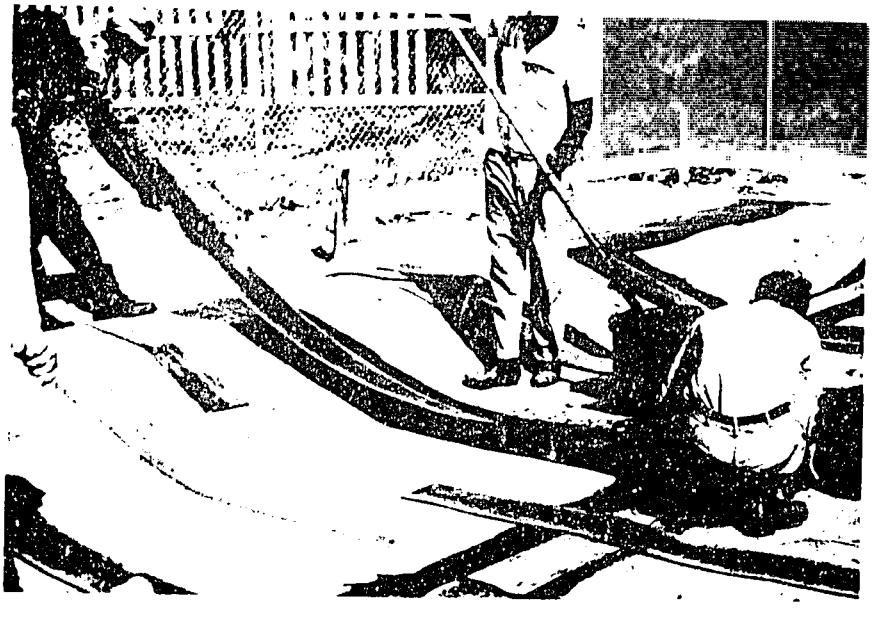

Figure A-8. Gusset cover strips were placed over the joints of the mats using hot-mopping asphalt.

Figure A-9. As further protection against leakage, the edges of the gusset strips were pointed up with a fillet of asphaltic cement.

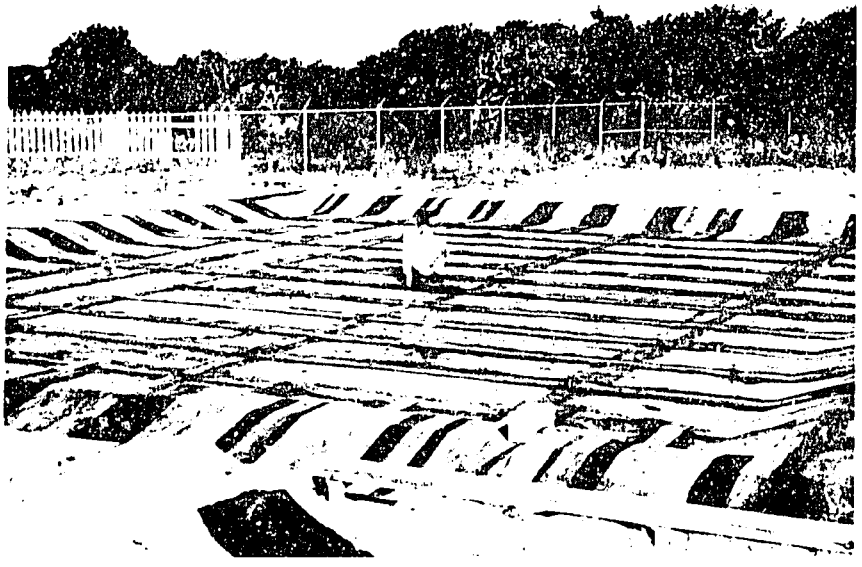

Figure A-10. The completed water-tight basin.

Figure A-11. Asphalt mat pads were placed in position to reinforce the liner at points where the glass-support pedestals were to rest.

Figure A-12. Special sea-water-resistant pedestal blocks 8 x 8 x 12 inches were set in place and leveled.

Figure A-13. The 8 x 8 x 8-inch cap of the pedestal blocks was set in place with grout.

Figure A-14. The concrete blocks of the end walls and the precast concrete beams at both ends of the still were set carefully in place.

Spacing sticks were used to ensure setting of the beams at the center-to-center distances.

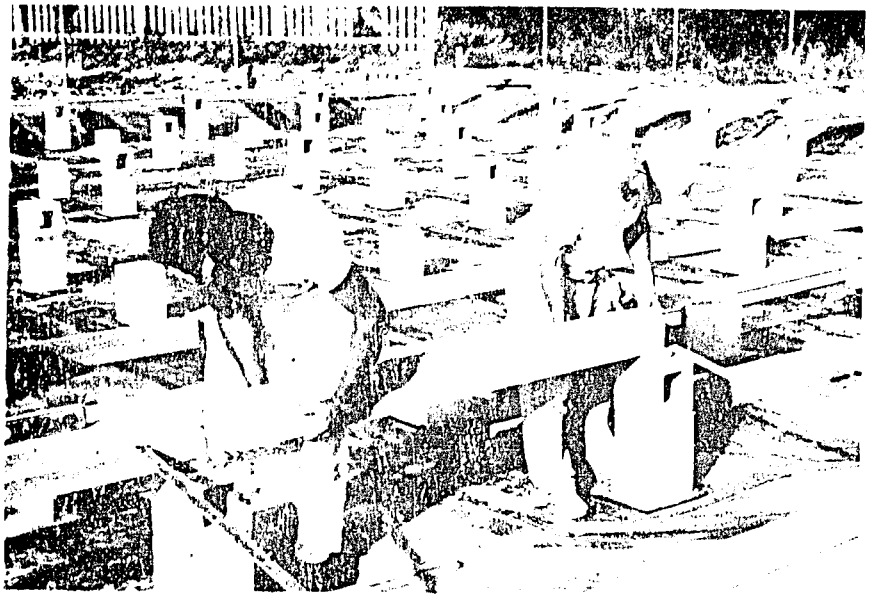

Figure A-15. A chalk line was used in placing the rest of the concrete beams in each row. Spacing sticks were used on all beams to ensure proper spacing. Care was taken that the glass-carrying surfaces were in line at joints.

Figure A-16. With all the precast concrete beams in place, the still was ready for the installation of the distillate troughs and the glass cover.

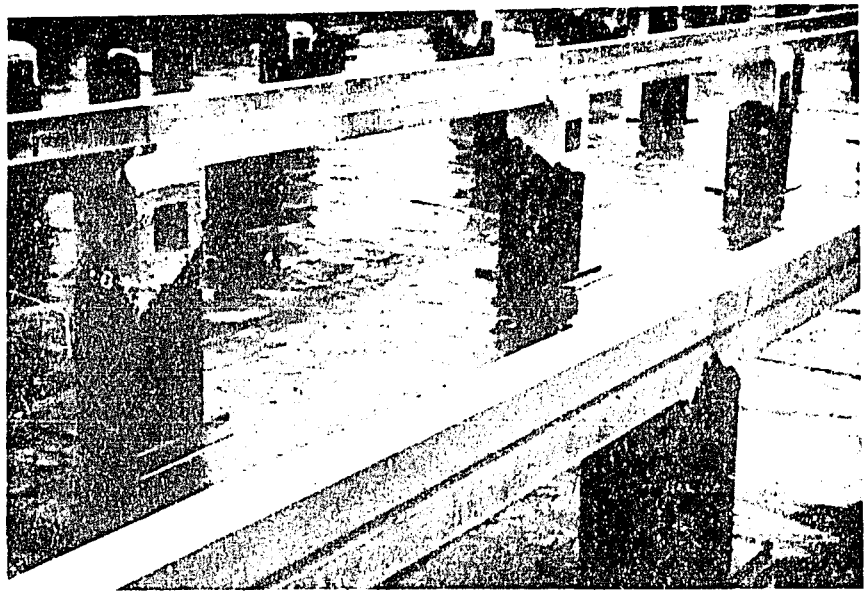

Figure A-17. Just prior to the installation of the distillate troughs and glass cover, the basin liner was given a coat of hot-mopped asphalt as an added protection against leakage and to give black surface.

The special sea-water-resistant blocks were also coated as added protection.

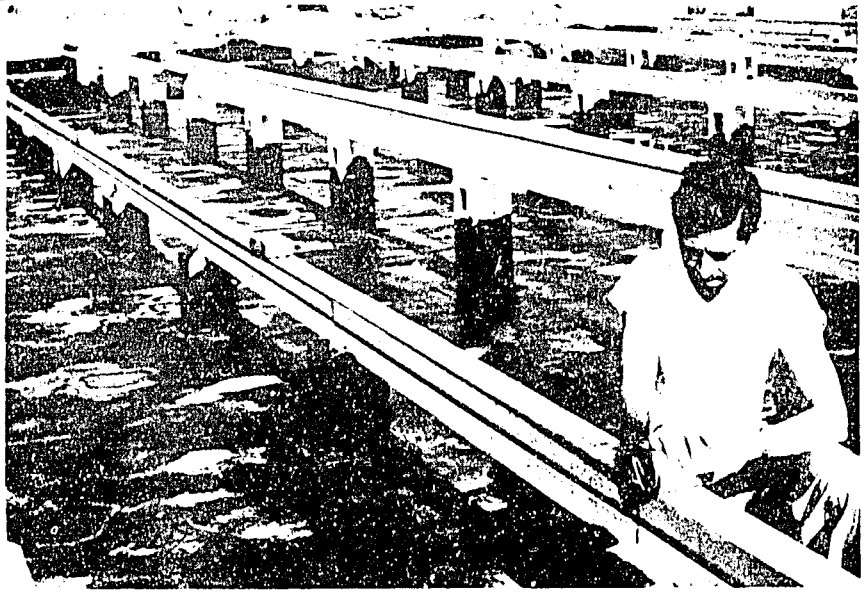

Figure A-18. The continuous copper strips (4 inches x 0.005 inch thick) which were to form the distillate trough were rolled out on top of the lower beam.

Figure A-19. The edge of the copper strip to be inserted into the groove in the lower beam was formed by folding it upward.

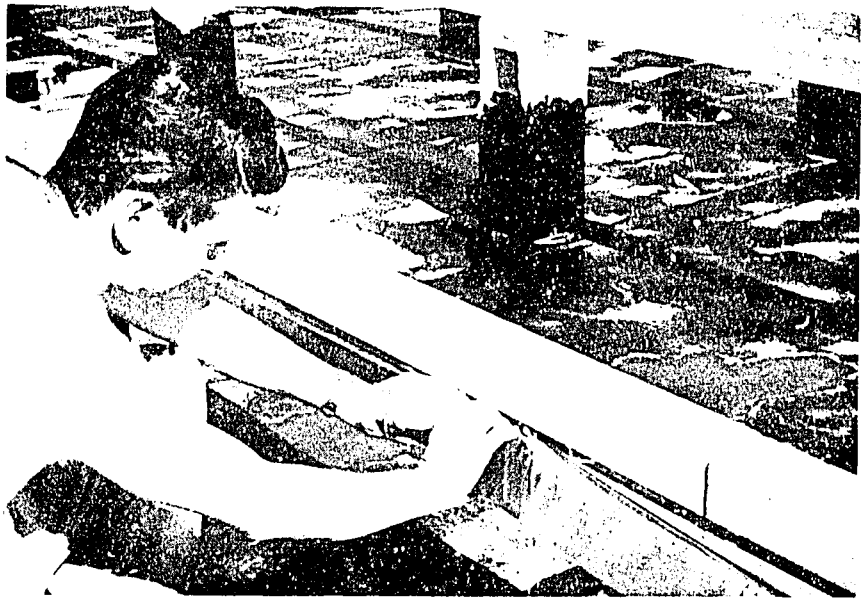

Figure A-20. The folded edge of the copper strip was inserted in the groove of the beam. The rest of the strip was folded down along the beam.

Figure A-21. Wooden slats were used to hold the copper strips in place while the rest of the trough was being formed and until the glass was installed.

Figure A-22. The distillate trough was completed by folding the strip up around a stick.

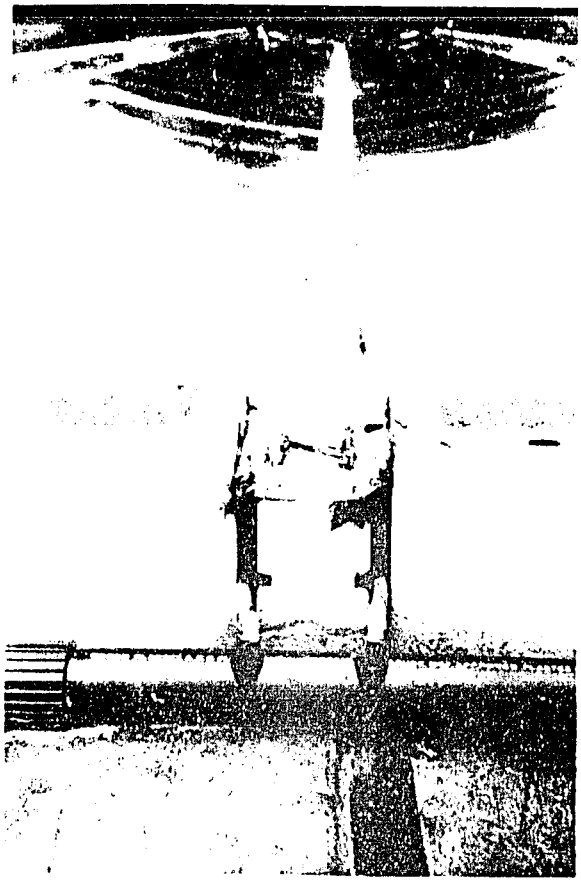

Figure A-23. The distillate troughs were extended through the end wall at one end. A plastic header pipe, suitably notched, was placed beneath the end of the troughs to collect the distillate.

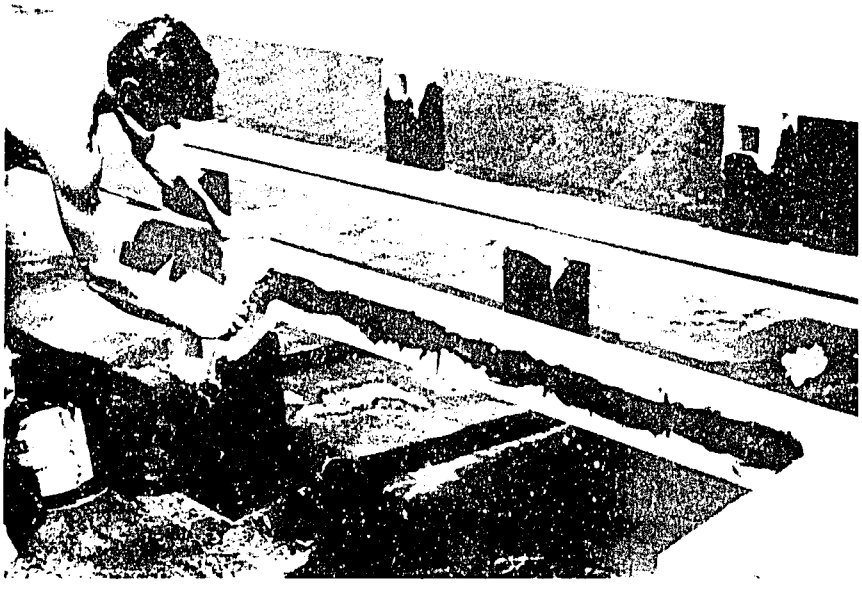

Figure A-24. A heavy layer of asphaltic cement was placed on the lip of the upper beam prior to laying the glass in place.

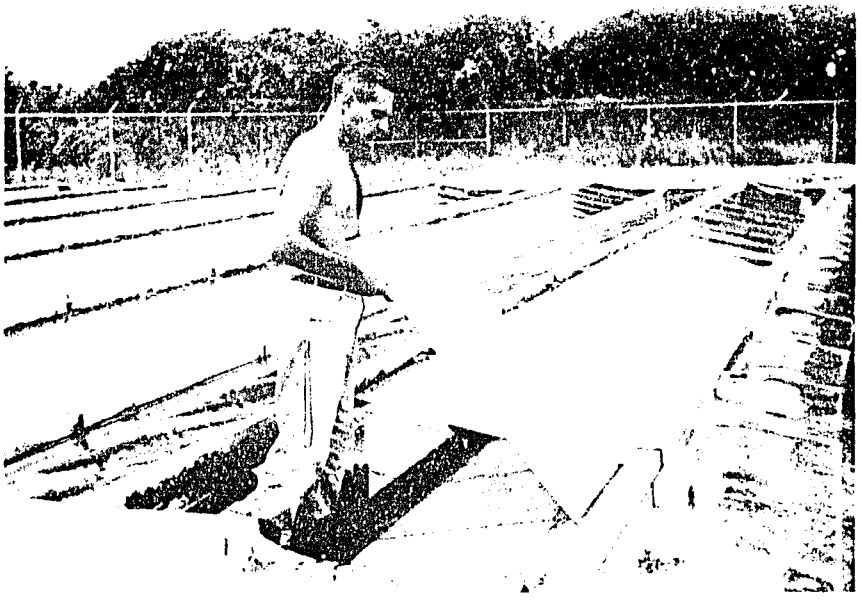

Figure A-25. The first step in laying the glass cover panes was to set the lower edge of the pane in the groove of the lower beam.

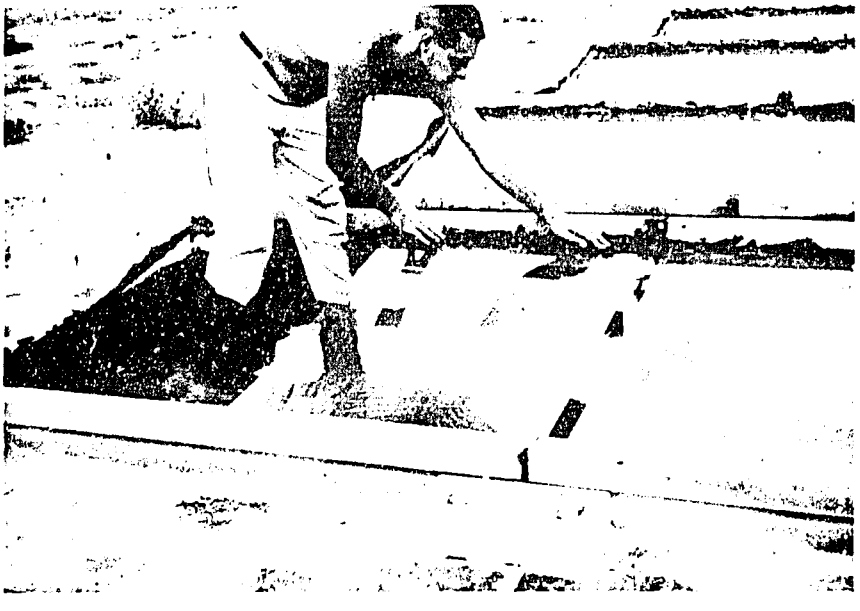

Figure A-26. The next step was to lay the glass pane on the upper beam and press it against the layer of asphaltic cement.

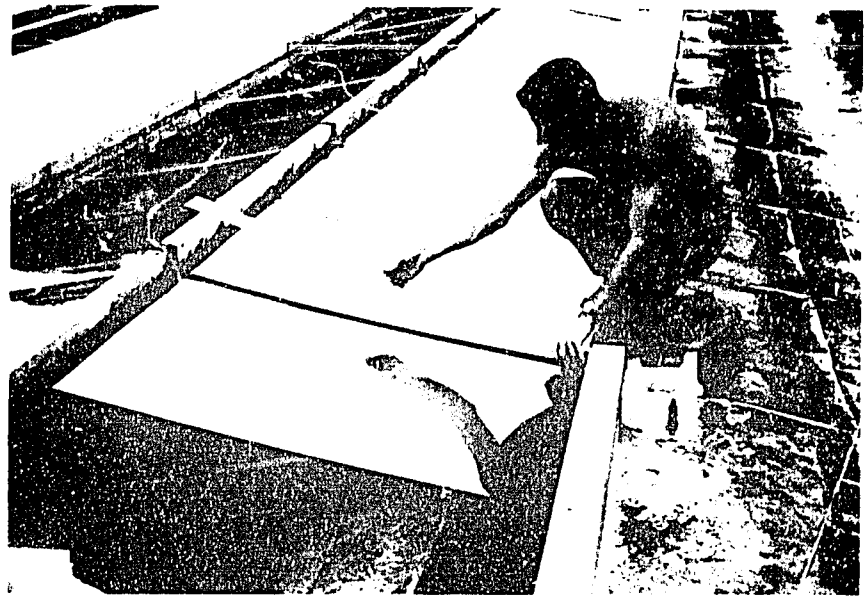

Figure A-27. The glass joint strips were placed over the gaps between adjacent panes.

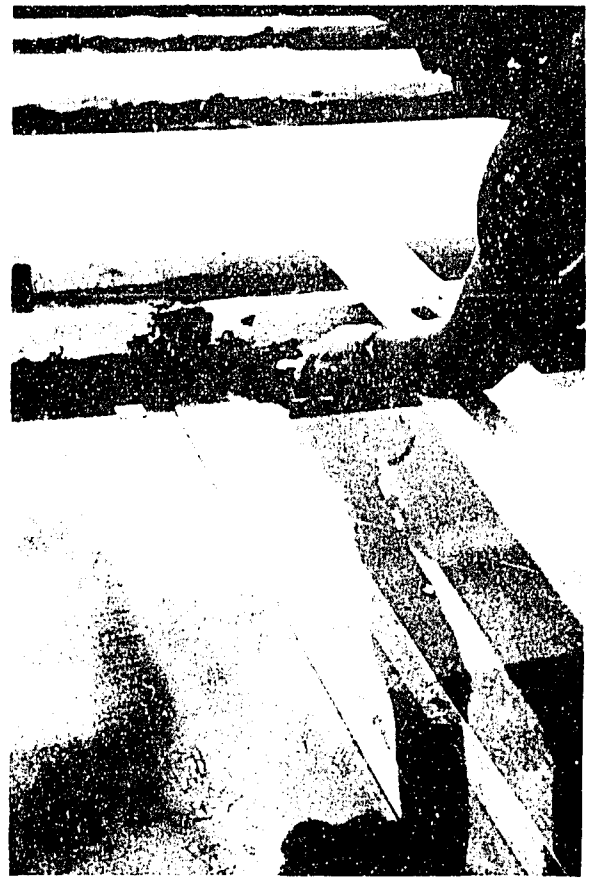

Figure A-28. A layer of asphaltic cement was placed on the upper end of the cover strips to prevent the strips from being lifted in strong winds.

Figure A-29. The groove in the lower glass-support beam was filled with asphaltic cement. This holds the glass in place and helps prevent rainwater leakage.

Figure A-30. At the edges of the still, the gaps between the glass and the concrete blocks were sealed with asphaltic cement.

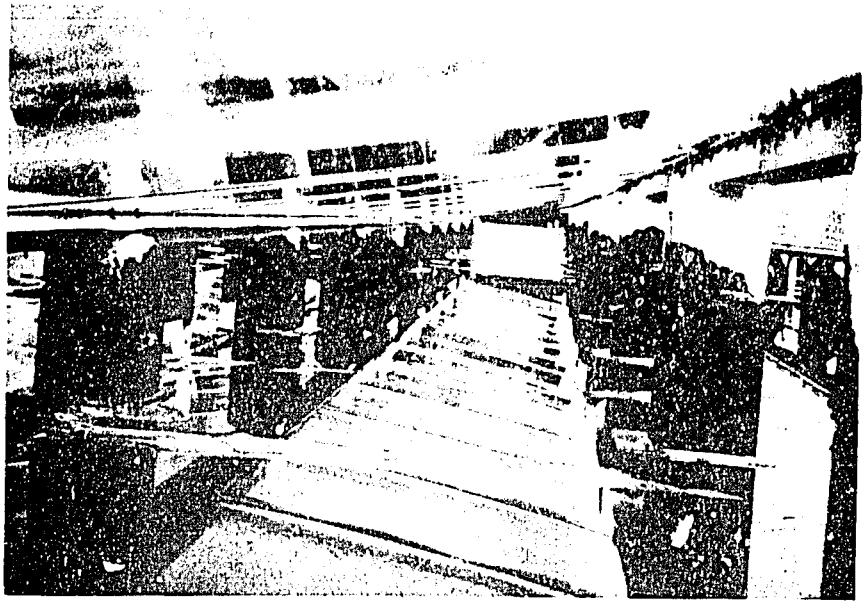

Figure A-31. A view beneath the cover of the still as seen during the early stages of filling the basin with sea water.

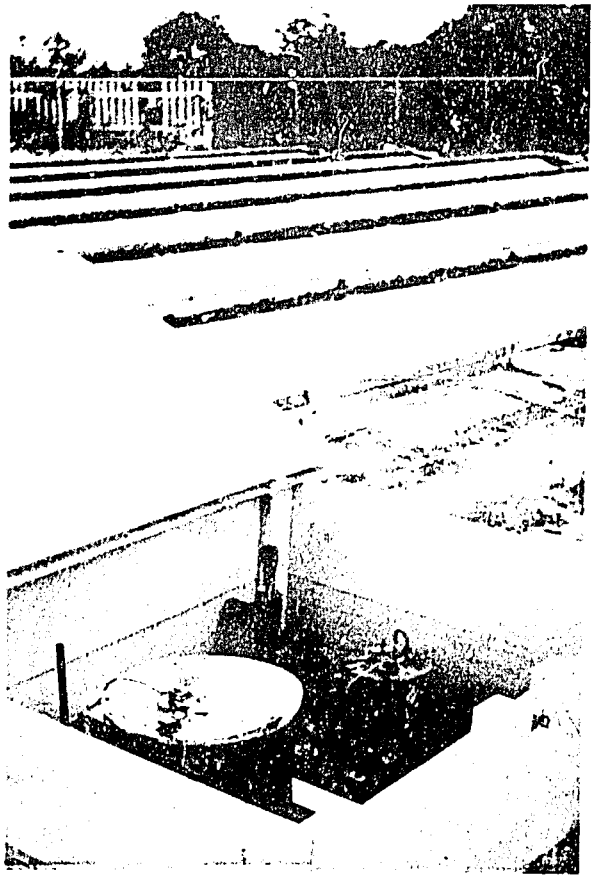

Figure A-32. Automatic dump-type water meters were installed near the still to measure distillate and overflow.

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