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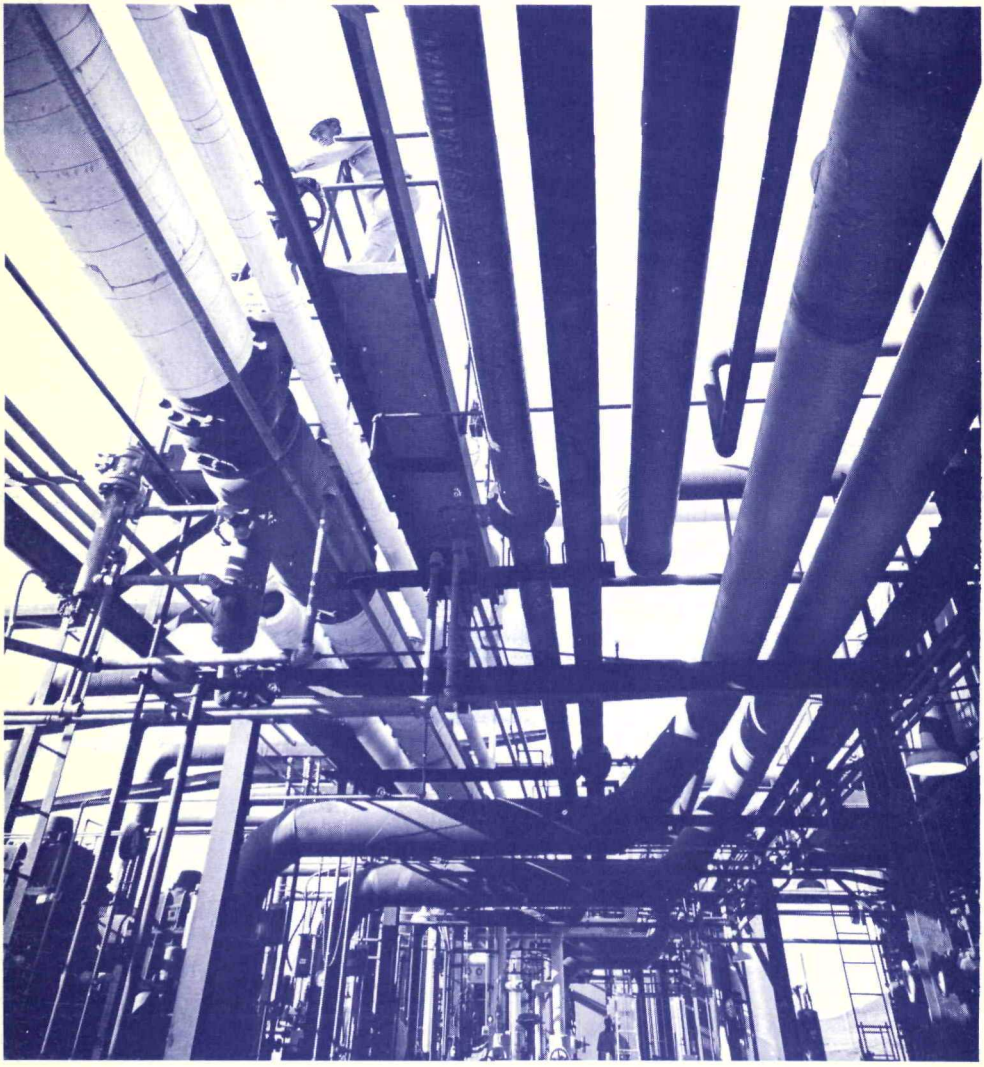
Nuclear Energy for Desalting



U.S. ATOMIC ENERGY COMMISSION / Division of Technical Information

The Understanding the Atom Series

Nuclear energy is playing a vital role in the life of every man, woman, and child in the United States today. In the years ahead it will affect increasingly all the peoples of the earth. It is essential that all Americans gain an understanding of this vital force if they are to discharge thoughtfully their responsibilities as citizens and if they are to realize fully the myriad benefits that nuclear energy offers them.

The United States Atomic Energy Commission provides this booklet to help you achieve such understanding.

Edward J. Brunenkant

Edward J. Brunenkant, Director
Division of Technical Information

UNITED STATES ATOMIC ENERGY COMMISSION

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Nuclear Energy for Desalting

by Grace M. Urrows

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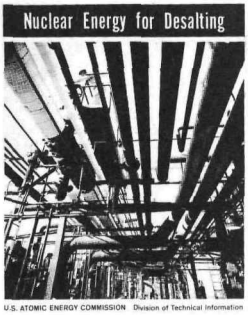

THE COVER

On a catwalk atop a maze of pipes at a desalting plant in San Diego, California, an engineer opens a steam valve to heat brine before it is piped to evaporators and "flashed" into fresh water. This plant, later moved to Cuba, was designed and built for the Office of Saline Water, Department of the Interior, by the Westinghouse Electric Corporation. (Also see illustrations on pages 10, 11, and 22.)

THE AUTHOR

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Nuclear Energy for Desalting

By GRACE M. URROWS

MAN IS THREE-FOURTHS WATER

You are three-fourths water. That's not a comment, it's a statement of fact that dramatizes why you cannot live without it. Your life, your health, your food, and even your prosperity require a continuing supply of water.

The Ancients couldn't enumerate the body's constituents as modern scientists can, but simple observation told them of water's importance and influence.

In the Old Testament of the Bible, the Hebrew poets sang of "A good land, a land of brooks and waters, of fountains and depths that spring out of valleys and hills" (Deuteronomy 8: 7).

In the Koran Mohammed warned, "No one can refuse surplus water without sinning against Allah and against man".

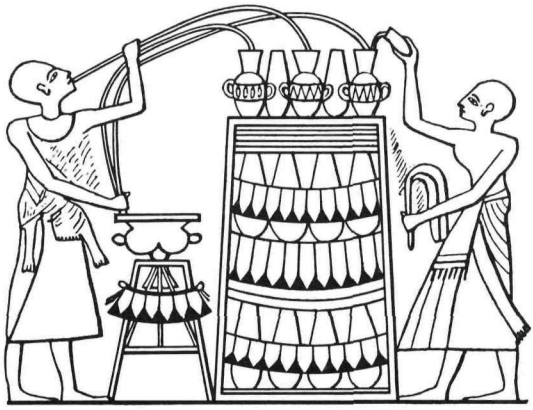
In the fourth century B.C., Hippocrates, the venerated Greek physician and philosopher, believed that the physiques, fertility, industriousness, and illnesses of the people of his world were in large measure a result of the waters available to them.

Although progress in science and medicine has shown the nature of these characteristics to be vastly more complex and subtle, the influence of water on man's life and well-being remains undeniably great.

Early Water Management

Man has focused much of his creative imagination and engineering skill on the management of water supplies. Fifty centuries ago the Mohenjo-daro civilization of the Indus Valley in India enjoyed the benefits of well-designed water supply and drainage systems, as well as public swimming pools and baths.

Sanskrit writings, said to go back 20 centuries B.C., describe several methods for making foul water pure, such as boiling or filtration through sand and gravel. Pictures on the tomb of an Egyptian king, 12th Century B.C., show the use of siphons to carry off water clarified by precipitation.



This picture on a 12th century B.C. Egyptian tomb shows the use of siphons to draw off Nile River water purified by sedimentation.

And who would know better than sailors, surrounded by hundreds of miles of salt water, the value of the simple process of distillation—boiling salt water and condensing the steam into pure water?

Life, Health, and Growth

In primitive living conditions a minimum of 5 gallons of water per day per person suffices, and millions of people today still must scoop this amount up from shallow pools or foul streams; some must haul it long distances. In Madagascar women carry home heavy pails of water, balanced on their heads, across miles of hot sands. Hollowed-out tree trunks provide an army of small water reservoirs in parts of the Sudan. After the trunk has been filled with water the opening is sealed with wet clay to protect the contents from contamination.

Somalian women collecting drinking water from puddles after a rain.

But technological societies place an increasingly heavy burden upon resources that must provide water not only for drinking but also for sanitation, irrigation, production of power, and countless industrial operations.

Huge quantities of fresh water are needed by industry. For instance it takes 240,000 gallons of water to produce 1 ton of acetate, 660,000 gallons to make 1 ton of synthetic rubber, and 1,115,000 gallons to derive 100 barrels of synthetic fuel from coal.

Agriculture is also a tremendous consumer of water. From 75 to 100 billion gallons per day are required in the United States for irrigation alone. It takes 37 gallons of water to make 1 slice of bread, 3750 gallons to produce 1 pound of beef, and 200,000 gallons to grow 1 ton of alfalfa.

Simple household uses require more water than most people realize. Every time a toilet is flushed, 7 gallons of fresh water are used. In a 5-minute shower you draw 25 gallons, and if you water your lawn for an hour, you need 300 gallons.

ESTIMATED WATER USE IN THE UNITED STATES

(In billions of gallons daily average)

Year	Total water use
1900	40
1910	66
1920	92
1930	110
1940	135
1944	188
1945	175
1946	168
1950	203
1955	262
1960	312
1965	359
1970	405
1975	453

Office of Saline Water, The Department of the Interior

For all these needs in the United States we presently require about 390 billion gallons of fresh water per day, or about 2000 gallons per person. Moreover, water use is growing at the rate of 25,000 gallons per minute. So it is with good reason that even a water-rich country like ours views its future water needs and supplies with some anxiety.

GROWING CONCERN

A tremendous volume of water—324 million cubic miles of it—covers three-quarters of the globe. As drinking water, it's useless to us in its present state because it contains 3½% salt, and man can only tolerate 0.2%. Beyond that, the salt burden is more than human kidneys can secrete, and the body becomes dehydrated in its efforts to rid itself of the excess. The purer the water the better, although our taste buds do not agree: Absolutely pure water is tasteless, and most people prefer to drink water with some slight mineral content.

In 1000 communities in the United States alone, the water supply is "brackish", and, though in some cases the salt concentration is within body tolerance, the water tastes harsh and bitter. Residents of these areas have to transport potable water long distances or purchase bottled drinking water.

WATER QUALITY TABLE

Fresh	Water containing less than 1000 dissolved parts of salt per million parts of water (ppm)*
Brackish	Water ranging from 1000 ppm up to the dissolved salt content of seawater mildly brackish—1000 ppm to 5000 ppm moderately brackish—5000 ppm to 15,000 ppm heavily brackish—15,000 ppm to 35,000 ppm
Seawater	Water containing approximately 35,000 ppm
Brine	Water containing more dissolved salt than seawater, such as the Great Salt Lake or the Dead Sea

*ppm means parts per million.

Office of Saline Water, The Department of the Interior

After World War II this country's expanding industrialization and explosive growth in population made heavy demands on water supplies. The evolving water problem was seen by some farsighted legislators as serious enough to warrant Federal Government research into the possibility of economically converting saline or brackish sources to potable water.

Some Congressional interest was aroused, but it was not until 1952 that Congress passed a bill authorizing the expenditure of $2 million in a 5-year program to produce quality water from brackish water or seawater. The bill enabled the Secretary of the Interior to establish the Office of Saline Water within the Department of the Interior. The program was later extended to June 1963, with the funds increased to $10 million.

Seated at his desk in the White House, President Kennedy pressed a button made of magnesium extracted from seawater to start fresh water flowing from the desalting plant in Freeport, Texas, on June 21, 1961.

Under a bill sponsored by Senator Clinton P. Anderson of New Mexico and passed by Congress in 1958, the Office of Saline Water was authorized to build five or more saline water conversion plants to demonstrate the most promising techniques.

Shortly after he took office in 1961, President John F. Kennedy pledged his administration to redouble desalting efforts. Submitting to Congress a bill to expand and extend the saline water conversion program, the late President said, "Water—one of the most familiar and abundant compounds on the earth's surface—is rapidly becoming a limiting factor on economic growth in many areas of this nation and the world. As time goes on, more and more communities will be faced with the prospect of economic distress and stagnation unless alternative sources of suitable water are developed.

"It is essential, therefore, that we make every effort at this time to search for low-cost processes for converting sea and brackish water into fresh water to meet our future water needs and those of our neighbors throughout the world. I know of no Federal activity that offers greater promise of making a major contribution to the ultimate economic well-being of all mankind than this program."

In 1961 Congress passed the Anderson-Aspinall Act, named for its cosponsors, Clinton P. Anderson, the New Mexico Senator, and Representative Wayne N. Aspinall of Colorado. This new act authorized expenditures of $75 million for fiscal years 1962 through 1967 and placed heavy emphasis upon the importance of an expanded basic and applied research program. A 1965 amendment extended the program through 1972 and provided additional funds.

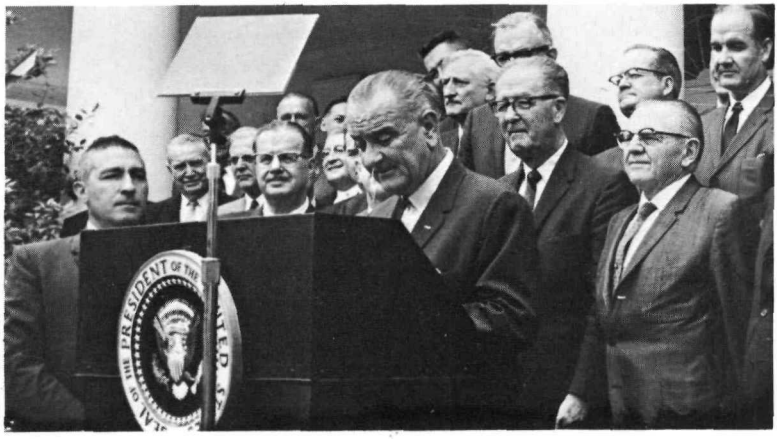
Call for Action

In 1964 President Lyndon B. Johnson, whose interest in water purification began during his early days in the Senate, provided the spur for a new, accelerated desalting effort. The President asked the Department of the Interior and the Atomic Energy Commission to prepare a plan for an aggressive and imaginative program to advance large-scale economic desalting of seawater.

Plans to construct a nuclear desalting plant in California were announced in August 1966 by (from left) AEC Commissioner James T. Ramey, Secretary of the Interior Stewart L. Udall, Mayor Samuel Yorty of Los Angeles, and Joseph Jensen, Board Chairman of the Metropolitan Water District of Southern California *(see page 16).*

TECHNOLOGY AT THE CROSSROAD

President Johnson's decision to put real "push" behind a desalting program came at a strategic time not only in terms of the nation's growing water needs but also in relation to the technologies essential to large-scale purification efforts.



On August 11, 1965, President Johnson addressed a group assembled for the signing of the amendment that expanded the Anderson-Aspinall Act of 1961. Directly behind the president in the front row are (left to right) Senator Clinton P. Anderson and Representative Wayne N. Aspinall. On the far left of the photograph is Stewart L. Udall, Secretary of the Interior.

Since its founding in 1952, the Department of the Interior's Office of Saline Water had fairly well defined the state of the technology, investigated a number of desalting techniques, and stimulated the interest of many scientists and engineers in water-desalting problems. Much research had reached a critical point requiring an intensified development effort to bring it to successful conclusion.

For almost the same length of time the Atomic Energy Commission, with the cooperation of Congress and American industry, had been developing nuclear power plants to serve as sources of energy for the production of electricity. From 1954, when the nation's Atomic Energy Act was amended to permit expanded participation in atomic development by private companies, nuclear power plants were

designed, prototypes tested, and finally large plants built that could satisfy the demands of the electric utilities for commercial power.

Nuclear power plants already under construction or firmly planned are expected to produce power at prices competitive with those of fossil-fuel plants in many areas of the United States. The nuclear plants have the capacity range of 400,000 to over 1,000,000 kilowatts and are expected to produce power for about 2.5 to 5 mills* per kilowatt-hour. From this point forward spectacular growth in the nuclear power industry is anticipated. Sixteen plants with a capacity of nearly 2.5 million kilowatts are now in operation or soon will be, and over the next 13 years power authorities predict this figure will increase at least 40 times over. By 1980 the nation is expected to have a nuclear generating capacity of about 150 million electrical kilowatts.†

Joining Forces

Could the burgeoning technologies of nuclear power and water desalting be joined to help solve civilization's immediate and projected needs for potable water? The idea was not entirely new.

In 1959 plans for a small seawater distillation plant utilizing a nuclear heat source were made by the Department of the Interior and the Atomic Energy Commission as a joint project. The plan called for the use of an experimental process heat reactor coupled to a million-gallon-per-day demonstration seawater distillation facility.

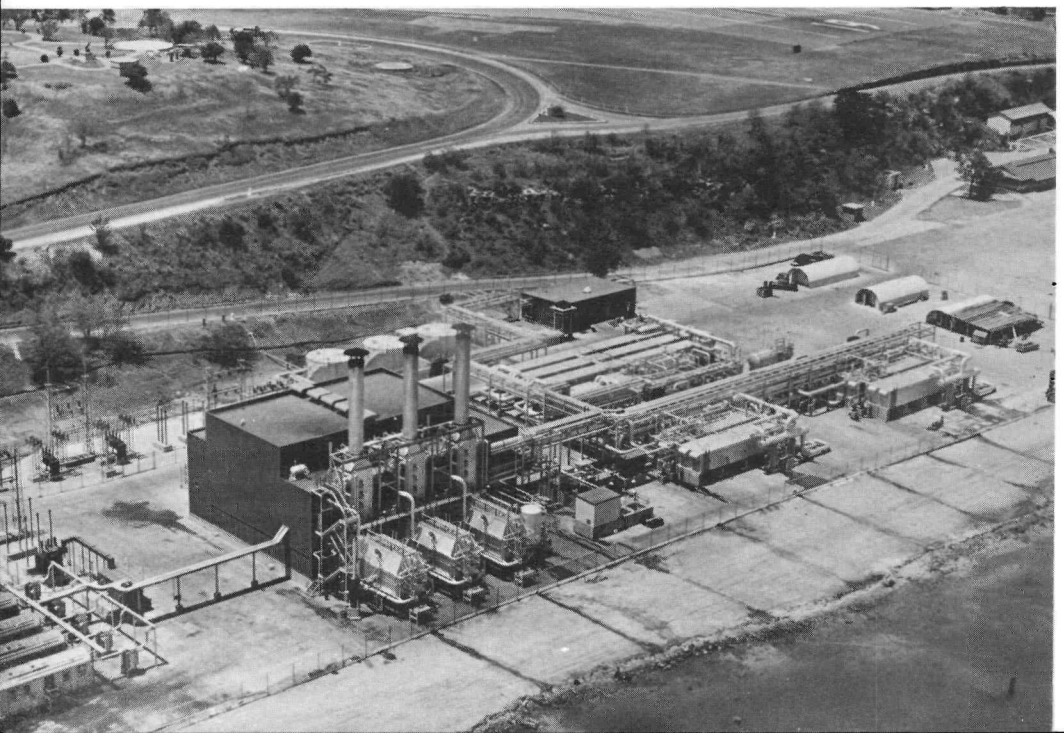
Unfortunately, it was difficult to find the proper site for the reactor portion of the plant, and the joint venture was abandoned. However the Department of the Interior went forward with its part of the plan and a highly successful distillation plant was built in San Diego, California. This is the same plant that in 1964 was dismantled and reassembled at Guantanamo Bay, Cuba.

The uprooted San Diego unit was one of the plants built by the Office of Saline Water to demonstrate the different,

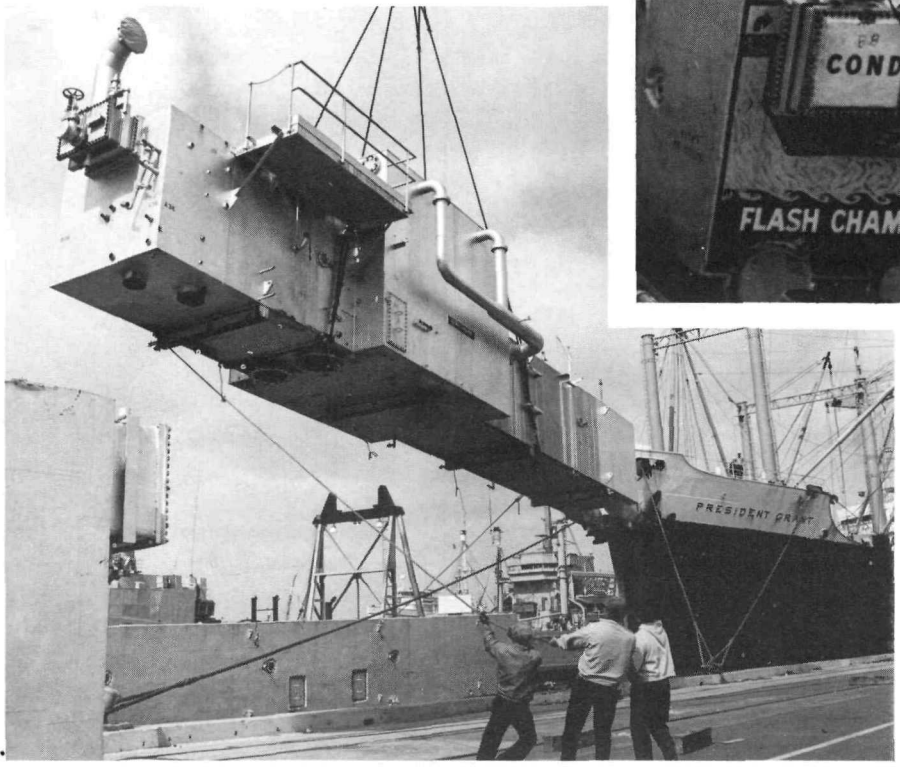
*A mill is equal to $1/10$ of 1 cent.

†Power is measured in electrical watts, heat in thermal watts.

In 1964 the Cuban government shut off the water supply to the Guantanamo Naval Base. Since construction of a new desalting plant would have taken 3 years, the U. S. Government decided to move a desalting plant already in operation in San Diego 3600 miles to Cuba. Above, the San Diego plant before it was disassembled. Below, the plant as rebuilt at Guantanamo. Opposite, the plant being loaded. Inset shows the flash chamber and condenser aboard ship. The dismantling, shipping, and reassembly was accomplished in 5 months.



promising processes for water conversion. The plant was producing 1.4 million gallons of water per day at approximately $1 per thousand gallons, which is about three times the cost usually regarded as economic. Demonstration plants, however, are not expected to achieve the economy and efficiency possible in second- and third-generation operating facilities. The San Diego plant was successful since it did acceptably demonstrate a promising technique, and is still doing so in Cuba.



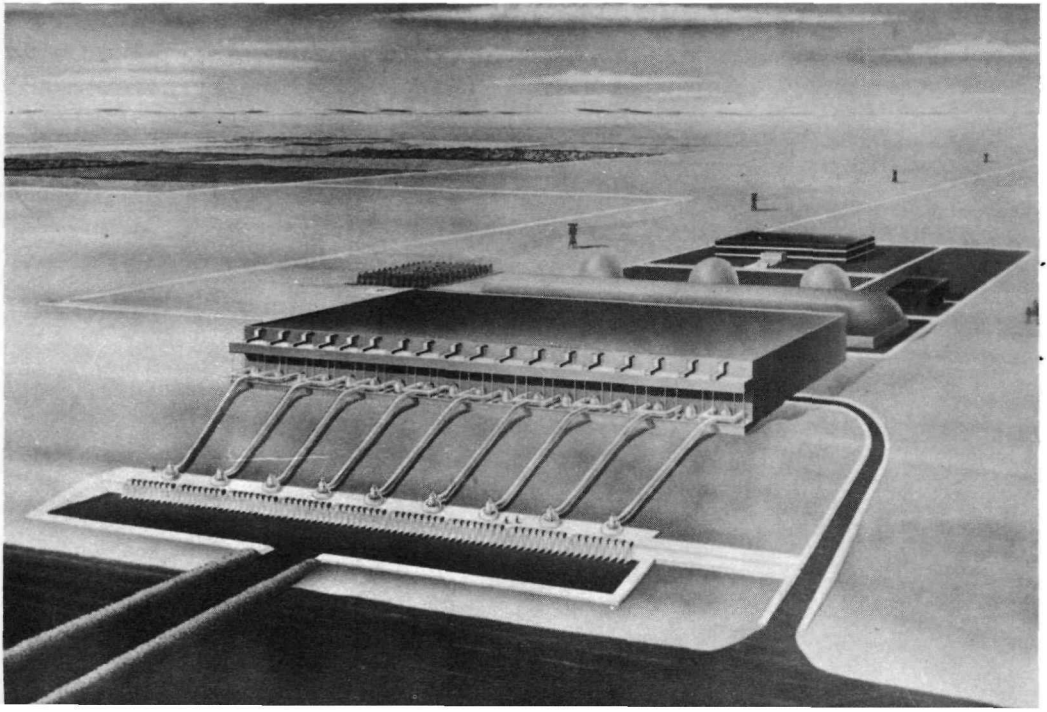
The Time Is Right

With the improvement of nuclear reactors as sources for the production of electrical energy, and their increasing acceptance by utilities and the public, interest was again stimulated in the possibility of dual-purpose nuclear-power and water-production plants.

A 1962 report, by Dr. R. Phillip Hammond and his associates at the Atomic Energy Commission's Oak Ridge National Laboratory, advanced the thesis that very large reactors coupled to very large desalting facilities could economically produce quantities of electric power and fresh water from the sea. This report attracted the attention of the President's Office of Science and Technology. Dr. Jerome Weisner, director, appointed a group of experts to evaluate Hammond's findings.

The group said, "Although we are less optimistic than Oak Ridge National Laboratory we have confirmed the essential validity of the ORNL conclusion—that relatively low-cost fresh water can be obtained with very large scale, dual-purpose operations where there is a sufficiently large market for electric power, and that nuclear energy plants appear to have better economic potential in these very large sizes than fossil-fueled plants".

Artist's conception of a nuclear-powered seawater-conversion plant that would produce 1 billion gallons of fresh water per day and 4,500,000 electrical kilowatts of power. Three natural uranium reactors would generate steam, which would operate the turbogenerators to produce electricity. The steam would then travel through a flash evaporator plant converting the seawater to pure water.



Thus when President Johnson requested that the two agencies prepare an aggressive and imaginative program, he also requested that the plan propose "an optimum strategy and time schedule for relating nuclear-power technology to the development of large scale desalting technology".

In his message to the Third International Conference on the Peaceful Uses of Atomic Energy in Geneva in August 1964, President Johnson said, "The time is coming when a single desalting plant powered by nuclear energy will produce hundreds of millions of gallons of fresh water—and large amounts of electricity—every day."

NUCLEAR POWER'S CONTRIBUTION

All processes for making potable water from saline water consume energy, and it doesn't matter whether that energy comes from a fossil-fuel-burning plant or one that uses nuclear fuel. The choice of a heat source can therefore be based upon economic considerations, and it has been found that nuclear power is the more economical alternative in large sizes.

Currently the most promising process for large-scale production of fresh water—50 million gallons per day or over—is distillation. This system requires quantities of low-temperature steam, and one of the places that steam of this temperature can be found is in the turbines of modern thermoelectric power plants.

In these plants high-temperature steam is produced to turn the large turbogenerators that generate electrical power. As the steam passes through the turbine its temperature decreases until a point is reached where it is low enough so that it might be used for saline water distillation. Thus, the steam used to generate electricity could also be used to provide energy to the water plant.

Plant economics are enhanced by using the higher temperature energy for power generation and the lower temperature exhaust steam for desalting. By combining the two processes (power generation and desalting) in one plant, larger heat sources can be used, requiring lower unit capital investments. In dual-purpose plants important items

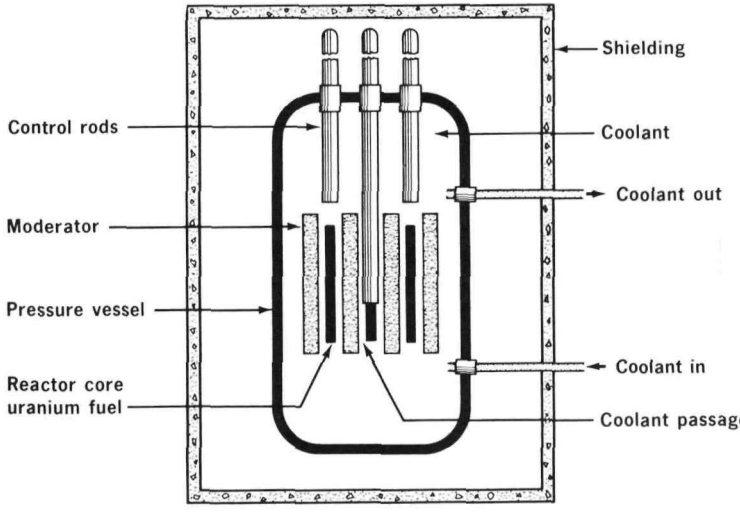
of equipment and facilities (such as water intake and discharge lines, control rooms, maintenance shops, etc.) could be shared to provide significant cost savings.

It is axiomatic that the lower the price of the energy used in a water conversion process the lower the price of the water produced. The least expensive source of energy is therefore the preferred one for that process. In considering large plants, nuclear energy power sources become very attractive because the long-term cost of nuclear fuel is expected to be lower than the cost of most fossil fuel.

A nuclear reactor is a furnace that "burns" atomic fuel, such as uranium or plutonium. Instead of *combustion,* which takes place when coal or oil is ignited, the process by which heat is released from the atoms of uranium fuel is known as *fission.* Fission occurs when a subatomic particle called a *neutron* strikes an atom, causing it to split into two parts and at the same time releasing tremendous amounts of energy in the form of heat. As an atom is split, two or three more neutrons are set free, and if there is a sufficient amount of *fissionable* material close-by this process will continue in what is called a *chain reaction.*

In a nuclear reactor this chain reaction is controlled. The neutrons are slowed down by a *moderator,* possibly

PARTS OF A REACTOR



graphite or heavy water,* to a speed at which they are most likely to collide with other fuel atoms. Another major reactor component is the *coolant*, which is now usually light water, but which could be heavy water, liquid metal, or even a gas, such as helium or carbon dioxide. It flows through or around the fuel core to remove the heat generated by the fissioning atoms.†

In a nuclear *power* reactor the fuel core is so arranged that the fission will generate very high temperatures—the greater the heat the more efficient a power source the reactor becomes. This heat is carried away by the coolant. A number of power reactor concepts include a secondary heat transfer system so that the coolant can give up its heat to produce high-temperature steam for use in generating electricity or in an industrial process.

For Early Desalting

Most existing U. S. reactors, and those now being ordered by utility companies, are of the boiling-water or pressurized-water type. They are available in ranges up to about 1000 electrical megawatts and will generate electricity at a cost as low as about 2.5 mills per kilowatt-hour.

Dual-purpose electric-power and water-desalting plants, using these proven light-water reactors, could be brought into operation by the early 1970s. There has been limited experience in constructing or operating nuclear power plants coupled to desalting units, so careful analysis and study will be needed to avoid mismatch of one process or system with the other. While there appear to be no great technical obstacles in the coupling, attention will also have to be paid to the operating characteristics of a combination plant to tailor its output to the needs for both power and water.

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*Heavy water is water containing deuterium atoms in place of some ordinary hydrogen atoms; it is effective in slowing neutrons. To distinguish it, ordinary water is sometimes known as "light water".

†For more information on reactors, see *Nuclear Reactors*, a companion booklet in this series.

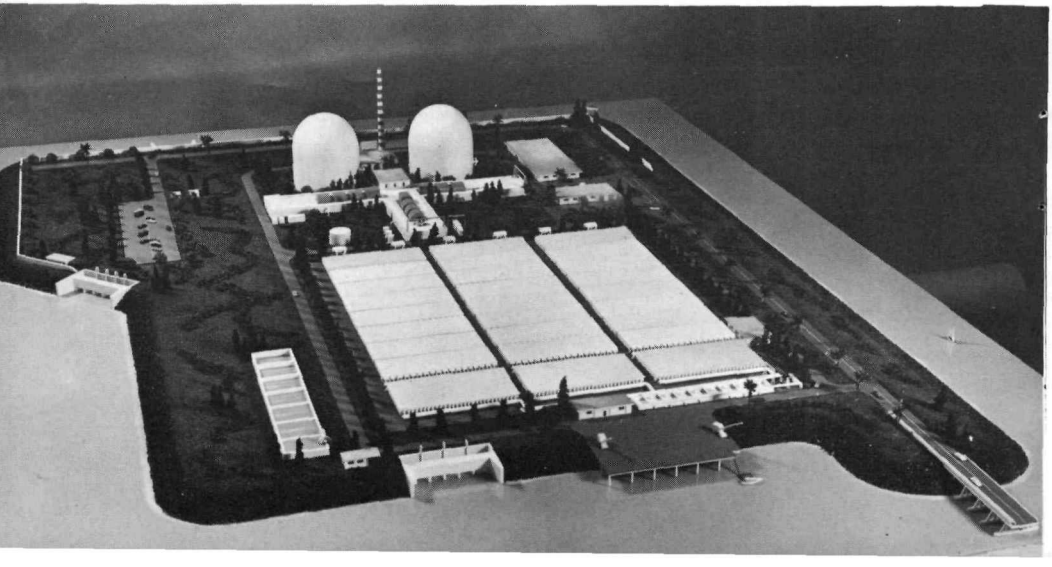
Dual-Purpose Plant Studies

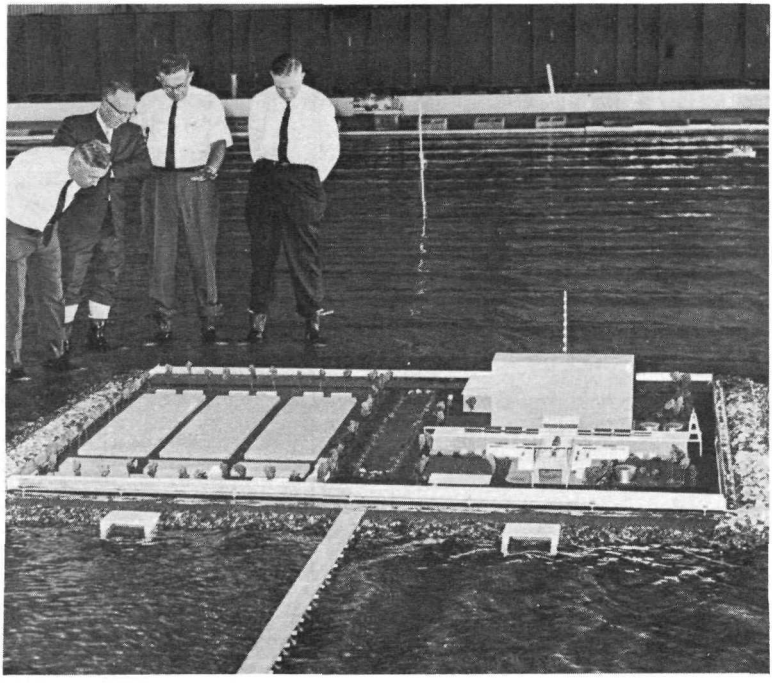
A study, made in 1964 by the Catalytic Construction Company of Philadelphia under contract to both the Office of Saline Water (OSW) and the Atomic Energy Commission (AEC), investigated the economics of dual-purpose plants of 200 to 1500 thermal megawatts. In nearly all cases it was found that where size, energy source, power sales, and capital investment charges are comparable, water is produced more cheaply in dual-purpose plants than in single-purpose ones.

In another study, AEC and OSW asked the engineering consultant firm of Burns and Roe to investigate the potential use of a dual plant to provide fresh water to Key West, Florida. Water, which is in short supply there, now comes through an overloaded 128-mile aqueduct from the mainland. The company found that a dual-purpose nuclear-powered distillation plant was a possible solution to the area's needs.

The AEC and the OSW also cooperated with the Metropolitan Water District of Southern California (MWD) in supporting a study, by the Bechtel Corporation, of a large nuclear-power desalting plant on the California coast. Based on the favorable conclusions of this study, a cooperative project was authorized for participation by the AEC, OSW, MWD, and the electric utilities serving the area. The plant, when completed in 1973, will have an

Model of the Southern California nuclear-power desalting plant.





Experts studying model of the MWD plant in a 90 × 130 foot tank to determine the effects of ocean waves on the man-made island.

initial water capacity of 50 million gallons per day and generate 1,800,000 kilowatts of electricity. Additional capacity can be added later to produce a total of 150 million gallons per day—enough for a city of about 750,000. The power output will exceed that of Hoover Dam, or enough for a city of about 2 million.

Two large conventional light-water nuclear reactors, of about 3000 thermal megawatts each, will be the energy source. The water plant will consist of three large multistage flash distillation sections, each producing 50 million gallons of water per day. Due to the high price of coast property, a man-made island will be constructed about 3000 to 4000 feet offshore in water 25 to 30 feet deep. This first U. S. island site will have approximately 45 acres in usable surface area and will be connected to the shore by a causeway. The plant will be about 30 times larger than the largest existing water-desalting plant.

The Civilian Nuclear Power Program

One of the important objectives of the AEC's civilian nuclear power program has been the improvement of reactors for the generation of economic electric power.* This goal is nearing realization in the United States. But the benefit society may expect from nuclear power plants does not stop there. The AEC expects to perfect for commercial use other, more economic classes of reactors—one of which is the advanced converter. A converter is a nuclear reactor that produces one kind of fuel as it consumes another.

Development of advanced converters will not only lower the cost of power and increase the utilization of nuclear fuel but also will add to the technology of a third class of reactors called "fast breeders". As the term implies these reactors make or "breed" more fuel than they consume.

All reactors produce some fissionable material while they are operating, in addition to consuming some. The advanced converters change larger quantities of fertile material (uranium-238 or thorium-232) into fissionable material (uranium-233 and plutonium-239) than do present-day reactors. Breeders will have the remarkable ability to produce more fuel than they consume, enabling man to tap a virtually endless source of energy.

The Federal Power Commission has estimated that by 1980 the United States will require almost three times the electrical energy that was produced in 1964. That is a staggering expansion, and we will need all our sources of energy—coal, oil, gas, hydroelectric, and nuclear—to satisfy that demand. Much work remains to be done on development of breeder reactors, but it is hoped that economic fast breeders can be operating by the late 1980s.

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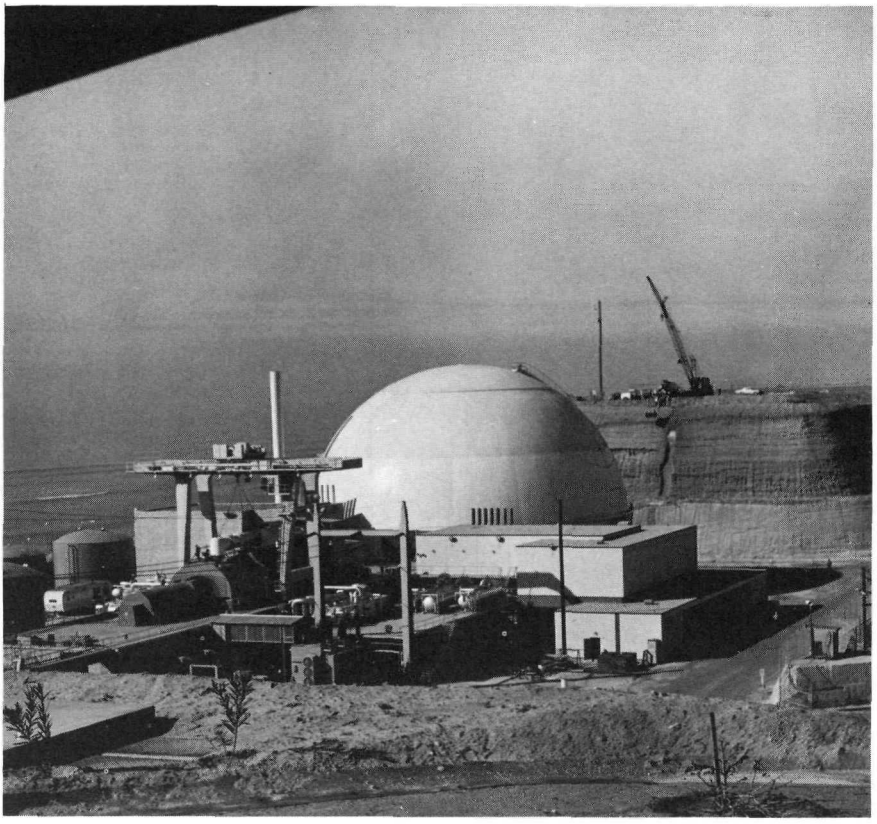
*For more information on using atomic energy in electric power production, see *Nuclear Power Plants*, another booklet in this series.



The San Onofre Nuclear Generating Station, developed under the AEC's civilian nuclear power program, began commercial operation in 1967. Located on the coast of Southern California two miles from San Clemente and about 60 miles north of San Diego, the plant incorporates a pressurized-water reactor with 430,000-net-electrical kilowatt capacity. It is owned and operated by the Southern California Edison and San Diego Gas and Electric companies. The AEC supported the research and development for this plant and will obtain data from it relating to design, construction and operation of large pressurized-water reactors. The plant is expected to produce electricity more cheaply than conventional generating stations in the area.

AEC's Desalting Plan

It can be seen that the AEC's contribution to the desalting program will rest heavily on the technology that has already been developed. A new factor — the needs of the desalting program — will be added as the AEC seeks engineering data on the problems of coupling nuclear reactors to desalting operations.

The AEC has adjusted its schedules and given certain of its projects somewhat greater concentration in response to the call for a major desalting effort. It is the conviction of AEC experts, however, that hard steady work, rather than a dramatic technological breakthrough, will shape its contribution.

DESALTING THE WATER

Providing a source of adequate, low-cost energy is only one part of the desalting problem and is, in fact, a major requirement in only some instances. The basic question is how most efficiently and economically to convert saline water to fresh, making it useful for human consumption and industrial purposes.

The ideal desalting process would require low-energy input, and have low capital costs, and low-cost operation and maintenance. Not all these attributes are present simultaneously in any process based on present-day technology. But some existing techniques are highly promising for particular degrees of water salinity, geographic locations, and amounts of pure water required.

Desalting Techniques

Desalting processes fall into two basic classifications. First are those that take the water away and leave concentrated brine behind — for example, distillation, freeze separation, solvent extraction, reverse osmosis, and gas hydrates processes. These are mostly applicable to seawater. In the second category are those that remove salt and leave fresh water behind, such as electrodialysis and ion exchange. These are generally more economical for purifying brackish water. Distillation and electrodialysis

are the conversion systems presently being used on a commercial basis. This booklet will consider several of these processes in detail. Some others, that depend principally on chemical reactions for separation (solvent extraction, and the gas-hydrates and ion-exchange processes), are of less importance for large-scale desalting.

Distillation

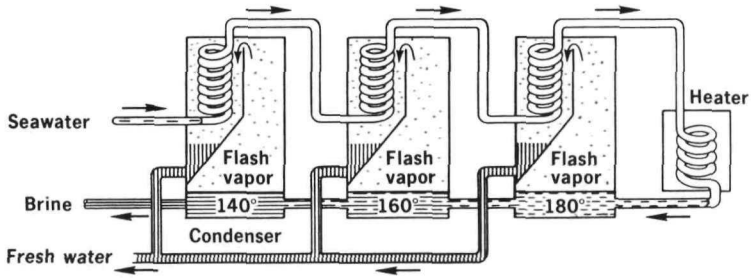
Simply put, distilling emulates nature by applying heat to boil the water off the salt, and then condenses the vapor as pure water. The process was known to the Ancients. Aristotle said, "When seawater evaporates it becomes fresh and the condensation from its steam is not salt."

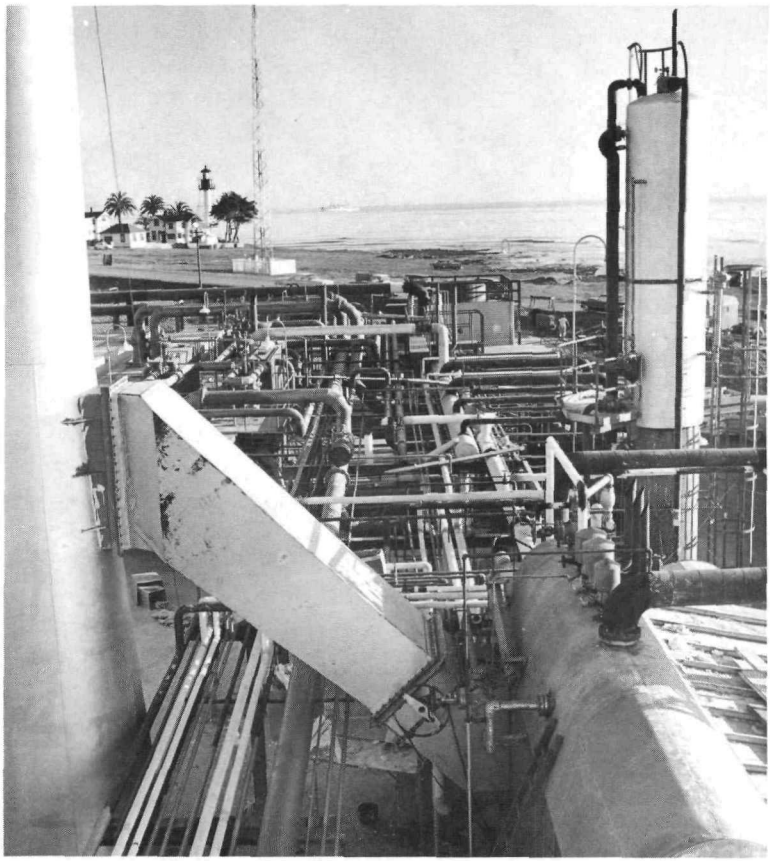
There are modern variants of this venerable process, such as multistage flash distillation, multiple-effect distillation, forced-circulation vapor-compression distillation, and combinations of these. Distillation is the principal means of purifying saline water throughout the world today, and the multistage flash process is the most popular version. It also seems most appropriate for coupling with nuclear power reactors, because it is readily adaptable to large-size plants and because nuclear plants produce the low-energy steam that distillation requires.

In the *multistage flash distillation* process, heated seawater is introduced into a low-pressure chamber. When the seawater enters the chamber, reduced pressure causes it to boil immediately, or "flash" into steam; the steam is then condensed. This operation is repeated successively in a series of similar chambers, or multistages, at progressively higher vacuum and lower temperature. This is the method employed in the successful Point Loma – Guantanamo Bay plant. (See figure on page 22.)

At Freeport, Texas, the Office of Saline Water has a demonstration plant using the Long-Tube Vertical (LTV) *multiple-effect distillation* process. In this, the seawater passes through bundles of tubes in a series of evaporators under progressively reduced pressures. This plant has a million-gallon-per-day capacity, and like multistage flash distillation, appears suitable for application to very large plants. (See figure on page 23.)

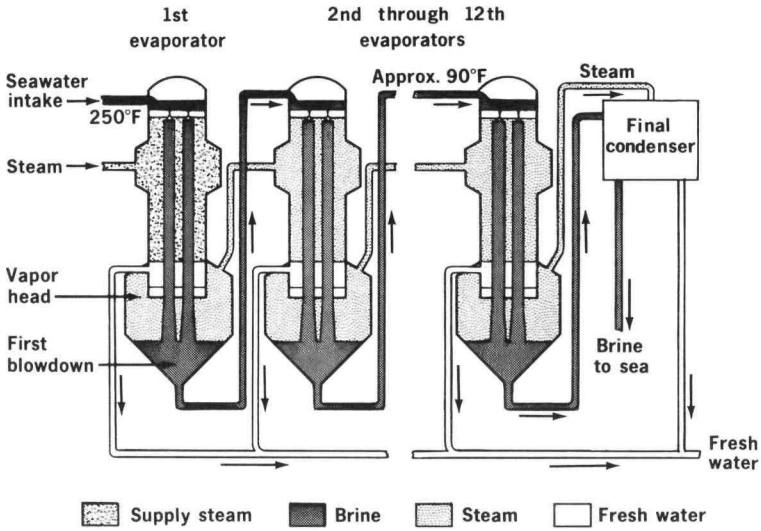
MULTISTAGE FLASH DISTILLATION

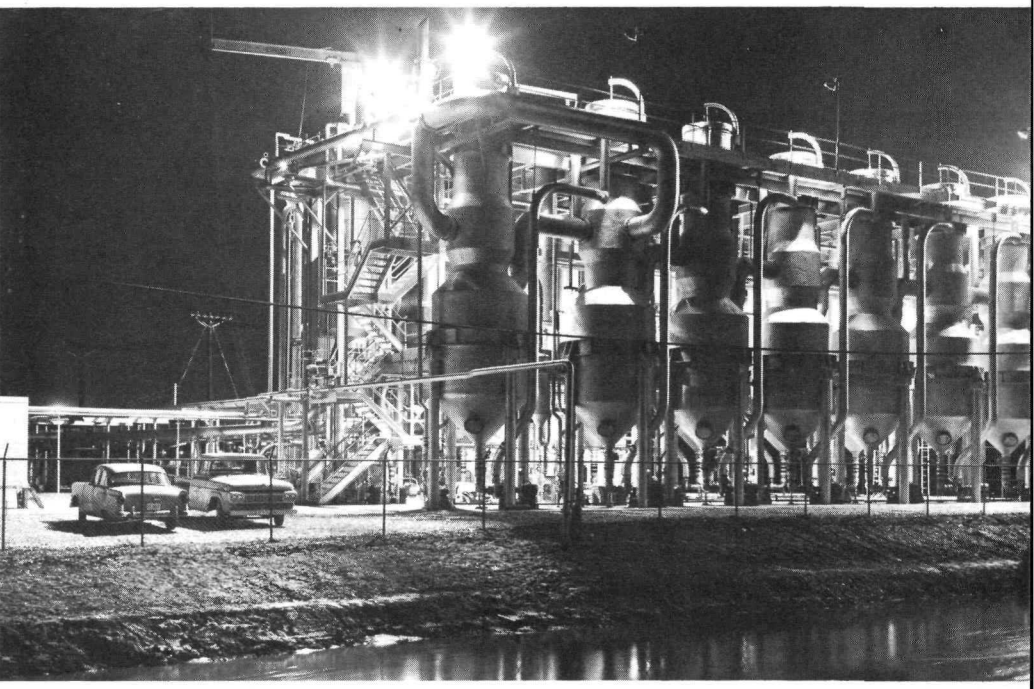




This view, across the top of the desalting plant at San Diego, illustrates the multiple piping systems needed for the multistage flash distillation process. This is the plant that was moved to Guantanamo Bay, Cuba, in 1964.

LONG-TUBE VERTICAL MULTIPLE-EFFECT DISTILLATION





This plant in Freeport, Texas, desalts the water by the Long-Tube Vertical multiple-effect distillation process.

At Roswell, New Mexico, another OSW demonstration plant, using the *forced-circulation vapor-compression* method, converts brackish to potable water, which is then purchased by the city of Roswell. In this plant the saline water is forced up through a tube bundle within an evaporator. A mixture of vapor and hot brine emerges at the top of the tubes; the vapor is compressed, thus raising its temperature, after which it is returned to the evaporator. As it condenses the vapor yields sufficient heat to boil the salt water in the tubes. The condensed vapor becomes the fresh product, water.

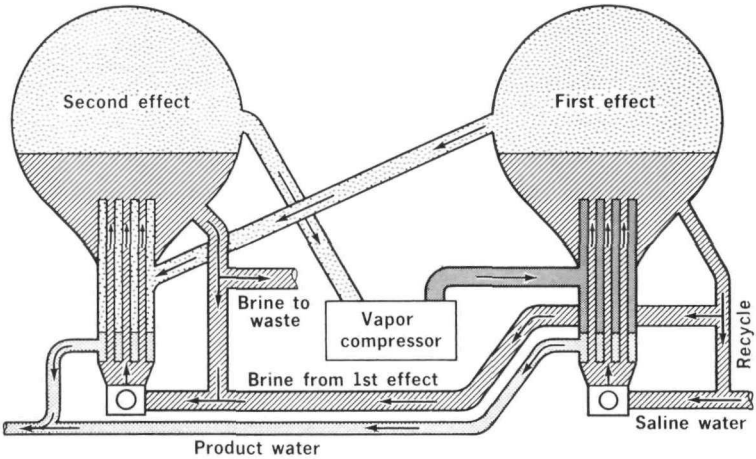
One problem common to all types of distillers that operate at temperatures of 170°F and over is the accumulation of scale* in pipes and vessels. Scale lowers the efficiency of heat transfer, so many systems treat the input water with chemicals, such as sulfuric acid, to minimize scale formation. The treatment raises the cost of operation and maintenance, and hence the cost of the pure water product. Since the rate of scale deposit increases with temperature, low distillation temperatures have been used most often. Higher temperatures produce more water, however. Obviously, removal of offending minerals from the water as it comes in and before it has circulated through the plant is highly desirable.

At the OSW's Wrightsville Beach testing center in North Carolina, W. R. Grace and Company has constructed a pilot plant that uses chemicals to remove scale-forming constituents. Not only would the process increase the efficiency of distilling but, in addition, the separated scale-forming material could be converted to high-grade fertilizer. W. R. Grace scientists estimate that about 37 tons of fertilizer can be produced for each million gallons of seawater processed. (See figure on page 26.)

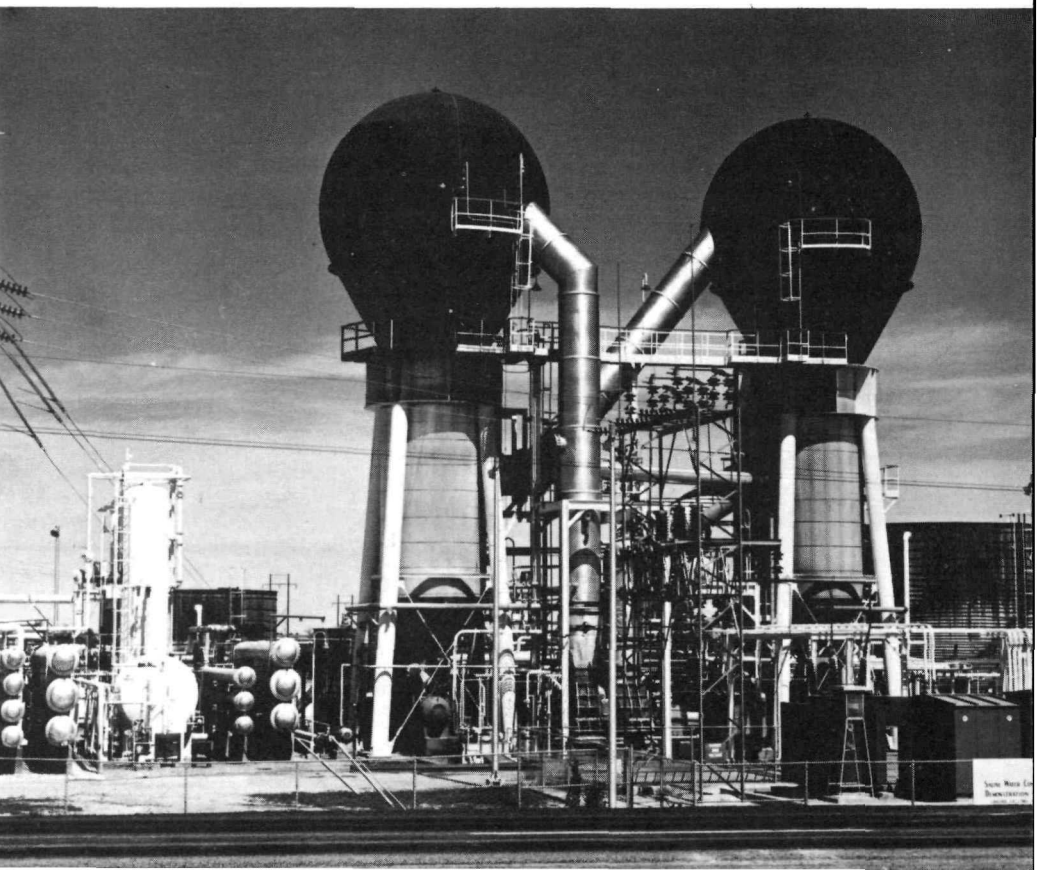
Various additional by-product development and utilization ideas are being investigated by Office of Saline Water scientists to see which may appreciably reduce overall desalination costs. This leads to the possibility that even-

*Scale is composed primarily of calcium carbonate, magnesium hydroxide, and calcium sulphate present in seawater. It gradually deposits on heated surfaces, clogs the equipment, and must be periodically removed.

FORCED-CIRCULATION VAPOR-COMPRESSION DISTILLATION



This plant in Roswell, New Mexico, desalts water by the forced-circulation vapor-compression method.



tually there may be large *tri-purpose plants* incorporating a nuclear power plant to produce large quantities of electricity, millions of gallons of potable water, and valuable mineral by-products.

A scientist samples magnesium ammonium phosphate made from seawater. This phosphate shows considerable promise as fertilizer for many plants including tree seedlings, grasses, and vegetables.

If 10% of the additional water needed by 1975 comes from the ocean, it will be necessary to process about 9 trillion gallons of seawater a year. What quantities of minerals are contained in this amount of seawater and what are their values? A look at the chart on the facing page will convince you that it is considerable. Very little has been done to extract the sea's dissolved salts, except for recovery of salt, bromine, and magnesia. Until recently, the idea of pumping huge volumes of water through a process to recover minerals has been inconceivable. But since we will have to pump the water for desalting anyway, it now becomes foolish *not* to try to capture this mineral wealth. Which minerals will be extracted and how much of each are questions that will be answered by research.

SOME OF THE MINERAL WEALTH CONTAINED IN 9 TRILLION GALLONS OF SEAWATER

Mineral	Tons (per year)	Approx $ value	U. S. production, 1959 (tons)
Salt	1,000,000,000	250,000,000*	25,000,000
Magnesia	76,000,000	43,000,000*	870,000
Potash	18,000,000	230,000,000*	2,300,000
Bromine	2,500,000	29,000,000*	97,000
Strontium	500,000		
Boron	190,000	29,000,000*	180,000†
Fluorine	50,000		
Rubidium	7,600		
Lithium	3,800		
Barium	3,400		
Iodine	1,900	4,100,000	
Copper	950	590,000	
Zinc	900	216,000	
Molybdenum	600	1,500,000	
Manganese	380	106,000	
Titanium	340	27,000	
Lead	300	50,000	
Vanadium	270	1,300,000	
Nickel	230	370,000	
Arsenic	190		
Selenium	150		
Uranium	125	1,100,000	
Tin	115	270,000	
Chromium	95	160,000	
Cesium	75		
Gallium	20		
Antimony	8		
Bismuth	8		
Silver	6	150,000	
Cobalt	4	12,000	
Tungsten	4		
Mercury	1	5,000	
Gold	600 (lbs)	510,000	

*Calculated on the basis of 1959 U. S. production and one-half current market value.

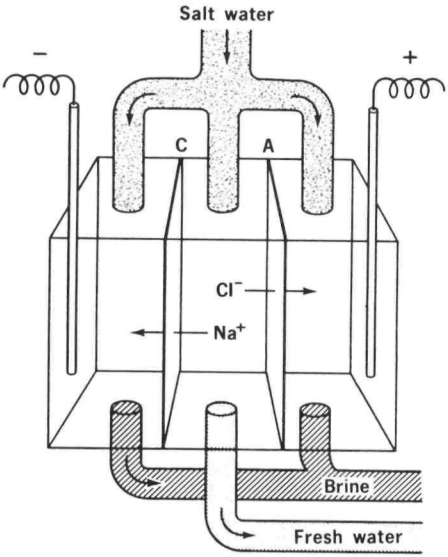
†Usage in terms of borax was 619,000 tons.

Electrodialysis

Electrodialysis is the only commercially used desalting method among those that remove the salt from water, instead of removing the much larger amount of water from the salt. It is an exceedingly promising approach, although its use appears to be limited by economics to low-salinity brackish water. The OSW operates a 250,000-gallon-per-day electrodialysis demonstration plant in Webster, South Dakota.

Electrodialysis takes advantage of the fact that salts, when dissolved, are in the form of positively charged ions called "cations" and negatively charged ions called "anions". The electrodialysis equipment consists of a sandwich of alternating cation- and anion-permeable membranes. Upon the application of an electric current, positively charged ions, such as sodium, pass through the cation-permeable membranes. The negatively charged ions, of which chloride is one, move in the opposite direction and pass through the anion-permeable membranes. The water in the center of each sandwich is thus depleted of salt, while the water

ELECTRODIALYSIS



This is the electrodialysis unit in the desalting plant in Webster, South Dakota.

accumulating on the outside of the membranes is enriched in it.

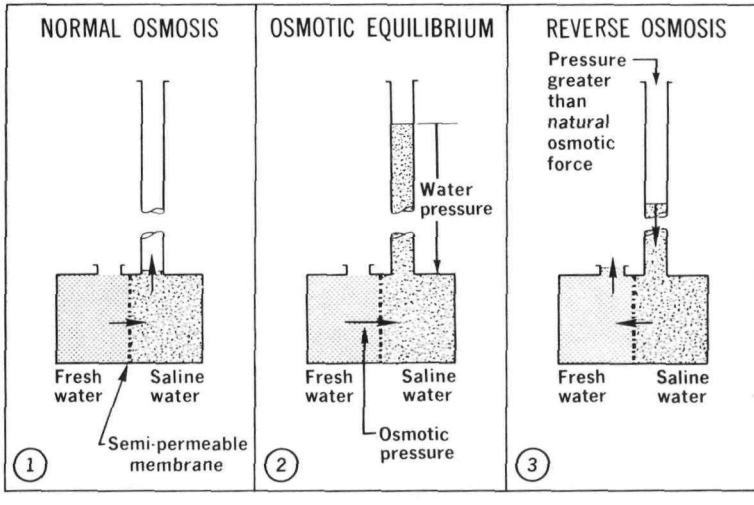
Membranes usually are a sheet plastic material, such as cellulose acetate, in which the ion-exchange substances have been embedded. This process is still being developed and additional work may lower costs.

Reverse Osmosis

An imaginative new process considered highly promising is *reverse osmosis,* which also employs membranes. As the name implies, it reverses nature's osmotic pressure that normally causes liquids to flow through a semipermeable membrane. (Our own body cells are surrounded by semipermeable membranes and depend for much of their activity upon osmosis.)

When saline water and fresh water are separated by a semipermeable membrane, osmosis will create a flow of fresh water through the membrane into the salt water.

OSMOSIS



A membrane divides a tank containing fresh water on one side and salt water on the other. (1) The fresh water tends, through the natural force of osmosis, to move through the membrane and dilute the solution on the other side. (2) If you put a pipe over the salt water tank, the moving fresh water will fill the salt side and move up the pipe until the counteracting force of water pressure halts it. (3) In reverse osmosis a pressure of at least 350 pounds per square inch is provided on the side of the tank containing the salt water. Now the water passes from the salt side to the fresh leaving both dissolved and solid material behind.

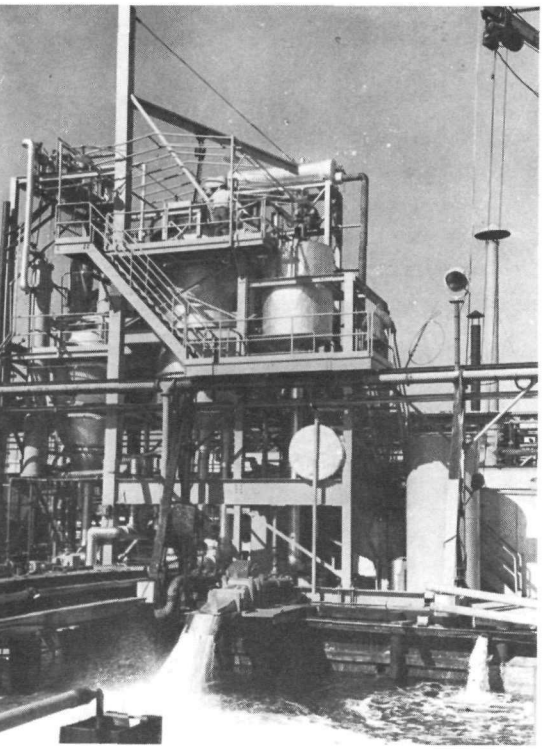
However, if the saline water is subjected to pressure greater than the natural osmotic force, the process is reversed. Water in the brine is forced through the membrane to the freshwater side, leaving the concentrated salts behind.

The reverse osmosis process holds hope of significantly reducing the cost of converting saline water, because it is inherently simple and requires little energy. Improvement of the process depends to a large degree on the development of suitable membranes. Very little is understood concerning membrane structure, ion-transport mechanisms, or even how to fabricate membranes. Little is known, too, about membrane lifetime, optimum pressures for operation, boundary layer limitations, and pressure effects on materials.

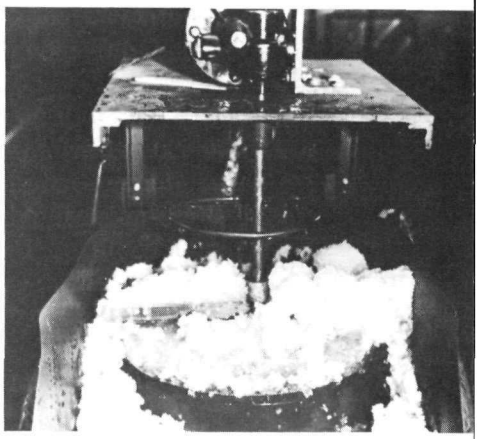
Although much research remains to be done, results so far have been highly encouraging. The OSW plans to build an experimental 50,000-gallon-per-day osmosis plant in 1967 to use brackish water. After this prototype is successfully operating, improved design and components may permit construction of more efficient, larger modules for operation with seawater.

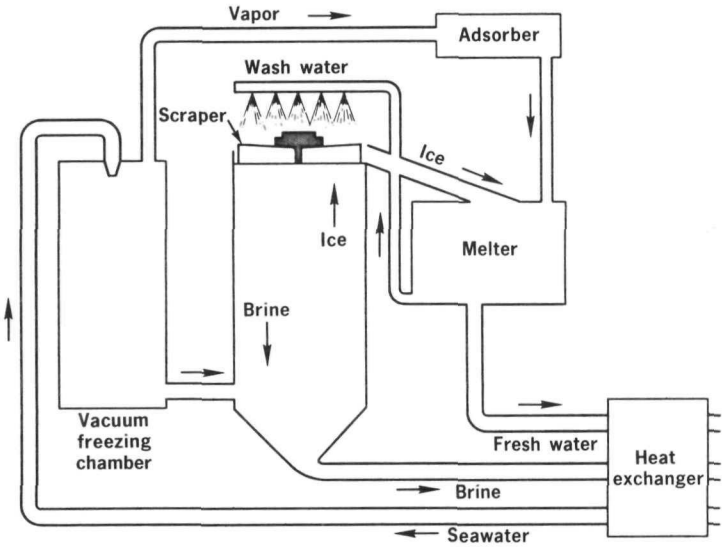
Freeze Separation

Like distillation, freezing also emulates nature; it removes heat to separate the water from the salt. (See diagram on page 32.) It takes less energy to freeze seawater than to evaporate it, and this makes the technique attractive. Its main disadvantage lies in the tenacity of the brine film that adheres to the crystals of pure water and must be removed. The Office of Saline Water now operates a 100,000-gallon-per-day freezing plant.



On the left is the plant at Wrightsville Beach, North Carolina, which desalts water by using freeze separation. Below is a close-up view of the ice being scraped off the top of the vat in the freezing plant by a rotating blade (see diagram on the next page).





To Meet the Need

It is important to keep in mind that no single water-conversion process can be applied universally. Each conversion plant must be designed to take advantage of the cheapest source of energy found at its particular locale, the available labor, and the geography of the site. As research proceeds it is possible that some techniques will be discarded, additional emphasis placed on others, and entirely new approaches discovered.

Therefore the Office of Saline Water conducts a broad program that aims at advancing the technology of water desalting. The goal is to ensure that techniques will be available everywhere within the next decade to meet municipal and industrial requirements for high-quality water.

In support of a program of this magnitude, the OSW has plans to continue and enlarge the basic research effort it now has underway, augment it by applied research applicable to large distillation plants, and develop and test promising items of equipment.

In addition, the OSW expects to build prototype plants when new or improved techniques require demonstration. Among these may be the 150-million-gallon-per-day multistage distillation and nuclear power plants proposed by the Metropolitan Water District of Southern California.

The OSW also now operates a desalting test center on the West Coast where full-scale components will be subjected to conditions approximating those in the finished plant.

WATER NEEDS IN THE UNITED STATES

A 1963 report by the Federal Council for Science and Technology cited regions within the United States where projected water requirements will approach the limit of available supplies by the year 2000. Listed were the Pacific Southwest, the upper Colorado Basin, the western Gulf, the upper Missouri, the Rio Grande–Pecos Basins, and the Great Basin. In some of these, particularly the Pacific Southwest, large quantities of additional water will be required well before that year, if restrictions on economic development and population growth are to be avoided.

Three distinct water-use areas can be identified in the Pacific Southwest. They are the southern California coastal region where water is used primarily for municipal and industrial purposes, Arizona where water is used for municipal, industrial, and agricultural purposes, and the interior of southern California where most available water is used for agriculture.

Water-resource planners generally agree that the principal decisions on future water supply for the coastal area of southern California should be made by the mid-1970s. Desalting plants may provide the most economical source of water for this area.

Much of the existing inland deficiency is being met now by "mining" groundwater, that is, by pumping from deep wells. In the interior valleys of southern California and Arizona, groundwater tables (the underground levels at which fresh water lies) have dropped as much as several

hundred feet as a result, and the situation in some places is critical.

The Colorado River is the principal source of water for the entire Pacific Southwest. Approximately 1,100,000 acre-feet* of Colorado River water is delivered to the southern California coastal area annually. Desalting plants, constructed on the coast, could provide new sources of pure water to supplement that available from the Colorado River.

Coastal areas requiring large supplies of water, and capable of using additional large supplies of power, are the logical sites for the big dual-purpose nuclear-powered distillation plants proposed. The Metropolitan Water District project, described on page 16, will probably be the first of these. Large plants might also provide auxiliary water in the Northeast, which periodically suffers from a drought condition such as that in the Connecticut–New York–New Jersey area from 1962 through 1965.

Another potential application for large-scale desalting may be in the highly industrialized section of the Texas Gulf coast. If additional sources of water are not developed soon, the area from Houston to Corpus Christi is expected to experience critical shortages.

Soon the semiarid south coast of Puerto Rico will also require substantial additional water if economic development is to proceed as planned. Approximately 50 million gallons per day will be required by 1980.

A survey made for the American Water Works Association shows that over 1000 United States communities are using brackish water. Several cities, such as Coalinga, California, Buckeye, Arizona, and Port Mansfield, Texas, have invested in their own desalting plants to improve and bring down the cost of potable water.

*One acre-foot is the amount of water that would cover one acre of ground to a depth of one foot, or 325,893 gallons.

How Much Does Water Cost?

The price of water is a relative thing. Where water is naturally plentiful the cost is low. In many communities its delivery is subsidized by governmental units, so the price per thousand gallons does not always reflect its true cost. Where water is plentiful, consumers can pay as little as 15¢ per thousand gallons, but in water-short areas the charge may run to $1 or more.

Before 1959 when it became the first municipality to operate its own desalting plant, the City of Coalinga, California, was importing fresh water by railway tank car for $7 per thousand gallons. Now its electrodialysis plant produces 28,000 gallons per day, or 5 gallons per resident, at $1.45 per thousand gallons. It supplies water only for drinking and cooking, and the remainder of the town's needs are met by brackish water. In 1965 Coalinga passed another desalting milestone by putting into operation the first reverse osmosis unit. It produces 6000 to 7000 gallons per day.

In 1962 Buckeye, Arizona, became the first town to have *all* its water supplied by its own electrodialysis desalting plant. The unit in Buckeye, 34 miles west of Phoenix, turns out 650,000 gallons of fresh water daily. The cost is about 60¢ per thousand gallons.

Because its salt content is greater, the cost of purifying seawater is higher than for brackish water. In 1952 the cost of converted seawater was estimated at $4 to $5 per thousand gallons. Now the cost has gone down to about $1 per thousand gallons. And technical methods are now available to bring it down to about 20¢ to 30¢ per thousand gallons in large plants.

President Johnson's request was for desalting methods that will provide pure water economically. As has been noted, the scarcity of water determines the price users are willing to pay and therefore what is economic. It is impossible to calculate the most economical price for desalted water in various parts of the country until more information is available on present costs of water, costs of new water resources, and pricing policies used in water development and distribution. The Office of Saline Water is undertaking a survey to obtain this information.

WATER COSTS FOR SEVERAL REACTOR-POWERED DUAL-PURPOSE STATIONS

Power value is estimated as the lowest cost of power from large established grid system. Fixed charge rate equals 7%. Plant load factor equals 80%.

Reactor size, Mw(t)	Type of reactor	Station built for operation in	Station by-product power, Mw(e)	Power value, mills/kwh	Water produced, M-GPD	Water price at plant	
						¢/1000 gal	¢/cu. meter
200	Water cooled*	1970	22	3.6	29	65	17.1
600	Water cooled	1970	73	3.6	88	40	10.6
1000	Water cooled	1970	133	3.6	119	36	9.5
1500	Water cooled	1970	212	3.6	155	31	8.2
1500	High temperature†	1970	387	3.6	128	31	8.2
3220	Water cooled	1970	420	3.6	350	31	8.2
3500	High converter‡	1970	550	3.6	310	27	7.1
8300	High converter	1975	1460	2.4	620	23	6.1

*Water cooled reactor represents a boiling, pressurized, or heavy water reactor.

†High temperature reactor represents a gas, sodium, or superheated steam cooled reactor.

‡High converter reactor represents a high neutron economy reactor such as graphite or heavy water moderated reactors.

The survey will include studies of costs incurred in the original purchase, replacement, and repair of plumbing fixtures, household appliances, and municipal water treatment and distribution facilities. The needs of industry for high-quality water will also be investigated as will the economics of blending desalted water with brackish water for municipal purposes.

Economics of Large-Scale Desalting

The President's message further emphasized the need for large-scale desalting plants for areas such as the Pacific Southwest. This is the first large water-short area where desalting is being given specific consideration.

Two factors that are vital in combined power generating and distillation plants are the cost of fuel and the capital costs. In large plants nuclear power becomes competitive with "conventional" power (that generated by non-nuclear energy sources). Fuel costs are lower for nuclear reactors and the relatively high capital cost of nuclear plants does not increase proportionately with size. This is expected to become increasingly true as nuclear technology provides improvements and as supplies of fossil fuels are diminished.

Cost comparisons between a 125,000-kilowatt fossil-fuel plant and a nuclear-power desalting plant of equal capacity are made in the chart on page 38. The cost of a single-purpose conventional power plant producing the same amount of electricity is also shown. (For this calculation, desalting is assumed to be by flash distillation.)

Note the enormous advantage in fuel costs of the nuclear plant, even though it generates the same amount of power and almost double the amount of water. Annual fuel costs for nuclear power are only $5.42 million as against $7.20 million in fossil fuel. And the nuclear plant could produce water at 56¢ per thousand gallons whereas the fossil-fueled plant price would be 65¢ per thousand gallons.

In a 1964 report, the Office of Science and Technology estimated that by the mid-1970s a large dual-purpose plant could produce 1000 to 1500 megawatts of electricity at a cost of 2.3 to 2.5 mills per kilowatt-hour and 500 to 800 million gallons of water per day at a cost of 20¢ to 25¢ per thousand gallons. By the 1980's, plants embodying

several nuclear reactors in a single installation, with a total capacity as high as 25,000 thermal megawatts, could be in operation. A plant like this would produce 5950 electrical megawatts at 1.6 mills per kilowatt-hour and 1,300,000 gallons of water per day at 19¢ per thousand gallons.

INTEGRATED PLANTS		
	Fossil Fuel	Nuclear
Electrical Capability (If only power)	226,000 kw	280,000 kw
Electrical Output (When integrated)	125,000 kw	125,000 kw
Capital Cost	$29,000,000	$58,800,000
Annual Fuel Cost	$ 7,200,000	$ 5,420,000
Water Plant Capacity per Day	38.3 Million Gal	69 Million Gal
CONVENTIONAL COSTS–125,000 KW		
Capital	$18,800,000	
Annual Fuel Cost	$ 3,850,000	
WATER PLANT COSTS		
Capital–Water Plant	$30,000,000	$53,800,000
Capital–Power Plant	$10,200,000	$40,000,000
Total Capital for Water	$40,200,000	$93,800,000
Annual Capital for Water @10%	$ 4,020,000	$ 9,380,000
Annual Fuel for Water	3,350,000	1,570,000
Operating Costs for Water	1,220,000	2,440,000
Total Annual Costs	$ 8,590,000	$13,390,000
Water Production–1000 Gal/Yr	13,300,000	23,900,000
¢/1000 Gal	65¢	50¢

Reproduced with permission from *Fresh Water from Saline Waters*, Philip Sporn, Pergamon Press, 1966.

Water and power costs vary widely, as do interest rates on capital, water-conveyance charges, and labor and land prices. Each case must be considered individually in estimating cost. For instance, it is possible that in some communities the power plant and the water-production plant will be owned separately and the reactor-heated steam for distillation will be sold by the power company to the water company. In this case fixed charges might differ from those in other cities.

Enormous technical advances have been made in both nuclear power and desalting over the past decade. It is reasonable to expect, therefore, that the accelerated program that began in 1964 will produce new improvements that will have pronounced effect on the economics of desalting.

AROUND THE WORLD

No detailed study of worldwide water requirements exists, but in 1964 the United Nations published the results of a survey of 43 countries entitled *Water Desalination in Developing Countries.* It found that there are about 20 areas of the world that need desalting and 41 others that may soon. Since there is usually only sketchy information regarding *unused* water supplies that might supplement those now being tapped, it's often difficult to know whether desalting is an absolute need in a specific country or whether other undiscovered resources await development.

Already there are numerous desalting plants in operation in many parts of the world. Many of these are in Africa, some in Asia, some in the Caribbean and Latin America, and a few in Europe. The majority are owned by individual companies and are used to meet the water needs of their industrial processes and their personnel. Many produce quite small amounts of water.

The largest single desalting plant, producing 2.63 million gallons per day, is at Key West, Florida. At Shuwaikh in the oil-rich kingdom of Kuwait there are several government-owned desalination units at one site with a total capacity of 10 million gallons per day. Other desalting installations with capacities of a million or more gallons per day are in Qatar, also on the Persian Gulf, the islands of Curaço and Aruba off the coast of Venezuela, the Bahamas, Italy, Saudi Arabia, Holland, the Canary Islands, Malta, and Tijuana, Mexico.

To prevent lack of water from acting as a brake on the growth of its economy, Israel has been exploring all possible ways for desalting seawater. When Israel's freshwater supplies are fully developed the nation will still only be able to meet projected demands through 1970. The United States and Israel are jointly studying the pos-

sibilities for a 100-million-gallon-per-day nuclear-powered desalting plant that also will produce 200 megawatts of electricity.

The United Arab Republic is interested in installing a nuclear power and desalting plant to produce 150 megawatts of electricity and 5 million gallons of water per day at Borg El Arab, near the Mediterranean Sea. This area receives only about 6 inches of rainfall annually. The plant would be used in a pilot project to determine the most efficient use of desalted water for agricultural purposes, principally the cultivation of olives. A team of specialists from the International Atomic Energy Agency* and the U. S. consulted with officials of the U.A.R. in 1965 concerning this proposal.

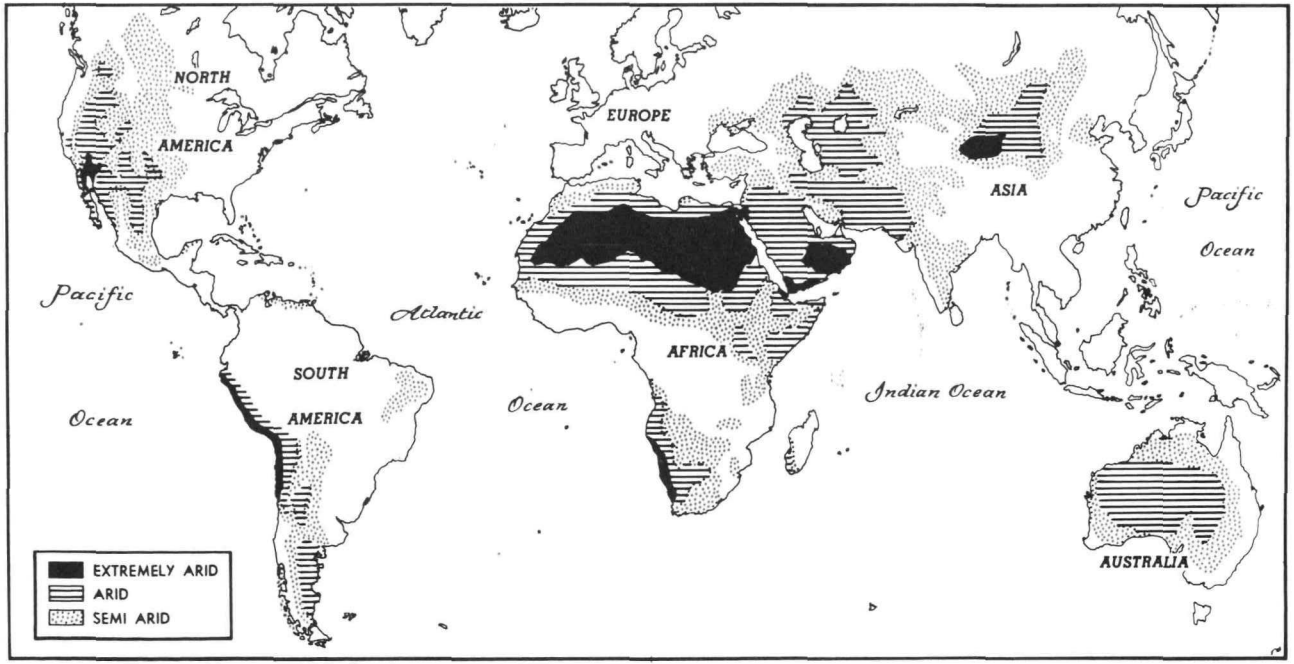
Mexico is 60% arid. The portion close to the California border is developing rapidly, and an aqueduct over 160 miles long has been planned to supply 25 million gallons of water per day. Since the area has over 5000 miles of coastline the Mexican government is interested in the possibility of building a dual-purpose nuclear desalting plant. With the cooperation of the International Atomic Energy Agency, the governments of Mexico and the United States have agreed to examine the feasibility of installing a large nuclear combination power-desalting plant on the Gulf of California to meet the needs of both countries in that region. (See photo on page 43.)

Tunisia, in North Africa, is already in desperate need of water. Its 4.2 million people suffer from a critical shortage. Humans need about 1.25 liters (1.3 quarts) of water per day each as a minimum requirement. Although a salt content of 2.5 grams (0.09 ounce) per liter (1.05 quarts) is usually not considered unpalatable, the U. S. Public Health Service says that drinking water should not contain more than 0.5 gram per liter. The saline content of water in southern Tunisia varies from 1.5 to 7 grams per liter and in some places is as high as 24 grams per liter.

The extreme shortage of fresh water goes hand in hand with a low grade of agriculture, and in spite of conservation efforts by the government, the Tunisian arid zone is

*The International Atomic Energy Agency is a United Nations organization to promote peaceful uses of atomic energy. Its headquarters is Vienna.

ARID REGIONS OF THE WORLD



As the world population grows and more lands become industrialized, the demand for fresh water soars. Arid regions, shown on the map, are becoming increasingly populated. In those designated "extremely arid" there are periods of a year or more in which no rain falls.

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spreading in a northeasterly direction. Southern Tunisians, especially young people, are migrating northward. The Tunisian government is considering development of an industrial complex in southern Tunisia that would provide a demand for electrical power and water based on a sizeable dual-purpose nuclear-power plant. The industry would stabilize the economy and reverse the flow of population.

In November 1964 the United States and the Union of Soviet Socialist Republics signed an agreement to cooperate in desalting, including methods that use atomic energy. The agreement provides for exchange of scientific accounts, reports, and other documents. It calls for the organization of regular symposia and scientific meetings and provides that the International Atomic Energy Agency will receive copies of all reports and other documents that originate in the meetings, which appropriate member nations of the IAEA also will be invited to attend.

The U.S.S.R. now has a 1.5-million-gallon-per-day desalting unit that converts brackish water at Shevchenko, a new city on the arid eastern shore of the Caspian Sea. Construction of a dual-purpose plant using a nuclear heat source is also underway there. According to a Soviet report, this plant may incorporate the country's first large breeder reactor. It will supply approximately 350 megawatts of power and possibly 30 to 40 million gallons of fresh water per day. In Russia, nuclear desalting plants may also be built in the Donets Basin, an important industrial district that will have a water deficit by 1970. A third potential area of the U.S.S.R. for nuclear-powered desalting plants is the desert of central Kazakhstan and other parts of central Asia.

The United States to Help

By means of joint undertakings, such as those with Israel and Mexico, and agreements, such as that with the U.S.S.R., the United States has made clear that it wishes to share its capability in water purification with the rest of the world. The United States has offered to provide experts to the International Atomic Energy Agency to assist in its nuclear-desalting activities, to provide orientation visits for IAEA staff workers to U. S. facilities, and to establish grants and

fellowships to bring qualified trainees from other lands to study desalting methods in the United States.

After signing the agreement with Mexico before delegates to the First International Symposium on Water Desalination held in Washington on October 7, 1965, President Johnson said, "The United States is prepared to contribute its share of the resources needed for an international crash program to deal with world water resources. We ask other nations to join us in pursuit of a common objective.

"Since the beginning of time, fresh water has always been one of humanity's most precious needs. For it many wars have been fought throughout history. Without it whole civilizations have vanished from the earth.

"Now, we of this generation have an opportunity to put an end to all of that. Our generation realizes that we have the power. It is the power of science. But if we are to use that power effectively we must use it together.

"The Earth's water belongs to all mankind. Together we just must find ways to make certain that every nation has it in full share and that there is really enough of it for all nations."

On October 7, 1965, the United States and Mexico signed an agreement to study the feasibility of building a nuclear-power desalting plant to serve portions of both countries. Left to right are Hugo Margain, Mexico's Ambassador to the U. S., Glenn T. Seaborg, Chairman of the USAEC, President Lyndon B. Johnson, and the late Nabor Carrillo Flores of the Mexican Nuclear Energy Commission.

WHAT WE CAN ACCOMPLISH

The world's gathering water-shortage crisis has many causes. In only a few specific places can natural aridity be blamed. In areas well endowed with water resources man has allowed his rivers and lakes to become polluted with industrial and municipal wastes. He has not prudently guarded his water fortune but has spent it with lavish recklessness, and now finds himself impoverished.

As an expanding industrial society and an exploding population increase the world's thirst, all avenues of investigation must be followed.

A verse in the Book of Ecclesiastes in the Old Testament reads:

> All the rivers run into the sea;
> Yet the sea is not full.
> Unto the place from whence the
> rivers come,
> Thither they return again.

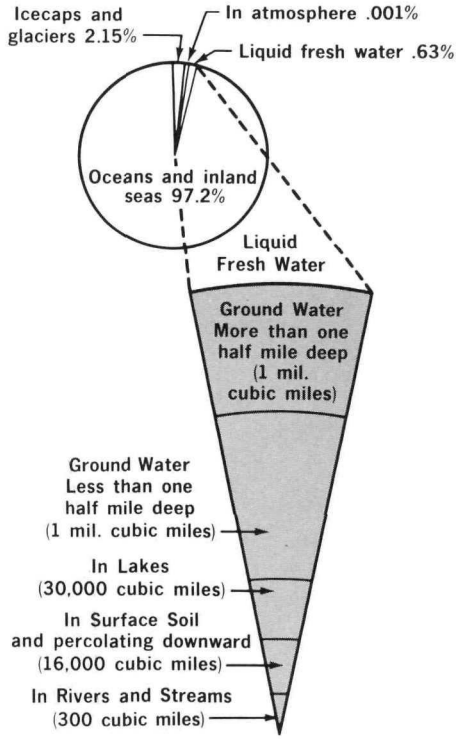
This simple statement is still true as well as beautiful. Hydrologists believe, however, that deep underground there are ancient natural reservoirs into which little, if any, water is now being returned and from which none is being taken. Since these reservoirs are protected from evaporation they could play a vital role in meeting water needs if they can be found.

In the fall of 1965, U. S. government geologists, for instance, found a river of vast dimensions under the eastern part of the State of Maryland. Test drillings revealed a channel 2 miles long and half a mile wide; there were indications that it extends 35 miles. It is a buried freshwater treasure.

In an attempt to conserve existing water supplies, scientists also are trying to develop a substance that will coat the surface of lakes and reservoirs to prevent evaporation. Efforts have also been made to keep heavy runoffs from rushing down to the sea, by diverting the water and spreading it over gravel beds through which it will seep into the ground to raise the water table.

A concerted international scientific effort, the International Hydrological Decade, began on January 1, 1965. For

THE WORLD'S WATER



Most of the world's water, as shown in this diagram, is in the oceans or the ice sheet covering Antarctica. Most of the water on land is underground. The percentage readily accessible in lakes is small. One of the goals of the International Hydrological Decade is to find ways to exploit underground reserves without depleting them. Copyright 1964 by *The New York Times* Company. Reprinted by permission.

10 years water scientists all over the world will direct their labors toward understanding the complexities of the water cycle.

In the United States a Federal Resources Council will investigate all aspects of the water problem and ways to solve it.

President Johnson's request to the Atomic Energy Commission and the Department of the Interior to join the growing competence of nuclear power and the advancing technology of desalination, is intended to help this nation and the world meet water requirements.

Desalting of water is not a panacea for all mankind's water needs. Every sound approach, every technologically feasible means of increasing the supply of potable water will be needed to meet the staggering demands of the future. Nuclear-powered desalting units will be prominent among the methods by which we will obtain large amounts of additional fresh water. Fortunately for the world's thirst, nuclear power for desalting will be available soon, rather than late.

At the request of the Government of Israel, experts from the United Nations Technical Assistance Administration are helping to explore and develop that country's water resources. This modern rotary drilling rig is being used in the Negev Desert during explorations for underground water. The drill bit had just been brought up from a depth of 500 meters.

SUGGESTED REFERENCES

Books

Water Production Using Nuclear Energy, Roy G. Post and Robert L. Seale (Eds.), The University of Arizona Press, Tucson, 1966, 392 pp., $7.50.

Fresh Water from Saline Waters: The Political, Social, Engineering, and Economic Aspects of Desalination, Philip Sporn, Pergamon Press, New York 10022, 1965, 48 pp., $2.45.

Water, Luna B. Leopold, Kenneth S. Davis, and the Editors of *Life,* Time Inc. Book Division, Time-Life Books, New York 10020, 1966, 200 pp., $3.95. Pp. 186-189.

Water: The Yearbook of Agriculture, U. S. Department of Agriculture, Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402, 1955, 751 pp., $2.00. Conversion of Saline Waters, David S. Jenkins, R. F. McNiesh, and Sidney Gottley, p. 109. (Out of print but available through libraries.)

Water and Man: A Study in Ecology, Jonathan Forman and Ollie E. Fink (Eds.), Friends of the Land, Columbus, Ohio, 1950, 407 pp., $4.50. (Out of print but available through libraries.)

Principles of Desalination, K. S. Spiegler (Ed.), Academic Press, New York, 1966, 566 pp., $21.00.

Fresh Water From Salty Seas, David O. Woodbury, Dodd, Mead, and Company, New York 10016, 1967, 96 pp., $3.50.

Reports

Policy Considerations in Desalting and Energy Development and Utilization, (TID-23872), James T. Ramey, U. S. Atomic Energy Commission, Division of Technical Information Extension, P. O. Box 62, Oak Ridge, Tenn. 37830, free.

Nuclear Energy . . . Potential for Desalting, (S-24-65), James T. Ramey, John A. Swartout, and William A. Williams, Jr., First International Symposium on Water Desalination, Oct. 8, 1965, U. S. Atomic Energy Commission, Division of Public Information, free.

Desalination Research and the Water Problem (Publication 941), Report of the Desalination Research Conference at Woods Hole, Massachusetts, June 14–19, 1961, National Academy of Sciences—National Research Council, Washington, D. C. 20418, 85 pp., $1.50.

The following reports are available from National Agency for International Publications, 317 East 34th Street, New York 10016:

Desalination of Water Using Conventional and Nuclear Energy, Technical Report Series 24, International Atomic Energy Agency, February 1964, 53 pp., $1.00.

Costing Methods for Nuclear Desalination, Technical Report Series 69, International Atomic Energy Agency, November 1966, 42 pp., $1.00.

The following reports are available from the United Nations, Sales Section, New York, N. Y. 10017.

Water Desalination: Proposals for a Costing Procedure and Related Technical and Economic Considerations, United Nations, 1965, 56 pp., $0.75.

Water Desalination in Developing Countries, United Nations, 1964, 325 pp., $4.00.

The following reports are available from the Superintendent of Documents, U. S. Government Printing Office, Washington, D. C. 20402:

1966 Saline Water Conversion Report, Office of Saline Water, U.S. Department of the Interior, 1967, 340 pp., $1.75.

Use of Nuclear Power for the Production of Fresh Water from Salt Water, Hearings before the Joint Committee on Atomic Energy, Congress of the United States, 88th Congress, 2nd Session, 1964, 155 pp., $0.40.

An Assessment of Large Nuclear Powered Sea Water Distillation Plants, Office of Science and Technology, Executive Office of the President, March 1964, 31 pp., $0.35.

Appendices to the above, 478 pp., $3.25.

The A-B-Seas of Desalting, Office of Saline Water, U. S. Department of the Interior, 1966, 24 pp., $0.25.

Proceedings of the First International Symposium on Water Desalination, Washington, D. C., Oct. 3–9, 1965, 632 pp., $3.25.

The following reports are available from the Clearinghouse for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virginia 22151:

Mineral By-Products from the Sea (PB 181588), Research and Development Progress Report No. 91, Office of Saline Water, U. S. Department of Interior, March 1964, 130 pp., $2.75.

Proceedings of the Conference on Saline Water Conversion (PB 181322), Report of the conference in Washington, D. C., March 28, 1962, Office of Saline Water, U. S. Department of the Interior, 1962, 134pp., $2.75.

Nuclear Reactors Applied to Water Desalting (A/CONF.28/P/220), James T. Ramey, James K. Carr, and Robert W. Ritzmann, U. S. Atomic Energy Commission, 1964, 16 pp., $1.00.

Articles

Fresh Water from the Sea, Allen J. Barduhn, *Oceanology International,* 2: 28 (March-April 1967).

Water: Worldwide Use and Misuse, *Time,* 86: 70 (Oct. 1, 1965).

Desalting Technology 1965: Putting Water Where the World Needs It, *Nucleonics,* 23: 43 (September 1965). This special report issue contains the following articles on desalting:

Why Not Single-Purpose Reactors for Desalting? S. Baron and M. Zizza, p. 44.

The Prospects for Dual-Purpose Plants, Frederick E. Crever, p. 48.
Nuclear Desalting for Agricultural Water, R. Philip Hammond, p. 51.
The People—Water Crisis, *Newsweek*, p. 48 (Aug. 23, 1965).
Making the Sea Fit to Drink, Glenn T. Seaborg, *U. S. News and World Report*, 59: 64 (July 19, 1965).
Desalination of Water, Philip H. Abelson, *Science*, 146: 1533 (Dec. 18, 1964).
The World is Getting Thirstier: Hope to Turn Salt Water into Fresh, Lawrence Galton, *New York Times Magazine*, p. 94 (Sept. 27, 1964).
Rushing a Cuban Water Cure: Guantanamo, *Business Week*, p. 34 (July 4, 1964).
Desalting Water by Freezing, A. E. Snyder, *Scientific American*, 207: 41 (December 1962).

Motion Pictures

The Crisis at Guantanamo, 12 minutes, sound, color, 1965. Produced by and available from Westinghouse Electric Corporation, Visual Communications Department, 3 Gateway Center, Box 2278, Pittsburgh, Pennsylvania 15230. When the freshwater supply was shut off in 1964 at the Guantanamo Naval Base, an immediate source was needed for 2½ million gallons of fresh water every day. This film describes how an OSW desalting plant, already in operation in San Diego, California, was moved 3600 miles to solve the problem in 5 months. Two more plants and a power station were in operation on Guantanamo after 11 months.

New Water for a Thirsty World, 22 minutes, sound, color, 1965. Produced by the Office of Saline Water, Department of the Interior. Available on loan from Sterling Movies USA, 43 West 61st Street, New York 10023, or from Chief Engineer, Bureau of Reclamation, Denver Federal Center, Building 53, Denver, Colorado 80201.

Water Famine, 55 minutes, sound, black and white, 1961. Produced by the Columbia Broadcasting System, Inc. Available on loan for $15.00 from Carousel Films, Inc., 1501 Broadway, Suite 1503, New York 10036.

Desalting the Seas, 17 minutes, sound, color, 1967. Produced by AEC's Oak Ridge National Laboratory. Describes various methods of purifying saline water through the use of large dual-purpose nuclear-electric desalting plants that would purify water and produce large amounts of electric power simultaneously. Available for loan without charge from the AEC Headquarters Film Library, Division of Public Information, U. S. Atomic Energy Commission, Washington, D. C. 20545 and from other AEC film libraries.

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