Freshwater from Nuclear Desalination

by Christine Craig

A proven technology whose time has come.

IAEA

Japan began nuclear desalination in 1978 at the Ohi nuclear plant, and now 10 Japanese nuclear plants desalinate water on a small scale, mostly for in-plant use.

Early in the 1960s, foreseeing a time when freshwater needs would outstrip available supplies, the U.S. Department of Interior's Office of Saline Water (OSW) authorized funding for five research facilities to study and develop desalination technologies for the country. These facilities were strategically placed in Freeport, Tex.; Roswell, N.M.; Webster, S.D.; Wrightsville Beach, N.C.; and San Diego, Calif.

The Wrightsville Beach facility on Harbor Island, set up in the early 1960s, was dubbed the "world center for experimental development in saline water conversion," by the director of the OSW at that time, C.F. McGowan. Its mission was to study and assess the feasibility of a variety of possible desalination technologies—freezing, reverse osmosis (RO), electrodialysis, and distillation—of which the most promising were RO and distillation. While the lab was still in operation during the 1960s and 1970s, a huge sign covered the three freshwater storage tanks for the research station, proclaiming mysteriously: "Fresh Water from the Sea."

Desalination is by no means a modern concept. The importance of fresh water would be inescapable to any long-distance seafaring people. As Samuel Coleridge's ancient mariner lamented: "Water, water, everywhere, nor any drop to drink." Japanese (and undoubtedly many other) early mariners used heat evaporation and cooling condensation to provide emergency fresh water on voyages. Thomas Jefferson even wrote a technical paper in 1791 on an improved form of distillation process for desalination aboard ships. And with the advent of sea-going steam ships, desalination became absolutely necessary to provide the relatively pure water necessary for the steam process. Nowadays, regardless of what powers an ocean-going vessel, desalination of potable water is the norm, and eminently more sensible than trying to carry a hold full of drinking water across the wide ocean.

Nuclear: Perfect to Power Desalination

Modern desalination techniques require large amounts of electricity or process heat for large-scale production of fresh water, and nuclear power is the perfect candidate to supply it.

Nuclear desalination seemed a natural outgrowth of the potential envisioned for nuclear power by the Atoms for Peace Project initiated by President Dwight D. Eisenhower after World War II. In fact, in 1967, just days after the Six Day War, former President Eisenhower and Adm. Lewis L. Strauss, former chairman of the Atomic Energy Commission, proposed an ambitious program for development in the Middle East, which was an extension of Eisenhower's 1953 Atoms for Peace program. This program, called "A Proposal for Our Time," aimed at promoting peace and stability in a war-torn region by priming the pump with a massive infrastructure project to bring cheap fresh water to the region—a nuclear water-desalination project.

This proposal envisioned the construction of three huge, multi-purpose nuclear plants, two on the Mediterranean and one on the Gulf of Aqaba, which would be capable of generating more than a billion gallons of fresh water per day, using the well-studied distillation technique. At the same time, the plants could be used for electricity production in the region. Based on studies done by the Oak Ridge National Labs, Eisenhower was confident that the price of water generated at these facilities could be made cheap enough for agricultural use, making possible an agro-industrial oasis in the desert.

Early Nuclear Desalination Projects for America

As early as 1964, an announcement was made of a partnership among the Department of the Interior, the Atomic Energy Commission (AEC), and the Metropolitan Water District of California to study the construction of a 150-million-gallon per day (MGD) desalination distillation plant near the OSW test facility in San Diego. According to then-Secretary of the Interior Stewart Udall, "Preliminary reports indicate that a well-designed plant using nuclear energy can produce fresh water at seaside for 22 cents a thousand gallons and generate electric power for as little as 3 mills per kilowatt hour."

The Bolsa Island Dual-Purpose Nuclear Power and Desalination Project, as it came to be called, grew out of an early desire of the Metropolitan Water District of Southern California to explore desalination as a way to augment water supplies for the fast-growing region. It began preliminary studies in 1959, and in 1964 signed a contract with the AEC and Department of the Interior for joint feasibility studies, to be carried out by Bechtel Corporation, for a 50-150 MGD desalination plant coupled with a 750-megawatt-electric (MWe) nuclear plant.

During the study period, in 1965, two Southern California utility companies, San Diego Gas and Electric and Southern California Edison, plus the Department of Water and Power of the City of Los Angeles proposed to join the project, if the generating capacity of the plant were increased to 1,800 megawatts-electric. They would bear the financial responsibility for the generating plant, leaving the desalination plant costs to the Metropolitan Water District and Federal agencies. Bechtel Corporation was to be the project coordinator.

The group chose a unique site for the nuplex: Bolsa Island, a man-made island to be created for the sole purpose of housing the plants. The island would be built off Bolsa Chica State Beach, south of Los Angeles. The 1,800-MWe nuclear plant would be coupled to a multi-stage flash distillation (MSF) desalination plant, supplying up to 750,000 people with fresh water and electricity in the arid southern California desert.

By the 89th Congress, in September 1966, the Metropolitan Water District project was well along, and was touted as "the first dual-purpose desalting application of its kind and size in the world" in the Joint Committee on Atomic Energy hearings on the project.

The project was never completed.

U.S.-Mexico Desalination Plan

In 1965, the United States, Mexico, and the International Atomic Energy Agency signed an agreement to assess the technical and economic feasibility of a nuclear co-generating plant in northern Mexico producing electricity and desalinated water from the Gulf of California. The plans called for plants capable of producing 1 billion gallons per day of fresh water and 2,000 megawatts of electricity. In the near-term, two 5,000-MW-thermal light water reactors would be built by the mid-1990s. The desalination plant would consist of multistage flash distillation units. It was projected that a second phase of the project might utilize the newer liquid-metal fast-breeder reactors, which would reduce water costs. Capital costs were estimated at from $850 million to $1.2 billion.

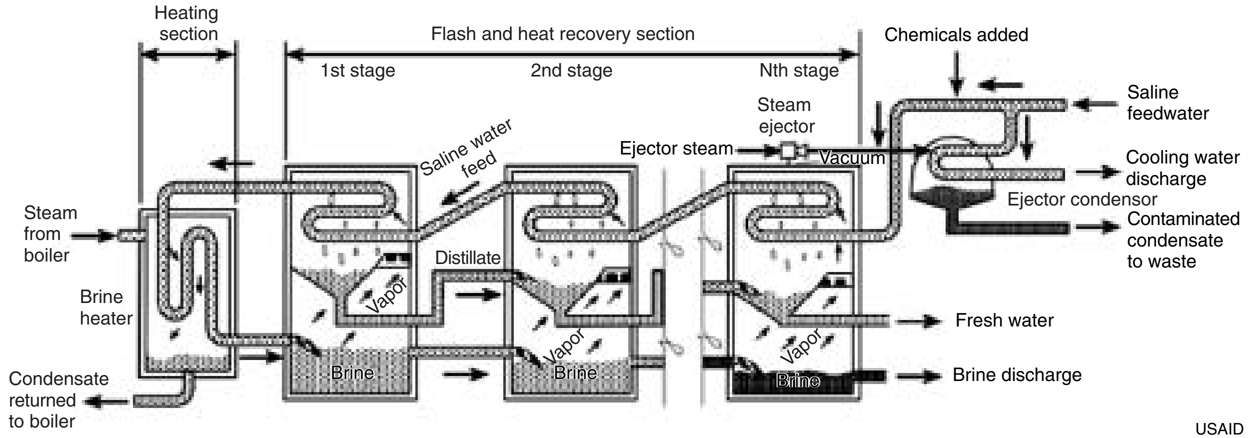
One of likely sites proposed was El Golfo de Santa Clara on the Sonora side of the northernmost extent of the Gulf of California. Product water would be piped to reservoirs for storage, one in Mexico, and one on the U.S. side. The big worry in 1965 was: Who would use all that electricity? You can't store electricity as you can water. They considered replacing

How Desalination Systems Work

There are two main types of desalination technologies: thermal and membrane.

The thermal processes are elaborations of the basic evaporation/condensation cycles of water. Under partial vacuum, boiling will occur at lower temperatures, as at high altitude. Simple distillation, such as that used by higher-class liquor bootleggers, is energetically expensive relative to the amount of product. Coupling many evaporation/condensation stages in series, though more complex to construct and run, gives much more product for the amount of heat added. Even more efficiency can be added by carefully controlling the pressure in each stage to be lower than the last one. When properly designed, the process only requires heat at the first stage, and cascades through the other stages on that impetus, with product water and brine collected at each stage.

- **Multi-stage flash (MSF) distillation.** In MSF, saline water is sent through tubing from the last stage through the first, and into the brine heater, where heat is applied, usually from steam. The



USAID

Figure 1
MULTI-STAGE FLASH PLANT

some of the electricity generators with vapor compressors coupled to a multiple-effect evaporator, with this coupled to the MSF system. Their study never considered coupling industrial applications like fertilizer plants to the nuplex, even though much of the water was destined for agricultural uses.

The project never got off the ground.

Unfortunately, Eisenhower's "Proposal for Our Time" was never implemented, as the nation's optimism for nuclear power was manipulated and transformed into fear and pessimism by nuclear non-proliferation fanatics and their puppets in the environmental movement.

Other Nations Move Ahead

As nuclear desalination languished in the United States, other nations have amassed decades of experience coupling the two technologies. The first large-scale nuclear production of fresh water was at a Soviet-era 150-MWe liquid-sodium-cooled fast breeder reactor in Aktau, Kazakstan—the BN-350. From 1973 until its decommissioning in 1999, the BN-350 reliably and safely produced 80,000 cubic meters per day of fresh water by multi-stage flash distillation and multiple-effect distillation (MED). The water was used in plant operations and for municipal water consumption in the arid Mangyshlak Peninsula, on the east coast of the Caspian Sea.

Japan first harnessed nuclear power for desalination back in 1978, with its Ohi Nuclear Power Station's 1,175-MWe Pressurized Water Reactors. Since then, 10 of Japan's 53 electricity-producing nuclear plants have used waste heat or electricity to desalinate water on a small scale—100 to 3,900 cubic meters per day—mostly for in-plant use for steam generators and potable water. The desalination technologies used by these plants have included all of the major types.

More recently, Pakistan hooked up its KANUPP 137-MWe Pressurized Water Reactor to an RO desalination system, producing 454 cubic meters per day of water as an emergency source of feed water to the steam generator. In the last few months, the reactor staff has also installed a larger demonstration MED unit capable of producing 4,500 cubic meters per day.

India has done the same with its Kalpakkam PHWR in the southern state of Tamil Nadu.

Even in the United States, which long ago turned its back on nuclear desalination, the Diablo Canyon Nuclear Power Station, owned by Pacific Gas & Electric, quietly has operated a desalination unit powered by its two 1,100-MWe Pressurized Water Reactors, which produces 4,500 cubic meters per day by RO for in-plant use. The desalination plant was originally conceived as a joint project of the California State Department of Resources and the OSW.

So, nuclear desalination is not a radical untested idea. It is a mature technology which has been waiting in the wings, perfecting itself for the call to action by a world (including the United States) waking up to the nuclear power imperative.

heated brine is emptied into the first stage, where the lower pressure leads to flash evaporation. The vapor condenses on the tubing of the cooler saline water moving toward the brine heater, and is collected and emptied into the next stage, and so on. As it condenses, it heats the saline water stream in the tubing, setting up a heat gradient in the tubes, which works in concert with the pressure gradient in the stages.

Separate from this stream of product water, the brine moves through the stages, collecting at the bottom of each. In each stage, some of it flashes at the lower pressures, moving up into the vapor phase, condensing, and joining the product stream. After the last stage, the product fresh water is collected and stored, and the brine is discharged to waste.

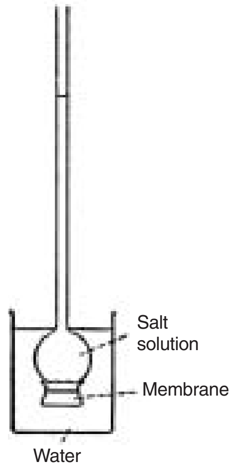


Figure 2
HOW OSMOSIS WORKS

The principle of osmosis was discovered in 1824 by Henri Dutrochet and elaborated by a series of investigators in the 19th Century. Imagine the thistle tube in the diagram filled with a solution of salty water and covered with a semi-permeable membrane, such as an animal bladder, which allows passage of the water molecules but not the salt. By immersing the inverted tube in pure water, a pressure (called osmotic pressure) is created across the membrane, causing the pure water to enter the tube and dilute the saline solution.

If a reverse pressure is applied, for example by blowing into the tube, the pure water will be driven out, and the salinity of the solution in the tube will be increased. This is the principle applied in reverse osmosis to purify salty water.

- **Multiple-effect distillation (MED).** MED has a similar series of chambers, called effects, and a similar temperature/pressure gradient through them. It differs in the plumbing connections of the water components to the effects. In this system, a steam loop in the first effect introduces heat through tubing. Saline water is sprayed onto the hot tubing, leading to vaporization. The vapor is collected and moves through tubing to the second effect, where saline water is sprayed onto it, vaporizes, and is collected and fed into the next. This vaporization on the tubing from the previous effect causes cooling and condensation within the tube of fresh water, which is then directed out to a product stream from each effect. The unvaporized brine in each effect is collected into a brine stream.

- **Reverse osmosis (RO).** RO is the predominant modern membrane process, especially in the United States. It requires the high-pressure pumping of pre-treated saline water through layers of semi-permeable membranes which selectively block the movement of the salts. Units of these membrane cartridges are hooked in series, and water moves through in a product stream, with brine collected into a waste stream. Pre-treatment is necessary because the membranes can be fouled by certain chemicals naturally in the introduced saline water.