adjuvant chemotherapy. "What is different about the Mayo Clinic population?" asks Charles Pratt of St. Jude's Hospital in Memphis. He points out that the patients are mostly white, middle- or upper-middle-class, and may receive treatment earlier in the course of the disease than poorer patients from urban areas or the rural South.

Abelson points out that it is hard to draw conclusions about a trial consisting of only 37 patients. This is not to fault the Mayo Clinic—only about 1000 people in this country develop osteogenic sarcoma each year. But in order to detect a 20 percent difference in survival between two groups, a trial would have to include at least 180 patients, according to Abelson. Even then, he says, there would still be a 5 percent chance of a false negative. "It is patently impossible for a single institution to do [an appropriately sized] study. It's almost mandatory to do a multi-institutional trial."

The NCI has been trying for several years to interest other institutions in joining it in a controlled trial of adjuvant chemotherapy in osteogenic sarcoma. Until very recently, it has had no success. Following the announcement of the Mayo Clinic results, however, six institutions are willing to consider joining the NCI in such a trial, Levine says. Abelson, who is among those now interested in a controlled trial, explains that he believes a trial is warranted because "the historical control problem is so substantial and the issues raised are so provocative." Others, as would be expected, believe so strongly in adjuvant chemotherapy that they feel ethically constrained from participating in such a trial. "I would not like my patients entered in such a trial," says Jaffee.

—GINA BARI KOLATA

Tapping Sun-Warmed Ocean Water for Power

A successful experiment boosts ocean thermal energy into favor, but hurdles remain to commercialization of the process

Late last summer, in an experiment near Hawaii, usable power was generated for the first time from temperature differences in ocean water. This successful demonstration of ocean thermal energy conversion (OTEC) triggered enthusiasm for the process. President Carter just signed into law two measures to spur OTEC research and speed commercialization.* Yet OTEC remains a hope, not a firm solution for the energy crisis. Although the experiment showed that OTEC can produce electricity, it did not prove that commercial-sized plants, generating a few hundred megawatts, could run continuously for many years, providing power at a competitive price.

This is one of a series of occasional articles about the prospects and problems of alternative energy sources.

The appeal of OTEC is that its fuel—sun-warmed ocean water—is free and virtually unlimited. Oceans in the tropics are heated so much that in theory they could provide several times more electricity than is consumed in the world. The temperature difference of 20° to 25°C between surface and deep water can operate a heat engine to generate electricity.

The critical question is whether it is feasible to extract the free energy for a reasonable price. Building commercial OTEC plants will be a major challenge, as many components are huge. Furthermore, keeping the plants operating in the harsh marine environment may be overly expensive. Storms, waves, and marine organisms growing on equipment can all threaten an OTEC facility.

Although the United States is shy of warm territorial waters, the Department of Energy (DOE) is enthusiastic about OTEC's potential to fill a significant portion of the world's energy needs. About 5 percent—$37 million—of DOE's solar energy budget funds OTEC research and development. For U.S. use, electricity from OTEC could be cabled to shore in Hawaii, Puerto Rico, Guam, the Virgin Islands, and along the Gulf Coast. Moreover, energy-intensive products could be manufactured in the tropics with OTEC energy and shipped to shore, says William Avery, head of an OTEC research group at Johns Hopkins University. Ammonia manufacturers, currently heavy consumers of natural gas, are eager to move to sea, according to John Babbitt, president of DEVCO in Tulsa and one of the founders of Solaramco, a newly formed consortium of ammonia manufacturers interested in OTEC.

When last summer's experiment worked, it boosted OTEC into favor: for the first time the prospects for OTEC appeared to outweigh the problems that have colored researchers' perspectives of the process in the past (*Science*, 14 October 1977). The plant, dubbed Mini-OTEC, was launched by Lockheed Missiles and Space Company, the Dillingham Corporation, Alfa-Laval Incorporated of Sweden, and the state of Hawaii, with no federal funding. "Fifteen months after the four parties shook hands on the agreement [to cosponsor the $3 million experiment], we had net power generation," says Roger Fuller of Lockheed. Roughly 40 of the 50 kilowatts generated were used to power the plant, leaving 10 kilowatts to light some flood lamps.

"Once Mini-OTEC started up, it ran and ran. There was nothing for us to do but go fishing," relates Fuller. Housed on a surplus barge loaned by the Navy, the plant worked as well as or better than its designers predicted. Moreover, none of the problems touted by OTEC skeptics interfered with the generation of electricity.

Mini-OTEC is a miniaturized version of what is envisioned as a first-generation OTEC plant. Warm water from the ocean surface evaporates ammonia. The vapor expands through a turbine and is then condensed by cold seawater pumped through a pipe from a depth of nearly 700 meters. In Mini-OTEC, the turbine drives a 50-kilowatt generator.

Although Mini-OTEC was built hurriedly with off-the-shelf components, it surprised skeptics by generating net power. But, as anticipated, the yield was not very high: 80 percent of the electricity was needed to operate the plant, primarily to pump the seawater. A carefully designed plant built of components specifically suited to OTEC should do much better, leaving perhaps 65 to 70

*On 17 July President Carter signed the Matsunaga-Fuqua Bill (OTEC Research, Development, and Demonstration Act), which establishes goals for OTEC research and mandates that OTEC plants be producing 10,000 megawatts by 1999. The Studds-Inouye Bill (OTEC Act of 1980) was signed into law on 3 August. It sets up licensing regulations for OTEC plants and establishes a loan guarantee program to aid their construction.

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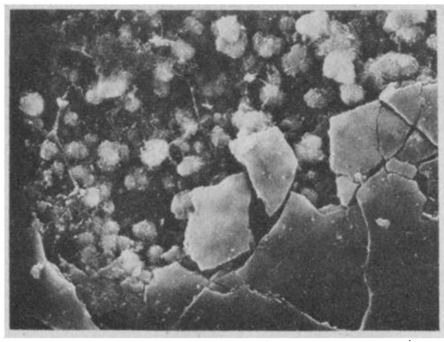
percent of the power for use by a utility.

That Mini-OTEC's power output did not deteriorate as the plant operated is more noteworthy than its overall efficiency, according to Fuller. Large marine organisms, such as barnacles, did not clog the pipes or interfere with the pumps. Moreover, no scum of microorganisms grew on the metal surfaces of the heat exchangers, devices that allow heat to flow between the seawater and ammonia without permitting the two fluids to mix. It takes only a very thin layer of slime on the heat exchangers to reduce the yield of power significantly. Mini-OTEC's heat exchangers were "sparkling clean" at the end of the experiment, says Fuller. A tiny amount of chlorine added continuously to the seawater kept the microorganisms from attaching or growing.

Mini-OTEC has been OTEC's best advertisement. "We got into OTEC after Mini-OTEC demonstrated its viability," says Richard Bell of Hawaiian Electric Company. Bell is guardedly optimistic that OTEC will fill some of Hawaii's electricity needs within a decade. Hawaiian Electric may be buying OTEC power as soon as next year if Lockheed plans for Mini-OTEC pan out, "but we're not going to make any money on it [the sale]," says Lockheed's Lloyd Trimble. Both the utility and Lockheed are eager to test the feasibility of cabling power from an OTEC plant to shore. Currently, Mini-OTEC is in Honolulu harbor, where it will be modified to improve its performance when industrial sponsors finalize an agreement to share the $2 million cost of its second fling.

Bell and others are not completely convinced that commercial-sized plants will work reliably for 30 years. Many problems unique to the bigger facilities were not addressed by the demonstration. The brief operation of Mini-OTEC was no real test of the potential of marine organisms to hassle the plant. Moreover, the experiment was so small as to have had no effect on the ocean, and also small enough to be engineered much more easily than the larger plants.

Because of its short duration, Mini-OTEC may have barely scratched the surface of the biofouling problem, cautions David White of Florida State University, Tallahassee. His recent research indicates that it takes several weeks for a spanking clean heat exchanger to accumulate enough slime to reduce its effectiveness. (Mini-OTEC operated intermittently for 3 months.) But once the first scum forms, even scrubbing does not get it all off—subsequent fouling occurs much faster. According to White, it



Biofouling is a bigger problem for aluminum heat exchangers than for more expensive titanium ones because aluminum corrodes in seawater. Here filamentous microorganisms interleave with the corrosion products (×1300). [Source: David White]

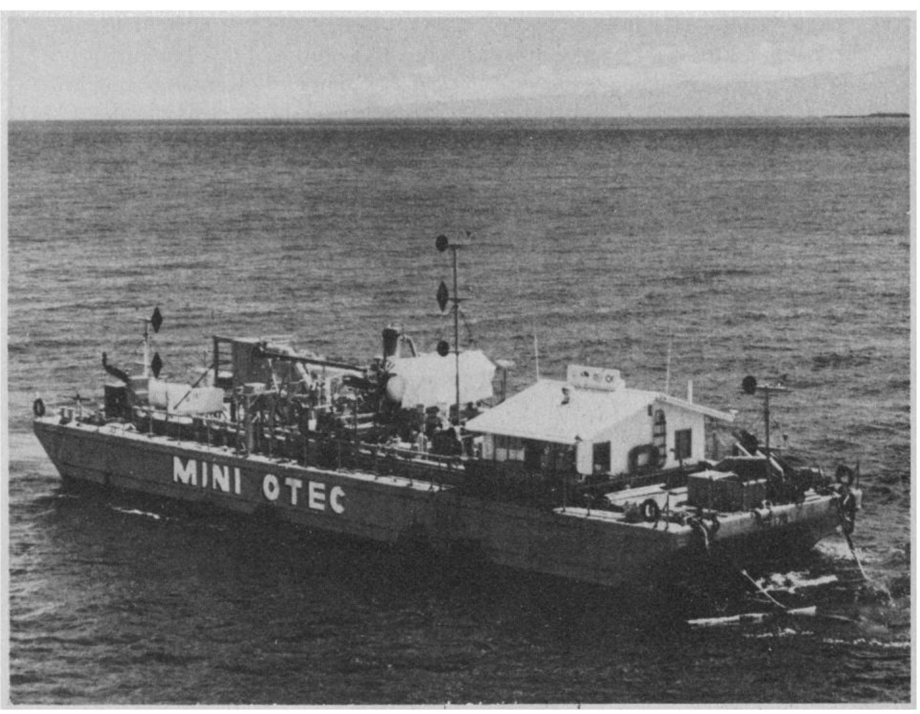
is as if the heat exchanger surface were primed for fouling by the first organisms to settle there.

For OTEC to be successful, the heat exchangers "must be kept cleaner than anything has ever been kept at sea," says White, and kept clean for 30 years, the projected life of a plant. Chemical agents, such as the chlorine used in Mini-OTEC, may do the job, but they may not be environmentally acceptable. "On a research basis, no one cares if you chlorinate. But on a commercial level, with plants generating 400 megawatts, someone won't like it," warns David Jopling of Florida Power and Light Company. On an encouraging note, DOE tests near Panama City, Florida, indicate that extraordinarily small amounts of chlorine—only 0.5 part per million added to the seawater for 15 minutes per day—may keep the heat exchangers clean.

The DOE plans to evaluate other promising cures for biofouling this summer as part of a large OTEC testing program. A refitted Navy tanker, now named OTEC-1, cruised last month to its site off the Kona Coast of Hawaii (30 kilometers from Keahole Point). Unlike Mini-OTEC, OTEC-1 will not produce any electricity; its purpose is to conduct engineering and performance tests of OTEC components, particularly heat exchangers, under real ocean conditions.

Since thermodynamics limits to a few percent the amount of heat energy that can be extracted from ocean water, "you need a very efficient heat exchanger" to get as much of the available energy out as possible, says David Hillis of Argonne National Laboratory. Hillis, with Anthony Thomas and James Lorenz of Argonne, has been testing heat exchangers in a laboratory in search of the best and least expensive designs for the low temperature differences characteristic of OTEC. Many models perform well, much better than anticipated, under the ideal conditions studied at Argonne. Because specially treated freshwater, instead of seawater, was circulated through the heat exchangers, neither corrosion nor biofouling occurred. Studies with OTEC-1 are expected to focus on those factors.

Many experts view the design, construction, and installation of a cold water pipe able to withstand the abuse it will receive in the ocean as the greatest challenge facing OTEC engineers. To get the cold water, the pipe must reach to a depth of about 1000 meters. To handle



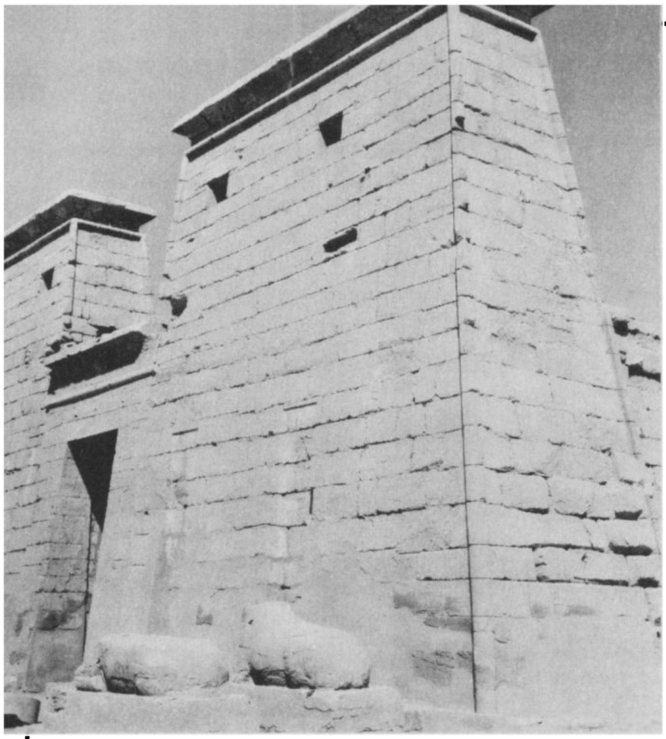
Mini-OTEC power plant. [Source: Lockheed] the required water flow for a commercial plant—some 3000 cubic meters per second or about as much as the Nile River carries—it must be 30 meters in diameter. The Washington Monument would fit easily inside.

Such a cold water pipe "stretches today's technology," says Richard Scotti of the National Oceanic and Atmospheric Administration in Rockville, Maryland. Scotti has been estimating the forces the pipe will experience, and they are huge. According to William Richards, head of DOE's ocean energy program, concrete or steel could survive these forces, and specially reinforced plastic looks promising and is about to be tested. With the cold water pipe, as with other challenging OTEC components, the crucial question is not whether it can be built, but how cheaply it can be built and maintained.

While tests and experiments can help to solve some of the problems facing and raised by OTEC, others may be recognized only the hard way. One of these is the influence of OTEC on the oceans. Although there is little doubt that, individually, even commercial-sized OTEC plants will not disturb the ocean, a fleet of facilities exploiting the resource to the hilt may affect the ocean adversely. For instance, if a significant fraction of ocean heat is converted to electricity and redistributed by OTEC pumps, then the ocean surface may cool slightly, with unforeseen consequences for local weather patterns. In a way, the effect of OTEC on the oceans is self-limited: if the temperature difference between surface and deep water decreases, so does OTEC's power output and benefit-cost ratio. Other problems include spillage of ammonia, and legal questions that must be addressed before plants start operating.

Of the problems facing OTEC, "none appears to be a showstopper," says Robert Cohen of DOE. The consensus of experts is that OTEC plants can be built and operated with existing technology. If OTEC-1 tests are encouraging, then the next step, they say, is to build a pilot plant. It would be designed to generate around 40 megawatts of electricity continuously and cost on the order of $250 million—the price of 1 day's oil imports. If the pilot plant is successful, OTEC would presumably be on its way. Already, Puerto Rico, Hawaii, and ammonia companies are clamoring to use the first commercial OTEC electricity, because according to current estimates OTEC power will be cheaper to generate, where there is warm ocean water, than power from fossil fuels.

—Beverly Karplus Hartline



U.A.R. State Tourist Administration Photo

Temple of Karnak at Luxor, Egypt.

Irrigation Threatens Egyptian Temples

The annual flooding of the Nile River has, for centuries, been slowly destroying the ancient temples along its banks. Although the floods are now curbed by dams, the temples, such as those in the Karnak area, continue to deteriorate, and two Canadian chemists think they know why. The culprit is salt, they say, the same agent that attacked the shrines during the predam era. As it crystallizes, salt mechanically breaks apart the sandstone foundations and walls of the temples.

In bygone years, the salt came from the river. As the temples dried out after each flood, the tiny amount of salt dissolved in the river water remained in the sandstone and caused it to crumble. Archeologists hoped that the dams, by stopping the flooding of the Nile, would stop the decay of the temples. Yet recent inspections reveal that deterioration continues.

The salt now comes from water that runs through the ground from nearby irrigated fields, say Thomas Billard and George Burns of the University of Toronto. They calculate that near the Great Temple of Karnak about 2.4 grams of salt per year crystallize in a square meter of land, as the underground water seeps toward the surface and evaporates. "The current salinization of the temple is more insidious [than that caused by flooding], because it is continuous and cumulative," explains Billard. "Over a period of 50 to 100 years it should cause a lot of deterioration."

The Great Temple is on unirrigated land where the water table has been raised to within 2 to 3 meters of the surface by intense irrigation of nearby fields. Because the water table is so close to the surface, water drawn out of it by capillary action evaporates readily. Dissolved salt remains in the soil (and in the foundations of the temple). According to the calculations of Billard and Burns, more than 90 percent of the water draining from fields near Karnak evaporates in unirrigated ground. The remaining water returns to the river.

Salting of foundations may be a problem in other arid regions where fields are irrigated, Billard and Burns warn. It may threaten the existence of many great monuments in Egypt. According to Billard, the Egyptians are working on a solution. They hope that, by draining the area of the Great Temple, salinization will be reduced to a harmless level. If the water table is far underground, water will not evaporate as rapidly as it does now; thus much less salt should be deposited near the surface.

—Beverly Karplus Hartline