PROJECT OBJECTIVES

The object of our research was to conduct a technology assessment of three alternative options for siting large thermal-electric generating stations; and to relate our findings to the impact each of these options would have on water resources. Virtually all large generating stations in the United States today utilize either natural water bodies for once-through cooling or, where this is not feasible, evaporative cooling towers, using a fresh-water source, are installed. These typical installations served as the basis of comparison against which the proposed technologies were measured.

In addition to this comparative analysis, we also looked at the as yet unresolved technical, environmental and economic uncertainties.

Specifically our goal was to analyze three new technologies:
1. Floating nuclear plants
2. Salt-water cooling towers
3. Underground nuclear plants

Floating Nuclear Plants

In regard to floating nuclear plants, we set out to examine the status of the plants of this type that have been ordered, and for which environmental impact statements have already been prepared. Specifically, we wanted to understand the technical issues relating to the design and construction of the breakwater, the dispersion of the thermal condenser discharge plume, and nuclear safety. Finally, we attempted to evaluate the technical, economic and environmental aspects of these issues in contrast to comparably-sized conventional land-based nuclear plants.

Salt-water Cooling Towers

In regard to salt-water cooling towers, we set out to investigate the extent and quantity of drift of salt from the top of the tower and the technical state of the art for minimizing such salt-release; and the consequences of relatively concentrated
saline discharges to the aquatic environment; the reliability of the methods used
to predict the transport patterns of salt and where it lands on the ground. We also
wanted to find out what are the effects of increased concentrations of salt on
plants and soils, and on the microclimate, since these effects would impact on the
location of cooling towers.

**Underground Nuclear Plants**

Our objective here was to obtain some understanding of two factors: one, whether
there are technical and safety advantages in locating nuclear plants underground
that would permit them to be put near cities; and two, whether the waste heat from
such an underground nuclear plant, close to an urban center, might be beneficially
used.

**ACHIEVEMENT OF OBJECTIVES**

Approximately 60% of the research effort was spent on the study of floating
nuclear plants, 30% on salt-water cooling towers, and about 10% on underground nu-
clear plants. As a result of our technology assessment, we concluded that both float-
ing nuclear plants and salt-water cooling towers probably present reasonable power-
plant siting alternatives and may have less of an impact on the environment than
conventional nuclear plants. While there are still some issues that need to be re-
solved, there are probably sufficient studies underway, that within a few years these
issues ought not to delay the technology.

On the other hand, underground nuclear plants do not seem to have sufficient ad-
vantages—at this time with the present types of light water reactors—to warrant
undertaking the additional costs of construction and exposing urban populations to
the increased risk. The additional safety from undergrounding would not offset the
additional difficulty of construction; and it is improbable that safety criteria
would permit underground plants to be located any nearer to population centers than
is now the case with above-ground plants.

**RESEARCH PROCEDURES USED**

The research comprised three types of inquiry: that based on published reports
and open files of government agencies and companies under contract with the govern-
ment; discussions and private interviews with experts; and independent evaluation
and assessment by the authors. In the case of floating nuclear plants, since firm
orders have already been placed, we used the environmental impact statement on the
Atlantic Generating Station, the environmental report submitted by Offshore Power
Systems, Inc. in applying for a license to manufacture the plant, and open file
 correspondence with the Atomic Energy Commission, more recently with its successor,
the Nuclear Regulatory Commission.

Since some salt-water cooling towers are being built, we had access to the en-
vironmental impact statement of the Forked River Nuclear Plant, reports published
by the Maryland Power Siting Commission on the Chalk Point Oil-Fired Plant, and
technical reports by Westinghouse and other designers of cooling towers.
Underground nuclear plants are not now in the planning stage. Hence, we used survey studies that had been prepared by research organizations and, beyond that, had discussions with technical specialists from the Federal government and from industry.

RESULTS AND CONCLUSIONS

Floating Nuclear Plants

The floating Nuclear plants would be technically identical to the standard Westinghouse 1,150 MWe pressurized water reactor. Therefore, the basic safety characteristics are not affected by whether the plant is mounted on a barge or conventionally located on land. Similarly, the efficiency of the plant is not altered. The same quantity of heat must be disposed of. Floating plants are subject to the same criteria regarding population density in the surrounding regions, but because they are to be located some three miles off shore there are far fewer people in relatively close proximity of the reactor -- up to five miles-- than would be near a land-based plant. The other population density criteria set by NRC, 120,000 persons within a ten-mile radius, 500,000 within 20 miles, and two million within 40 miles, must be met regardless of siting.

There are, however, several characteristics that distinguish the two types of plants:

Land-based plants are built upon a bed-rock foundation whose geological integrity is a subject of intensive investigation. Sites have been rejected sometimes with a financial loss, where evidence of geologic faulting was exposed during the foundation preparation stage. On the other hand, floating plants are located in 44-70 foot depths of water and are protected by a breakwater which almost completely surrounds the plant. The breakwater is essential for the protection of the plant, and therefore it must be designed to withstand the most severe conditions of wind, tide, waves, and collision with a moving vessel. The geology on the ocean floor must be capable of supporting the weight of the breakwater, and there must be no risk of any seismic activity that could undermine the structure. Inside the breakwater, the floating plants are designed for only minimal movement other than the normal vertical shift caused by the tide.

The floating power plant will be connected to the shore by undersea high-voltage electrical cables. The technology for this is well understood. However, one terminal for the cable will be located at the breakwater. There will thus have to be a flexible coupling between the power plant and the transmission terminal in the breakwater, and this will require the development of some new technology, although it does not appear to be too difficult to achieve.

In addition to not requiring valuable coastal land, floating plants offer the advantage of being better able to dissipate the waste heat than most shore-based plants. If properly located with respect to currents, and with the correct design of the condenser discharge, floating plants would seem to be able to reduce the impact of the nuclear generating station on the marine environment. For example, a floating plant of 2,300 MWe, withdrawing 4,000 cfs, will have about 10 acres of surface waters at 3ºF or higher. By contrast, at the Millstone Point site, 2,600 MWe, withdrawing 4,155 cfs, will enclose 175-273 acres within its 3ºF isotherm. Calculations for
other land-based plants give similar results. Part of the reason for the decreased thermal impact of floating plants is that they are able to withdraw cooler water near the floor of the ocean, and land-based plants may not, except at high cost, be able to do the same.

Regarding radioactive releases from routine operations, floating plants have some advantage because there is no population within three miles and while shore-based plants not only have populations in proximity but in most areas of the country the population in these coastal areas is projected to continue to increase during the period in which the plant will be operating. We were unable to develop firm answers in regard to accidental releases of radioactivity. On the one hand, the ocean will act as a dilutant. On the other hand, marine organisms may well act as concentrators. It was beyond the scope of our study to enter this controversy.

Public concern has been expressed about loss of coolant accidents (LOCA). Floating plants may have an advantage in this regard, since an immense amount of cooling water would be immediately available. However, this whole question, both for land-based and floating nuclear plants, is under intensive review by NRC.

The cost of the nuclear plant itself may well be somewhat less for floating than for land-based, because it is planned that the floating plant would be fabricated on an assembly-line basis in a single factory, and towed, mounted on a barge, to the site. Terrestrial plants, in contrast, must be field fabricated. On the other hand, the breakwater can be very costly, approximately 30% of the total cost for the Atlantic Generating Station, Units 1 and 2. The total floating plant, including breakwater, is expected to cost 10%-20% more than the equivalent land-based plant, including cooling towers. The question for the electric utilities is whether the reduced lead-time, better quality-control, and greater flexibility with regard to siting, is worth the extra cost. In some areas, such as New Jersey, it is possible that suitable sites for land-based nuclear plants may simply not exist.

With the assistance of the Coast Guard and survey maps, a number of possible sites for floating plants were identified by the authors in Long Island Sound from east of Bridgeport-Port Jefferson, to Buzzards and Cape Cod Bays. To date the sites identified by the power industry have been off the coast of Florida, South Carolina and New Jersey, in open ocean. Our conclusion is that until necessary experience has been gained, the preferred location would be in semi-sheltered waters, such as Long Island Sound and Cape Cod Bay, where a high degree of protection from major storms is naturally available.

At one time eight floating nuclear plants had been ordered, with the first ones scheduled to be delivered in the mid-1980's for installation off southern New Jersey. As a result of the recent reduction in the demand for electricity and the very high interest rates, six of these plants have been canceled and the two for New Jersey have been postponed until 1990 at the earliest. OffShore Power Systems, Inc. had required a minimum of eight orders to warrant the construction of a manufacturing plant in Jacksonville, Florida. In the present climate of uncertainty, plans for this factory have been shelved.
Salt-Water Cooling Towers

Evaporative natural draft cooling towers, using salt or brackish water, water containing in excess of 1,000 ppm of dissolved solids, are being constructed in southern New Jersey at the Forked River nuclear plant and in Maryland at Chalk Point oil-fired plant on the Patuxent River. At both sites there are already once-through cooling systems in place at earlier constructed units. The assimilative capacity of the natural water body is thus fully utilized and the existing plants are having some difficulty conforming to the applicable state thermal discharge standards. It was clear from the start that additional capacity at those plants would only be permitted with closed, i.e., evaporative cooling systems.

In theory, salt-water cooling towers have some major advantages over other cooling methods. They do not need to discharge any heat to the aquatic environment. At most, the two towers just mentioned may, under routine operations, discharge 5% as much heated water as once-through cooling. Salt-water towers obviously make no demands on the available fresh-water. They evaporate water for which there is little other use and of which there is no shortage. They use far less land area than cooling ponds, only about 1%. They reduce the need for remote-siting with the associated high transmission costs.

The main question has to do with the fact that some salt inevitably will escape as drift through the top of the cooling tower, and will be transported by the wind and deposited some distance from the tower. The chlorine present in salt can cause leaf burning and the sodium can alter soil characteristics. Acute dosages can lead to loss of the plant, while chronic dosages may cause slower growth and reduced yield for certain crops. Salt is incorporated into the leaf structure of certain plants, such as tobacco and green beans, and can spoil the taste. The following factors will influence the extent of the damage: relative humidity, amount of rainfall, and the actual amounts of salt at various stages in the growing cycle of the plant. Detailed studies are being undertaken in the area surrounding Chalk Point which will confirm whether these damages are as severe as feared.

The damages to the environment are a function both of the amount of salt emitted by the cooling tower and the amount of naturally occurring background salt in the atmosphere. Thus, cooling towers near the ocean will, in general, cause less damage to vegetation than cooling towers located on an estuary several miles from the sea. Vegetation near the ocean has adapted itself to relatively high background levels of salt, and thus can tolerate the additional increment from the towers without ill effects. Chalk Point is located at least thirty miles from the ocean, in an area of commercial agriculture, and it remains to be seen whether detectable damage is done over a period of a few years. In the humid east, rain will wash away most of the salt and prevent higher concentrations from building up, but it is possible that during drought periods problems could occur.

Under adverse meteorological conditions, salt droplets can serve both to stabilize clouds and to stimulate precipitation by seeding. A major question is whether synergisms between the salt, the water vapor and other air pollutants, especially if the power plant uses fossil fuels, can lead to undesirable micro-meteorological conditions. The studies at Chalk Point will determine if there is any substance to this concern.
Improvements in the design of natural draft towers, by using a sophisticated configuration of internal baffles and drift eliminators, can probably reduce the amount of salt escaping from the tower to a low, but not negligible level. Some modeling of the iso-salt concentration deposition regions has been undertaken. These models now need to be verified by measurements of actual operations.

Evaporative cooling towers are not, strictly speaking, completely closed systems. Apart from the water vapor and salt which escapes from the top of the tower, requiring a continuous water replenishment at 1%–3% of the rate once-through cooling systems, about 12,000 gpm for a 1,100 MWe nuclear plant, there is a small but steady release of water directly from the system, called blowdown, which serves to limit the increase in the salt concentration of the circulating water. The volume of the blowdown can be varied so that a greater volume will result in reduced salt-concentrations in the circulating water and hence a lower quantity of salt in the drift. On the other hand, if saline discharges to the receiving waters need to be reduced at any particular point because of fish spawning, for example, this can be done, but the trade-off will entail a larger quantity of the salt entering the atmosphere. The actual volume of blowdown is small, about 4% of the circulating water, or 24,000 gpm for a 1,100 MWe nuclear plant and is a function of the actual salinity of the intake water. In estuarine areas, the salinity varies depending on the weather, the season, and the tides. Since estuaries are regions of critical ecological importance, it is important to design the discharge method for blowdown carefully to avoid any adverse effects resulting from the saline discharge. The blowdown is slightly more dense than the receiving water and will thus tend to sink, with possible damage to the deeper-living marine organisms.

Salt-water cooling towers cost about 2%–4% more than fresh-water cooling towers, the increase being for the larger size necessary and the more expensive corrosion resistant construction materials required. Research is being done to reduce the amount of drift. The present state of the art is about 0.002% of the circulating water.

Underground Nuclear Plants

Proponents see two advantages in locating nuclear plants underground. The one is safety and the other is that they can be located nearer to urban centers. Nuclear plants today are about 32% efficient which means that for every kilowatt-hour of electricity generated about 6,800 BTU/s of waste heat must be disposed of. The challenge is to determine whether beneficial use can be made of the large quantity of low-grade heat.

By locating the plant underground, an additional barrier will supplement the conventional containment systems in the event of an accident. The nuclear plant can be located either in an excavated underground rock cavern or back-filled in a shallower cavity. In either case the land-use impacts are minimized and the surface can be used for a park or some other purpose if safety regulations permit.

The cost of undergrounding has been estimated at between 10% and 25% higher than for conventional above-ground locations. On the other hand, transmission costs should be somewhat reduced owing to the proximity to the load centers. There seem to be some major disadvantages associated with undergrounding. The difficulty of constructing a large, complex facility in difficult working conditions and the
subsequent problems of inspection and repair appear formidable. Neither the electric utility industry, the reactor manufacturers, nor the Federal agencies have shown much interest in this option.

The claimed safety advantages are also questionable since the reactor will have to be linked to the turbine and this creates one possible path for a breach of the containment. Then the condenser requires cooling water and a linkage to the district heating system, and this is a second area of interaction between the plant and the environment. In other words, the underground nuclear plant cannot be strictly isolated from the environment around it, and for this reason it is unlikely that the NRC will relax its population density criteria.

Apart from the location of the plants, there are some genuine difficulties associated with comprehensive utilization of waste heat. The first problem is that the heat is rejected at between 10°F and 20°F above the intake water temperature, so that in winter the thermal discharge would be at about 60°F which is of no use for district heating, while in summer reject temperature would be on the order of 90°F. The thermal efficiency of a Rankine cycle engine is directly related to rejecting waste heat at the lowest possible temperature. Thus, although the actual quantity of BTU's being disposed of this way may be great, it is of little or no economic value because of the very modest temperature at which the heat is supplied. Rejecting at a higher temperature means losing some thermal efficiency in a linear relationship; temperatures on the order of 250°F to 300°F would be needed for district heating and absorption air conditioning. Unfortunately, if the nuclear plant operated to reject such high-temperature heat, its thermal efficiency would fall from 32% to about 20%-22%; in other words, there would be a net loss of about 30% in electrical output.

The other difficulty with using nuclear plants in this way is that the demand for electricity may not exactly parallel the demand for steam. In other words, there will be periods such as in the late spring when electricity is demanded but steam is not needed. The system, thus, has to be designed with some redundancy; back-up cooling systems have to be installed for periods when district heating is at a minimum, while reserve heating systems are needed in case the electrical generating plant is not fully available. All these factors tend to raise the cost as does the fact that district heating requires many miles of underground insulated pipe, and may therefore be practicable only in new communities.

An alternate to large nuclear underground plants would be to utilize conventionally-sited intermediate-sized fossil generating stations preferably of the internal combustion type, such as gas turbines and diesels which naturally reject heat at a high temperature, in excess of 700°F. In fact, the more efficient the gas turbine, the higher the reject temperature. These plants come in smaller sizes and can be decentralized which will reduce the heat loss in transmission. Also the gas turbines can be run in conjunction with steam turbines and in this way a very simple balancing of the supply and demand for steam can be achieved.

PUBLICATIONS

None to date.
ABSTRACT

A technology assessment of three unconventional power plant siting options: floating nuclear plants, plants utilizing salt-water cooling towers, and underground nuclear plants was undertaken. Floating nuclear plants have some environmental benefits, less land-use and reduced thermal impact on the marine environment. Salt-water cooling towers offer more flexibility in power-plant siting, but emit salt to the atmosphere which in areas of low ambient salt concentrations could cause damage to certain agricultural crops and in some regions micro-meteorological problems. Underground nuclear plants do not appear to offer sufficient advantage to offset the added construction costs, and it is unlikely that they will be permitted to be built any closer to population centers than conventional nuclear plants.

KEYWORDS

nuclear power plants
electric generating stations
salt-water cooling towers
cooling towers
floating nuclear plants
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power plant siting
cooling water

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