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WATER USE IMPLICATIONS FOR NUCLEAR POWER STATIONS IN THE UNITED STATES OF AMERICA

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The problems in selecting reactor sites are discussed in terms of population density, coolant water demand, thermal pollution and engineered safeguard measures during construction and operation.

In the next twenty years the energy consumption of the United States is supposed to double. It is assumed that the needed energy will be covered not only by increasing conventional sources such as coal, petroleum, natural gas and water resources but also by nuclear power (Figs. 1 and 2). By 1982, one hundred sixty nuclear power plants will be in operation with a capacity of 142 457 Mwe. (U.S. Atomic Energy Commission, December 1972). Fig. 3 and Table 1 show location and description of power plants as of March 31, 1973. In April 1973 alone, one utility ordered six power reactors having a capacity of 7200 Mwe.

It has been recognized for some time that the location of nuclear power plants must be contemplated in relation to their total environment. There are different considerations concerning population density around power reactor sites. One reactor siting policy is the Czechoslovakian approach, based on the use of well-proven types of reactors at two urban sites under development in the central region of the city of Prague (Branik-Modřany and Holešovice) and a further nuclear plant in the city of Brno (Amato 1971). Another approach is to build the reactor offshore (Little Egg Harbor Inlet, New Jersey) in "shallow" waters within the three mile limit where the plant must be protected against hurricanes and ship collision. Conditions characteristic for population density in existing power reactor areas in the United States and elsewhere are given by Fig. 4 and 5.

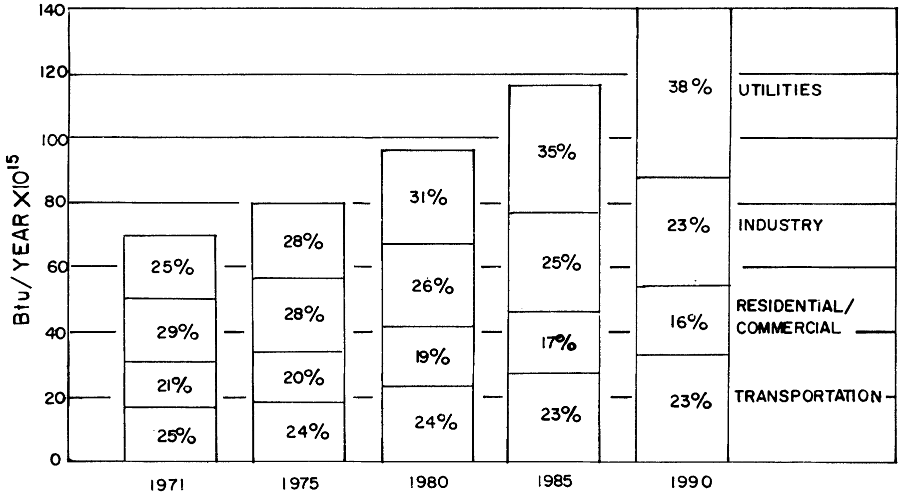

Fig. 1.

Energy consumption in the United States by consuming sectors;* 1 Btu = 0.259 cal; 10^{15} Btu ≌ 172 x 10^6 barrels of oil. 970 x 10^9 cubic feet of natural gas, 41.7 x 10^6 tons of coal.

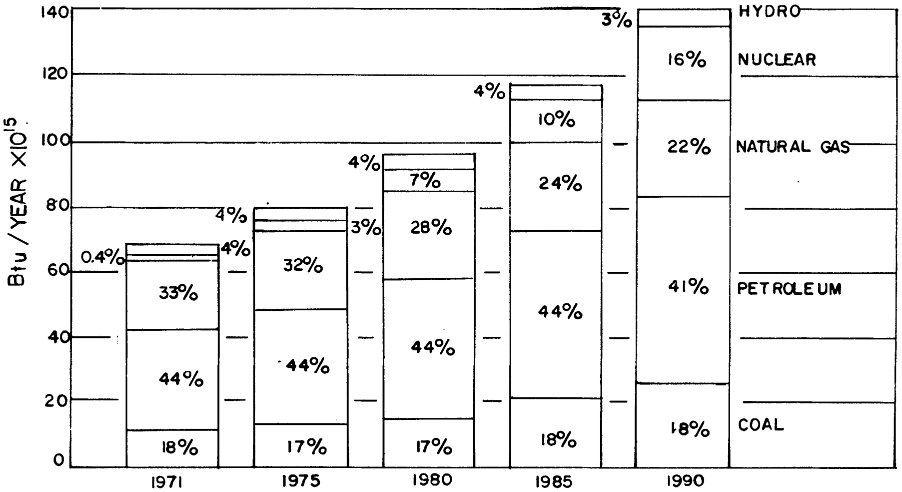

Fig. 2.

Energy consumption in the United States by source*. See Fig. 1 caption.

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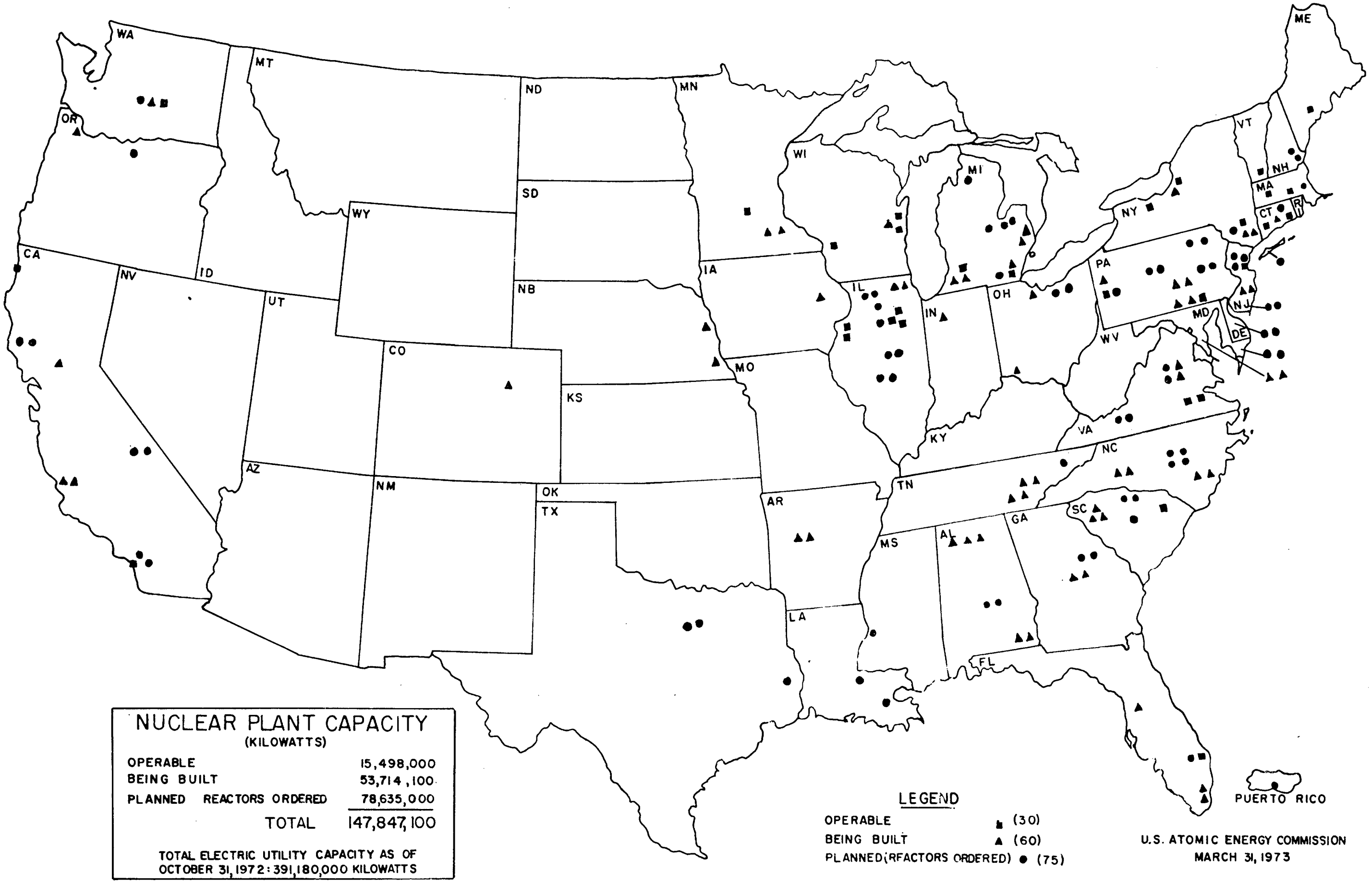
* Data: Bureau of Mines, *U.S. Energy Through the Year 2000.* Washington, D.C.: U.S Department of the Interior, December 1972.



NUCLEAR PLANT CAPACITY
(KILOWATTS)

OPERABLE	15,498,000
BEING BUILT	53,714,100
PLANNED REACTORS ORDERED	78,635,000
TOTAL	147,847,100

TOTAL ELECTRIC UTILITY CAPACITY AS OF OCTOBER 31, 1972: 391,180,000 KILOWATTS

Fig. 3. Nuclear power reactors in the United States.

Table 1.
Nuclear power reactors in the United States.

SITE	PLANT NAME	CAPACITY (Net Kilowatts)	UTILITY	INITIAL DESIGN POWER
ALABAMA				
Decatur	Browns Ferry Nuclear Power Plant: Unit 1	1,065,000	Tennessee Valley Authority	1973
Decatur	Browns Ferry Nuclear Power Plant: Unit 2	1,065,000	Tennessee Valley Authority	1974
Decatur	Browns Ferry Nuclear Power Plant: Unit 3	1,065,000	Tennessee Valley Authority	1974
Dothan	Joseph M. Farley Nuclear Plant: Unit 1	829,000	Alabama Power Co.	1975
Dothan	Joseph M. Farley Nuclear Plant: Unit 2	829,000	Alabama Power Co.	1977
Selma	Orville: Unit 1	1,100,000	Alabama Power Co.	1981
Selma	Orville: Unit 2	1,100,000	Alabama Power Co.	1982
ARKANSAS				
Russellville	Arkansas Nuclear One: Unit 1	820,000	Arkansas Power & Light Co.	1973
Russellville	Arkansas Nuclear One: Unit 2	902,000	Arkansas Power & Light Co.	1976
CALIFORNIA				
Humboldt Bay	Humboldt Bay Power Plant: Unit 3	68,500	Pacific Gas and Electric Co.	1963
San Clemente	San Onofre Nuclear Generating Station: Unit 1	430,000	So. Calif. Ed. & San Diego Gas & El. Co.	1967
San Clemente	San Onofre Nuclear Generating Station: Unit 2	1,140,000	So. Calif. Ed. & San Diego Gas & El. Co.	--
San Clemente	San Onofre Nuclear Generating Station: Unit 3	1,140,000	So. Calif. Ed. & San Diego Gas & El. Co.	–
Diablo Canyon	Diablo Canyon Nuclear Power Plant: Unit 1	1,060,000	Pacific Gas and Electric Co.	1974
Diablo Canyon	Diablo Canyon Nuclear Power Plant: Unit 2	1,060,000	Pacific Gas and Electric Co.	1975
Clay Station	Rancho Seco Nuclear Generating Station	804,000	Sacramento Municipal Utility District	1974
Pt. Arena	Mendocino Power Plant: Unit 1	1,128,000	Pacific Gas & Electric Co.	1978
Pt. Arena	Mendocino Power Plant: Unit 2	1,128,000	Pacific Gas & Electric Co.	1979
*	–	770,000	Southern California Edison Co.	1981
*	–	770,000	Southern California Edison Co.	1982
COLORADO				
Platteville	Ft. St. Vrain Nuclear Generating Station	330,000	Public Service Co. of Colorado	1973
CONNECTICUT				
Haddam Neck	Haddam Neck Plant	575,000	Conn. Yankee Atomic Power Co.	1967
Waterford	Millstone Nuclear Power Station: Unit 1	652,100	Northeast Utilities	1970
Waterford	Millstone Nuclear Power Station: Unit 2	828,000	Northeast Utilities	1974
Waterford	Millstone Nuclear Power Station: Unit 3	1,150,000	Northeast Utilities	1979
DELAWARE				
Middletown	Delmarva Unit 1	770,000	Delmarva Power & Light Co.	1978
Middletown	Delmarva Unit 2	770,000	Delmarva Power & Light Co.	1981
FLORIDA				
Florida City	Turkey Point Station: Unit 3	693,000	Florida Power & Light Co.	1972
Florida City	Turkey Point Station: Unit 4	693,000	Florida Power & Light Co.	1973
Red Level	Crystal River Plant: Unit 3	825,000	Florida Power Corp.	1973
Ft. Pierce	St. Lucie Plant: Unit 1	801,000	Florida Power & Light Co.	1975
Ft. Pierce	St. Lucie Plant: Unit 2	801,000	Florida Power & Light Co.	1979
GEORGIA				
Baxley	Edwin I. Hatch Nuclear Plant: Unit 1	786,000	Georgia Power Co.	1973
Baxley	Edwin I. Hatch Nuclear Plant: Unit 2	795,000	Georgia Power Co.	1976
Waynesboro	Alvin W. Vogtle, Jr. Plant: Unit 1	1,121,000	Georgia Power Co.	1978
Waynesboro	Alvin W. Vogtle, Jr. Plant: Unit 2	1,121,000	Georgia Power Co.	1979
ILLINOIS				
Morris	Dresden Nuclear Power Station: Unit 1	200,000	Commonwealth Edison Co.	1960
Morris	Dresden Nuclear Power Station: Unit 2	809,000	Commonwealth Edison Co.	1970
Morris	Dresden Nuclear Power Station: Unit 3	809,000	Commonwealth Edison Co.	1972
Zion	Zion Nuclear Plant: Unit 1	1,050,000	Commonwealth Edison Co.	1972
Zion	Zion Nuclear Plant: Unit 2	1,050,000	Commonwealth Edison Co.	1973
Cordova	Quad-Cities Station: Unit 1	800,000	Comm. Ed. Co.-Ia.-Ill. Gas & Elec. Co.	1972
Cordova	Quad-Cities Station: Unit 2	800,000	Comm. Ed. Co.-Ia.-Ill. Gas & Elec. Co.	1972
Seneca	LaSalle Co. Nuclear Station: Unit 1	1,078,000	Comm. Ed. Co.-Ia.	1977
Seneca	LaSalle Co. Nuclear Station: Unit 2	1,078,000	Comm. Ed. Co.-Ia.	1978
Byron	Byron Station: Unit 1	1,120,000	Comm. Edison Co.	1979
Byron	Byron Station: Unit 2	1,120,000	Comm. Edison Co.	1980
Braidwood	Braidwood: Unit 1	1,100,000	Comm. Edison Co.	1980
Braidwood	Braidwood: Unit 2	1,100,000	Comm. Edison Co.	1981
Clinton	Clinton Nuclear Power Plant	950,000	Comm. Edison Co.	1980
Clinton	Clinton Nuclear Power Plant	950,000	Comm. Edison Co.	1982-3
INDIANA				
Dune Acres	Bailly Generating Station	660,000	Northern Indiana Public Service Co.	1977
IOWA				
Palo	Duane Arnold Energy Center: Unit 1	529,700	Iowa Electric Light and Power Co.	1973
LOUISIANA				
Taft	Waterford Generating Station	1,165,000	Louisiana Power & Light Co.	1976
St. Francisville	River Bend Station	934,000	Gulf States Utilities Co.	1979

Table 1 continued.

SITE	PLANT NAME	CAPACITY (Net Kilowatts)	UTILITY	INITIAL DESIGN POWER
MAINE				
Wiscasset	Maine Yankee Atomic Power Plant	790,000	Maine Yankee Atomic Power Co.	1972
MARYLAND				
Lusby	Calvert Cliffs Nuclear Power Plant: Unit 1	845,000	Baltimore Gas and Electric Co.	1974
Lusby	Calvert Cliffs Nuclear Power Plant: Unit 2	845,000	Baltimore Gas and Electric Co.	1974
Douglas Point	Douglas Point Project: Unit 1	1,178,000	Potomac Electric Power Co.	1981
Douglas Point	Douglas Point Project: Unit 2	1,178,000	Potomac Electric Power Co.	1981
MASSACHUSETTS				
Rowe	Yankee Nuclear Power Station	175,000	Yankee Atomic Electric Co.	1961
Plymouth	Pilgrim Station: Unit 1	664,000	Boston Edison Co.	1972
Plymouth	Pilgrim Station: Unit 2	1,180,000	Boston Edison Co.	1978
MICHIGAN				
Big Rock Point	Big Rock Point Nuclear Plant	70,300	Consumers Power Co.	1963
South Haven	Palisades Nuclear Power Station	700,000	Consumers Power Co.	1971
Lagoona Beach	Enrico Fermi Atomic Power Plant: Unit 2	1,123,000	Detroit Edison Co.	1976
Lagoona Beach	Enrico Fermi Atomic Power Plant: Unit 3	1,125,000	Detroit Edison Co.	1980
Bridgman	Donald C. Cook Plant: Unit 1	1,060,000	Indiana & Michigan Electric Co.	1973
Bridgman	Donald C. Cook Plant: Unit 2	1,060,000	Indiana & Michigan Electric Co.	1974
Midland	Midland Nuclear Power Plant: Unit 1	492,000	Consumers Power Co.	1977
Midland	Midland Nuclear Power Plant: Unit 2	818,000	Consumers Power Co.	1978
St. Clair County	Greenwood: Unit 2	1,240,000	Detroit Edison Co.	1979
St. Clair County	Greenwood: Unit 3	1,240,000	Detroit Edison Co.	1981
Quanicassee	Quanicassee: Unit 1	1,150,000	Consumers Power Co.	1981
Quanicassee	Quanicassee: Unit 2	1,150,000	Consumers Power Co.	1981
MINNESOTA				
Monticello	Monticello Nuclear Generating Plant	545,000	Northern States Power Co.	1971
Red Wing	Prairie Island Nuclear Generating Plant: Unit 1	530,000	Northern States Power Co.	1973
Red Wing	Prairie Island Nuclear Generating Plant: Unit 2	530,000	Northern States Power Co.	1974
MISSISSIPPI				
Port Gibson	Grand Gulf Nuclear Station	1,290,000	Mississippi Power & Light Co.	1978
NEBRASKA				
Fort Calhoun	Ft. Calhoun Station: Unit 1	457,400	Omaha Public Power District	1973
Brownville	Cooper Nuclear Station	778,000	Nebraska Public Power District and Iowa Power and Light Co.	1973
NEW HAMPSHIRE				
Seabrook	–	1,100,000	Public Service of N.H.	1979
Seabrook	–	1,100,000	Public Service of N.H.	1981
NEW JERSEY				
Toms River	Oyster Creek Nuclear Power Plant: Unit 1	640,000	Jersey Central Power & Light Co.	1969
Forked River	Forked River Generating Station: Unit 1	1,070,000	Jersey Central Power & Light Co.	1978
Salem	Salem Nuclear Generating Station: Unit 1	1,090,000	Public Service Electric and Gas, N.J.	1974
Salem	Salem Nuclear Generating Station: Unit 2	1,115,000	Public Service Electric and Gas, N.J.	1975
Bordentown	Newbold Nuclear Generating Station: Unit 1	1,067,000	Public Service Electric and Gas, N.J.	1978
Bordentown	Newbold Nuclear Generating Station: Unit 2	1,067,000	Public Service Electric and Gas, N.J.	1979
Little Egg Inlet	Atlantic Generating Station: Unit 1	1,150,000	Public Service Electric and Gas, N.J.	1980
Little Egg Inlet	Atlantic Generating Station: Unit 2	1,150,000	Public Service Electric and Gas, N.J.	1981
NEW YORK				
Indian Point	Indian Point Station: Unit 1	265,000	Consolidated Edison Co.	1963
Indian Point	Indian Point Station: Unit 2	873,000	Consolidated Edison Co.	1973
Indian Point	Indian Point Station: Unit 3	965,000	Consolidated Edison Co.	1974
Scriba	Nine Mile Point Nuclear Station: Unit 1	625,000	Niagara Mohawk Power Co.	1970
Scriba	Nine Mile Point Nuclear Station: Unit 2	1,080,000	Niagara Mohawk Power Co.	1978
Ontario	R.E.Ginna Nuclear Power Plant: Unit 1	420,000	Rochester Gas & Electric Co.	1970
Brookhaven	Shoreham Nuclear Power Station	819,000	Long Island Lighting Co.	1977
Scriba	James A. Fitzpatrick Nuclear Power Plant	821,000	Power Authority of State of N.Y.	1973
NORTH CAROLINA				
Southport	Brunswick Steam Electric Plant: Unit 1	821,000	Carolina Power and Light Co.	1975
Southport	Brunswick Steam Electric Plant: Unit 2	821,000	Carolina Power and Light Co.	1974
Cowans Ford Dam	Wm. B. McGuire Nuclear Station: Unit 1	1,180,000	Duke Power Co.	1975
Cowans Ford Dam	Wm. B. McGuire Nuclear Station: Unit 2	1,180,000	Duke Power Co.	1977
Bonsal	Shearon Harris Plant: Unit 1	915,000	Carolina Power & Light Co.	1977
Bonsal	Shearon Harris Plant: Unit 2	915,000	Carolina Power & Light Co.	1978
Bonsal	Shearon Harris Plant: Unit 3	915,000	Carolina Power & Light Co.	1979
Bonsal	Shearon Harris Plant: Unit 4	915,000	Carolina Power & Light Co.	1980
OHIO				
Oak Harbor	Davis-Besse Nuclear Power Station	906,000	Toledo Edison-Cleveland Electric Illuminating Co.	1974
Painesville	Perry Nuclear Power Plant: Unit 1	1,100,000	Cleveland Electric Illuminating Co.	1979
Painesville	Perry Nuclear Power Plant: Unit 2	1,100,000	Cleveland Electric Illuminating Co.	1980
Moscow	Wm. H. Zimmer Nuclear Power Station: Unit 1	810,000	Cincinnati Gas & Electric Co.	1976

Table 1 continued.

SITE	PLANT NAME	CAPACITY (Net Kilowatts)	UTILITY	INITIAL DESIGN POWER
OREGON				
Prescott	Trojan Nuclear Plant: Unit 1	1,130,000	Portland General Electric Co.	1975
Boardman		1,200,000	Portland General Electric Co.	1980
PENNSYLVANIA				
Peach Bottom	Peach Bottom Atomic Power Station: Unit 1	40,000	Philadelphia Electric Co.	1967
Peach Bottom	Peach Bottom Atomic Power Station: Unit 2	1,065,000	Philadelphia Electric Co.	1973
Peach Bottom	Peach Bottom Atomic Power Station: Unit 3	1,065,000	Philadelphia Electric Co.	1974
Pottstown	Limerick Generating Station: Unit 1	1,065,000	Philadelphia Electric Co.	1978
Pottstown	Limerick Generating Station: Unit 2	1,065,000	Philadelphia Electric Co.	1979
Shippingport	Shippingport Atomic Power Station: Unit 1	90,000	Duquesne Light Co.	1957
Shippingport	Beaver Valley Power Station: Unit 1	852,000	Duquesne Light Co. Ohio Edison Co.	1974
Shippingport	Beaver Valley Power Station: Unit 2	852,000	Duquesne Light Co.-Ohio Edison Co.	1978
Goldsboro	Three Mile Island Nuclear Station: Unit 1	819,000	Metropolitan Edison Co.	1973
Goldsboro	Three Mile Island Nuclear Station: Unit 2	905,000	Jersey Central Power & Light Co.	1975
Berwick	Susquehanna Steam Electric Station: Unit 1	1,052,000	Pennsylvania Power and Light	1979
Berwick	Susquehanna Steam Electric Station: Unit 2	1,052,000	Pennsylvania Power and Light	1981
[1]	Philadelphia Electric Co.: HTGR No. 1	1,140,000	Philadelphia Electric Co.	1979
[1]	Philadelphia Electric Co.: HTGR No. 2	1,140,000	Philadelphia Electric Co.	1981
SOUTH CAROLINA				
Hartsville	H. B. Robinson S.E. Plant: Unit 2	700,000	Carolina Power & Light Co.	1971
Seneca	Oconee Nuclear Station: Unit 1	841,000	Duke Power Co.	1972
Seneca	Oconee Nuclear Station: Unit 2	886,000	Duke Power Co.	1973
Seneca	Oconee Nuclear Station: Unit 3	886,000	Duke Power Co.	1973
Broad River	Virgil C. Summer Nuclear Station: Unit 1	900,000	South Carolina Electric & Gas Co.	1977
Lake Wylie	Catawba Nuclear Station: Unit 1	1,180,000	Duke Power Co.	1979
Lake Wylie	Catawba Nuclear Station: Unit 2	1,180,000	Duke Power Co.	1980
TENNESSEE				
Daisy	Sequoyah Nuclear Power Plant: Unit 1	1,140,000	Tennessee Valley Authority	1974
Daisy	Sequoyah Nuclear Power Plant: Unit 2	1,140,000	Tennessee Valley Authority	1975
Spring City	Watts Bar Nuclear Plant: Unit 1	1,169,000	Tennessee Valley Authority	1977
Spring City	Watts Bar Nuclear Plant: Unit 2	1,169,000	Tennessee Valley Authority	1978
Oak Ridge	Fast Breeder Demonstration Plant	400,000	Tennessee Valley Authority	1980
TEXAS				
Glen Rose	Commanche Peak Steam Electric Station: Unit 1	1,150,000	Texas Power & Light Co.	1980
Glen Rose	Commanche Peak Steam Electric Station: Unit 2	1,150,000	Texas Power & Light Co.	1982
Newton County	Blue Hills: Unit 1	950,000	Gulf States Utilities	1980
VERMONT				
Vernon	Vermont Yankee Generating Station	513,900	Vermont Yankee Nuclear Power Corp.	1972
VIRGINIA				
Gravel Neck	Surry Power Station: Unit 1	788,000	Virginia Electric & Power Co.	1972
Gravel Neck	Surry Power Station: Unit 2	788,000	Virginia Electric & Power Co.	1973
Mineral	North Anna Power Station: Unit 1	898,000	Virginia Electric & Power Co.	1974
Mineral	North Anna Power Station: Unit 2	898,000	Virginia Electric & Power Co.	1975
Mineral	North Anna Power Station: Unit 3	900,000	Virginia Electric & Power Co.	1977
Mineral	North Anna Power Station: Unit 4	900,000	Virginia Electric & Power Co.	1978
[1]	–	900,000	Virginia Electric & Power Company	1980
[1]	–	900,000	Virginia Electric & Power Company	1981
WASHINGTON				
Richland	N-Reactor/WPPSS Steam	800,000	Atomic Energy Commission	1966
Richland	WPPSS No. 1	1,120,000	Washington Public Power Supply System	1980
Richland	WPPSS No. 2	1,103,000	Washington Public Power Supply System	1977
WISCONSIN				
Genoa	Genoa Nuclear Generating Station	53,200	Dairyland Power Cooperative	1969
Two Creeks	Point Beach Nuclear Plant: Unit 1	497,000	Wisconsin Michigan Power Co.	1971
Two Creeks	Point Beach Nuclear Plant: Unit 2	497,000	Wisconsin Michigan Power Co.	1972
Carlton	Kewaunee Nuclear Power Plant: Unit 1	541,000	Wisconsin Michigan Power Co.	1972
PUERTO RICO				
Puerto De Jobas	Aguirre Nuclear Power Plant	583,000	Puerto Rico Water Resources Authority	1975

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[1] Site not selected.

[1]	–	1,189,000	Tennessee Valley Authority	1977
[1]	–	1,189,000	Tennessee Valley Authority	1978
[1]	–	1,120,000	Tennessee Valley Authority	1980
[1]	–	1,120,000	Tennessee Valley Authority	1981
[1]	–	1,120,000	Tennessee Valley Authority	1981
[1]	–	1,120,000	Tennessee Valley Authority	1982

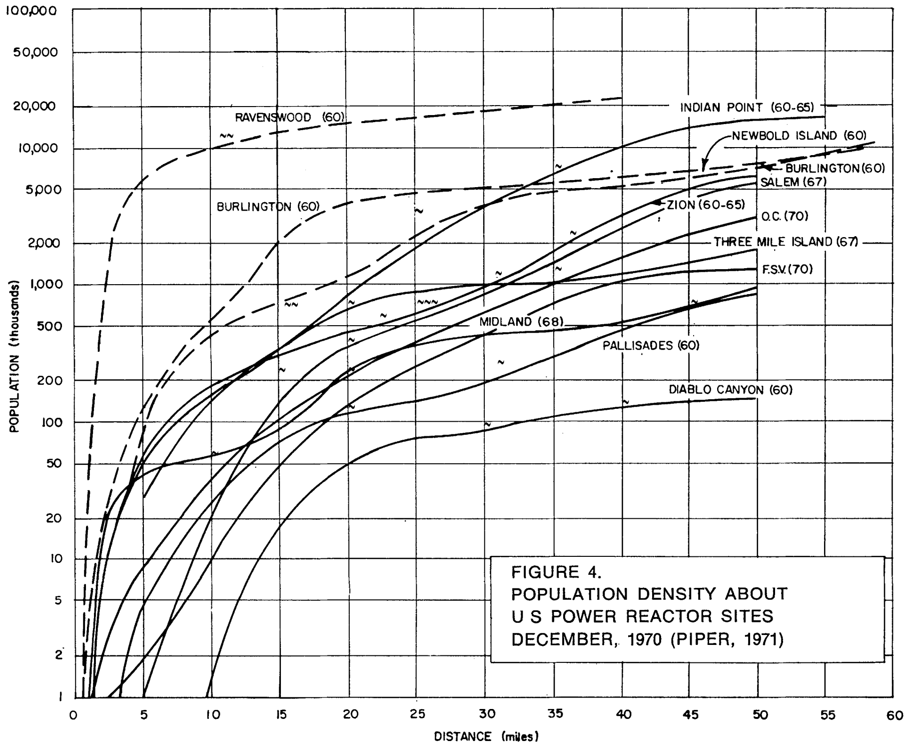

Fig. 4.

The coolant water demand, including reject heat management, is a major problem in selecting a reactor site. The critical period for water consumption and thermal pollution is the late hot summer season combined with the effect of a drought. This generally coincides with the lowest surface flow, highest fresh water demand for domestic, public, agricultural and industrial purposes, together with the highest temperature of air and water, extreme evaporation and most critical concentration of pollution in surface water.

Thermal pollution is defined as heat added to natural bodies of water by the activities of man in such a way that it may cause undersirable effects. In the United States, thermal standards are currently based on the protection of fish, particularly migratory fish. Increased heat changes may reduce the oxygen con-

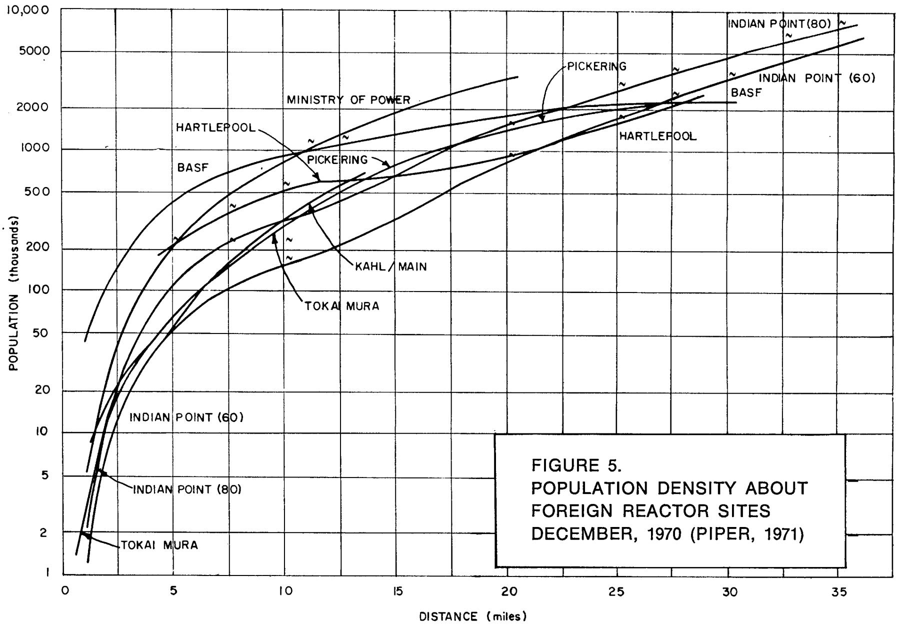

Fig. 5.

tent below levels required for some desirable organisms or for some major uses. Heat may adversely affect the ability of the water body to assimilate organic wastes.

Both fossil and nuclear power plants are heat engines operating on the Rankine cycle. Fossil fueled power stations send 15 % to 19 % of the reject heat "up the stack" to the atmosphere. In a plant equipped with some form of once-through cooling, the balance of the reject heat is delivered to a receiving body of water. Power reactors reject all waste heat to a receiving body of water. New super-critical fossil plants operate at an efficiency of not more than 39 %; the light water reactor (LWR) efficiency is 33 % and the high-temperature gas-cooled reactor (HTGR) efficiency is 38 to 39 %. The result is that an LWR reactor rejects 39 % more heat to water than a modern super-critical plant of the same capacity. Turbine condenser temperature increments ($\triangle$ t's) fall in the range from 17°F to 25°F for both classes of plants. To achieve these $\triangle$ t's, turbine condenser pumping rates for LWR's range from 642 k gpm to 918 k gpm for a 1.1 GWe unit (from 39 m^3/sec to 58 m^3/sec for a 1 000 MWe unit).

The temperature increment in a unit volume of flow of the receiving water is a function of the quantity of the reject heat and volume flow rate. For example, the discharge of 2,2 MBtu/sec from a 1,1 GWe LWR into a flow of 42 m^3/sec will produce a temperature rise of 11,7°F in the receiving water and a rise of 3,5°F in a flow of 140 m^3/sec. The initial temperature decrease in the receiving water is due to dilution. The region where dilution controls temperature decrease is called the near field. In the absence of good longitudinal mixing in the far field, the temperature will drop slowly in an exponential manner. Significant distances (which may be unacceptable) may be required before the receiving water downstream temperature returns to ambient or attains a maximum allowable incremental temperature. The distance over which this condition may be attained defines a mixing zone. In the event that a satisfactory mixing zone cannot be attained, one of several approaches might be used to control temperature: (1) flow augmentation (increased dilution); (2) cooling pond or spray ponds; (3) total dependence on cooling towers. Model studies show that mixing zones are usually from one to eight km long, with temperature changes less than 5°F in a small area around the discharge points before the receiving water returns to normal (Widmer 1972).

Under most circumstances, temperatures that are only 1.5°F above ambient during the critical summer months at the mixing zone-ambient interface will be accepted and all standards require maximum temperatures less than 86°F. Although large-scale temperature changes in extended areas have not yet resulted from this type of pollution, the heating of certain rivers or lakes to a few degrees above ambient level has already been noticed in connection with power-plant cooling water discharges. This problem becomes especially acute in subtropical climates, where the summer temperatures are too high to permit the efficient cooling of thermal effluents. Some power plants in Florida (Turkey Point fossil plant), the effluents of which raised the temperature of the receiving waters to 90°F in the warm summer months, managed to eradicate completely the biotic communities from their lagoons for a longer period. (Claus & Halasi-Kun 1972).

Experts in the United States are very reluctant to consider any temperature changes between intake and outlet coolant water temperature outside the mixing zone. Therefore, it is not permissible to reduce the permitted temperature difference (up to 9°F) due to the lower temperature of the accumulated coolant water body near the bottom of the reservoir built for these purposes, in comparison with the surface flow temperature of the upper water, as is calculated at some reactors in East-Central Europe.

The problems of thermal pollution by coolant water of reactors were summarized by Mackenthun and Keup (1969) as follows:

"Available data indicate that commercial and key food-chain estuarine animals cannot tolerate temperature greater than approximately 90°F regardless of the temperature to which they have been acclimated. Thus, natural peak summer water temperatures in a subtropical or tropical estuary may be near the tolerance threshold for a number of desirable marine organisms.

The National Technical Advisory Committee on Water Quality Criteria, in reporting to the Secretary of the Interior, recommended that the discharge of any heated materials into coastal waters be closely managed. This Committee stipulated that any rise owing to such discharges should be restricted to 1.5°F during the critical summer months, outside of established mixing zones. To make water quality standards more meaningful, mixing zones must have definition. The Committee suggested only that adequate passageways be provided at all times for the movement or draft of organisms, and that mixing areas must not be used for, or considered as, a substitute for waste treatment, or as an extension of, or substitute for, a waste treatment facility.

The National Technical Advisory Committee on Water Quality Criteria, composed in part of the nation's leading fishery experts, recommended that, to maintain a well-rounded population of warm water fishes, heat added to a fresh water stream not exceed that which would raise the water temperature more than 5°F at the expected minimum daily flow for the month involved. (U.S. Federal Water Pollution Control Administration, 1968). In lakes, the temperature of the upper waters should not be raised more than 3°F above that which existed before heat was added. The increase should be based on the monthly average of the maximum daily temperatures. Temperature should be measured in those areas where important organisms are most likely to be affected adversely."

Most recently, the Environmental Protection Agency of the United States does not permit temperature changes outside the mixing zone specified by the permit issued for the power plant on an individual basis.

These statements indicate a potential policy based on protection of fish and their food-chain in the coastal area, safeguard against depletion of the fresh-water resources and securing necessary fresh-water withdrawals for municipal, agricultural and industrial consumptive use.

Because of the possibility of water shortages in some areas of the United States – especially in arid areas – increasing consideration is being given to the use of dry cooling towers for waste heat rejection and to improving efficiency of existing and planned reactors.

Typical means for air cooling existing types of nuclear plants, as an alternative solution, generally involve the use of large natural convection or forced draft towers and large extended cooling surfaces. Sacrifice of plant performance as a result of higher back pressures on the turbine generally would be incurred. The amount of such sacrifice is dependent on ambient air temperatures which are generally higher and more variable than those provided by water coolants. The existing light water reactor (LWR) systems would suffer a substantial disadvantage because the relatively low plant efficiency that they provide requires rejection of about one-third more heat than does either a modern fossil fuel plant or a newly developed high-temperature gas-cooled reactor (HTGR).

The HTGR leads to an improved cycle efficiency of close to 40 %, which matches the efficiencies available from the most modern fossil-fired steam-electric plants. The high efficiency minimizes the thermal discharge and reduces the cost of cooling ponds or wet cooling towers if once-through water cooling is not available or is environmentally not acceptable. Many areas of the United States may very soon, however, face the problem of either the unavailability of fresh water for wet cooling makeup (as in arid areas) or the lack of suitable ocean sites. Further advantage of the newly developed reactor is that a HTGR needs substantially less coolant water than a LWR, according to research conducted by the Gulf General Atomic Co., San Diego, California in 1971 (Goodjohn, 1971). A graphical summary of the cooling water demand for both types of reactors for a once-through cooling system is given by Fig. 6.

From these figures it is evident that the demand on coolant water is enormous, but by recycling with the help of cooling ponds or towers, the consumption can

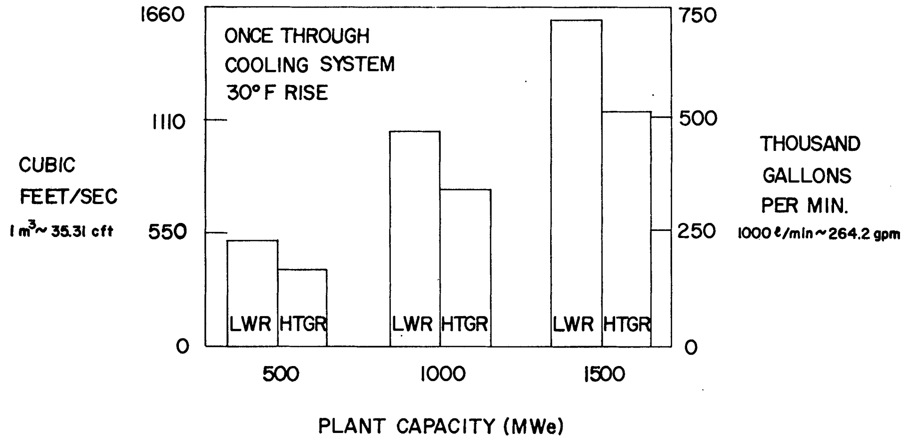

Fig. 6.
Approximate Cooling Water Requirements for Once-Through Cooling System.
(Goodjohn, A. J. and Fortescue, P. 1971).

be reduced drastically to evaporation and seepage losses. In accordance with the data presented by V. Dalal, Federation of American Scientists, Princeton, September 1972, the evaporation loss is 0.45–0.7 m^3/sec per 1000 Mwe, for a LWR (Dalal, 1972). This loss is 25 % less at HTGR plants. Salem Nuclear Generating Station (HTGR plant), New Jersey has an evaporation loss of 0.35 m^3/sec per 1000 Mwe according to Public Service Electric and Gas Co., New Jersey. Daily tower make-up requirements for an LWR and an HTGR of the same capacity are 136,000 m^3 and 91,000 m^3, respectively. These losses are still significant, and they must be considered as the minimum requirements of water, besides the amount for recycling, when a reactor site is selected.

The burden upon receiving water and available water supplies may be eased by two possibilities resulting from HTGR characteristics. With Cs ion injection, a HTGR could be designed with an MHD (magnetohydrodynamics) topping cycle producing a potential combined cycle efficiency of 60 %, thereby quite significantly reducing the magnitude of reject heat. Secondly, a HTGR can operate on the Brayton cycle with a gas turbine rejecting heat to the atmosphere using air condensers (an air condenser is not a dry cooling tower).

The intake and the return of condenser water in coastal areas can create additional problems. The seepage from the intake channel ought to be eliminated in order to prevent undesirable salt water intrusion into the groundwater regime, as has been the case at Oyster Creek Power Plant in New Jersey (Widmer 1972). In the same area, it has been found necessary to provide for crossing of the lagoons in returning the coolant water and to avoid its mixing with the intake water inside the mixing zone. On the other hand, the Chalk Point Plant's cooling tower in Maryland, U.S., showed clearly the necessity of studying the eventual ill-effect of the drift rate and salt deposit of the dispersed water from the cooling tower on the adjacent agricultural land and products as far as four km away (Green 1973).

The problems in selecting reactor sites are enormous, considering not only the aspects of population density, coolant water demand, thermal pollution and engineered safeguard measures during construction and operation, but also the cost involved and consideration of other environmental requirements. On the other hand, the accelerated trend in energy demand in the decades to come, the restricted available "natural" energy resources (coal, water, oil and gas) and our limited knowledge and technology in harnessing geothermal and solar energy force us to cope with the increasing "Energy Crisis" by developing and building nuclear power plants to full-scale capacity without any further delay. This will be the only way to gain the necessary time until we improve our technology sufficiently that we may secure energy from other, hitherto undeveloped, sources.

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