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EFFECTS OF SITE LOCATION
ON THE CAPITAL COSTS
OF NUCLEAR ELECTRIC PLANTS

March 1969

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EFFECTS OF SITE LOCATION
ON THE CAPITAL COSTS
OF NUCLEAR ELECTRIC PLANTS

By

F. J. Kempf and J. F. Fletcher

Systems Engineering Department
Physics and Engineering Division

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ABSTRACT

Cost estimates were made for the construction of a 1000 MW_e light water reactor nuclear power plant at the USAEC hypothetical site and at nine typical sites at various locations in the United States. Comparisons were made of the variation of costs estimated to be incurred in the construction of power plants of essentially identical design at the various sites considered, using a 1060 MW_e BWR plant as a model for development of cost data. Because of the important effect on capital costs of methods for rejecting heat from the main steam condensers, cost comparisons were made at each site for plants utilizing different types of heat rejection systems.

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EFFECTS OF SITE LOCATION
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INTRODUCTION

First generation nuclear power plants were units of small capacity featuring "one-of-a-kind" designs and requiring large expenditures for engineering and for research and development. Cost experience with these plants did not favor their widespread substitution for fossil-fueled plants as central power stations. Subsequent development of nuclear plant technology, accumulation of operating experience, and a trend to larger plant sizes have changed the economic posture of the nuclear industry markedly within the last 4 or 5 years. Nuclear fueled plants are now competitive with fossil-fueled plants in most areas of the United States, as evidenced by the proliferation of nuclear plant orders since mid-1966.

The rapid increase in new plant orders has created a need for large numbers of nuclear plant sites, and increasingly greater numbers of these sites will be required in the future. The increasing uses of nuclear power, and the trend toward larger plant sizes (currently up to the 1000 to 1100 MW_e range) have intensified the economic incentives for location of plant sites close to load centers to minimize costs of power transmission. The historical precedent of locating nuclear power plants in areas far removed from load centers, dictated by a primary concern for maximum safeguards, has remained in effect due to inadequate operating experience with the newer, larger-sized plants. Added complexities introduced by the recent emphasis on water quality and resultant restrictions on the amounts of heat dissipated into natural bodies of water have required substantial cost additions for plant cooling facilities at some sites.

These factors tend to complicate nuclear plant capital cost evaluations by emphasizing local site conditions, thus adding to such geographically dependent factors as labor and materials costs and shipping costs.

The effects of geographical location on nuclear power plant economics, as yet only imperfectly correlated, are of interest in evaluating costs of nuclear plants now under construction and in predicting future trends in these costs.

PURPOSE

This study was conducted to identify those nuclear electric plant differential capital costs arising as a result of geographic location. To the extent possible, emphasis has been placed on local siting factors affecting plant construction costs.

SCOPE

The scope of this study has been limited to the consideration of capital costs of nuclear power plants. These costs include all direct and indirect construction costs, interest charges on funds used for construction, and startup costs for the plant. They do not, however, include the costs of the initial fuel charge, separately accounted for as part of the fuel costs. Since this study was concerned with costs of the production plant, the costs of transmission facilities were not included.

The costs of power generation, in standard accounting practice, are composed of (1) fixed charges consisting principally of interest and depreciation charges on the plant capital investment, (2) operating and maintenance costs, (3) fuel costs, including fuel cycle costs for nuclear plants, and (4) costs of power transmission. Full evaluation of a plant site would include the consideration of all these power cost components. While all of these factors will vary to some

extent with site location, usually the most sensitive by far are the plant capital costs, dependent on both site location and site conditions, and the transmission costs, dependent primarily on distance from site to load center. Plant operating costs and fuel costs will be affected very little by sites located within the marketing area of a single utility. Plant capital costs constitute the dominant factor to be balanced against transmission costs in the evaluation of sites.

A major exception to this general case occurs in the case of plants equipped with cooling towers or, in some cases, with cooling ponds. Operating costs and generation penalties associated with the use of these cooling facilities can significantly affect power costs. Although detailed consideration of these cost variations is beyond the scope of this report, approximate cost effects of cooling towers have been considered for certain of these sites.

The primary site-dependent factors demonstrating potentially significant effects on the capital costs of a nuclear power plant are:

- Local labor rates
- Local costs of construction materials
- Shipping charges for major equipment items
- Site preparation costs
- State sales tax on materials and equipment
- Local and state (property) taxes during construction
- Land and land right costs
- Special facilities not required at all sites, such as long circulating water lines at some coastal sites, or cooling towers or ponds at others.

Additional factors, now or in the future, may alter plant capital costs at particular sites. These include costs

attributable to earthquake protection in areas of high seismic probability, and the additional costs for containment and engineered safeguards possibly required at locations in or near densely populated areas.

A detailed evaluation of seismic protection requirements at specifically selected sites was considered beyond the scope of this study. Estimates of earthquake protection costs, apparently reasonable for various seismic zones, must be viewed as order of magnitude values in the absence of a detailed structural analysis for specific sites.

Significant cost additions would undoubtedly result from more stringent requirements for containment and other engineered safeguards for nuclear plants at sites in or near centers of population. Considerable economic incentive exists for the siting of nuclear power plants close to urban centers. Several unsuccessful attempts have been made in the last few years to obtain approval for close-in siting. It is clear that any eventual acceptance of urban or near-urban siting will entail the substantial addition to requirements for engineered safeguards, probably including highly reliable containment systems, "zero leakage" features, and some form of additional blast and radiation shielding. However, no comprehensive forecast of safeguards requirements permitting development of realistic cost estimates can be made at this time. Ultimate enumeration of safeguards requirements will probably await the accumulation of experience from the operation of larger power reactors now under construction, and the completion of development programs such as the Containment Systems Experiment⁽¹⁾ being conducted by Battelle-Northwest.

Therefore, while urban siting costs were considered briefly, no estimates of cost differentials for urban sites

are presented. Estimates for these cases would not be meaningful because the required safeguards features at urban sites have not been adequately defined.

Other potentially significant cost variables include the cost of legal and technical work associated with licensing activities, public relations costs tending to fluctuate with population density and potential land use, and equipment price fluctuations due to marketing factors. These costs can be highly variable. The effect of marketing factors on equipment cost is a particularly good example of the type of cost variable dependent upon additional industry experience for definition.

STUDY BASIS AND ASSUMPTIONS

The plant design used as a reference in this study is a 1000 MW_e class, BWR plant similar to the type under construction for TVA at Brown's Ferry, Alabama. The reference plant, featuring a reactor of 3293 MW thermal design capacity, is capable of producing 1060 MW_e net output when operated with a once-through cooling system providing a turbine exhaust back pressure of 1.5 in. mercury. Direct cost components were adjusted to reflect recent trends in plant costs. Indirect costs of construction were estimated in accordance with AEC ground rules for investor-owned utilities, as detailed in the AEC Guide to Nuclear Power Cost Evaluation.⁽²⁾ These indirect costs were estimated as percentages to be sequentially added to direct construction costs. The percentage values then were adjusted to reflect recent trends in plant construction cost estimates.

Table 1 shows the cost summary for construction of the reference plant at a hypothetical site as defined in the AEC ground rules in Reference 2. The costs assumed for this plant are compared in Table 2 with published cost data for typical

TABLE 1. *Capital Cost Summary for Reference Plant
(Hypothetical Site: North River, Mass.)*

<u>Account</u>	<u>Labor</u>	<u>Materials</u>	<u>Equipment</u>	<u>Shipping</u>	<u>Total</u>
21 Structures + Improvements	7,444*	4,303	2,130		13,877
22 Reactor Plant Equipment	6,620	3,063	40,450	200	50,333
23 Turbine-Generator Equipment	3,588	1,434	31,570	124	36,716
24 Accessory Electrical Equipment	764	182	3,066		4,012
25 Misc. Power Plant Equipment	<u>143</u>	<u>117</u>	<u>603</u>	<u>—</u>	<u>863</u>
Subtotal	18,559	9,099	77,819	324	105,801
General + Administrative (6.2%)					6,560
Miscellaneous Construction Costs					<u>1,140</u>
Subtotal					113,501
Engineering Design, AE (5.8%)					<u>6,583</u>
Subtotal					120,084
Nuclear Engineering (3%)					3,603
Startup Costs					723
20 Land + Land Rights					<u>360</u>
Subtotal					124,770
Contingency (7%)					<u>8,734</u>
Subtotal					133,504
Interest During Construction (12.06%)					<u>16,101</u>
Total Construction Cost					149,605

* Includes \$825,000 site preparation costs.

TABLE 2. *Comparison of Reference Plant Costs with Recent Published Cost Data*

Plant	Type	Capacity MW _e	Costs in Thousands of Dollars			Unit Cost, \$/kW _e
			Direct ^(a)	Indirect	Total	
Reference Plant	BWR	1060	105,801	43,804	149,605	141.1
Brown's Ferry 1	BWR	1075	94,500	41,920	136,420	126.9
Brown's Ferry 3	BWR	1075	107,759	32,830	140,589	130.8
Diablo Canyon 1	PWR	1060	118,720 ^(b)	34,913	153,633	144.9
Diablo Canyon 2	PWR	1060	116,330 ^(b)	34,140	150,470	142.0
Zion 1	PWR	1050	130,597 ^(c)	27,948	158,545	151.0
Zion 2	PWR	1050	123,420 ^(c)	30,695	154,115	146.8
Peach Bottom 2	BWR	1065	132,740	32,410	165,150	155.1
Peach Bottom 3	BWR	1065	119,870	26,490	147,360	138.4
Cook 1 and 2	PWR	2-1054	233,812 ^(d)	60,691 ^(d)	294,503 ^(d)	139.7
[Cook: Single Plant] ^(e)	PWR	1054	[116,906] ^(e)	[30,346] ^(e)	[147,252] ^(e)	139.7
Salem 1	PWR	1050	110,630	45,598	156,228	148.8
Salem 2	PWR	1050	100,255	28,588	128,842	122.7

a. Direct cost not including land and land rights.

b. Includes contingency and startup allowance.

c. Includes costs of licensing and construction power cost.

d. Combined cost estimate for two plants.

e. One-half cost of two plants.

Brown's Ferry 1 costs derived from dual-unit plant estimate given in Reference 4; other costs as quoted in Atomic Energy Clearing House Newsletter.

plants of the 1000 MW_e size. This plant design utilizes a boiling water reactor with internal steam separation and pressure suppression containment. The reactor steam is saturated at 1015 psia, while condenser vacuum is 1.5 in. mercury absolute at average water temperature of 57 °F. Power conversion is accomplished in an 1800 rpm, tandem-compound turbine with 43 in. last-stage blades driving a 1280 MVA generator, and operating in a steam cycle utilizing six stages of feedwater heating.

Employed in the early phases of this study was a reference design developed in 1963 and 1964 in a feasibility study performed by the General Electric Company.⁽³⁾ This earlier design differed substantially from BWR plants of the 1000 MW_e size class, subsequently offered for sale and presently under construction. Thus, a change to this more representative reference model was dictated.

Sites for capital cost comparisons which were selected to represent typical nuclear power plant locations across the country, either have existing nuclear facilities or are proposed as nuclear plant locations. The existing and proposed nuclear plant sites were also selected to take advantage of currently available detailed site descriptions documented in preliminary hazards reports and other documents. Cost data at the various sites were developed and referenced to the construction cost estimate at the hypothetical AEC site. The sites selected for study are listed in Table 3.

The reference plant, while located near an existing (or proposed) smaller plant at each site, was assumed to be sufficiently removed that the exclusion zone would not overlap that of the existing plant, and that no plant services would be shared with that plant. This procedure permitted cost estimation essentially on a "first plant on a site" basis.

TABLE 3. *Assumed 1000 MW_e Nuclear Plant Locations*

Region	Site and Nearest Town
Eastern U.S.	Hypothetical (North River, Massachusetts) Turkey Point (Miami, Florida) Maine Yankee (Wiscasset, Maine) Connecticut Yankee (Haddam Neck, Connecticut) Nine Mile Point (Oswego, New York) Oyster Creek (Toms River, New Jersey)
Midwestern U.S.	Dresden (Morris, Illinois)
Western U.S.	Hanford (Richland, Washington) Malibu (Malibu Beach, California) San Onofre (San Clemente, California)

Local site topography and geology were considered in estimating site preparation costs. The site preparation estimates should be representative of the costs incurred in the general locale of each selected site but not sufficiently refined for application to any specific site.

It was assumed for this study that the licensing and public acceptance of a 1000 MW_e nuclear plant at any of the considered sites would present no unusual problems. Whether true or not for such a plant actually proposed at a specific site, this assumption permits the application of uniform costs for the legal and technical work associated with licensing activities and for public relations work. These costs, therefore, were not considered as variables in the study.

Perhaps the strongest single site-dependent variable affecting capital costs of a nuclear power plant is the effect of local site conditions on the design and performance of the plant heat dissipation system and the effects of statutory limitations on the rejection of heat to many bodies of water. Because of the importance of the heat dissipation system design in determining the capital costs of a plant, R. W. Beck and Associates were retained as consultants to evaluate the costs of different types of heat rejection systems at the

various sites assumed in the study. The cost data developed by these consultants, modified slightly to reflect geographical differences in labor and material costs, were incorporated into the plant cost estimates for the various sites. To further illustrate the effects of heat rejection systems on plant costs, four separate estimates made at each site assumed plants to use (1) once through systems with shoreline intake and discharge, (2) once through systems with deep water outfalls (and with deep intake lines for sites where they may be needed), (3) recirculating, natural draft (hyperbolic) evaporative cooling towers, and (4) recirculating, induced-draft evaporative cooling towers.

SUMMARY AND CONCLUSIONS

Table 4 compares the direct and indirect capital construction costs and the major cost components for constructing, at each of the sites considered in the study, a reference plant utilizing a once-through, shoreline-intake, shoreline-discharge circulating water system. The direct cost components are shown in this table for comparison purposes as cost differences referenced to construction costs at the AEC hypothetical site. Differences in total direct costs and in total capital costs are also shown for comparison. This table indicates, for the sites considered, a spread of about \$9,200,000 in direct costs for constructing the reference plant, while total capital costs are indicated to differ by approximately \$19,000,000 among the various sites.

The effect of differences in design of the plant heat rejection system, one of the most influential site-related cost variables affecting plant construction costs, is summarized in Table 5. This table compares direct construction costs and total capital costs for plants using four different types of heat rejection systems--once-through plants using shoreline

**TABLE 4. Summary of Capital Cost Comparisons:
Once-Through Plants, Shoreline-Discharge**

	<u>Hypothetical</u>	<u>Turkey Point</u>	<u>Maine Yankee</u>	<u>Connecticut Yankee</u>	<u>Nine Mile Point</u>	<u>Oyster Creek</u>	<u>Dresden</u>	<u>Hanford</u>	<u>Malibu</u>	<u>San Onofre</u>
Direct Cost Differences* from Hypothetical Site:										
Labor (less site preparation)	0	-1,719	-1,089	69	-796	1,583	-167	2,837	1,968	4,726
Materials (locally procured)	0	1,049	0	0	473	-478	275	369	681	681
Equipment	0	504	504	0	0	504	0	0	504	504
Shipping	0	-24	0	0	-21	4	-114	336	586	486
Site Preparation Costs	0	2,825	230	620	180	495	220	-660	2,875	2,860
Total Direct Construction Cost	<u>105,801</u>	<u>108,436</u>	<u>105,446</u>	<u>106,490</u>	<u>105,637</u>	<u>107,909</u>	<u>106,015</u>	<u>108,683</u>	<u>112,415</u>	<u>115,058</u>
Total Direct Cost Difference	<u>0</u>	<u>2,635</u>	<u>-355</u>	<u>689</u>	<u>-164</u>	<u>2,108</u>	<u>214</u>	<u>2,882</u>	<u>6,614</u>	<u>9,257</u>
Indirect Construction Costs										
General and Administrative Costs (6.2%)	6,560	6,723	6,538	6,602	6,549	6,690	6,573	6,738	6,970	7,134
Miscellaneous Construction Costs	1,140	1,125	1,097	1,154	1,176	1,104	1,241	1,200	1,198	1,256
Engineering Design and Inspection, AE Services (5.8%)	6,583	6,744	6,559	6,626	6,575	6,711	6,602	6,764	6,994	7,160
Nuclear Engineering (3%)	3,603	3,691	3,589	3,626	3,598	3,672	3,613	3,702	3,827	3,918
Startup Costs	723	655	654	746	740	808	761	830	828	919
Land and Land Rights	360	455	147	560	420	410	173	0	8,400	0
Contingency (7%)	8,734	8,948	8,682	8,806	8,729	8,911	8,748	8,954	9,844	9,481
Interest During Construction (12.06%)	<u>16,101</u>	<u>16,495</u>	<u>16,005</u>	<u>16,234</u>	<u>16,091</u>	<u>16,428</u>	<u>16,127</u>	<u>16,507</u>	<u>18,147</u>	<u>17,478</u>
Total Indirect Costs	43,804	44,836	43,271	44,354	43,878	44,734	43,838	44,695	56,208	47,346
Total Capital Cost	<u>149,605</u>	<u>153,272</u>	<u>148,717</u>	<u>150,844</u>	<u>149,515</u>	<u>152,643</u>	<u>149,853</u>	<u>153,378</u>	<u>168,623</u>	<u>162,404</u>
Capital Cost Difference	0	3,667	-888	1,239	-90	3,038	525	3,773	19,018	12,799

* Costs in thousands of dollars.

TABLE 5. *Effect of Heat Rejection System
on Capital Costs*

Site	Differential Costs in Thousands of Dollars			
	Once-Through Systems		Recirc. Systems	
	Shoreline Discharge	Deep Water Discharge	Natural Draft Towers	Induced- Draft Towers
Hypothetical				
Direct Costs	0	-- (a)	7,173	3,987
Total Costs	0	-- (a)	9,952	5,457
Turkey Point				
Direct Costs	2,635	14,445	9,906	7,016
Total Costs	3,667	20,056	13,757	9,748
Maine Yankee				
Direct Costs	-355	702	5,935	2,909
Total Costs	-888	579	7,840	3,640
Connecticut Yankee				
Direct Costs	689	-- (a)	8,336	4,932
Total Costs	1,239	-- (a)	11,851	7,128
Nine Mile Point				
Direct Costs	-164	965	7,389	3,894
Total Costs	-90	1,477	10,392	5,541
Oyster Creek				
Direct Costs	2,108	12,233	9,597	6,265
Total Costs	3,038	17,008	13,431	8,807
Dresden				
Direct Costs	214	-- (a)	7,811	4,424
Total Costs	248	-- (a)	10,791	6,091
Hanford				
Direct Costs	3,194	3,701	10,577 ^(b)	6,760
Total Costs	4,205	4,908	14,451 ^(b)	9,154
Malibu				
Direct Costs	6,191	11,736	16,125 ^(b)	12,197
Total Costs	18,432	26,125	32,217 ^(b)	26,767
San Onofre				
Direct Costs	8,834	16,562	19,017 ^(b)	14,812
Total Costs	12,212	22,936	26,343 ^(b)	20,507

a. Deep discharge system not estimated at these sites.

b. Natural draft towers probably not compatible with climate at site; costs shown for comparison purposes only.

discharge and deep water (piped) discharge systems, and evaporatively-cooled recirculating systems using natural-draft and induced-draft towers. Again, costs are shown as incremental costs referenced to a plant using a shoreline-discharge system at the hypothetical site. Cost comparisons for these systems are given in greater detail in the body of the report.

DIRECT COST VARIATIONS--"SHORELINE" PLANTS

Differences in direct costs as shown in Table 4 range up to about \$9,000,000 over the various sites considered. These cost differences are those encountered in building essentially identical plants at each of the sites included in the study. Although site preparation costs are dependent mainly on the topography of a given site, the remaining direct cost components shown in the table depend primarily on geographical location of a site.

Labor Costs

Labor costs at the eastern and midwestern sites surveyed, excluding those for site preparation work, were for the most part slightly lower than costs at the hypothetical site. Of the eastern sites, only Oyster Creek evidenced higher labor costs (about 7% above those of the hypothetical site).

Costs for the three western sites were appreciably above those at the hypothetical site, ranging from 9 to 25% above costs at that site.

Materials Costs

Costs of locally purchased materials were as high as or higher than those at the hypothetical site for all locations except Oyster Creek. West coast materials prices, as with labor costs, were appreciably higher than at other sites. It should be noted that, while materials costs calculated in this study are based on prices at the Engineering News-Record "index" city nearest each site, actual prices at a site may vary somewhat from the index values.

Equipment Costs

The costs of factory-fabricated equipment items, except those associated with shipping charges, normally do not vary geographically, as borne out by the uniformity of equipment costs shown. The only variation in these costs, an increase of about \$500,000 at sites using salt or brackish water for cooling, reflects the use of more costly, corrosion-resistant materials for circulating water system components.

Transportation Costs

In this category are estimated shipping costs for major items of equipment, including shipping and unloading charges for the reactor pressure vessel. These costs do not appear to be significant as long as the pressure vessel can be shipped to the site by water. If more than minimal handling or overland transportation of the pressure vessel is required, however, these costs can mount rapidly.

For all except the two California sites considered in this study, shipping cost estimates were found to vary by about \$360,000. Added requirements for vessel handling at Malibu and San Onofre are estimated to increase shipping costs to these sites by \$150,000 to \$250,000 above any of the other sites considered.

Site Preparation Costs

Site preparation costs can vary widely because of topological and geological conditions unique to a specific location. The largest site preparation costs in this study are estimated for the coastal sites of Malibu, San Onofre, and Turkey Point. Malibu, because of unfavorable terrain adjacent to the site of the currently proposed 530 MW_e plant, would require extensive earth excavation to prepare the reference plant site. The estimated \$3,700,000 cost for site preparation for this plant

is about \$2,000,000 greater than that believed necessary for the proposed 530 MW_e plant, located in the most favorable area in Corral Canyon.

Site preparation costs approaching \$4,000,000, while high, are representative of costs which may be encountered at coastal sites in much of the region bordering the Pacific Ocean. Site preparation costs at San Onofre, essentially equal to those estimated for Malibu, reflect the need for extensive site excavation and additional requirements for a sea wall to protect the plant site to about 30 ft above Mean Sea Level.

Turkey Point, characterized by flat and swampy tide land, requires additional site preparation expenditures for removing the bed rock overburden of swamp soil. Fill material is required for sufficient load bearing capacity, and the Turkey Point Site must be provided with sea protection to about Mean Sea Level plus 20 ft.

Land and Land Right Costs

Land prices can vary widely with geographic location, particularly when comparing inland or river sites with coastal property near recreation areas.

Land cost, determined generally by prices paid for existing acreage at each site, appears to be a relatively insignificant capital cost except near Malibu. This land cost, estimated at \$20,000 per acre, is reasonable in view of other reported⁽⁵⁾ California coastal land values. San Onofre and Hanford land costs are considered negligible in view of their location on government controlled land. The current land lease agreement at San Onofre typifies the type of arrangement which could be applied at Hanford. If the reference plant were not located on the Camp Pendleton military reservation, \$20,000 per acre would most likely be an appropriate value near San Onofre also.

In the absence of cost data applicable to land near the Maine Yankee site, an average cost of \$350 per acre was used.

It should be noted that in Table 4, as elsewhere in this report, the costs of land and land rights are listed separately from the direct cost compilations. Land costs represent a nondepreciating investment, as opposed to the other direct plant cost components, and are normally listed separately to facilitate accounting of plant depreciation. Furthermore, procedures used herein estimate indirect costs as cumulative percentages of the direct plant construction costs. For proper application of these percentage additions, it is essential that land costs be accounted separately from plant construction costs.

COST EFFECTS OF COOLING SYSTEM DESIGN

If the requirements for the heat rejection system of a plant entail other than a simple shoreline intake-discharge arrangement for the circulating water system, significant increases in direct construction costs may result. These costs would depend both on the type of cooling system used and on individual site conditions. For the sites considered in this study, as indicated in Table 5, direct costs for alternate systems ranged up to \$19,000,000, and total capital costs ranged up to \$32,000,000, above the costs for a plant utilizing a once-through shoreline system at the hypothetical site. In comparing various system costs at a site above those for a shoreline system at the same site, the use of piped outfalls directing the effluent discharge to deep water (and of piped deep-water intakes when required) resulted in indicated direct cost increases ranging from \$600,000 at the Hanford site on the Columbia River to about \$12,000,000 at Turkey Point, where a line across Biscayne Bay to the open sea was assumed. Evaporative cooling systems employing natural draft cooling towers entailed direct cost additions ranging from

\$6,100,000 to \$9,600,000 at the various sites. When induced-draft towers were assumed, the additions ranged from about \$3,000,000 to \$5,400,000.

When considering evaporative cooling systems, comparison of capital costs alone can be misleading. These systems significantly increase the expense of operation and maintenance. Costs are also affected to some extent by water quality at a particular site, while generation losses are dependent upon system sizing and meteorological conditions. These factors tend to equalize the effective costs of natural draft and induced draft towers, and materially increase the effective costs of both types of system.

EFFECT OF TAXES ON CONSTRUCTION COST

The major taxes likely to affect construction costs are state sales taxes on materials and equipment used in the plant (sometimes augmented by local sales or use taxes), and state and local property taxes levied during construction. Sales taxes, when levied, add to the direct cost of a plant, while property taxes are accounted as an indirect cost of construction. These taxes can add materially to plant costs at some sites. For the sites and reactor design variants studied, sales taxes ranged up to an estimated \$3,700,000, and property taxes could add up to \$5,000,000 to the indirect costs of construction. The tax allowance contained in the 6.2% indirect adder for general and administrative costs is insufficient to cover tax costs of this magnitude.

The basing of cost estimates on published tax rates can often produce misleading results. In many states, attempts to attract new industries take the form of various tax benefits offered as outright waivers of taxes, tax deferments, reduction of taxation bases, and the like. Tax relief methods may be generally applied or may be negotiated with

specific industries, and may or may not apply to utilities within fixed franchise areas. The net result of the application of tax relief mechanisms is an effective reduction of capital costs during the construction period, of subsequent costs of operation, or of both.

Because of the uncertainties of tax application, the potential effects of taxes on plant costs were estimated in this study but were excluded from the cost summaries in Tables 4 and 5.

SITE COST FACTORS FOR REFERENCE SHORELINE-DISCHARGE PLANT

Modification of the reference cost estimate (Table 1) to reflect site-related differences in construction costs entailed the consideration of a number of cost factors. The derivation of these factors and their influence on costs at the various sites are discussed in the following paragraphs.

LABOR COSTS

Labor costs for the various sites included in the study were based on construction labor wage rates at each of the sites during the first half of 1967. These wage rates, for the major trades involved in nuclear plant construction, were obtained through contact with trade union representatives at each site. The wages used were thus those actually in effect or applicable for each craft at each site during early 1967. The wage rates used include direct wages, fringe benefit payments, and travel allowances when applicable.

Wage rates were weighted for each construction account by assuming a typical construction crew composition for performing the work in each direct cost construction account. The weighted wage rates for each account were increased by percentage factors to allow for added payroll burden for workmen's compensation, unemployment compensation, and similar costs. Also included in this computation were allowances for general overhead and

subcontractors profit. The resulting computed wage rates were then ratioed to those at the hypothetical site to provide a labor cost index for each site, referenced to the hypothetical site.

The labor cost indexes calculated for the various sites, and the labor costs associated with the construction of the reference shoreline-discharge nuclear plant at each of the sites considered, are summarized in Table 6. Details of computation of the labor cost indexes are given in the appendix to this report, Tables A-1 through A-5. Labor cost calculations for plants with alternate cooling systems are discussed later in the section on heat dissipation systems.

TABLE 6. *Labor Cost Summary (Shoreline-intake, shoreline-discharge plant: Costs in thousands of dollars)*

Site	Acct. 21*		Acct. 22		Acct. 23		Acct. 24		Acct. 25		Total Labor Costs
	Index	Cost	Index	Cost	Index	Cost	Index	Cost	Index	Cost	
Hypothetical	1.00	6,619	1.00	6,620	1.00	3,588	1.00	764	1.00	143	17,734
Turkey Point	0.900	5,957	0.899	5,951	0.910	3,265	0.932	712	0.906	130	16,015
Maine Yankee	0.900	5,957	0.952	6,302	0.964	3,459	1.036	792	0.947	135	16,645
Connecticut Yankee	1.038	6,837	0.985	6,521	0.981	3,520	1.029	786	0.970	139	17,803
Nine Mile Point	1.022	6,765	0.899	5,951	0.927	3,326	1.001	765	0.914	131	16,938
Oyster Creek	1.129	7,473	1.101	7,289	1.060	3,610	1.038	793	1.066	152	19,317
Dresden	1.050	6,950	0.937	6,203	0.964	3,459	1.074	821	0.939	134	17,567
Hanford	1.155	7,645	1.167	7,725	1.147	4,115	1.209	924	1.135	162	20,571
Malibu	1.151	7,618	1.086	7,189	1.079	3,871	1.142	872	1.066	152	19,702
San Onofre	1.283	8,492	1.251	8,282	1.248	4,478	1.352	1,033	1.226	175	22,460

* Account 21 costs in this table do not include site preparation costs.

CONSTRUCTION MATERIAL COSTS

There are a number of general purpose construction and building cost indexes, each of which might be selected for construction cost comparisons throughout the country. The more generally used indexes are the Engineering News Record (ENR) Building Cost Index; the Associated General Contractors, 12-City Average Index; and the U.S. Department of Commerce Composite Index. In addition to these general purpose indexes,

a number of special purpose, valuation, public utility and contractor building price indexes have been developed on various bases and are applicable to special types of construction.

Both the ENR Construction and Building Cost Indexes include a materials component or weighted index of constant quantities of structural steel, Portland cement, and lumber. These indexes have proven reliable indicators of both the degree and direction of cost trends. The ENR Materials Price Index, employed in the monitoring of steel, lumber, and cement (the "big three" construction materials) in 20 cities since 1913, was selected as the most appropriate index for capital cost comparisons.

The cost of materials in Account 21 at each site was derived from the February 1967 ENR price index values⁽⁶⁾ (steel, lumber, and cement) for that city of the 20 in the index closest to the nuclear plant site. The cost of materials in Accounts 22 through 25 was based on structural steel index values⁽⁶⁾ at the corresponding cities. Multipliers were determined on the basis of materials costs at the hypothetical site and were applied to the other sites in a fashion similar to that used in estimating labor cost differences.

The derived materials cost indexes for the various sites, and corresponding materials prices for a shoreline-discharge plant, are given in Table 7. Details of the derivation of the cost index values are given in Table A-6 in the appendix. It should be noted that these indexes are based on prices at the index city nearest each site. In some cases a site may be considerably distant from the nearest index city. The Turkey Point site, for instance, is over 600 miles from Atlanta, Georgia, its closest index city. Actual materials prices at a site may thus vary from those based on the ENR index.

TABLE 7. *Materials Cost Summary (Shoreline-intake, shoreline-discharge plant: Costs in thousands of dollars)*

Site	Cost Index		Acct. 21 Costs	Acct. 22 Costs	Acct. 23 Costs	Acct. 24 Costs	Acct. 25 Costs	Total Materials Costs
	Acct. 21	Acct. 22-25						
Hypothetical	1.00	1.00	4,303	3,063	1,434	182	117	9,099
Turkey Point	1.04	1.183	4,475	3,624	1,696	215	138	10,148
Maine Yankee	1.00	1.00	4,303	3,063	1,434	182	117	9,099
Connecticut Yankee	1.00	1.00	4,303	3,063	1,434	182	117	9,099
Nine Mile Point	1.05	1.054	4,518	3,228	1,511	192	123	9,572
Oyster Creek	0.87	1.043	3,744	3,076	1,496	183	122	8,621
Dresden	1.112	0.957	4,785	2,931	1,372	174	112	9,374
Hanford	0.99	1.086	4,260	3,326	1,557	198	127	9,468
Malibu	0.99	1.151	4,260	3,525	1,650	210	135	9,780
San Onofre	0.99	1.151	4,260	3,525	1,650	210	135	9,780

The maximum variation in materials costs estimated for a shoreline-discharge plant at the various sites is about \$1,000,000, equivalent to 1% of the total direct costs.

SHIPPING COSTS

Estimates of shipping costs for major items of equipment, apart from the reactor pressure vessel, were based on published rail freight rates for Class 43 (heavy equipment) and on transcontinental commodity rates where applicable. An allowance estimated to cover shipping and handling costs for the pressure vessel was added to the rail freight shipping cost estimate at each site. The estimated costs of shipping are summarized in Table 8.

Rail shipments were assumed to terminate at the plant site spur line. No additional transshipment or handling charges were assumed. The main steam condensers were assumed to be shipped as subassemblies, with final assembly and tubing at the site. No estimate is included for shipping of the turbine-generators. Both General Electric and Westinghouse, currently the only U.S. suppliers of nuclear turbine-generators, allow freight for these units to any point in the conterminous United States.

TABLE 8. Equipment Shipping Costs

Item No.	Quantity	Description	Est. Total Wt., cwt	Assumed Origin	(Rate) and Cost to Site (Costs in Dollars)									
					Hypothetical	Turkey Point	Maine Yankee	Connecticut Yankee	Nine Mile Point	Oyster Creek	Dresden	Hanford	Malibu	San Onofre
1	3	Condensers (228,000 ft ² ea.)	33,750	Milwaukee, Wisc.	(2.50)* \$84,375	(1.75) 59,063	(2.50) 84,375	(2.50) 84,375	(3.00) 101,250	(2.50) 84,375	(0.75) 25,313	(3.71) 125,213	(3.71) 125,213	(3.71) 125,213
2	18	Feedwater Heaters	10,800	Toledo, Ohio	(2.50) 27,000	(1.75) 18,900	(2.50) 27,000	(2.50) 27,000	(3.00) 32,400	(2.50) 27,000	(1.00) 10,800	(3.71) 40,068	(3.71) 40,068	(3.71) 40,068
3	3	Circulating Water Pumps	7,020	Lowell, Mass.	(0.50) 3,510	(2.00) 14,040	(0.50) 3,510	(0.50) 3,510	(1.00) 7,020	(1.00) 7,020	(2.50) 17,550	(3.90) 27,378	(3.90) 27,378	(3.90) 27,378
4	2	Primary System Recirc. Pumps	1,000	Lowell, Mass.	(0.50) 500	(2.00) 2,000	(0.50) 500	(0.50) 500	(1.00) 1,000	(1.00) 1,000	(2.50) 2,500	(3.90) 3,900	(3.90) 3,900	(3.90) 3,900
5	3 3	Condensate Pumps Condensate Booster Pumps	900	Milwaukee, Wisc.	(2.50) 2,250	(1.75) 1,575	(2.50) 2,250	(2.50) 2,250	(3.00) 2,700	(2.50) 2,250	(0.75) 675	(3.71) 3,339	(3.71) 3,339	(3.71) 3,339
6	3	Feedwater Pumps	2,700	Toledo, Ohio	(2.50) 6,750	(1.75) 4,725	(2.50) 6,750	(2.50) 6,750	(3.00) 8,100	(2.50) 6,750	(1.00) 2,700	(3.71) 10,017	(3.71) 10,017	(3.71) 10,017
Major Equipment Shipping Costs (Excluding reactor pressure vessel)					124,385	100,303	124,385	124,385	152,470	128,395	59,538	209,915	209,915	209,915
Rounded Shipping Costs					124,400	100,300	124,400	124,400	152,500	128,400	59,500	210,000	210,000	210,000
Pressure Vessel Shipping + Handling Allowance (from Table IX)					200,000	200,000	200,000	200,000	150,000	200,000	150,000	450,000	700,000	600,000
Equipment Shipping Costs Including Vessel					324,400	300,300	324,400	324,400	302,500	328,400	209,500	660,000	910,000	810,000
Shipping Cost Difference from Cost to Hypothetical Site:														
Excluding Vessel					0	-24,100	0	0	+28,100	+4,000	-64,900	+85,600	+85,600	+85,600
Including Vessel					0	-24,100	0	0	-21,900	+4,000	-114,900	+335,600	+585,600	+485,600

* Figures in parentheses are rail shipping rates, dollars per hundred weight.

The pattern of shipping costs shown in Table 8 could vary considerably for equipment items procured and shipped from locations different than the assumed points of origin. The effects of variations in shipping costs for nonnuclear equipment, however, would not significantly change overall plant capital costs.

Pressure Vessel Shipment

The only two U.S. firms offering prefabricated pressure vessels for larger-size reactors are Combustion Engineering at Chattanooga, Tennessee, and Babcock and Wilcox at North Bend, Indiana. The production plants for Combustion Engineering and Babcock and Wilcox are located on the Tennessee and Ohio Rivers, respectively, and thus accessible to the Mississippi River navigation system.

The pressure vessel for a 1000 MW_e BWR, with shipping yoke attached, weighs about 800 tons, has a clearance diameter of about 28 ft, and is some 60 ft in length. The vessel head adds about 100 tons to the shipping weight. These vessels are normally shipped on specially built, variable-draft seagoing barges furnished by the vessel fabricator. Although actual shipping costs for these vessels are not published, it is believed that a cost increment of about \$250,000 would be associated with shipment through the Panama Canal to a Pacific site, as compared with an Atlantic Coast site. Allowances for shipping and normal handling assumed for the study were \$150,000 for sites accessible to the Mississippi River or Great Lakes, \$200,000 for Atlantic Ocean sites, and \$450,000 for Pacific sites (including the Hanford site, accessible via the Columbia River).

Unloading procedures at all but two of the sites were assumed to consist of beaching the barge, skidding the vessel from the barge to the plant, and lifting the vessel into the reactor building and setting it in place by means of a heavy duty crane erected for this purpose.

At the Malibu site, an alternate route of U.S. Highway 101 runs between the plant site and the beach. Transportation of the vessel across the highway to the site would probably involve the use of a specially built trailer and the grading of a temporary roadway to the site. The vessel shipping and handling allowance for this site was increased by \$250,000 to account for the extra work involved in moving the vessel to the site.

The necessity for hoisting the vessel over a low bluff paralleling the shore at San Onofre would require an extra erection and subsequent dismantling of the vessel handling crane, thus adding about \$150,000 to the vessel shipping and handling allowance.

The costs allowed in this study for pressure vessel shipping and handling are summarized in Table 9. The effect of these costs on the total capital costs of a nuclear plant site directly accessible by water would not be great. These costs could mount rapidly, however, for overland transportation of the pressure vessel. Costs for an overland journey of only a few miles could well make a site economically unattractive.

Field fabrication of BWR pressure vessels is currently employed at some sites. In this procedure, formed sections of the vessel are shipped to the site and joined, vessel fabrication is completed, and acceptance testing is performed using facilities set up at the site. Costs of a field fabricated vessel are believed to be about \$1,000,000 above the costs of a shop-fabricated vessel as delivered to a water-accessible site. The availability of field-fabricated vessels thus tends to set an upper limit to vessel transportation costs. Should transportation costs exceed the incremental costs of field fabrication, a field-fabricated vessel would be preferred.

TABLE 9. *Reactor Pressure Vessel Shipping and Handling Allowances (Allowances include unloading costs at site.)*

<u>Site</u>	<u>Allowance</u>	<u>Notes</u>
Hypothetical	\$200,000	a
Turkey Point	200,000	a
Maine Yankee	200,000	a
Connecticut Yankee	200,000	a
Nine Mile Point	150,000	b
Oyster Creek	200,000	a
Dresden	150,000	b
Hanford	450,000	c
Malibu	700,000	c, d
San Onofre	600,000	c, e

Notes:

- a. Access to site via Atlantic Ocean.
- b. Access to site via Mississippi/Great Lakes waterways.
- c. Pacific site: Access via Panama Canal.
- d. Includes \$250,000 allowance for overland transfer at site.
- e. Includes \$150,000 allowance for vertical lift at site.

SITE PREPARATION COSTS

The site preparation costs considered in this study are those associated with:

- Land clearing
- Grading
- Excavation, filling, and dredging
- Drainage
- Flood or sea protection
- Access road construction.

Differential costs resulting from local labor rates and materials cost variations among the sites considered were not included in developing the site preparation costs. Costs for this work are very sensitive to local site conditions, and cost variations caused by differing site conditions tend to mask out variations due to differing labor rates and materials prices.

At each site, the preparation of about 25 acres of level area was assumed for the plant complex. The plant structures, parking facilities, etc. were assumed to occupy 16 acres. The switchyard, not necessarily at the same level as the plant grade, was allotted the remaining 9 acres. Additional leveling would be required for those sites employing cooling towers.

With foundations of the reactor building and turbine generator building at 40 ft and 16 ft below grade, respectively, site preparation would require excavation of an estimated 50,000 yd³ for the reactor building and 45,000 yd³ for the turbine generator building. The reactor building can apparently be founded directly on bedrock or on material of adequate bearing capacity at all sites considered in this study. Direct-bearing foundations were assumed at all sites. However, in preparing foundations for the turbine-generator building and other buildings, the use of piling may be preferable at some sites to the extra work required in the development of direct-bearing foundations. Costs of piling were not developed for any of the sites, although the sites where piling might be considered are noted in the following paragraphs describing the individual sites.

Location of the 1000 MW_e BWR is assumed to be near existing or proposed plants at each site, but sufficiently removed to require full development of a new exclusion area and provision of all new plant facilities. Additional access roads and rail

spurs were assumed to be required at each site to connect to the new plant. Estimates were made for sea walls and flood protection where applicable.

Major cost variations in site preparation are largely a consequence of conditions unique to a particular location. For example, excavating costs may vary from \$1/yd³ for removing sandy soil to \$10/yd³ for bedrock. Topology also plays an important role in establish leveling costs. Excavation to bedrock or to an acceptable load bearing soil structure is essential in swamp and tidelands, and subsequent refilling is also necessary. Flood and sea or tidal wave protection requires construction of revetments or sea walls' at some locations. Other sites may require extensive circulating water intake and discharge canal dredging. The costs of grubbing, clearing, and drainage requirements vary to only a minor degree. Estimates of site preparation costs are shown in Table 10.

TABLE 10. *Site Preparation Costs*

<u>Site</u>	<u>Site Preparation Cost, dollars</u>	<u>Differential Cost, dollars</u>
AEC Hypothetical	825,000	-0-
Turkey Point	3,650,000	2,825,000
Maine Yankee ^(a)	1,055,000 ^(b)	230,000
Connecticut Yankee	1,445,000	620,000
Nine Mile Point	1,005,000	180,000
Oyster Creek	1,320,000	495,000
Dresden	1,045,000	220,000
Hanford	165,000	-660,000
Malibu	3,700,000	2,875,000
San Onofre	3,685,000	2,860,000

a. Allowance only; full estimate not made for Maine Yankee site.

b. Includes \$55,000 diversion dam required for shoreline discharge case only.

At the AEC hypothetical site, the major preparation cost would be due to the excavation of soil and limestone for the reactor and turbine generator buildings. Excavation costs would run about \$750,000, with total site preparation cost about \$825,000.

A flat, swampy tideland with 4 to 8 ft of organic mangrove swamp soil overlying limestone bedrock typifies the Turkey Point location. The swamp soil must be removed to bedrock, and material of sufficient load bearing capacity must be filled in to prepare the reactor and switch yard areas. These areas must have sea protection to about Mean Sea Level plus 20 ft.

Site description data for the Maine Yankee site were not available at the time the site preparation cost estimates were made. Therefore, an allowance of \$1,000,000 was made for preparation work at this site. To this estimate was added \$55,000 for an earth-fill diversion dam, required for the shoreline-discharge case only, to prevent effluent recirculation. Costs of this dam were deleted for other heat dissipation system options.

At the Connecticut Yankee site, a major cost item is dike construction to provide the site with flood protection to about 10 ft above the site grade. Although the site has some organic swampy soil, bedrock is 10 to 20 ft below the surface except at the river edge where the depth may be 30 to 50 ft. The turbine-generator and reactor building would probably be founded on bedrock. Some of the service buildings and the pump house may require pile foundations, although no cost estimates were developed for the piling.

The geology at Nine Mile Point is characterized by relatively poor load bearing soil, about 11 ft thick, overlaying sandstone. The turbine generator and reactor buildings would be founded on sandstone. Excavation for these buildings would

constitute the major site preparation cost. Other buildings might be more economically located on pilings rather than excavating to bedrock.

A poor load bearing soil is also typical of the Oyster Creek site. The reactor building would be founded at a depth where the soil load capacity is adequate, but the turbine generator building and pumphouse would require some additional excavating and refilling or pile supports. The soil will endure the load of other buildings without pile support. Extensive additional dredging of existing circulating water canals would also be required.

The major site preparation cost at Dresden would be due to excavation in sandstone and limestone underlying a shallow top soil.

Of the sites considered, Hanford apparently would require the least capital investment for site preparation. This site is characterized by flat topography with minimum vegetation, an easily graded and excavated sand and gravel soil of sufficient load bearing capacity, existing access roads, no requirement for flood protection, and only a minimum drainage requirement. Site preparation costs at Hanford would be about \$120,000, or \$650,000 less than for the AEC hypothetical site.

The site presently under consideration at Malibu occupies the most favorable area in Corral Canyon. Preparation of an additional site would require grading and, because of extremely unfavorable terrain, excavation of about 2,300,000 yd³ of earth. Preparation costs at the Malibu site would be about \$3,500,000 merely for grading and leveling.

At San Onofre, preparation of the site would require excavation of about 2,000,000 yd³ of earth to prepare a level area at the present site elevation. A sea wall must also be constructed for protection to about mean-low-low-water plus 30 ft.

Site preparation costs at the two California locations and at Turkey Point are high compared with other sites considered in the study. However, it is often economically preferable to accept site preparation costs of this order than to transmit power from more remote, though physically better suited, locations.

SEISMIC CONSIDERATIONS

In areas susceptible to seismic activity, added costs may be incurred in extensive stress analyses required to define needed construction features and in providing the required earthquake-resistant construction.

The Uniform Building Code⁽⁷⁾ defines zones of roughly equal seismic probability in the United States. Classification of these zones ranges from Zone 0 (no probable damage) to Zone 3 (major damage probable). Zones 1 and 2 indicate areas with probabilities of minor and moderate damage, respectively. These zones are convenient for preliminary assessment of added design requirements, although much more specific data are needed for actual design at a specific site.

The extent of seismic activity at a nuclear plant is of particular concern in the design of acceptable containment structures. Calculational methods employed in seismic design analysis also have an important bearing on structural integrity. The Uniform Building Code specifies static loading analysis methods which could result in design deficiencies for structures and components having resonant frequencies within the major vibration frequency range of earthquakes. These methods are not satisfactory for nuclear construction.

Work is proceeding toward better definition of containment design criteria.⁽⁸⁾ Currently, however, the assurance of adequate construction requires comprehensive analysis of reaction forces likely to be experienced at a given site, and the utilization of design procedures incorporating dynamic response techniques. The procedures and design methods outlined by Housner⁽⁹⁾ are representative of methods by which earthquake resistance may be reasonably assured in containment design.

Seismic Design Factors

Several factors⁽¹⁰⁾ must be considered in the seismic design of containment structures and other critical plant components. The major factors requiring evaluation to define structural requirements include the following:

- Seismic history near the site, and the authenticity of available seismic historical records
- Location, apparent age, and activity of faults in the vicinity of the site, and their distances from the site
- Elastic properties and frequency-response characteristics of ground formations underlying the site
- The maximum probable forces, vibrational frequencies, and corresponding ground accelerations which must be withstood by the containment structure and by other critical plant components.

Design of the critical plant components to withstand predicted earthquake forces in areas of high seismic probability may often entail a considerable degree of conservatism due to uncertainties in the magnitude of predicted forces. Areas where firm anchoring of plant foundations to bedrock formations cannot be assured may be particularly troublesome, and may introduce additional design conservatism in assuring sufficient anchorage to provide adequate transmission of forces from building to ground, and in allowing for possible resonant enhancement of forces at certain frequencies.

Very little published information is available which permits separate identification of additional capital costs attributable to earthquake-resistant design. For the 150 MW_e Japanese nuclear plant at Tokai Mura, embodying a Calder Hall-type reactor of British design, costs attributable to earthquake protection were estimated to increase plant cost by 1 to 3%.⁽¹¹⁾ However, Housner,⁽⁹⁾ in an evaluation of various reactor types, singled out the gas-cooled, graphite-moderated reactor (the type utilized at Tokai Mura) as particularly likely to cause problems in earthquake-resistant design. The rigidity and high strength characteristic of commercial light-water reactors give them a high degree of inherent shock resistance. Similarly, the containment enclosures are high-strength structures. Additional bracing and strengthening, and the provision of adequate anchorage would not be expected to greatly increase the cost of these facilities.

The costs for earthquake protection of large fossil fuel fired steam power plants in zones of high seismic probability, equivalent to Zone 3 of the Uniform Building Code designations, are estimated at approximately \$1.25/kW_e.⁽¹²⁾ Costs of the same order might be expected for nuclear power plants. On this basis, approximate cost additions for construction in different seismic zones might be as follows:

<u>Zone</u>	<u>Additional Capital Cost</u>
0 or 1	Insignificant
2	\$400,000-\$800,000
3	\$1,000,000-\$1,500,000

The additional capital cost shown for Zone 3 in the preceding tabulation represents about 1.0-1.4% of direct construction costs, or 0.7-1.0% of the reference plant total capital cost at the hypothetical site.

STATE SALES TAXES

Taxes on retail sales are levied by many states. In some cases, excise or use taxes based on sale prices and thus serving as sales taxes are levied by county or municipal governmental units. These sales taxes would add to the direct construction costs of a plant and the effects, as is shown in Table 11, can be appreciable.

TABLE 11. *State Sales Tax: Effect on Costs (Shoreline-intake, shoreline-discharge once-through plants)*

<u>Site</u>	<u>Materials and Equipment Costs, \$ thousands</u>	<u>Tax Rate, %</u>	<u>Sales Tax Costs, \$ thousands</u>
Hypothetical	86,918	0 ^(a)	-0-
Turkey Point	88,471	3	2,654
Maine Yankee	87,422	4	3,497
Connecticut Yankee	86,918	3.5	3,042
Nine Mile Point	87,391	2	1,748
Oyster Creek	86,944	0 ^(a)	-0-
Dresden	87,193	3.5	3,052
Hanford	87,287	4.2 ^(b)	3,666
Malibu	88,103	4 ^(c)	3,524
San Onofre	88,103	4 ^(c)	3,524

a. *Massachusetts and New Jersey sales taxes of 3% not applicable to new construction.*

b. *Following period covered by estimate, sales tax rate increased to 4.5%*

c. *Includes 1% local use tax.*

Sales tax rates applicable to new construction materials and equipment⁽¹³⁾ during the period of the estimates ranged from zero at the Massachusetts hypothetical site and the Oyster Creek site in New Jersey to 4.2%* at the Hanford site

* *The Washington state sales tax rate was increased to 4.5% in 1967, following the period for which estimates were made.*

in Washington State. For the Malibu and San Onofre sites, a 4% effective tax rate was applied. This rate consists of a 3% California state sales tax and a 1% local use tax which is believed to apply in all counties of California. Although both Massachusetts and New Jersey levy sales taxes at a 3% rate, the fact that these taxes do not apply to new construction explains the indicated lack of sales tax at the hypothetical site and at Oyster Creek.

Attempts to attract new industry have led many states to offer various incentives in the form of tax relief. These incentives may or may not apply to utilities. Some states, as previously reported, exempt new construction from sales taxes. In other states, tax payment may be deferred. In still others, the amounts paid in sales tax on construction are credited against subsequent payments of property taxes or other taxes. Property taxes or other taxes paid during or subsequent to construction may be reduced, deferred, or waived for varying periods, or preferential tax base adjustments may be made. In some states, tax relief is applied generally to new industries as a matter of policy. In other states, it may be negotiated with individual firms.

There is thus considerable uncertainty in the extent to which sales taxes or other taxes may be levied during construction, or in the extent to which they may affect capital costs in many parts of the United States. Therefore, the sales taxes levied at published tax rates (see Table 11) were not included in the Table 3 capital cost summaries or elsewhere in this report. Similar treatment accorded the calculated property taxes paid during construction is discussed in a subsequent section.

LAND AND LAND RIGHTS

Land acquisition costs at most nuclear power plants to date have been a relatively insignificant part of plant capital

cost. The low land costs can be attributed, at least in part, to remote siting criteria currently in effect for nuclear plants. In the future, accumulated operating experience and added engineered safeguards will presumably result in relaxation of distance criteria. With increased emphasis on reduced transmission charges and similar cost incentives, sites closer to load centers will become more attractive and land costs at such sites can be expected to become a more significant factor.

Land costs at representative nuclear plant sites are shown in Table 12. The sites included in this table vary widely in acreage and in the number and rating of the plants they contain. Areas of several of the large sites reflect future plans of the owners or special facilities peculiar to a site. The 2480 acre Rancho Seco site, for example, contains a reservoir for cooling water supply. Unit land costs vary from about \$200 per acre for the Rancho Seco site to \$6000 per acre for the Zion site on the shore of Lake Michigan.

Appreciably higher land costs may be encountered at some sites. Appraisals made as part of a feasibility study for the Bolsa Island nuclear power and desalination plant⁽¹⁴⁾ indicated land costs at potential California coastal sites near Los Angeles to range from \$20,000 to \$75,000 per acre. While these figures may represent near-extremes in land cost by today's standard, future sites located close to, or within, major metropolitan areas may well be appraised at costs of this magnitude in several areas of the United States.

Evaluation of Land Costs

The most appropriate method of evaluating land costs for the 1000 MW_e plant uses average unit acreage cost for the existing selected sites adjusted with appropriate escalation factors to provide for the normal increase in real estate value

TABLE 12. *Representative Nuclear Site Land Costs
for Existing and Proposed Plants*

<u>Site</u>	<u>No. of Units and Power</u>	<u>Site Acreage</u>	<u>Published Cost, \$</u>	<u>Unit Cost, \$/acre</u>
Connecticut Yankee	1-463	450	600,000	1,333
Nine Mile Point	1-500	1500	1,500,000	1,000
Oyster Creek	1-515 1-900	800	775,000	970
Dresden	1-200 2-715	940	387,000	412
Rancho Seco	1-800	2480	540,000	218
Diablo Canyon	2-1060	750	273,000	364
Zion	2-1050	250	1,500,000	6,000
Surry	2-800	840	380,000	452
Salem	2-1050	700	1,080,000	1,543
Brown's Ferry	3-1075	840	600,000	714
Cook	2-1100	650	1,215,000	1,869
Ft. Calhoun	1-450	382	230,000	602

since purchase. Area requirements, particularly at high land cost locations, should consider hazards analyses at each site and appropriately credit engineered safeguards and/or lower containment leakage rates in reducing exclusion and low population zone distance requirements. A preliminary hazards analysis of the reference reactor at each site, required to define quantitatively the extent of the exclusion area, is beyond the scope of this study. However, in most circumstances, an exclusion zone about 2500 to 3500 ft in radius may be appropriate for a 1000 MW_e nuclear plant.⁽¹⁵⁾ An approximate required plant area of 450 to 900 acres would result. However, a portion of the exclusion area at most plant sites would extend over water, thus reducing the area included in the purchase. For purposes of this study, the site area at each location, except the hypothetical site, was

assumed to be 420 acres. The resultant land costs are shown in Table 13. The standard AEC ground-rule site area of 1200 acres, at \$300 per acre, was assumed at the hypothetical site.

TABLE 13. *Estimated Land Costs for Study*

Site	Unit Cost, \$/acre	Assumed Area, acres	Site Land Costs, \$
Hypothetical	300	1,200	360,000 ^(a)
Turkey Point	1,083	420	455,000
Maine Yankee	350	420	147,000
Connecticut Yankee	1,333	420	560,000
Nine Mile Point	1,000	420	420,000
Oyster Creek	970	420	410,000
Dresden	412	420	173,000
Hanford	---	420	--- ^(b)
Malibu	20,000	420	8,400,000
San Onofre	---	420	--- ^(c)

a. Land area and cost from References 2 and 3.

b. Site assumed leased from USAEC for nominal charge.

c. Site assumed leased from U.S. Navy for nominal charge.

Land costs for four of the sites in this table-- Connecticut Yankee, Nine Mile Point, Oyster Creek, and Dresden--were derived from published cost data summarized in Table 12. Lease agreements covering the Hanford and San Onofre sites located on federally owned land, were assumed to be available at nominal rates from the U.S. Atomic Energy Commission and the U.S. Navy, respectively.

No published land cost data were available for the Turkey Point, Maine Yankee, or Malibu sites. Land costs at these sites were estimated indirectly from other sources. The nuclear plant currently under construction at Turkey Point shares its site with two fossil-fired steam power plants. No

cost data are available for this site. However, published cost surveys^(16,17) indicate land investments ranging from \$0.14 to \$1.24 per net kilowatt capacity for fossil-fueled plants in the South Atlantic Region as defined by the Federal Power Commission. Derived land costs for these plants range from about \$450 to \$7400 per acre. A smaller-capacity (320 MW_e) fossil-fueled plant located on Biscayne Bay in the general area of the Turkey Point plant, built immediately after World War II, reported land costs of \$105,000, or about \$0.33/kW.⁽¹⁸⁾ The Turkey Point site and cost of \$1083 per acre, assumed for purposes of this study, reflects probable upgrading of the Biscayne Bay land values since the 1940's and results in a land cost for the site of \$455,000.

Land in the vicinity of the Maine Yankee site is described as composed of idle farm lands and forested land.⁽¹⁹⁾ No published data are available on land values in this region, although there are some indications that unit cost of the original Maine Yankee site may have been as low as \$100 per acre. A value of \$350 per acre was assumed for this report and resulted in a land cost of \$147,000 for a 420 acre site.

The extreme variance in Southern California land costs was previously discussed. A unit cost of \$20,000 per acre was assumed for the Malibu site (actual costs unavailable) as a typical land value in the region near Los Angeles. This assumption results in a land cost of \$8,400,000 for the Malibu site, the highest land cost considered in the study.

The two sites located on federal land, Hanford and San Onofre, are assumed to be leased for nominal fees, as was previously mentioned. The existing San Onofre site, located on the Camp Pnedleton military reservation, and the site of the Hanford Generating Plant (NPR) at Hanford offer precedent for arrangements of this type. In the event lease arrangements should not be consummated, land costs in the area of San Onofre

would probably approximate the \$20,000 per acre assumed for the Malibu site. Land costs at Hanford might be on the order of \$300 to \$350 per acre, or \$125,000 to \$150,000 for a 420 acre site. These prices are typical of irrigable land near Hanford in Franklin County on the east side of the Columbia River.

LOCAL AND STATE TAXES DURING CONSTRUCTION

Apart from sales taxes which may be levied on construction materials and equipment, a property tax is the only tax normally applied during construction. This tax, because of differences in local tax assessment, varies widely among communities within the same state and is also variable with the type of industry considered. In the state of Washington, for example, a comparison of local property taxes paid by a hypothetical corporation having branch plants in the food, chemicals, fabricated metals, and electrical machinery industries showed property taxes to vary by a factor of about 2.5 between highest and lowest taxed counties.⁽²⁰⁾ The same study showed similar tax variations between high and low taxed counties in Oregon, Idaho, and California. The highest rate, in Oregon, was 3.25 times the low rate among the industrial counties of that state. The states in which the selected nuclear sites of this study are located can be expected to show similar property tax variations between counties.

Several factors complicate the evaluation of nuclear plant local property taxes at different geographic locations. Local methods of tax assessment are often inconsistent. Utility property taxes may be levied on different property bases (land plus buildings, land plus total plant, etc.) and, in areas where the value of the plant is high relative to the balance of the taxation base, a favorable assessment may be established by negotiation. Furthermore, as was pointed out in

the case of sales taxes, efforts to attract industry to an area may take the form of reduction, deferral, or waiver of taxes during construction. Favorable tax treatment of this sort may, in different areas, be applied generally to new plant construction or may be negotiated with specific firms on an individual basis. Because of the resulting considerable uncertainty in estimating the effects of taxes on capital costs, property taxes were calculated for the various sites. Although the potential effects of these taxes are considered in this section, they are not included in the capital cost summaries elsewhere in this report.

In calculating taxes during construction, the effective annual tax rate was selected as the best available indication of property tax comparisons between sites. This rate includes all local, county, and state property taxes and is defined as the ratio of the average amount of tax to the true and fair (or market) value of land and structures affixed to the land. The most serious limitation in using the effective tax rate is its disregard for property tax variations between counties in each state.

Taxes during construction were calculated from the equation,⁽²¹⁾

$$\text{Tax} = \frac{rT}{100} (L + 0.45Q)$$

where r (%) is the effective annual tax rate, T is the construction time in years, L is the land cost, and Q is that portion of plant cost to which property tax is applicable. The constant 0.45 is an averaging factor which recognizes the uneven rate at which monies are spent during the construction period. The preceding equation assumes that the land is paid for at about the time construction begins, and that construction

expenditures follow the classical sigmoid form.* For study purposes, taxes during construction were based on Q equal to the direct construction cost at each site.

Table 14 shows the estimated direct construction cost, effective tax rate, and calculated taxes during construction for an assumed four-year construction period at each of the selected sites.

TABLE 14. *Property Tax During Construction: Effect on Costs (Based on 4-year construction period; shoreline-intake, shoreline-discharge plant)*

Site	Estimated Tax Base, \$ Thousands		Effective Tax Rate, (a) %	Taxes During Construction, (b) \$ Thousands
	Land Cost	Direct Construction Cost		
Hypothetical	360	105,801	2.4	4,605
Turkey Point	455	108,436	1.1	2,167
Maine Yankee	147	105,446	2.4	4,569
Connecticut Yankee	560	106,490	1.6	3,103
Nine Mile Point	420	105,637	2.1	4,028
Oyster Creek	410	107,909	2.3	4,505
Dresden	173	106,015	1.5	2,872
Hanford	---	108,683	0.9	1,761
Malibu	8,400	112,415	1.4	3,303
San Onofre	---	115,058	1.4	2,899

a. Effective tax rates based on data in Reference 22.

b. Potential taxes if levied at effective rates.

INDIRECT CONSTRUCTION COSTS

Indirect costs for plant construction were estimated either as dollar amounts or as cumulative percentage multipliers in accordance with the AEC ground rules for nuclear plant evaluation given in Reference (2). In several cases,

* The rate of expenditures for a typical construction project will be low at the start of the project, will increase to a maximum during the major part of the construction period, and will taper off again as construction nears completion. A plot of expenditure versus time will thus show a characteristic S-shaped, or sigmoid, form.

however, estimated costs or percentages were modified to reflect recent trends in construction costs and trends toward maturity in the nuclear power industry. Estimates and factors considered for each category of indirect construction costs are discussed in the following.

General and Administrative Costs

This cost category contains allowances for general administrative costs incurred during construction for such items as field engineering, accounting, purchasing, medical, fire protection, insurance, construction contractor fees, and allowance for taxes (other than payroll taxes) during construction. These allowances were taken as a multiplier of 6.2% to be applied to direct construction costs, in accordance with the ground rules in Reference (2). In view of the previously discussed potential impact of property taxes during construction, this allowance percentage would not be sufficient to cover property taxes levied at the level indicated by the effective tax rate compilation.

Miscellaneous Construction Costs

This category includes the cost of temporary construction facilities such as roads, fences, shops, warehouses and offices, and the supplying of utilities (power, water, etc.) during the construction period. The AEC ground rules denote this cost category as a percentage of direct construction costs. However, a dollar value estimate of these costs was made for the hypothetical site and, using the developed labor and materials indexes used for the Account 21 category of direct costs, the estimated miscellaneous construction costs were modified for each of the sites.

Engineering Design and Architect-Engineer Services

For costs covering these services, a percentage multiplier of 5.8% was applied for all cases. This value, while

considerably lower than the 10 to 12% recommended in Reference (2), is much more representative of recent costs incurred in this category and of recent estimates for these services. The reduction in these costs reflects to a large degree the standardization of equipment designs in large nuclear power plants.

Nuclear Engineering

A percentage multiplier of 3% was used for nuclear engineering services allowances. This factor, like the previous one, is somewhat lower than the 3.5 to 4% recommended in Reference (2). The lower value reflects the pre-performance of some of the nuclear engineering services by the reactor manufacturer. Costs for those services would be prorated and added to the direct cost of the nuclear equipment.

Startup Costs

This allowance covers costs of operating and maintaining the reactor during its startup testing period before it goes on line. These costs were estimated in accordance with the ground rules for the hypothetical site, and were modified for other sites on the assumption that labor and materials cost for operation and maintenance vary from site to site in the same manner as the comparable Account 21 construction costs.

Contingency

A contingency factor of 7% was assumed for all cases in the study to allow for unexpected expenses, variance of costs from estimates, and overtime pay. This factor falls considerably below the 10% contingency prescribed in the ground rules. However, contingency allowances specifically identified in several cost estimates published in recent years for actually proposed plants varied from 2.5 to 8.9% of the total capital costs less interest. While it is doubtful that these contingencies were calculated on comparable bases, the trend toward

lower contingencies appears to confirm the use of a 7% rather than 10% factor as a reasonable contingency for construction of late-model nuclear plants.

Interest During Construction

Typically, the capital required to meet plant construction costs is provided by investor-owned utilities partly by sale of interest-bearing revenue bonds and partly through the commitment of equity capital. Interest on the bonds is determined by financial market conditions at the time of sale. Required return on the equity, and the debt/equity structure to be used depend on the circumstances of the individual firm. The net equivalent interest resulting from apportionment of bond interest and equity returns is applied, during the construction period, to the committed capital. Assuming a four-year construction period, interest payments were estimated by the formula

$$\text{Interest} = \frac{rT}{100} (L + 0.45Q),$$

analogous to the estimation of property taxes as discussed previously.

According to a comparison of some 12 published cost estimates for nuclear plants by investor-owned companies, the estimated total interest payments amount to from 6.4 to 12.7% of the total construction costs. If four-year construction periods are assumed for all cases, apparent interest rates of 3.6 to 7.1% result. The smaller apparent interest rates may reflect unusually favorable financing conditions such as partial financing by public agencies. For this study, an interest rate of 6.7% was taken as representative of financing by an investor-owned utility. Applied over a four-year construction period, this rate results in an estimated interest payment equivalent to 12.06% of the total costs incurred during the period.

Cost Escalation Considerations

All cost estimates developed in this study were based on 1967 cost levels and did not include escalation allowance for future construction. Procedures are available⁽²³⁾ for deriving escalated costs for future plant construction.

COST EFFECTS OF HEAT DISSIPATION SYSTEM DESIGN

The facilities required for condensation of exhaust steam from the turbine generators, and dissipation of waste heat to the environment, represent an important factor in the site-to-site variation of plant capital costs. The type, size, and cost of a heat dissipation system for a nuclear power plant are dependent on, among other things, the topography of a specific site; on the quantity and temperature of available cooling water; on regulatory legislation controlling or limiting the addition of heat to bodies of water; and, in the case of evaporative systems, on meteorological conditions at a site.

In addition to affecting the capital cost of a plant, the choice and sizing of a heat dissipation system can have sizeable effects on the operating costs for the plant, the net electrical output capacity, and the plant heat rate. These factors must be considered along with capital costs in selecting and sizing a heat dissipation system, and in determining the total effect of the system on the cost of power generated at the plant.

ONCE-THROUGH COOLING SYSTEMS

Once-through systems for circulating cooling water through the turbine condensers usually entail lower capital and operating costs than do alternate cooling systems. Hence, once-through systems are preferred and are usually employed where sufficient cooling water is available.

For a 1000 MW_e nuclear power plant, once-through circulating water systems will usually be sized to deliver cooling water at rates of 500,000 to 800,000 gal/min with optimum flow rates depending on water conditions and head requirements of the system.

The cost and complexity of once-through systems can vary considerably at different sites because of topographical factors affecting supply and discharge of cooling water and environmental factors affecting the methods by which heated water may be discharged. These variations in cost are caused largely by differences in the length and construction of the circulating-water intake and discharge conduits.

Shoreline-Intake/Discharge

The simplest type of once-through circulating water system, and by far the least expensive, is that in which an intake structure at the shoreline receives water by direct inflow. After appropriate screening, the water is pumped directly to the conduits leading to the condenser inlets and the heated effluent water from the condensers is returned to the source stream via a simple discharge canal. In plants with favorable shoreside locations and short discharge canals, cost for the circulating water system may not be appreciably above the basic costs for the intake structure, pumps and screens, and the required distribution tunnels connecting to the condensers. The low cost and simplicity of systems of this type has led to their use in most nuclear plants and in many fossil-fueled plants constructed to date.

Use of a shoreline-discharge may entail operational disadvantages or undesirable environmental effects. In lakes or slow-moving streams, density effects will cause the heated effluent to form a stratified layer spreading over the water surface. Unless the point of discharge is a considerable distance from the plant intake, some recirculation of the

heated water back through the intake may occur. This recirculation causes increased back pressure in the condenser and reduces generating capacity of the plant. In faster flowing streams, recirculation is less of a problem. However, the heated effluent tends to hug the shoreline for considerable distances downstream before it is dispersed by mixing with the main body of water. In these regions, undesirable biological effects such as heavy growth of algae may occur. These growths, carried downstream by currents, could contribute to pollution of downstream waters. In many streams, potential damage to game or food fish by the heated effluent needs to be considered in design and placement of an outfall.

Deep Water Discharge

In locations where shoreline-discharge of the effluent cooling water is undesirable, use of a deep water outfall may be required to provide an offshore discharge and to promote mixing. Outfalls of this type are normally applicable in the larger rivers, in lakes, or at marine locations. Often the waters receiving the effluent are navigable. Therefore, placement of the outfall line so as not to interfere with navigation is essential. Usually the line is placed in a trench excavated along the bottom and is covered with riprap or with a concrete shroud for protection against damage from current-carried debris, ships' anchors, or similar hazards.

To carry the effluent water from a 1000 MW_e nuclear power plant, an outfall line 12 to 14 ft in diameter would normally be required. The required line size will vary with length of the outfall line and with the available discharge head. Lines can be of steel or concrete.

Where water conditions permit it, trenching and placement of the line near shore is performed within a cofferdam structure. In deeper water, the work is usually done from barges with assistance from skin divers. Because of the

widely varying conditions at different locations the costs of line construction can vary considerably. At favorable locations, costs of around \$300/ft of line may be incurred.

In deeper waters beneath navigation depths, or in locations where bottom formations are hard rock, it may be preferable to omit the trenching and to lay the line directly along the bottom. In such cases the line must be securely anchored and well protected by riprap cover.

Deep Water Intake

In lakeside or marine locations where recirculation of the heated effluent into the plant intake could cause operating problems, advantage may often be taken of the thermal stratification of the effluent by drawing the intake water from lower levels. This may be done by extending a line from the intake structure to the desired intake depth--usually 20 ft or greater depth is specified to assure that no mixing with surface waters occurs at the point of intake. If a deep-water discharge line is also used, the intake point should be separated from the outfall by several hundred feet to avoid possible lateral mixing. The intake line should enter the intake pump structure below normal water levels to permit gravity flow of the water into the screen wells. Because of the low head available, inlet lines may need to be of larger diameter than discharge lines for comparable flows.

Construction considerations and costs for deep-water inlet lines are similar to those for discharge lines.

Marine Lines

Special considerations are required in the case of intake and discharge lines at seaside locations. Marine shoreline areas are usually biologically rich and often support animal or plant life having considerable commercial or recreational value. Marine tidal or wind-driven currents are often weak

and variable, resulting in considerable variation in the size of an effluent plume and in its direction of dispersion. Shallow offshore regions adjoining many shores and zones of turbulent surf further complicate the design and placement of marine lines.

At many locations, of course, favorable currents and noncritical shoreline conditions permit the use of shoreline intake and discharge systems protected by breakwaters, when required. When problems of recirculation or biological effects exist, however, long lines may often be required to avoid the surf zone, to provide adequate plume dispersion, and to provide unheated intake water free of suspended sand or organic matter. For example, at the San Onofre nuclear plant site, the effluent line extends 2600 ft offshore, while the intake line extends some 3200 ft;⁽²⁴⁾ water depths at the intake and outfall points are some 25 to 30 ft. Similarly, at three fossil-fueled plants in the Los Angeles area, intake and discharge lines extend 2000 ft or more from shore, with the intake and discharge points being separated by 300 to 600 ft.⁽²⁵⁾

As with other deep-water lines, the construction cost for marine lines will depend heavily on the bottom composition and the slope away from the shoreline. Ocean tides and wave action also influence their construction costs markedly. The usual construction method in laying a line through a surf zone is to build a trestle extending through the zone and carrying a traveling crane. Excavation of the trench and laying of the line is then performed with the crane. The trestle itself must be of heavy construction to withstand wave action. Depending on bottom conditions, additional breakwater protection may be needed to prevent premature filling of the trench by wave-generated currents. After the pipe is installed and buried, the filled trench must be protected with heavy riprap

or a concrete cap to prevent uncovering of the line by scouring action and possible consequent breakage. Costs for traversing the surf with a large-diameter line may reach or exceed \$1500/ft of line.

In the deeper water beyond the surf zone, less costly construction methods may be used. Excavation and pipe handling can be performed from barges or from mobile floating towers--essentially barges with extendable legs which can form stable working platforms at moderate water depths. Hydraulically actuated frameworks can be used for alignment of pipe sections in deeper water, and divers can be used for underwater work beyond the turbulent surf zone. Construction costs in this region typically are much less than in the surf zone, although costs increase both with line size and with depth of water. Ocean Science and Engineering, Inc., in an appendix to an ORNL conceptual design study,⁽²⁶⁾ estimated deep-water installation costs for pipelines 8 to 10 ft in diameter as a function of depth. The estimates, including trenching and provision of rock cover, are:

<u>Depth</u>	<u>Unit Cost</u>
Up to 100 ft	\$380/ft of pipe length
100 to 300 ft	\$480/ft of pipe length
200 to 300 ft	\$960/ft of pipe length

Table 15 compares the recorded construction costs and descriptive data for several large-diameter marine lines installed along the Pacific Coast. Table 16 lists similar data and cost estimates for marine lines associated with several nuclear power-and-desalination plant concepts reported in the literature. Comparison of costs of the various lines is made difficult by variations in line diameter, length, and terminal depth; by differences in time of construction or of estimating; and undoubtedly by differences in bottom conditions at the various sites. Considerable differences in the

TABLE 15. *Typical Construction Costs for Marine Lines*

Site and Function	No. Lines	Line Diam., ft	Line Length, ft	Terminal Depth, ft	Overall Unit Cost, \$/ft	Surf Zone Cost, \$/ft	Deep Water Cost, \$/ft	Design Capacity, gal/min	Reference
Los Angeles Sanitary Dist. White Point Plant Sewage Outfall	1	7.5	8,000 ^(a)	200 ^(a)	233	~1250	136	167,000	27
Sewage Outfall	1	10	7,440 ^(a)	165 ^(a)	415	~1400	312	257,000	27
City of Los Angeles San. Dept. Hyperion Plant Sewage Outfall	1	12	27,500 ^(a)	195 ^(a)	632		487	417,000	27,28
City of San Diego Sewage Outfall	1	9	11,450 ^(a)	200 ^(a)	553		490	162,500	27
Seattle Metro San. Dist. Sewage Outfall	1	8	3,050 ^(a)	210 ^(a)	270	None ^(b)	270	225,000	27
El Segundo Station (S. Cal. Edison) Circ. Water Inlet Circ. Water Discharge	1 1	10 10	2,600 2,100	30 30	553			143,600	25
Redondo Station (S. Cal. Edison) Circ. Water Inlet Circ. Water Discharge	2 2	10 10	1,700 2,000	30 30	595 ^(c)			323,200	25
Huntington Beach Station (S. Cal. Edison) Circ. Water Inlet Circ. Water Discharge	1 1	14 14	~1/2 mi ~1/2 mi	30 30	872			355,500	25
San Onofre Nuclear Plant Circ. Water Inlet Circ. Water Discharge	1 1	12 12	3,200 2,600	30 25				350,000	24

a. Data for main run of line only; diffuser sections not included.

b. Protected waters; no surf zone.

c. Cost per foot of each of two parallel lines.

TABLE 16. Marine Line Cost Estimates for Nuclear Plant Concepts

	<u>No. Lines</u>	<u>Diameter, ft</u>	<u>Length, ft</u>	<u>Terminal Depth, ft</u>	<u>Estimated Unit Cost, \$/ft</u>	<u>Design Capacity, gal/min</u>	<u>Reference</u>
Nuclear Power/Desalination							
Pelican Point Concept							
Circ. Water Inlet	1	14	3,000	100	1255	{ 530,000 670,000 530,000 670,000 }	14
Circ. Water Inlet	1	16.5	3,000	100			
Circ. Water Discharge	1	14	2,500	~85			
Circ. Water Discharge	1	16.5	2,500	~85			
Alternate Pelican Point Concepts							
Circ. Water Inlet	1	14.75	2,500	70	964	{ 560,000 432,000 }	14
Circ. Water Discharge	1	13.5	2,000	~60			
Circ. Water Inlet	1	15	2,500	70	1000	{ 550,000 550,000 }	14
Circ. Water Discharge	1	15	2,000	~60			
Circ. Water Inlet	2	14.5	2,500	70	865	{ 1,053,000 949,000 }	14
Circ. Water Discharge	2	14	2,000	~60			
Circ. Water Inlet	2	15	2,500	70	907	{ 1,100,000 1,100,000 }	14
Circ. Water Discharge	2	15	2,000	~60			
Circ. Water Inlet	2	18	2,500	70	1218	{ 1,637,000 1,533,000 }	14
Circ. Water Discharge	2	18	2,000	~60			
Israel Power/Desalination Plant							
Circ. Water Inlet	{ 1 1 }	{ ~15 ~15 }	{ 1,650 1,350 }	{ ~20 ~20 }	967	570,000	29
ORNL Desalination Concept							
Circ. Water Inlet	1	24	2,000	~30	1440	{ 496,000 322,000 }	26
Circ. Water/Brine Discharge	1	24	2,500	~30			

relationships between line diameter and flow capacity are also apparent, due to different criteria for optimization. The overall line costs, however, are reasonably consistent and the unit costs (dollars per foot of line) generally increase with increasing line size. Costs for the White Point sewage outfall in Los Angeles illustrate dramatically the difference between surf zone and deep-water construction costs.

For the circulating water flow rates of 500,000 to 800,000 gal/min, which may be required for a 1000 MW_e nuclear plant, marine lines about 14 to 16 ft in diameter would usually be required--although, as was pointed out, relationships between optimum line size and capacity may vary from site to site. Overall unit construction costs for lines of this size range would be expected to be about \$800 to \$1000/ft of line. A value of \$1000/ft was used for cost evaluations in this study, including the terminal structures at the points of intake and discharge. Varying conditions at individual sites would cause considerable variance in this cost, but the \$1000/ft used is considered to be a valid average for "typical" coastal conditions.

EVAPORATIVE COOLING SYSTEMS

At some plant sites the use of once-through condenser cooling may not be feasible. Some sites may be attractive from other considerations but may not have sufficient water supply for once-through cooling. At other sites, water quality standards recently adopted or being adopted by various states may so restrict the addition of heat to bodies of water that once-through cooling cannot be used. In cases such as these it may be desirable to cool the circulating water by evaporation, using cooling ponds or cooling towers.

The use of an evaporative cooling system nearly always entails greater capital costs than for a once-through system. There may also be operating penalties, including both

additional costs of operation and reduction of generating capacity. Esthetic unpleasanties associated with these systems may cause problems in public acceptance in some locations. However, the use of a costlier evaporative system at a site situated favorably with respect to load centers may be economically preferable to the transmission of power from sites which can use once-through cooling but are remote from load centers.

Evaporative cooling towers and cooling ponds may be used in either "open cycle" or "closed cycle" circulating water systems. The open cycle system is essentially a modified once-through system in which the condenser effluent water is passed through a cooling pond or towers to reduce its temperature before it is returned to the body of water from which it was drawn. In the closed cycle system, condenser effluent water is cooled in a pond or towers, and the cooled water is returned to the condenser inlet. Only a small purge or "blowdown" flow is returned to the water body, and only enough makeup water is drawn to replace process losses--primarily through evaporation and through the blowdown flow.

Evaporative cooling is a consumptive use of water: the water evaporated is permanently removed from the lake or stream from which it is supplied. In most states, laws governing water rights must be considered in planning the use of evaporative systems.

Cooling Ponds

At sites where topography is favorable and sufficient land is available at reasonable prices, a cooling pond may be the economic choice as an evaporative cooling system. However, cooling pond installations may require pond surface areas of from about 1500 to 2500 acres--or even larger--to provide suitably low condenser temperatures in a 1000 MW_e nuclear power plant. At specific sites, required pond size will vary

considerably due to differing meteorological conditions. In arid regions, for example, pond size will be smaller for a given specified performance than in humid areas. Pond size and performance may also be varied as a trade-off between capital costs of the pond and generating capability of the plant.

The cooling action of a pond is due primarily to evaporation of water from its surface, although convective heat transfer to air and radiation to space aid to a small extent in cooling. Performance of a pond is therefore sensitive to temperature and humidity of the surrounding air and to wind velocity. Because of the large surface area required for the pond, heat input from solar radiation will be significant and must be considered along with the heat load from the plant in selecting the size of a pond.

At sites having sufficient flat land near the plant, cooling ponds may be constructed economically by erecting earth dikes; at other sites, natural depressions in the land surface may be dammed off to form ponds. At such sites, ponds may be constructed for costs of \$1,000,000 or less. At other sites additional work may be required: extensive clearing and grading may be required to prepare the bed of the pond, baffles may need to be built to assure proper flow patterns and prevent "short-circuiting" of the water from plant discharge to intake, or special treatment of the pond bed may be needed to prevent excessive seepage. Resultant costs can vary over a wide range.

The intake and discharge arrangement for the plant circulating water system in a cooling pond-equipped plant are essentially equivalent to that for a simple once-through system, and costs should be equivalent. In addition, a smaller intake structure, pumps, and supply line must be furnished for make-up water to replace that lost by evaporation, seepage,

and blowdown. The make-up requirements may vary considerably, but will usually range between about 20,000 to 50,000 gal/min unless exceptional seepage problems are encountered. Make-up pipeline costs are usually nominal unless the plant and cooling pond are located a considerable distance from the water source.

Dissipation of the heat from a 1000 MW_e nuclear power plant will result in evaporation rates from the pond surface as high as 30 to 35 ft³/sec, or 14,000 to 16,000 gal/min. (This rate may double during warm summer days due to solar heating of the pond). Severe fogging problems may result during cooler portions of the year. Fog formation may affect plant operations (mainly through ice formation on exposed equipment) and may present a hazard in the area surrounding the site. Fog is also undesirable esthetically, and may cause public acceptance problems at some sites. The avoidance of hazard or nuisance problems from fogging may require the relocation of highways, transmission lines, etc., adding materially to plant capital costs or it may preclude the use of cooling ponds at some sites.

Hyperbolic Natural-Draft Cooling Towers

Towers of this type are characterized by large, hollow, reinforced-concrete shells usually hyperbolic in vertical cross section. These shells serve as chimneys to establish and maintain air circulation through the structure. The actual cooling function occurs in a packed section, some 30 to 50 ft high, at the base of the tower. The packing--various designs use slats, bars, laths, or corrugated sheets--provides an extended surface for air-water contact. In counterflow towers, this packing is suspended within the lower portion of the tower, and air flows upward through the packing. In crossflow towers, the packing is contained in a peripheral structure surrounding the base of the tower; air is drawn horizontally through the packing as it enters the tower. In either type,

water entering the tower is distributed across the top of the packed section and falls through the packing to a reservoir at the base of the tower.

Air entering the tower is warmed and humidified by contact with the water in the packing; its density as it leaves the packed section is thus less than the ambient air outside the tower. The air inside the tower therefore tends to rise, and a draft is created maintaining air circulation through the tower.

Performance of the packing in cooling the water is a function of (1) the flow rate of water through the packing, (2) the temperature change in the water (fixed for a given heat load and water flow rate), (3) the ratio of water flow to air flow (L/G ratio) through the packing, and (4) the wet-bulb temperature of the ambient air. The ability of the tower structure to maintain air flow, depending on the decreased density of the air after it passes through the packing, is affected by both wet-bulb and dry-bulb temperatures (that is, by both temperature and humidity) of the ambient air. An interesting result of this dependency is that natural-draft towers for power plants are more effective in moist climates than in dry ones.

The reduction in air density as it passes through the packing--necessary for maintenance of the draft in the tower--is a result of the evaporation of water (since water vapor is lighter than air) and of increasing the temperature of air. Normally, both mechanisms contribute to the density change as the air passes through the packing.

If the ambient air is moist, it will be both warmed and humidified upon passing through the packing; the entering air is relatively near saturation, and the evaporation necessary for cooling the water can occur only as the temperature of the air is increased. The warm, humid air leaving the packing will

thus have undergone a sufficient decrease in density that a draft will be readily established through the tower. A balance point for steady flow will be reached at which the density difference creates a pressure differential just sufficient to overcome inertial and frictional resistance to air flow.

In a hot, dry climate, on the other hand, tower performance will be reduced even though ambient wet-bulb air temperature may be relatively low. In this case, air entering the tower can readily assimilate water vapor; under adiabatic conditions it would be cooled by water evaporation (as in a "swamp cooler" evaporative air conditioner). Heat transfer from water to air will occur primarily through water evaporation. Although the air leaving the packing will be humidified, its temperature (dry-bulb temperature) may not be much higher than that of the incoming air. The lowering of air density will be less than in the moist air case, and the ability of the tower to establish a draft will be reduced. The use of natural-draft towers under these conditions will usually require the use of taller towers to augment the draft effect, the use of more or larger towers to increase cooling capacity, or operation at higher water temperatures with consequent decrease in generating capability. Because of their reduced performance in dry climates, natural-draft towers are usually not recommended for locations where summertime humidities drop below about 35%.

Cooling tower performance is commonly stated in terms of an approach temperature: the amount by which the cooled water temperature exceeds the wet-bulb temperature of the ambient air at designated design conditions. The magnitude of this approach temperature is dependent, among other things, on the effective surface area provided in the packing. For most applications, the best economy of tower operation is obtained

with a design-point approach temperature around 18 to 25 °F. The approach temperature will change as ambient air conditions change from those at the design point.

Some control of tower water temperatures may be obtained through the use of louvres to regulate air flow or through variation in water flow rates. These means, however, are at best only partially effective in controlling temperature. Water temperature will tend to vary in accordance with changes in atmospheric conditions.

Since the warmer temperatures of summer normally limit the generating capability of a cooling tower equipped power plant, design conditions typical of this period are usually selected. An often used design point is the "5% level" temperature: a wet-bulb temperature, with coincident dry-bulb temperature, which statistically is equaled or exceeded for 5% of the four summer months, or 146 hr per year. Typically this design point is characteristic of summer afternoons and is exceeded for only a few hours per day on hot days. For critical applications more stringent design conditions may be applied: for example, "2 1/2% level" or "1% level" conditions, temperatures which statistically are exceeded 73 and 30 hr/yr, respectively. Weather records have been statistically correlated for many localities in the United States and elsewhere, and temperatures for various levels of design have been derived and published as aids in the design of heating and cooling equipment. These data are available from several sources; typical data are given in References 30, 31 and 32.

The largest cooling towers offered to date by manufacturers are approximately 400 ft in diameter at the base and 400 ft in height (diameter and height vary somewhat among different manufacturers). Two of these towers would be required for service with a 1000 MW_e nuclear power plant. Typical performance curves for such a tower are shown in Figure 1.

FIGURE 1. *Typical Performance Curve
for Crossflow Natural-Draft
Cooling Tower*

Towers of this size may cost from \$3,000,000 to \$3,500,000 each. Substantial foundation costs may also be incurred unless solid bedrock footings are available. Because of the higher condenser temperatures incurred in cooling-tower-equipped systems (as compared with once-through systems), economic balances usually favor additional condenser investment--either in larger condensers, or double-pass, or split-temperature designs. Additional costs for circulating-water conduits will also be incurred. However, hyperbolic towers may be placed close to the plant structures and as little as 100 ft apart, minimizing the piping additions needed.

The total capital cost increment for a cooling tower equipped plant as compared to a once-through plant may range from \$8,000,000 to \$11,000,000 for various site conditions; costs outside this range may occasionally be encountered. Additional operating costs are also incurred when a cooling tower is used. Delivery of the circulating water to the tower packing requires 50 ft or more of unrecoverable pumping head. Once-through plants, by comparison, may require as little as 10 ft effective pumping head if located close enough to water level to permit head recovery by syphon action of the discharge stream. Chemical treatment of the circulating water is required to inhibit algae and fungus growth in the tower packing. In closed-cycle systems, treatment for rust and scale inhibition is required. Chemical costs, which vary with quality of the makeup water, can be a considerable cost factor in hard-water areas. There will also be some loss in generating capability of a tower-equipped site (closed-cycle system) during periods of warm weather. The severity of this loss will depend on climatic conditions at a specific site, and to some extent on the relationship between daily temperature cycles and peak power demand periods.

The large size of hyperbolic cooling towers may cause public acceptance problems based on esthetics at some sites, or may present hazards at locations near airports, etc. In some cases, the chemical content of the blowdown stream from the towers may present disposal problems. The height at which air is discharged from the towers usually does not lead to fogging problems. However, in some cases, fog formation may be induced in an already fog-prone atmosphere. Esthetic and public acceptance factors such as these can affect capital costs, directly or indirectly, at specific sites, and must be considered for sites where evaporative cooling systems may be used.

Mechanical-Draft Cooling Towers

Mechanical-draft towers utilize power-driven fans to circulate air through the tower packing. These towers are classified as forced-draft towers, with fans at the tower inlet, and induced-draft, with fans in the exhaust air stream. In the larger sizes pertinent to power station cooling service, induced-draft towers are almost universally employed when mechanical-draft towers are required. Placement of the fans in the exhaust air stream provides more uniform air flow through the tower packing, and requires somewhat less power for given cooling duty as compared to inlet fans. Induced-draft towers are available in both countercurrent and cross-flow designs.

Induced-draft towers in larger sizes are constructed as a series of individual cells with one fan providing the draft for each cell. Commonly, several cells are joined end-to-end in a single tower structure. Cell size is limited by the size and capacity of the fans. The largest fans commonly furnished are multibladed units about 28 to 32 ft in diameter, driven by 150 hp gear-reduced motors. A typical cell utilizing such a fan may be about 35 by 50 ft in plan section at its base; cells are commonly about 35 to 40 ft high exclusive of fan shrouds.

The number of cells required for an induced-draft cooling tower for a 1000 MW_e power plant will depend on the design-point wet-bulb temperature at a specific site and on the required approach to wet-bulb temperature. The tower size thus depends on an economic balance of plant investment, operating costs, and equivalent costs of generating capacity losses at the site in question. For most cases about 30 to 40 cells would be required. These would be arranged in several tower structures containing from 5 to 10 cells each. Total tower

costs, including basin and foundations, would be \$2.5 million to \$3,500,000. For purposes of this report, a 34-cell tower with a basic cost of \$2,600,000 was assumed at the hypothetical site.

The performance of induced-draft towers, like that of natural-draft towers, depends on water and air flow rates, temperature change in the water, and wet-bulb temperature of the ambient air. However, use of the fan-induced draft eliminates the dependency on dry-bulb air temperatures which is characteristic of natural-draft towers. Furthermore, by varying fan speed or by shutting down one or more cells the air-water flow ratios can be varied, providing more flexibility of operation.

The tower structures must be spaced and located relative to prevailing winds to minimize the likelihood of recirculation of effluent air from one tower into the intake of the next. A typical grouping might cover an area 10 acres or more in extent. Piping to and from the towers will be more extensive than for natural-draft towers which can be situated closer to the condensers.

Consideration of operating costs for induced-draft towers are similar to those for natural-draft towers. However, additional power requirements for fan operation (about 4 MW of power are required for a 34-cell tower) and costs of maintenance of the fan system increase the operating costs for induced-draft towers above those for natural-draft systems of equivalent capacity.

The low profiles of induced-draft towers may be esthetically preferable in many instances to the tall hyperbolic natural-draft towers, despite the large area covered by the former. However, the discharge of effluent air at relatively low heights (around 40 to 50 ft) from the induced draft towers

may produce severe fogging or icing problems during cold weather. The problem of fog formation may preclude the use of these towers at sites near highways, airports, or other facilities which could be adversely affected. Fogging from the towers would also be esthetically undesirable and may lead to problems in public acceptance.

DRY COOLING TOWERS

Cooling towers of the "dry" type maintain the condenser circulating water in a closed piping system; heat is dissipated to the air by sensible heat transfer only. There is no air-water contact in these towers; therefore, they consume no water, emit no visible plumes, and produce no fogging or icing. Towers of this type are potentially of interest in areas where insufficient water supply is available for use of evaporative towers, where the supplying of make-up water would be difficult or expensive, or where fogging problems would make the use of evaporative cooling systems undesirable.

Dry cooling towers may be of either the natural-draft or mechanical-draft types, analogous to the evaporative towers previously discussed. However, since these towers transfer sensible heat only, their performance is determined by atmospheric dry-bulb temperature rather than wet-bulb temperature; these towers are not sensitive to air humidity. Thus, the approach temperature of a dry tower is defined relative to the dry-bulb rather than the wet-bulb temperature. Water temperatures in a dry-tower system will be higher than in an evaporative tower system designed for the same approach temperature. This difference in operating temperatures for equivalent towers will be around 20 °F for design conditions at most sites, but may range to 30 °F in desert areas.

Dry heat transfer also requires considerably more air flow and larger heat transfer surface than evaporative cooling;

hence the cooling towers must be larger for equivalent cooling service. Sizing of a dry tower for lowest total cost usually results in the selection of a higher approach temperature as a trade-off against tower size than in the case of an evaporative tower. This tends to further increase the disparity in water temperatures for the two systems and incurs greater penalties in reduction of generating capability.

On the other hand, since the circulating water in a dry tower is in a closed system, the system can be filled with water of the same quality as that used to generate steam for the turbines. Feedwater and circulating water may then be intermixed, permitting the use of a jet condenser rather than a surface condenser. In a jet condenser, the cooled water from the tower is sprayed directly into the condenser chamber. It condenses steam by contact, eliminating the temperature difference between circulating water and condensing steam and thus offsetting, to some extent, the higher operating temperatures of the dry tower. A jet condenser is also considerably simpler and less costly than a tube-and-shell surface condenser.

Dry cooling towers have gained some acceptance for use in chemical process industries where the temperatures involved are high enough to make them competitive with evaporative towers. They have gained only limited acceptance to date for heat dissipation service with power plants; most applications have been in plants with small rated capacities. The largest dry cooling tower used to date for heat dissipation from a power plant is a hyperbolic natural-draft tower at the 120 MW_e Rugely power station in Staffordshire, England. The Rugely installation illustrates the difference in size requirements between dry and evaporative towers. Designed for a 20 °F approach temperature, this tower has a hyperbolic shell larger

than one of the two evaporative natural-draft towers required to serve a 1000 MW_e nuclear plant, although each of the latter towers operates at about five times the heat load of the Rugely tower.

Generally, cost estimates for dry-tower systems range from three to five times those of evaporative tower systems. The high cost of these systems--some \$30,000,000 or more for a 1000 MW_e nuclear plant--have removed them from consideration for use with large-capacity plants. Since dry-tower systems are not currently competitive as heat dissipation systems for power plants, they were not considered in this study.

In the future, however, continuing increases in power demand and in alternate uses for water could reach the point, at least in some areas, where insufficient water is available for evaporative cooling. This point may be reached soon in arid regions of the Southwest. There is, therefore, incentive for development efforts to improve performance and lower capital costs of dry cooling towers, to thus make their use more attractive for heat disposal systems.

SITE COST EVALUATIONS: HEAT DISSIPATION SYSTEMS

Estimated costs for deep-discharge systems and for evaporative systems utilizing natural-draft and induced-draft cooling towers were estimated for the various sites in the study as cost increments over the costs for a reference shoreline-discharge plant. For the estimates involving cooling towers, costs of additional site preparation work required for the towers were added to Account 21 (plant structures and improvement) costs. All other incremental costs were added to Account 23 (turbine-generator equipment) costs. However, the cost difference between sites due to differences in labor wage rates and materials prices were estimated for all cases using the cost indexes developed for Account 21 costs; the work

involved more nearly resembles the general construction work in that account than the more equipment-oriented work characteristic of the other plant cost accounts.

Cost estimates were not made for plants using cooling ponds or dry cooling towers. In the case of cooling ponds, sufficient data on the region surrounding the site were not available to permit making meaningful estimates on construction of ponds of about 2000 acres. In the case of Maine Yankee, Connecticut Yankee, Malibu, and San Onofre, sufficient level ground does not appear to be available. At Hanford, highly permeable soil may require lining of a pond to minimize seepage. At the remaining sites, land costs alone may range from \$1,000,000 to over \$2,000,000, assuming the requisite level land to be available. Detailed studies would be needed at those sites to determine the feasibility of cooling ponds and their costs relative to cooling towers.

As was noted earlier, the technology of large dry cooling towers is not well developed at present, and apparent costs of systems using these towers are too high to warrant consideration of their use.

Deep-Water Discharge System Costs

The added direct costs, above those for a shoreline-discharge plant, for construction of deep-discharge systems at the sites considered in the study ranged from \$820,000 to about \$12,000,000. The costs estimated for plants using these systems are summarized in Table 17.

Plants at Turkey Point and Oyster Creek would require the highest cost for deep-water discharge systems of any of the sites considered. These plants are similarly located on the landward side of bays opening into the Atlantic Ocean--Biscayne Bay in Florida and Barnegat Bay in New Jersey, respectively. The entrances to both bays are nearly closed

TABLE 17. *Estimated Costs of Plants
Using Deep Discharge Systems*

Site	Direct Costs, \$ Thousands		Total Capital Costs, \$ Thousands	
	Increment ^(a)	Net Costs	Increment ^(a)	Net Costs
Hypothetical	(b)	---	---	---
Turkey Point	11,810	120,246	16,389	169,661
Maine Yankee	1,057	106,503	1,467	150,184
Connecticut Yankee	(b)	---	---	---
Nine Mile Point	1,129	106,766	1,567	151,082
Oyster Creek	10,125	118,034	13,970	166,613
Dresden	(b)	---	---	---
Hanford	819	109,502	1,135	154,513
Malibu	5,122	117,537	7,107	175,730
San Onofre	7,305	122,363	10,137	172,541

a. *Incremental cost above shoreline-discharge plant costs*

b. *Deep discharge systems not estimated for these sites*

by sandbars or reefs. In either case, it is assumed that in order to avoid undesirable thermal effects it would be necessary to extend the discharge lines across the bay and place the outfall offshore in the open sea.

At Turkey Point, a line length of some 42,000 ft would be required to reach open water; added direct costs due to this line would be about \$11,800,000. At the Oyster Creek site, a line or canal some 10,000 ft in length would be required to reach from the plant site to the bay shore; another 30,000 ft of line would be needed to extend across Barnegat Bay to open water. About \$10,100,000 are estimated to be added to direct costs by the added discharge facilities. At both sites a shoreline-intake is assumed, unchanged from the reference case. At both sites the discharge lines will run either underground on land or beneath protected waters for nearly their entire runs.

At the Maine Yankee site, a line extending about 4000 ft downstream in the Back River is assumed to be required to minimize water recirculation during flood tides. Costs of this line are estimated at about \$1,000,000. A shoreline-intake is assumed. The estimated cost includes a credit of \$55,000 for deletion of a diversion dam required for a shoreline-discharge system but not needed with the deep-water outfall line.

At this site a shorter discharge line than that estimated may be acceptable if a deep-water intake is provided to avoid recirculation. A detailed analysis of the two systems would be needed to determine which provides the requisite cooling ability at lowest cost.

At Nine Mile Point, water intake and discharge for the existing 525 MW_e plant are accomplished using concrete-lined tunnels extended through sandstone bedrock beneath the bed of Lake Ontario. At this site both intake and discharge lines were assumed to be required for a 1000 MW_e plant. These lines, about 1100 ft in length, would be laid in trenches in the bedrock at an estimated cost of about \$1,100,000. Since the original plant used tunnels rather than pipe, they may be preferred for the large plant as well. More detailed analysis would again be required for a choice of designs, but costs would not be expected to be greatly different for either system.

A plant at the Hanford site would require the least expenditure for outfall lines of any site considered in the study. At this site, a line extending some 1800 ft into the Columbia River would increase direct costs by an estimated \$819,000.

Plants at Malibu and San Onofre are both located on the open seacoast, and require both intake and outfall lines extending through surf to deep water. The existing San Onofre

plant has an intake line 3200 ft in length and a discharge line extending 2600 ft. A 1000 MW_e plant was assumed to have lines of equal length, to reach water of comparable depth. At Malibu, a steeper slope away from shore is expected to shorten the required line lengths; a 2500 ft intake line and 2000 ft discharge line were assumed. Added direct costs at Malibu were estimated at \$5,100,000 and at San Onofre, \$7,300,000.

Deep-water discharge systems were not estimated for the hypothetical site or for plants at the Connecticut Yankee or Dresden sites. These sites are situated on comparatively small rivers; appreciable fractions of the total river flow (perhaps 5 to 20%) would be circulated through the plant condensers in a once-through system. It is doubtful that the use of deep-water outfalls would be applicable at these sites. If they were provided, costs would be considerably below those estimated for the Hanford site.

Natural-Draft Cooling Towers

Cost estimates for the use of recirculating systems employing hyperbolic natural-draft towers, assembled from estimates by consultants and vendors' equipment estimates, were verified by comparison with a study of cooling tower requirements at the 525 MW_e Vermont Yankee plant.⁽³³⁾ The use of natural-draft towers in a once-through system was not considered in this study.

The construction of a natural-draft cooling tower system at the hypothetical site would result in an increase in direct costs of about \$7,000,000 above the costs of a shoreline-discharge reference plant; the total capital costs would be increased by about \$9,700,000. A breakdown of the estimate of incremental direct costs is given in Table 18. In addition to the basic cooling tower costs at this site of about \$6,000,000, the substitution of double-pass condensers for the single-pass units used in the once-through plant is estimated to add about

TABLE 18. *Incremental Direct Costs*
for Natural-Draft Tower System
at Hypothetical Site*

Item	Estimated Incremental Costs, \$ Thousands*				
	Labor	Materials	Equipment	Shipping	Total
Account 21:					
Site Preparation:					
10 Acres Additional	<u>8</u>				<u>8</u>
Total Account 21:	<u>8</u>				<u>8</u>
Account 23:					
Cooling Tower, with basins and foundations	3,330	2,626			5,956
Double Pass Condenser	143		1,065	40	1,248
Lines and Conduits	111	87			198
Structures	-143	-185			-328
Pumps, Screens, etc.	<u>1</u>		<u>90</u>		<u>91</u>
Total Account 23:	<u>3,442</u>	<u>2,528</u>	<u>1,155</u>	<u>40</u>	<u>7,165</u>
Total Incremental Direct Costs	3,450	2,528	1,155	40	7,173

* *Estimated increment of direct costs above costs for shoreline-discharge plant.*

\$1,250,000 to direct costs of the plant. Added circulating water lines increase costs by about \$200,000; increased pumping head requirements and the addition of make-up pumps add about \$90,000; and \$8,000 is estimated to be needed for site preparation work, readying an additional 10 acres on which the towers are constructed. Reduction in size of the river intake structure, and relocation of the main circulating water pumps to a simpler structure within the plant building complex, effect a cost reduction estimated at \$328,000 for these structures.

The corresponding cost increments involved in the application of natural-draft cooling towers at each of the sites included in the study are summarized in Table 19. At each site the incremental cost listed for Account 21 is the estimated cost for preparation of an additional 10 acres at the plant

site (assuming two 400 ft diameter towers on 500 ft centers). Site preparation costs become appreciable only at the Turkey Point, Malibu, and San Onofre sites. At the Maine Yankee site, the deletion of a diversion dam--which is required only for a shoreline-discharge plant--results in a net reduction of \$31,000 in site preparation costs. Cooling towers at the Malibu and San Onofre sites were assumed to operate on salt water; at all other sites fresh water operation was assumed.

TABLE 19. *Estimated Costs of Plants Using Natural-Draft Cooling Towers
(Costs in thousands of dollars)*

Site	Direct Construction Costs				Total Capital Costs	
	Account 21 Increment*	Account 23 Increment*	Total Increment*	Total Direct Costs	Increment*	Total
Hypothetical	8	7,165	7,173	112,974	9,952	159,557
Turkey Point	300	6,971	7,271	115,707	10,090	163,362
Maine Yankee	-31	6,321	6,290	111,736	8,728	157,445
Connecticut Yankee	10	7,637	7,647	114,137	10,612	161,456
Nine Mile Point	6	7,547	7,553	113,190	10,482	159,997
Oyster Creek	6	7,483	7,489	115,398	10,393	163,036
Dresden	6	7,591	7,597	113,612	10,543	160,396
Hanford	6	7,507	7,513	116,378	10,426	164,056
Malibu	1,400	8,111	9,511	121,926	13,199	181,822
San Onofre	1,200	8,560	9,760	124,818	13,544	175,948

* Estimated increment above costs for shoreline-discharge plant at the same site.

The increment in direct construction costs at each site, above costs for a shoreline-discharge plant, varied from \$6,100,000 at the Maine Yankee site to \$9,600,000 at San Onofre. Only the Malibu and San Onofre sites had increments in excess of about \$7,500,000. Corresponding increments in total capital costs ranged from \$8,500,000 to \$13,300,000. Again, only at the two California sites did the increment exceed \$10.5 million.

It should be noted that the dry summertime climates at Hanford, Malibu, and San Onofre would probably reduce the effectiveness of natural-draft towers so seriously that their

use would not be considered at those sites. More detailed analysis at each site would include the optimization of equipment size by balancing capital costs against operating costs, taking local weather conditions into consideration. At some sites, savings in site preparation and excavation costs may be realized by situating the plant higher above water levels than would be feasible for a once-through plant. Such savings would also enter into the optimization. Although no such optimization was included in this study, the equipment selected for each site is believed to be reasonably close to optimum.

Induced-Draft Cooling Towers

Cost estimates for plants using induced-draft cooling towers, like those for natural-draft tower equipped plants, were assembled from consultants' estimates and vendors' estimated costs, and were compared with Vermont Yankee estimates published in Reference 32. Again, only recirculating (closed) tower systems were considered.

The estimated cost increment, above a shoreline-discharge plant, for a plant equipped with induced-draft towers (at the hypothetical site) is indicated in Table 20. The estimated basic cost for these towers, assuming a 34-cell tower complex with basins and foundations, is about \$2.6 million at this site. The cost increments for condensers and the savings in intake structures are assumed to be the same for these towers as for natural-draft towers. Costs for pumps are reduced slightly--\$87,000 compared to \$91,000 estimated for the natural-draft tower--reflecting the somewhat lower head requirements with the induced-draft tower. However, the spacing required between cell groupings, to avoid air recirculation, results in a higher cost for intake and discharge lines. The estimated cost increment for these lines is \$350,000 compared to about \$200,000 line costs using natural-draft towers.

TABLE 20. *Incremental Direct Costs*
for Induced-Draft Tower System
at Hypothetical Site*

Item	Estimated Incremental Costs, \$ thousands*				
	Labor	Materials	Equipment	Shipping	Total
Account 21:					
Site Preparation:					
10 Acres Additional	8				8
Total Account 21:	8				8
Account 23:					
Cooling Tower, with basins and foundations	1,016	1,444	160		2,620
Double Pass Condenser	143		1,065	42	1,250
Lines and Conduits	196	154			350
Structures	-143	-185			-328
Pumps, Screens, etc.	1		86		87
Total Account 23:	1,213	1,413	1,311	42	3,979
Total Incremental Direct Cost	1,221	1,413	1,311	42	3,987

* *Estimated increment of direct costs above costs for shoreline-discharge plant.*

In estimating the costs of induced-draft tower installation at the various sites in the study, estimates were first made of the relative cooling area (referenced to the towers at the hypothetical site) which would be required at each site to cool the circulating water to the same temperature at all sites, based on published values for prevailing summer weather at or near each site.^(31,32) Costs for the basic tower were assumed to vary in direct proportion to these required areas. These adjusted costs were then modified by applying the appropriate labor and materials cost indexes for each site.

Towers at the various sites would, under the above assumptions, be composed of 30 cells (at the three Pacific

area sites) to 40 cells (at Turkey Point). Actual tower costs would rise in discrete steps as cells were added. However, the assumed linear variation is believed to approximate more closely the combined cost variations for towers and condensers which would result from system optimization at each site.

At all sites a 10 acre plot of ground was assumed to be required to accommodate the induced-draft towers. Site preparation costs for the towers at each site were thus assumed to be the same as for the natural-draft towers. At some sites, local topography and prevailing wind conditions would dictate the orientation and spacing of induced-draft towers. Combined with the varying number of cells required, these factors may result in required areas larger than the assumed 10 acres at some sites. The resulting effects on site preparation costs, however, would be negligible except, perhaps, at the California sites. Tower spacing requirements due to wind conditions, moreover, are likely to have greater effect on area requirements than are variations in the number of cells. Since spacing requirements were not evaluated because of lack of sufficiently detailed data, the assumption of constant area requirement is believed satisfactory for purposes of this study.

Costs estimated for the installation of plants equipped with induced-draft towers at each of the sites considered are summarized in Table 21. The incremental direct construction costs for these plants, above the costs for shoreline-discharge plants at the same sites, range from \$3.26 million to \$4.38 million except at the two California sites. Here high costs of site preparation boost the increments to about \$5.6 million.

As is the case with plants using natural-draft towers, more detailed studies including optimization of capital and operating costs would be expected to result in some variance

TABLE 21. *Estimated Costs of Plants Using Induced-Draft Cooling Towers (Costs in thousands of dollars)*

Site	Assumed No. of Tower Cells	Direct Construction Costs			Total Capital Costs	
		Account 21 Increment*	Account 23 Increment*	Total Increment*	Total Direct Costs	Total Increment*
Hypothetical	34	8	3,979	3,987	109,788	5,457
Turkey Point	40	300	4,081	4,381	112,817	6,081
Maine Yankee	33	-31	3,295	3,264	108,710	4,528
Connecticut Yankee	36	10	4,233	4,243	110,733	5,889
Nine Mile Point	34	6	4,052	4,058	109,695	5,631
Oyster Creek	38	6	4,151	4,157	112,066	5,769
Dresden	36	6	4,204	4,210	110,255	5,843
Hanford	30	6	3,872	3,878	112,561	5,381
Malibu	30	1,400	4,183	5,583	117,998	7,749
San Onofre	30	1,200	4,355	5,555	120,613	7,708

* Estimated increment above costs for shoreline-discharge plant at the same site.

of these capital costs. However, the assumed equipment sizing is believed to result in reasonably near-optimum costs for the sites considered.

Comparison of the estimates for induced-draft and natural-draft tower installations indicates a substantially lower capital investment to be required for the former. However, as was previously pointed out, the lower capital costs of these towers are offset by higher operating costs--mainly the costs of operating, maintaining, and replacing the fans, motors, and drive trains utilized in induced-draft towers, including power costs for the fan driven motors.

As discussed earlier, some reduction in efficiency, relative to that of a once-through plant, is likely to occur when either type of tower is used. Site-to-site variations in efficiency will differ somewhat for natural-draft and induced-draft towers. As a result, a fairly rigorous comparison of tower operating characteristics and costs is often required to make an economic choice between the two types.

Summary of Heat Rejection System Cost Effects

The estimated costs developed in this study for plants utilizing various heat dissipation schemes at each site are grouped for comparison in Table 22. This comparison clearly shows the cost advantages of once-through, shoreline-discharge systems at any site where conditions permit their use.

TABLE 22. *1000 MW_e Plant Cost Summary for Different Heat Rejection System Designs (Costs in thousands of dollars)*

Site	Once-Through System Costs		Evaporative System Costs	
	Shoreline Discharge	Deep-Water Discharge	Natural-Draft Towers	Induced-Draft Towers
Hypothetical				
Direct Costs	105,801	--	112,974	109,788
Total Costs	149,605	--	159,557	155,062
Turkey Point				
Direct Costs	108,436	120,246	115,707	112,817
Total Costs	153,272	169,661	163,362	159,353
Maine Yankee				
Direct Costs	105,446	106,503	111,736	108,710
Total Costs	148,717	150,184	157,445	153,245
Connecticut Yankee				
Direct Costs	106,490	--	114,137	110,733
Total Costs	150,844	--	161,456	156,733
Nine Mile Point				
Direct Costs	105,637	106,766	113,190	109,695
Total Costs	149,515	151,082	159,997	155,146
Oyster Creek				
Direct Costs	107,909	118,034	115,398	112,066
Total Costs	152,643	166,613	163,036	158,412
Dresden				
Direct Costs	106,015	--	113,612	110,225
Total Costs	149,853	--	160,396	155,696
Hanford				
Direct Costs	108,683	109,502	116,378	112,561
Total Costs	153,378	154,513	164,056	158,759
Malibu				
Direct Costs	112,415	117,537	121,926	117,998
Total Costs	168,623	175,730	181,822	176,372
San Onofre				
Direct Costs	115,058	122,363	124,818	120,613
Total Costs	162,404	172,541	175,948	170,112

The greatest site-to-site cost variance was exhibited by the deep-water discharge systems; incremental capital costs for these systems above shoreline-discharge system costs ranged from slightly over \$1 million at Hanford to over \$16 million at Turkey Point. At three of the marine sites included in the study, the capital costs for deep-water discharge systems exceeded those for induced-draft cooling tower systems; at two of these sites they exceeded the indicated costs for natural-draft tower systems as well. However, comparisons of operating costs as well as capital costs would be needed to determine the most economic system at each site.

At the remaining sites the costs of cooling tower-equipped systems are clearly higher than those of once-through systems. The use of cooling towers, then, is usually economic only at sites possessing inadequate water supplies for once-through cooling, where high site preparation costs are involved in establishing the plant sufficiently near water level to avoid excessive pumping costs, or where restrictions on heated discharges preclude once-through operation or place undesirable restrictions on plant power levels and periods of operation. In these cases, power costs from a tower-equipped plant may well be competitive with those from a once-through plant.

Future increases in power demand throughout the United States are expected to result in more and more intensive use of available cooling water supplies. Coupled with the nationwide promulgation of water quality standards which limit discharge of heat into natural waters, this is expected to result in increasing utilization of cooling towers or ponds for heat dissipation from future power plants.

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APPENDIX

FIGURE A-1. Assumed Configuration
for Natural-Draft
Cooling Towers

FIGURE A-2. Assumed Configuration for 34-Cell Induced-Draft Cooling Tower

TABLE A-1. Site Labor Cost Indexes
for Account 21--Structures
and Improvements

Assumed Crew		Hypothetical ^(c)		Turkey Point		Maine Yankee		Conn. Yankee		Nine Mile Point		Oyster Creek		Dresden		Hanford		
Craft	No.	Craft Rate ^(a)	Crew Rate ^(b)	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate
Bricklayer	2	5.60	11.20	4.62	9.24	5.60	11.20	5.90	11.80	5.15	10.30	5.95	11.90	5.70	11.40	6.91	13.82	5.3
Bricklayer Helper	2	4.02	8.04	2.85	5.70	3.05	6.10	4.29	8.58	4.03	8.06	3.60	7.20	4.50	9.00	4.45	8.90	4.5
Carpenter	102	4.96	505.92	4.46	454.92	4.20	428.40	5.12	522.24	5.10	520.20	5.70	581.40	5.50	561.00	5.64	575.28	5.8
Cement Finisher	12	5.60	67.10	4.62	55.44	5.60	67.20	5.90	70.80	5.15	61.80	5.95	71.40	5.26	63.12	5.64	67.68	6.3
Electrician	8	5.40	43.20	5.04	40.32	5.59	44.72	5.55	44.40	5.41	43.28	5.61	44.88	5.80	46.40	6.53	52.24	6.1
Operating Engr.	14	4.85	67.90	4.95	69.30	5.46	76.44	5.40 ^(d)	75.60 ^(d)	5.63	78.82	9.13	127.82	5.55	77.70	6.12	85.68	6.1
Ironworker	40	6.26	250.40	5.77	230.80	5.87	234.80	5.83	233.20	5.95	238.00	6.15	246.00	5.90	236.00	6.62	264.80	6.3
Laborer	49	3.75	183.76	2.85	139.65	3.05	149.45	4.29	210.21	3.84	190.12	3.60	176.40	4.30	210.70	4.30	210.70	4.9
Painter	9	4.58	41.22	4.55	40.95	2.90	26.10	4.84	43.56	4.88	43.92	5.23	47.07	4.90	44.10	5.53	49.77	5.8
Plumber	24	6.21	149.04	5.53	132.72	5.95	142.80	6.26	150.24	5.45	130.80	7.15	171.60	5.82	139.68	7.53	180.72	6.9
Sheet Metal Wkr.	33	5.40	178.20	5.41	178.53	5.15	169.75	5.83	192.39	6.51	214.83	6.55	216.15	5.48	180.84	6.96	229.68	6.5
Total Crew	295		1506.08		1357.57		1357.16		1563.02		1540.13		1701.82		1579.94		1739.27	
Average Rate		5.11		4.60		4.60		5.30		5.22		5.77		5.36		5.90		5.8
Payroll Burden 10%		0.51		0.46		0.46		0.53		0.52		0.58		0.54		0.59		0.5
		5.62		5.06		5.06		5.83		5.74		6.35		5.90		6.49		6.3
Overhead & Profit 32%		1.80		1.62		1.62		1.87		1.84		2.03		1.89		2.08		2.0
Developed Rate		7.42		6.68		6.68		7.70		7.58		8.38		7.79		8.57		8.3
Labor Cost Index		1.000		0.900		0.900		1.033		1.022		1.129		1.050		1.155		1.1

(a) Hourly wage rate, including benefits and travel pay.
(b) Extended hourly wage rate for indicated crew size.
(c) Hypothetical site wage rates based on rates at Springfield, Mass.; 20 miles travel assumed.
(d) Estimated rate; actual wage rate not available.

TABLE A-1. Site Labor Cost Indexes
for Account 21--Structures
and Improvements

Hypothetical ^(c)		Turkey Point		Maine Yankee		Conn. Yankee		Nine Mile Point		Oyster Creek		Dresden		Hanford		Malibu		San Onofre	
Craft Rate ^(a)	Crew Rate ^(b)	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate	Craft Rate	Crew Rate
.60	11.20	4.62	9.24	5.60	11.20	5.90	11.80	5.15	10.30	5.95	11.90	5.70	11.40	6.91	13.82	5.30	10.60	6.91	13.82
.02	8.04	2.85	5.70	3.05	6.10	4.29	8.58	4.03	8.06	3.60	7.20	4.50	9.00	4.45	8.90	4.54	9.08	5.21	10.42
.96	505.92	4.46	454.92	4.20	428.40	5.12	522.24	5.10	520.20	5.70	581.40	5.50	561.00	5.64	575.28	5.80	591.60	6.28	640.56
.60	67.10	4.62	55.44	5.60	67.20	5.90	70.80	5.15	61.80	5.95	71.40	5.26	63.12	5.64	67.68	6.39	76.68	6.14	73.68
.40	43.20	5.04	40.32	5.59	44.72	5.55	44.40	5.41	43.28	5.61	44.88	5.80	46.40	6.53	52.24	6.16	49.28	7.30	58.40
.85	67.90	4.95	69.30	5.46	76.44	5.40 ^(d)	75.60 ^(d)	5.63	78.82	9.13	127.82	5.55	77.70	6.12	85.68	6.16	86.24	7.22	101.08
.26	250.40	5.77	230.80	5.87	234.80	5.83	233.20	5.95	238.00	6.15	246.00	5.90	236.00	6.62	264.80	6.37	254.80	7.31	292.40
.75	183.76	2.85	139.65	3.05	149.45	4.29	210.21	3.84	190.12	3.60	176.40	4.30	210.70	4.30	210.70	4.54	222.46	5.21	255.29
.58	41.22	4.55	40.95	2.90	26.10	4.84	43.56	4.88	43.92	5.23	47.07	4.90	44.10	5.53	49.77	5.81	52.29	6.55	58.95
.21	149.04	5.53	132.72	5.95	142.80	6.26	150.24	5.45	130.80	7.15	171.60	5.82	139.68	7.53	180.72	6.93	166.32	7.99	191.76
.40	178.20	5.41	178.53	5.15	169.75	5.83	192.39	6.51	214.83	6.55	216.15	5.48	180.84	6.96	229.68	6.56	216.48	7.19	237.27
	1506.08		1357.57		1357.16		1563.02		1540.13		1701.82		1579.94		1739.27		1735.83		1933.63
.11		4.60		4.60		5.30		5.22		5.77		5.36		5.90		5.88		6.55	
.51		0.46		0.46		0.53		0.52		0.58		0.54		0.59		0.59		0.66	
.62		5.06		5.06		5.83		5.74		6.35		5.90		6.49		6.47		7.21	
.80		1.62		1.62		1.87		1.84		2.03		1.89		2.08		2.07		2.31	
.42		6.68		6.68		7.70		7.58		8.38		7.79		8.57		8.54		9.52	
.000		0.900		0.900		1.033		1.022		1.129		1.050		1.155		1.151		1.283	

ing benefits and travel pay.
e for indicated crew size.
ates based on rates at Springfield, Mass.; 20 miles travel assumed.
age rate not available.

TABLE A-2. *Site Labor Cost Indexes for Account 22--Reactor Plant Equipment (Assumed Crew Composition: 70% Pipefitter, 30% Ironworker)*

Site	Wage Rate, \$/hr ^(a)			Payroll Burden (10%)	Overhead, Profit (32%)	Developed Rate	Labor Cost Index
	Pipefitter	Iron Worker	Weighted				
Hypothetical ^(b)	6.21	6.26	6.23	0.62	2.19	9.04	1.000
Turkey Point	5.53	5.77	5.60	0.56	1.97	8.13	0.899
Maine Yankee	5.95	5.87	5.93	0.59	2.09	8.61	0.952
Connecticut Yankee	6.26	5.83	6.13	0.61	2.16	8.90	0.985
Nine Mile Point	5.45	5.95	5.60	0.56	1.97	8.13	0.899
Oyster Creek	7.15	6.15	6.85	0.69	2.41	9.95	1.101
Dresden	5.82	5.90	5.84	0.58	2.05	8.47	0.937
Hanford	7.53	6.62	7.26	0.73	2.56	10.55	1.167
Malibu	6.93	6.37	6.76	0.68	2.38	9.82	1.086
San Onofre	7.99	7.31	7.79	0.78	2.74	11.31	1.251

a. Hourly wage rate, including benefits and travel pay.

b. Hypothetical site wage rates based on rates at Springfield, Mass.; 20 miles travel assumed.

TABLE A-3. *Site Labor Cost Indexes for Account 23^(a)--Turbine Generator Plant Equipment (Assumed Crew Composition: 40% Pipefitter, 40% Ironworker, 20% Electrician)*

Site	Wage Rate, \$/hr ^(b)				Payroll Burden (10%)	Overhead, Profit (32%)	Developed Rate	Labor Cost Index
	Pipeftr.	Ironwkr.	Electr.	Weighted				
Hypothetical ^(c)	6.21	6.26	5.40	6.07	0.61	2.14	8.82	1.000
Turkey Point	5.53	5.77	5.04	5.53	0.55	1.95	8.03	0.910
Maine Yankee	5.95	5.87	5.59	5.85	0.59	2.06	8.50	0.964
Connecticut Yankee	6.26	5.83	5.55	5.95	0.60	2.10	8.65	0.981
Nine Mile Point	5.45	5.95	5.41	5.64	0.56	1.98	8.18	0.927
Oyster Creek	7.15	6.15	5.61	6.44	0.64	2.27	9.35	1.060
Dresden	5.82	5.90	5.80	5.85	0.59	2.06	8.50	0.964
Hanford	7.53	6.62	6.53	6.97	0.70	2.45	10.12	1.147
Malibu	6.93	6.37	6.16	6.55	0.66	2.31	9.52	1.079
San Onofre	7.99	7.31	7.30	7.58	0.76	2.67	11.01	1.248

a. Shoreline-discharge plants only. Additional costs for other heat rejection systems calculated using Account 21 indexes.

b. Hourly wage rate, including benefits and travel pay.

c. Hypothetical site wage rates based on rates at Springfield, Mass.; 20 miles travel assumed.

TABLE A-4. *Site Labor Cost Indexes for Account 24--Accessory Electrical Equipment (Assumed Crew Composition: 100% Electrician)*

Site	Wage Rate ^(a)	Payroll Burden (10%)	Overhead, Profit (32%)	Developed Rate	Labor Cost Index
Hypothetical ^(b)	5.40	0.54	1.90	7.84	1.000
Turkey Point	5.04	0.50	1.77	7.31	0.932
Maine Yankee	5.59	0.56	1.97	8.12	1.036
Connecticut	5.55	0.56	1.96	8.07	1.029
Nine Mile Point	5.41	0.54	1.90	7.85	1.001
Oyster Creek	5.61	0.56	1.97	8.14	1.038
Dresden	5.80	0.58	2.04	8.42	1.074
Hanford	6.53	0.65	2.30	9.48	1.209
Malibu	6.16	0.62	2.17	8.95	1.142
San Onofre	7.30	0.73	2.57	10.60	1.352

a. Hourly wage rate, including benefits and travel pay.

b. Hypothetical site wage rates based on rates at Springfield, Mass.; 20 miles travel assumed.

TABLE A-5. *Site Labor Cost Indexes for Account 25--Miscellaneous Power Plant Equipment (Assumed Crew Composition: 50% Pipefitter, 50% Ironworker)*

Site	Wage Rates, \$/hr ^(a)			Payroll Burden (10%)	Overhead, Profit (32%)	Developed Rate	Labor Cost Index
	Pipefitter	Iron Worker	Weighted				
Hypothetical ^(b)	6.21	6.26	6.24	0.62	2.20	9.06	1.000
Turkey Point	5.53	5.77	5.65	0.57	1.99	8.21	0.906
Maine Yankee	5.95	5.87	5.91	0.59	2.08	8.58	0.947
Connecticut Yankee	6.26	5.83	6.05	0.61	2.13	8.79	0.970
Nine Mile Point	5.45	5.95	5.70	0.57	2.01	8.28	0.914
Oyster Creek	7.15	6.15	6.65	0.67	2.34	9.66	1.066
Dresden	5.82	5.90	5.86	0.59	2.06	8.51	0.939
Hanford	7.53	6.62	7.08	0.71	2.49	10.28	1.135
Malibu	6.93	6.37	6.65	0.67	2.34	9.66	1.066
San Onofre	7.99	7.31	7.65	0.77	2.69	11.11	1.226

a. Hourly wage rate, including benefits and travel pay.

b. Hypothetical site wage rates based on rates at Springfield, Mass.; 20 miles travel assumed.

TABLE A-6. *Site Materials Cost Indexes
for Accounts 21 Through 25*

Site	Closest "ENR" Index City	Account 21		Accounts 22-25 ^(a)	
		"ENR" ^(b) Index	Study Index	"ENR" ^(c) Index	Study Index
Hypothetical	Boston	107	1.00	93	1.00
Turkey Point	Atlanta	111	1.04	110	1.183
Maine Yankee	Boston	107	1.00	93	1.00
Connecticut Yankee	Boston	107	1.00	93	1.00
Nine Mile Point	Cleveland	112	1.05	98	1.054
Oyster Creek	Philadelphia	93	0.87	97	1.043
Dresden	Chicago	119	1.112	89	0.957
Hanford	Seattle	106	0.99	101	1.086
Malibu	Los Angeles	106	0.99	107	1.151
San Onofre	Los Angeles	106	0.99	107	1.151

- a. *Additional Account 23 (turbine-generator plant equipment) costs above shoreline-discharge plant costs, for plants using alternate heat rejection system designs, were calculated using materials cost index for Account 21.*
- b. *"Big 3" index (concrete, steel, timber), Reference (6).*
- c. *Structural steel index, Reference (6).*

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