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ADVANCED DESIGN NUCLEAR POWER PLANTS: COMPETITIVE, ECONOMICAL ELECTRICITY

An Analysis of the Cost of Electricity From Coal, Gas and Nuclear Power Plants

ENERGY ANALYSIS

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USCEA

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ACKNOWLEDGEMENT

This analysis was conducted by the U.S. Council for Energy Awareness (USCEA) technical staff. The capital and operating and maintenance costs for the fossil fueled alternatives were developed for USCEA by the Integrated Energy Systems Division of the Electric Power Research Institute (EPRI). The capital cost estimates for the advanced-design standardized nuclear plants were provided by United Engineers & Constructors, Inc. (UE&C) under a contract jointly funded by EPRI and USCEA. In addition, UE&C functioned as a technical coordinator, actively assisting USCEA in the preparation of this study. Operating and maintenance costs for the nuclear plants were provided by the Nuclear Power Division of EPRI.

The specific input assumptions for the advanced design-standardized nuclear power plants were also reviewed and accepted by the EPRI Advanced Light Water Reactor Utility Steering Committee.

The methodology, data and assumptions were developed in conjunction with, and subsequently reviewed by, an expert panel assembled by USCEA for its experience with cost estimation and financial issues. This panel reviewed drafts and the final study, and their comments are reflected in this paper.

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EXECUTIVE SUMMARY

This report presents an updated analysis of the projected cost of electricity from new baseload power plants beginning operation around the year 2000. Included in the study are: 1) advanced-design, standardized nuclear power plants, 2) low emissions coal-fired power plants, 3) gasified coal-fired power plants, and 4) natural gas-fired power plants.

This analysis shows that electricity from advanced-design, standardized nuclear power plants will be economically competitive with all other baseload electric generating system alternatives. This does not mean that any one source of electric power is always preferable to another. Rather, what this analysis indicates is that, *as utilities and others begin planning for future baseload power plants, advanced-design nuclear plants should be considered an economically viable option to be included in their detailed studies of alternatives.*

Even with aggressive and successful conservation, efficiency and demand-side management programs, some new baseload electric supply will be needed during the 1990s and into the future. The baseload generating plants required in the 1990s are currently being designed and constructed. For those required shortly after 2000, the planning and alternatives assessment process must start now. It takes up to ten years to plan, design, license and construct a new coal-fired or nuclear fueled baseload electric generating plant and about six years for a natural gas-fired plant.

This study indicates that for 600-megawatt blocks of capacity, advanced-design nuclear plants could supply electricity at an average of 4.5 cents per kilowatt-hour versus 4.8 cents per kilowatt-hour for an advanced pulverized-coal plant, 5.0 cents per kilowatt-hour for a gasified-coal combined cycle plant, and 4.3 cents per kilowatt-hour for a gas-fired combined cycle combustion turbine plant.

Likewise, the study found that for 1200-megawatt blocks of capacity, advanced-design nuclear plants could supply electricity for between 3.8 cents (single, large nuclear plant) and 4.1 cents per kilowatt-hour (two mid-size nuclear plants) versus 4.6 cents per kilowatt-hour for an advanced pulverized-coal plant, 4.8 cents per kilowatt-hour for the gasified-coal combined cycle plant, and 4.2 cents per kilowatt-hour for the gas-fired combined cycle combustion turbine plant.

All of the projected costs are 30-year average generating costs presented in non-inflated, constant January 1992 dollars.

This study's findings are derived from today's knowledge of Advanced Light Water Reactor technology designs. Because uncertainties inherently exist with regard to future cost projections, particularly when dealing with new technologies, a series of sensitivity analyses for various key assumptions are included in this study.

The results of the study continue to support conclusions reached in USCEA's January 1991 assessment of the comparative economics of advanced-design nuclear power plants and their alternatives (Ref. 1). Specifically:

- Nuclear power plants built and operated under stable regulatory conditions are among the least-cost ways to meet future baseload electricity needs.

- Sensitivity analyses indicate that even when less favorable assumptions are made regarding key elements such as plant performance, operating and maintenance costs or capital-related expenses, advanced-design nuclear plants remain cost competitive with other baseload alternatives.

- New nuclear plants will use standardized, pre-approved designs to help provide investment protection for plant owners. With this approach, the significant regulatory issues affecting plant design and engineering will be settled before construction and large capital outlays begin. The use of this new licensing process assures effective review of such issues before construction, but prevents inappropriate re-review of the same issues before operation. Such a process prevents inappropriate lengthening of the construction period, and thus provides greater assurance on the final cost for the power plant.

- In addition to progress achieved in licensing reform, electric utilities must have reasonable assurance that they will be able to recover their investment in new baseload capacity, nuclear or otherwise.

- Cost and performance uncertainties exist for all types of power plants. Nuclear energy has certain financial uncertainties. But other fuels also carry uncertainties, for example -- fluctuating fuel prices or changing environmental requirements. For both 600 and 1200 megawatts of capacity, the advanced-design nuclear plants maintain competitiveness with their fossil-fuel alternatives, considering a range of basic input assumptions.

INTRODUCTION

The *Strategic Plan for Building New Nuclear Power Plants* (Ref. 2) issued by the Nuclear Power Oversight Committee in November 1990 identified the actions required to achieve orders for new advanced-design nuclear power plants. Consistent with this Strategic Plan, several advanced-design standardized nuclear plants are being developed in a cooperative program involving the electric utility industry, nuclear equipment suppliers, and the U.S. Department of Energy.

These advanced designs include "evolutionary" improvements on today's large (1200-1300-megawatt) light water reactors and mid-sized (600-megawatt) advanced light water reactors with additional passive (or "natural") safety features. These advanced-design nuclear plant initiatives are being guided by design and performance requirements established through the Electric Power Research Institute (EPRI) (Ref. 3). To provide utilities with a range of available nuclear capacity, advanced designs are being developed for both 600-megawatt and 1200-1300-megawatt plants. This will allow utilities to accommodate their particular electric demand growth projections, ownership relationships, fuel diversity requirements, nuclear plant operating experience, and other economic factors.

Both the passive plants and the evolutionary plants will include all of the lessons-learned from the design and generation of today's nuclear plants in their initial design - making the new advanced-design plants even safer than today's plants. The new plants will also incorporate advances in technology - like the use of fiber optics for instrumentation and control systems. Advances in the design of how the nuclear fuel is consumed will improve the efficiency and cost of operating the plants. For both types of advanced designs, improvements in construction through the use of modular construction techniques will help control capital costs and shorten the construction schedule for the plants. For the mid-size plants, the selective substitution of natural or "passive" systems in place of some pumps and motors should even further simplify construction, operations and maintenance.

Currently, there are four standardized designs -- two for the larger-sized plants and two for the mid-sized plants. The two designs for the larger-sized plants are currently being reviewed by the Nuclear Regulatory Commission (NRC). Both of the designs for the mid-sized plants are scheduled to be submitted to the NRC for review by the summer of 1992. The first of the "evolutionary" designs should be certified by the NRC in late 1993, the second by late 1994; and the two remaining mid-sized plant designs should be certified by mid-1995. In addition to the progress on design certification, many of the other conditions necessary to support the use of advanced-design nuclear plants exist:

- A clear need exists for new baseload electric generation in the early part of the next decade. This need exists even after considering aggressive demand-side management and efficiency initiatives, which will decrease, but not eliminate, the need for new baseload power plants (Ref. 4).

- Increasing concern about the environment, coupled with growing awareness that nuclear power plants do not emit greenhouse gases or other pollutants into the atmosphere.

- Broad public recognition that nuclear energy should play an important role in satisfying our future energy needs (Ref. 5).

- An extensive set of "Utility Requirements" established by the likely purchasers of the next nuclear power plants - electric utilities. These requirements, including technical, safety, performance, and economic characteristics, have been developed with extensive electric utility involvement through EPRI (Ref. 3).

- A broad-based program, involving the federal government, the utility industry and the nuclear equipment suppliers, to complete the design and engineering requirements on several advanced-design plants, beyond that necessary to secure NRC certification (Ref. 6).

- Recognition that without a continued and expanded use of nuclear energy to produce electricity, the gains made in decreasing the use of oil in this sector of the economy could be lost.

- An improved process for licensing the next nuclear plants, supported by an NRC rulemaking issued in April 1989, and by energy legislation being considered in Congress.

- Support for nuclear power from leading congressional figures in both parties and strong support for it in the Executive Branch.

- Recognition that there is an acceptable and achievable technical solution for the long-term disposal of nuclear waste, and progress toward resolving the institutional obstacles to siting and building both a monitored retrievable storage facility and a permanent geological repository.

But even with these and other factors working in their favor, advanced design nuclear power plants must be able to compete economically with alternative electric generating plant systems. The results of this study indicate that they are capable of competing economically with the viable alternatives.

DISCUSSION OF RESULTS AND ASSUMPTIONS

This analysis compares electricity costs from nuclear, coal, and gas-fired baseload electric generating plants beginning service in 2000.

Capital and production costs for the advanced design standardized nuclear plants are calculated under the assumption that the following critera, identified in the Nuclear Power Oversight Committee's Strategic Plan, are met:

1) The final certified nuclear plant designs will be basically the same as the standardized designs submitted to the Nuclear Regulatory Commission (NRC) by the responsible nuclear equipment suppliers.

2) The revised NRC licensing process, while providing effective and ample opportunity for public participation, will not allow a plant constructed consistent with its license to be subjected to pre-operational hearings and prevented from operating unless new and significant safety issues are found to exist.

3) The stable and predictable regulatory process imposed on the operation of new standardized advanced-design nuclear power plants will also be greatly simplified, acknowledging the inherent benefits of standardization. This simplified regulatory process will allow significant productivity improvements in the operation of the new nuclear plants.

In general, capital cost-intensive projects, such as nuclear and coal-fired electric generating plants, are more expensive in the early years of operation than fuel cost-intensive, gas-fired plants. As the capital cost depreciates, nuclear and coal plants can produce electricity at a cost advantage over gas-fired electricity, due to their lower production costs. In this study, the cost comparisons are being made on the basis of the average levelized cost of electricity over a period of 30 years. The 30-year period is based on the typical time frame over which plant equipment is depreciated for accounting purposes. This period is generally used for studies of alternative generating plants.

Because the advanced-design standardized nuclear plants comprise units of both 600-megawatt (mid-size passive plants) and 1200-megawatt (evolutionary design) plants, this analysis compares the nuclear plants to coal and gas-fired alternatives of approximately the same size. All costs are presented in non-inflated January 1992 dollars. The basis for the selection of the methodology used in this study is discussed in Appendix 1.

Figure 1 presents the results of the analysis for the 600-megawatt advanced-design standardized nuclear plant and the alternative fossil-fuel plants. As shown, the 30-year average cost of electricity for a single 600-megawatt nuclear unit is 4.5 cents per kilowatt-hour (kwh). This estimated cost is competitive with the estimates for the coal and gas-fired alternatives. The estimated nuclear electricity cost is between 7 and 10 percent less than the electricity cost from pulverized-coal or gasified-coal plants, and within 5 percent of the cost of electricity from a gas-fired combined-cycle combustion turbine plant.

Figure 1 also shows that two 600-megawatt advanced-design standardized nuclear plants are even more competitive with the fossil-fired alternatives than the single unit was. The average cost of electricity from the two 600-megawatt units is 4.1 cents/kwh as compared to 4.6 cents/kwh for the pulverized-coal plant, 4.8 cents/kwh for the gasified-coal plant and 4.2 cents/kwh for the gas-fired plant. The approximate 10 percent reduction in electricity cost for the two-unit nuclear plant versus the one-unit plant is primarily a result of economies achieved through construction and operation of multiple units at the same site (commonly referred to as benefits of replication). It should be noted that such benefits are also derived by the fossil-fired alternatives and have been included in their cost estimates.

Figure 2 presents the results of the analysis for the advanced-design standardized 1200-megawatt nuclear power plant and its alternatives. The estimated cost of electricity from the 1200-megawatt nuclear plant (3.8 cents/kwh) is again very competitive with the alternatives. The larger size nuclear plant can produce electricity for approximately 20 percent less than the cost of electricity from comparable pulverized-coal or gasified-coal plants, and about 10 percent less than the cost of electricity from a gas-fired combined cycle combustion turbine plant. Furthermore, *Figure 2* again shows the benefits of replication in that two 1200-megawatt nuclear units at the same site would produce electricity at 3.5 cents/kwh, or about 10 percent less than from one 1200-megawatt plant.

The results presented in *Figures 1 and 2* indicate that with either 600 megawatts or 1200 megawatts of capacity, the nuclear plants are competitive with their fossil-fired alternatives. In this regard, as electric utilities and others assess the need for future baseload alternatives, advanced-design standardized nuclear plants represent an alternative that should be included in their studies.

Figures 3 and 4 present the basic performance and cost assumptions used in the assessments of the mid-size (600-megawatt) nuclear plant and the large-size (1200-megawatt) nuclear plant, respectively.

Figure 5 identifies the financial assumptions used in the study. It should be noted that no risk premium, in addition to the average cost of capital, is included in this study's base-case assumptions for the nuclear plants. It is believed that under a favorable regulatory environment, and given their high performance and operation standards, Advanced Light Water Reactors should not be treated differently than alternative large power plant projects. However, an assessment of the impact of a risk premium on generation costs has been included in the sensitivity analyses (*Figure 21 and 22).*

Appendix 2 compares the basic inputs used in this study with those used in USCEA's January 1991 study (Ref. 1).

The following sections of this chapter discuss the key assumptions contained in *Figures 3 and 4*. The next chapter contains sensitivity analyses for a number of the key assumptions.

Capital Costs

The initial capital costs are based on construction costs in 1992 dollars. The construction cost includes parts, materials, equipment, services, and labor to design and build the plant. Additional sums are added for contingencies and owners costs to yield the total overnight capital costs (construction costs before financial charges). These costs are shown in *Figures 3 and 4*.

The overnight capital cost accrues "real" (inflation-free) interest charges of 6.2 percent per year during construction to yield completed capital costs as shown in *Figure 6*.

The overnight capital cost estimates for the pulverized-coal, gasified-coal and gas-fired plants were provided by the Integrated Energy Systems Division of the Electric Power Research Institute (EPRI). This division of EPRI has responsibility for developing economic assessments of alternative generating technologies, and is responsible for maintaining EPRI's "Technical Assessment Guide" (Ref. 7). The overnight capital cost estimates for the advanced-design standardized nuclear plants were provided by United Engineers and Constructors (UE&C) under a contract jointly funded by EPRI and the U.S. Council for Energy Awareness. The development of the construction costs used in this analysis conform with generally accepted practices used by experts in the field -- including EPRI, Oak Ridge National Laboratory, UE&C, and the Energy Information Administration of the Department of Energy.

In all cases, the capital costs are reflective of an "Nth of a kind" plant, not the first-of-a-kind plant. The "Nth-of-a-kind" nuclear plant included in the analysis can be considered to be the third to sixth plant built within each of the standardized designs. These costs do not include certain initial (i.e. first-of-a-kind) costs that might be incurred as part of the completion of initial engineering and design, or other one-time expenditures that could then be employed with future standardized plants to support construction and start-up activities.

The electricity costs presented are figured on a "real" (non-inflated) cost basis to compare the various supply options. Only charges above the underlying inflation rate are applied. The numbers presented in *Figure 6* should not be directly compared to the completed capital cost expenditures for nuclear and fossil-fired plants operating today. This is particularly true for the nuclear plants because of the major difference between the construction of pre-approved standardized plants as compared to plants that were being built in the late '70s and '80s. High capital costs for those plants reflected the climate in which they were built: very high inflation and interest rates; tremendous regulatory changes imposed during construction, which required major rework; and steady increases in the time for construction and receipt of an operating license -- from five to six years in the early 1970s to about 14 years in the 1980s.

This analysis assumes success in creating a stable regulatory climate in which the utility industry builds advanced-design, standardized, pre-approved plants -- plants that are licensed up-front for construction and operation, so all significant regulatory issues are settled before construction and large capital outlays begin. Under these conditions, significantly shortened construction time periods, a stable design basis and associated plant capital cost are achievable.

Interim Replacement Cost

In calculating the 30-year generating cost for the nuclear plants an allowance is made for a significant capital expenditure for equipment replacement. The cost was calculated assuming a major equipment replacement 25 years after the plant began operation. This charge was assumed to be $75 million for the 600-megawatt plant and $85 million for the 1200-megawatt plant. These costs would add $28 per kilowatt for the 600-megawatt plant and $16 per kilowatt for the 1200-megawatt plant to the overnight costs shown on *Figures 3 and 4,* respectively. In addition to these costs, the operating and maintenance expenses (see following discussion) include the costs for routine replacement of parts and equipment over the life of the plant. No comparable costs for major equipment replacement have been included for either the coal or gas-fired power plants.

The interim replacement cost does not include backfitting or retrofitting costs required to meet changes in safety or environmental requirements. Many of the current nuclear power plants underwent costly design modifications required after operation began. The lessons learned from these design changes are being incorporated into the design of the next generation of nuclear power plants. Furthermore, the standardized nuclear plants included in this analysis will have an NRC certified design and should not experience major plant-specific design changes during construction or operation. Likewise, while the coal and gas-fired plants represent the expected clean-burning technologies that will be available for operation around the year 2000, the analysis does not include potential costs for backfitting additional pollution control equipment if new requirements are imposed to restrict toxic pollutants, nitrogen oxides or carbon dioxide emissions.

Operating and Maintenance Costs

The operating and maintenance (O&M) costs used in this study for both the nuclear and fossil-fired plants were developed by the Electric Power Research Institute (EPRI).

The nuclear plant O&M inputs are based on EPRI assessments of the staffing requirements, outage frequencies and durations, and routine equipment and parts replacements required to operate the new advanced-design nuclear plants. The numbers also reflect the expectation that improvements and simplification of the regulatory process will allow utilities to achieve significant productivity improvements in the future operation of nuclear plants. Furthermore, it is important to recognize that the O&M costs for the advanced-design nuclear plants are derived from a bottoms-up analysis, not by extrapolating from the costs for operating the existing nuclear plants.

The new nuclear plants are designed for greater ease in operation and periodic maintenance. Increased use of automated monitoring and instrument control will reduce the operator's work and increase plant reliability. Fewer parts and simpler designs will require less replacement work, and improved layout of work spaces will facilitate and expedite maintenance. As part of the EPRI Advanced Light Water Reactor program, detailed evaluations of how to minimize outage duration, inspections and surveillances are all contributing to controlling O&M costs.

In addition to the above examples, standardization itself has a very positive impact on O&M costs. For example, procedures and training programs can be simplified, optimized and prepared in advance for an entire plant series. Maintenance planning and implementation can occur more effectively, and spare parts inventories can be more efficiently managed. The combination of the way the new plants are designed to consciously and deliberately reduce O&M costs - coupled with the inherent benefits of standardization to both utility operations and regulatory simplification - make it inappropriate to just extrapolate costs from today's plants to the new plants. Conversely, since the O&M cost estimates provided in this study are for standardized advanced-design nuclear plants, and not for the plants operating today, the cost estimates contained in this study cannot be directly projected to today's operating plants.

It can be noted, however, that some existing plants in the 600-megawatt size range are already operating with O&M costs as projected by EPRI for the passive advanced-design plant. This performance, while not directly applicable, reinforces the likelihood that the newer, simpler plants can operate with low O&M costs. Appendix 3 contains additional information on the EPRI estimates for staffing requirements for the advanced-design nuclear plants.

The O&M costs for the coal and gas-fired plants were provided by the Integrated Energy Systems Division of EPRI based on their assessments of the technologies. These plants will satisfy all currently applicable Clean Air Act requirements for sulfur dioxide, particulates and nitrogen oxide emissions. In addition, an operating cost associated with the price of sulfur dioxide emission allowances has been included in the analysis for the coal-fired plants. The cost was based on an assumed emissions allowance price of $500 per ton. Sulfur dioxide emission rates of 3.8 pounds per megawatt-hour for the pulverized-coal plant (95 percent removal efficiency) and 0.7 pound per megawatt-hour for the gasified-coal plant (99 percent removal efficiency) were used. The coal was assumed to be high sulfur (4 percent) Illinois No. 6 coal.

Fuel Costs

Fuel costs are an important part of this analysis. The fuel cost assumptions in this study utilize actual national average 1991 fuel costs and escalate them to the start of commercial operation and then over the 30-year period of the analysis.

The basis for all fuel costs is the projections made by the Energy Information Administration (EIA) to support the National Energy Strategy (Ref. 8). This source was selected because it represented the only authoritative source that made consistent fuel cost projections for all of the fuels considered out to the year 2030, the period covered by this analysis. While many other responsible organizations have projected the cost for coal, gas and nuclear fuel, in general the projections stop in the year 2010.

The starting point for the coal and gas costs was the actual cost for these fuels in 1991, as determined by EIA. Expressed in January 1992 dollars, these costs were $30.40 per ton for coal, and $2.20 per thousand cubic feet (MCF) for gas. The actual 1991 cost for nuclear fuel was not yet available from EIA, so the actual cost from 1990 was used as the starting point. The nuclear fuel cost used, in January 1992 dollars, is 70 cents per million Btu. Given that the cost for both natural uranium and enriched uranium decreased during 1991, it is likely that the use of the 1990 actual fuel cost is somewhat conservative.

With the starting costs established, the EIA projections through the year 2030 for the real, above inflation, increases in fuel costs were used in the analysis (see *Figures 3 and 4*).

In this analysis, the nuclear fuel costs do not increase above the general inflation rate. This assumption slightly biases the analysis against nuclear energy, since the EIA expects future nuclear fuel costs to decline in real terms. The nuclear fuel cost includes the current fee of one-tenth of a cent per kilowatt-hour collected for the Nuclear Waste Fund.

It should be noted that, as stated earlier, the new advanced-design nuclear power plants will be more fuel efficient than the current plants. This improved efficiency is estimated to result in about a 14 percent reduction in fuel costs. The base-case analyses in this study have not taken credit for the improved fuel efficiency of the nuclear plants. If the expected improvements in nuclear fuel efficiency were included in the analysis, it would reduce the electric generating cost by about 0.1 cent per kilowatt-hour for all of the nuclear plant capacities studied.

Based on the EIA projections, coal costs will rise annually at approximately 1.2 percent above inflation from 1992 through 2030. In arriving at the 1.2 percent value, a straight line average between 1990 and 2030 was used. In reality, the EIA projections have a number of different rates of real cost increases over the 40-year period. The use of the straight line average will yield a slightly lower estimated cost of electricity from the pulverized-coal and gasified-coal fired plants than if the individual yearly rates of real cost increase over the 40-year period were modeled in the analysis.

For the natural gas-fired plant, the fuel cost was projected to escalate at approximately 3.5 percent per year. Again, this value represents a straight line average of the EIA projections for the real escalation rate between the years 1990 and 2030. The EIA gas price projections show a relatively rapid rate of real escalation between the years 1990 and 2000 (7.7 percent), with a much smaller rate of increase out to 2030. Since the cost of electricity for the gas-fired plant is particularly sensitive to the cost of the fuel, and since a steeper growth rate in fuel costs during the early years of a present worth analysis can significantly impact the results, the use of the 3.5 percent per year increase value in the base-case analysis yields a conservative, or low, estimate of the cost of electricity from the gas-fired plant. The sensitivity analysis in the next chapter includes the estimated gas-fired electricity costs for the actual (non-average) real gas cost escalation as projected by EIA.

Decommissioning

Decommissioning costs are assumed to be \$165 million and \$265 million in 1992 dollars for the 600-megawatt and 1200-megawatt nuclear plants, respectively. The cost assumptions are adopted from an EPRI/NRC decommissioning study (Ref. 9) and correspond with current industry decommissioning cost projections (Ref. 10). For the nuclear plants, charges collected in electricity rates by utilities for this purpose are generally invested in state and municipal bonds in an external sinking fund and gradually accumulate over 30 years of plant operation to the required level.

While the assumed decommissioning costs for the nuclear plants represent reasonable projections given the existing experience and projected costs, some uncertainty does exist. In this regard, *Figure 7* shows the impact on nuclear electricity costs of increases in the cost of decommissioning. As evident, while decommissioning costs are an important component of the total cost for a nuclear plant, even a tripling of this cost would only marginally affect the 30-year average cost of electricity from the nuclear plants.

Some decommissioning costs would be incurred for the coal and gas-fired power plants. However, it is unlikely that the magnitude of the costs would significantly affect the estimated 30-year average electric generating cost. Therefore, no decommissioning costs for the fossil-fired plants have been included in this analysis.

Plant Descriptions

Size: The nuclear plants analyzed in this study were one and two 600-megawatt plants and one and two 1200-megawatt plants. ALWR capital cost estimates consider existing UE&C studies (Ref. 11, 12 and 13), as well as the specific deliberations of the expert panel and UE&C's on-going evaluations of these designs. The comparable estimates for the 600-megawatt and 1200-megawatt coal and gas-fired plants were provided by EPRI based upon multiple unit sites closely approximating the desired 600 and 1200-megawatts of capacity. In the case of the pulverized coal plants, the plant sizes used were one and two 600-megawatt units. For both the gasified-coal plant and the combined-cycle combustion turbine gas-fired plant, the actual sizes used were 500 megawatts and 1000 megawatts comprised of 250-megawatt units.

Construction Time: Consistent with the Utility Requirements Document (Ref. 3), the analysis uses a five-year construction period (through start of commercial operations) for the 600-megawatt nuclear plant, and a six-year period for the 1200-megawatt nuclear plant. These durations are shown in more detail in *Figure 8.* These construction periods are considered feasible for a standardized, pre-approved, design with the modified licensing process.

Construction time for the smaller size pulverized-coal and gasified-coal plants is 3.5 years. For the larger size plants the construction time is four years. The construction times for the gas-fired combined-cycle combustion turbine are two and three years, for the small and large-size plants, respectively. These construction periods were provided by EPRI and are consistent with the EPRI Technical Assessment Guide.

Plant Life: The cost estimates are based on 30 years of operation. This is a typical time period for economic comparisons of electricity supply systems. The advanced-design standardized nuclear plants are being designed for a 60-year life. If a longer service life were used in the analysis, it would decrease the cost of electricity from the nuclear plant, and to a lesser extent from the coal-fired plants. Essentially, as the period over which the initial capital cost is amortized gets longer, plants with higher initial costs derive greater benefit.

Capital and operation costs used in this study were normalized to the standard EPRI East/West Central site conditions. Regional assessments should first be converted to the standard EPRI site conditions for equal basis cost comparison purposes.

Operating Characteristics

Capacity Factor: Each plant - nuclear, coal, natural gas - is assumed to operate at an 80 percent capacity factor. Capacity factor is the ratio of the amount of kilowatt-hours produced by a generating plant to what could have been produced by the plant if the plant had operated continuously at its maximum kilowatt-hour production rate.

The Utility Requirements Document (Ref. 3) specifies an 80 percent capacity factor for future ALWRs.

As the existing 110 nuclear power plants have modified the time between refueling outages from 12 months to between 18 and 24 months (which is more representative of the advanced-design nuclear plants), the capacity factors for these plants have been increasing. The increase in capacity factors for the existing plants also reflects other operational and maintenance program improvements. While the advanced-design nuclear plants are being specifically designed to achieve higher capacity factors, about one-third of all U.S. nuclear energy plants achieved a capacity factor of 80 percent or better in 1991.

Heat Rate: Assumptions about heat rates (number of Btu input required for one kilowatt-hour output) in this analysis were provided by EPRI based on better performing, currently available, fossil technologies. The values used in the study were: mid-size nuclear 10,400 Btu/kwh, large nuclear 10,200 Btu/kwh, pulverized-coal 9,700 Btu/kwh, gasified-coal 8,950 Btu/kwh, and gas-fired combined-cycle 7,514 Btu/kwh, all are based on high heating values.

SENSITIVITY ANALYSIS: RESULTS WITH DIFFERENT ASSUMPTIONS

Figures 9 and 10 display the major cost contributors driving the estimated generation costs for the nuclear and fossil-fired alternatives evaluated in this study. As is apparent from these figures, the basic differences in cost structure among today's traditional fuel types still exist for the next generation of plants: nuclear options are typically capital intensive, coal plants are both capital and fuel intensive, while the gas alternative is primarily fuel intensive.

USCEA has conducted a number of sensitivity analyses to gauge the cost impact of changing the critical input parameters from the base-case assumptions. These sensitivity analyses include various assumptions for capacity factor, fuel price escalation, initial capital cost, operating and maintenance costs, construction time, and the impact of a nuclear plant financing premium.

The sensitivity analyses have been prepared in the form of a series of curves for each of the above items. These curves provide the reader with the ability to assess the change in electricity cost for specific operating plant alternatives, and for each of the specific parameters analyzed.

Capacity Factor

Figures 11 and 12 present the results of the sensitivity analyses for the impact of capacity factor changes on the 600-megawatt and 1200-megawatt plants, respectively. In the base case, an 80 percent capacity factor was used for all of the generating alternatives.

As shown in *Figure 11*, the cost of electricity from the 600-megawatt nuclear plant would be very competitive with the cost of electricity from the coal-fired plant, even if the nuclear plant capacity factor dropped to 75 percent, while the coal plant remained at 80 percent. This figure also shows the impact of capacity factor changes on the cost of electricity from two replicate 600-megawatt nuclear units.

Figure 12 indicates that the larger size nuclear plant would remain competitive with all of the alternatives, including the gas-fired plant, at a nuclear plant capacity factor as low as 70 percent with its alternatives operating at the base-case level of 80 percent.

Fuel Price Escalation

Of the three primary fuel types (i.e., nuclear, gas and coal) assessed in this study, the cost of electricity from the gas-fired combined cycle combustion turbine plant is by far the most sensitive to changes in the cost of fuel. As shown in *Figures 13 and 14*, small changes in the projected real escalation rate for the cost of gas results in relatively large changes in the cost of electricity produced by the gas plant. These figures also show that the cost of electricity from the nuclear plant is relatively insensitive to changes in the cost of the fuel. The electricity costs from the pulverized and gasified coal plants are somewhat more sensitive than the nuclear plant to changes in the cost of fuel, but still significantly less so than the gas-fired plant.

The base case for the 600-megawatt capacity plants found the gas plant to produce electricity at about 0.2 cent/kwh less than the advanced-design standardized nuclear plant, assuming a real gas cost escalation rate of 3.5 percent a year. From *Figure 13* it can be seen that an increase of less than half a percentage point over the base-case fuel cost escalation rates would raise the cost of electricity from the gas plant to that of the nuclear plant. Furthermore, a one percent increase would result in the cost of electricity from the gas plant exceeding the cost of electricity from the nuclear plant by about 0.5 cent/kwh. This figure also shows the impact of changes in the real escalation rate of nuclear fuel on the two 600-megawatt plants.

Figure 14 shows that, assuming all other base-case assumptions did not change, the nuclear plant would hold its cost advantage over the other alternatives, even with significant (2 percent per year or more) increases in the real escalation rate for nuclear fuel.

As indicated in the discussion of the base-case analyses, this study used a straight line average value of 3.5 percent per year for real escalation of gas prices. If the actual EIA projections of real price escalation between the years 1990 and 2000, and then 2000 to 2030, were used, the estimated cost of electricity for both the smaller and larger gas-fired plants would be 5.7 cents/kwh. This cost would significantly exceed the base-case electricity costs from the 600- and 1200-megawatt nuclear plants, which were 4.5 cents/kwh and 3.8 cents/kwh, respectively.

Capital Cost

Nuclear and, to a lesser degree, coal-fired electric plant costs are capital-intensive. Therefore, deviation from the base-case capital cost assumptions would produce the most marked total cost changes for the nuclear plant, followed by the coal and gas plants.

Figures 15 and 16 show the impact of changes in the capital costs on the final cost of electricity from the 600- and 1200-megawatt plants, respectively. As indicated in *Figure 15*, with a 10 percent increase in capital cost, the mid-size advanced-design nuclear plant would still produce electricity at or below the cost of the base-case pulverized-coal plant. It would take approximately a 20 percent increase in the capital cost of the mid-sized nuclear plant for its cost of electricity to approach that of the base-case gasified-coal plant. *Figure 15* also shows the impact of changes in the capital cost on the electricity cost for two 600-megawatt nuclear units.

At 1200 megawatts of capacity, *Figure 16* indicates that it would require about a 20 percent increase in the capital cost of the large evolutionary nuclear plant for the cost of its electricity to equal the cost of electricity from the base-case gas-fired plant. It would take greater than a 30 percent increase in the capital cost of the nuclear plant for its cost of electricity to approach that of the base-case pulverized-coal plant. Figure 16 also includes a sensitivity curve for changes in the capital cost of a two-unit evolutionary plant (two 1200-megawatt). This curve is offered as an example of how the cost of electricity for replicate evolutionary size plants is affected by changes to the capital cost.

Construction Time

Figures 17 and 18 present sensitivity analyses for changes in the time period for construction. It is apparent from these figures that only minor changes (approximately 0.1 cent/kwh) would result from a one- to two-year change in the construction schedules for any of the plants.

These analyses were prepared with the following conditions: For shorter construction times, the commercial operation year remained at 2000 and the project start year was shifted to allow for varying construction lengths. For the longer construction time case, the project start year was moved back to 1995 and the commercial operation year was held at 2000 with the exception of the nuclear plant. For this case, the nuclear plant's commercial operation year is pushed forward past the year 2000 to allow for the assumed construction period without requiring actual construction to begin prior to 1995.

This analysis is not equivalent to a delay in commercial operation after completion of the plant. It is understood that extended delays in commercial operation of a plant after construction is completed could significantly increase the capital cost of the plant and the cost of electricity produced by the plant. However, the revised nuclear licensing process, assumed as a prerequisite in this analysis, is intended to eliminate such post-construction delays for nuclear units. Therefore, a scenario that assumes delayed operation of a completed plant was not considered in this study.

Operating and Maintenance Costs

The impact of up to a 15 percent change in operating and maintenance costs on the cost of electricity from the 600- and 1200-megawatt alternative fueled power plants is presented in *Figures 19 and 20,* respectively. As indicated by the curves on these figures, even with a 15 percent increase in the base-case operating and maintenance costs for the nuclear plants, they still maintain cost competitiveness with the other generating plant alternatives.

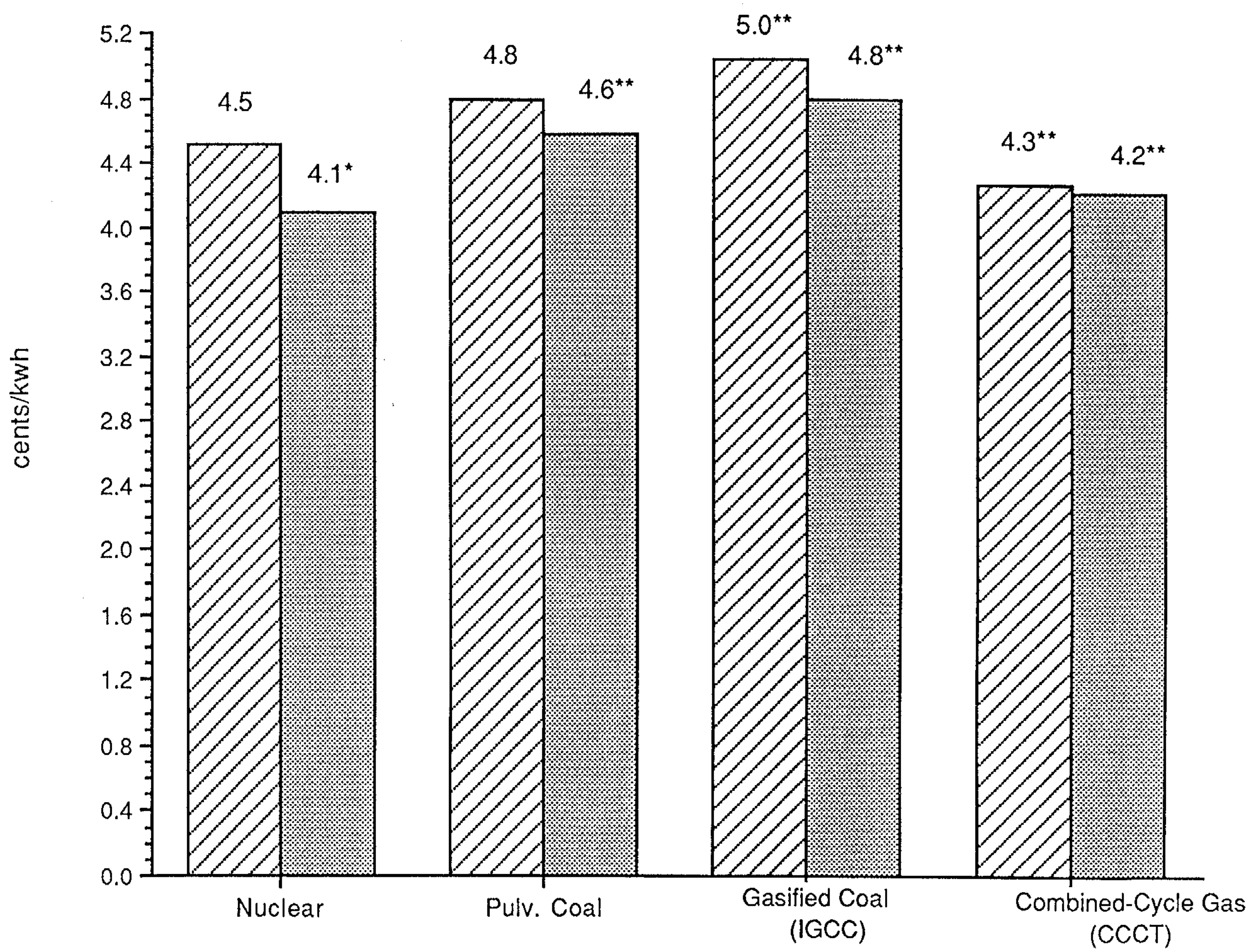
Cost of Capital

Figures 21 and 22 show the impact that increases in the cost of capital would have on the price of electricity for the mid-size and large-size advanced-design nuclear plants. These figures show, for example, that it would take greater than a 100 basis point increase in the cost of capital for the 600-megawatt nuclear plant before its cost of electricity exceeds the cost for the base-case pulverized-coal plant. In the case of the larger nuclear plant, it would take increases in the cost of capital of well over 200 basis points before the cost of electricity from the plant approached the cost of electricity from the base-case pulverized-coal plant.

The reference cost of capital assumptions for both fossil and nuclear plants are listed in *Figure 5.*

Figure 1

Comparative Generating Costs - 600-MWe Passive Design Advanced Light Water Reactors



Legend of Capacity

- 600 MWe
- 1200 MWe

* Two 600-MWe units at same site.

** Multiple unit fossil plants.

Figure 2

Comparative Generating Costs - 1200-MWe Evolutionary Design Advanced Light Water Reactor

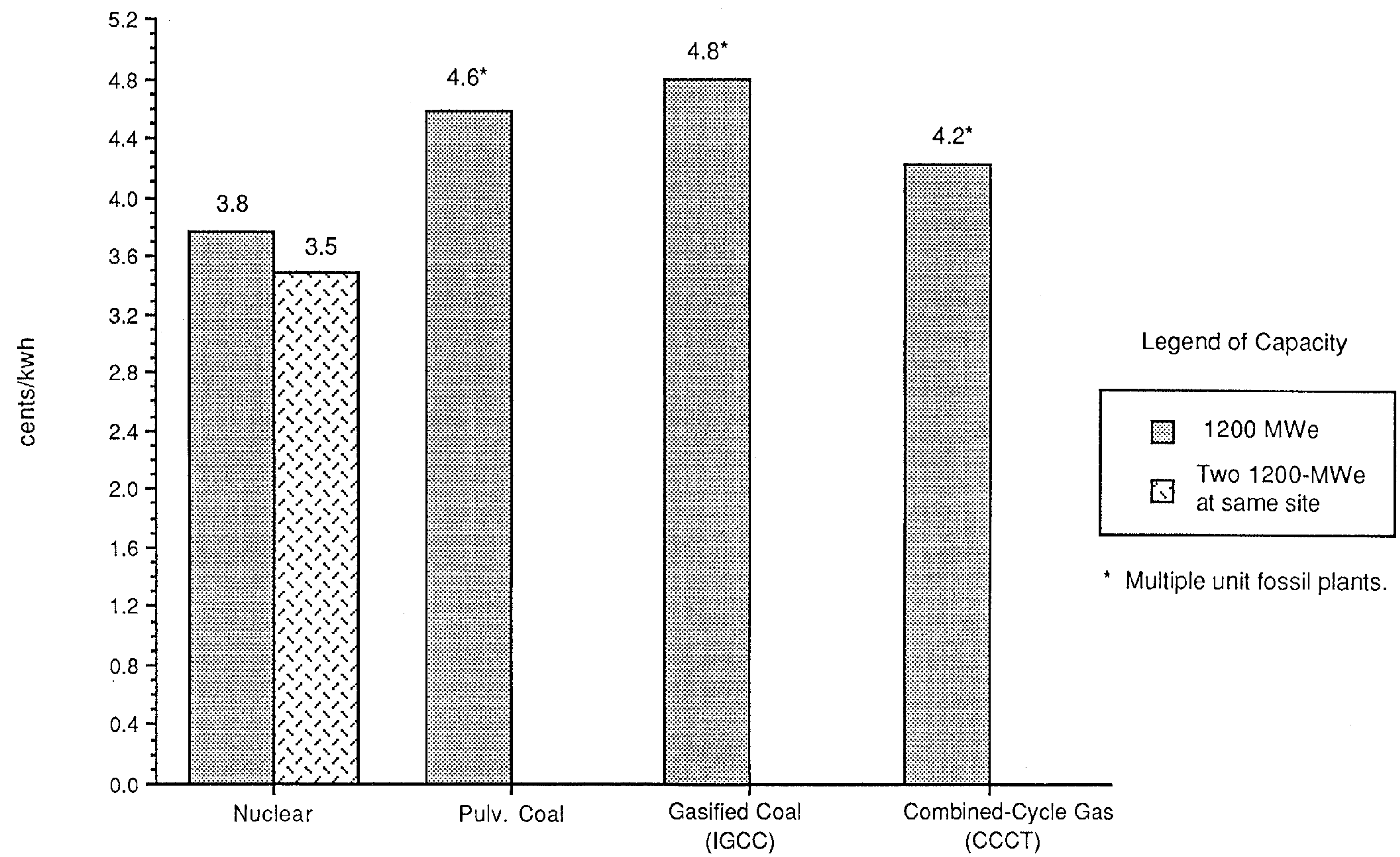


Figure 3

Performance and Cost Assumptions
Mid-Size Advanced Light Water Reactor and Fossil-Fired Alternatives

	Nuclear (one 600-MWe)	Nuclear (two 600-MWe)	Pulv. Coal[1]	IGCC[2]	CCCT[3]
Levelized Generating Cost (¢/kwh)	4.5	4.1	4.8	5.0	4.3
Total Overnight Cost (before AFUDC) ($/KWe)	1650	1472	1268	1567	532
Fixed O&M ($/KWe/year)	60	51	28.5	41.3	8.5
Variable O&M (mills/kwh)	0.6	0.5	4.0	1.8	0.6
Initial Fuel Cost (¢/million Btu)	70.0	70.0	146	146	214
Real Fuel Escalation Rate (%/year)	0	0	1.2	1.2	3.5
Construction Time (months)	60	60	42	42	24
Heat Rate (Btu/kwh)	10,400	10,400	9,700	8,950	7,514

[1] Pulverized coal: one 600-MWe unit
[2] Integrated-gasification-combined cycle: two 250-MWe units
[3] Combined-cycle combustion turbine: two 250-MWe units

Figure 4

Performance and Cost Assumptions
Large-Size Advanced Light Water Reactor and Fossil-Fired Alternatives

	Nuclear Evolutionary (one 1200-MWe)	Nuclear Evolutionary (two 1200-Mwe)	Pulv. Coal[1]	IGCC[2]	CCCT[3]
Levelized Generating Cost (¢/kwh)	3.8	3.5	4.6	4.8	4.2
Total Overnight Cost (before AFUDC) ($/KWe)	1359	1212	1171	1465	500
Fixed O&M ($/KWe/year)	42	40	24.7	36.6	7.5
Variable O&M (mills/kwh)	0.5	0.5	3.9	1.6	0.5
Initial Fuel Cost (¢/million Btu)	70.0	70.0	146	146	214
Real Fuel Escalation Rate (%/year)	0	0	1.2	1.2	3.5
Construction Time (months)	72	69	48	48	36
Heat Rate (Btu/kwh)	10,200	10,200	9,700	8,950	7,514

[1] Pulverized coal: two 600-MWe units
[2] Integrated-gasification-combined cycle: four 250-MWe units
[3] Combined-cycle combustion turbine: four 250-MWe units

Figure 5

Financial Assumptions

Security	Percent	Return*
Debt	45%	4.8%
Preferred Stock	10%	4.8%
Common Stock	45%	8.0%
Average Cost of Money		6.2%

	Nuclear	Fossil
Cost of Capital - Real*	6.2%	6.2%
Tax Recovery Period**	15 years	20 years
Fixed Charge Rate - Real*	10.3%	10.6%

* Inflation free (Implied inflation rate 5.0%).

** Book life 30 years.

Figure 6

Total Capital Costs, Including AFUDC
(1992 Dollars)

	600-MWe	1200-MWe*
Nuclear Plants ($/KWe)**	1859	1567 - 1668 ***
Pulverized-Coal Plants ($/KWe)	1394	1302
Gasified-Coal Plants ($/KWe)	1728	1629
Gas-Fired Plants ($/KWe)	558	537

* Multiple unit fossil plants.

** Excluding interim replacement cost

*** Completed construction cost for two 600-MWe units at the same site = 1668 $/KWe.

Figure 7

Effect of Increased Decommissioning Costs on Single Unit Nuclear Electricity Cost*

Decommissioning Cost Factor	Nuclear Electricity Cost (1992 ¢/kwh) 600-MWe	1200-MWe
Base Case	4.5	3.8
Twice the Cost	4.6	3.8
Three Times the Cost	4.7	3.9

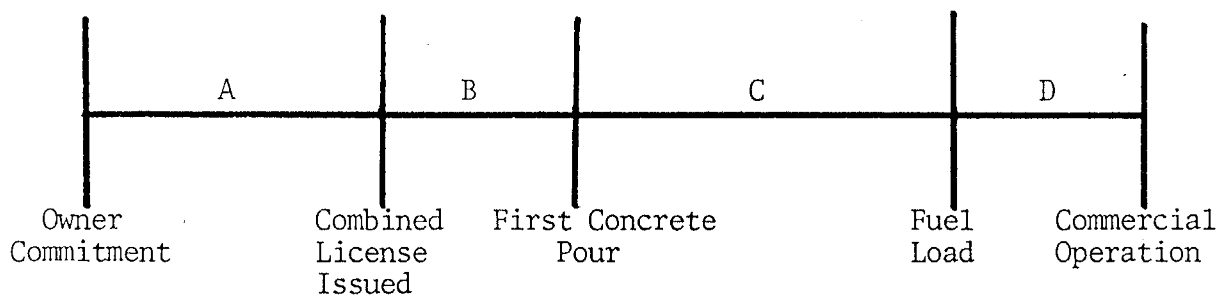
* Base-case Decommissioning Cost: $165 (million) 600-MWe plant
$265 (million) 1200-MWe plant

Figure 8

Advanced Design Standardized Nuclear Plant Construction Durations

Construction Duration in Months

Plant Type	A	B	C	D	Total
One 600-MWe	12	6	36	6	60
Two 600-MWe	12	6	36	6	60*
One 1200-MWe	12	6	48	6	72



* Cost calculations are based on an 18 month lag time between start of construction for the first and the second unit.

Figure 9

Levelized Generating Cost Breakdown
600-MWe Capacity Alternatives

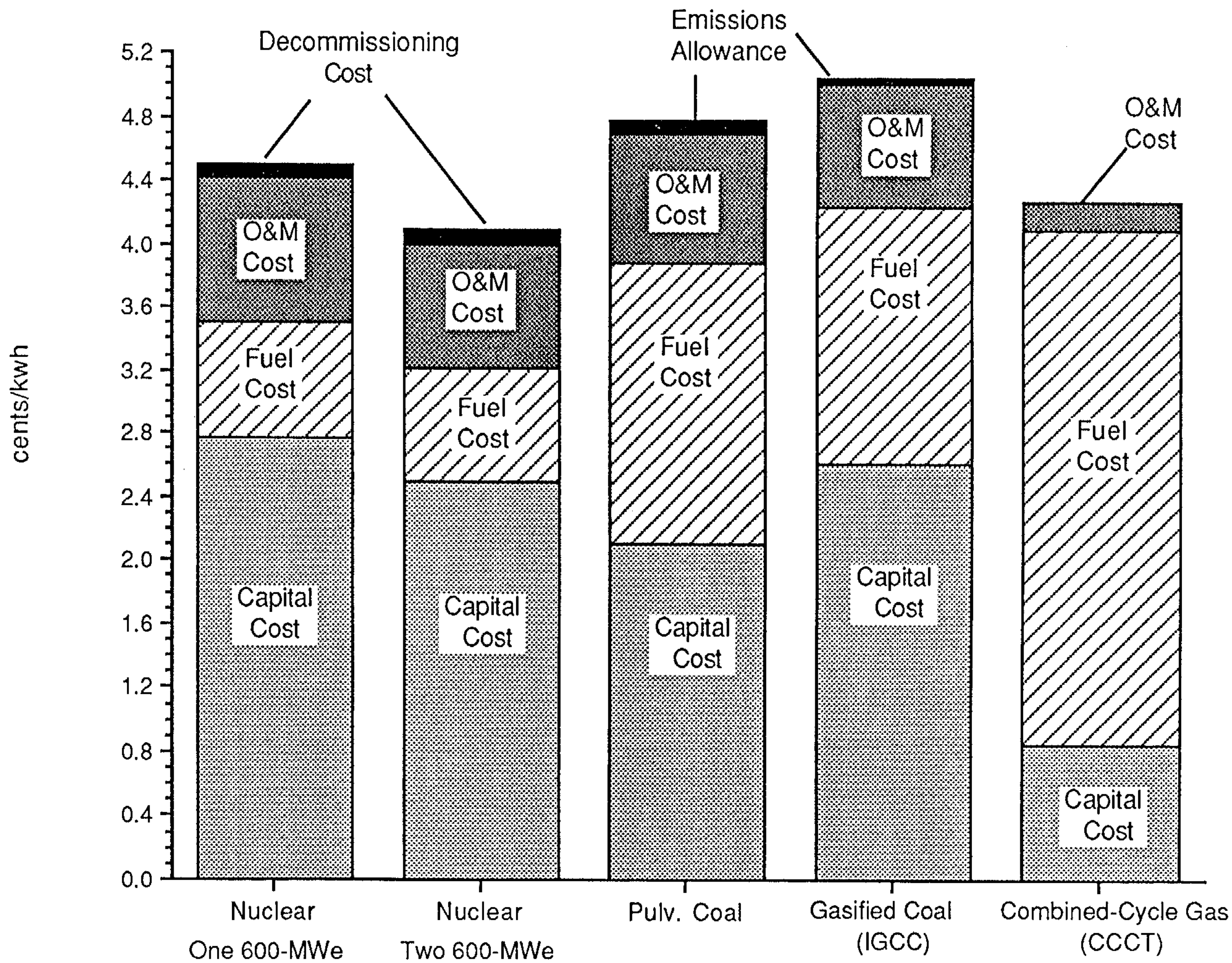


Figure 10

Levelized Generating Cost Breakdown
1200-MWe Capacity Alternatives

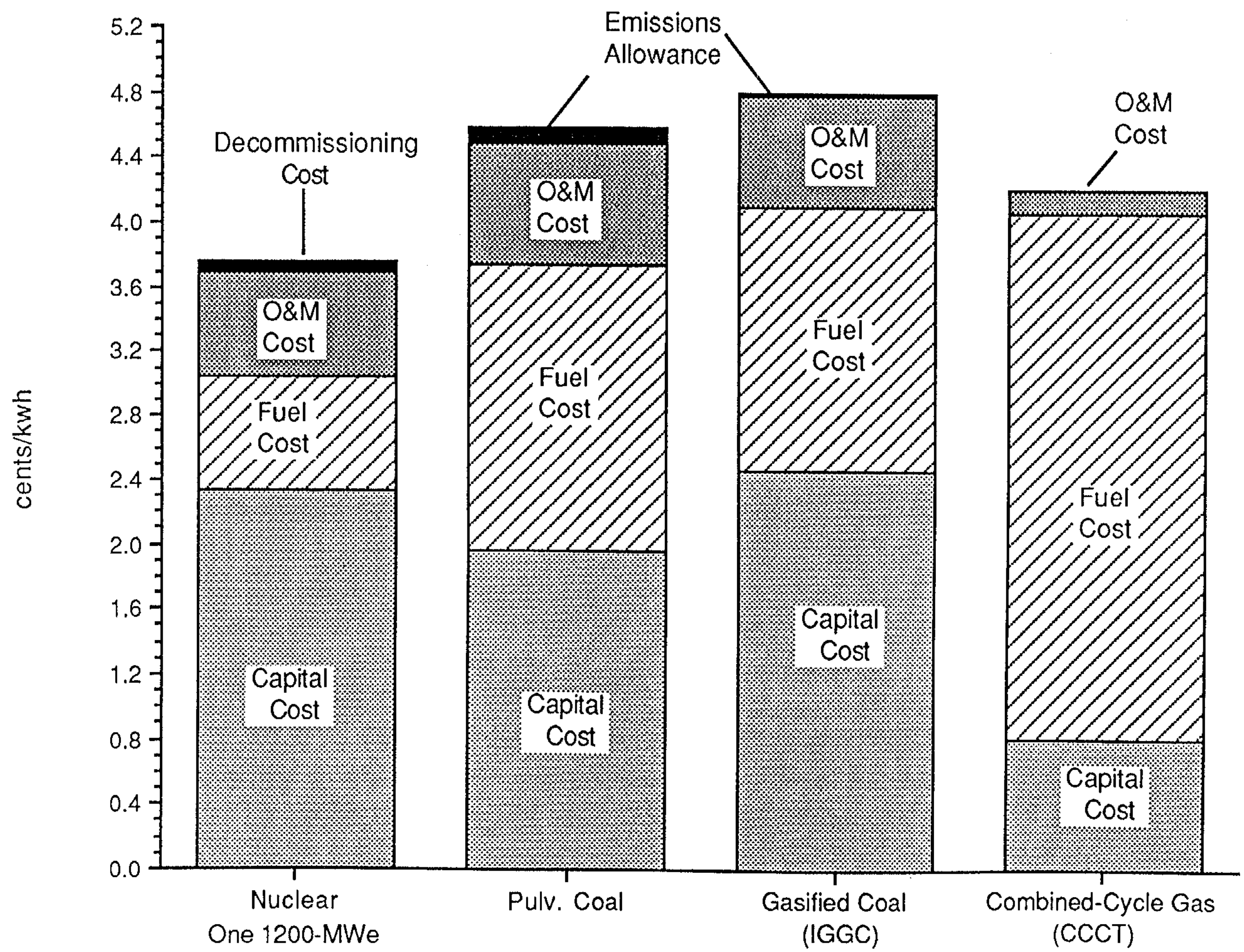


Figure 11

Levelized Generating Costs at Various Capacity Factors 600-MWe Capacity - Passive ALWR

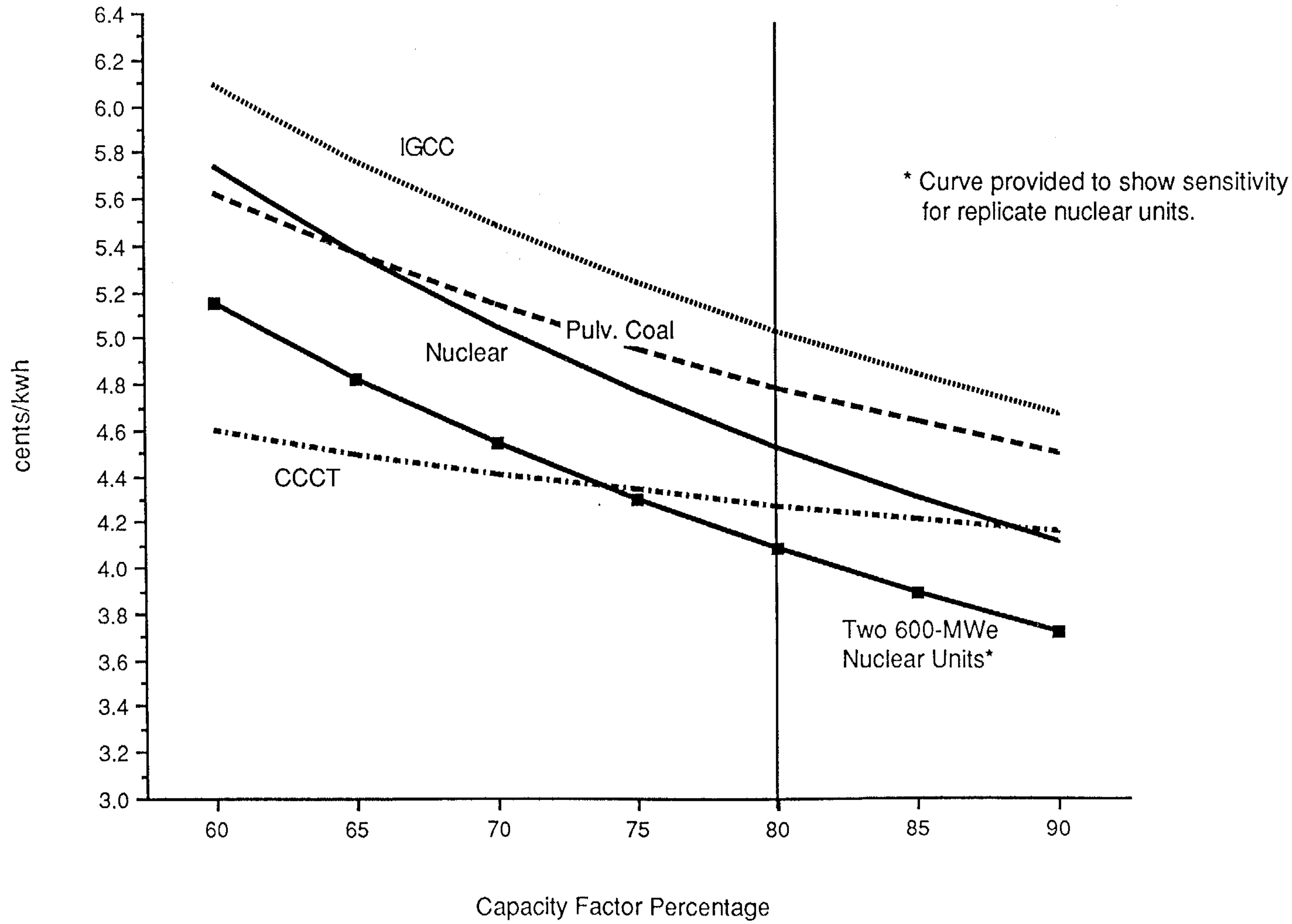


Figure 12

Levelized Generating Costs at Various Capacity Factors
1200-MWe Capacity - Large Evolutionary ALWR

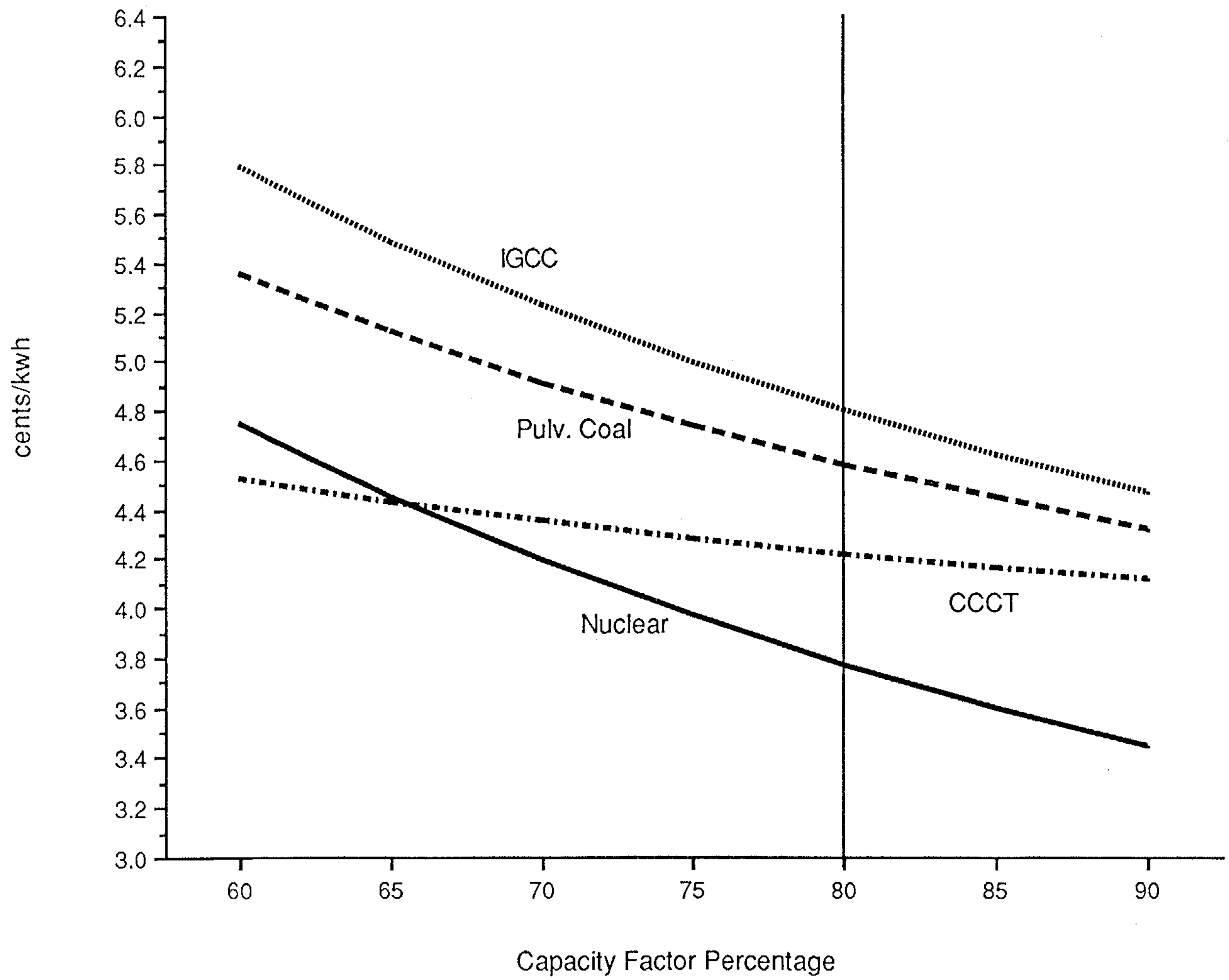


Figure 13

Levelized Generating Costs
at Various Annual Fuel Escalation Rates
600-MWe Capacity - Passive ALWR

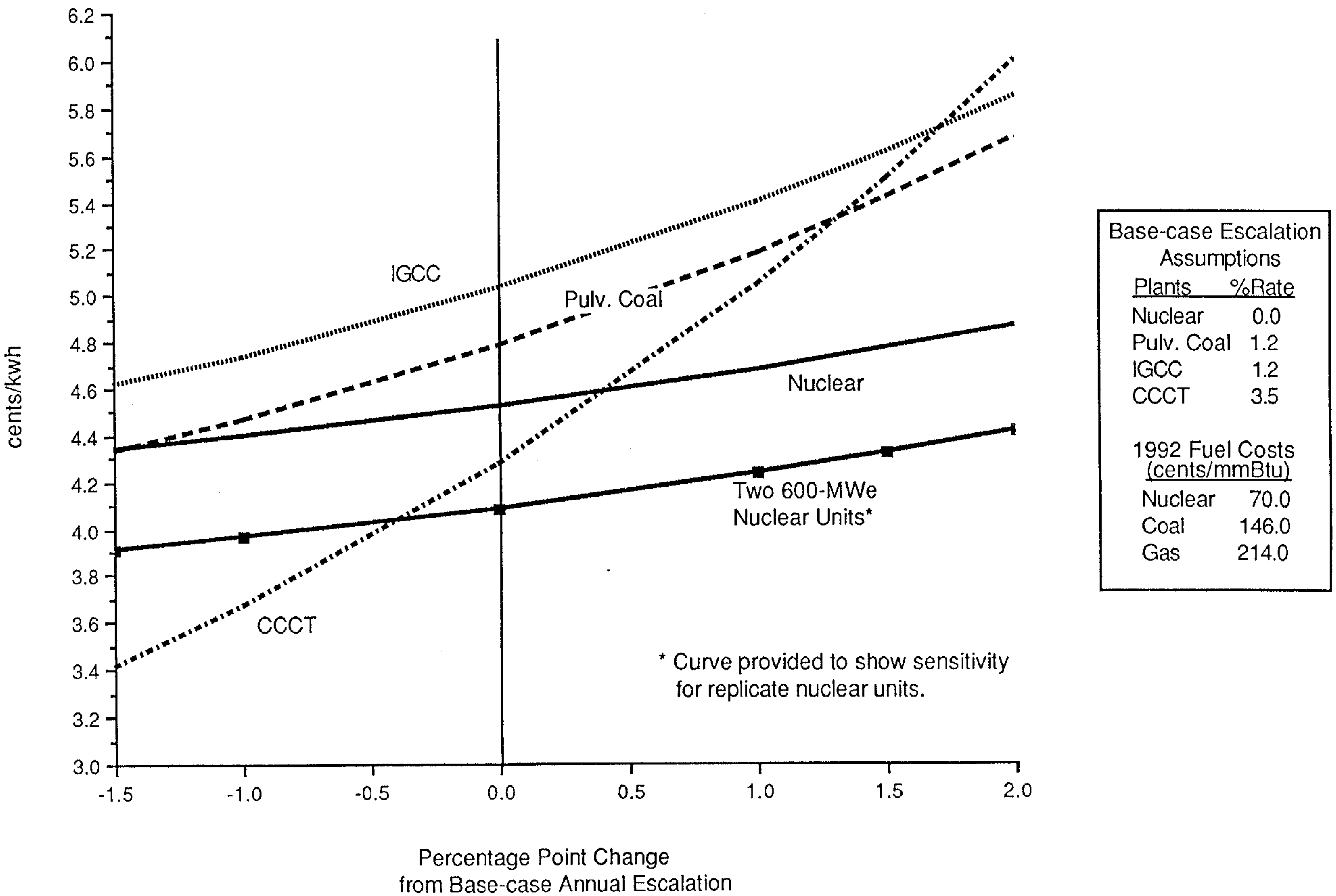


Figure 14

Levelized Generating Costs
at Various Annual Fuel Escalation Rates
1200-MWe Capacity - Large Evolutionary ALWR

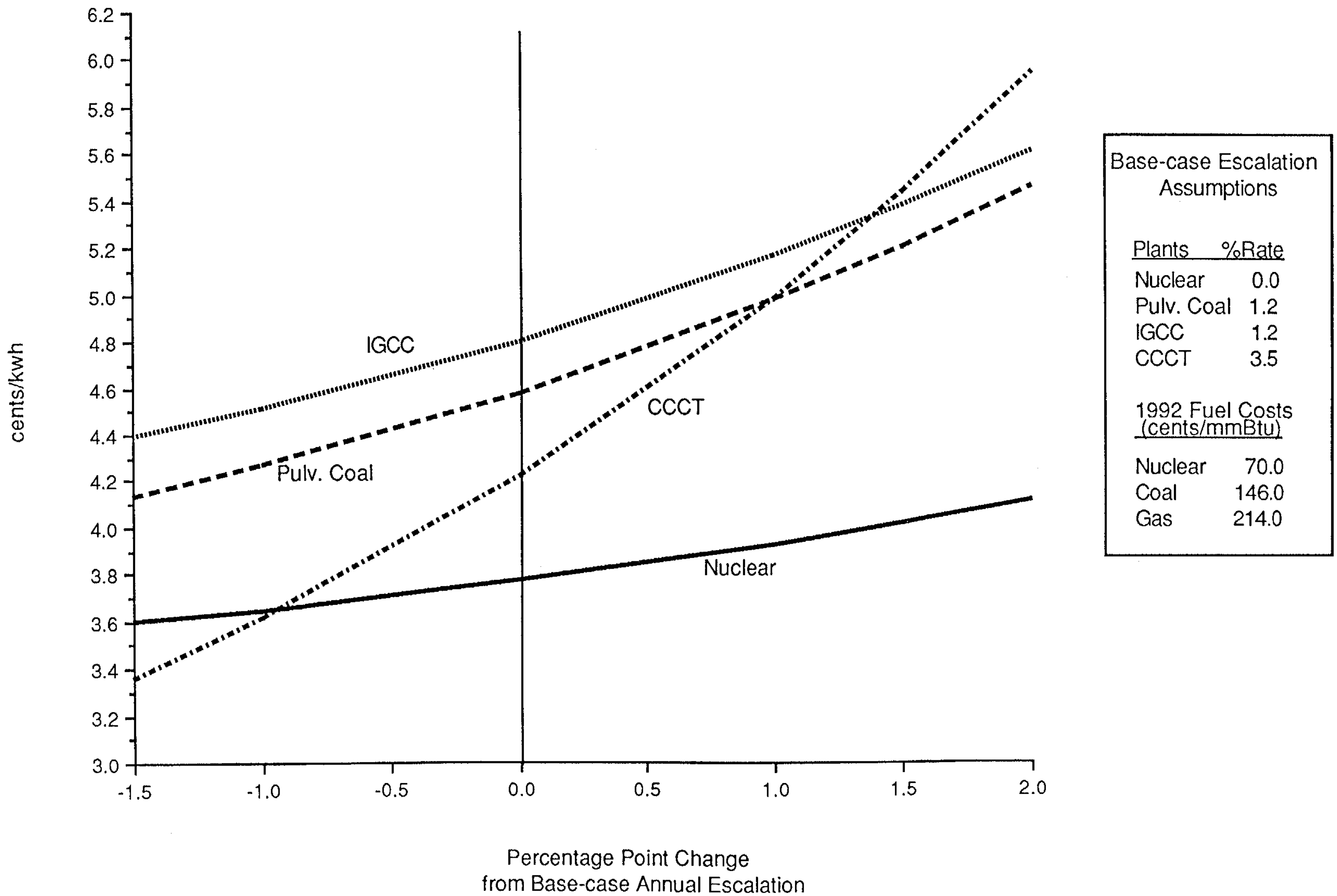
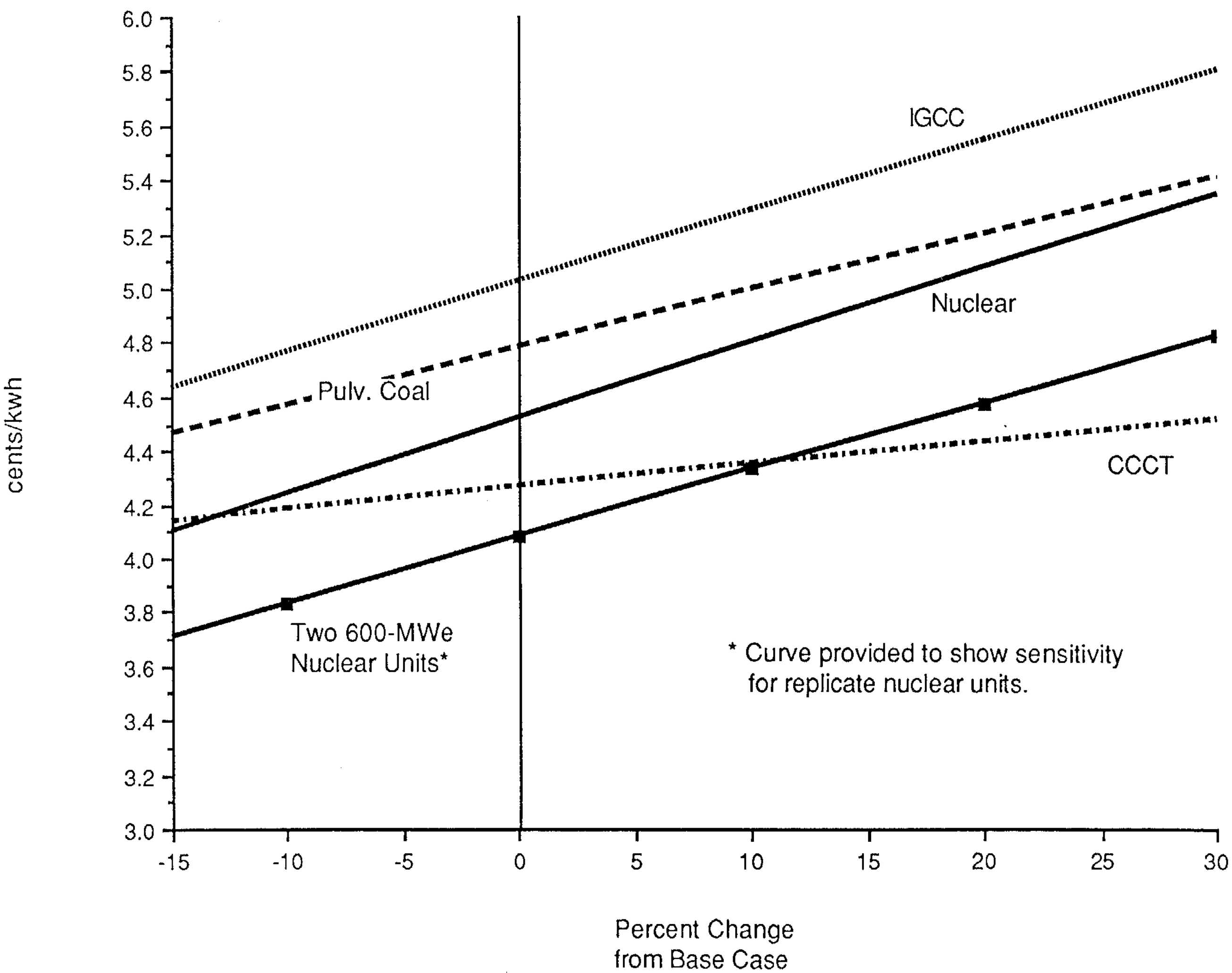


Figure 15

Levelized Generating Costs at Various Capital Costs
600-MWe Capacity - Passive ALWR



Base-case Capital Cost Assumptions

Plants	$/KWe
1-Nuclear	1650
2-Nuclear	1472
Pulv. Coal	1268
IGCC	1567
CCCT	532

Figure 16

Levelized Generation Costs at Various Capital Costs 1200-MWe Capacity - Large Evolutionary ALWR

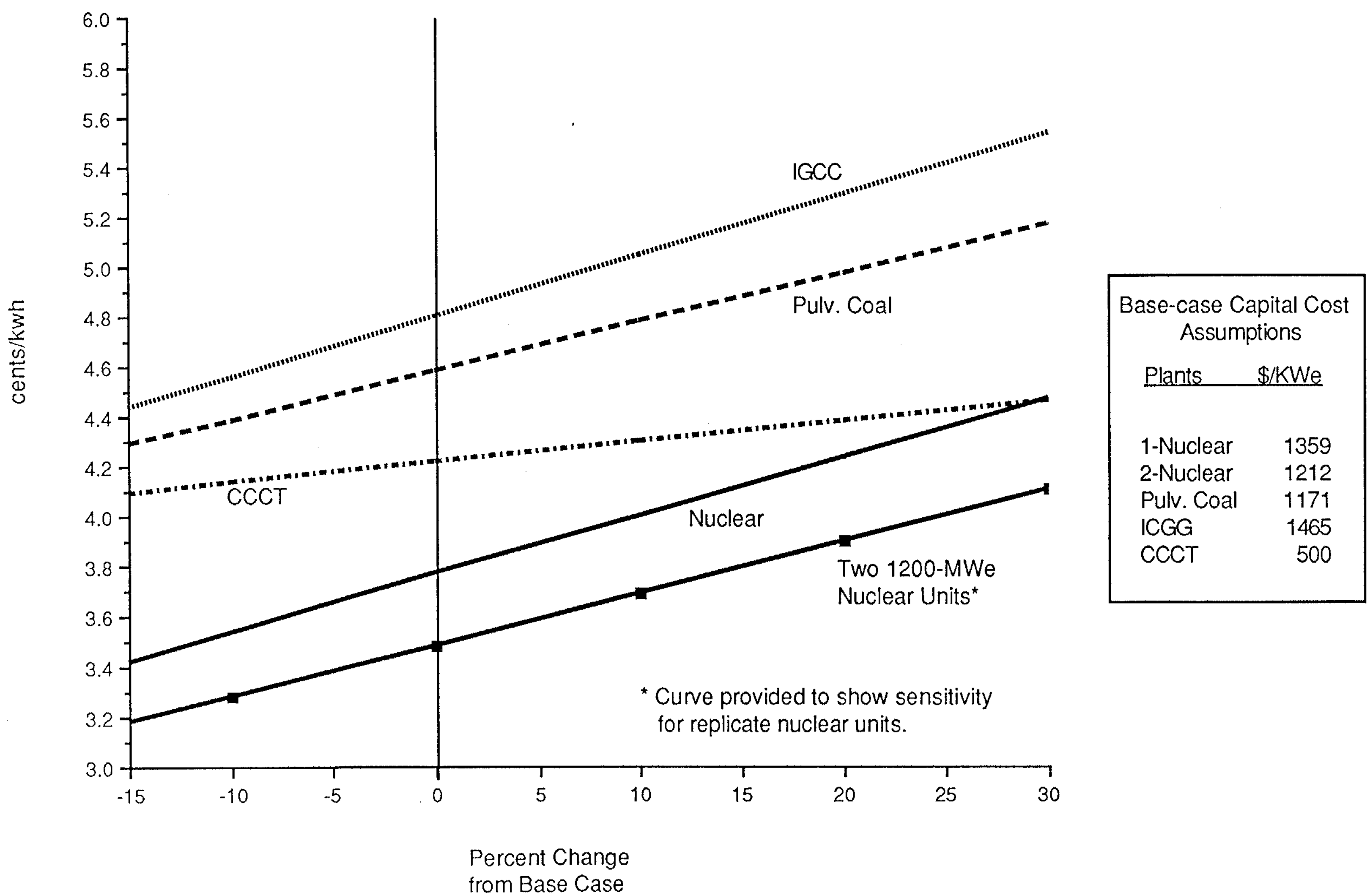


Figure 17

Levelized Generating Costs at Various Construction Times
600-MWe Capacity - Passive ALWR

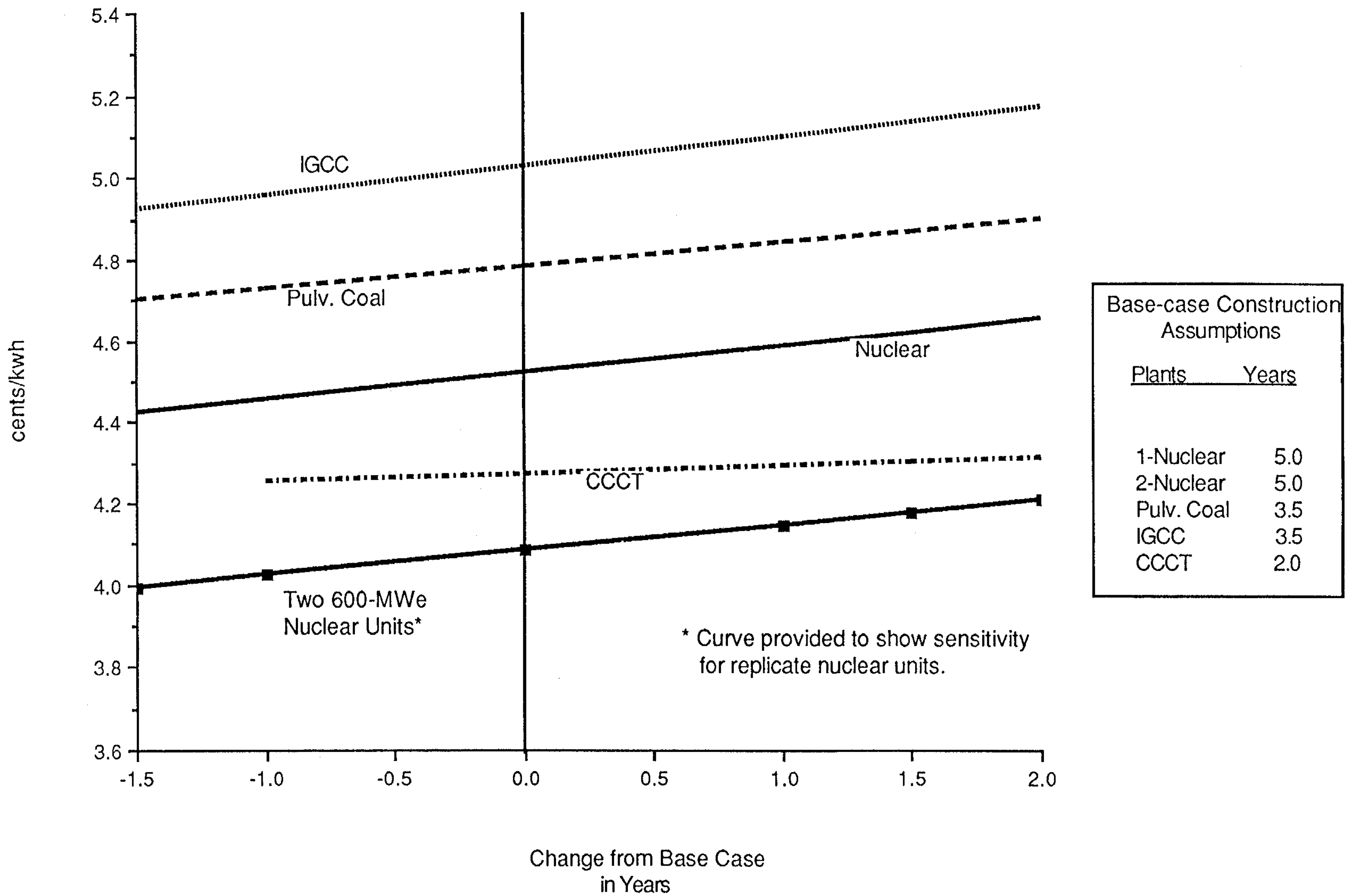


Figure 18

Levelized Generating Costs at Various Construction Times 1200-MWe Capacity - Large Evolutionary ALWR

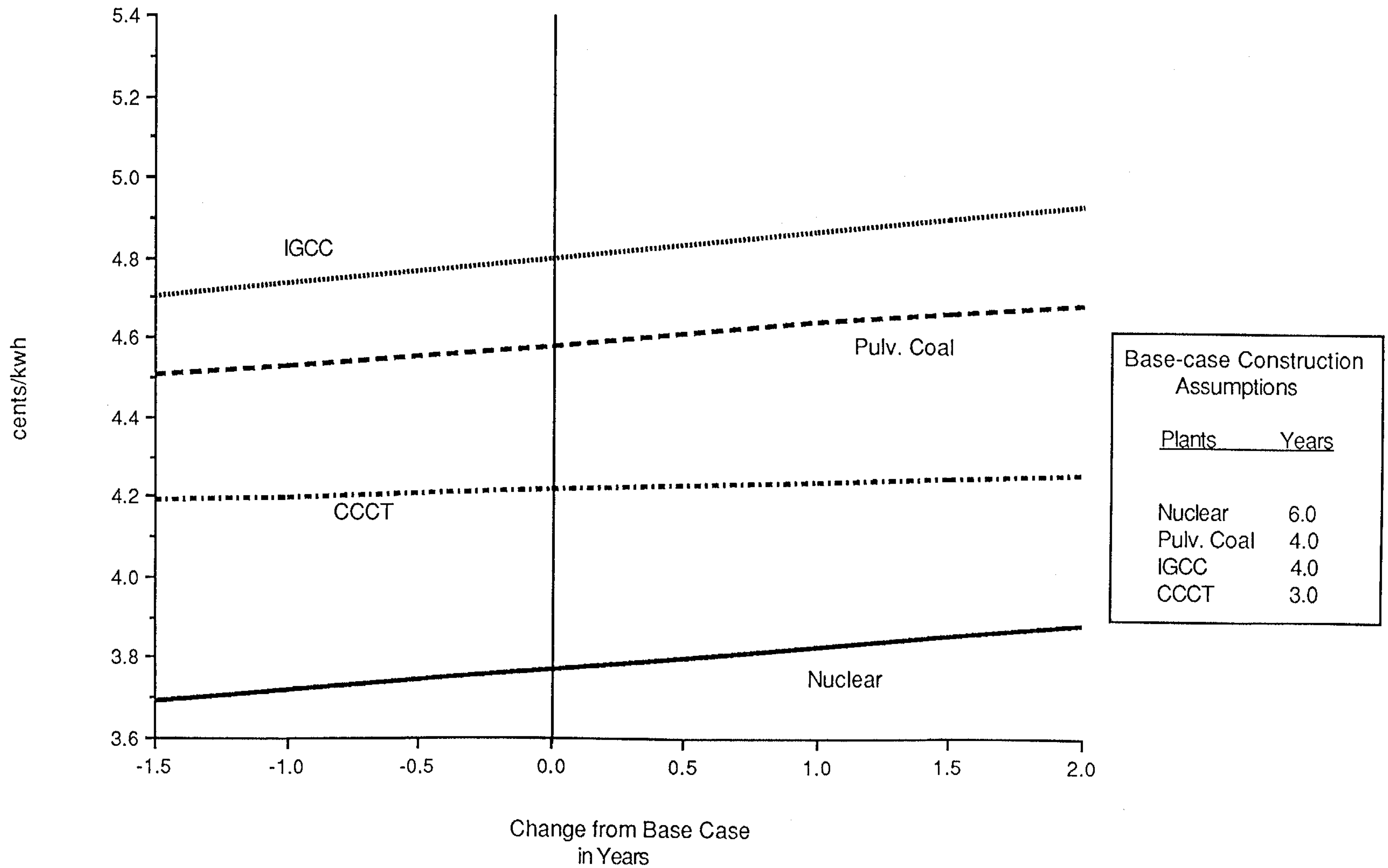
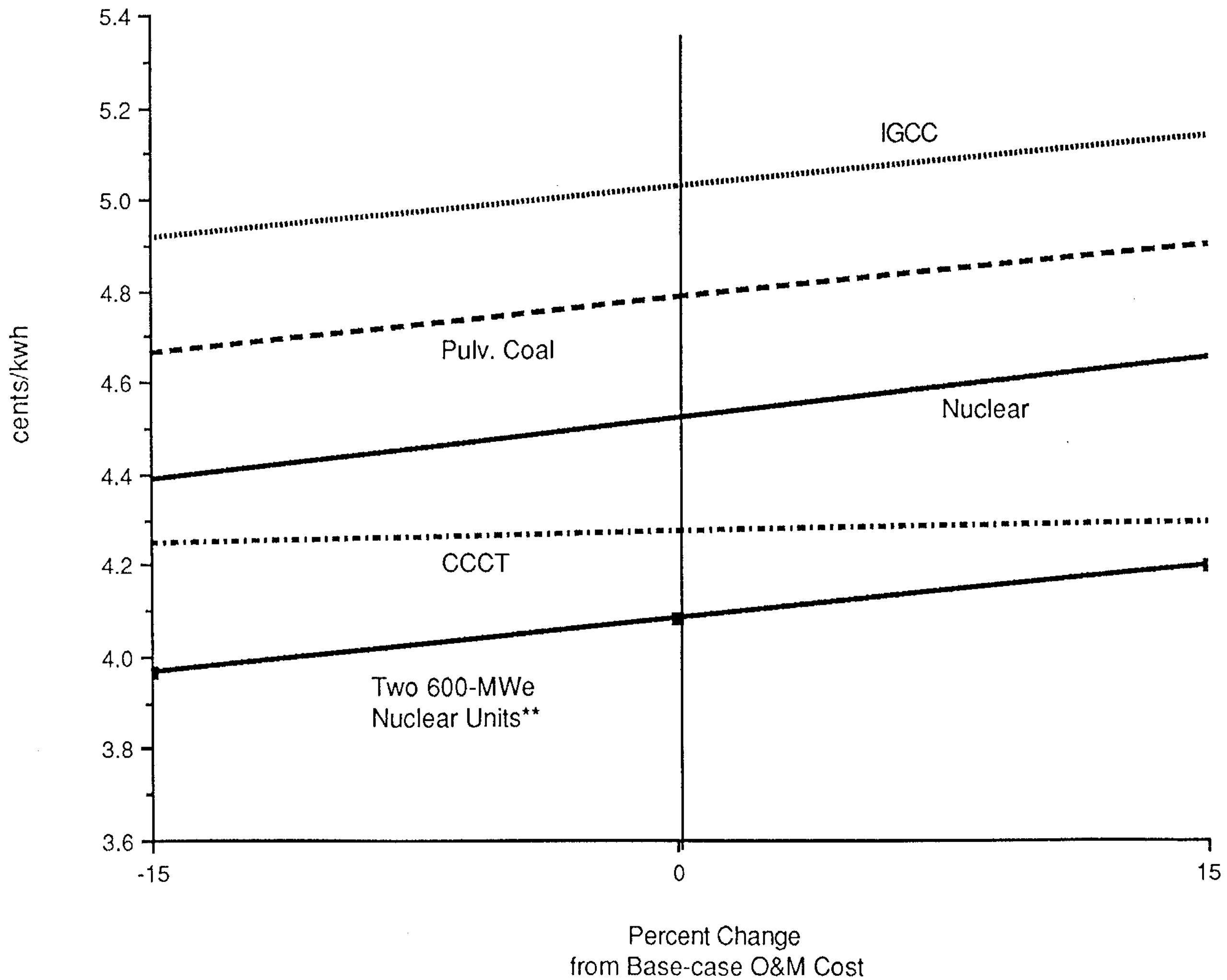


Figure 19

Levelized Generating Costs at Various O&M Costs*
600-MWe Capacity - Passive ALWR

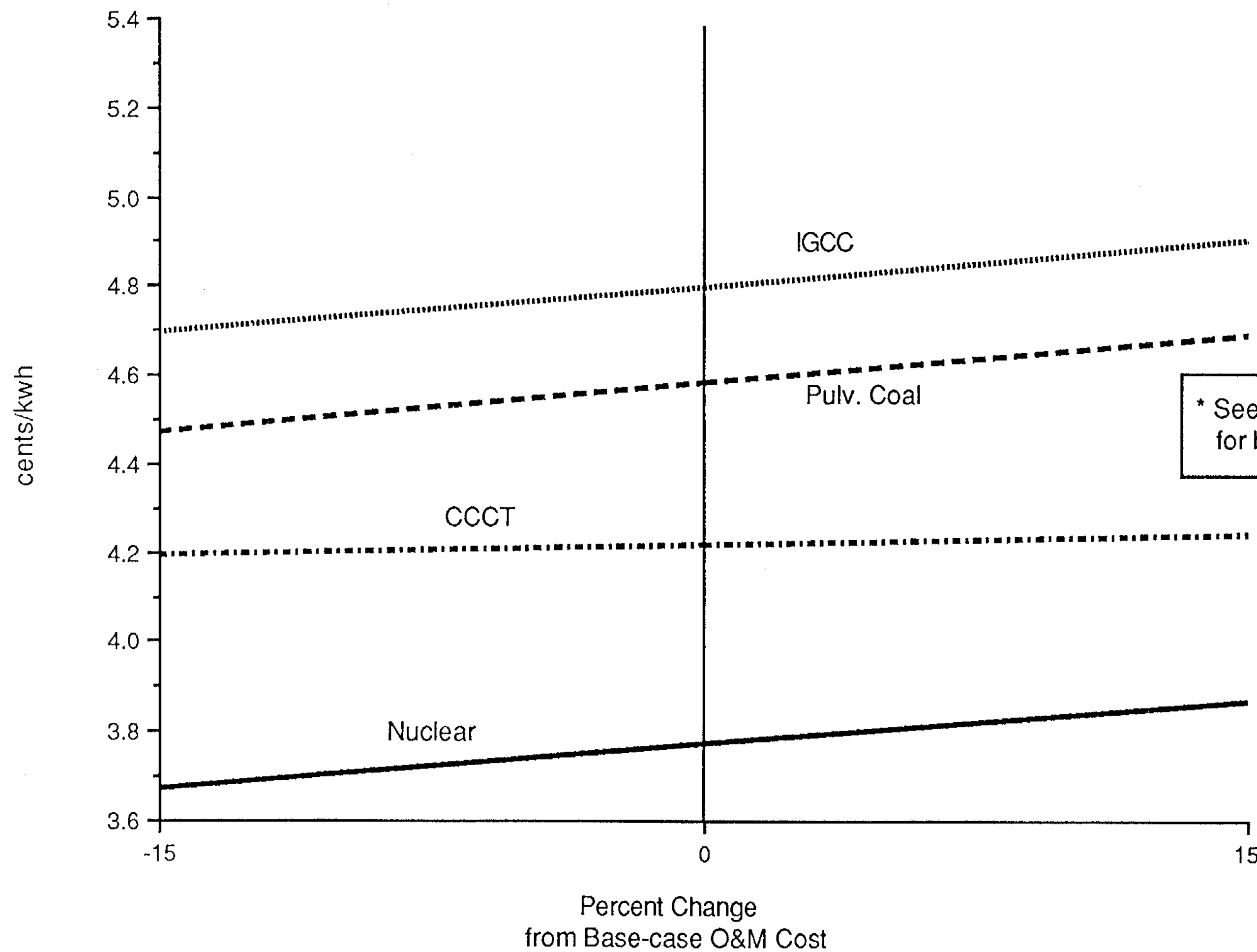


* See Figure 3 for base-case O&M costs.

** Curve provided to show sensitivity for replicate nuclear units.

Figure 20

Levelized Generating Costs at Various O&M Costs*
1200-MWe Capacity - Large Evolutionary ALWR



* See Figure 4
for base-case O&M costs.

Figure 21

Levelized Nuclear Generating Cost
Premium on Cost of Capital
600-MWe Capacity - Passive ALWR

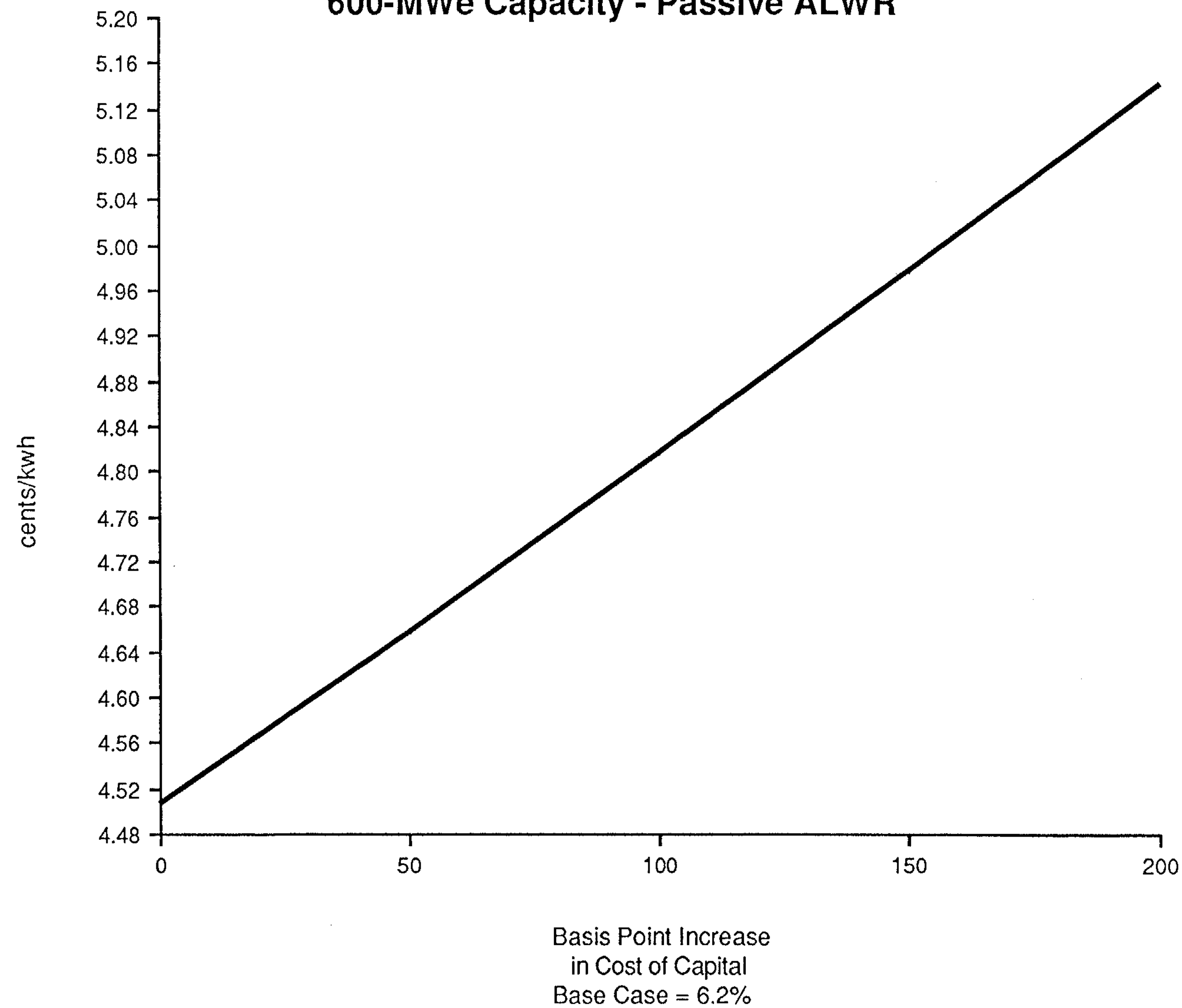
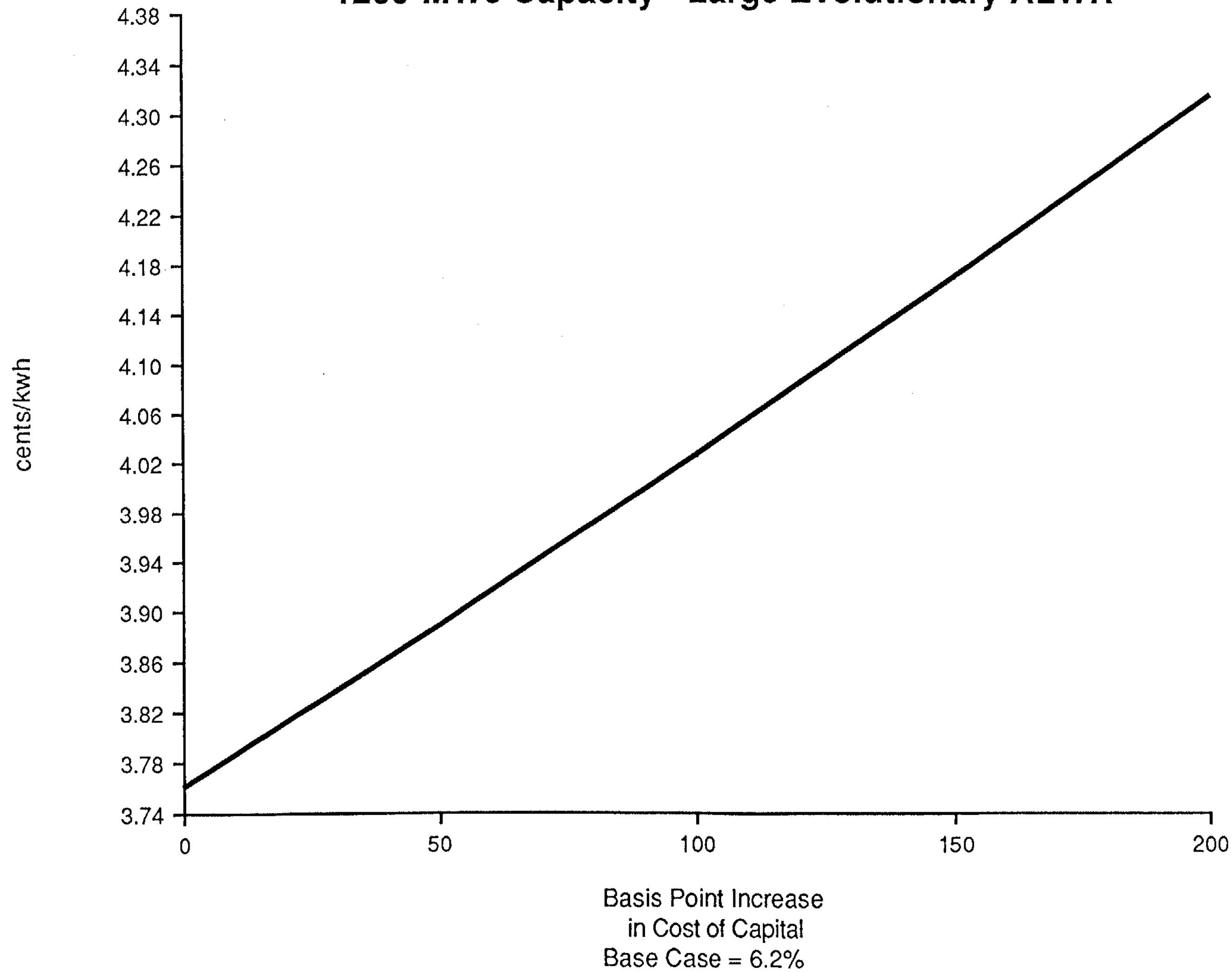


Figure 22

Levelized Nuclear Generating Cost
Premium on Cost of Capital
1200-MWe Capacity - Large Evolutionary ALWR



APPENDIX 1

Cost Study Methodology

This appendix discusses the evaluation methodology used in performing the cost analyses contained in this study.

Revenue Requirements

The methodology used to evaluate electricity generation technologies in this report is a revenue requirement, levelized cost method. Details of the method are published by the U.S. Department of Energy (Ref. 14) and are consistent with the Electric Power Research Institute's (EPRI) 1989 Technical Assessment Guide (Ref. 7).

The revenue requirements method is used by electric utilities for both rate making and project evaluation purposes. In this method the revenues required by the utility to pay all operating costs, taxes, return on undepreciated capital and capital investment depreciation are calculated. Normalized accounting procedures are used to take advantage of accelerated tax depreciation schedules.

The figure of merit that is used to compare different technologies at different unit sizes is a levelized unit cost. It is calculated by summing the present worth of the revenue requirements over the lifetime of the project. Present worth revenue requirements (PWRR), is a single amount of money which is equivalent to the string of annual revenue requirements. The PWRR is obtained by discounting the annual revenue requirements to the year of plant start-up (2000) using the average before-tax cost of money and then summing up the stream of discounted values. This cost analysis uses a 6.2 percent inflation-free average cost of money as the discount rate.

Levelization

The PWRR is then levelized to reflect the average lifetime annual generation cost present-valued to the year 2000. The levelized cost is an equivalent single cost that produces the same present worth value as the stream of actual year-by-year costs.

Constant versus Current Dollar

Constant and current dollar levelized costs are two different ways of expressing the same value for purposes of comparing alternatives.

This study is based on inflation-free costs, expressed in constant January 1992 dollars. This methodology was chosen over the current or inflated dollar approach for the following reasons:

The use of constant dollar versus current dollar analysis depends upon the purpose of the analysis. In general, studies that are short term in nature, (less than five to seven years) are best presented in current dollars. Current dollar analysis more closely approximates future cash flows.

Longer term studies (10-40 years) are best presented in constant dollars so that the effect of many years of inflation does not distort the costs to the point that they bear no resemblance to today's experience. Constant dollar analysis gives a clearer picture of real cost trends.

Regardless of which method is used, constant or current dollar, the relative advantage of one technology to another will remain the same.

In this study, levelized power generation costs are shown in 1992 constant dollars for the different technologies evaluated because of the long time frame over which the baseload capacity additions are evaluated. This approach is consistent with methodologies used by the international community -- including the Organization for Economic Cooperation and Development, the International Atomic Energy Agency, and electric utilities worldwide -- to evaluate nuclear, coal and other power generation technologies.

<u>APPENDIX 2</u>

Tables comparing input data assumptions from the

1991 USCEA Comparative Cost Study

with the assumptions used in this study.

Comparison of Input Data
1200-MWe Advanced Light Water Reactor

Base-case Assumptions*	1991 Study**	1992 Study
Heat Rate (Btu/kwh)	10,200	10,200
Capacity Factor (%)	75	80
Construction Duration (years)	5	6
Overnight Capital Cost ($/KWe)	1458	1359
Base Year Fuel Cost (¢/million Btu)	73.5	70.0
Fuel Cost Real Annual Increase (%)	0.0	0.0
Fixed O&M Cost ($/KWe/year)	66.7	42.0
Variable O&M Cost (mills/kwh)	1.2	0.5
Cost of Capital (%/year)		
Nominal	11.0	N.A.
Real	6.5	6.2
Fixed Charge Rate (%/year)	10.2	10.3
Decommissioning Cost (million dollars)	210	265

* 1991 study assumed North East "Middletown" nuclear plant site. 1992 study assumed EPRI East/West Central site.

** Values have been changed to 1992 dollars for comparison purposes.

N.A. = Not Applicable

Comparison of Input Data
1200-MWe Pulverized Coal Plant

Base-case Assumptions*	1991 Study**	1992 Study
Heat Rate (Btu/kwh)	9,700	9,700
Capacity Factor (%)	75	80
Construction Duration (years)	4	4
Overnight Capital Cost ($/KWe)	1271	1171
Base Year Fuel Cost (¢/million Btu)	157	146
Fuel Cost Real Annual Increase (%)	1.0	1.2
Fixed O&M Cost ($/KWe/year)	23.6	24.7
Variable O&M Cost (mills/kwh)	5.2	3.9
Cost of Capital (%/year)		
Nominal	11.0	N.A.
Real	6.5	6.2
Fixed Charge Rate (%/year)	10.5	10.6
Decommissioning Cost (million dollars)	26	N.A.
Emissions Allowance Price ($/ton)	0	500

* 1991 study assumed North East "Middletown" nuclear plant site. 1992 study assumed EPRI East/West Central site.

** Values have been changed to 1992 dollars for comparison purposes.

N.A. = Not Applicable

Comparison of Input Data
1200-MWe Gas-Fired Combined-Cycle Plant

Base-case Assumptions*	1991 Study**	1992 Study
Heat Rate (Btu/kwh)	8,000	7,541
Capacity Factor (%)	75	80
Construction Duration (years)	2	3
Overnight Capital Cost ($/KWe)	542	500
Base Year Fuel Cost (¢/million Btu)	262	214
Fuel Cost Real Annual Increase (%)	4.0	3.5
Fixed O&M Cost ($/KWe/year)	4.1	7.5 ***
Variable O&M Cost (mills/kwh)	4.1	0.5 ***
Cost of Capital (%/year)		
Nominal	11.0	N.A.
Real	6.5	6.2
Fixed Charge Rate (%/year)	10.5	10.6
Decommissioning Cost (million dollars)	N.A.	N.A.

* 1991 study assumed North East "Middletown" nuclear plant site. 1992 study assumed EPRI East/West Central site.

** Values have been changed to 1992 dollars for comparison purposes.

*** Changes in O&M costs are due to increases in capacity factor from 30 to 80 percent per EPRI Technical Assessment Guide methodology.

N.A. = Not Applicable

APPENDIX 3

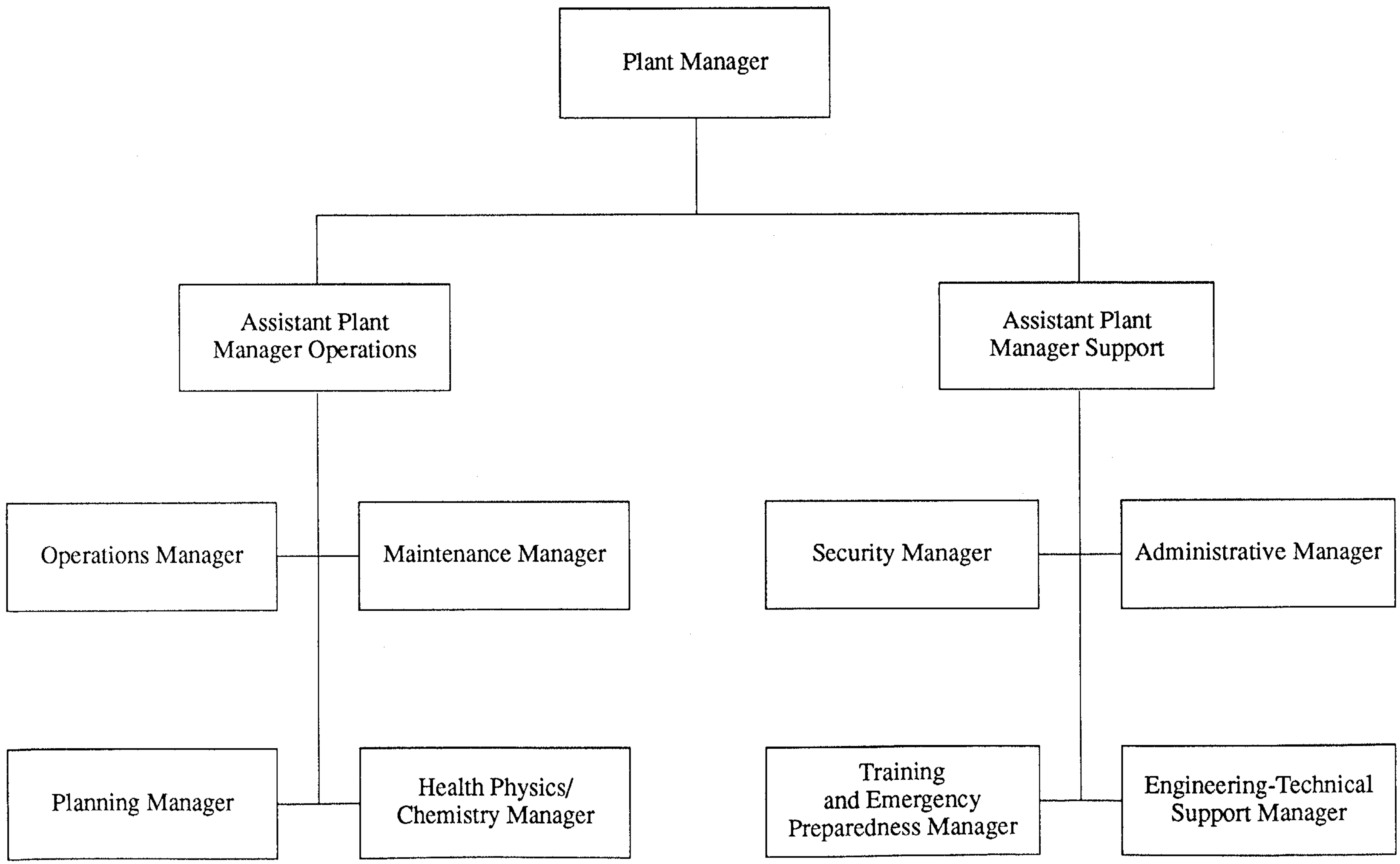
Advanced-Design Nuclear Plants - Staffing Requirements

The advanced-design nuclear plant operating and maintenance costs used in this study were provided by EPRI, based on an evaluation of the plant staffing requirements and other components (consumable materials, etc.) that make up annual O&M costs at a nuclear plant. These assessments considered the beneficial impacts of standardization and new designs on staffing, material requirements, outage durations, etc. In addition, since standardization will allow for the creation of common support staffs (e.g. generic licensing, design engineering, etc.) for families of plants, the EPRI derived staffing requirements reflect the existence of such groups, which are included in the O&M costs as support services expenditures. Furthermore, the charts presented in this Appendix do not depict other designated non-plant staff, such as quality assurance personnel. Finally, the staffing requirements also reflect expected productivity improvements commensurate with standardization and the associated simplification of the future regulatory process.

Figure A3-1 provides the typical advanced light water reactor (ALWR) organization chart. Using this organizational structure, as well as more detailed departmental breakdown charts (e.g., *Figure A3-2*), EPRI assessed the general staffing requirements for each functional area of activity. Based on the EPRI assessment, it was concluded that a staff (utility plus contractors) of between 350 and 400 people would be required for the 600-megawatt advanced-design plant, and that between 500 and 550 people would be required for a 1200-megawatt plant. These staffing levels are lower than what currently exist at operating nuclear plants, and reflect the operational and maintenance benefits expected as a result of standardization and simplification of the regulatory process.

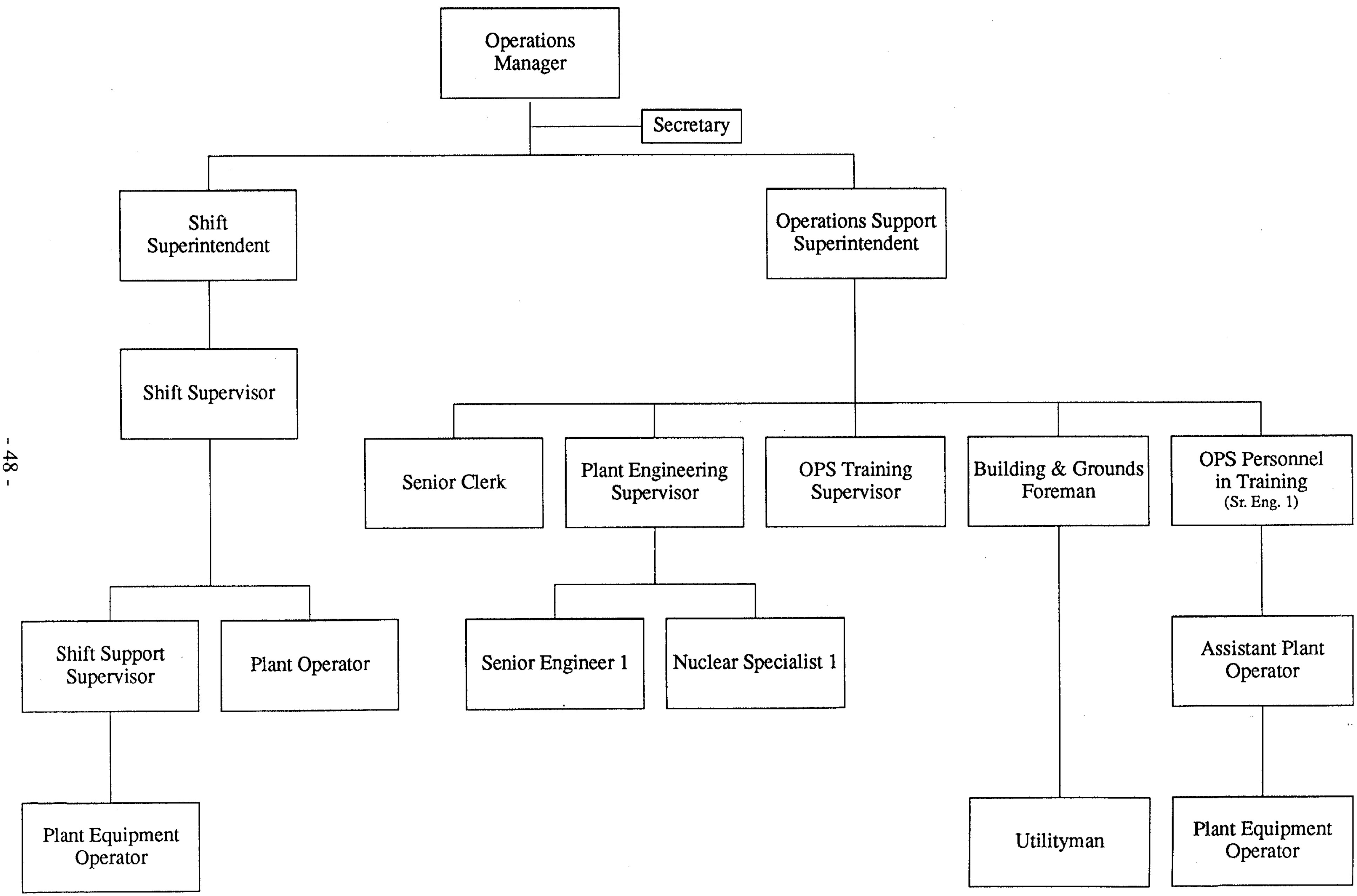
Typical Advanced Light Water Reactor Organization

Figure A3-1



Advanced Light Water Reactor Program Operations Department

Figure A3-2



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