# NUCLEAR ECONOMICS—ISSUES AND FACTS*



C. R. Hudson†

Nuclear economics has become one of the more prominent topics related to nuclear power. Beyond the subjects of nuclear safety and waste disposal, questions and concerns of nuclear power economics have emerged with growing frequency in utility board rooms, in state and federal regulatory proceedings, and in the media. What has caused nuclear power economics to become such a popular topic? This paper addresses issues and facts related to

- historical nuclear plant costs,
- new nuclear plant projections, and
- warning signals for future plants,

using data primarily from the Federal Energy Regulatory Commission FERC Form 1 and supplemented from a variety of sources (Energy Information Administration, Public Utilities Fortnightly, U.S. Nuclear Regulatory Commission, U.S. Department of Energy, U.S. Council for Energy Awareness).

Much of today's coverage concerning nuclear power economics relates to current operating plants. It is therefore useful to develop an understanding of current plant economics and some of the reasons for the present status. As shown in Fig. 1, average U.S. nuclear generation costs began a divergence from average coal-fired busbar costs in the early 1980s

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†Engineering Technology Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831.

because of a stability in coal-fired generation costs (actually, a decline in costs on a constant dollar basis due to declining fuel prices) and real increases in nuclear busbar costs. These increases in average nuclear generation costs were predominantly driven by capital (i.e., construction) cost growth, as is clear from Fig. 2.

While the data in Figs. 1 and 2 represent average costs for all U.S. nuclear plants, an evaluation of plant capital cost by year of commercial operation, as shown in Fig. 3, points out a tremendous growth in unit capital cost (i.e., $/kWe) in the years following the accident at Three Mile Island (TMI). This growth in cost is the result of a number of factors. First, following the TMI accident, a large number of new regulations and requirements were prescribed for nuclear plants. Many of these regulations required review and recalculation of design parameters, increased quality assurance/quality control (QA/QC), and retrofits of plant equipment and structures. Because each plant in the United States is essentially unique in design and construction, these reviews and redesigns had to be performed individually for each plant under construction, with little ability to share analyses and related costs.

In addition, energy consumption in this country was undergoing fundamental changes initiated by the oil embargoes of the 1970s. With the increase in fuel prices, all forms of energy, including electricity, increased in price. This restructured the demand for electricity. Whereas electricity demand had grown at 6 to 7% per annum before the oil embargoes, the new demand growth was <3%/year. As nuclear plants had a 6- to 8-year planning/construction horizon utilities found themselves in the midst of a construction program with an evaporating future demand. Over 100 units were canceled, and the construction of many units that were under way was slowed to match the reduced demand.

The impact of these events on capital cost was twofold. First, construction durations increased as shown in Fig. 4. As is evident in Fig. 5, the interest on funds used during construction was directly influenced by the longer durations. Second, the additional analysis, design, and construction requirements caused large indirect cost increases (e.g., engineering, design, QA/QC, and site supervision) and time delays, which also influenced the interest costs. As a result, interest and indirect costs were six times higher for a plant coming on-line in 1987 than they were for a plant starting up in 1976.

The discussion thus far has concentrated on the major driver of nuclear busbar cost growth, capital cost. However, with few plants

currently under construction, much has been said recently regarding operating and maintenance costs (O&M) or production costs (which is the sum of O&M and fuel cost). As can be seen in Fig. 6, average production costs for nuclear plants have risen through time. What was one of nuclear power's economic advantages—that of lower production costs than fossil plants—shrank and was lost by 1987. A great deal of effort has been put into reducing these costs and, as the last 3 years on the chart indicate, nuclear production costs have declined, narrowing the gap between nuclear and fossil production costs.

Two factors have been primarily responsible for the recent reduction in nuclear production costs. First, average nuclear plant capacity factors (i.e., the amount of electrical energy generated) have been increasing. When costs are expressed on a per unit energy basis as in mills per killowatt hour, the larger denominator makes for a smaller unit cost. Second, the growth in O&M costs (which represents roughly 70% of nuclear production cost) has slowed. As shown in Fig. 7, both cost per unit capacity and cost per unit energy have declined recently. While cost per unit energy benefits from higher average capacity factors, cost per unit capacity (i.e., $/kWe) represents absolute O&M costs. As capacity factor improvement has its practical limits, both cost expressions need to be monitored for an accurate measure of future O&M cost behavior. What does seem to be evident is a continuing growth in utility personnel at nuclear plants. Figure 8 indicates that utility employment at nuclear plants has doubled in the last 10 years. Offsetting this expense is perhaps a reduction in consultant personnel, which in some past cases has been equivalent in number to utility staff and generally with a higher unit cost. Unfortunately, there are no publicly available data to confirm this supposition.

One final observation regarding current O&M costs has relevance to future plants. Figure 9 shows that there is a wide spread of nuclear plant O&M costs. Efforts should be made to understand and reduce costs for those plants on the "right tail" of the distribution curve, so as to reduce the current nuclear O&M cost average. Furthermore, greater consistency will be needed in the cost performance of any future nuclear plants.

In regard to future plants, let us shift the focus to nuclear plant projections. A number of efforts are under way within the nuclear industry, U.S. Department of Energy, and the U.S. Nuclear Regulatory Commission (NRC) to develop and commercialize a new generation of nuclear

plants. These plants have various descriptive names such as evolutionary, advanced, inherently safe, etc. From an engineering economics perspective, they all have some common threads. One commonality is that they all intend to have a standardized design, which will be certified by the NRC in much the same way as a particular aircraft type is certified by the FAA in the airline industry. Thus, if a plant is constructed according to the certified design, licensing should be much simpler. In addition, the new plant designs plan to take advantage (to some degree) of modular construction, in which portions of the plant would be constructed in a factory environment and shipped to the field for assembly. This is in contrast to the construction method for current nuclear plants in which the plants were constructed on-site piece-by-piece. These features have the potential to lead to shorter construction times and elimination of redesign, which in turn, will improve capital costs in the two areas having the greatest historical growth: indirect and interest costs.

As shown in Fig. 10, the expected nuclear capital cost improvement is dramatic. While not getting back fully to the 1976-vintage cost levels, future plants are expected to contain indirect and interest costs through the strategies mentioned earlier. Improvements in direct costs are also expected through elimination of unnecessary components and systems and segregated construction techniques whereby nuclear-related portions of the plant can be constructed to more rigorous and demanding standards than the non-nuclear balance of plant. These improvements in capital cost combined with control of O&M costs yield an expected busbar cost that is competitive with future fossil plants. As shown in Fig. 11, the expected range of nuclear generation costs is competitive with coal-fired generation as well as gas-fired combined cycle plants under certain fuel price conditions. Because of the great uncertainty in future gas prices, busbar costs for combined cycle plants are displayed in Fig. 11 as a function of average future gas price escalation. New nuclear plants are expected to be competitive with gas-fired combined cycle plants at average gas price escalations in excess of 2%/year on a real (above inflation) basis.

As a check on the expectations of these future nuclear plants, it is useful to compare the future plant busbar values to current nuclear busbar costs. Figure 12 shows that the future plants are expected to achieve busbar costs similar to the mode of the distribution of today's plants (i.e., similar to the most frequently occurring cost of current plants). As observed in Fig. 9 for O&M costs, current nuclear busbar costs also have a great spread of outcomes. This wide spread will need to

be contained in future plants if industry expectations are to be achieved. Can these expectations be realized? Possibly, but only if there is a stable state and federal regulatory environment and if plants are constructed from a standardized, certified design.

As we contemplate a second nuclear era, allow me to offer a few warning signs of potential economic problems for future nuclear plants:

- relaxation of design standardization;
- low percentage of design completion before construction start;
- lack of a certified design;
- problems in obtaining a combined construction permit/operating license;
- large Inspections, Tests, Analyses and Acceptance Criteria (ITAAC) requirements; and
- problems in achieving lower plant staffing levels.

Attentiveness to these warning signs will provide valuable insight as to the likelihood of new nuclear plants being able to achieve their stated economic goals.

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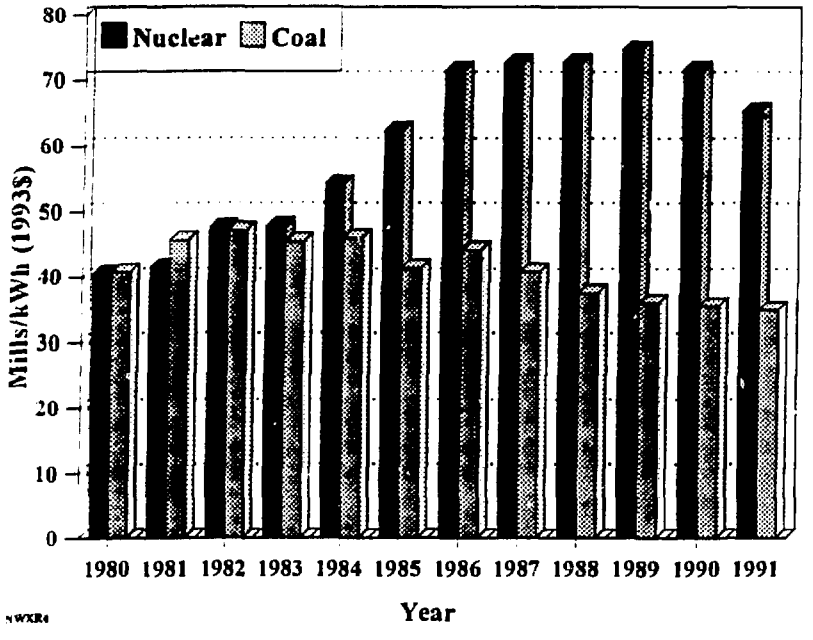


Fig. 1. Average U.S. busbar generation cost.

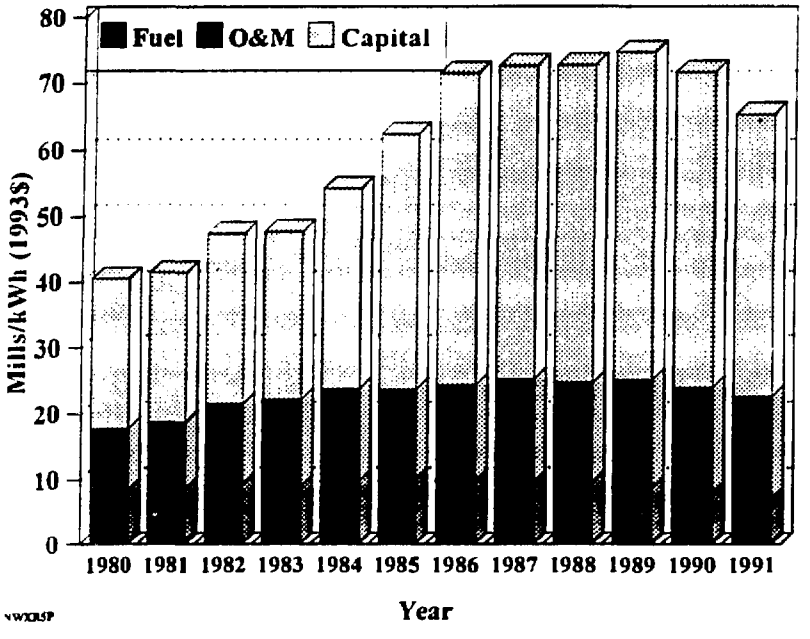


Fig. 2. Average U.S. nuclear busbar cost.

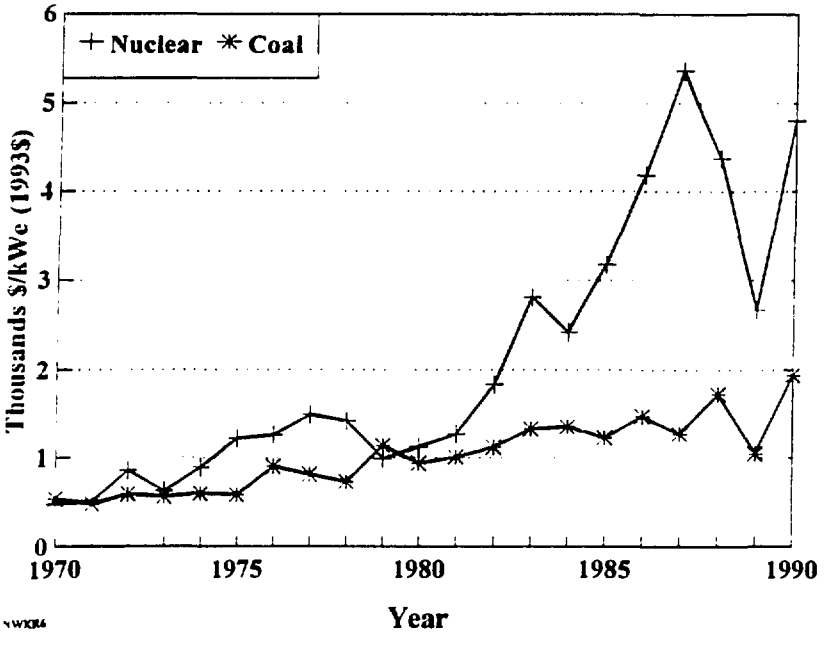


Fig. 3. Average capital cost by year on-line.

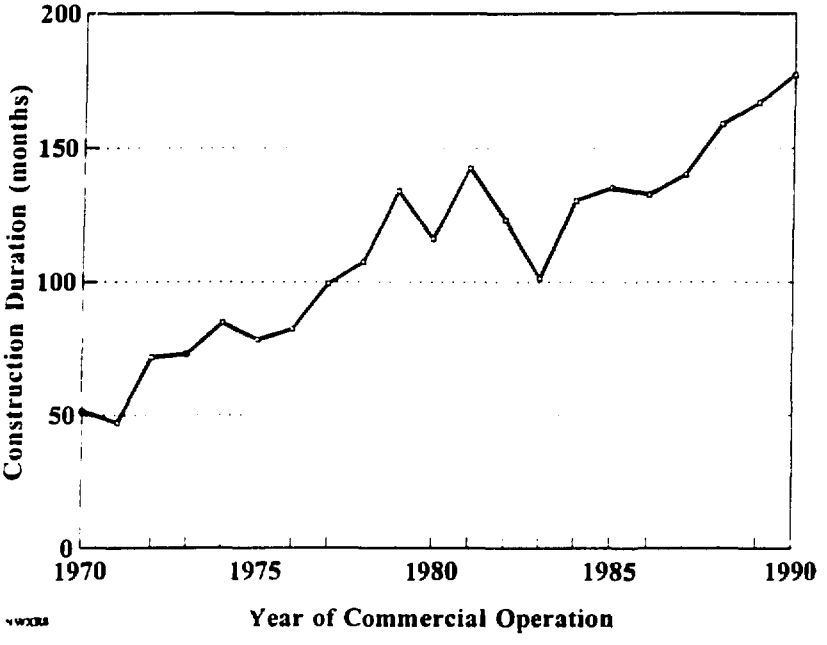


Fig. 4. Average nuclear plant construction duration.

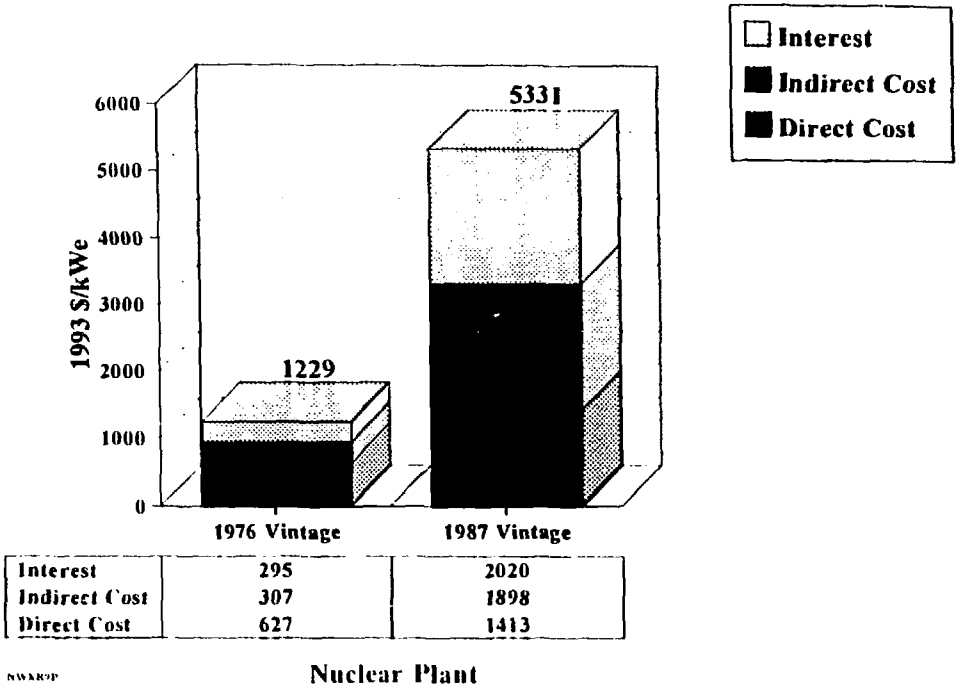


Fig. 5. Nuclear plant capital costs.

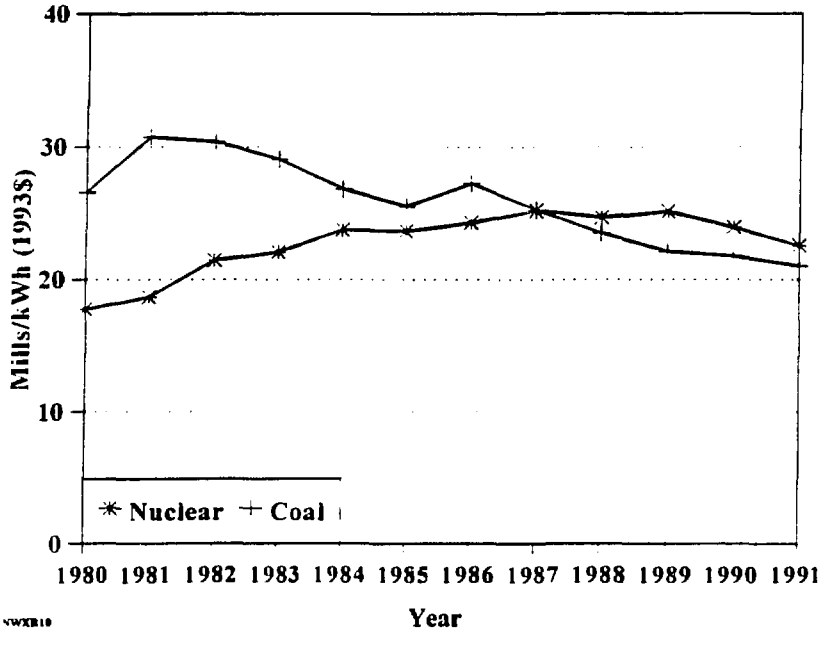


Fig. 6. Average plant production costs.

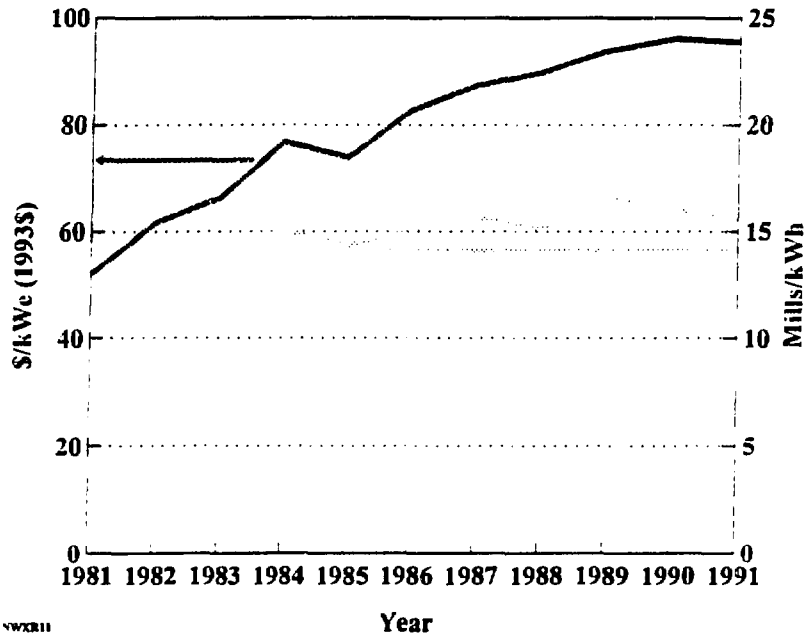


Fig. 7. Nuclear plant O&M costs.

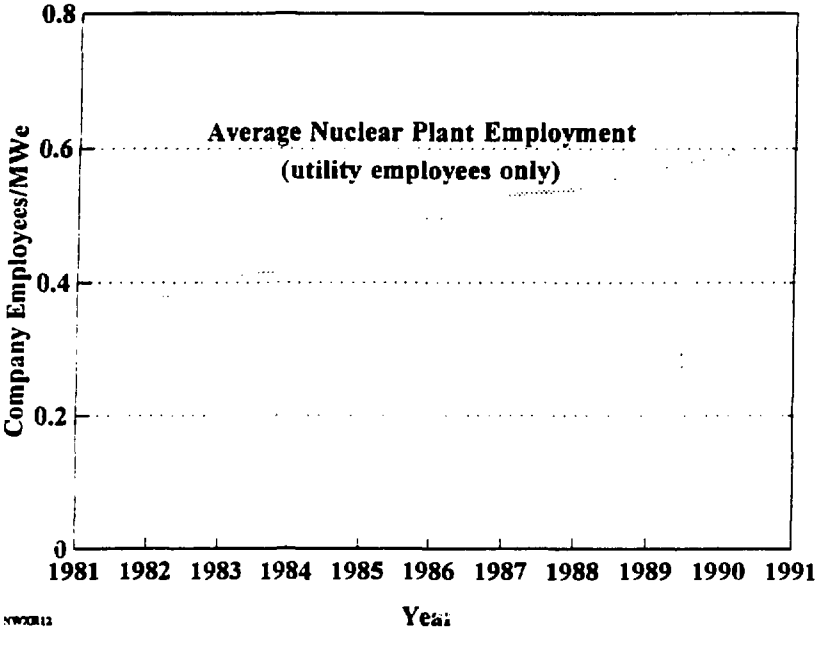


Fig. 8. Average nuclear plant employment.

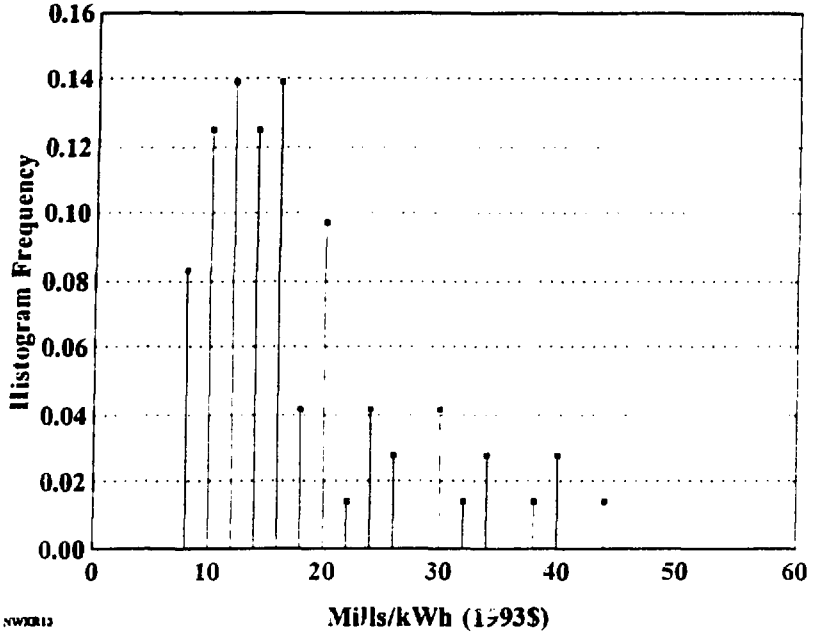


Fig. 9. Nuclear plant O&M cost variation.

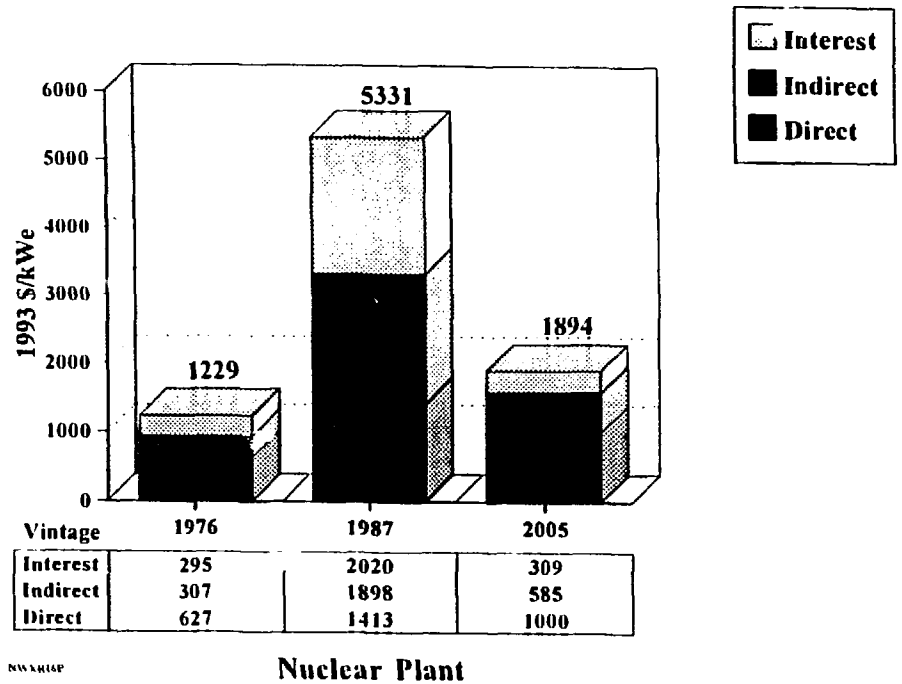


Fig. 10. Comparison of historical and projected nuclear capital costs.

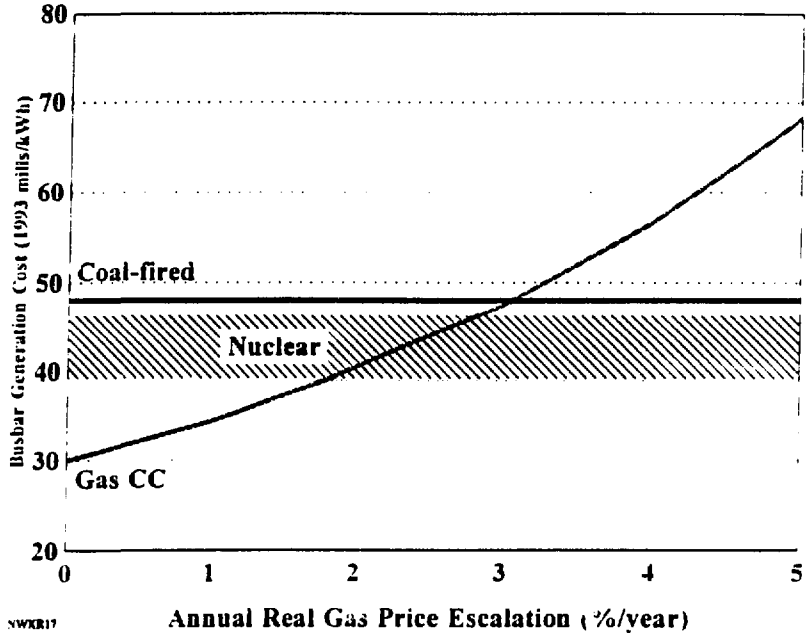


Fig. 11. Comparison of current and projected nuclear plant busbar costs.

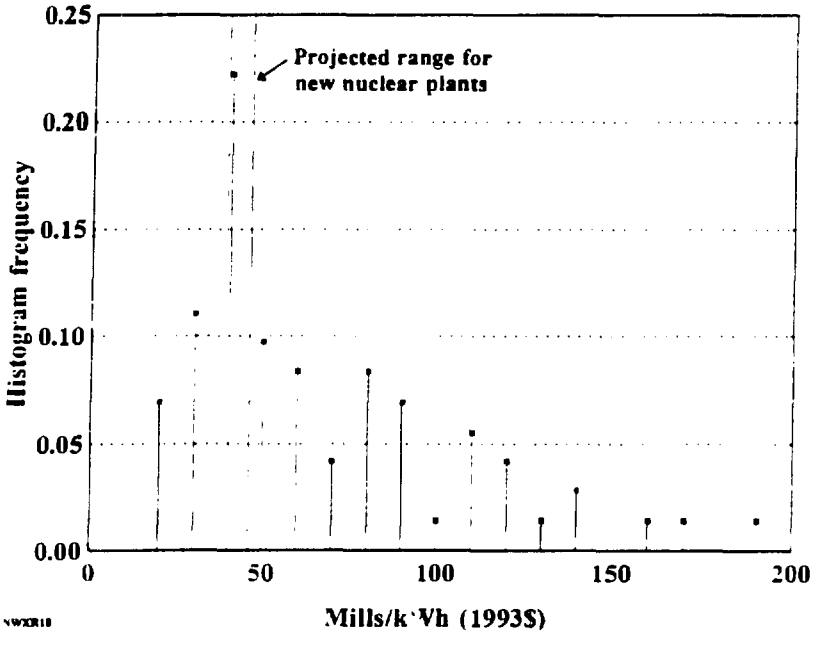


Fig. 12. Comparison of current and projected nuclear plant busbar costs.

# Nuclear Economics Issues and Facts

C. R. Hudson

Engineering Economic Evaluations Group

Oak Ridge National Laboratory

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# This presentation will address

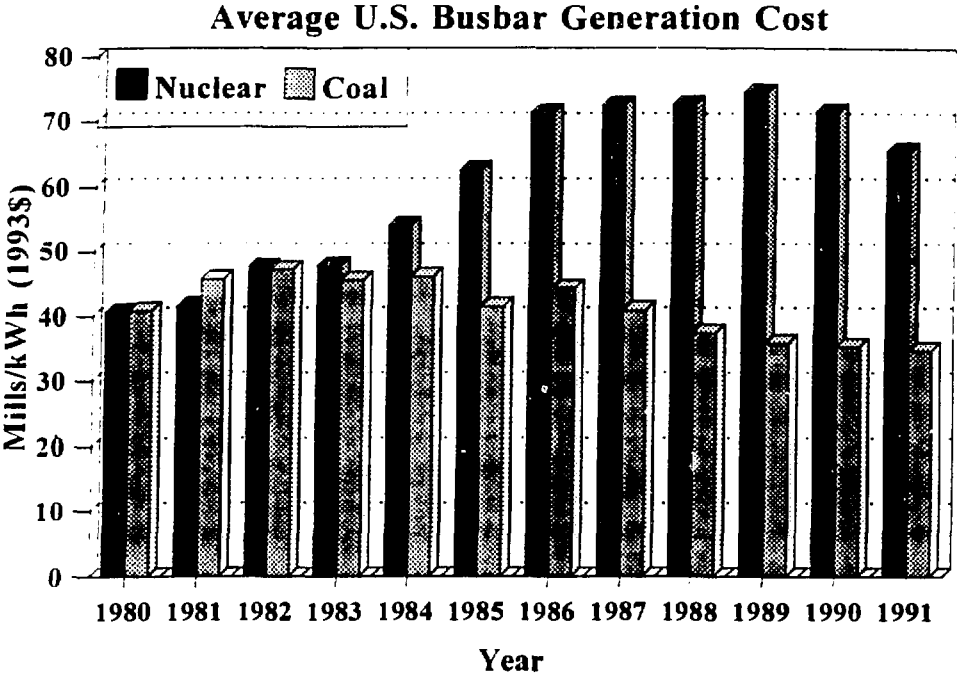
- Historical nuclear plant costs
- New nuclear plant cost projections
- Warning signals for future plants

NW2

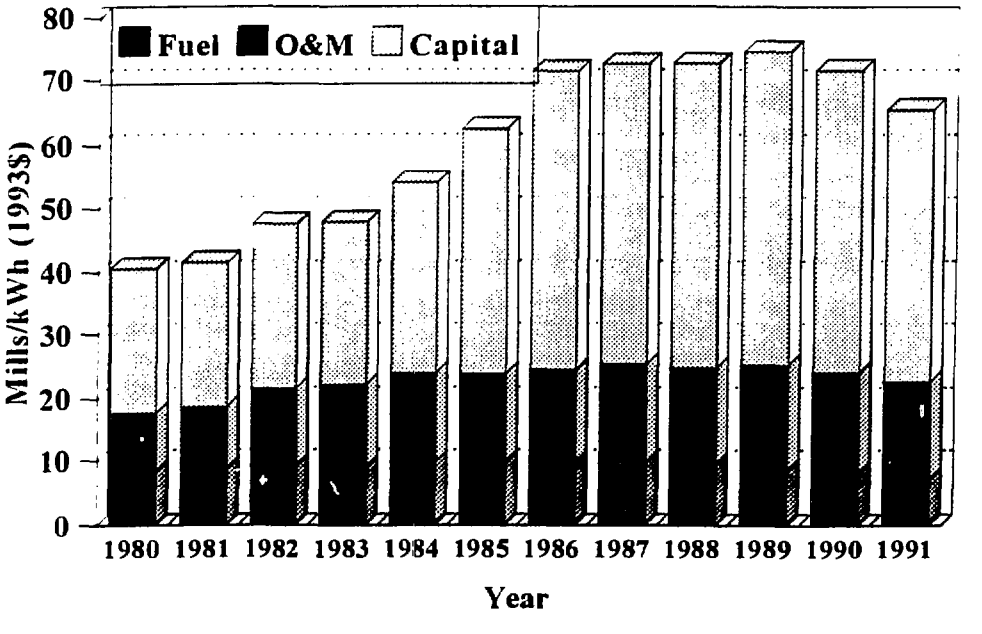
"In order to know where you're going, it's important to know where you've been."

NW3A

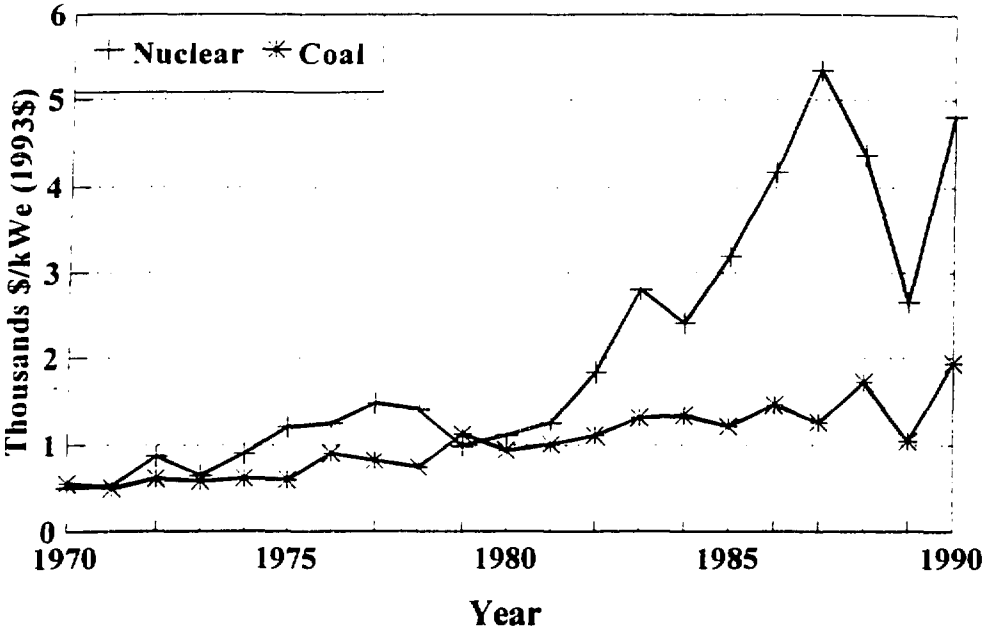
# Along the way of the first nuclear era, something happened to nuclear power costs.




# Nuclear plant capital cost is the major component of busbar cost.



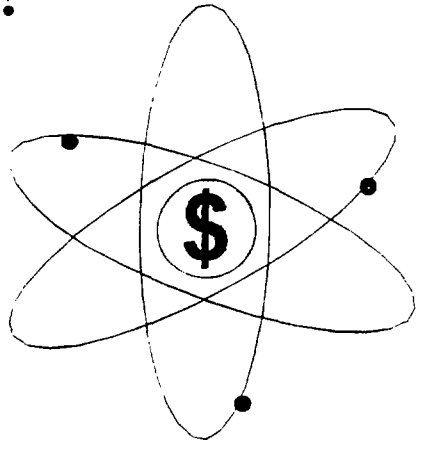
# New nuclear plant capital cost grew rapidly after the TMI accident.




NW6

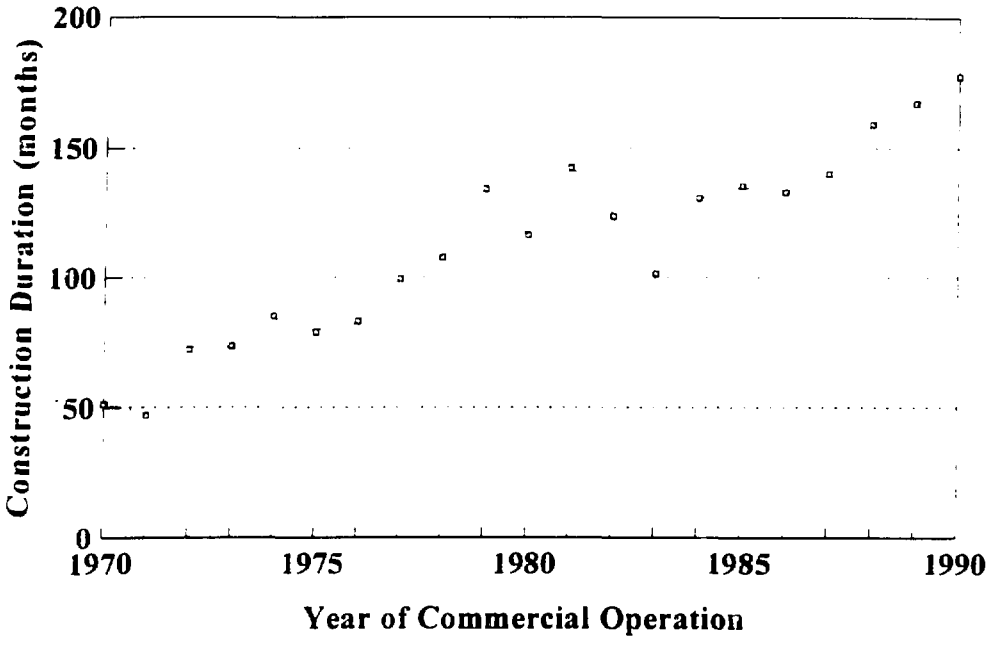
# What caused nuclear plants to cost so much?

- Changes/growth in regulations
- Lack of design standardization
- Changes in electricity demand

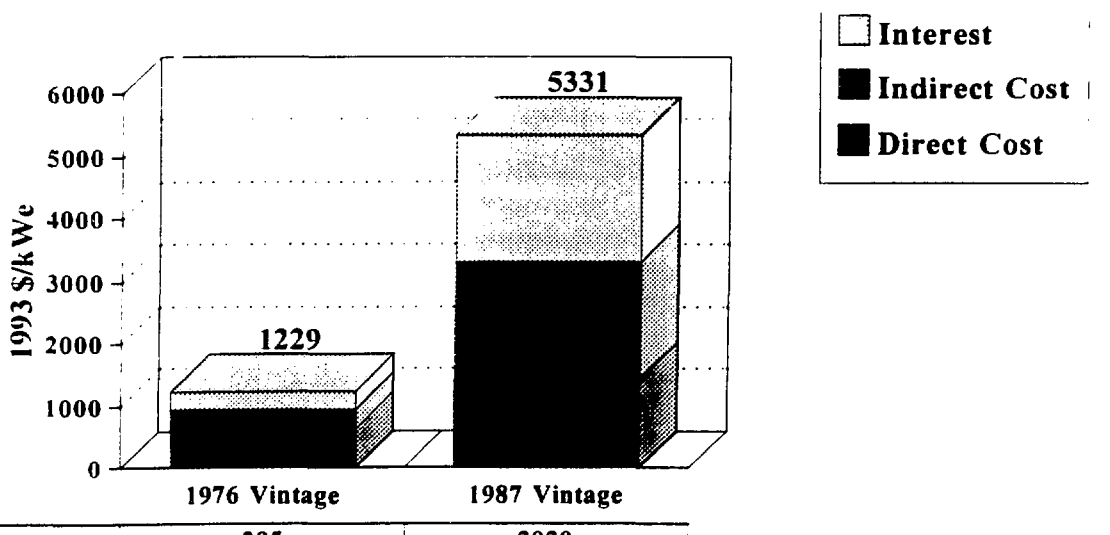



NW7

# As a result, construction durations increased for nuclear plants.



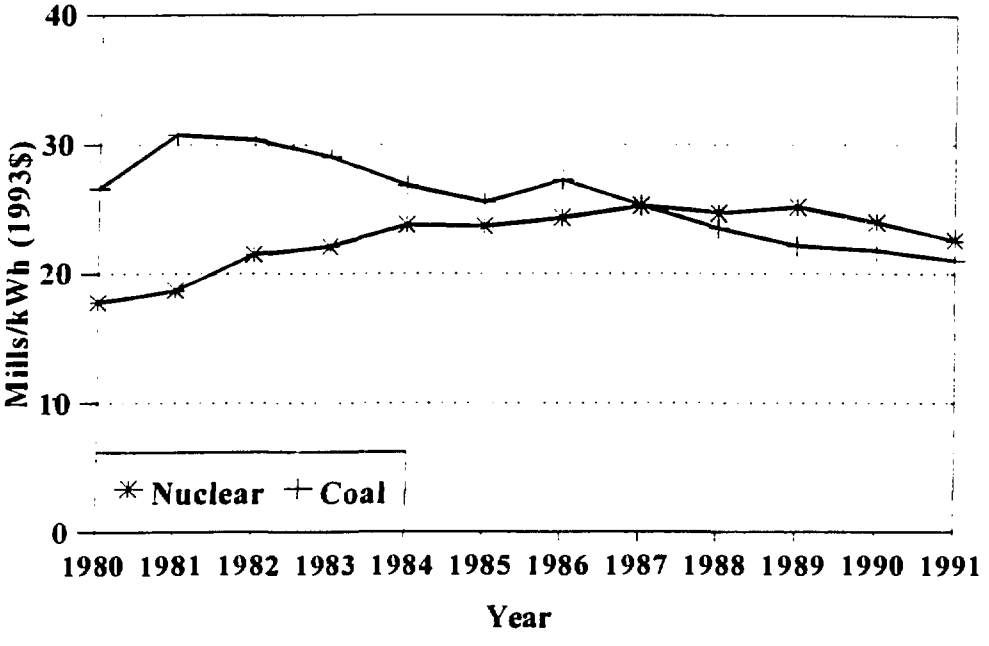

# Long construction durations and lack of design standardization affected capital costs.




| | | |
|---|---|---|
| Interest | 295 | 2020 |
| Indirect Cost | 307 | 1898 |
| Direct Cost | 627 | 1413 |

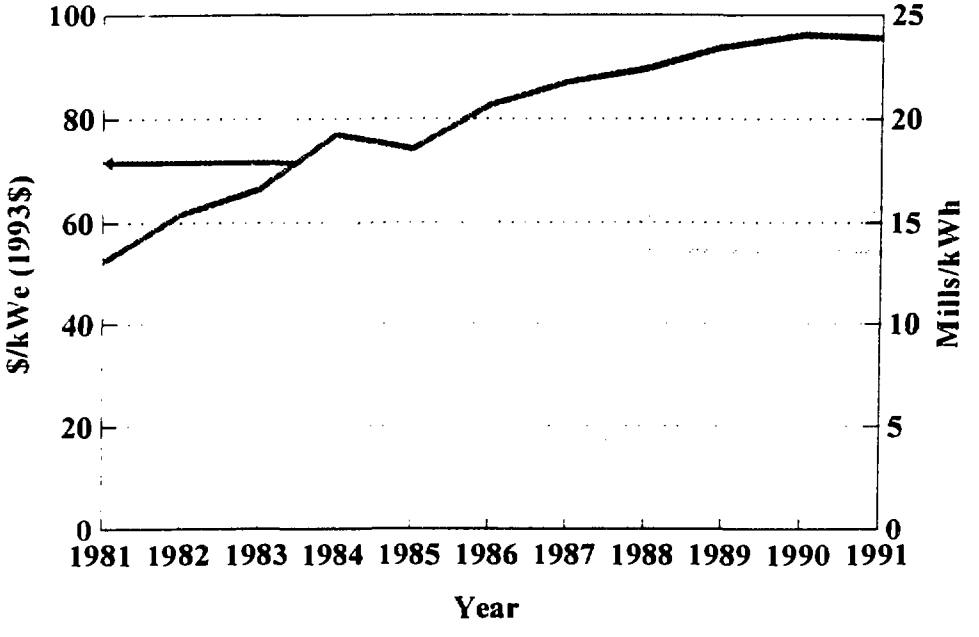
Nuclear Plant

# Differences in average production costs have narrowed.



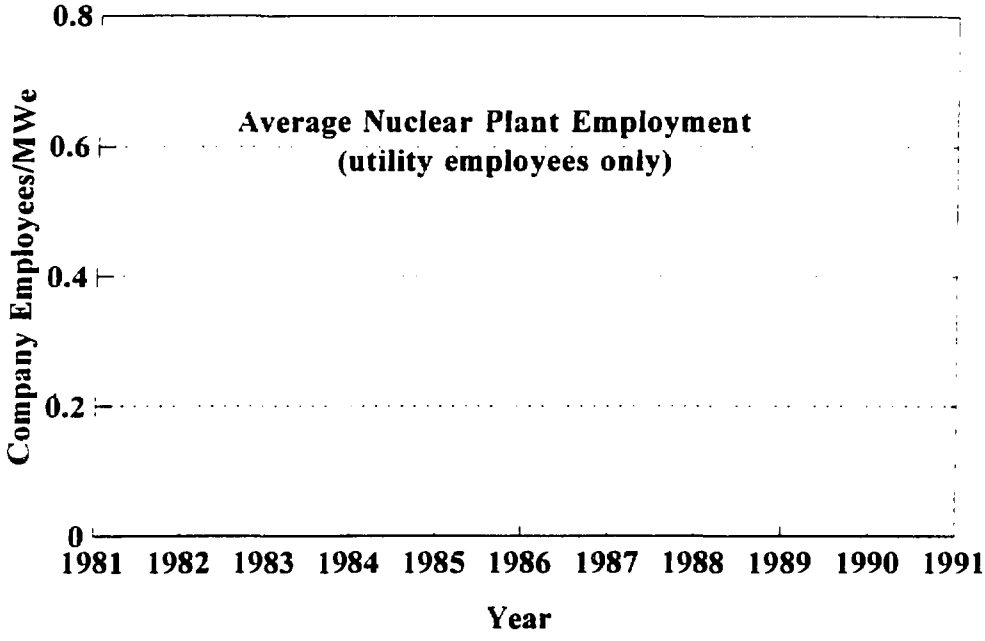

NW10

# O&M is a major contributor to nuclear production cost.



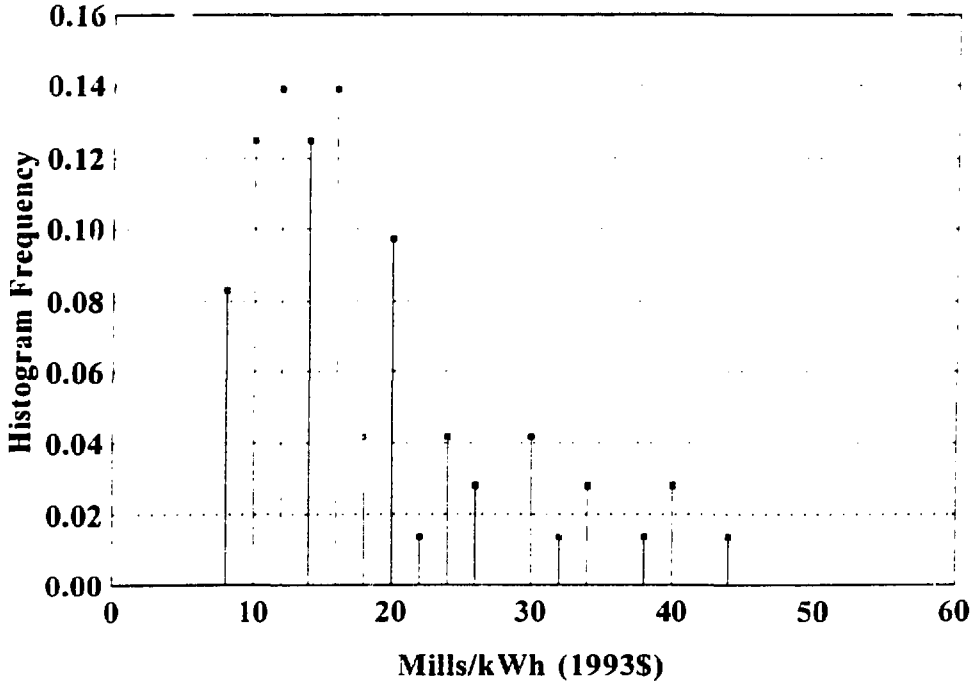

NW11

# Personnel growth is a major contributor to O&M cost.




NW12

# Nuclear plant O&M costs vary widely.




NW13

# What does the future hold?

NW14

# For nuclear power:

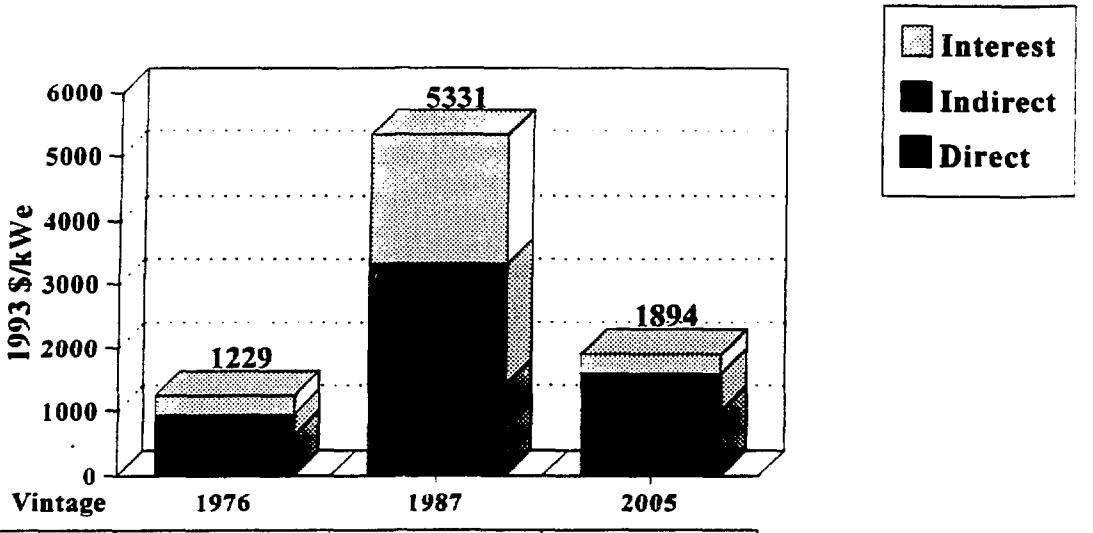
- Standardized, certified designs
- Modular construction

**which could lead to**

- Shorter construction time
- Elimination of redesign
- Lower, more predictable costs

NW15P

# How might nuclear plant capital costs differ from earlier experience?



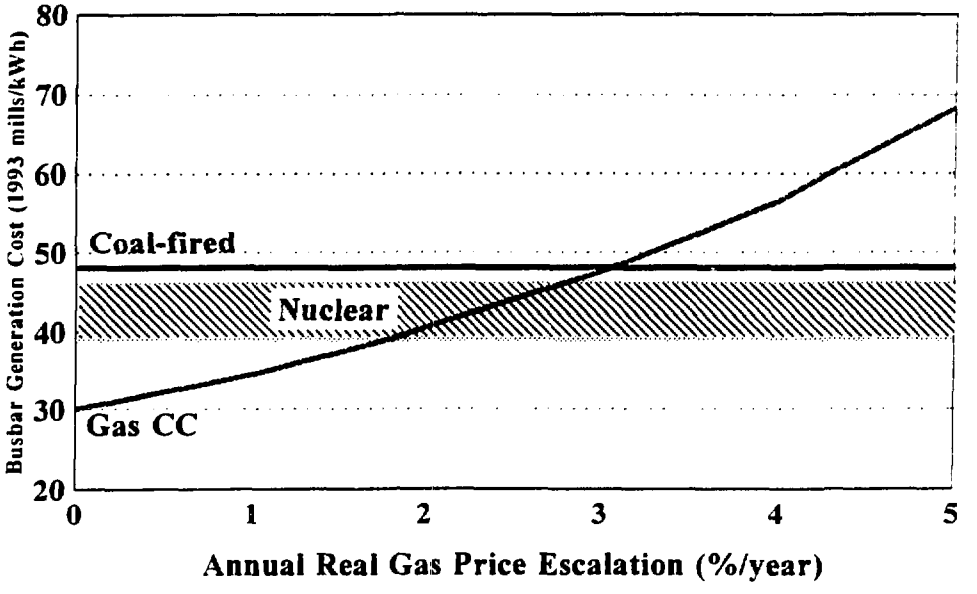

| | | | |
|---|---|---|---|
| Interest | 295 | 2020 | 309 |
| Indirect | 307 | 1898 | 585 |
| Direct | 627 | 1413 | 1000 |

Nuclear Plant

NW16P

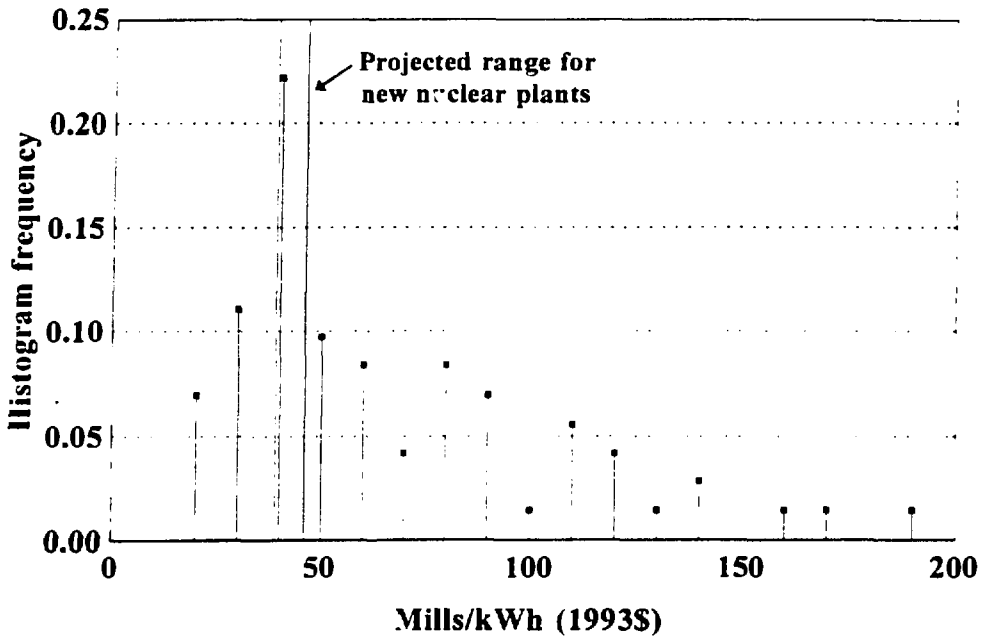
# Busbar projections show nuclear to be competitive.

## (Year 2000 Start-up)




NW17

# Projected busbar costs of future plants are being achieved by current plants.




NW18

# Can nuclear plants achieve these cost projections?

**Possibly ... if**

- **There is a stable state and federal regulatory environment**
- **Plants are constructed from a standardized, certified design**

NW19

# Here are some warning signs of potential economic problems for future nuclear plants:

- Relaxation of design standardization
- Low percentage of design completion before construction start
- Lack of certified design
- Problems in obtaining combined construction permit/operating license
- Large ITAAC requirements
- Problems in achieving lower plant staffing levels

NW20