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Analysis of Nuclear Power Economics

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ANALYSIS OF NUCLEAR POWER ECONOMICS

by

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ABSTRACT

This document is a briefing booklet that contains the results of an analysis of nuclear power economics. The format, consistent with a visual display, consists of charts, tables, and graphs interspersed with brief discussion sections.

The booklet does not attempt to cover all issues related to nuclear power economics, but does answer the following key questions.

- What are the components of the cost of nuclear power?
- How does the cost of generating electricity from a new nuclear plant compare with the cost of generating electricity from a new coal-fired plant?
- Where does the Federal Government have leverage regarding the cost of nuclear power?
- Is the reprocessing of spent nuclear fuel cost effective?
- At what point is the Liquid Metal Fast Breeder Reactor cost effective?

ANALYSIS OF NUCLEAR POWER ECONOMICS
OBJECT – ANSWER THE FOLLOWING QUESTIONS:

(1) What are the components of the cost of nuclear power?

(2) How does the cost of generating electricity from a new nuclear plant compare with the cost of generating electricity from a new coal–fired plant?

(3) Where does the Federal Government have leverage regarding the cost of nuclear power?

(4) Is the reprocessing of spent nuclear fuel cost effective?

(5) At what point is the Liquid Metal Fast Breeder Reactor cost effective?

TOTAL POWER COSTS FOR A PRESSURIZED WATER REACTOR ON THE ONCE-THROUGH CYCLE

Nuclear power costs can be grouped into three general categories--capital cost, operation and maintenance cost, and fuel cost. The capital cost component includes all capital cost related items such as income tax on invested capital, recovery of capital investment, return on capital investment, property insurance, property taxes, and interim capital replacements.

The fuel cost component consists of four main categories: uranium purchases, enrichment costs, fabrication costs, and back-end costs. Back-end costs for the once-through cycle are spent-fuel shipping costs and permanent spent-fuel disposal costs.

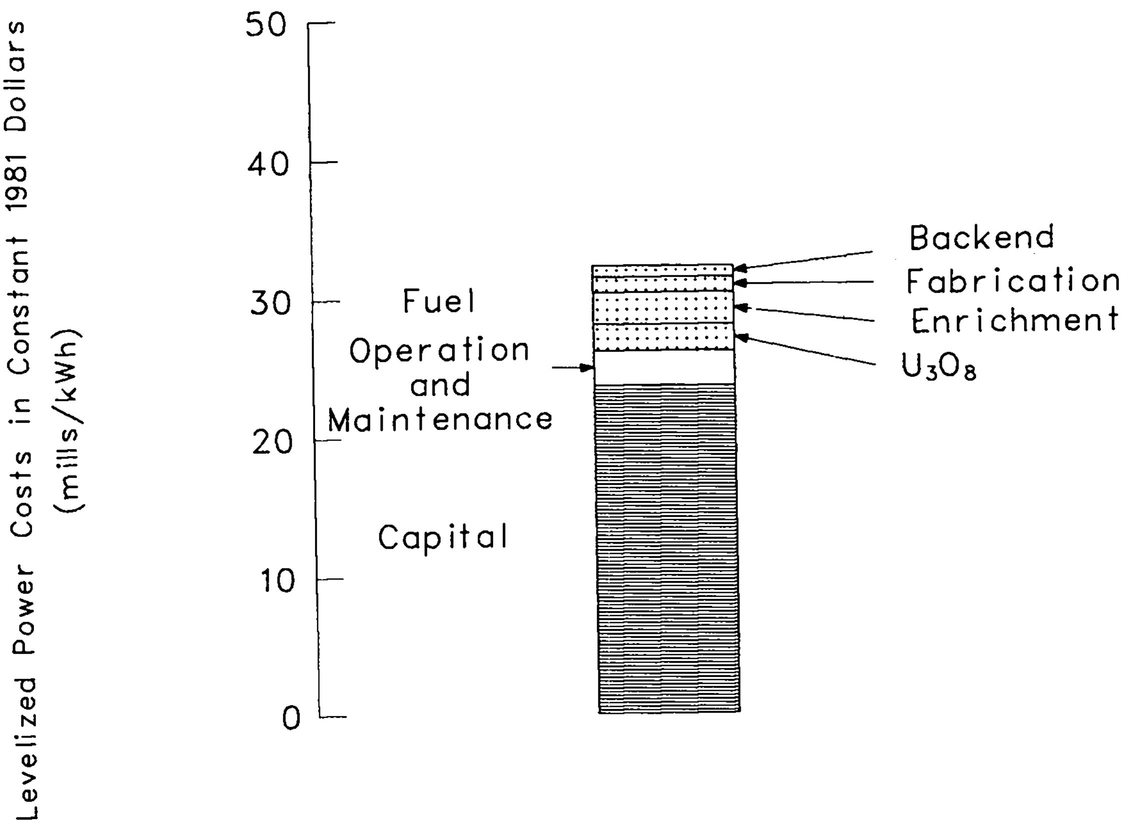
There are two important points to be made from this figure. First, the capital cost component dominates the total power cost, contributing about 75% to the total.

Second, the incentive for reprocessing and for the LMFBR is to reduce or eliminate the U_3O_8 and enrichment component. However, these two components are fairly small, contributing only about 13% to the total power cost.

TOTAL POWER COST COMPONENTS IN mills/kWh[a]

Component	Nuclear Power Cost[b]	
Capital	23.7	
Operation and Maintenance	2.5	
Fuel	6.1	
U_3O_8		1.9
SWU		2.3
Fabrication		1.1
Backend		0.8
-----	-----	
Total	32.2	

[a]All costs are in constant January 1, 1981, dollars.
[b]Pressurized water reactor on the once-through cycle.



Total Power Costs for a Pressurized Water Reactor on the Once-Through Cycle

COMPARISON OF TOTAL POWER COST COMPONENTS FOR A PRESSURIZED WATER REACTOR ON THE ONCE-THROUGH CYCLE WITH A COAL-FIRED POWER PLANT

This figure compares the total power cost of a PWR on the once-through cycle with a coal-fired power plant. For the nuclear plant, the price of U_3O_8 was varied from $25/lb (the current price) to $75/lb. For the coal plant, the price of coal was varied from $10/ST to $40/ST.

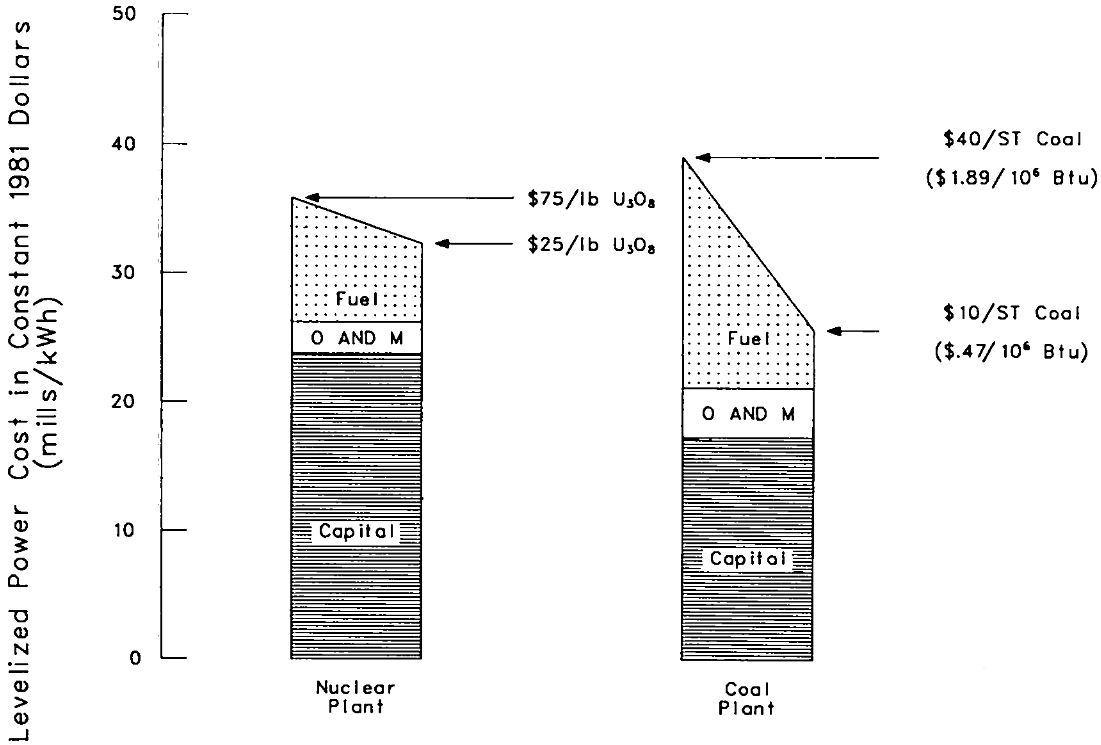
Because the heat content of coal can vary by almost a factor of two, a better measure of coal costs is cents per million Btu. This calculation assumed a coal heat content of 10 560 Btu/lb (about equal to the US average). Therefore, on this basis the range of coal costs shown is 47¢ to 189¢ per million Btu.

At today's U_3O_8 prices, the coal price at which the cost of power from a nuclear plant is equal to the cost of power from a coal plant is about 118¢ per million Btu. For coal with a heat content of 10 560 Btu/lb, this translates to $25/ST.

TOTAL POWER COST COMPONENTS IN mills/kWh[a]

Component	Nuclear[b]	Coal
Capital	23.7	17.3
Operation and Maintenance	2.5	3.8
Fuel	6.1	4.5[c]-18.0[d]
Total	32.3	25.6[c]-39.1[d]

[a]All costs are in constant January 1, 1981, dollars.
[b]Pressurized water reactor on the once-through cycle, $25/lb U_3O_8.
[c]$10/ST coal (47 cents/$10^6$ Btu).
[d]$40/ST coal (189 cents/$10^6$ Btu).



Comparison of Total Power Cost Components for a Pressurized Water Reactor on the Once-Through Cycle with a Coal-Fired Power Plant

COAL DATA FOR 1979

The average delivered price for coal in 1979 varied from 67¢ to 153¢ per million Btu with a US average of 122¢. This corresponds to a range of $13/ST to $41/ST of coal.

In general, the western part of the US had coal prices that were less expensive than the East, even taking into account the fact that the heat content of the coal from the West tended to be lower than the coal from the East.

Five of the nine regions had delivered-coal prices greater than the coal-nuclear breakeven price of 118¢ per million Btu. Because these data are for 1979, by now the west North Central and west South Central regions may also have coal costs exceeding the 118¢ value.

COAL DATA FOR 1979

	HEAT CONTENT (BTU/lb)	AVERAGE DELIVERED PRICE ($/TON)	($/10^6 BTU)
New England	13400	41	1.53
Middle Atlantic	12100	31	1.28
East North Central	10800	29	1.35
West North Central	9200	18	1.00
South Atlantic	12000	34	1.42
East South Central	11500	31	1.34
West South Central	7400	15	1.01
Mountain	9800	13	.67
Pacific	8100	14	.84
TOTAL US	10560	26	1.22

SOURCE: "Cost and Quality of Fuels for Electric Utility Plants--1979," DOE/EIA-0191(79), Energy Information Administration, US Department of Energy (June 1980).

COMPARISON OF CHANGE REQUIRED TO INCREASE TOTAL POWER COSTS BY 1 mill/kWh WITH CURRENT COSTS

For nuclear plants, it is obvious that the capital cost is where there is the most leverage regarding the total power cost. A change of only 4% in the capital cost changes the total power cost of a nuclear plant by 1 mill/kWh. The other components of nuclear power, including fuel cycle costs, have much less impact on the total power cost. A change of more than 45% is required in the other parameters to change the total nuclear power cost by 1 mill/kWh.

For coal plants, the capital cost also has a great deal of leverage. However, in contrast to nuclear plants where the fuel cycle components are fairly small, relatively minor changes in coal costs can have a large impact on the total power cost. For example, an increase of only $2.25/ton (or 11¢ per million Btu) increases the total power cost of a coal plant by 1 mill/kWh.

COMPARISON OF CHANGE REQUIRED TO INCREASE TOTAL POWER COST BY 1 mill/kWh WITH TYPICAL CURRENT COSTS*

NUCLEAR PLANT**	CHANGE TO EQUAL 1 mill/kWh	CURRENT COSTS
Capital cost	55 $/kWe	1335 $/kWe
Separative work cost	50 $/kg of SWU	112 $/kg of SWU
U_3O_8	15 $/lb	25 $/lb
Fabrication cost	180 $/kg HM	228 $/kg HM
Fuel cycle backend cost	250 $/kg HM	195 $/kg HM
FOSSIL PLANT		
Capital cost	55 $/kWe	975 $/kWe
Coal cost	2.25 $/ton	10–40 $/ton

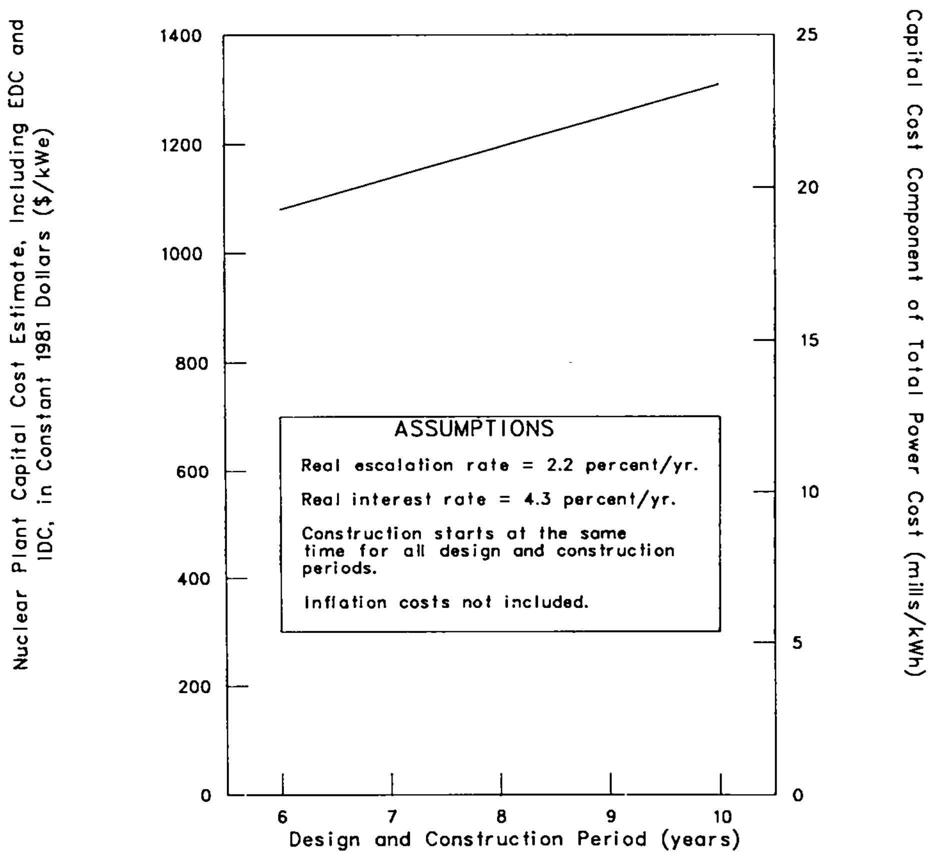
*All costs are in constant 1/1/81 dollars.
**Pressurized water reactor using low-enriched uranium on the once-through cycle.

IMPACT ON CAPITAL COST OF DECREASING THE DESIGN AND CONSTRUCTION PERIOD (WITHOUT INFLATION)

One method for reducing nuclear plant capital costs is to reduce the design and construction period. This figure shows the effect on capital costs, including escalation during construction (EDC) and interest during construction (IDC), of compressing the design and construction period from 10 years to 6 years.

These calculations assume that construction for all design and construction periods started at the same time. Consequently, the plant with a 6-year design and construction period would come online 4 years before the plant with a 10-year period.

Reducing the design and construction period from 10 years to 6 years reduces the capital cost by $161/kWe in 1981 dollars. This translates into about 3 mills/kWh, or approximately 10% of the total cost of nuclear power.



Nuclear Plant Capital Cost Estimate, Including EDC and IDC, in Constant 1981 Dollars ($/kWe)
1400
1200
1000
800
600
400
200
0
25
20
15
10
5
0
Capital Cost Component of Total Power Cost (mills/kWh)
ASSUMPTIONS
Real escalation rate = 2.2 percent/yr.
Real interest rate = 4.3 percent/yr.
Construction starts at the same time for all design and construction periods.
Inflation costs not included.
6
7
8
9
10
Design and Construction Period (years)

IMPACT ON CAPITAL COST OF DECREASING DESIGN AND CONSTRUCTION PERIOD (WITH INFLATION)

As shown in the previous figure, in constant dollars there is a fairly modest impact on total power cost by reducing the design and construction period. However, the impact in current dollars with high inflation rates is much larger. This table shows that, with a 15% inflation rate, reducing the design and construction period from 10 years to 6 years halves the construction cost in current dollars. Therefore, with high inflation rates, long design and construction periods could severely restrict access to capital markets.

This table also shows the impact of a nuclear power plant being completed in 10 years and then waiting 4 years for start-up approval. With a high inflation rate, this can more than double the plant cost in current dollars.

IMPACT ON CAPITAL COST OF DECREASING DESIGN AND CONSTRUCTION PERIOD

DESIGN CONSTRUCTION PERIOD (YEARS)	CAPITAL COST ESTIMATES, INCLUDING EDC AND IDC ($/kWe) CONSTANT DOLLARS	CURRENT DOLLARS (.05 INFLATION)	CURRENT DOLLARS (.10 INFLATION)	CURRENT DOLLARS (.15 INFLATION)
6	1174	1573	2080	2715
8	1249	1845	2677	3820
10	1335	2175	3462	5400
14[a]	1580	3126	6000	11180

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[a] ASSUMES THE PLANT IS COMPLETED IN 10 YEARS, AND THEN WAITS 4 YEARS FOR START-UP APPROVAL.

COMPARISON OF TOTAL POWER COST FOR A THERMAL REACTOR RECYCLE SYSTEM WITH A PWR ON THE ONCE-THROUGH CYCLE

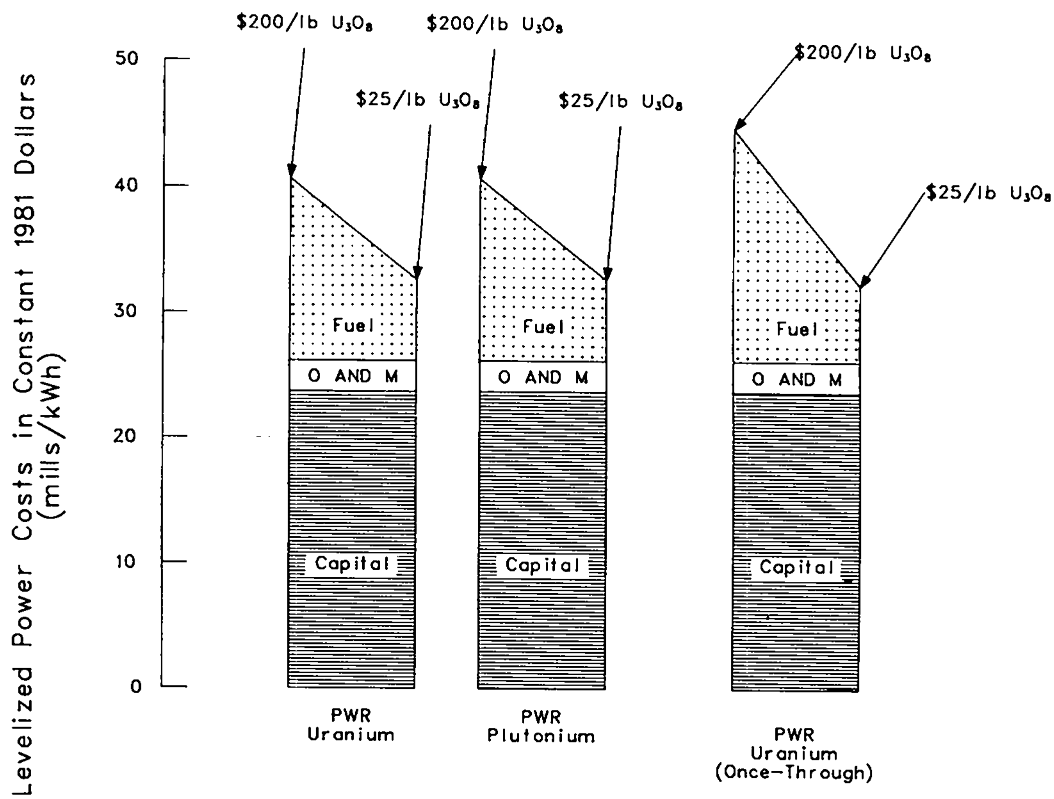
For fuel cycle systems that contain more than one reactor type, the total power cost of the complete system must be calculated. A related problem is to determine the value of the fissile plutonium that is produced. This analysis used the concept of "indifference prices" to determine fissile plutonium prices. The logic of indifference price calculation is the following.

Consider a closed fuel-cycle system consisting of a PWR loading low-enriched uranium and another PWR loading plutonium. Therefore, one reactor is a net producer of plutonium and the other reactor a net consumer of plutonium. If the value of the plutonium produced in this system is very high, the total power cost of the plutonium-producing reactor would be less than the power cost of the plutonium-consuming reactor. Consequently, more plutonium-producing reactors would be built to take advantage of the reduced costs.

With the increased availability of the produced fissile plutonium, its value would eventually decrease until an economic balance was achieved between the cost of producing and consuming the fuel. At equilibrium, the indifference price of plutonium is that price which equalizes the total power cost of the reactor producing plutonium and the reactor consuming plutonium. This is demonstrated in the accompanying figure where the total power cost of both reactors is identical.

Using the above approach and assuming $25/lb for U_3O_8, the total power cost for a thermal reactor recycle system is 32.7 mills/kWh compared to 32.3 mills/kWh for a PWR on the once-through cycle. This small difference is well within the uncertainties of the cost assumptions. Therefore, at today's uranium prices and with the cost assumptions used in this analysis, there is little economic incentive for thermal reactor recycle. As a result, because of the financial risk involved, there is little chance of industry initiative in this area.

This figure also shows that the total power cost for a thermal reactor recycle system is considerably less sensitive than a PWR on the once-through cycle to the price of U_3O_8. For example, when U_3O_8 reaches $200/lb, the total power cost for a thermal reactor recycle system is 40.6 mills/kWh compared to 44.4 mills/kWh for the once-through cycle. As shown earlier, an increase of $15/lb in the price of U_3O_8 raises the total power cost of a PWR on the once-through cycle by about 1 mill/kWh. For thermal reactor recycle, the price of U_3O_8 has to increase by nearly $22/lb to raise the total power cost of the system by 1 mill/kWh.



Comparison of Total Power Cost for a Thermal Reactor Recycle System with a PWR on the Once-Through Cycle

COMPARISON OF TOTAL POWER COST FOR A LMFBR FUEL CYCLE SYSTEM WITH A PWR ON THE ONCE-THROUGH CYCLE

The concept of indifference prices used for the thermal reactor recycle system was also used for the LMFBR fuel cycle system. For this system, the net producer of plutonium is the LMFBR whereas the net consumer is a PWR loading plutonium.

For reasons explained in the description of the thermal reactor recycle system, the total power costs of both reactors in the LMFBR system are identical. For the assumptions used in this analysis, the LMFBR fuel cycle system is more expensive than the PWR once-through system when uranium is less than about \$165/lb of U_3O_8.

There are two principal reasons why uranium must reach such a high price before the once-through system is more expensive than the LMFBR system. The first reason is the relative insensitivity of the total power cost of the once-through system to the price of uranium. Each \$15/lb increase in the price of U_3O_8 only increases the total power cost of the once-through system by 1 mill/kWh. The total power cost of the LMFBR fuel-cycle system is, of course, independent of the price of U_3O_8.

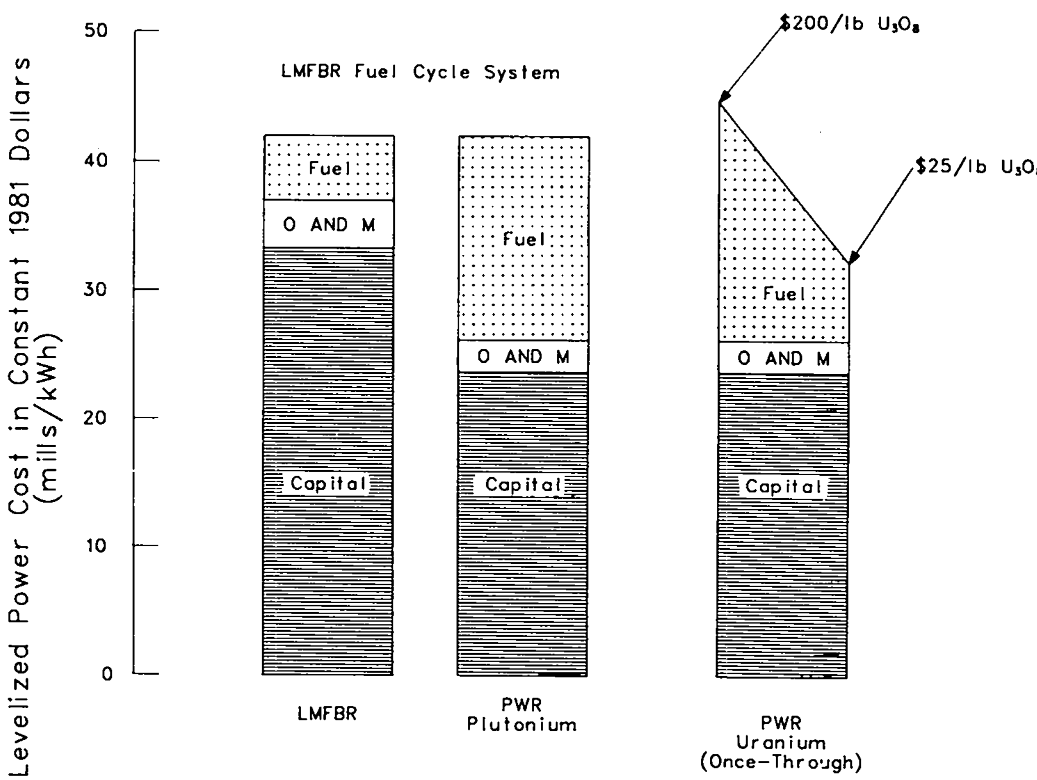
The second reason is the higher LMFBR capital cost. This analysis assumed that the LMFBR is 40% more expensive than a comparable size PWR (or \$535/kWe more) and previous tables showed that total power costs are very sensitive to capital cost.

This is a time-independent analysis that only considers equilibrium systems. It does not draw any conclusions as to <u>when</u> U_3O_8 prices are likely to reach \$165/lb, or how long it would take for an LMFBR system to reach equilibrium. Such an analysis needs to be done.

TOTAL POWER COST COMPONENTS IN mills/kWh[a]

Component	LMFBR Fuel Cycle System: LMFBR	LMFBR Fuel Cycle System: PWR (Plutonium)	PWR Once-Through (Uranium Fuel)
Capital	33.3	23.7	23.7
Operation and Maintenance	3.7	2.5	2.5
Fuel	5.0	15.8	6.1[b]-18.2[c]
Total	42.0	42.0	32.3[b]-44.4[c]

[a]All costs are in constant January 1, 1981 dollars.
[b]\$25/lb U_3O_8.
[c]\$200/lb U_3O_8.



Comparison of Total Power Cost for a LMFBR Fuel Cycle System with a PWR on the Once-Through Cycle

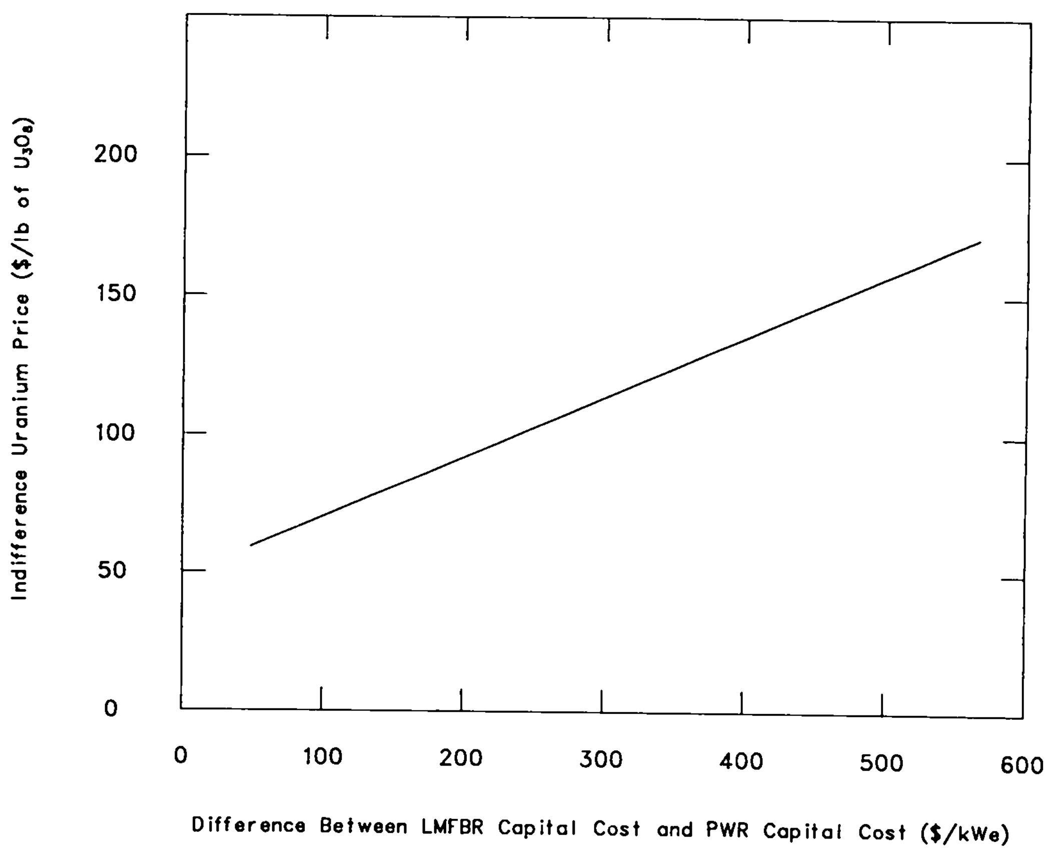
EFFECT OF REDUCING THE DIFFERENCE BETWEEN LMFBR CAPITAL COSTS AND PWR CAPITAL COSTS

The results of the LMFBR economics calculations shown in the previous figure were that the LMFBR fuel-cycle system is more expensive than the PWR once-through system when U_3O_8 is less than $165/lb. The price of U_3O_8 where the total power costs of both systems would be equal is referred to as the U_3O_8 indifference price.

The key variable in the calculation of U_3O_8 indifference prices, and the one producing the largest uncertainty, is the difference between the LMFBR capital cost and the PWR capital cost. A U_3O_8 indifference price of $165/lb corresponds to a capital cost difference of $535/kWe.

This figure illustrates the impact that reducing this capital cost difference has on the U_3O_8 indifference price. If the LMFBR is only $100/kWe more expensive than the PWR, the U_3O_8 indifference price decreases to about $70/lb.

In general, the U_3O_8 indifference price decreases by about $22/lb for each $100/kWe decrease in capital cost differential. Therefore, reducing the difference between LMFBR and PWR capital costs would greatly enhance the economic viability of the LMFBR.


Indifference Uranium Price ($/lb of U_3O_8)
200
150
100
50
0
0
100
200
300
400
500
600
Difference Between LMFBR Capital Cost and PWR Capital Cost ($/kWe)

ANALYSIS OF NUCLEAR POWER ECONOMICS

CONCLUSIONS

(1) The capital cost contributes about 75 percent to the total cost of nuclear power.

(2) Electricity from new nuclear power plants would be less expensive than new coal power plants if coal is more than approximately 25 dollars/ton.

(3) The most leverage regarding the cost of nuclear power is in the capital cost.

(4) Reducing the design and construction period from 10 years to 6 years would reduce the total cost of nuclear power by approximately 3 mills/kWh (ignoring inflation), but other considerations are important.

(5) At today's uranium prices, reprocessing spent fuel for thermal reactor recycle is marginally cost effective.

(6) An equilibrium LMFBR fuel cycle system is more expensive than the current once-through cycle until U_3O_8 prices are more than approximately $165/lb. Timing estimates were not made.

ASSUMPTIONS FOR ANALYSIS OF NUCLEAR POWER ECONOMICS

Levelized life-cycle power costs were calculated for both nuclear and coal-fired plants using the payout method for determining revenue requirements. The fundamental assumption in this method is that the income over the lifetime of the plant must equal the expenses associated with the project. Income is derived from the revenue received from the sale of electricity. Expenses include the recovery of the investment, return on the investment, operation and maintenance costs, and fuel cycle costs.

A total of three nuclear reactor plant types and one coal plant were used in this analysis.

PWR (uranium fuel)

This reactor is a 1270-MWe pressurized water reactor (PWR) based on a Combustion Engineering design. The fuel is low-enriched (approximately 3%) uranium with a burnup of 30 MWd/kg heavy metal (HM).

On the once-through cycle, the 30-year U_3O_8 requirements are 7320 short tons and the enrichment requirements are 43.8×10^5 kg of SWU. With reprocessing and uranium recycle, the 30-year U_3O_8 requirements are 5550 short tons, the enrichment requirements are 41.3×10^5 kg of SWU, and 6650 kg of fissile plutonium are produced.

PWR (plutonium fuel)

This reactor is also a 1270-MWe PWR based on a Combustion Engineering design. The fuel is plutonium and uranium with a burnup of 30 MWd/kg.

LMFBR

This reactor is a 1196-MWe liquid metal fast breeder reactor based on a General Electric low-temperature, homogeneous design. The fuel is plutonium and uranium in the core and uranium in the blankets. The core discharge exposure is 62 MWd/kg, and the breeding ratio is 1.355.

COAL PLANT

This plant has a power level of 1232 MWe (3299 MWt) with evaporative cooling towers and flue gas desulphurization equipment. The heating value of the coal was assumed to be 10 560 Btu/lb, and the plant requires 3.27×10^6 tons of coal per year.

ASSUMPTIONS FOR ANALYSIS OF NUCLEAR POWER ECONOMICS

METHODOLOGY – Levelized life-cycle costs were calculated using the payout method.

PLANT TYPES – PWR (Uranium Fuel)

PWR (Plutonium Fuel)

LMFBR (Plutonium Fuel)

COAL (With Scrubbers)

KEY PLANT-DEPENDENT COST ASSUMPTIONS

The accompanying table gives a comparison of the key plant-dependent cost assumptions used in this analysis. The costs shown were largely obtained from the "Final Report and Initial Update of the Energy Economic Data Base (EEDB) Program" (UE&C-DOE-790930), "Power Plant Capital Investment Cost Estimates: Current Trends and Sensitivity to Economic Parameters" (DOE/NE-009), the Replacement Production Reactor (RPR) project, and the Nonproliferation Alternative Systems Assessment Program (NASAP). Costs that were not in 1/1/81 dollars were converted using the GNP implicit price deflators.

The single most important cost variable is the capital cost. The basic source for PWR capital costs was a United Engineers and Constructors study that was part of the RPR project. The 40% cost penalty for LMFBRs compared to PWRs was taken from the EEDB and NASAP. The 37% cost penalty for PWRs compared to coal plants (with scrubbers) was taken from DOE/NE-009.

The remainder of the costs shown in this table are from the EEDB or NASAP.

KEY PLANT-DEPENDENT ASSUMPTIONS[a]

	PWR (U FUEL)	PWR (Pu FUEL)	LMFBR	COAL
Electric power level (MWe)	1270	1270	1196	1232
Capital cost ($/kWe)	1335	1335	1870	975
O and M charges ($/yr)				
Fixed	18.8×10^6	18.8×10^6	26.2×10^6	12.9×10^6
Variable	0.8×10^6	0.8×10^6	1.5×10^6	22.1×10^6
Fabrication cost ($/kg HM)				
Core	228	627	750	---
Axial blanket	---	---	750	---
Radial blanket	---	---	228	---
Backend cost ($/kg HM)				
Spent fuel shipping	23	28	121	---
Reprocessing				
Core	361	361	477	---
Axial blanket	---	---	477	---
Radial blanket	---	---	380	---
Waste shipping	13	13	32	---
Permanent waste storage	80	80	250	---
Permanent spent fuel storage[b]	172[b]	---	---	---

[a]All costs are in 1/1/81 dollars.
[b]Used for the once-through cycle.

KEY PLANT-INDEPENDENT ASSUMPTIONS

The accompanying table lists the key plant-independent assumptions used in this analysis. These values were largely obtained from recent trade periodicals (for example, current U_3O_8 and enrichment costs) and from the Nonproliferation Alternative Systems Assessment Program.

Although there is some evidence to indicate that capacity factors for nuclear plants are greater than for coal plants, a 70% value was assumed for all plant types. This is consistent with average capacity factors in 1979 for nuclear plants in the 400-749 MWe range--these plants had an average capacity factor of 69.4%. Larger plants had lower capacity factors, mainly because of two factors. First, the larger plants tended to be newer units and therefore encountered more shake-down problems. Second, the Three-Mile Island incident resulted in reduced operation. For example, five units were shut down to check safety calculations for their piping.

The reference case used the current cost for U_3O_8 of $25/lb, but calculations were also performed for U_3O_8 costs of $75 and $200/lb. The assumed enrichment cost of $112/kg SWU represents an average of the current cost of $114 for requirements contracts and $110 for fixed-commitment contracts. The other parameters shown have relatively minor impacts on the results.

KEY PLANT-INDEPENDENT ASSUMPTIONS[a]

Plant lifetime (years)	30
Capacity factor (percent)	70
Uranium enrichment cost ($/kg SWU)	112
Uranium cost ($/lb U_3O_8)	25
Tails composition (percent)	0.2
U_3O_8-to-UF_6 conversion cost ($/kg U)	5.0
U_3O_8-to-UF_6 conversion losses (percent)	0.5
Fuel fabrication losses (percent)	1.0
Fuel reprocessing losses (percent)	1.0

[a]All costs are in 1/1/81 dollars.

FINANCIAL PARAMETERS

This table shows the financial parameters used in this analysis. The real rates of return on debt and equity and the debt and equity fractions were taken from the Nonproliferation Alternative Systems Assessment Program. These values were based on historic electric utility money costs from 1949 to 1973 and are consistent with money costs used in other analyses.

While all costs are in constant 1/1/81 dollars, the calculations were performed assuming a 6% inflation rate. The reason for assuming an inflation rate even though the final results are in constant 1981 dollars is to account for income tax effects that result from inflation.

FINANCIAL PARAMETERS

Real rate of return on debt (percent/yr)	2.5
Real rate of return on equity (percent/yr)	7.0
Debt fraction	0.55
Equity fraction	0.45
Income tax rate (percent)	50.0
Inflation rate (percent/yr)	6.0
Investment tax credit rate (percent)	10.0
Property tax rate (percent/yr)	2.5
Interim capital replacement rate (percent/yr)	0.35
Property insurance rate (percent/yr)	0.25

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076-100	8.00	A05	226-250	14.00	A11	376-400	20.00	A17	526-550	26.00	A23
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