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THE COMPETITIVE ECONOMICS OF NUCLEAR POWER

FINAL REPORT

Richard Hellman
Professor of Economics
University of Rhode Island
Kingston, RI 02881

March 2, 1981

Prepared for

THE U.S. DEPARTMENT OF ENERGY
UNDER CONTRACT NO. EN-77-S-16-3098

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ABSTRACT

Some 12 components of a valid study of the competitive economics of a newly ordered nuclear power plant are identified and explicated. These are then used to adjust the original cost projections of four authoritative studies of nuclear and coal power economics.

SUMMARY

In the comparison of nuclear with coal power costs, and with alternatives, the time horizon is specified here as a plant ordered for commercial operation in 1993-2000. In this time frame, the use of low sulfur Appalachian coal with little or no flue gas desulfurization (FGD) becomes feasible in terms of availability. The use of high sulfur coal without FGD will probably also become feasible within five to ten years as new and more sophisticated combustion technologies become available, such as fluidized bed burning. To an important degree, more thorough coal cleaning and preparation will reduce FGD. These factors affect the competitive economics of a near future plant substantially.

Phase 1 of this study raises the question of what constitutes a valid study of the competitive economics of nuclear power, and identifies some dozen components of such a study. Among the more important are technical sufflation of costs, construction times, plant life, capacity factor, cost of replacement power, the YOYO factor (nonpredictability of availability), O & M, repairs and replacements, and decommissioning costs. The degree to which published studies meet these tests of validity is rated for each component on a scale of 10 = optimal achievable. On this scale, nuclear power studies are rated at 2.6 and coal studies at 4.5

Therefore, it is concluded that a valid study of nuclear power economics has yet to be published:

Phase 2 is an analysis of four authoritative case studies comparing nuclear and coal busbar costs. These are by the Atomic Energy Commission in 1975, the Energy Research and Development Administration in 1976, the Nuclear Regulatory Commission in 1979, and a private EXXON study of 1977. Adjustments were made to the original cost projections for a new plant, the adjustments being based on the data and logic explicated in Phase 1.

Because of differences in assumptions, methodologies and computational methods, the four cases cannot be compared directly by busbar costs. This problem is cir-

cumnavigated by comparing coal/nuclear ratios of each case. Unadjusted, in the studies of the three Federal agencies, coal ranged from 15 to 28 percent higher in total busbar cost; EXXON was 5.5 percent lower (for the first year of commercial operation). When adjusted for some 13 components, coal was cheaper by 55 to 64 percent. Coal would be cheaper still if three of these nuclear components could be estimated: the YOYO, repairs and replacements, and decommissioning.

For those interested in how to improve the performance and economics of existing and future nuclear power plants, an important derivation of the analysis presented here is a map of pathways by which to achieve this goal.

ACKNOWLEDGEMENT

The collaboration of Caroline J.C.
Hellman is gratefully acknowledged

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ABBREVIATIONS AND REFERENCES

Abbreviations and references are almost always explained at the initial mention. Several frequently used in this report are explained below.

CF: capacity factor. Also known as "plant factor."

FF: fossil fuel.

FGD: flue gas desulfurization, usually shown as with = w/FGD, or without = w/o FGD.

HF: human factors in operation of nuclear power plants.

KW and MW: kilowatt and megawatt.

KWH: kilowatt-hour

LWR, BWR, PWR: light water, boiling water or pressurized water reactors.

NP: nameplate rating.

AEC: Atomic Energy Commission.

ERDA: Energy R&D Administration.

DoE: Department of Energy.

NRC: Nuclear Regulatory Commission.

FPC: Federal Power Commission. FERC: Federal Energy Regulatory Commission.

TVA: Tennessee Valley Authority.

TMI: Three Mile Island nuclear power plant.

EPRI: Electric Power Research Institute, an industry organization.

BCEGB: British Central Electricity Generating Board.

EDF: Electricité de France.

NOTES OF DISCUSSIONS OF EUROPEAN NUCLEAR ECONOMICS:

V. 1: England. V..2: Germany. V. 3: France

Example of abbreviated page references: G-23.

Case study 1: AEC, The Nuclear Industry 1974. WASH 1174-74 (1975).

Case study 2: ERDA, Comparing New Technologies for the Electric Utilities, 12/9/76. ERDA 76-141, Draft Final Report.

Case study 3: NRC, Draft Environmental Statement, New England Power Units 1 and 2, NUREG-0529, published May 1979.

Case study 4: An Outline for a Discussion on the Economics of Nuclear Power with Dr. Richard Hellman of the University of Rhode Island, November 18, 1977 and subsequent conversations in 1979, by EXXON Research and Engineering Company.

I

INTRODUCTION

I. INTRODUCTION

The overall objective of this paper is to focus on the competitive economics of a nuclear plant ordered for commercial operation in 1990-2000.

The focal problem is that there is no positive track record to serve as a basis for prediction: a very wide gap exists between the designed and the actual performance of nuclear power units. The design for all nuclear units operating today in the U.S. specifies two key performance standards: (1) an 80% capacity factor (or better) and (2) a level of control (predictability) of availability necessary for baseload operation. In the past 20 years of commercial operation of nuclear power plants, the average CF has run somewhere between 55 and 60 percent, with the averages since TMI closer to 55%. There has also been a fairly high degree of uncontrolled availability, with units frequently restricting or shutting down operation at primary and secondary peaks unexpectedly. The spread of units above and below the average CF has ranged from fair performance (few averaging above 70% lifetime) to catastrophic performance running from "0" CF on up, particularly when the cost of power to replace shutdowns is factored into the economics. There is no pattern of variation, i.e., the distribution is stochastic. Moreover, there has been no learning curve, and there is some evidence to indicate a negative learning curve.¹

While this gap between performance and design has evoked a few lawsuits by utilities against suppliers, in the main the utilities have accepted the gap passively. This raises questions of why such great risks must be taken in the design and purchase of a nuclear power plant by the utility. What are the inherent technological characteristics of nuclear power? What are

¹Manuscript, "An Analysis of Learning in the U.S. Nuclear Power Industry," by Caroline J. C. Hellman (in preparation).

the interrelated human factors in the design, manufacture, construction, operation, maintenance and repair of nuclear power plants, which create the costly gaps of theory, versus design, versus real world operation?

Finally and most importantly, how can CFs and control of availability be improved, and at what cost?

An unexpected problem in answering these elementary questions is the fact that a valid study of nuclear power economics has not been published to date.

The organization of this paper stems from the dual purpose of defining the components of a valid economic study of nuclear power, and predicting the competitive costs of a future plant. The data base of presently operating nuclear power plants is too sparse to afford a basis for prediction of performance of a future plant by extrapolation from regression analysis. Even if the data base were adequate, extrapolations would be unreliable because the data patterns are too stochastic and inconsistent. The only feasible foundation for prediction, if any can do the trick, is qualitative analysis of (1) the problems of technology and human factors which determine performance, (2) the possibilities of improvement, and (3) the costs. Statistics, of course, are necessary and used.

Accordingly, the organization of this paper is as follows:

1. A statement of what constitutes a valid study of competitive nuclear power economics. A baker's dozen components of a valid study are identified. The components are listed in the Table of Contents. The author is not aware of any published studies which come close to fulfilling these requirements. The degree to which each component has been explicated in print is evaluated and given a quantified index on a scale of 10-optimum achievable.

2. Analyses of four specific studies of the comparative economics of nuclear and coal power, with some attention to alternatives. The studies are among the most thorough and authoritative available, and being from the in-

dustry, are not biased against nuclear power. They include:

- the AEC studies of 1974-75, the first to state systematically its assumptions and sensitivity analysis;
- the ERDA study of December 1976;
- the Exxon study of 1977-79, unpublished but made available to the author;
- the NRC Environmental Impact Statement on the proposed nuclear power plant for Charlestown, Rhode Island. The author prepared a review of the economics part as consultant to the Governor of Rhode Island.

3. Overall findings.

II

THE COMPONENTS OF A VALID ECONOMIC STUDY

II. THE COMPONENTS OF A VALID ECONOMIC STUDY

The components discussed here are of course interrelated. Definitions, though fundamental, are confused and therefore must be treated first. Since capital investment is so great for both nuclear and FF plants, the derivative elements of plant life, lifetime kwh and annual depreciation expense are treated next. The capital factors depend on senescence assumed for plants, and this is therefore treated third. The integration of the above three factors is given a short additional note.

Then follows a trilogy of crucial qualitative factors: the design and technological risks, with scaling up of plant size sufficiently important to be given a separate section; and the interrelated Human Factors (HF). Material is drawn from the author's three volumes on the economics of nuclear power in England, France and Germany. While there is much in the literature on technology and HF, it is largely retrospective, and what might be applicable to a future plant is not translated into the necessary economics.

A few other items are then explicated. Part II is completed with two tables quantifying the adequacy of published material for each component.

A. Capacity Factor: Definitions

The most important single measure of economic comparison between nuclear and coal power is capacity factor, which in turn depends on the definition of capacity and energy. For a variety of reasons, there are several measures of capacity in use among reporting entities, and several variations of kwh. It is often difficult to know exactly which definitions are being used and why, which confuses analysis and comparison.

In order to provide a guide for the explication which follows, it might be helpful to start by stating my conclusion that the only valid definition for purposes of economic comparison is the use of nameplate rating on the generator for MW capacity, and net kwh sent out of the generating unit after deducting in-house usage.

1. Net kwh. For calculating generation costs, obviously what counts is the end product, which is net electricity sent out of the plant. In calculating CFs, the FERC/FPC have always used net kwh. AEC before 1973 used gross, but has since used net. IAEA has used the gross count in the past, but presently uses the net count. There is no doubt that net kwh should generally be the numerator in calculating capacity factor for economic comparisons.

2. Capacity. The following usages are found in the industry for capacity:

a. Nameplate (NP): is the gross MW specified on the brass plate attached to the generator unit by the manufacturer and which is generally his warranty of performance. Since this is the final output of the entire generating system, there is a logical presumption that the capacities of components throughout the system behind the generator are sized, generally, to the nameplate rating. These components would include steam turbine, boilers, piping, valves and pumps. The nameplate rating generally is permanent, finite, objective, known, warranted by the manufacturer and, above all, logical. None of the alternative measures discussed below meet these specifications as well. Nameplate is the only capacity used by FERC/FPC. In its annual statistical reports of Steam-Electric Plants, for example, line one for each generating plant is nameplate MW, line two, is net kwh, and line three is "plant factor" (=capacity factor), derived from these two numbers as denominator and numerator, respectively.

b. Net Maximum dependable capacity. This is the capacity concept preferred by NRC and Edison Electric Institute. It is defined as the maximum dependable capacity, winter or summer, whichever is less. This limitation depends on conditions of cooling water and air temperatures, which are factors in generating efficiencies. While this is a useful concept for planning the contribution of a generating unit to power supply, it is not valid as the basic measure for economic comparison of coal and nuclear power. MDC may be determined by the limitation for a relatively few hours at the worst season of the year. It thus ignores either the average capability over the year or availability for a peak which may occur at another time of the year, and the fact that the entire system is designed around the nameplate rating of the generator. Beyond these functional defects, MDC in fact will fluctuate from year to year and season to season with the amount and temperatures of cooling water and air temperatures. It does not meet the tests of permanence, manufacture's warranty, and economic validity for comparisons.

c. Design electrical rating, net (DER). This measure of capacity is used by NRC in addition to MDC. It is the output specified by the ordering utility for plant design. DER and NP for every unit appear in the NRC Gray Book. The sum of DER capacities for the 67 operating plants at January 1, 1980 was 94.6% of nameplate ratings, which is about the normal ratio of net to gross kwh. While DER is useful before a new unit is completed, thereafter it is obsolete and should not be used for computing CFs.

d. Authorized power. This designation is used by IAEA in its annual reports, OPERATING EXPERIENCE WITH NUCLEAR POWER PLANTS IN MEMBER STATES. Examination from the first report in 1970 shows variations for the same unit from year to year and within the same year, to the point where the kwh, MW and CFs reported are often more confusing than helpful, and require a great deal of work to make them consistent and accurate. The IAEA data make an excellent

argument for using nameplate rating exclusively in economic comparisons.

e. Other definitions. There is a broad variety of other capacity ratings used in various countries. The British, for example, use "derated" capacities. This is the experienced average capacity. It can vary widely from year to year and within the same year. Derating is useful in planning power supply. It may also be a factor in labor negotiations² and it may have other uses. Since it is the only measure published, its variability is a strong argument for using nameplate rating as the basic measure of economic performance.

2. NUCLEAR VS FOSSIL FUEL CFs: THE HYDRO ANALOG

A basic technological and economic characteristic of nuclear power is that it has a comparatively low incremental cost per kwh. In Exxon's study, e.g., comparing 1,000 MW coal and nuclear units located in New England, the ratio of fuel to total cost, including capital, per kwh is 19% for nuclear, 39% for Appalachian coal with flue gas desulfurization (FGDS), 47% for low sulfur Appalachian coal without FGDS and 75% for low sulfur fuel oil at \$15/barrel (85% at \$30). Therefore nuclear would be run baseload in preference to coal and oil. It is analogous to run-of-stream (ROS) hydroelectric power whose incremental cost is zero (or even slightly negative). It would be used before all other sources of fuel generation. The few times this might not hold true would be when ROS hydro exceeds the demand, or e.g., when water must be spilled over a dam to maintain a nine-foot navigation depth on the TVA river system, or to provide water supply for Los Angeles from the Colorado River. But there would then be an advantage to transmit excess nuclear power to adjoining areas to substitute for FF generation.

As a general rule, therefore, it is real world logic to expect that nuclear power plants would be generating electricity at close to 100% of availability.

²Conversation with Dr. Trevor Broom, Director of Operations. British Central Electricity Generating Board (BCEGB).

This is clear from the Service Factors (SF) in the three U.S. regions where there is much hydro, particularly RoS. SF is the ratio of hours generator is on line to period hours. Taking the three Browns Ferry units in the TVA, the Fitzpatrick and Indian Point-2 units of the Power Authority of New York, and the Trojan unit in the Pacific NW, in every case their SFs are identical with the availability factors in 1979. The ~~corollary~~ is that virtually all nonavailability is forced; although there may be some leeway in delaying the time of nonavailability. Some evidence of this is seen in the Gallic logic of French power supply. In France, with one of the highest overall ratios of electricity generated by hydro, about 40%, the SF is 99%.

B. ECONOMIC LIFE OF PLANTS

1. Introduction. The economic life of nuclear power plants is highly problematic because of the pioneer technologies. These technologies may be discussed under the categories of the primary radioactive circuit, and the secondary conventional circuit.

The radioactive circuit, in addition to being new and complex, is without a known historical analog. Also, these units were scaled up in size so fast, that there was no time to accumulate and embody the experience from the smaller sizes in the larger sizes.

The secondary circuit, though using generically known FF technologies, were complicated by two elements of newness. First, operating at approximately half the temperatures, and a third to a fourth of the pressures of FF plants, LWRs require for the same output much larger components such as pumps, valves, piping and turbogenerators. These sizes have involved extrapolations beyond

the experienced limits of scaling for FF units of the same size. Second, this scaling problem is further complicated by leaks of radioactivity from the primary into the secondary circuits, with resulting corrosion and other degradations of materials.

These problems help explain why the secondary circuits have had more casualties than the primary circuit. (See below the section of Technology on Scaling.)

2. Fossil Fuel Lives. The economic life of a FF plant is generally assumed to be 30 years. This number has ample validating experience, plus a confirmed extension of usefulness beyond 30 years for standby and peaking.

3. Nuclear Plant Lives. In the U.S., the economic life for nuclear power units is usually stated as 30 years. There are, however, certain indicators for an assumption of an economic life less than 30 years. In Europe, the following economic lives are used:

Electricité de France: 20 to 21 years.

British Central Electricity Generating Board: 20 years

RWE, the largest German utility: 20 years based on "internal calculations."

Dr. Schoch, manager of the generating station at Mannheim and head of the national and Baden TÜVs, has told me that he thinks the nuclear plant life is under 20 years, and would have to cost more to bring it up to 20 years.

In the U.S., significant deviation from the 30-year assumption is found in the study done for the New England Power Company (NEP) by Arthur D. Little's subsidiary, Stoller, in 1975. The report itself does not state the assumed life of coal and nuclear, but at my request NEP found out from ADL that a 30-year life was assumed for a coal plant, but 28 years for nuclear.

This drop is important not so much for the particular number of 28 years, but as an indicator that ADL/Stoller felt that nuclear power units would have technological problems which would shorten its life below the conventional

30 years.³

4. Conclusion. If FF economic life is taken as 30 years, the light water reactor generating plant, existing or ordered, today seems unlikely to equal it. Given the problems of radioactivity and scaling, some life between the 20 years of the French-British-German assumptions and the 28 years of ADL/Stoller would be more conservative than 30.

However, nobody really knows, because of the lack of a body of experience that can serve as a predictor for nuclear power unit lives. Of the first three U.S. units, Indian Point-1 is permanently shut down; Dresden-1 was shut down October 31, 1978 and is not scheduled to return on line until July 1981.

The unit size now being ordered is above 1,000 MW, but the oldest such unit did not become commercial until August 1973 (Indian Point-3, at 1013 MW), giving only seven years experience. If it is assumed that this size is a direct descendant of the 828-MW Dresden-2 its commercial date is August 1970, giving only a 10-year span of experience.

5. To Be Done.

a. It would be valuable to go back and explore with ADL/Stoller, the British, the French, the Germans, Westinghouse, GE and a few utilities with suitable engineering staffs and experience and willingness, the factors determining economic life, how they evaluate them, and why.

³The assumption of 30 years is not pure on the upside. NRC in its Charlestown study also mentioned nuclear unit lives of 40 years at three points. Some utilities, including NEP, have been making sounds in the direction of 40 years for nuclear units, perhaps to make nuclear costs seem lower, but this is unsystematic and not to be credited at this time.

C. SENESCENCE

Senescence is the decline in capacity factor with age of the plant. It has had little explication in the literature except for an ERDA memorandum of 1975, and several variations.

Most explicit predictions of capacity factor over time assume a low point during the first year, and a rise to a third year peak which lasts for the balance of the assumed 30-year unit life. Alternately, a falling CF may be assumed after some age. While there is a fairly good historical record to gauge senescence of FF units, nuclear units are too young and the technology has been too immature for definite predictions.

In appraising nuclear senescence, there are important differences from FF plants. Radioactivity is highly corrosive: how much over lifetime we don't know, but it has been greater than anticipated. Scaling, another important difference, is discussed in a later section. Leakage of radioactivity from the primary into the secondary circuits is also a factor.

1. The 1975 ERDA Memorandum. This is an unpublished mimeographed memorandum of February 1975 which gives the following sequence of senescence for a nuclear power plant.⁴

Years 1&2	65% capacity factor
3-15	75% high } the authors of this program would now 70% low } use 65%, see below.
16-30	minus 2% per year to a minimum of 40%

With the 70% plateau, the 30-year CF is 67.0%. Using 65% it drops to 63.0%. The significance is not in the specific CFs, but in the introduction of the principle that there is a senescence factor.

⁴ERDA, TOTAL ENERGY, ELECTRIC ENERGY, AND NUCLEAR POWER PROJECTIONS, Feb. 1975, mimeographed, by Robert Bown and Mrs. Artha J. Snyder.

In conversations in the Summer of 1980, Mrs. Snyder, one of the two authors, said that their senescence sequence has become "a classic," and that she was not aware of any disagreement with the pattern although some people said they would rather not use it.

Mr. Bown, the other author, stresses the absence of senescence in the literature, the empirical basis of his sequence, and the lack of history for a better basis. To his recollection, only one person, at the PNW Labs in Richland, questioned his sequence, but only to suggest that the fall off be less abrupt.

2. The RWE comment. While discussing European nuclear economics with the head of the nuclear division of Germany's largest electric utility, RWE at Essen, I showed him the Bown-Snyder sequence. He observed that the senescence was a correct principle, based on their experience and studies. However, they would start the decline in the 18th rather than the 16th year.

3. NRC. The NRC/EIS⁵ assumes a base CF of 60% over the 30-year life of both nuclear and FF plants, with alternatives of 50% or 70%. There is no mention of senescence. However, NRC staff elsewhere does make a senescence assumption derived from the Bown-Snyder sequence.⁶

4. New England Electric Power. For the proposed Charlestown (RI) nuclear power plant, NEP in October 1977 assumes a rise from the first year to a plateau from the sixth year on through the 30-year life, as follows:

Year	CF %	Source: NRC/DES
1	59.2	
2	60.9	
3	66.8	
4	71.0	
5	71.0	
6-30	76.2	
30-yr average	74.5	
40-yr average	74.9	
28-yr average	74.3	

⁵NRC, DRAFT ENVIRONMENTAL STATEMENT, Charlestown, RI Nuclear Power Plant, NUREG-0529, May 1979.

⁶Conversation with Darryl A. Nash, July 1, 1980. The sequence is found in COAL AND NUCLEAR: A COMPARISON OF THE COST OF GENERATING BASELOAD ELECTRICITY BY REGION, by J.O. Roberts, S.M. Davis and D.A. Nash, NUREG-0480, NRC, Dec. 1978.

This is a typical sequence found in the literature of the industry. It assumes zero senescence.

5. A.D. Little/Stoller Study, 1975⁷ This study was done for New England Electric Company (NEP), and served as the basis on which the NEP decided to build the Charlestown nuclear power plant. It assumes a rise in CF for the first four years, and a leveling thereafter at 70%:

<u>Year</u>	<u>Nuclear & Coal w/FGD</u>	<u>Coal (& oil) w/o FGD</u>
1	53%	57%
2	60	64
3	65	69
4+	70	75

It also assigns 62% from the fourth year as a low CF for nuclear, and 78% as the high option, 70% being the average.

6. The ERDA-76 Study⁸. This ERDA study, done by Mitre and TRW companies, assumes a senescence factor which, however, is not expressed precisely. It assumes that coal and the LWR generation will have similar lifetime CFs. These start at 50%, rise to 70% after two or three years, and "later steadily decreasing until the plant is retired."

In an appendix illustrating revenue requirements, coal w/FGD is used which starts up in 1981, with the following senescence sequence:

<u>Year</u>	<u>CF</u>	<u>Notes</u>
1	60	
2	65	
3	70	The peak.
4-18	69.7	Dropping steadily to 60.
19-30	58.6	Dropping more sharply, but steadily to 30.

It is not clear, however, whether this illustration is intended to be a representation of how both nuclear and coal with and without FGD would behave.

⁷ ECONOMIC COMPARISON OF BASE-LOAD GENERATION ALTERNATIVES FOR NEW ENGLAND ELECTRIC, Arthur D. Little, Inc./S.M. Stoller Corp., 1975, p. 71.

⁸ COMPARING NEW TECHNOLOGIES FOR THE ELECTRIC UTILITIES, 12-9-76, ERDA 76-141, p. 102-3 and A-5.

7. AEC 1974 and 1975. In its annual review published in 1974, AEC gives its first analysis of the competitive economics of nuclear and coal units. It simply assumes a lifetime CF of 80% for both, without any mention of senescence. The review in 1975 drops CF to 75%⁹

8. Conclusion

There has been virtually no qualitative in-depth analysis of the senescence factor in the literature, the only expression being that I received personally from Bown-Snyder. The time pattern of senescence and the rate of fall-off if any, are indeterminate at this point, unless we accept the Bown-Snyder ERDA/Mitre variant.

9. To Be Done

1. Examine the British studies, and those commissioned by the German TUV/Government to the University of Stuttgart, and discuss with key people in these countries in research, operation and manufacture.

2. Discuss with key U.S. utility managements such as TVA, Commonwealth Edison and American Electric Power, and NRC and DOE personnel.

3. Research U.S. and other literature for cases, e.g., the Turkey Point steam generator replacements.

4. Finally, discuss with Westinghouse, GE, Bechtel, etc.

D. CAPACITY FACTOR

This is dependent on points A, B and C above. Two cautions may be noted.

1. NRC cumulative, i.e., lifetime, capacity factor starts not from day of commerciality, but from first electricity. These dates can differ by months or as in the case of the Ft St Vrain unit, by years.

2. Capacity factor and reliability are not, as is generally assumed in the industry, one and the same. This is elaborated in the section which follows.

⁹AEC, THE NUCLEAR INDUSTRY 1974, WASH1174-74p. 20 and THE NUCLEAR INDUSTRY 1973, WASH 1174-73, p. 15.

E. THE YOYO EFFECT, OR "RELIABILITY"

If one looks at the annual chart of daily CFs for nuclear power plants, which are known as histograms, he will see that these CFs rise and fall like a YoYo effect or factor with considerable frequency. This fluctuation can be more important than the CF itself. The YoYo Factor is vital in any economic comparison of nuclear and FF power, but it has been virtually ignored in the literature. The closest it comes is in discussions of "reliability." But analysis of those places where reliability is mentioned shows that it is generally equated with CF, which is, however, an error. Therefore some clarification of definitions is necessary.

1. Definition. Capacity factor is the percent of nameplate rating which is actually achieved over a specified time period. In calendar 1979, e.g., U.S. nuclear power units operated at about 55% of nameplate rating. Reliability properly defined, is a different matter. It includes CF, but also, more importantly, it includes the degree to which on-line availability can be predicted and controlled. Thus two plants with 55% CFs can be entirely different if for one the availability can be controlled to be had at peak times, while for the other it is only poorly predictable.

On histograms of nuclear power units, shutdowns occur frequently during peaks and at other times when the utilities obviously would not choose to shut down voluntarily. Therefore there is a strong element of stochastic variation.

2. Cause. The explanation for the YoYo effect in nuclear power plants is in good part due to their high sensitivity to safety. Automatic shutdowns (scrams) are frequent, and may be due to faults in metering, sensing and controls, as well as to breakdowns in primary or secondary circuit equipment. For the same reasons, manual shutdowns are also frequent.

3. FF Comparison. The nuclear power industry is unique in publishing monthly and annual histograms for every unit in the US, and annual histograms for non-Communist countries. These permit visualization of the YoYo effect. Such histograms, however, are not published for FF units. I have tried to obtain them from EDF in France, the German utilities, the UK's BCEGB, the municipal plant in Vienna, and from US and Canadian utilities, without success. EDF arranged for me to visit their generating station at Porcheville, on the idea that the histogram might be available there, but no luck, although the plant people did their best. Dr. Schoch of Mannheim kindly supplied the nearest thing to a histogram, but it does not permit comparisons with the nuclear histogram.

Therefore, it is impossible to compare nuclear and FF performance by histograms. Moreover, CF histograms for FF units would not be directly comparable. This is because nuclear units should be used whenever available, so that their CF would measure true availability in principle. The FF unit, being load following, would have a CF lower than true availability. Therefore the correct comparison would be between nuclear CF and FF availability histograms.

There is some logic to believe that FF compared with nuclear units would have an availability histogram with much less of a YoYo pattern. Dr. Schoch, who must sell his power wholesale competitively, told me he could not operate with the nuclear histogram. He must have 90% availability at the winter peak, with 3 hour overload capability. The nuclear histogram is one of the main reasons, he told me, for his not recommending purchase of a nuclear plant.

Other reasons for a lesser YoYo for FF units are:

- a. A more mature technology.
- b. A safer technology requiring much less provision for automatic scrambling.
- c. A less complex technology, much more within human capability to operate and maintain.
- d. Much less breaching of scale on the larger units.

Due to the absence of FF histograms for availability and CFs, however, a comparison cannot be visualized very well. The unsolved difficulty of finding a single quantified measure of comparability also hinders comparison.¹⁰

4. Conclusion. The YoYo Effect must be factored into any valid comparison of economics of nuclear and FF power. It is more important than CF. FF histograms need to be developed for this purpose, and if possible a single quantified measure of the YoYo Factor. Some logic and evidence has been adduced, nevertheless, to support a finding that the factor is greater for nuclear than for FF generating units.

5. To be done.

- a. Develop quantitative definitions and measurement of the YoYo Factor.

¹⁰Two examples of ambivalence with regard to "reliability" may be cited. ERDA-76 ranks existing and prospective technologies by complexity in the following order: coal w/o FGD, solar, ocean thermal, atmospheric fluidized bed (coal), coal w/FGD, hydrothermal, LWR -- followed by open cycle (gas turbine/steam with integrated gasifier), the LMFBR, fusion and solar satellites (at p. 172). Nevertheless, it assumes equal CFs for coal and the LWR: "In effect, this assumption involves treating all technologies as having comparable reliability regardless of their inherent complexity" (at p. 103). The NRC/DES goes farther: "...the New England nuclear plant (at Charlestown) will increase the reliability of the region's power supply" (at p. 10-7). It gives no explanation, except possibly that nuclear fuel is a more reliable supply than imported oil.

- b. Make lifetime histograms for nuclear plants.
- c. Develop parallel histograms for FF units, at least for typical samples.
- d. Review productivity literature for possible light on the YoYo Factor.
- e. Discuss the YoYo Effect, and ways and costs of improving it, with key people: TVA, American Electric Power, the manufacturers, NRC, DOE, operators and manufacturers in Europe, et al.

F. DESIGN/TECHNOLOGICAL RISKS - SCALE

I. Comparative Nuclear and Fossil Fuel (FF) Scaling

The design of nuclear power plants has involved 2 classes of technological risks which have received little or no mention in the literature of nuclear power economics:

- 1. The scaling up of orders by jumps so big as to create design and operating problems;
- 2. The associated scaling up of orders for the conventional circuits of nuclear power units well beyond the physical dimensions already operating in FF plants.

I first became aware of the scaling problem as an economic factor in my discussions with the Nuclear Division of Siemens in Erlangen (Germany) in the summer of 1977. I asked why the conventional part of nuclear power plants seemed to have more casualties than the reactor part. The reason, they answered, is that for the same MW capacity, the components of a nuclear power plant have to be much bigger physically than those same components in a FF plant; e.g. turbines, generators, boilers, piping, valves,

and pumps. Thus if the largest FF unit in operation was 1300 MW and a 1300-MW nuclear unit was ordered, the conventional part of the nuclear unit would exceed in physical dimensions the corresponding sizes in the FF unit, and would involve projections of scale beyond experienced sizes.

From the scaling jumps in Table 1, it may be seen:

a. Reactor circuit. The first generation of nuclear power consisted of 3 units of 185 to 285 MW ordered in 1955-56 and commercial in 1961-62. But during the entire period 1962-67, when orders rose from 590 to 1158 MW, the largest size of nuclear unit operating remained 285 MW. Thus there was a quadrupling of scale without intermediate operating experience with the reactor.

b. Conventional circuit. The conventional part of the 285-MW unit of the first 3 nuclear units was, when ordered, well within the operating experience of FF units. But the 590-MW Haddam Neck unit ordered in 1963 exceeded the largest FF unit then operating. Ordered in 1965, the 850-MW Dresden-2 unit compared with the 550-MW FF unit, Colbert-B, which became commercial the same year. Subsequent extensions of commercially operating FF sizes were Bull Run with 950-MW in 1967, Paradise at 1150-MW in 1970 and 1300 MW in 1973. In 1973, also, 6 nuclear units of 1300 MW were ordered, plus another 10 of this size in the first 9 months of 1974.

Two facts emerge from this scaling sequence: the nuclear units ordered, after the first group of 3, always exceeded substantially the largest sizes of FF units already operating; and the scaling risk was compounded by the need for physically larger components than for the same FF size.

Table 1: Size Escalation of Nuclear Power Units Newly Announced or Awarded
Compared with Largest Nuclear and Fossil Fuel Units Then Operating a/

Year Nu Unit Awarded	MW - Nameplate		Unit Names				Year Award Unit Became Commercial	
	Award	Operating	Largest Nu	FF	Award Unit	Largest Unit Then in Operation		
						Nuclear Unit		Fossil Fuel Unit
1955-6	185-285	--	b/		(Dresden, Ind. Pt-1 (Yankee Rowe	--	b/	'60 (Dr&YR) '62 (Ind Pt)
1960				496			Breed (Ind&Mich)	
62	600	285	"		Haddam Neck	Indian Pt-1	"	'68
63	670	"	"		Oyster Creek	"	"	'69
65	828	"	550		Dresden-2	"	Colbert-B (TVA)	'71
"	1,013	"	"		Indian Pt-2	"	"	'73
66	1,152	"	"		Browns Ferry-1	"	"	'74
	1,170	"	"		Salem-1	"	"	'77
67				950			Bull Run (TVA)	
68	1,183	600	"		Sequoah 1&2	Haddam Neck	"	'80-1 ?
"	1,290	"	"		Fermi	"	"	?
69		642	"			Nine Mile Pt	"	
70			1,150				Paradise-B (TVA)	
71		769	"			Robinson-2	"	
72		848	"			Surry-1	"	
73	1300 X 6	1,098	1,300		Various	Zion-1	Cumberland & Amos	?
74	1300 X 10	1152	"		Various	Br Ferry, Pch Bottom	"	?

Source: Announcements and awards from Annual Reviews of AEC, and FPC's annual Statistics of Steam Electric Plants. Capacities and commercial dates from NRC monthly Gray Books and " " "

a/ The year announced and awarded are about the same. Construction generally started 1 to 2 years after announcement/award. The distinction between announcement and award is not often clear. The announced and nameplate MW usually do not differ by more than 10-50 MW. '74 Awards are for 9 mos.

b/ The 285-MW nuclear unit was well within the scale of operating fossil fuel units.

2. Why the Scaling Risk?

Three of the factors causing the physical dimensions and scaling of nuclear power units to exceed those of FF units are steam temperature, steam pressure (psi), and turbine revolutions per minute (rpm). This can be seen from Table 2, where I have matched up coal and nuclear units as far as possible by age and size.¹¹

a. Temperature. Nuclear steam temperature is a bit over half that of FF, about 500 to 575 F versus 1000 F or a bit more.

b. Pressure. Most psi's are in the 700 to 950 range for nuclear, but for FF run mainly at 3500.

c. RPM. Nuclear turbines seem to be standardized at 1800 rpm, FF at 3600.

These 3 characteristics also explain the greater volumes of fluids and steam that must be moved through pipes, valves, pumps and boilers of the conventional circuit of nuclear power plants, and therefore their scaling problems.

3. Conclusion

The scaling risks of nuclear power reactors and the components of their conventional circuits have been substantial. They account for a major part of the troubles besetting nuclear power plants of all vintages, and of the relatively narrow plateau of

¹¹FPC/FERC's annual reports are by plants, not by units. A plant may consist of anywhere from 1 to 10 units or more. Therefore it is possible to cull out unit data only where the plant consists of 1 unit, or the company voluntarily reports by single units --usually the larger and newer units, or the unit must be reported separately as one of the Best By Heat Rate. This limits the number of units to make the comparisons given here.

TABLE 2: Pressures and Temperatures of Coal
and Nuclear Power Plants

UNIT	COAL				NUCLEAR				
	Mana- tee	Wans- ley	Mans- field	Bull Run	Browns Ferry	Trojan	Beaver V	St. Lucie	Indian Point 3
Company	Fl PL	GaPC	PaPL	TVA	TVA	PtInd	PA	FlPL	PASNY
MW	863	952	914	950	1152	1216	923	850	1125
Year Built	'76	'76	'76	'67	'74	'76	'76	'76	'76
Type					BWR	PWR	PWR	PWR	PWR
Turbine:									
a. PSI	2400	3500	3500	-	950	873	735	750	715
b. °F	1000	1000	1000	-	575	533	517	513	507
c. RPM	3600	3600	3600	-	1800	1800	1800	1800	1800
Boilers:									
a. Number	1	1	1		2				
b. PSI	2500	3625	3785	3650	1005	895	781	750	
c. °F	1000	1000	1000	1003	575	533	517	513	507

Source: FPC/FERC, Statistics of Steam Electric Plants, 1976 and earlier years.

CFs, averaging for the industry between 53 and 60%. There is little in the literature to indicate how these problems will be resolved so that CFs can rise closer to their original design of 80%, and almost nothing of that little has been translated into economics.

4. To be done

1. Quantification more precisely of the physical dimensions of the important conventional components of nuclear power units, as compared with the same MW sizes of FF units.

2. A parallel quantification of cost differentials.

3. Exploration with key utilities, manufacturers, architect-engineers, government experts, and Europeans of:

- .the dimensions of the problem
- .the paths of improvement
- .the costs of improvement and the gains
- .the time scale for accomplishing these goals
- .the above for units existing and under construction, and units to be ordered in the future.

G. DESIGN-TECHNOLOGY RISKS, OTHER THAN SCALE

1. Introduction

The focus here is on a unit ordered in the future for service after 1992. Experience with presently operating units is of interest chiefly as it helps predict the economics of future orders. The significance of this distinction is that catalogs of historical analyses of casualties, such as the fine study done recently for EPRI by Stoller, may or may not have predictive value for

design-technology risks of future units.¹² They may not tell us, e.g., whether the best state of art of welding is up to the life-time requirements of the nuclear containment vessel. They do not tell us how much of a gap there is between the best state of the art of metallurgy and the minimum requirements of the plant. Most important, they do not translate the technological information into nuclear economics.

The risks being considered here are not limited to, but include the following for nuclear power plants:

- Corrosion, radioactive
- Corrosion, conventional

- Welding
- Metallurgy, general

- Tubing, piping, walls: thickness and metallurgy
- Valves, pumps, meters: quality, adequacy, proof

- Controls: automaticity, sensitivity, redundancy, design
- Safety: a combination of the above factors.

Competitiveness of nuclear power plants will be affected by coeval improvements in the technologies of burning fossil fuel and of substitutes such as solar development. Some of these are fairly short term, such as fluidized bed burning of cheaper high sulfur coal, and solar hot water heaters. Both will be experiencing fairly rapid commercialization within the next 10 years.

2. The Literature

The literature on design-technology risks of nuclear power is largely limited to the US, England and Germany. In the US there is a voluminous record of specific outages in the reports required

¹²NUCLEAR AND LARGE FOSSIL UNIT OPERATING EXPERIENCE, EPRI NP-1191, September 1979, by S.M. Stoller Corp.

of operators and published in the reports of the NRC/AEC. But the fundamental questions of state of the art either have to be dug out in bits, if at all, or are not available. Hints may be extracted from proceedings of industry meetings and publications, but there is relatively little questioning of design risks in terms of economics.

There has been such questioning, however, in systematic and often public ways in England and Germany, and this is detailed in the sections immediately following.

The French have been adherents of the pure abstract logic of nuclear power plants, i.e. the design expectations. Adding to this the political decision to become independent of imported oil and gas and to minimize dependence on coal, resulted in 1976 in a single order for 22 replicated nuclear power plants to be built on a pre-set sequence to provide the most economical construction cost. Further large orders have been given since. While there is a fairly strong questioning of nuclear power by "environmental" groups, the pattern in France appears to be for the Government not to be deterred by this questioning, but to forge ahead with an enlarged program of nuclearization. There is thus relatively little literature of the kind found in England and Germany on the fundamental design risks of nuclear power.

The results of my studies in Europe have been embodied in my 3 volumes titled Notes of Discussions of European Nuclear Economics, for England, Germany and France. These are listed in the Abbreviated Legend found in the preface to this study. Relevant parts of these volumes are summarized below. Page references in the volumes are given in parentheses.

3. England

The British have had a public soul-searching as to nuclear power technologies for some 25 years. They have successively committed themselves to the Magnox, the AGR, the SGHWR, and in January 1978 again to the AGR, with a promise of a future PWR which was realized in orders for the PWR in 1979-80. There is still hope in some quarters for the HTR, but without any commitment either to research or an operating unit (15-24).

Professional unions, the Energy Minister, the AEA, the BCEGB, the Scottish EGB, the equipment manufacturers, the constructors, have all been in shifting alliances for or against specific technologies. The official reports afford valuable insights into the science and art of such factors as welding, containment vessels, piping, and the safety of LWRs.

Reliability. "The key commercial factor" in choosing a nuclear or FF power unit is stated by the British to be reliability. In its report of 1974 to Parliament, "Choice of Thermal Reactor Systems," the Nuclear Power Advisory Board stated:

The Electricity Boards have laid particular stress on the need to base their main requirements on tried and reliable systems....Lack of reliability can rapidly erode any apparent difference in construction costs between reactor systems....As an example, the CEGB estimate that with the AGRs the cost of fuel to replace the electricity production lost through delays will exceed the original estimated cost (12).

The Board then points out the problems of scaling and extrapolating from existing sizes: "If parameters such as pressures and temperatures are increased or new materials used, this will introduce fresh risk which cannot be assessed with confidence until there is operating experience" (12).

Safety/Technology. When the Secretary for Energy (SFE) in 1978 decided on immediate orders for 2 twin AGRs, he also held out a promise that there would be future orders for PWRs provided that there was clearance on the safety factor (22). Earlier in December 1976, the Select Committee on Science and Technology of the House of Commons, in its report, The SGHWR Programme, wrote:

In our 1974 report we ... drew attention to the conflict of expert opinion on the safety of American light water reactors (LWR), and recommended ... one of the British nuclear technologies which is already proven, since this is likely to satisfy the Nuclear Inspectorate without undue delay (18).

From my conversations in England and my readings, safety has been of greater concern in a reactor choice than competitive costs. This is partly explained by the lack of cost data to sustain a debate. Thus, safety has been at the heart of the PWR alternative. In 1976 a 2-part study of safety was undertaken, one on the pressure vessel to be done by Dr. Walter Marshall of the UK AEA, and the second on other aspects to be done by the NII itself (34).

The Marshall report stated that the PWR's pressure vessel could be safe provided it were modified to higher UK standards, higher even than in France and Germany. Problems concerned the integrity of the reactor vessel from cracks, metal fatigue and behavior during transients. This proviso was substantial, and found dissenters.

Sir Alan Cottrell, former Chief Scientific Adviser to the Government, wrote to the SFE of his concern with the PWR, particularly with regard to senescence. The Marshall report, he observed,

argues that if very great care is taken, these pressure vessels can be reliable at the start of service, but it offers no certainties for the later years when effects such as metal fatigue may weaken the structure (35).

He questioned that the "outstanding technical excellence" of engineering and operating staffs could be obtained. Marshall had been told by ultrasonic operators that defects might not be detectable unless over 1" deep. "Yet," Cottrell noted, "this depth is comparable with the critical crack size calculated for some emergency and fault conditions" (35).

Degradation with age troubled Cottrell: knowledge of long term changes in properties of materials and critical defect sizes was insufficient. The AEA shared this concern: "The information on the laws covering crack growth rates is not fully satisfactory from a scientific point of view." It felt that thorough research should be undertaken on corrosion-fatigue crack rates.

The interrelation of technology and human limitations shows up as vital. Cottrell was skeptical of achieving the degree of human perfection needed for the PWR, and this the SSEB took as confirmation of their own view that "to have a safe vessel it is essential to fabricate it well nigh perfectly, from well nigh perfect materials, and carry out well nigh perfect inspection throughout its life" (35-6).

The PWR alternative was questioned by the Institution of Professional Civil Servants, whose members are scientists and administrators advising the Minister for Energy on policy. To the Select Committee it expressed its concern that pressure vessel failure was "a credible eventuality." It felt that the greater population density of England required more stringent

safety features than in the US. It thought the PWR loss of cooling possibility was such that the safety standards being applied to the SGHWR "are not met by current PWR designs" (36). It recommended that the NII report on why the German Reactor Safety Commission required additional safety precautions for the PWR at Ludwigshaven, and the cost (36-7).

The need for a secondary shutdown system for a UK PWR was raised by the Whetstone Nuclear Power Branch of the Association of Scientific, Technical and Managerial Staffs. An off-the-shelf PWR was not acceptable to CEGB, they told the Select Committee (37).

At the UK's AEA, Mr. Hunt, of Long Range Planning in the Economics and Programme Branch, told me in the summer of 1977 that the UK does not accept the safety of the Westinghouse PWR. A main question was on the pressure vessel, on crack propagation in the brittle steel vessels (38).

4. Germany.

Nuclear power plants in Germany are subject to much more intense regulation than in other countries. There is official scrutiny at all stages: design, siting, manufacture, construction and continuing operations. RWE estimated for me that 15% of the factors explaining higher capacity factors and reliability is due to "regulation and courts," while KWU gave 10% (47). At the heart of the official inspection process are the Federal Reactor Safety Commission (Reaktorsicherheitskommission) and the TÜVs. The State Minister which is the licensing authority and the RSK use these nonprofit provincial engineering groups to perform the various inspection and testing functions. The essential characteristic emphasized for these TÜVs is that they are "independent" (22-26).

An important activity of the RSK is the sponsoring of studies of materials used in nuclear power reactors, e.g. those made at the University of Stuttgart on cracks. This type of testing has been going on since 1964, and has found many serious flaws, such as walls too thin. Dr. Schoch, who has been the head of the Baden provincial TUV and of the national TUV serving as an umbrella for the 11 provincial TUVs, had been proposing for some 3-1/2 years that a special group be set up under him to develop a research program to solve materials problems by testing etc. This group would contain component producers, steel fabricators, welding specialists and scientists. Finally he won his point and in 1977 the group was created by the Secretary for Technology Research (Forschungsministerium), to run for 4 to 5 years. The budget is DM 50 million. The goal is to determine how long material components of nuclear power plants will last (51-52).

It is worth noting a few of the observations made to me by Dr. Schoch. He feels (summer of 1977) that the theoretical problems have been solved for nuclear power plants, but not the translation into equipment and operational performance. The danger, he feels, is that the heads of organizations, e. g. reactor safety, don't fully know the real problems in materials, construction, welding etc. -- they are physicists. He observes that the prices of nuclear power plants have been too low from the manufacturer's viewpoint, so that suppliers have had to cheapen quality. For example, tubing is too thin, with cracks occurring in main feedwater tubing at Phillipsburg before start

of operations. Overall, he feels that safety can be solved technologically but that the economic problems of availability and capacity factor are much more difficult to solve (51-52).

5. Conclusion as to Technology

For some as yet obscure combination of reasons, the US nuclear power industry, the government included, in the late 1950s and early '60s made a heroic decision to bypass the normal gradualism in the development and commercialization of a new technology -- especially an exotic and extraordinarily sensitive technology like nuclear power -- and to go rapidly to a \$100 billion commitment, and ultimately far more. Fundamental operational questions of the quality and amount of radioactive corrosion, its interrelation with conventional corrosion, the practicality of welding art, the required science and art of metallurgy, the ability of the best available valves, pumps, meters to meet the demands, the adequacy of the best state of the art of controls, the acceleration of scaling up, human factors, and the summation of all the technological factors in the end products of capacity factor, reliability, safety and economics: all of these and more were too little understood, too little researched, too little acknowledged.

Thus today the industry -- if it is to be realistic about the technological and economic results it is achieving with nuclear power plants -- may have to face up to the fundamental pre-commercialization questions which it has so far ignored more than acknowledged and wrestled with.

In a nutshell, these questions are: is it possible to

design
manufacture
construct
operate
maintain
repair

nuclear power plants subject to the ineluctable tyranny of around-the-clock operation of a technology as sensitive to malfunction as nuclear power, and to do that safely and economically?

Acknowledging and solving these problems are the only route by which our \$200-plus billion industry can be successful.

6. To Be Done

(a) Examine the documents produced in England as to which technology for nuclear power to choose. I refer, not to those I have already abstracted in my Notes, but to those which have been produced since January 1978 which are public; and those before and after which have not been published by the government, but to which access may be obtainable.

(b) Do the same for Germany. Particularly gain access to the DM 50 million of work at University of Stuttgart.

(c) Discuss the problems with NRC/DOE; and with key industry people who are knowledgeable, intelligent and verbal -- TVA, American Electric Power, etc. Include a few utilities operating high problem plants, such as Trojan and Palisades; and a few of the best plant operators.

H. Operation and maintenance costs

O&M costs are available for nuclear and fossil fuel plants in the necessary detail mainly in the FPC/FERC Form-1 reports of utilities. Since so much of the low capacity factor below the 80% design for nuclear plants is due to technological

problems, they should be reflected in erratic patterns of O&M from year to year as CF fluctuates. As CF drops, O&M, if fully reflected in utility accounts, should rise. Conversely for fossil plants, assuming in general that lower CFs are due to load following (i.e. drops in demand), O&M should drop.

NRC's DES for Charlestown (1979) uses a comparison of 2 x 1150 MW nuclear units with 3 x 767 coal units with flue gas desulfurization (w/FGD). O&M is given as follows:

CF	<u>Mills per Kwh</u>		<u>Coal with Nuclear = 100</u>
	<u>Nuclear</u>	<u>Coal</u>	
50	7.4	11.2	151
60	6.2	10.1	163
70	5.4	9.4	174

To see what O&M of actual plants look like, I have prepared from FPC data the following comparison for the Millstone nuclear power plant #1, 662 MW, commercial in 1970, with the Canal fossil fuel plant in Massachusetts, 542-MW, commercial in 1968, and burning fuel oil.

<u>Year</u>	<u>Mills/kwh</u>		<u>Nuclear = 100</u>	<u>CF</u>	
	<u>Nuclear</u>	<u>Canal</u>		<u>Nuclear</u>	<u>Canal</u>
1976	3.73	1.45	39	65	73
5	3.09	1.00	32	67	81
4	2.72	1.38	51	62	71
3	4.07	.74	18	32	81
2	2.42	.72	30	55	78
1	.91	.78	86	62	78

I have also compared 3 midwestern plants burning coal with the Kewaunee nuclear plant. The coal units range from 460 to 668 MW,

the nuclear is 535 MW. Kewaunee O&M was 3.17 mills/kwh in 1976, compared with 0.66 and 0.69 and 0.84 mills for the 3 coal plants. With Kewaunee at 100, the coals were 21, 22 and 26. CFs for coal were 60%, 52% and 49%, and for Kewaunee 72%. Point Beach nuclear plant, one of the better managed apparently, operated at .92 mills, with the coals then being 72, 75 and 91 percent respectively of Point Beach.

Thus the actual numbers, selected at random, are opposite to the O&M relationships of nuclear and fossil fuel plants assumed by the NRC staff. This illustrates my point that some qualitative analysis of O&M is essential in an economic analysis of nuclear versus coal, and that this is entirely missing from the DES.

What is needed is a more thorough empirical study of actual O&M experience with coal and nuclear power plants, and a restatement of projections of O&M for future nuclear and coal plants. For the latter this must include the new burning technologies that may be feasible within the next few years, as noted in the previous section on technology.

Obtaining the needed information involves explorations with utilities like TVA and American Electric Power (AEP), the equipment manufacturers, other involved Federal agencies, and foreign sources like the British Central Electricity Generating Board which has recently begun operating a full-scale commercial fluidized bed coal burning plant.

I. Human Factors -- "Errata"

1. Introduction

An exceptionally high level of quality control is essential at all stages of nuclear power manufacture, construction and operation, and this depends on labor, management and design personnel, as much as on pure technology. Two limitations operate on the nuclear power industry in terms of human factors.

1. The rule of "Errare humanum est" must constrain everything that industry does. Given the inherently sensitive technology, the continuing task of attracting, training and maintaining the highest level of personnel imposes upon industry stringent responsibilities.

2. There is a balance, yet to be worked out, between the degree of automation and discretion at the control panels of nuclear power plants to minimize human error. In Germany, Siemens has told me they lean toward a higher automation, while the French told me that they tend toward less automation. The degree of automation is a function of technological sensitivity and safety, and far exceeds that in fossil fuel plants. Through the frequency of automatic scrams, it accounts for a good part of the YoYo Effect.

Before outlining here what constitutes a valid study of the economics of "human factors," it would be helpful, I think, to sketch that part of my relevant professional background from which I write.

As a Naval Instructor of logistics in the Naval Reserve Officers School in the 1960's, I devoted a fourth of the course to a subject which was not listed in the official curriculum, i.e. to the logistics of brains and skills. I had seen that as much

as half of our Military's peacetime equipment was not operational due to lack of skills and brains to operate, maintain and repair. Therefore I raised the question of whether there was an adequate absolute supply to meet the needs of society, and of how far the Military could attract the share it needed. I discussed this question frequently with a friend who was head of Human Factors Research in the Army. He had a computer on which everybody in the Army was encoded by standardized skill modules. When a new weapon was at the stage of being approved for full-scale production, it was first sent to this office and broken down into corresponding modules. The quantities demanded were then matched up with the human supplies available. Not infrequently the weapon was returned as unacceptable because the supply of human modules could not meet the need, and it would either have to be redesigned to be within limits of supply, or scrapped. In the early 1960's, the Navy was faced with a problem which has already begun to show up in the nuclear power industry and will become progressively more acute -- a low rate of attraction and retention of skilled personnel (in uniform). In December 1964 the Secretary of the Navy formed a Task Force on Navy/Marine Corps Personnel Retention. The Chairman of the TF asked me to serve as Civilian Director but as I was already engaged as Economist to the President's Cabinet Committee on the Economics of the Supersonic Transport, I was unable to contribute more than as a Reserve Officer consultant. But I was fully familiar with the work of the entire study, advising and even writing the Preface of the Report. At the 20th Anniversary Conference of the IAEA in Salzburg in the

summer of 1977, I discussed the issues of supply and demand of skills and brains for the industry.

With this prolegomenon, I now outline the five requisites of an adequate study of the economics of nuclear power as it relates to the logistics of brains and skills.

1. Demand. What are the requirements, as to quality and as to numbers, for bearers of brains and skills in the nuclear power industry?

2. Supply.

a. What is the absolute supply of bearers of these skills and brains in the national population?

b. What are the competing demands of other sectors for the same supply?

c. What is the ability of nuclear power to compete for and attract these bearers?

3. Training. What kinds and how much initial and progressive training should be given to these bearers?

4. Cost. How much will it cost to attract, train and retain this supply of manpower?

5. The design corollary. How do we design and redesign nuclear power systems to operate at the desired standards and what are the costs?

How badly is the above approach needed by the industry? Since Browns Ferry and TMI-2, the industry has begun to wrestle with its Human Factor deficiencies. I have followed the reports being issued, such as Kemeny's and Rogovin's, but I wonder if the systems analysis approach adequate to do the job is understood or being pursued effectively.

Some hint of what may be in store is seen in the "manpower crisis" reported to be facing the industry because college students are avoiding it. Although many jobs in health physics and radiation protection are available in the industry, enrollments in this field have dropped by two-thirds at the University of Lowell in Massachusetts since 1971 (Providence Bulletin, August 11, 1980).

2. The best plants and Human Factors: German and Spanish

a. Atucha. In Erlangen in 1977 I asked Siemens which of all the plants they supplied had the best record. They named Atucha in Argentina. The superiority was due, they said, chiefly to the fact that when the order was placed, the men to operate and maintain the plant were carefully chosen and sent to Siemens to work in the manufacture, and later in the installation and testing. Because of the high cost, the Argentines have not done this for later plants.¹³ The CF for its 5.5-year lifetime through 1979 were successively 40, 68, 69, 41, 78 and 87%.¹⁴

b. The Spanish units. In the summer of 1979, while visiting with the Director of Research, Sr Sevilla, of the Junta d'Energia Nuclear, I observed that Spain's 3 operating nuclear power plants (with a combined lifetime CF of 69% through 1979), had one of the highest, if not the highest, CFs of any country. While he hadn't realized this, after some discussion, he said it

¹³Dr. Schoch told me that Argentina had hired the TUV to advise on Atucha but discontinued halfway through because of the expense (G-17).

¹⁴Adapted from basic data in IAEA's OPERATING EXPERIENCE WITH NUCLEAR POWER PLANTS IN MEMBER STATES, annual reports for 1974-8, and from "Annual Review - 1979" in NUCLEAR ENGINEERING INT'L 3-80. The commerciality dates, nameplate capacity, and the nameplate lifetime CFs through 1979 are Zorita August 1969, 161 MW, 72%; Garona May 1971, 463 MW, 61%; Vandellos, July 1972, 505 MW, 73%.

boiled down to Human Factors. As with Atucha, the personnel to operate these 3 plants were pre-selected carefully and pre-trained. Also like Atucha, Sr Sevilla told me he didn't think this would be done for subsequent plants because of the expense.

3. The best plants: the US

A perceptive discussion of Human Factors and nuclear power operations, written a year before TMI-2, is found in an industry meeting on reliability of nuclear power plants held in April 1978.¹⁵ Notes from several of the papers dealing with Human Factors are given below.

a. Glenn A. Reed, Wisconsin EPC.¹⁶ In 1952 Mr. Reed worked on 2 prototype nuclear power plants, and since 1956 he has been involved in the initial and continuing staffing of the Yankee Rowe, Haddam Neck and Point Beach plants. In 1977 he was Manager of the Nuclear Power Division of his company. He characterizes these 3 plants as among the best in the world. At the time of his talk he was Manager of the Nuclear Power Division of his company.

Given this background in the industry, Mr. Reed's analysis of the sources of past and future improvement in the reliability of nuclear power plants is noteworthy.

First, looking at the "glaring" differences in reliability among nuclear power plants, he gives as the major reason, "people performance." This involves selection, training, utilization and motivation.

¹⁵RELIABLE NUCLEAR POWER TODAY, Proceedings of American Nuclear Society, Piedmont Carolinas and East Carolina Sections, Meetings at Charlotte, N.C., April 10-13, 1978 (ISBN: 0-89448-102-9).

¹⁶"High unit availability from people performance."

Second, speaking of technology, he makes the remarkable assertion that future improvement of nuclear power has reached a plateau and, except for steam generators, "not much improvement in unit availability in the future should be expected from this quarter."

Third, he characterizes the current (1977) state of human factors management in the industry as backward. "People training and development aspects were not in good shape in the early 1960's. This aspect strengthened about 1970 and then fell behind again about 1972, and still remains that way to a degree presently."

From the above it can be concluded that Mr. Reed feels that the future improvement in reliability of nuclear power lies mainly in human factors. The published transcript contains much detail that is worth studying.

b. Richard H. Graves, Haddam Neck plant.¹⁷ In explaining the performance of this unit, which he characterizes as one of the world's most successful, Mr. Graves' first 3 reasons are initial selection of personnel, slow promotion so that the men know their jobs better, and motivation -- all human factors. His fourth is maintenance, an important part of which is highly skilled people and planning. The fifth involves certain reactor circuit equipment favored by Haddam Neck's management. But of the secondary circuit, he says, "Quality in the design, manufacture, and installation of conventional power plant equipment is definitely lacking. ...Perhaps an initial investment of a few million dollars in equipment of better quality would have saved millions

¹⁷"Connecticut Yankee - A Decade of Dependability."

of dollars in replacement power costs."

c. Drew C. Smith, Peach Bottom Atomic Power Station.¹⁸ For improving reliability of nuclear power plants, Mr. Smith puts human factors first, and then equipment and skilled maintenance:

I believe that the goal of increased plant availability can be achieved by a qualified and motivated plant staff support in fact (not just words) by an enlightened corporate management. The most important items in any plant are people. Without the people, the most sophisticated equipment in the world is just so much junk. The attitude, skills, and training can make or break any operation. The other cornerstone of an operation with high availability is reliable equipment. This should be obtained through a program of preventive maintenance as well as performance and failure review.

4. A few German notes

From several German sources, I was told that the quality and motivation of labor had deteriorated substantially, and that this is true in Germany as well as other Western countries, and in Iron Curtain countries (G-55).

Pre-training of personnel slated to operate nuclear power plants is important. It should begin when the order for the plant is first given.

In Germany, every shift on a nuclear power plant must have a graduate engineer. This is a licensing requirement (G-10, 18).

5. Conclusion

Given the size of the US nuclear power industry, the systems approach described above for the logistics of brains, skills and training should be considered in order to bring it up to its best potential. Benefits should exceed the costs substantially.

¹⁸"Minimizing unscheduled outages."

6. To be done:

1. Cull the literature for a systematic codification of what is available on Human Factors. This includes the 20 or so volumes on productivity conferences in the US, and what's been done in Europe.

2. Find and discuss with the best informed thinkers and writers on the subject the lines of solution to the problems.

3. In particular, discuss intensively with the Army's Human Factors group how their work can be transferred over into nuclear power. From my discussions with them, they feel that there is substantial transferability. It is quite possible, after my discussions with them that they entered into relationships with DOE and/or NRC along these lines.

4. Explore Human Factors more intensively with Siemens, Sevilla and the TUVs; and, in the US, with TWA, AEP, the managements of the "best" plants, the manufacturers and A/E's.

5. Cost-benefit the Human Factors component of nuclear power.

J. Capital Costs

For a future nuclear power plant, there are 3 ways of estimating capital cost (independently of inflation):

1. Obtaining estimates for a given technology level and time from suppliers. This has been the custom so far. It almost invariably has resulted in performance well below design, and costs well above the initial contract estimates.

2. Statistically estimating costs by extrapolation from regression analysis of past costs.

3. Setting a desired and realistically achievable level of performance, and pricing that realistically. This means in-depth analysis of the problems of achieving the CF and control of availability necessary for a successful plant.

#1 has not been a good basis for estimation so far.

#2 has the problem of an inadequate data base, inconsistent and widely scattered numbers for the nuclear units built. Overall it affords a view of the past rather than a basis for estimating costs of a future plant.

#3 is the basic route to go, and depends on all the factors with the various limitations and provisions described in the sections above: it requires an information base to a degree which does not exist today.

There is an aspect of capital cost which has received little attention in print: the reversed ratio of fuel to total cost of generation by a FF unit, and the implications for raising capital investment per kw in order to reduce fuel per kwh. I shall treat this briefly here, just enough to indicate the stakes. In late 1973, for a newly ordered plant, coal represented about 30% of the total cost of generation.¹⁹ Today it is probably 60-70%. Obviously capital intensity for greater fuel economy can yield payoffs which are worth investigating. This holds for new plants, nuclear or FF, and the economic possibilities of renovating some existing plants.

¹⁹AEC - 73p. 15.

K. Other Factors, Nuclear

Other factors affecting LWR technology and economics include enrichment, reprocessing, the fast breeder, waste disposal, decommissioning and fusion. In the time horizon of ordering a plant for initial operation in 1990-2000, too little is known, public policies are too clouded, and technologies are too immature to support quantified discussion of any of them here.

These other factors have two possible outcomes in economic analysis:

1. If nuclear, ex them, is more expensive than coal or other alternatives as of the time of analysis, there is not an urgency to know them.
2. If nuclear, ex them, is cheaper, they become immediately relevant, but subject to the limitations already noted.

L. Other factors, Coal

Along the lines outlined above for nuclear generation, but with considerably less uncertainty of technology, a valid study of competitive nuclear power requires a number of important technological/economic predictions for generation by coal. They involve mainly large plants of 800 to 1300 MW. For these the areas of production include:

1. Senescence
2. Economic life of plant
3. The YoYo Effect and control of availability
4. Use of low sulfur Appalachian coal, particularly in the East.
5. Mechanical removal and cleaning as a partial substitute for low sulfur coal.

6. The dynamics of the state of the art for the next 5 years of stack gas cleaning, fluidized bed burning, and low Btu coal gasification at the generating plant.
7. Low cost transportation of coal by rail, water and slurries.

When, as of January 1, 1974, the price of oil quintupled as compared with a year earlier, and tripled again by 1979, for a multiplier of 15 times over 5 years, great forces were set in motion to bring to rapid commercialization the technologies which were known but, because of economics, were not urgent. Among these are factors 5, 6 and 7 above. A good rule of thumb, derived intuitively from observation, is that it takes an average of about 10 years to bring known but as yet uncommercialized technologies to the point where commercial and economic feasibility is demonstrated and routine replication occurs. We are presently 7 years into this stage, with a fairly rapid rate of innovation.

M. Quantification of adequacy of published materials

The factors essential to a valid statistical and qualitative analysis of the competitive economics of nuclear and coal power are listed in Table 3. Each is rated on a scale of 10 equal to optimal explanatory adequacy of published material. While the ratings are necessarily approximate, they are, I believe, a fairly good indicator of the zone of adequacy. What is of overriding significance in these ratings is not an individual rating, but the pattern reflecting the total picture. It is the pattern which is quintessential. The arithmetic averages of factors are, I think, a fairly valid overall approximation

of how far published materials afford a valid study of the comparative economics of nuclear and coal generation.

The average of components for nuclear generation is 2.6 and for coal 4.5.

Table 3: LWR and Coal Plants: Explanatory Adequacy of Published Materials for Components of a Valid Economic Study

<u>Item</u>	<u>10 = Optimal Adequacy</u>	
	<u>Nuclear</u>	<u>Coal</u>
1. Capacity factor: a conceptual, definitional, functional and methodological examination	2	3
2. Economic life of plants	2	5
3. Senescence	3	5
4. Lifetime capacity factor (1+2+3)	3	2
5. The YoYo effect, or "reliability"	0	1
6. Design/Technological risks - Scale	1	6
7. Design/Technological risks - Other	3	6
8. O&M Costs: historical versus design data	1	5
9. Human factor constraints: post-TMI 2	4	-
10. Capital costs	6	-
11. Coal mining: cost vs price, reserves US and abroad	-	6
12. Coal transportation: future costs, technologies, unit trains, other rail, water, slurry		6
13. Coal waste disposal	-	5
14. Secondary environmental impacts: global heat and CO ₂	<u>4</u>	<u>4</u>
15. Simple arithmetic average	2.6	4.5

III

THE FOUR COST COMPARISON CASES:

METHODOLOGY

A. Introduction: Conceptual and Methodological Framework of Case Comparisons

1. Obtaining Authoritative Data

The cost per kwh for a nuclear power plant ordered today (or later) for operation in 1993 (or later) can be predicted, if at all accurately, only from data assembled directly from the architect engineers (A/E), equipment manufacturers, constructors, utilities, uranium producers and the NRC. They alone, if anyone, can provide authoritative data as of the day an order is booked. Nobody else really knows enough to provide a useful body of costs. The lack of a pattern in past costs does not permit costing of a future unit by statistical extrapolation. In fact, a chief value of statistical analysis of existing plants has been to demonstrate the absence of such a predictive pattern. Nuclear capital cost estimates as of the time of a contract award have been so far short of final realized costs as to be of dubious usefulness in prediction. As for operating performance and costs, again the nuclear design predictions have been so far short of actual results as to make the predictions not only useless, but of negative value. They have given misleading signals to suppliers, utilities and regulatory agencies. Obviously, there are inherent uncertainties of technology and costing, without considering inflation, which have created this unpredictability.

2. Technological Sufflation

Cost inflation, an additional uncertainty, consists of two unrelated components: pure price inflation, which should generally apply equally to nuclear and coal costs; and technological

sufflation,²⁰ which results from technological uncertainty at the design stage. The galloping inflation of nuclear power costs relative to coal plant costs has been due preponderantly to technological sufflation. It is reflected in the low capacity factors of nuclear power compared to design, and the related concerns for safety. Both taken together have resulted in regulatory "fixes" and constraints on future construction and operation which have increased costs faster than for the surer technologies of coal generation. It is an axiom in the industry that the construction cost of a nuclear power plant, as contracted by the A/E, does not include a great element of technological risk; and that therefore, the direct and indirect costs of actual performance below design are to be paid, essentially, by the utility rather than by the A/E. Otherwise, the A/E would have to charge a much higher price to account for such costs, assuming they were predictable with reasonable quantification.

It was stated above that only the industry "can" provide "authoritative" data on costs of a future plant. It should be clear that "authoritative" does not necessarily mean acceptably accurate. Nor does "can" mean "will." Suppliers of nuclear power plants have been eager to obtain orders, and it is understandable that their cost proposals may have been more optimistic than the technological uncertainties have warranted. This partly explains why the large manufacturers have been long-term losers on the

²⁰To avoid confusion, the old word "sufflation" has been used for technological inflation, reserving "inflation" for pure price level rises.

plants they have supplied, as well as the utilities, so far.

Having said all this does not necessarily imply that the economics of a plant ordered at some future date is necessarily unfavorable. It is a notice, however, that the analyst of comparative costs must be cautious to recognize the importance of all those factors delineated in Part II under the components of a valid economic study, or his design may turn into fool's gold.

3. The Methodological Significance of Controversy

The controversy over the technology and economic safety of nuclear power, and the inherent inability of opponents of nuclear power to tender their own authoritative data for a future plant, reduce the objective analyst to using the design data of the proponent, i.e., the industry. This creates a methodological posture somewhat as follows:

a. If the industry's design performance and costs, when adjusted for those actually being realized, are unfavorable compared to coal, then the analysis may be taken as fairly definitive. The burden of proof that future results will reverse present and past results falls on nuclear proponents. This methodological assumption circumnavigates controversy because it is based entirely on the proponent's own design and performance. It is as authoritative and noncontroversial as can be obtained.

b. But if the industry design, adjusted for reality, is more favorable than coal generation, then at least in terms of economics it has the advantage. There then remain only the issues of safety of operation and waste disposal. These are resolvable for each person mainly by his own value structure. This assumption,

therefore, becomes much more complex and inherently controversial than the purely economic factor.

A word on precision: nuclear power cost data are at best approximations with a wide zone of possible error. Past predictions have proven unacceptably uncertain. Predictions for a future plant can only be better insofar as the components of a valid prediction can be bettered. Finally, it would be spurious accuracy to calculate beyond decimal points, so to speak, when the data are good only to whole hundreds.

4. Noncomparability of Methodologies in the Four Cases

Two enormous problems that become apparent to the analyst comparing different estimates of future costs of nuclear and coal power generation are (1) that different bundles of assumptions and methodologies are used which are almost impossible to reconcile to a common basis, and (2) that assumptions and mills/kwh are in cases poorly given, or given not at all. These variations and gaps create a time-consuming morass from which to extricate useful cost comparisons.

Differences among the four cases are found in the following illustrative items:

- a. Projected inflation rates during and after construction for capital, fuel and O&M.
- b. Interest rates during construction (IDC).
- c. Methods of converting future costs, such as simple projection, levelized costs, and discounted present value.
- d. Construction times for coal and nuclear plants.
- e. Heat rates.

- f. Differential fuel escalation rates.
- g. Coal prices.
- h. Use of low sulphur Appalachian coal w/o FGD.
- i. Btu per pound of coal.
- j. Fixed charges on capital.
- k. Capacity factors.

5. The Ratio Analysis Solution

Using the original mills/kwh in the four cases when available, or deriving them by reasonable procedures when not available, these base numbers are adjusted for the factors described in Part II above. While the resultant mills/kwh are not directly comparable with each other, a valid comparison can be made by comparing the adjusted components and totals in terms of ratios of nuclear to coal costs within each case. These ratios can be compared for the four case studies with a reasonable degree of validity. They yield valuable, quantified approximations of competitive costs of nuclear and coal power generation.

B. The 13 Basic Adjustments

Adjustments have been made on a standard format for the four cases according to the following procedure:

Step-1: the original mills/kwh are shown at the head of the table for capital, fuel, and O&M without fuel.

Step-2: Adjustments are then shown for the 13 basic items, where feasible. Some cannot be computed due to nonavailability of the information or because my research has not found it: these are shown with blanks in order to indicate that such an adjustment should be included.

Step-3: The adjusted totals of mills/kwh are converted into ratios of coal to nuclear busbar costs. The four cases can then be compared by ratios.

The 13 adjustments are:

1. Technological sufflation, a capital item;
2. Construction time, a capital item;
3. A 25-year life for nuclear power, a capital item;
4. Capacity factor, a capital item;
5. The YoYo factor, both a capital and operating factor;
6. Btu per pound of coal;
7. Projected coal prices;
8. Heat rate (Btu/kwh);
9. Cost of replacement power;
10. Use of low sulfur Appalachian coal;
11. O&M without fuel;
12. Repairs;
13. Decommissioning.

The time horizon of the adjustments

As a rule, the adjustments to the original base estimates have been made as of the time the latter were made. For example, AEC made its estimates as of September 1974. The adjustments are in terms of what was visible at that time. They did not assume, as a rule, hindsight.

The logical sequence of adjustments

The first item to be adjusted is capital, and the first adjustment is for technological sufflation, which establishes a new capital base. This is then adjusted for construction time, i.e.,

for interest during construction (IDC). This new base is adjusted for a 25 rather than a 30 year life. Then this is adjusted for capacity factor. The YoYo adjustment is both a capital and operating factor. The other adjustments are non-capital items (except possibly for major repairs) and follow in sequence.

Each of the 13 adjustments is now given a discussion common to the four cases. Factors unique to an individual case are discussed under that case.

Adjustment 1. Technological sufflation.

The adjustment for technological sufflation was developed for the AEC case, and extended to the other three.

AEC assumed an 8% annual escalation in capital costs for both coal and nuclear units which, because applied to both, must be assumed to be price level inflation. This could not be justified for nuclear power as of 1974-75.

The persistence of nuclear CF's in the 55% zone was a clear indicator of these problems. For lifetime CF's to be brought up the assumption of 75%, capital costs would have to increase. Even assuming a continued 55% zone of performance, it was clear that technological/safety fixes would be required that would escalate the cost of the plants. In its sensitivity analysis, the AEC adopted the example of a 30% increase in capital costs, equivalent to 4.66 mills/kwh. This was probably low as of that time, and certainly low in retrospect from 1980. It is used here, however, as a convenient and conservative adjustment for all four cases, in order just to maintain the approximate 55% CF. The calculation is made by multiplying the capital component's mills/kwh by 1.30.

Adjustment 2. Construction times.

These, for all cases, were too high for coal and too low for nuclear units, even as of the time each of the original projections was made. The adjustments vary with each case.

AEC, for example, assumed 8 years for construction of a nuclear power plant from award, and 6 1/2 years for coal. But the largest FF units awarded in 1971 (550 to 1300 MW) were scheduled to be completed in 3 to 6 years, mostly 4 to 5 years. Of the 11 units, 7 were completed as scheduled, and 4 took an extra year. In the case of nuclear power units, it was known in 1973-74 that the delays in construction were substantial. The FPC, due to concern with this problem, undertook a survey which found 27,000 MW of nuclear power were in delay at that time. General Peters, appointed by the AEC to study solutions for the problem, reported to both AEC and the nuclear power industry that its entire frame of reference would have to be changed radically, that nuclear power plants could not be built the same way as FF plants.

Since nuclear power is capital-intensive, interest and price escalation during construction (IDC and EDC) are substantial items.

The calculation is made by multiplying IDC and EDC by the ratio of the original and adjusted construction times.

In all four cases, adjusted FF construction time was taken as 4.5 years, but adjusted nuclear times varied according to each case.

Adjustment 3. Plant life.

An economic life of 30 years is assumed in all four cases

for both nuclear and coal units. For coal this is consistent with experience. For nuclear, due to technological factors of corrosion, size, etc. discussed in Part II, 25 years appears justified as a maximum, and is used as the basis of adjustment.

Capital recovery consists of return on investment (ROI), depreciation and taxes. Under the shorter life, the same amount of depreciation is recovered, but at a greater annual rate. The ROI is an annual constant. Taxes tend to be a constant. The chief variable is that the capital cost is recovered for fewer kwh, so that the mills/kwh rises. If it is assumed that the last 5 of the 30-year life average the same CF as the first 25, then the simplest approximation of the increase in mills/kwh due to the shorter life would be 30/25ths of the capital component. If it is assumed that due to senescence the last 5 years have a lower CF, there is less of an increase in mills/kwh.

The adjusted CF of 55% assumed for nuclear plants over their lifetime represents the experience of an average 55% CF and lack of a learning curve improvement to date, and all the other factors described in Section II above. A specific senescence factor has not been isolated because there is not yet a body of experience or empirical theory by which to arrive at a quantification. Such an estimate, when available, is more likely to reduce rather than keep even the lifetime 55% CF assumption.

Therefore the simplest approximation for the 25-year life would seem to be to adjust by lifetime kwh. The adjusted capital recovery then becomes:

$$\frac{30}{25} \text{ (mills/kwh for the capital component)}$$

Adjustment 4. Capacity factors (CFs)

CFs have been adjusted on the basis of what coal or nuclear units can achieve in the real world.

Nuclear units have experienced a lifetime CF of about 55%. $\pm$ a few percentage points in any one year. Since they operate on a base load, run-of-stream hydro analog as explained in Part II, their CF must be taken as the maximum achievable under actual long run conditions. Furthermore, there are indications of a retrogressive learning curve.

Thus, in making nuclear cost projections from this base, it is necessary to start with the 55%. Any assumption of much higher CFs puts the burden of proof on the advocate, and such a proof has yet to be made.

For coal, there is evidence that CFs of 70 and 75% are within range of experience. For 1972, FPC data for the 24 most efficient coal burning units in the U.S. utility industry (those using under 9100 Btu/kwh) showed an average CF of 76%. For 1974 the 18 such units averaged 77%. Since FF units are load following, with dispatchers giving preference to run-of-stream hydro, then hydro storage at peaks, followed by nuclear units, these are fairly high numbers. Later, parallel FF CFs begin to be distorted by the expansion in nuclear units. Therefore, as achievable coal CFs, 70 and 75% have been used.

The variability of original CF assumption for the four cases may be seen in the tabulation below.

<u>Case</u>	<u>Nuclear</u>	<u>w/FGD</u>	<u>Coal</u> <u>w/o FGD</u>	<u>LSFO Oil</u>
AEC	75%	75%	--	--
ERDA	65	58	--	--
NRC	60	60	--	--
EXXON	60	66	70%	77%

The calculations to adjust the above CFs are made by multiplying the ratio of the original and the new CFs by the mills/kwh for the capital component.

Adjustment 5. The YoYo Factor.

This, as explained in Part II is the unpredictable fluctuation in availability of nuclear power units at their full capacity. As a result, substantial additional reserves must be maintained. It is a substantial cost item, especially at peaks.

However, an estimate of differential costs is beyond the resources of this study. Therefore the item is noted on the tables of adjustments, but with a question mark.

Adjustment 6. The Btu Per Pound of Coal.

This is a conventional measure which was used by AEC and NRC. ERDA and Exxon used ¢/million Btu, which bypasses the pound measure.

AEC used 10,900 Btu/lb, and NRC 12,000. The lower AEC estimate is an error. It is actually the average of all coals used by utilities in 1974, including low sulfur lignite.²¹ Steaming coal has about 12,000 Btu.

²¹This is exactly the Btu/lb shown for bituminous and lignite coals combined as used by electric utilities in 1974. See Monthly Energy Review of DoE, inside back cover showing conversion rates.

Many plants show coal values at 12,500 Btu and higher. A trend to better cleaning and preparation of coal at the mine is under way and will definitely result in higher Btu/lb at the generating plant. With the higher freight rates for moving coal in the past several years, and the lower costs of handling at the generating plant, it is inevitable that heating values of coal will improve above 12,000 Btu within the time that plants now ordered will be on the line.²²

After the oil embargo of the fall and winter of 1973-74, there was a squeeze on coal supply which resulted in a deterioration of delivered quality and Btu/lb. This phase is being supplanted by demand for better coal and greater competition among coal suppliers, which should result in upped quality.

A value of 12,000 Btu/lb of Eastern and Midwest coals has been used for AEC adjustments.

Adjustment 7. Fuel Prices (Projected)

The main adjustments here are with the AEC and are discussed below under that section.

In general, there is much more domestic and international competition among suppliers of coal than within the uranium and OPEC cartels. The initial price surge for coal after the oil embargo of 1973-74 peaked in 1975. It was followed by expanded supply which continues to grow on a world basis. The result has been not only a leveling off of coal prices in constant dollars, but a drop. This goes back to the competitive situation in coal

²²See, e.g. EPRI Journal, November 1980, p. 40, "Coal-cleaning test facility."

production. As a recent study stated, "Fundamentally the price of coal is determined by its production cost."²³

Adjustment 8. Heat rate (Btu/kwh).

Heat rate is expressed in Btu of coal per kwh. Those used by the four cases for high sulfur coal are:

AEC	9500 Btu
ERDA	9751
NRC	10000
Exxon	9420 w/FGD 9050 w/o FGD 9000 low sulfur fuel oil (LSFO).

The main problem turns on the rate for high sulfur coals. Coal has a lower heat rate than oil or gas because it contains less hydrogen. Since Exxon shows 9000 Btu for LSFO, then, other things being equal, coal w/o FGD could be expected to show a lower heat rate. This is indicated in FPC's annual statistical reports of steam plant generation. The "best" generating units are classified as having heat rates of less than 9200 Btu for coal, and 9700 for gas and oil.²⁴

In 1972 some 24 coal generating units using bituminous had heat rates under 9100 Btu, ranging down to 8546. In 1977, there were 11 units with rates under 9200 Btu, ranging down to 8842.

W/o FGD, therefore, a figure of 9,000 Btu is reasonably

²³President's Commission on Coal, Coal Data Book, 1980, p. 96.

²⁴FPC, STEAM-ELECTRIC PLANT CONSTRUCTION COST AND ANNUAL PRODUCTION EXPENSE. Starting in 1974, FPC raised its standards for "best" heat rates by 100 Btu from 9100 for coal and 9600 for oil and gas.

attainable for new, well designed and well built units using coal cleaned and prepared to state of the art standards.

FGD uses additional energy for its operation equal to 1% to 2% of total generation of a unit. Using 2% would bring the 9000 Btu w/o FGD to 9180 Btu. Therefore, 9200 Btu has been used as the base heat rate.

Adjustment 9. Cost of Replacement Power.

As the largest nuclear power units have come on line, and as prolonged unplanned outages have occurred with some frequency, it has become clear in recent years that the cost of replacement power is a major charge on their economics.

Every nuclear plant in operation today was stated in its design to operate at 80% CF, or higher. Long range balances of power supply and demand were made on these CF assumptions. The 55% average CF actually realized has created shortages of supply which concentrate at those plants with unplanned complete shutdowns. Examples are the 2 Browns Ferry units and 2 TMI units.

This is a "distress" type of unplanned demand for replacement power, as distinguished from power purchases made by utilities on long term commitments. Distress power is very high cost. It is obtained either from the utility's own units which are marginal and less efficient because of higher heat rates; or it is bought from sources which charge on the basis of full costs of their marginal and less efficient units. Distress power contrasts with much cheaper power purchased on long term commitments for government hydro or joint ownership of hydro and FF generating units.

There are two ways to estimate cost of replacement power

for nuclear plants:

1. Use each case's stated cost of coal generation, which is base load and would not include the higher actual costs of oil and gas units. To this add 50% for the distress factor.

2. Take the average purchased power cost in the industry for the reference year of each case, and add 50% for distress factor.

The national average cost of purchased power includes all types; distress, hydro, joint ownership, gas, oil, coal, and nuclear. The cost has risen from 8 to 23 mills between 1973 and 1979. The increase of 178% is due mainly to higher fossil fuel costs. The general inflation as measured by the GNP Price Deflator increased by only 56%.

To give some idea of how distress power is priced, the TMI shutdowns of 2 nuclear power plants on March 20, 1979, which continue into 1981, have had the following effect on purchased power of Metropolitan Edison Company:

Cost of Purchased Power, cents/kwh

<u>Year</u>	<u>Met Ed</u>	<u>U.S.</u>
1978	1.42¢	2.02¢
1979	<u>4.79</u>	<u>2.346</u>
Increase	237%	16%

Source: DoE, STATISTICS OF PRIVATELY OWNED ELECTRIC UTILITIES IN THE U.S., 1979.

Which of the 2 ways of computing the cost of replacement power for nuclear power plant shutdowns is specified under each of the four cases.

The calculation of the additional charge to total nuclear power costs is obtained as follows:

$$A = m \left(\frac{d}{55} \right) \quad \text{where} \quad \begin{array}{l} m = \text{mills/kwh of replacement energy} \\ d = \text{assumed CF} - 55\% \\ 55 = \text{adjusted CF} \\ A = \text{the adjustment to cost of kwh produced at 55\% CF} \end{array}$$

Adjustment 10. Use of Low Sulfur Appalachian Coal.

The only comparison made by AEC, ERDA and NRC was of nuclear with high sulfur coal. Exxon, however, also compared with low sulfur Appalachian coal, which did not require FGD under Federal Pollution standards in effect at the time of its estimate in November 1977. This makes for a much more economical coal cost estimate. Exxon's coal w/oFGD had a busbar cost 20% less than w/FGD, and 25% less than nuclear.

Low sulfur (less than 1%) "recoverable" reserves of bituminous coal in the Appalachian region are 14.5 billion tons, plus 1.1 billion in the Midwest, for a total of 16 billion tons. This is half the "demonstrated" reserves.^{25a}

At the 1990 projected use of about 540 million tons of coal by electric utilities, there would be 29 years supply of low sulfur coal. Obviously not all of this would be used by the utilities, as much of it is metallurgical coal.^{25b}

The time horizon for evaluating life of these low sulfur coals is bounded by the fact that within 5 to 10 years, raw burning of

^{25a}President's Commission on Coal, COAL DATA BOOK, pp. 71, 75.

^bThe 540 million tons is approximated by taking use in the regions burning Appalachian and Midwest coal, and prorating them to the Commission's national projections for all coal use (pp. 29, 34, and 35).

coal will be an obsolete technology. Improved cleaning and preparation, and processes such as fluidized bed combustion (FBC), make it feasible to use coals of high sulfur content with less or no FGD.

Therefore it is economically feasible to use the low sulfur Appalachian and Midwest coals now, with the understanding that new processes will open up the use of high sulfur coals within 5 to 10 years on a large commercial scale.

Thus the Exxon comparisons using low sulfur coal may be taken as a reference for the optimum solution over the next 10 years for new coal burning plants. As far as economically feasible, such plants should be built with provision in the designs for conversion to FBC or other processes at a later date.

Adjustment 11. Operations and Maintenance, exc. fuel (O&M.

The four cases all show nuclear O&M per kwh as less than for coal, but the actual experience shows the opposite consistently and by a wide margin.

In general, as explained in Section II, nuclear is like RoS hydro and would be used whenever available. Capacity factors below design are due to technological restrictions such as breakdowns or partial operation. As a result of the combined factors of higher repairs and other maintenance, and lower CFs, both dollar and per kwh costs should go up as CFs go down.

Conversely, baseload FF generation, being more load following, should show lower dollar and per kwh costs as CF drops.

In 1977, for all plants, O&M was 35% higher for nuclear than for FF steam generation. It was 90% higher in 1979.

For large units of over 800-MW in 1978, the 19 nuclears averaged 28% more than all nuclear units. But the 15 coals averaged 27% less than all coal units. The large nuclear units averaged 109% more than the large coal units. Of the 15 large coal units (in 6 plants), most were in the 1300-MW size.

Obviously, the lower nuclear O&M posited in the four cases is a design goal which is reversed in the real world. Adjustments have been made to correct for this understatement in each case. (Note in NRC case the high variance cost component of coal O&M.)

Adjustment 12. Repairs.

Associated with the low capacity factors experienced by nuclear power plants is high repair cost. This should be included in O&M as reported to FPC/DoE. However, in comparing reported nuclear O&M costs by year and CF, it is found that the reported data at times do not seem consistent. Large drops in CF, indicating large repairs, may not show corresponding increases in O&M. Much of the non-routine repair work is made, not by regular O&M personnel, but by outside contractors. Such expenses may not always be reported in the O&M accounts for the particular unit under repair. The reported O&M would then understate actual O&M. There is no way of estimating underreporting from published data, short of detailed audits at the plant.

Large repairs may be capitalized, or amortized over several years. A few cases have been reported where replacement of large components like steam generators may cost as much as half of the full original cost of the entire plant.

Adjustments for underreporting of repairs as O&M therefore can not be made in the four case studies, but a line is included in the adjustment matrix for each to indicate that such adjustments, if they could be made, might be substantial.

Adjustment 13. Decommissioning Costs.

Decommissioning costs have so many unknowns at this time, that it is impractical to estimate them.

Therefore a line is included in the matrix table for each case to show that it is an important cost element, but left blank to indicate that it cannot be computed at this time.

A note of caution. The industry's extraordinarily low costs per lifetime kwh for decommissioning, when based on discounting future cost to present value, are deceptive, as shown by the following example.

a. Each \$1,000,000 of decommissioning cost in 2011, i.e., at the end of the assumed 30-year life of the nuclear plant, becomes, at a 10% discount rate, only \$57,000 present value in 1981.

b. Each \$1,000,000 of protection and maintenance of the radioactive site in the 30th year after decommissioning, or 2041, at 10% discount becomes only \$3,249.

c. Each \$1,000,000 of protection and maintenance at 2101, 90 years after decommissioning, becomes only \$11.

This sequence can go on indefinitely, because the lives of the radioactive wastes are thousands of years. They will require substantial protection and maintenance by a "priesthood" for these several thousand years.

The sums involved run into of billions of future

dollars for the industry. For example, if the cost for decommissioning one plant, at an assumed inflation rate of 5%, in 1981 dollars is \$100,000,000, this becomes \$432 million in 2011 after a 30-year life. At an 8% rate, it becomes \$1.01 billion. Thereafter protection and maintenance costs multiply at similar compounding.

While present value has a purely theoretical validity in this case, its real world validity is nil. The fact is that virtually no corporation puts money aside today to accumulate a future value 30 or 100 or 1000 years from now. Corporate financing does not work that way.

In the case of decommissioning, and future protection and maintenance of decommissioned entities, one result of present value is to make the future costs seem smaller by orders of magnitude. Realistically, it is only the sums of money required at the future dates of decommissioning and for subsequent annual support of the protecting priesthood which count.

IV - I

THE AEC CASE

Introduction

The first authoritative statement of nuclear and coal generation costs was issued in February 1974 by the AEC in its annual review, The Nuclear Industry 1973. This was the first time that assumptions were clearly stated, and sensitivity analysis was performed. As the price of oil had just quadrupled to \$10. a barrel from \$2.25 on October 1, 1973 (FOB Ras Tanura, S. Arabia), AEC recognized that price relationships for coal, oil and nuclear fuels were in a state of upheaval. However, the dust had settled somewhat by the following year, so that it is a better choice for analysis, since the format of assumptions and sensitivity was the same. The basic analysis of costs below is therefore from The Nuclear Industry 1974, whose text is current as of November 15, 1974, though printed and issued about May 1975. (After issue of this report, AEC was dissolved into NRC and ERDA.)

The base AEC cost comparison, and the adjustments made to those projections to bring them from design down to a reality that was largely visible at the time AEC made its own projections, are summarized as follows:

	AEC		Adjusted		
	<u>N</u>	<u>C</u>	<u>N</u>	<u>C-70%</u>	<u>C-75%</u>
1. Capacity Factor	75.	75.	55.	70.	75.
2. Total cost, mills/kwh	22.6	28.9	62.4	24.9	22.2
3. Nuclear = 100	100.	128.	100.	39.8	35.6

It is of the utmost importance to understand that the nuclear costs would be much higher if adjustments for 3 big items could have been quantified: the YoYo factor, repairs and decommissioning.

Coal is 28% more costly than nuclear in the original AEC estimates. After adjustments, it becomes 60% cheaper at 70% CF, and 64% cheaper at 75%. Nuclear rises from 22.6 to 62.4 mills/kwh, coal drops to 24.9 mills at 70% and 22.2 mills at 75%.

The itemized adjustments are shown in Table 4. The largest adjustments to nuclear power are: replacement power at 12.1 mills, CF at 9.8, O&M at 3.8, technical sufflation at 4.65, and 25-year life at 4.47 mills. The total of adjustments is 41.6 mills which, added to the base total, gives 64.2 mills, an increase of 184%.

Coal at 70% CF drops from 28.9 to 24.9 mills, or 14%. At 75% CF the drop is to 22.23 mills, or 23%.

The general basis for the individual adjustments has been given in Part III above. Annotations for the specific computations are numbered below to correspond to the numbers of the adjustments shown in Table 4.

Notes on Specific Adjustments

1. Technical Sufflation

This is a 30% increase in capital costs as explained in Part III under Adjustment 1, or 4.65 mills/kwh.

2. Construction Times

a. Nuclear

AEC assumed a construction time of 8 years for nuclear units, when it was already evident that it was much higher. An adjustment to 10 years has been used. This raises interest during construction (IDC) and pure price level inflation by 25%, or 2.22 mills/kwh. The computation is:

Table-4: AEC: Adjusted Costs of Nuclear and Coal Generating Units
(Mills/kwh)

A. BASE COSTS	Nuclear	Coal with FGD	
1. Capital	15.5	13.0	
2. Fuel	5.6	12.2	
3. <u>O&M</u>	<u>1.5</u>	<u>3.7</u>	
4. Total	22.6	28.9	
5. CFs	75%	75%	
B. CAPITAL ADJUSTMENTS		<u>70% CF</u>	<u>75% CF</u>
1. Technical sufflation	+ 4.65		
New capital	<u>20.15</u>		
2. Construction times	+ 2.22		- 1.50
New capital	<u>22.37</u>		<u>11.50</u>
3. <u>25-year life</u>	+ 4.47		
New capital	<u>26.84</u>		
4. <u>Capacity factor</u>	+ 9.76	+ 0.82	
New capital	<u>36.60</u>	<u>12.32</u>	
5. The YoYo factor	+ ?		
C. FUEL ADJUSTMENTS			
6. Btu/lb of coal		- 1.12	- 1.12
7. Fuel prices	+ 2.8	- 3.66	- 3.66
8. Heat rate		- 0.39	- 0.39
9. Replacement power cost	+12.13		
10. Use of low-S Appal. coal		- ?	- ?
D. Other adjustments			
11. O&M exc. fuel	+ 3.80	+ 0.26	
12. Repairs	+ ?		
13. Decommissioning	+ ?		
E. Sum of adjustments	+ 39.830 ^{a/}	- 4.09	- 6.67
F. Adjusted totals	<u>62.43 ^{a/}</u>	<u>24.81</u>	<u>22.23</u>
Nuclear = 100	100.0	39.7	35.6

^{a/} Plus substantial adjustments for the YoYo factor, repairs and decommissioning.

Capital cost of AEC in 1982	=	\$680/kw
of which IDC at 8%	=	116.5 for 8 years
and inflation at 8%	=	183.5 for 8 years
IDC + inflation	=	300.0 per AEC

At 10 years construction time:

$$\text{take } \frac{10}{8} \times \$300 = \$375 = +75$$

$$\frac{75}{680} = +11.03\%$$

$$\begin{array}{rcl} \text{Capital after Adjustment-1} & = & 20.15 \text{ mills/kwh} \\ & \times & 0.1103 \\ & = & \underline{+2.22 \text{ mills/kwh}} \end{array}$$

b. Coal at 75% CF

AEC's 6.5-year construction time for coal units is adjusted to 4.5 years as explained in Part III. This reduces capital cost by 1.50 mills/kwh as follows:

AEC's capital cost/kw	=	\$570. which includes
IDC	=	<u>103.5</u>
+ Escalation	=	<u>110.0</u>
IDC + inflation	=	<u>213.5</u> = 37.456% of \$570.

$$\frac{4.5}{6.5} \times 213.5 = 147.81$$

$$213.5 - 147.81 = 65.69$$

$$\frac{65.69}{570} = 11.52\% \text{ reduction in capital cost}$$

AEC's capital cost = 13.0 mills/kwh

$$13.0 (0.1152) = 1.50 \text{ mills/kwh reduction}$$

Adjusted capital cost = 13.0 - 1.50 = 11.5 mills.

3. 25-Year Life

The increase is to $\frac{30}{25}$ (capital mills/kwh) or by 4.47 mills/kwh.

4. Capacity Factor

In its Review for 1973, AEC assumed CFs of 80% for both nuclear and coal. This was lowered to 75% for 1974's Review. The

75% assumption could be supported by experience for coal. For example, for 1972 the FPC data for the 24 most efficient coal burning units (those with under 9100 Btu/kwh) showed an average CF of 76%. For 1974, the 18 units with less than 9200 Btu/kwh (the standard was raised by 100 Btu that year) averaged 77%. For coal, CFs of 70% and 75% have been used.

But for nuclear units, the 75% did not conform to experience. Nameplate CFs were 53% in 1973, 55% in '74 and 55% in '75. A 55% CF was used in the adjustments, which raised cost by 9.76 mills/kwh. This adjustment is 75/55ths of capital.

5. The YoYo Factor

This is substantial, but it was not feasible to make an estimate of the increased nuclear cost, as explained in Part III.

6. Btu/lb of Coal

The AEC value of 10,900 Btu, being the average of all coal used by utilities, including lignites, was adjusted up to 12,000 Btu, as explained in Part III. This reduced the price of coal by 1.12 mills/kwh. The computation is:

$$\frac{12,000 - 10,900}{12,000} \times 12.2 \text{ mills} = 1.12 \text{ mills.}$$

7. Projected Fuel Prices

a. Nuclear fuel

Between its annual Reviews for 1973 and 1974, AEC changed its philosophy of nuclear fuel costs sharply. In 1973 it estimated the then current cost at 2.50 mills/kwh, and kept it constant, although other costs were raised by 5% a year. The rationale was that

"nuclear fuel costs . . . will remain constant because of improvements in technology and cost reductions as a result of increases in scale of manufacturing." For 1974, however, AEC escalated nuclear fuel as well as coal costs by 8% a year, because the former "are not expected to be offset by improved productivity and economies of scale."

AEC put nuclear fuel/kwh in 1974 at 3.02 mills. Escalated at 8%, this became 5.59 mills in 1982, or 1.85 times the 3.0. The cake component (U_3O_8) of the 3.0 mills is 0.75 mills or 25%, which was priced at \$13/lb in 1974 and \$24.05 in 1982. However, by 1979 it was already \$45 in the spot market, though falling back by 1981 to some figure around \$40. The drop is probably due to the fall in orders for new units, cancellations and delays for units ordered or under construction, and temporary selling of surplus uranium by U.S. utilities. This slack will probably be taken up by the rapid expansion of nuclear power plants in other countries, and may be temporary.

In any case, the rise in nuclear fuel costs was underestimated by AEC. In its sensitivity analysis, it uses a 50% increase and, since it is conservative and convenient, it is adopted here. The result is a rise in cost by 2.80 mills/kwh.

b. Coal

AEC in its sensitivity analysis assumed a 30% drop in coal prices. If this is interpreted as being relative to nuclear fuel prices, it may be valid. For the long range, the tight cartel for uranium ore and the near monopoly for enrichment in Europe must be

contrasted with the fairly high degree of competition in coal output and pricing. As pointed out in Section III, coal prices in constant dollars peaked in 1975, and have declined a bit since. It is not clear whether AEC's 12.2 mills/kwh for coal in 1982 is a levelized lifetime average. If it is, then an assumption seems fair that over the lifetimes of the coal and nuclear units, the relative inflation rate of coal prices will be less than that of nuclear fuel, particularly as the fast breeder cannot be a significant factor during the 30 years from 1982 to 2012.

Therefore the 3.66 mills adjustment of AEC for a 30% relative drop in price of high sulfur coal seems to be reasonable, and has been used as the adjustment here.

8. Heat Rate

AEC used 9500 Btu/kwh for coal. The adjusted heat rate is 9200. This gives a reduction of 0.39 mills/kwh, computed as follows:

$$\frac{300}{9500} \times 12.2 \text{ mills} = 0.39 \text{ mills/kwh}$$

9. Replacement power

As stated in Part III, the cost of purchased power in 1974 averaged 12.01 mills/kwh. Adding 50% for distress replacement power, or 6.005 mills, brings this to 18.02 mills. Applied to 55% instead of AEC's 75% CF gives an additional cost of 6.553 mills/kwh in 1974 computed as follows:

$$\frac{20}{55} (18.02) = 6.553 \text{ mills.}$$

Escalating to 1982 at 8% brings the 6.553 to 12.13 mills/kwh.

A logical case can be made out to use the adjusted cost/kwh

of AEC for coal, of 24.81 mills; plus 50% for distress gives 37.215 mills, for a net adjustment of 13.53 mills/kwh. The lower 12.13 mills has been used as the adjustment.

For coal, an adjustment has not been made when dropping from AEC's 75% CF to 70%. The logic is that the nuclear units were designed for 75%, would be baseloaded like run-of-stream hydro, and would be used whenever available as explained in Part III. Any drop below design therefore would require replacement power. But coal, being load following, could easily operate at 70% even though available at the 75% design, and therefore not require replacement power. (The adjustment, if made, would be minor: 0.87 mills/kwh,)

10. Use of Low Sulfur Appalachian Coal

As pointed out in Section III, no adjustment for this important factor is made in the AEC case, but it does come up in the Exxon case. See the rationale in Part III under Adjustment 10.

11. Operations and Maintenance (O&M) Excluding Fuel

The average O&M in 1978 for the 21 large nuclear units (over 800 MW) was 3.97 mills/kwh. The year 1978 is used because it is the latest date for which this information is available, and gives the most experience for the kind of plant that would have been ordered in 1974. Escalated to 1982 at AEC's 8% inflation rate brings it to 5.40 mills at 54% CF. Adjusted to a 55% CF, this becomes 5.30 mills/kwh generated, i. e.,

$$\frac{54}{55} \times 5.40 = 5.30$$

$$5.30 - 1.5 = 3.80 \text{ mills net increase}$$

For coal, AEC's 3.7 mills/kwh in 1982 is for a 75% CF. At 70% it becomes 3.96 millsper/kwh generated, an increase of 0.264 mills:

$$\begin{array}{rcl} \frac{75}{70} \times 3.7 & = & 3.964 \\ & - & \underline{3.7} \\ & & 0.264 \end{array}$$

12. Repairs

This is a very substantial item for nuclear power, but cannot be estimated. This line in Table 4 is therefore left blank, but shown to indicate its existence.

13. Decommissioning Costs

This too cannot be estimated, as explained in Part III, and is also shown in blank.1

IV - 2

THE ERDA CASE

NOTE ON SOURCES

The basic estimates and adjustments in the ERDA case are derived from the following sources:

1. Short citation: ERDA. ERDA, COMPARING NEW TECHNOLOGIES FOR THE ELECTRIC UTILITIES, 12/9/76, ERDA 76-141, Draft Report (Revision-A) 240 pp. + 10 pp. Appendix.
Note: this was also the final version.

Prepared under contracts by TRW and MITRE Corp. managed by a joint ERDA-TRW-MITRE task force.

2. Short citation: TRW. TRW, ELECTRIC UTILITIES STUDY: AN ASSESSMENT OF NEW TECHNOLOGIES FROM A UTILITY VIEWPOINT.- FINAL REPORT, November 30, 1976, prepared for ERDA.
3. Short citation: MITRE. MITRE/METREK DIVISION, ANALYSIS OF BENEFITS ASSOCIATED WITH THE INTRODUCTION OF ADVANCED GENERATING TECHNOLOGIES: DESCRIPTION OF METHODOLOGIES AND SUMMARY OF RESULTS, L. Goudarzi, Project Leader, March 1977, prepared for ERDA.
4. Short citation: GOUDARZI. Goudarzi, L., letter of December 5, 1980 to Professor Hellman, transmitting capacity factor profile used in ERDA study for coal economics and part of item 3 above by MITRE/METREK. Also nuclear-coal comparisons expressed in mills/kwh for each of following cost components separately: capital recover, fuel, O&M, and total received by telephone from Washington, January 12, 1981.

Introduction

The ERDA study of December 1976 compares the feasibilities of various existing and potential technologies for the generation of electricity to the years 2000 and 2020. Its primary focus is on "the economics of power production" and "the strategy of commercialization." It was intended as "a step in achieving a dialogue between ERDA, which sponsors the development of new technology, and the private sector, which would implement the newly developed technologies."

It was a tripartite study, and it is not clear what the division of inputs was. ERDA states (p. iv) that "Commercialization dates and capital and operating costs used in this report have been estimated by each of the cognizant ERDA offices developing the technologies." But it also states (p. v) that "The Analysis upon which this report is based was undertaken by TRW and the METREK Division of the MITRE Corporation," whose efforts were said to be documented in Volumes II and III "of this report." However, these volumes were never released as ERDA reports. The reports cited as TRW and MITRE probably are the equivalents. There was also an ERDA working group, which "participated actively in the study."

The ERDA study probably cost over half a million dollars. It was a prime, authoritative study by 3 knowledgeable, competent teams. By authority, funding and industrial links, they should have been able to provide a useful comparison of the 2 most important alternatives within their time horizons for the study, nuclear and coal generation.

Yet, after weeks of working with the ERDA study, this researcher

could only characterize the experience of trying to extract a usable data base as pure frustration and failure. The ERDA data on nuclear and coal comparisons were inadequate, ambiguous, and inconsistent internally. One reason may be that there were 3 cooks at one pot, competent as they were individually.

It is elementary that any useful comparison of nuclear and coal generating costs must in the end express the 3 major cost components in the standard measure of mills per kwh. These are capital, fuel, and O&M (excluding fuel); plus, of course, their sum. However, ERDA gives only O&M and the sum in mills. Capital and fuel are given in measures which are not additive. Therefore it is difficult or impossible and time-consuming to evaluate the ERDA cost analysis, or to apply the 13-adjustment matrix.

Attempts to convert the ERDA measures for capital and fuel to mills ran into the extraordinarily complex methodologies used in the study. The difficulty is recognized by ERDA, which includes an appendix, "Methodology for calculating levelized revenue requirements." "Because so much of the results of the report depend on the economic calculations of the revenue requirements of each technology, and because there is no unique accepted methodology for making such calculations, this appendix presents in more detail the methodology actually employed." The methodology used is life cycle costs 1975-2010. For each year, both revenues and kwh are reduced to present value. Levelized cost is defined as the ratio of the present value of revenue requirements to the adjusted present value of power output (kwh).

However, it is not at all clear that the illustrative methodology and assumptions of this appendix are those used consistently in the

body of the ERDA study or in the TRW and MITRE volumes. For example, the CF of 60% used in the appendix for high sulfur coal was not the same as that unspecified but used in the body of the report.

Some idea of the frustrations engendered by these problems may be seen in Table 5, which shows 7 different estimates of total/busbar costs that may be derived from the ERDA report.

For nuclear, the total costs ranged from 17.2 to 34.4, and for coal from 21.3 to 35.0 mills/kwh.

Data problems: "3 at the pot"

1. Capacity factor

In the body of the report, ERDA gives no specific CFs, fundamental as they are to the assumptions underlying comparative costs. The very vague clues turn out to be misleading rather than helpful.

At p. 102 it is stated that "the baseload technologies were assumed to have similar plant factor histories over their lifetimes -- typically starting at 0.5, rising to 0.7 after 2 or 3 years, and later steadily decreasing until the plant is retired. In effect, this assumption involves treating all technologies as having comparable reliability regardless of their inherent complexity." From this it might legitimately be inferred that nuclear and coal were given the same CFs ("plant factor" and CF are synonymous).

Similarly, but with differences, MITRE, at p. 51, states that "the capacity factor profile for each of the technologies was chosen in a manner that would allow all technologies to compete on a roughly equivalent economic basis in terms of the amount of utilization of capacity (i.e., similar capacity factors) but one that also recognized

Table 5: Three at the Pot:
Seven Versions of Total Busbar Costs of Nuclear
and Coal w/FGD -- for Southeastern Region (SERC),
for Initial Commerciality in 1982, and for the
year 2000 Expressed in Dollars of 1975.

(Mills/kwh)

<u>Source</u>	<u>Nuclear</u>	<u>Coal</u>
1. ERDA, p. 195	17.8	21.8
2. TRW, p. 3-5, interpolated from charts	34.4	35.0
3. ERDA, Bar charts p. 20	18.5	21.6
4. Richard Hellman	Tried to convert capital costs to mills/kwh @ ERDA's 15% for annual fixed charges, but gave up in frustration, thus no total	
5. Richard Hellman, inferring from ERDA p. 105	ERDA permits inference that \$105 million of capital costs equals 2.5 mills/kwh: Effort to expand this to total cost of capital also was abandoned in frustration.	
6. ERDA, p. A-2		26.9
7. Goudarzi to Richard Hellman	17.2	21.3
7. ERDA, p. 153		25.

Note: additional versions may be measured off the numerous charts.

technological differences (e.g., conventional technologies²⁶ would likely experience fewer break-in problems than advanced technologies; hence the former would have a higher initial capacity factor)."

Then MITRE, at p. 52, gives as the percent CFs for nuclear and coal respectively: 60 and 60 for the 1st year, 72 and 70 for the 3rd year, and 50 and 30 for the 30th year. However, no average lifetime CF is given for either. This omission is hard to explain, particularly as it indicates a higher achievable lifetime CF for nuclear than for coal. These numbers for coal are identical with those shown in ERDA, p. A-4 and Table A-3 of the Appendix, which specify a lifetime CF of 60%. The trouble is that this "illustrative" 60% was not the CF used in ERDA to obtain its total cost figures, as was learned from Goudarzi. In any event, no CF was shown in ERDA for nuclear, nor in MITRE.

The capacity factors as furnished personally by Goudarzi were 65.1% for nuclear and 58% for coal w/FGD (arithmetic averages of the 30-year lives). There was no way these numbers could be derived from ERDA or MITRE.

2. Fuel

These were expressed for coal in cents per million Btu, but differed widely as illustrated below. They are all for delivered costs in the Southeastern Region (SERC).

²⁶Nuclear and coal were both classified as "conventional," indicating that their CFs might be the same.

<u>Source</u>	<u>1975</u>	<u>2000</u>
ERDA, p. 77	89-119¢	111-149¢
TRW	53-94	70-135
MITRE, p. 42	77-104	100-135

For nuclear, there was no usable cost given anywhere.

3. Capital Cost

Attempts to convert the various costs/kw into usable mills/kwh failed.

The search for usable numbers

After weeks of working with the basic ERDA document, without being able to arrive at any numbers worth using, I began a search for persons who had managed the various original studies. By a chain of hand-ons, I arrived at people who were most helpful. They furnished sections of the TRW and MITRE documents. But these still did not permit obtaining mills/kwh for capital and fuel. This was finally accomplished through Mr. Goudarzi, who had been Project Leader for MITRE/METREK. He reconstructed the 3 components in mills/kwh, and the CFs. He did this over several weekends and evenings despite a heavy load of regular work. (His efforts are here gratefully acknowledged.)

Adjusted costs

The standard matrix showing the 13 adjustments to ERDA's bus-bar costs for nuclear and coal as furnished by Goudarzi is developed in Table 6. The general basis for the individual adjustments as given in Part III above, and the specific computational methods as used in AEC and applicable to ERDA, are also incorporated here by reference.

TABLE 6. ERDA: Adjusted Costs of Nuclear and Coal Generating Units
(Mills/kwh)

A. BASE COSTS	Nuclear	Coal with FGD		
		70% CF	75% CF	58% CF
1. Capital	8.03		7.034	
2. Fuel	7.79		11.532	
3. O&M	<u>1.35</u>		<u>2.693</u>	
4. Total	17.17		21.259	
5. CFs	65%		58%	
B. CAPITAL ADJUSTMENTS		70% CF	75% CF	58% CF
1. Technical <u>sufflation</u>	+ 2.41			
New capital	<u>10.44</u>			
2. Construction <u>times</u>	+ 0.76			-0.211
New capital	<u>11.20</u>			<u>6.823</u>
3. <u>25-year life</u>	+ 2.24			
New capital	<u>13.44</u>			
4. <u>Capacity factor</u>	+ 3.01	-1.170	-1.547	--
New capital	<u>16.45</u>	<u>5.653</u>	<u>5.276</u>	<u>6.823</u>
5. The YoYo factor	Substantial			
C. FUEL ADJUSTMENTS				
6. Btu/lb of coal		--	--	--
7. Fuel prices	--	--	--	--
8. Heat rate		-0.652	-0.652	-0.652
9. Replacement power cost	+ 4.90			
10. Use of low-S Appal. coal		Substantial		
D. Other adjustments				
11. O&M exc. fuel	+ 2.04	-0.46	-0.61	--
12. Repairs	Substantial			
13. Decommissioning	?			
E. Sum of adjustments	<u>+21.44</u>	<u>-2.282</u>	<u>-2.809</u>	<u>-0.863</u>
F. Adjusted totals	<u>38.61</u>	<u>18.977</u>	<u>18.450</u>	<u>20.396</u>
Nuclear = 100	100.	49.2	47.8	52.8

The base ERDA/Goudarzi cost comparison, and the adjustments to bring them from design down to a reality that was largely visible at the time the ERDA projections were made are summarized as follows:

	<u>ERDA/Goudarzi</u>		<u>Adjusted</u>			
	<u>N</u>	<u>C</u>	<u>N</u>	<u>C-70%</u>	<u>C-75%</u>	<u>C-58%</u>
1. CF 30 years	65.1	58	55	70	75	58
25 years	67.33	--	55	--	--	--
2. Total cost mills/kwh	17.2	21.3	38.7	19.0	18.4	20.4
3. Nuclear = 100	100	123.8	100	49.2	47.8	52.8

Coal, which is 24% more expensive in the original base estimates, becomes cheaper after adjustments by 51% at CF = 70, 52% at CF = 75, and 47% at CF = 58. For nuclear, the largest single adjustment is replacement power at 4.90 mills/kwh, followed by 3.01 for CF, 2.41 for technological sufflation, 2.24 for 25-year life, and 2.04 for O&M.

Annotations for specific computations are numbered below to correspond to the adjustment numbers in Table 6.

Notes on specific adjustments

1. Technical Sufflation

For nuclear the adjustment is 30% (capital = 8.03 mills/kwh), or 2.41 mills.

2. Construction Times

a. Nuclear. AEC assumed 7 years, which is adjusted to a conservative 10-1/2 years, or +50%. The computation is:

ERDA capital in 1975 = \$588.5 million
of which IDC @ 5% = 85.5 million or 14.53%, @ 7 years
Capital after
Adjustment-1 = 10.44 mills
$$\begin{array}{r} \times 0.1453 \\ = 1.52 \text{ mills @ 7 years} \\ \times 0.5 \quad @ 10-1/2 \text{ years} \\ \hline \end{array}$$

Increase for 10-1/2 years = 0.76 mill

b. Coal. ERDA's 6-year construction time has been adjusted to 4.5 years, with the following result:

ERDA capital = \$478.5 million
of which IDC = 57.5 = 12.0%
Capital = 7.034 mills/kwh
$$\begin{array}{r} \times .12 \\ \hline 0.844 = \text{IDC @ 6 years} \end{array}$$

$\frac{1.5}{6.5}$ years $\times 0.844 = 0.211$ mills/kwh decrease for 4.5 years
at 58% CF.

3. 25-Year Life, Nuclear

$\frac{5}{25} \times 11.20 = +2.24$ mills on adjusted capital at line-2.

4. Capacity Factor

For nuclear, $\frac{67.33}{55} \times 13.44 = +3.01$ mills/kwh

For coal, $\frac{58}{70} \times 6.823 = 5.653 = \text{drop of } 1.170 \text{ mills}$

$\frac{58}{75} \times 6.823 = 5.276 = \text{drop of } 1.547 \text{ mills.}$

5. YoYo. Substantial, not calculated, no need to add to previous discussions..

6. Btu/lb of Coal. Not applicable, as ERDA expressed costs in ¢ per million Btu.

7. Projected Fuel Prices. For nuclear, not enough quantified data were given to judge. For coal, ERDA projections were accepted.

8. Heat Rate, Coal. ERDA used 9751 Btu/kwh, which has been adjusted to 9200.

$$9751-9200 = 551 \quad \frac{551}{9750} \times 11.532 = -0.652 \text{ mill.}$$

9. Replacement Power: Nuclear. Using ERDA's base year of 1975, the average cost of purchased power to

U.S. utilities was 14.06 mills

$$\begin{aligned} +50\% \text{ distress} &= \frac{7.03}{21.09} \text{ mills} \\ \text{adjusted} &= \frac{7.03}{21.09} \text{ mills} \\ &\times \frac{1.03552}{1.03552} = \text{ERDA's real coal price} \\ &= 21.84 \text{ mills/kwh to 1982 adjusted} \\ &\quad \text{escalation} \\ &\quad \text{purchased power} \end{aligned}$$

$$67.33 - 55 = 12.33\% \text{ CF adjustment}$$

$$\frac{12.33}{55} \times 21.839 = +4.896 \text{ mills/kwh produced} \\ \text{@ 55\% CF}$$

An alternative is take 150% of adjusted coal cost at 70% CF, or 6.38 mills. However, the lesser 4.896 mills was used.

10. Use of Low Sulfur Appalachian Coal. No adjustment is made in the ERDA case for this important factor.

11. O&M, Excluding Fuel. For nuclear, O&M in 1978 for 21 large units averaging 54% CF was 3.97 mills/kwh, as explained in Adjustment-11 of AEC. Discounting this to \$1975 at ERDA's 5% inflation rate:

$$3.97 \times 0.864 = 3.43 \text{ mills/kwh}$$

$$\begin{aligned} 3.43 - 1.35 \text{ of ERDA} &= +2.08 \text{ mills/kwh at 54\% CF} \\ &= +2.04 \text{ mills/kwh at 55\%.} \end{aligned}$$

For coal, ERDA/Goudarzi use 2.693 mills/kwh at 58% CF. Since this is for coal w/FGD, and we have no better numbers, we accept that number. Adjusting for CFs of 75% and 70%:

$$\frac{58}{70} \times 2.693 = 2.23 = \text{drop of } 0.46 \text{ mill/kwh}$$

$$\frac{58}{75} \times 2.693 = 2.083 = \text{drop of } 0.61.$$

12. Repairs. Substantial but unestimated.

13. Decommissioning Costs. Substantial but unestimated.

IV - 3

THE NRC CASE

Introduction

NRC's 1979 study of the comparative economics of a nuclear generating plant in Charlestown, Rhode Island was done as part of its Environmental Impact Statement. Considering NRC's resources, its competent and knowledgeable staff, and its official access to outside sources, this study may be taken as authoritative -- though subject to adjustments. Before going on to these adjustments, a few introductory comments may be appropriate.

Capital costs

NRC states that "Cost trends of the past decade confirm that capital costs of coal-fired plants have increased about as fast as nuclear plant capital costs" (p. D-12). It also states that nuclear capital cost would have to be 24% above coal's to make coal competitive: "With the present trends of capital and fuel costs, these variations are considered unlikely. Therefore, the staff does not believe that the coal-fired option could achieve an economic advantage over nuclear power in New England" (p. 9-27).

Capital costs of the past decade for coal have been fairly close to target. But it has been evident for at least the same decade that nuclear capital costs have rapidly and consistently outrun original targets. In the tabulation below it will be seen that as of January 1, 1988 NRC's nuclear capital cost of \$1201/kw compares with \$2226 for Seabrook, \$2345 for Pilgrim-2, and \$3303 for Millstone-3.

<u>Unit</u>	<u>Year Com- mercial</u>	<u>MW</u>	<u>Capital, \$/kW</u>	<u>Adjusted to 1988^a</u>	<u>Index</u>
1. NRC, Charlestown	1988	1150	\$1201	\$1201	100
2. Seabrook (N.H.)	1983-5 ^b	1150	1831	2226	185
3. Millstone-3 (Conn.)	1986	1150	2996	3303	275
4. Pilgrim-2 (Mass.)	1987	1150	2233	2345	195

^aAdjusted by 5% escalation to January 1, 1988, a rate used by NRC. NRC also uses higher rates during construction for purchased equipment, site labor and site materials, which appear to average 7.2%. If the 7.2% is used, the adjusted capital costs for the Seabrook, Millstone and Pilgrim units would be higher (pp. 8-23 and D-4).

^bA midpoint of 1984 was used.

Source: Capital costs of Seabrook, Millstone-3 and Pilgrim-2, are from Public Service Company of New Hampshire as of February 1981.

Since actual costs of plants under construction in New England are running 85% to 175% higher than NRC's projection, and the greater part of this difference is due to technological sufflation rather than price level inflation, the 30% adjustment used in Table 7 for nuclear sufflation is conservative.

Unit size

NRC compares an 1150-MW nuclear unit with a 767-MW coal unit (i.e., 2 X 1150 with 3 X 767). As explained elsewhere above and at Adjustment-1A below, increased size should raise costs for nuclear more than for coal units. NRC does not explain the rationale for

it choice. In Adjustment-1A, the coal unit is brought up to 1150-MW.

Reliability and the YOYO factor

NRC states that nuclear power in New England "will increase the reliability of the region's power supply" (p. 10-7). This appears to be based on the politically uncertain supply of Arab oil. However it would not appear to apply to U.S. coal supply -- unless NRC also has in mind the possibility of very long strikes. But such strikes are largely offset by the usual 3-months supply of coal at the plant.

The main argument against NRC's increased reliability of power supply through nuclear units is the prevalence of the YOYO factor, which NRC does not mention. In the net, the performance of power supply from nuclear is much less reliable than from coal.

Decommissioning costs

Our position, as explained elsewhere above, is that not enough is known today to estimate decommissioning costs, and that the costs furnished by the industry are deceptively low because of the methodology of reducing distant future costs to present value, usually at a 10% rate. NRC/AIF's decommissioning costs illustrate the problem, as elaborated under Adjustment-13 below.

Summary

NRC's base cost for nuclear power of 76 mills/kwh becomes 138 mills after adjustments, an increase of 81%. Coal drops from the base 88 mills to 81 at 60% CF, 76 mills at 70% and 74 mills at 75%. This is shown below.

Table 8. NRC: Adjusted Costs of Nuclear and Coal Generating Units
(Mills/kwh)

A. BASE COSTS		Nuclear	Coal with FGD		
1. Capital		45.70		38.00	
2. Fuel		24.36		39.38	
3. <u>O&M</u>		<u>6.23</u>		<u>10.13</u>	
4. Total		76.29		87.51	
5. CFs		60%		60%	
B. CAPITAL ADJUSTMENTS			70% CF	75% CF	60% CF
1A. <u>Unit size</u>			-3.66	-3.66	-3.66
New capital			34.34	34.34	34.34
1B. <u>Technical sufflation</u>		+13.71			
New capital		59.41			
2. <u>Construction times</u>		+13.85			
New capital		73.26			
3. <u>25-year life</u>		+14.65			
New capital		87.91			
4. <u>Capacity factor</u>		+ 7.99	-4.91	-6.87	--
New capital		95.90	29.43	27.47	34.34
5. The YoYo factor	+ Substantial				
C. FUEL ADJUSTMENTS					
6. Btu/lb of coal					
7. Fuel prices					
8. Heat rate			-3.15	-3.15	-3.15
9. Replacement power cost	+11.00				
10. Use of low-S Appal. coal			Substantial		
D. Other adjustments					
11. O&M exc. fuel	+ 0.57				
12. Repairs	+ Substantial				
13. <u>Decommissioning</u>					
E. Sum of adjustments	+61.77		-11.72	-13.68	-6.81
F. <u>Adjusted totals</u>	138.06		75.79	73.83	80.70
Nuclear = 100	100.0		54.90	53.48	58.453

	NRC		Adjusted			
	<u>N</u>	<u>C</u>	<u>N</u>	<u>C-60%</u>	<u>C-70%</u>	<u>C-75%</u>
1. CF, %	60	60	55	60	70	75
2. Total cost mills/kwh	76.3	87.5	138.1	80.7	75.8	73.8
3. Nuclear = 100	100.		115.	58.3	54.9	53.5

The individual adjustments are shown in Table 7 and the accompanying discussion.

Notes on the 14 adjustments

1-A. Coal Unit Size

NRC compared the economics of two 1150-MW nuclear units with three 767-MW coal units. However, scale problems are much greater with very big nuclear than with very big coal units, as explained in Part II. It would seem more logical at least to use equal sizes. Of the four cases, NRC alone uses smaller coal units exclusively. AEC and ERDA use the same size for coal and nuclear. EXXON uses the same size, but also shows comparative costs for 3 X 800-MW Coal units.

The problem is how to convert capital costs of NRC's 3 X 767-MW to 2 X 1150. This is done by using the EXXon ratios of coal to nuclear as an analog. The computations are shown in Table 8.

1-B. Technical Sufflation

For nuclear, the adjustment is 30% of (capital = 45.70 mills), or +13.71 mills.

2. Construction Times

a. Nuclear

NRC assumed 6 years of construction and 2 years of design for

Table 8: Scaling of NRC 3 X 767-MW to 2 X 1150-MW Coal Units

Step-A:

	<u>NRC</u>	<u>EXXON</u>
1A, Nuclear unit size, MW	2 X 1150	2 X 1200
1B, Coal unit size, MW	3 X 767	3 X 800
1C, \$/kw, nuclear	\$2762	\$1150
1D, \$/kw, coal w/FGD	\$2297	\$ 920
1E, Ratio, $\frac{\text{coal}}{\text{nuclear}}$	83.16%	80.0%
2A, Nuclear unit size, MW	-	1 X 1000
2B, Coal unit size, MW	-	1 X 1000
2C, \$/kw, nuclear	-	\$1210
2D, \$/kw, coal w/FGD	-	\$ 875
2E, Ratio, $\frac{\text{coal}}{\text{nuclear}}$	-	72.3%

Step-B:

To convert NRC's coal capital cost by the analog of 2 X 1200-MW, the above capital cost ratios are utilized as follows:

$$\frac{\text{NRC's } 3 \text{ X } 767}{\text{EXXON's } 3 \text{ X } 800} = \frac{83.16}{80.0} = 1.0395$$

$$\text{EXXON's } 2 \text{ X } 1200 \text{ ratio} = 72.3$$

$$\text{X } \underline{1.0395}$$

$$= 75.16 = \text{Adjustment of NRC } \frac{\text{coal}}{\text{nuclear}} \text{ to same unit sizes}$$

\$2762 = NRC's nuclear capital cost

X 75.16%

=2076 = NRC's coal capital cost for 2 X 1150-MW

To sum up: NRC nuclear 2 X 1150 = \$2762/kw = 100.00
 NRC coal 3 X 767 = 2297 = 83.16
 NRC coal 2 X 1150 = 2076 = 75.16

Step C:

$$\text{Coal: } \frac{\text{NRC Adjusted}}{\text{NRC Original}} = \frac{2076}{2297} = 0.904$$

$$\begin{aligned} \text{NRC's capital cost for coal } 3 \text{ X } 767 &= 38.0 \text{ mills/kwh} \\ &\text{X } \underline{0.904} \\ &= \underline{34.34} \\ &= -3.66 \end{aligned}$$

for a total of 8 years. By 1979, it was obvious that from order to commercialization, the total was running 12 years. Since TMI-2 had already occurred, the 12 years was not likely to decrease in NRC's time horizon (1987-8). Therefore an adjustment to 12 years or 50% in IDC and EDC was used. This adds 13.85 mills/kwh:

Capital cost, 2 units	=	\$2,762 million
of which IDC	=	726 "
and EDC	=	<u>562</u> "
Total EDC + IDC	=	\$1,288 "

$$\frac{1288}{2762} = 0.4663$$

$$\begin{aligned} & \times \frac{59.41}{27.70} \text{ mills/kwh} = \text{adjusted capital at line 1B} \\ & = \text{"} = \text{EDC + IDC} \\ & \times \frac{.50}{13.85} = \text{upward adjustment for 12} \\ & = +13.85 \text{ instead of 8 years} \end{aligned}$$

c. Coal

NRC assumed a 4-year construction time for coal, plus an additional design time which cannot be ascertained from its report. However, it could be as little as a half year, which would bring the total to 4.5 years, the same as used by me in all four cases. Therefore, in the absence of a specific NRC design time, no adjustment is made in its coal IDC and EDC figures.

3. 25-year Life, Nuclear

$$\frac{5}{25} \times 73.26 \text{ mills/kwh at line 2} = 14.65 \text{ mills/kwh.}$$

4. Capacity Factor

$$\text{For nuclear: } \frac{60}{55} \times 87.91 = 95.90 = +7.99 \text{ mills/kwh}$$

For coal: $\frac{60}{70} \times 34.34 = 29.43 = -4.91$ mills/kwh

$\frac{60}{75} \times 34.34 = 27.47 = -6.87$ mills/kwh

5. YOYO

This is substantial, but not calculated as discussed elsewhere above.

6. Btu/lb of Coal

NRC's 12,000 Btu/lb of coal is the same as our adjusted basis, and therefore no change is made here.

7. Fuel Prices

NRC assumed that nuclear and coal fuel prices would escalate at equal rates: ". . . the staff does not believe that the escalation rates for the cost of the two fuels will differ significantly throughout the plant lifetimes because both fuels are similarly affected by consumer demand and resource depletion" (p. D-12).

As stated elsewhere above, however, coal production is still fairly competitive so that prices tend to approach cost of production in the long run. From 1976 to 1979 the real (deflated) price of coal was fairly constant, and has since, if anything, declined. By contrast, uranium ore is produced by a tight world cartel, and can more easily be escalated to maximize profit, like OPEC. The reserves of coal are huge. The reserves of uranium ore are fairly limited without the breeder. The breeder, in any case, is not a substantial factor in the lifetime of a generating unit becoming commercial in 1988.

Enrichment is a government monopoly in the U.S. and monopoloid

in Europe, so that prices can be maximized in Europe.

Notwithstanding the likelihood that nuclear fuel prices will escalate faster in relationship to coal prices, we have not been able to adjust for this factor due to time constraints. Therefore this line in Table 6 is left blank.

8. Heat Rate, Coal

NRC uses 10,000 Btu/kwh, which is adjusted to 9200, or 800 Btu less.

$$\frac{800}{10000} (39.38) = -3.15 \text{ mills/kwh}$$

9. Replacement Power: Nuclear

This adjustment is 11.00 mills/kwh generated in the nuclear power plant at 55% CF. It is derived as follows:

NRC projected cost for coal w/FGD @ 60% CF	=	<u>87.51</u>	mills/kwh
Adjusted @ 60% CF	=	80.70	
+ 50% for distress buying	X	<u>1.50</u>	
	=	121.05	
60 - 55 = + 5% CF adjustment: $\frac{5}{55} = .09091$	X	<u>.09091</u>	
	=	11.00	

An alternate method could have been to take the actual cost of purchased power for all U.S. utilities in 1978, and escalate it at NRC's rate to 1988. However, due to the complexity of its program for levelized, inflated and discounted costs, this would be difficult and time consuming. Therefore this alternate method was not used.

10. Use of Low Sulfur Appalachian Coal

No adjustment is made for this important factor, but see the EXXON case where such coal was used.

NRC did consider using low sulfur Far Western lignites, but the delivered costs and other factors brought the busbar cost so high that obviously it would not be used.

11. O&M, Excluding Fuel

NRC's computer program for projecting O&M costs breaks the total into 2 components, variable and fixed. For nuclear, the variable component is so small a part of the total -- 0.12 out of 3.72, or 3.2% -- that for simplicity O&M can be considered entirely a constant. Therefore adjusting to a lower capacity factor will increase O&M per kwh prorata. Thus

NRC's O&M for nuclear	= 6.23 mills/kwh
	X $\frac{60}{55}$
	= 6.80
	- <u>6.23</u>
Adjustment/kwh @ 55% CF	= 0.57

For coal, NRC's O&M program shows variable and fixed costs sufficiently close as to be treated as equal -- i.e., 3.08 mills fixed and 2.96 variable, with a ratio of 0.961. With this implying assumption, adjusting O&M for a rise in CF from NRC's 60% to 70% involves a change of only 1.2%; for 75% CF the change is 2.5%; the respective adjustments would be 0.12 and 0.25 mill respectively. These are too small to bother with, considering the inherent statistical errors of projection. Therefore NRC's O&M estimates for coal are used.

Note: The small net change in coal O&M for shifts in CF is due to the equal variable and fixed components moving in opposite directions.

F = fixed component

V = variable component

CF₀ = initial CF

OM₀ = initial O&M

CF₁ = adjusted CF

OM₁ = adjusted O&M

When V = F,

$$OM_1 = \left\{ F * \frac{CF_0}{CF_1} \right\} + \left\{ V * \frac{CF_1}{CF_0} \right\}$$

$$OM_1 = \frac{OM_0}{2} \left\{ \frac{CF_0}{CF_1} + \frac{CF_1}{CF_0} \right\}$$

Substituting OM₀ = 10.13 mills/kwh,

with a rise from 60% to 70% CF:

$$OM_1 = \frac{10.13}{2} * \left(\frac{60}{70} + \frac{70}{60} \right) = 10.25 = +1.2\%$$

To illustrate almost the necessity of accepting NRC's O&M costs, rather than starting with average O&M of all U.S. utilities in 1978 and escalating, one need but look at the complexity of duplicating these historical costs by NRC's methodology. It uses present worth, then annualized factors to 1988 first year costs, assuming 5% escalation during plant operation and a 10% discount rate. The sum of levelized unit component costs is the busbar cost in mills/kwh (p. D-9).

In the AEC, ERDA and EXXON cases, we have treated O&M as a fixed cost in adjusting for CF. With NRC, we have used its division of fixed and variable because it was furnished: it is difficult, however, to evaluate. For example, 45% of NRC's total O&M is for ash disposal, a variable (p. D-7). It is possible that this can

be reduced substantially by finding economic uses for the ash. Therefore NRC's treatment is for the worst case.

12. Repairs

Substantial but unestimated.

13. Decommissioning

NRC's methodology for computing decommissioning costs illustrates the invisibility of the process and the difficulty of interpreting the end result. The cost of decommissioning the 2 X 1150-MW units is given as \$5.6 million or 0.46 mill/kwh. This trivial cost is obtained on the following assumptions.

a. In 2020 the plant is mothballed for 50 years, which involves substantial costs for protective construction and continuing personnel.

b. "Ultimately," presumably in 2070, it is dismantled.

c. NRC starts with a cost in 1975 of \$22 million per unit, or \$44 million for two units. The \$22 million is from a study of the Atomic Industrial Forum, and not one made by NRC.²⁷ This is escalated to 2020 at 7%, giving \$925 million.

d. This is then discounted at 10% and annualized for the 30-year life of the plant to obtain the 0.46 mill/kwh, which is characterized by NRC as "insignificant" (pp. 9-27; 10-13 and D-11).

The item of Decommissioning is shown in Table 7 but left blank with the note that the decommissioning cost will be substantial but is unknown in 1981.

²⁷AIF, November, 1976, AIF/NESP-009 SR.

IV - 4

THE EXXON CASE

Introduction

This study was made by EXXON's Research and Engineering Company, which is staff for the entire corporation, as a guide to top management on future posture towards nuclear power. It was not done by the Nuclear Engineering Division. A private study, it was made available to me by EXXON. It reflects the objectivity, vast resources, competence and knowledge of the world's prime energy company.

A unique contribution of this study is that it made a set of projections for coal generation using low sulfur Appalachian coal without FGD. If the time horizon is considered to be for a transitional interim during which more sophisticated methods of coal cleaning and combustion will become commercial, and this interim is taken as the next 5 to 10 years, then the 30 billion tons of recoverable low sulfur Appalachian coal are more than ample for the interim. Therefore the EXXON projection for coal generation w/o/FGD may be taken as the base for comparison with nuclear power generation.

EXXON also has an estimate for light sulfur fuel oil w/o FGD which is given a CF of 77%, compared with 70% for coal w/o FGD, 66% for coal w/FGD and 60% for nuclear. This 77% for oil is an indication of what can be gained by more sophisticated methods of coal combustion, such as gasification at the power plant.

EXXON's base numbers are for the first year of operation in 1985, as explained in Adjustment-14 below. Coal w/FGD is 5.5% less expensive, and coal w/o FGD is 24.9% less expensive than nuclear busbar cost.

After adjustments to EXXON's base numbers, coal w/o/FGD is 55% less expensive at 70% CF, and 56% less expensive at 75% CF than nuclear generation. For coal w/FGD, costs are 47% and 51% less for CFs of 70% and 75% respectively. These adjustments include an item for lifetime escalation of fuel and O&M costs.

Total Busbar Costs

	<u>CF</u>	<u>Mills per kwh</u>	<u>Nu = 100</u>
A. EXXON base:			
1. Nuclear	60	52.7	100
2. Coal w/FGD	66	49.8	94.5
3. Coal w/o FGD	70	39.6	75.1
B. EXXON adjusted			
1. Nuclear	55	95.05	100
2a. Coal w/FGD	70	49.95	52.6
2b. Coal w/o/FGD	75	48.43	51.0
3a. Coal w/oFGD	70	42.29	44.49
3b. Coal w/o. FGD	75	41.17	43.3

Table 9 shows the 13 adjustment matrix for the EXXON case, plus an extra 14th.

Notes on 14 Adjustments

1. Technical Sufflation

EXXON's capital cost for a New England plant commercial in 1985 compares as follows with 3 plants in the same time frame:

TABLE 9. EXXON: Adjusted Costs of Nuclear and Coal Generating Units
(Mills/kwh)

A. BASE COSTS	Nuclear	Hi-S Appalachian Coal with FGD		Low-S Appalachian Coal w/o FGD	
		70% CF	75% CF	70% CF	75% CF
1. Capital	40.3				
2. Fuel	10.1				
3. O&M	2.3				
4. Total	52.7				
5. CFs	60%				
B. CAPITAL ADJUSTMENTS					
1. Technical <u>sufflation</u> New capital	+12.09 52.39				
2. Construction times New capital	+ 5.25 57.64	-2.32 24.18	-2.32 24.18	-1.61 16.79	-1.61 16.79
3. <u>25-year life</u> New capital	+11.53 68.68				
4. <u>Capacity factor</u> New capital	+ 6.24 74.92	-1.38 22.80	-2.90 21.28	-- 16.79	-1.12 15.67
5. The YoYo factor	+ Substantial				
C. FUEL ADJUSTMENTS					
6. Btu/lb of coal					
7. Fuel prices	--				
8. Heat rate	--	-0.45	-0.45	--	--
9. Replacement power cost	+ 3.29				
10. Use of low-S Appal. coal					
D. Other adjustments					
11. O&M exc. fuel	+ 3.95				
12. Repairs	+ Substantial				
13. Decommissioning	+ ?				
14. Coal Lifetime Cost, <u>fuel and O&M</u>		+4.3	+4.3	+4.3	+4.3
E. <u>Sum of adjustments</u>	+42.35	+0.15	-1.37	+2.69	+1.57
Adjusted totals	95.05 a/	49.95	48.43	42.29	41.17
Nuclear = 100	100.0	52.6	51.0	44.49	43.3

a/ Plus substantial adjustments for the YOYO factor, repairs, and decommissioning.

<u>Unit</u>	<u>Commercial</u>	<u>MW</u>	<u>\$/kw^a</u>	<u>Index</u>
1. EXXON	1985	1000	\$1210	100
2. Seabrook	1983-5	1150	1831	151
3. Pilgrim-2	1987	1150	2233	185
4. Millstone-3	1986	1150	2996	248

^aFor units other than EXXON, from PS Co. of N.H.,
February, 1981. For further discussion, see NRC, p.87.

In view of the above numbers, a technical sufflation of 30% appears more than justified, and is therefore used.

2. Construction Times

EXXON used 10 years as construction time for nuclear units, and 6 for fossil fuel units. We adjust the 10 to 12 years, and the 6 to 4.5 years. The general method, as in the other 3 cases, is to adjust the dollar amounts of IDC and EDC prorata the time in each case. While in the EXXON case, the dollar amounts of IDC and EDC have not been given, the annual percentages are, so that it is possible to derive the dollars by a mathematical computation known as the sum of a geometric series. For nuclear the increase is 5.25 mills/kwh. For coal the decrease is 2.32 mills w/FGD and 1.61 mills w/o FGD. The computation is summarized below.

$$(1) \quad K_1 = \frac{K_t (r-1)}{r^{n+1}-r}$$

$$(2) \quad EI = K_t - nK_1$$

where:

K_t = total capital invested/kw, including IDC and EDC

K_1 = capital outlay the first year without IDC/EDC

$r = 1 + (\text{annual \% IDC+EDC})$

n = number of years construction time

$K_1 = K_2 = \dots\dots\dots k_n$ because a linear rate is assumed in absence of a more specific progression of expenditures

Equations (1) and (2) are now applied.

(a) Nuclear IDC = 7.5%, EDC = 5%, $r = 1.125$, $K_t = \$1210$.

$$(1) K_1 = \frac{1210 (0.125)}{1.125^{11} - 1.125} = 59.824$$

$$10K_1 = \$598$$

$$(2) EI = 1210 - 598 = \$612$$

$$* \frac{0.2}{121.} = \text{adjustment from 10 to 12 years}$$

$$121/1210 = 10.03\%$$

$$52.39 \text{ mills/kwh} * 10.03\% = +5.2547 \text{ mills adjustment.}$$

(b) Coal w/FGD As with nuclear, $r = 1.125$.

$$n = 6, K_t = \$875$$

$$(1) K_1 = \frac{875 (0.125)}{1.125^7 - 1.125} = 94.64$$

$$6K_1 = 568$$

$$(2) EI = 875 - 568 = 307$$

$$* \frac{0.25}{77} = \text{adjustment from 6 to 4.5 years}$$

$$= \$77 \quad 77/875 = 8.77\%$$

$$26.5 \text{ mills/kwh} * 8.77\% = -2.32 \text{ mills adjustment}$$

(c) Coal w/o FGD $K_t = \$645$, $r = 1.125$, $n = 6$

$$(1) K_1 = \frac{645 (0.125)}{1.125^7 - 1.125} = 69.76$$

$$6K_1 = \$419$$

$$(2) EI = 645 - 419 = 226$$

$$* \frac{0.25}{56.5} = \text{adjustment from 6 to 4.5 years}$$

$$56.5/645 = 8.76\%$$

$$18.4 \text{ mills/kwh} * 8.76\% = 1.61 \text{ mills adjustment}$$

3. 25-Year Life, Nuclear

$$\frac{5}{25} * 57.64 \text{ mills/kwh after Adjustment-2} = +11.53 \text{ mills.}$$

4. Capacity Factor

For nuclear, EXXON's CF of 60% is adjusted to 55%:

$$\frac{60}{55} * 68.68 = 74.92 \text{ mills/kwh} = +6.24 \text{ mills adjustment}$$

For coal w/FGD @ 70% CF: EXXON's CF of 66% is adjusted to 70%:

$$\frac{66}{70} * 24.18 = 22.80 = -1.38 \text{ mills adjustment}$$

For coal w/FGD @ 75% CF: EXXON's CF of 66% is raised to 75%:

$$\frac{66}{75} * 24.18 = 21.28 = -2.90 \text{ mills adjustment.}$$

For coal w/o FGD @ 75% CF: EXXON's CF of 70% is raised to 75%:

$$\frac{70}{75} * 16.79 = 15.67 = -1.12 \text{ mills/kwh adjustment}$$

5. YOYO, Nuclear

This is substantial but not calculated.

6. Btu/lb of Coal

EXXON's data are on the basis of ¢ per million Btu, and don't require an adjustment for this factor.

7. Fuel Prices

The EXXON projections as adjusted in Table 9 are for the first year of commercial operation. Life costs therefore will depend on the relative escalation rates of nuclear and coal fuel and O&M. This is discussed under Adjustment-14. EXXON's fuel costs as of the first year of commercial operation are not adjusted.

8. Heat Rate

EXXON's heat rate for coal w/FGD is 9420 Btu/kwh, which is reduced to 9200. This results in a drop of 0.41 mill/kwh:

$$9420 - 9200 = -220$$

$$\frac{220}{9420} * (19.3 \text{ mills/kwh for fuel}) = -0.45 \text{ mill.}$$

For coal w/o/FGD, EXXON uses 9050 Btu/lb, which does not require adjustment.

9. Replacement Power, Nuclear

A differential of 3.95 mills/kwh generated at 55% CF was added for this factor, computed as follows:

19.63 mills/kwh = average purchased power in U.S. in 1977,
when EXXON made it projections.

$$X \frac{1.47745}{29.00} = \text{EXXON's 5\% inflation rate to 1985} = 1.05^8$$

$$X \frac{1.5}{43.50} \text{ for distress buying mills/kwh adjusted}$$

$$X \frac{5}{55} = 3.95 \text{ mills/kwh generated at 55\% CF.}$$

This 3.95 mills is substantially less than using EXXON's projections of coal costs, adjusted, w/FGD, but moderately more than w/o FGD:

<u>Basis</u>	<u>Mills/kwh</u>
1. U.S. average 1977, escalated at 5%	3.95
2. U.S. average 1979, escalated at 5%	4.29
3. Coal w/FGD @ 70 CF	6.81
4. Coal w/FGD @ 75 CF	6.60
5. Coal w/o/FGD @ 70 CF	5.77
6. Coal w/o/FGD @ 75 CF	5.61

10. Use of Low Sulfur Appalachian Coal

The economic feasibility of using low sulfur Appalachian and Midwest bituminous coal has been discussed elsewhere above. While the other 3 cases did not consider this possibility, EXXon did. This affords an insight into the comparative economics of plants using high sulfur coal with FGD, and those using low sulfur coal w/o/FGD.

Using EXXON's basic numbers for mills/kwh, the capital cost w/o is 31% less than w/FGD. O&M is 35% less; and fuel, surprisingly, is 3.6% less. The total is 39.6 vs 49.8 mills, or 20.5% less.

A part of this difference is due to CFs, which is 70% w/o and 66% w/FGD.

Using adjusted numbers, for totals, at 70% CF for both, w/o is 15% lower than w/FGD. At 75% CF, it is 15% lower.

11. O&M, Excluding Fuel

For nuclear, the adjustment is +3.4 mills/kwh, obtained as follows:

3.97 mills/kwh = O&M for large nuclear plants in 1978
X 1.40709 = EXXON's EDC = 1.057
5.59 mills at 1985
- 2.3 mills = EXXON's O&M
= 3.29 = adjustment to O&M

12. Repairs

Substantial but unestimated, as discussed elsewhere above.

13. Decommissioning

Substantial but unestimated. See this adjustment under NRC, and general discussion elsewhere above.

14. Adjustments After First Year of Operation

EXXON's base projections are for the first year of commercial operation, 1985, and the above 13 adjustments are on this basis too. In considering a projection for the operating life, capital cost will be fixed. Fuel and O&M will escalate. Since coal is a much greater part of total costs than nuclear fuel, the same rate of inflation for both would affect coal more than nuclear.

EXXON has shown on a chart what the effect of this differential escalation is on busbar costs. The midpoint of the adjusted 25-year plant life for nuclear is taken as 1997-1/2. For nuclear, EXXON's case of 7% escalation for fuel and 5% for O&M is used; and for coal 5% for each. As explained elsewhere above, nuclear fuel should escalate faster than coal. Under these assumptions, the net differential for coal to 1997-1/2 is 4.3 mills on the chart.

This 4.3 mills is added to the final adjusted coal costs.

It may be considered a conservative estimate in favor of nuclear power costs. One reason is that the first year of operation does not include a refueling shutdown, which is normally

given in the industry as one month. This amounts to 1/12th, or +8.33% on the CF. This will be reduced if the conventional assumption is accepted that the first year has a lower CF than the 2nd or 3rd year. Another reason is that O&M should rise faster for nuclear than for coal generation over this time period. A third reason is that EXXON's projections are for New England, whose fuel costs are higher than the U.S. average.

IV - 5

SUMMARY COMPARISON OF FOUR CASES
AND CONCLUSION

The four cases, as already noted, show problems of comparability due to differences in assumptions, methodologies, and dates of estimates and commerciality. Capital costs are a good example.

Capital Costs

The range of original projections of capital costs is as follows for \$/kw:

Nuclear: \$680 to \$2762

Coal w/FGD: \$570 to \$2297

Expressed in mills/kwh, the corresponding ranges are:

Nuclear: 8.03 to 45.70

Coal w/FGD: 7.03 to 38.00

In terms of ratios, however, the range narrows. With nuclear = 100, the coal w/FGD capital ratios are:

	<u>\$/kw</u>	<u>Mills/kwh</u>
AEC	83.8	83.9
ERDA	81.3	87.6
<u>NRC</u>	<u>83.2</u>	<u>83.2</u>
EXXON	72.3	65.8
EXXON w/o/FGD	53.3	45.7

It can be seen that the ratios for the 3 Federal agencies are remarkably close, ranging from 81.3 to 83.8 for \$/kw. But EXXON is only 72.3, giving coal a much lower investment.

The ratios are also fairly close for mills/kwh for the 3 agencies, but even lower for EXXON for coal w/FGD, and remarkably lower for coal w/o/FGD. The 3-agency range is 83.2 to 87.6 with EXXON at 65.8 and 45.7 for coal w/ and w/o/FGD.

The above, to repeat, is based on the original projections.

Table 10: SUMMARY OF FOUR CASES

Total Busbar Costs in Mills/kwh and Coal as a Percent of Nuclear Costs

(Adjusted CFs: Nuclear = 55% Coal = 70%)

Note: In addition to adjusted costs shown below, substantial but uncalculated costs will be incurred for the YOYO factor, repair and decommissioning.

	<u>Original</u> <u>Mills/kh.</u>		<u>Adjusted</u> <u>Mills/kh</u>		<u>Coal with</u> <u>NU = 100</u>	
	<u>NU</u>	<u>Coal</u>	<u>NU</u>	<u>Coal</u>	<u>Orig.</u>	<u>Adj.</u>
A. Coal w/FGD						
1. AEC-75	22.6	28.9	62.4	22.2	128	36
2. ERDA-76	17.2	21.3	38.6	19.0	124	49
3. NRC-79	76.3	87.5	138.1	75.8	115	55
4. EXXON	52.7	49.8	95.05	49.95	94	53
B. Coal w/o/FGD						
Low Sulfur Appalachian Coal						
5. EXXON	52.7	39.6	95.05	42.3	75	44.49

Totals (mills/kwh)

The original and adjusted totals of Busbar mills/kwh are shown in Table 10. As with capital costs, it shows the wide range of original and adjusted estimates in the four cases.

In terms of ratios with nuclear = 100, coal w/FGD in the original estimates is higher for the 3 agencies, ranging from 115 to 128, but EXXON is 94.

Adjusted, coal w/FGD is substantially lower:

AEC 64% lower

ERDA 51% lower

NRC 45% lower

EXXON 47% lower

EXXON's coal w/o FGD is 56% lower.

Coal would be much lower than these percentages if estimates could have been made for the added nuclear costs due to the YOYO factor, repairs and decommissioning.

Conclusion

The components of a valid study of the economics of nuclear power having been painstakingly applied to the four most authoritative cost comparison cases, with assumptions, methodology and computations painstakingly laid out, the conclusion is that coal is half the busbar cost of nuclear power; and even less by the unestimated costs of the YOYO factor, repairs and decommissioning.