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A REVIEW AND UPDATE

OF THE

COST-BENEFIT ANALYSIS

FOR THE

LIQUID METAL FAST BREEDER REACTOR (LMFBR)

A STUDY

PREPARED FOR THE USE OF THE

JOINT ECONOMIC COMMITTEE
CONGRESS OF THE UNITED STATES

MAY 27, 1976

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LETTERS OF TRANSMITTAL

MAY 18, 1976.

To the Members of the Joint Economic Committee:

Transmitted herewith for the use of the Members of the Joint Economic Committee and other Members of Congress is a study entitled "A Review and Update of the Cost-Benefit Analysis for the Liquid Metal Fast Breeder Reactor (LMFBR)," prepared by the U.S. Energy Research and Development Administration. This study provides recent information concerning energy demand projections, LMFBR uranium utilization and economics, and nuclear fuel waste management. The study reviews the need for the LMFBR in the context of our nation's energy programs.

HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee.

MAY 11, 1976.

Hon. HUBERT H. HUMPHREY,
Chairman, Joint Economic Committee,
U.S. Congress, Washington, D.C.

DEAR MR. CHAIRMAN: Transmitted herewith is a study entitled "A Review and Update of the Cost-Benefit Analysis for the Liquid Metal Fast Breeder Reactor (LMFBR)," prepared by the U.S. Energy Research and Development Administration, for the use of the Joint Economic Committee. The study was done at the suggestion of several Members of the committee.

This study presents the most recent projections of U.S. energy demand, uranium utilization, LMFBR economics, and nuclear waste management. It addresses the question of whether the U.S. needs an LMFBR in terms of its costs and benefits. It provides guidance as to the date at which such a reactor could be commercially feasible and could make a significant contribution to our energy supply.

ERDA has included in this study the Administrator's findings on the Final Environmental Statement (FES) of the LMFBR program (ERDA-1535); and the Cost-Benefit Analysis section (III-F) of the FES as originally published in December 1975.

The study concludes that a successful LMFBR will extend our uranium fuel resources for centuries and will eliminate potential fuel restrictions on the Nation's electricity generation growth. The sooner the LMFBR becomes a commercial nuclear power reactor, the lower the need for newly mined uranium will be.

The views expressed in this study are, of course, those of the authors and the Administration and are not necessarily those of the committee, any of its individual members, or the Joint Economic Committee staff.

Charles Bradford of the Joint Economic Committee staff managed and edited this study.

JOHN R. STARK,
Executive Director, Joint Economic Committee.

U.S. ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION,
Washington, D.C., May 4, 1976.

Mr. JOHN R. STARK,
Executive Director, Joint Economic Committee,
U.S. Congress, Washington, D.C.

DEAR MR. STARK: This is in reply to your committee's request for a study on the Liquid Metal Fast Breeder Reactor (LMFBR). You particularly requested a finding as to whether or not the United States needs an LMFBR in terms of its costs and benefits, and if so, when such a reactor would be commercially feasible and would be making significant contributions to our energy supply.

Enclosed is ERDA's study "A Review and Update of the Cost-Benefit Analysis for the LMFBR." Included in this present study are: Recent information concerning energy demand projections, LMFBR uranium utilization and economics, and nuclear fuel waste management; the Administrator's Findings on the Final Environmental Statement (FES) of the LMFBR Program (ERDA-1535); and the Cost-Benefit Analysis Section III-F of the FES as originally published in December 1975.

The Administrator's Findings are pertinent to the present Review because they detail the reasons for supporting the LMFBR Program and emphasize, along with other important considerations:

1. the need for the LMFBR in the context of ERDA's energy R&D program,
2. that due to large uncertainties in LMFBR cost-benefit analyses the assessments yield only a general indication that LMFBR benefits are large enough to support the program,
3. that conducting an LMFBR R&D program does not commit the U.S. to LMFBR commercialization, and
4. that a decision regarding commercialization of the LMFBR will not be attempted until 1986 when its economic, safety and environmental considerations will be better understood.

Some general conclusions, based on the enclosed material and the FES LMFBR cost-benefit analysis, are presented as follows:

1. Successful LMFBRs will extend our uranium fuel resources for centuries and eliminate potential fuel restrictions on the Nation's electricity generation growth. Characteristics of the LMFBR are such that it uses about 60% of the energy from uranium as compared to about 2% utilization by current light water reactors. It also uses as fuel the depleted uranium from enrichment plants, which would otherwise be considered a waste product. Over and above this conservation of resources, it generates more energy than it uses. Thus, it can keep the demands and prices for new uranium relatively low and stable.

The sooner the LMFBR becomes a commercial nuclear power reactor, the lower the resource needs.

2. Even at today's prices for U_3O_8, it appears that LMFBRs can be economically competitive. Consequently it is expected that each commercial LMFBR will offer large economic benefits when compared to other available converter reactor types. Also, the LMFBRs, by holding down the rate of consumption of uranium and the corresponding increase in uranium cost, will reduce the operating cost of other converter reactor types.

3. The need for the LMFBR is not keyed to any specific electricity demand projection. Analyses have shown that use of LMFBRs yield benefits to the consumer whenever it is used. The sooner the LMFBR is introduced, the sooner the benefits start to accrue and the greater the amount of benefits to consumers.

The policy for R&D should also support production planning. Thus, the option must be available to meet the higher projections. Because of the lead time for completion of R&D, the uncertainty in projection is greater than it is for production planning. Today, there is an additional problem to consider: That is, the fact that we know oil and gas will gradually be phased out of electrical production, because of economics and declining resources. It is reasonable also to expect that some of the uses of process heat, which are dependent on gas and oil, will be shifted to electrical energy. Consequently, the growth of electrical energy can be expected to remain substantially higher than total energy growth for the foreseeable future.

4. The strong emphasis in ERDAs broad program on the development of means for long term storage of commerial nuclear fuel wastes reflects its commitment to safe storage of all radioactive wastes. Successful completion of the program will resolve a major uncertainty concerning the use of nuclear power to meet the Nation's energy requirements.

We trust this information is helpful to you and if there is any further information you desire, we will be pleased to provide it.

Sincerely,

RICHARD W. ROBERTS,
Assistant Administrator for Nuclear Energy.

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A REVIEW AND UPDATE OF THE COST-BENEFIT ANALYSIS FOR THE LIQUID METAL FAST BREEDER REACTOR (LMFBR)

I. Recent Information Concerning the Major Assumptions of the 1975 Cost-Benefit (CB–75) Analysis

A. Electric Energy Growth Projections

Recent electric energy growth projections for the period 1975 to 1985 average 5.6 percent per year and the FEA reference projection for this period is 5.4 percent per year. These projections, as noted in Section III Electrical Energy Growth Projections, are in the range of projections used in the CB–75 analysis. Also, as noted in Section III, it is prudent to plan on the basis of the high projection for electric energy growth. The economic and societal penalties are much less for having an excess of generating capacity than having a short-fall.

The nuclear industry growth projections given in ERDA–76–1, "A National Plan for Energy Research," 1976, are 450,000 megawatts electric (MWe) to 800,000 MWe in the year 2000. This compares to 625,000 MWe to 1,250,000 MWe in the same period in CB–75. The base value in CB–75 was 900,000 MWe in the year 2000 which is sufficiently close to the high value given in ERDA–76–1 to consider the CB–75 base projection appropriate when planning on the basis of the high projection.

B. Uranium Price Projections

Recent prices for U_3O_8 delivered in 1976 are about $27 per pound. Figure 1 indicates uranium prices as a function of time as used in CB–75. The high uranium price curve indicates projected uranium prices reaching today's prices about the year 1995. However, we consider the high uranium price curve appropriate as the projected uranium prices after the year 1995, when the breeder benefits occur, are considered to be realistic.

C. Capital Cost Differential Between LWRs and LMFBRs

When the LMFBRs were first commercially introduced in the CB–75 analysis, they had capital costs that were 33 percent higher than LWRs. This capital cost differential between the plants was assumed to decrease to zero linearly thirteen years after the LMFBR's commercial introduction for the base projection. The decrease was attributed to economies of scale associated with a size change and to the classical learning effect. A variation in which the LMFBR capital cost was assumed to be at least 24 percent above the LWR through the year 2025 was also considered. A recent study by M. Levenson (Electric Power Research Institute), P. M. Murphy (Fast Breeder

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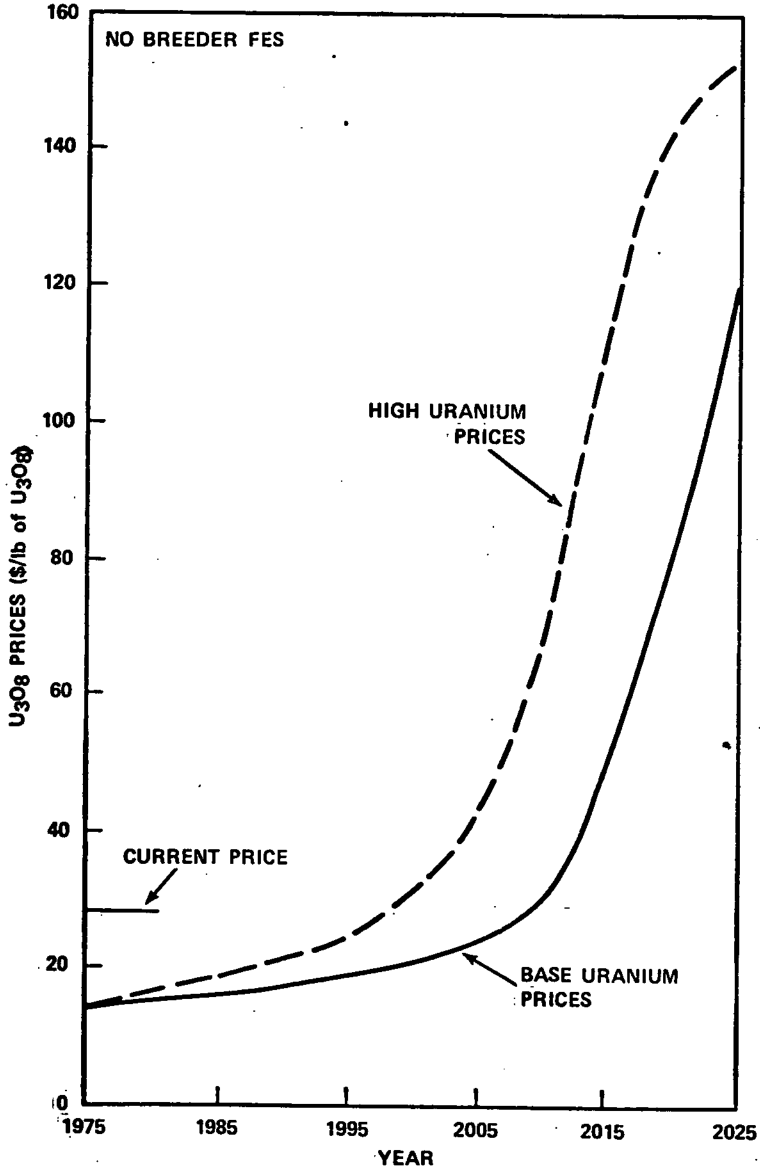


URANIUM PRICES BY YEAR CB-75

FIGURE 1

Reactor Department of the General Electric Company) and C. P. L. Zaleski (Director of Technicatome, France), as noted in Section II. LMFBR Uranium Utilization and Economics, concludes that the most likely capital cost differential between fully developed commercial-sized LMFBRs and LWRs will be less than 20 percent. The cost differential estimates ranged from about zero, based on recent French experience, to about 38 percent higher for the LMFBR, based on a comparison of early U.S. LWRs and sodium-cooled reactor power plants. Accordingly, the values of this parameter in the CB–75 Analysis are considered to be appropriate.

D. LMFBR Economics

As indicated in Section II, the LMFBRs will be economic when considering even the upper end of the range of the projected capital cost difference between LWRs and LMFBRs and the anticipated prices for U_3O_8 in the 1990's and thereafter. The LMFBR will make a meaningful impact on the U.S. energy resources about 10 years after its commercial introduction. About 25 years after commercial introduction, the LMFBR, if built in reasonable numbers, can also permit the U.S. nuclear power industry to be independent of mined uranium by self-generating all its fissile fuel requirements. This era of essentially unlimited and low cost fuel resources will result in stabilized low cost nuclear power.

E. Availability of HTGRs

The availability of HTGRs in the CB–75 analysis was limited to no more than 25 percent of new capacity. They were commercially available in 1983 with capital costs initially about 15 percent higher than LWRs. The capital cost differential was assumed to reach zero 6 years after the introduction of the HTGR due to the learning effect.

General Atomic Company, the developer of HTGRs, has recently stopped marketing HTGRs, and the electric utilities that did order HTGRs cancelled their orders. The limits on the availability of HTGRs in CB–75 are still considered appropriate. It also appears that HTGRs, if commercialized, will not be available prior to the 1990's.

F. Need to Revise the 1975 Cost-Benefit Analysis

Recent information concerning the major assumptions for the CB–75 analysis indicate that only the U_3O_8 cost versus supply assumption needs to be changed. Consequently, the CB–75 analysis is considered current on the basis of utilizing the high uranium U_3O_8 cost versus supply projection, as the appropriate base projection and the priorities for the other major assumption projections remain unchanged. Another analysis at this time would not significantly change the major results or the conclusions of the CB–75 analysis which indicated discounted benefits much greater than discounted costs for most cases considered.

II. LMFBR Uranium Utilization and Economics

The LMFBR should be viewed first in terms of its ability to conserve uranium and to eventually free the nuclear power industry from the need to mine uranium for hundreds of years; and then its ability to stabilize, in constant dollars, the cost of power at a relatively low level for all reactor types.

The fuel for the Light Water Reactors (LWRs) is enriched to about 3 percent in U^{235}, the fissile isotope of natural uranium. During the enrichment process, which concentrates the U^{235} from 0.7 percent to 3 percent, a large quantity of uranium depleted of U^{235} is produced as a byproduct. For example, for every ton of light water fuel, about 5 tons of natural uranium must be mined and about 4 tons of depleted uranium byproduct (about 0.2 percent U^{235}) are produced. This depleted uranium can be used as a fertile material for breeding in the LMFBR.

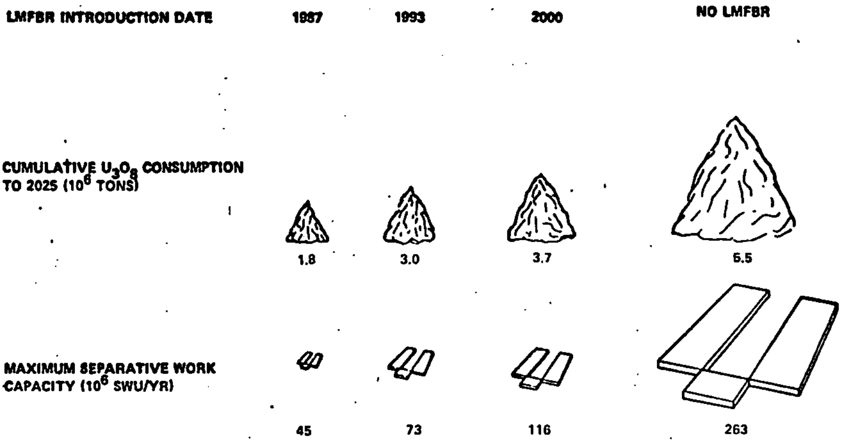
During normal operation of the LWR, the U^{238} (the other isotope of uranium in natural uranium) in the fuel captures neutrons and is transmuted into Pu^{239}, a fissile isotope. Much of this plutonium is burned in place and accounts for almost half of the total energy produced by the LWR. The unburned plutonium can be recovered from the discharged LWR fuel and used as the initial fissile load for an LMFBR.

The initial fuel load for a 1,000 MWe LMFBR would consist of some 3 to 4 tons of plutonium and about 36 tons of uranium obtained from the existing stockpile of depleted uranium. Once in service, the 1,000 MWe LMFBR will need between 1 and 2 tons of depleted uranium annually in exchange for which it will produce a surplus of about 0.3 tons of plutonium which can be used to supply the starting inventory for new LMFBRs or fuel for operating LWRs.

The LMFBR cost-benefit study (CB–75) presented in ERDA–1535, "The Final Environmental Statement of the LMFBR Program," used a computer model that simulates the U.S. electric power industry and optimizes on the basis of minimum total system cost. Figure 2 indicates cumulative uranium and maximum separative work requirements for different LMFBR introduction dates using an electric energy demand projection that had an average growth of about 5 percent per year to the year 2025.

For the no LMFBR case, as indicated in Figure 1, cumulative U_3O_8 requirements are 5.5 million tons by the year 2025 on an as used basis and the requirements continue to increase thereafter. The model imposed no restraint on separative work capacity for fuel enrichment services, and a capacity about 14 times greater than available at present is required by the year 2025.

For the cases where the LMFBR is available, total cumulative uranium requirements are capped at the indicated values. About 25 years after introduction of the LMFBR, with progression to designs that have about a 12-year fuel doubling time and with a reasonable rate of increase in the number of LMFBRs built, the fissile fuel requirements for all the nuclear power industry's operating and new plants can be met by the operating LMFBRs and LWRs. A large stockpile of depleted uranium (about 2 million tons of U_3O_8) will also be available at this time. Hence, with the use of the industry's self-

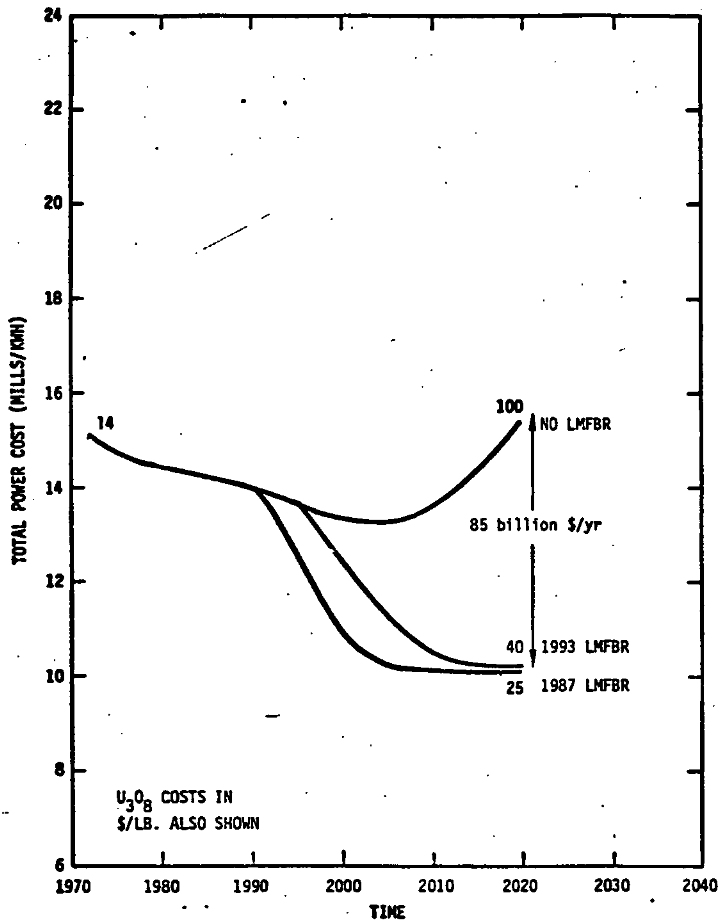


EFFECT OF A DELAY IN THE LMFBR PROGRAM

FIGURE 2

generated fissle material and stockpiled depleted uranium, there is no need to mine uranium for hundreds of years. Also, since the price of fissile material would no longer be associated with the price of mined uranium and would be in plentiful supply, it should stabilize at a relatively low price. The earlier the LMFBR is introduced, the smaller the cumulative uranium requirements. Even with a 1993 introduction at the average electrical demand growth rate of 5 percent per year, the projected requirements of about 3 million tons of U_3O_8 is close to ERDA's estimate of reasonable cost uranium resources of about 3.7 million tons of U_3O_8. About 3 million tons of the 3.7 million tons of U_3O_8 estimate are in the potential category which includes probable, possible and speculative resources. Lower or higher projections for the rate of growth of the nuclear industry can modify the cumulative uranium requirements. At an average growth of 4 percent per year for electrical energy, the cumulative uranium requirements for a 1993 LMFBR introduction date into the economy would be about 2 million tons of U_3O_8 and at an average growth of 6 percent per year, the cumulative uranium requirements would be about 4 million tons. However, irrespective of the electric energy growth rate, the earlier the introduction of the breeder, the sooner the nuclear industry becomes independent of depletable fuels, and electric power production costs are reduced and stabilized.

Figure 3 indicates how the power costs (in 1975 dollars) could vary for a nuclear industry with and without a breeder. Nuclear power costs decrease as the nuclear industry matures, i.e., as plutonium recycle is introduced and as unit costs for reactor construction, fuel fabrication and fuel reprocessing decrease. However, without the breeder, nuclear power costs ultimately begin to increase as the industry is forced to mine lower grade uranium ores. With the breeder, the supply of plutonium increases with time, and as a consequence, nuclear power costs fall quite rapidly. After the year 2010, nuclear power costs remain relatively constant since the basic fuel for the nuclear power industry is an increasing supply of self-generated plutonium rather than a diminishing supply of U_3O_8. In the year 2020 the savings in the nuclear power industry due to the breeder, as indicated in Figure 3, are about 85 billion dollars in undiscounted 1975 dollars. The savings are primarily due to not having to mine uranium or provide enrichment services in that year alone.



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
REFERENCE CASE (CB-75)

FIGURE 3

We can also obtain an indication of the relative economics of the LMFBR in terms of an allowable capital cost differential over the cost of LWRs. This capital cost differential can be determined against the cost of the uranium to fuel the LWR. A study by T. R. Stauffer, H. I. Wyckoff and R. S. Palmer, "Breeder Reactor Economics," shows that if the levelized cost of uranium for LWRs—expressed in 1975 dollars—is $20/lb., the LMFBR will be economical at an increased capital cost differential of about $115/KWe. The prevailing cost for LWRs is between $450 and $500/KWe in 1975 dollars. At a levelized cost of $60/lb. of U_3O_8, the LMFBR can have a capital cost about twice that of an LWR. The price of U_3O_8 ordered for delivery in 1976 is about $27/lb. For delivery in 1980, the price today is about $40/lb.

A recent study by M. Levenson, P. M. Murphy and C. P. Zaleski entitled "Economic Perspective of the LMFBR" indicated that the capital cost differential between LWRs and LMFBRs might range from a high of about 38 percent and a low of about zero. At the high value of 38 percent, a levelized uranium cost of $42/lb. provides for break-even economics for the LMFBR. Hence, it appears that the LMFBR could be economic even if it were introduced by 1980.

III. Electrical Energy Growth Projections

The energy demand projection's utilized in the FES CB–75 analysis approximate the projections used by the FEA in the recent study entitled "National Energy Outlook," February 1976. The FEA projected to the year 1985 and they ranged from a low of 4.9 percent per year in the conservation scenario to a high of 6.4 percent in the electrification scenario. Their reference scenario used a projection of 5.4 percent. They also indicated the average of eight other forecasts completed since 1973 as follows which had an average of 5.6 percent.

Source and year of study:	*Percentage of projected yearly growth rate 1974–85*
Oak Ridge—1973	4. 4
Arthur D. Little—1974	6. 4
Lawrence Livermore Laboratory—1974	5. 6
Hudson Jorgenson—1974	5. 5
Technical Advisory Committee, FPC—1974	6. 0
Oak Ridge—1975	5. 1
Westinghouse—1975	5. 0
Electrical World—1975	5. 8
Average	5. 6

The projected electrical energy growth rates used in the FES cost-benefit study were as follows:

PERCENT GROWTH RATE

Energy requirement	Initial 1975–85	Final 2015–25	Average 1975–2025
Small	5. 3	2. 6	4. 1
Reference	5. 9	4. 6	5. 2
Large	6. 7	5. 2	4. 9

The electrical energy growth rate projections in the FES in the 1975–1985 period were a little higher than the FEA projections in the same period.

We believe it is prudent to plan on the basis of the high projections for electrical growth. Electricity supplied from fuel sources other than oil and natural gas such as coal, nuclear, solar, geothermal and hydropower can help, along with conservation measures, to alleviate our dependence on foreign oil and natural gas. Also, the penalty for planning on the basis of a projection that turns out too low can be much more severe than planning on the basis of a projection that turns our to be high.

A recent study published March 1976 by the National Economic Research Associates (NERA) entitled "Costs of a Shortage of Generating Capacity" indicated that shortfalls in electric generating capacity by 1983 as indicated in the following table could lead to serious losses in national GNP and construction employment.

HOW ELECTRICAL CAPACITY SHORTAGES MIGHT AFFECT GNP IN 1983—MINIMUM GNP LOSS DURING 1ST YEAR OF SHORTAGE

Shortage [1]	Capacity factor (percent)		Millions of 1975 dollars		Percent of 1983 GNP [2]		Construction job losses
	High	Low	High	Low	High	Low	
5 percent	48.82	48.32	$273.2	$237.7	0.01	0.01	21,401
10 percent	50.39	49.86	1,668.7	1,148.0	.08	.06	42,802
15 percent	50.94	50.39	5,606.5	3,304.4	.28	.17	64,203
20 percent	50.94	50.94	15,892.3	7,307.5	.79	.37	85,604

[1] As applied to a capacity shortage, these percentages refer to the proportion by which actual capacity is short of that capacity level which would provide a 20 percent peak reserve margin.

[2] Based on the McGraw-Hill Economics Department forecast of a 1983 GNP of $2,002 billion.

Note: High and low values of all variables correspond to composite electricity price elasticities of 0.1 and 0.2 respectively.

If the capacity shortage persisted beyond the first year (as would be likely in the case of a reduced generating plant construction program and/or greater than forecast peak load growth), the NERA report estimates annual GNP losses subsequent to the first year would gradually decline as consumers adapted their consumption and production behavior to the electric energy shortage situation. Load management to improve the utility systems load factor and utilization of existing generating facilities could help here.

However, the losses in GNP mentioned above are primary losses only. They are associated with the higher production costs and production inefficiencies stemming from inadequate electric generating capacity. These negative production effects result from more frequent and longer service interruptions to industry and commerce and/or power rationing, which results in loss of production output or the substitution of alternative services and goods (usually more expensive). A secondary round of losses in GNP could be caused by primary cost increases reducing the aggregate demand for goods, exacerbated by reduced investment expenditures in view of a weakened market. Thus, the overall effect of generating capacity shortages could be even more serious than indicated by the tabulated values.

The quickest way to remedy the shortage in electrical generating capacity would be to build oil or gas fired plants to meet the extra demand. These plants can be built relatively quickly (3 to 5 years), are less capital intensive than coal or nuclear plants, but involve higher fuel costs. They will all raise consumer bills and utilize fuels that will have to be imported, contrary to a goal of reduced vulnerability from imported fuels. FEA estimates that if electric demand growth is 1 percent faster than expected and oil and gas plants must be used to meet the extra needs, oil equivalent imports could rise by over 1 million barrels per day in 1985.

On the other hand, if actual electrical consumption grows more slowly than forecast, utilities will overbuild and have idle generating capacity. Idle generating capacity is expensive for consumers since the carrying and overhead costs must be paid whether or not the equipment is used. FEA estimates that if energy demand is actually 1 percent below forecasts, utilities could have almost $50 billion of excess capacity in 1985. The added cost of carrying this extra capacity could be $7.2 billion annually, requiring an 8 percent increase in electric utility revenues. Of course, this extra capacity could be absorbed by the utilities in a few years by appropriate planning.

IV. Management of Radioactive Wastes

Althogh some radioactive wastes are generated in uranium mining, milling and enrichment operations, the major concern has been with the management of wastes generated in the "back end" of the commercial fuel cycle, which can be taken to include wastes from reactor plants, spent fuel storage basins, fuel reprocessing plants, and fuel refabrication plants. Of these, fuel reprocessing plant wastes are of most concern because of their high concentrations of intensely radioactive fission products, along with smaller quantities of long-lived transuranic radionuclides (e.g., plutonium). The present lack of specific plans for satisfactory long-term management of reprocessing wastes is a major issue in the ongoing public debate on the wisdom of pursuing the nuclear option in the United States.

ERDA's most recent response to this issue has been to identify an expanded waste management program which contemplates the use of underground geologic formations for the terminal disposal of solidified reprocessing wastes. As stated in the attached program announcement, ERDA plans to demonstrate multiple terminal underground waste storage facilities in various regions of the U.S. The basic reason for using certain kinds of geologic formations for terminal disposal is that their stability over long time periods will assure isolation for as long as necessary. This isolation could be further augmented if the geologic medium has capability to retard nuclear migration. Geologic media expected to be suitable include salt, material such as clay and shale, and rocks such as limestone, granite and basalt.

It should be noted that the quantities of reprocessing wastes which would require management in the future are relatively small. A volume of about 55 cubic feet would hold the high level radioactive wastes resulting from one year's operation of a 1,000 MWe powerplant. With careful handling and disposal of these small volumes,. there is little cause for concern that nuclear wastes would eventually contaminate large areas of the earth or require guarding by future generations.

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Nonetheless, critics have questioned the fairness of leaving to future generations the responsibility for perpetual surveillance of deeply-buried wastes. Although this question is not susceptible to examination by conventional methods (such as cost-benefit analysis), we have given it due consideration. For example, the recently completed environmental impact statement on the Liquid Metal Fast Breeder Reactor Program treats the subject at some length, and concludes:

> "Based on the information at hand, contemporary society may reasonably proceed on the assumption that it has the knowledge and the means to develop acceptable solutions to the problem of isolating nuclear wastes from the environment. No generation of man will ever be able to issue absolute guarantees on any activities whose impacts could extend into far distant future years any more than it can issue absolute guarantees on either the short-term or long-term effects of the dispersal into the atmosphere of non-radioactive materials whose biological hazards may not be as well understood as the effects of radiation. Society has no choice but to bear in mind its limitations and to act as wisely and as well as its best efforts will permit."

ERDA will continue to be sensitive to these non-quantifiable problems as we proceed with our expanded national program leading to safe terminal storage of nuclear wastes.

Attachment: ERDA Information Sheet No. 76-46.

[Information from ERDA, Washington, D.C., No. 76-46, for immediate release Thursday, Feb. 19, 1976]

ERDA Administrator Announces Expanded Program in Management of ERDA, Commercial Nuclear Wastes

Dr. Robert C. Seamans, Administrator of the Energy Research and Development Administration, today announced agency plans to embark on an expanded national program leading to safe, terminal storage of nuclear wastes.

Shortly after ERDA was formed last year, Dr. Seamans told Congress ERDA was putting together a program that will assure permanent disposal of radioactive wastes. This calls for a major increase in ERDA's waste management effort for fiscal year 1977.

ERDA's budget authorization request represents an expansion from $81.4 million in fiscal year 1976 to $151.8 million in fiscal year 1977.

The national effort, directed by ERDA's Division of Nuclear Fuel Cycle and Production, will include research, development and demonstration efforts to accomplish the following:

Conduct a national survey of multiple geographic locations with differing geologic formations to determine the best possible sites for terminal storage facilities for wastes generated by the commercial nuclear power plant industry.

Construct the first pilot demonstration underground storage facility in a dry bedded salt formation to store ERDA-generated plutonium contaminated wastes.

Develop the processing and packaging techniques for different types of waste in a form acceptable for delivery to a terminal storage facility, with an immediate task of selecting processes to convert the high-level liquid wastes into a solid form, such as glass or concrete.

Carry out a management program to process and control high-level liquid wastes safely at three major ERDA facilities and to move rapidly forward to more permanent solutions for these wastes.

Conduct an in-depth evaluation of current operational practices at ERDA land burial sites for low-level wastes, including development of criteria for selecting future burial grounds and for correcting undersirable conditions should they appear at existing ERDA grounds.

In 1972, the former Atomic Energy Commission announced its plans to build retrievable surface storage facilities capable of managing the solidified high-level waste to be generated by the commercial nuclear power industry, pending the availability of terminal storage.

ERDA, which inherited the operational waste management programs of the AEC, has determined that immediate construction of retrievable surface storage facilities is not needed in view of the expanded geologic program and delays in reprocessing plants availability.

However, ERDA is completing design and tests and therefore it will have the capability to provide above-ground storage should it be required.

In its expanded program for ultimate storage of commercial high-level wastes, ERDA has designated its Oak Ridge, Tennessee, Operations Office to have lead responsibility in overall program coordination.

The program is designed to find acceptable technical and environmental approaches for the ultimate storage of this waste through geologic investigations and technology demonstrations in various geologic formations at several locations in the United States. Under current federal regulations the private nuclear fuel reprocessing plants which generate the commercial waste may not retain the wastes for more than 10 years. These plants are not expected to be operating until the late 1970's and the 1980's.

Reporting to Oak Ridge Operations Office through a contractual arrangement will be a new Office of Waste Isolation, NuckearDivision, Union Carbide. Approximately $35 million is earmarked in fiscal year 1977 for this geological investigation program coordinated by the Oak Ridge Operations Office.

ERDA plans to demonstrate multiple terminal storage facilities in various regions of the U.S. Thus, it would not be necessary for one area to service the entire country as a waste site.

Geological formations to be studied and evaluated include: bedded salt in western and mid-western states; dome salt in Gulf Coast states; shales, which are widely distributed over the country; and a wide variety of granite and other crystalline rocks and volcanic formations.

The Office of Waste Isolation will utilize the expertise of regional and local companies, universities, and other organizations. State and federal agencies will be involved in establishing the suitability of the various geological formations.

The public will be kept informed of the work in various states growing out of the studies and evaluations of plans and findings will be discussed with local, state and federal authorities.

In regard to the first pilot demonstration storage facility, ERDA's Sandia Laboratories, Albuquerque, New Mexico, are conducting core drilling and other testing programs at a site about 30 miles east of Carlsbad, New Mexico.

If the site proves acceptable, the ERDA plutonium nuclear wastes would be stored in vaults carved out of a massive bedded salt formation, not the same geologic structure which contains the Carlsbad Caverns.

During the test period a geological site for any type of waste would incorporate a capability to permit its removal. Only upon successful completion of the test period would the waste be left in place permanently.

Facilities for long-term storage of both ERDA-generated and commercial high-level wastes will have to be licensed by the Nuclear Regulatory Commission.

ERDA also is expanding its research and development program on methods for solidifying wastes in physical and chemical forms which improve the margin of safety against accidental dispersal of the material while it is in retrievable storage or transport.

The agency has expanded its efforts related to the processing of wastes at nuclear materials production sites.

The liquid waste at Savannah River is presently being solidified by evaporation, both to reduce its mobility and tank requirements for storage of the waste. The fiscal year 1977 budget requests include a project for four tanks, and auxiliary and maintenance facilities to proceed with a program for replacing aging tanks.

At ERDA's Hanford Site, Richland, Washington, construction is progressing on a second evaporator-crystallizer that will speed up the removal of the large volume of liquid waste stored in tanks.

A major portion of the fission products, cesium-137 and strontium-90, is removed from the high-activity waste before evaporation. These products are being converted to solid salts and double encapsulated in high integrity containers for interim storage in water-cooled basins.

Waste solidification operations to convert the bulk of the liquid waste backlog at the Hanford Site to salt cake are nearing completion.

ERDA is asking Congress for authorization of funds for a new waste calcining facility at its Idaho National Engineering Laboratory to accelerate the conversion of liquid acid waste under high temperature into a granular solid with about a tenfold reduction in volume. The liquid waste, generated from the reprocessing of irradiated research and Navy fuels, is stored in underground stainless steel tanks prior to solidification in the present calcining facility. The present calcining facility, built more than 10 years ago, is nearing the end of its servicable life.

While the present interim waste management effort is directed toward solidifying the backlog of liquid waste, and the newly generated wastes at these three sites, ERDA is planning a permanent disposition of these wastes.

At ERDA's Savannah River Plant in South Carolina, engineering studies have increased on the options for long-term management of high-level waste, including conceptual design of the facilities needed to solidify and package the waste for on-site storage or off-site shipment.

Concerning low-level wastes, ERDA will conduct an in-depth evaluation of current operational practices at its own land burial sites. ERDA is cooperating with the U.S. Geological Survey and various regulatory groups in this study. The results of this study also may be helpful in improving commercial land burial grounds which are licensed by the state or the Nuclear Regulatory Commission.

Low-level wastes consist of a variety of materials containing radioactivity generated from all types of private and Government operations such as hospitals, laboratories, universities, nuclear power reactors, fuel fabrication plants, scrap recovery plants and chemical reprocessing plants.

The principal ERDA low-level waste burial sites are at Oak Ridge, Savannah River, Los Alamos Scientific Laboratory in New Mexico, Idaho Falls and Richland.

Dr. Seamans said this broad program reflects ERDA's commitment to safe storage of all radioactive wastes and will resolve a major uncertainty concerning the use of nuclear power to meet the nation's energy requirements.

(A budget summary is attached.)

CHART I

WASTE MANAGEMENT BUDGET SUMMARY—OPERATING

[Dollar amounts in thousands; fiscal years]

	Estimate 1976	Estimate 1977
Fuel cycle research and development program:		
Waste management (commercial):		
Terminal storage R. & D	$4,580	$33,700
Waste processing R. & D	5,355	19,870
Supporting studies and evaluations	1,990	6,400
Total, commercial	11,925	59,970
Weapons materials production program:		
Waste management (ERDA)—Long-term:		
ERDA radioactive waste R. & D	13,720	21,050
Storage operations and related activities	4,900	7,000
Supporting services	0	2,240
Total, long term	18,620	30,290
Waste management (ERDA)—Interim:		
Production reactor waste	43,250	51,260
Nonproduction reactor waste	3,640	4,840
Process development	3,045	4,765
Supporting services	930	645
Total, interim	50,865	61,510
Total	81,410	151,770

ADMINISTRATOR'S FINDINGS ON THE LIQUID METAL FAST BREEDER REACTOR PROGRAM, FINAL ENVIRONMENTAL STATEMENT*

1. On June 30, 1975, I issued my findings on the Proposed Final Environmental Statement (PFES) for the Liquid Metal Fast Breeder Reactor (LMFBR) Program which was released by the former Atomic Energy Commission on January 17, 1975. In summary, I found that the PFES amply demonstrated the need to continue research, development, and demonstration of the LMFBR concept, which could provide an essentially inexhaustible energy source to meet a significant share of our Nation's energy needs in the next century. However, I also found that significant problems had to be resolved satisfactorily before any decision could be made to place LMFBR's into widespread commercial use. Continuation of the program of research, development, and demonstration was necessary to resolve these problems, but would not prejudge any later decision concerning commercialization of this technology. Before issuing the Statement in final form, I called for an examination of alternative methods of conducting the program to be sure that—

(*a*) the research, development, and demonstration activities are properly directed to resolve the remaining technical, environmental, and economic issues in a definitive and timely way;

(*b*) these issues are resolved before a final decision concerning the acceptability of commercial deployment is made; and

(*c*) test and demonstration facilities that are needed in the LMFBR Program are conservatively designed to protect the health and safety of the public and to provide useful information for subsequent environmental, economic, and technical assessments.

Finally, I recognized that ERDA has a clear responsibility for making a determination, in accordance with the National Environmental Policy Act (NEPA), on whether commercial deployment of the LMFBR concept is warranted, even though no commercialization would be possible without favorable licensing action by the Nuclear Regulatory Commission and even though the Commission, as a result of the Energy Reorganization Act of 1974, is in no way bound by any future ERDA recommendation that the technology is ready for commercial use. I affirm all of these findings.

2. After review of the Final Environmental Statement (FES), which incorporates the PFES to the extent consistent with my earlier findings and provides the supplementary review of alternatives I called for, and upon the consequent conclusion of the NEPA process, I hereby make the following additional findings.

*Published December 1975 in ERDA–1535, the "Final Environmental Statement of the LMFBR Program."

3. I find that the FES is not, and cannot be at this stage of LMFBR technology development, a dispositive assessment of the impacts of wide-spread commercial deployment of that technology. Nevertheless, I find that the FES does provide sufficient information on the foreseeable impacts of such deployment and on the programmatic alternatives available to resolve the major areas of uncertainty affecting such deployment, so that I now am in a position to determine the structure and pace of a research, development, and demonstration program to provide a more dispositive assessment of those impacts and to resolve those areas of uncertainty in a timely manner.

4. The FES shows that the major areas of uncertainty lie in plant operation, fuel cycle performance, reactor safety, safeguards, health effects, waste management, and uranium resource availability. I find that the availability of sufficient information to resolve these areas of uncertainty is crucial before ERDA can render a meaningful decision on the commercialization of that technology, i.e., the environmental acceptability, technical feasibility and economic competitiveness of LMFBR technology for widespread commercial deployment.

5. ERDA has programs in place in each of these areas. The LMFBR Program has focused on plant operation through the development of experience in LMFBR demonstration plants, on fuel cycle performance through its base program of fuel cycle development, and on reactor safety which is an integral part of both the plant demonstration program and the base program. The other areas of uncertainty—safeguards, health effects, waste management and uranium resource availability—are not unique to the LMFBR, and are being addressed generically by other programs which have schedules not susceptible to significant acceleration. Measured against the schedules for these programs, the FES evaluates eight options for structuring the necessary research, development and demonstration program for LMFBR technology. These options are structured to reflect changes in the timing and number of prototype reactor plants and various component test facilities, and the consequent changes necessary in the supporting base program, thus reflecting a wide range of program strategies. The program alternatives are compared on a cost-benefit basis including the evaluation of risks resulting from acceleration of the program. They are also compared on the basis of meeting the requirement for operation of an LMFBR demonstration or large prototype plant in a utility environment and for sufficient assurance of the technical feasibility, economic competitiveness and environmental acceptability of an LMFBR economy prior to any irreversible commitment to widespread commercial deployment.

6. Using the foregoing requirements, I rejected those options involving rapid acceleration of the program because of the lack of any demonstration or large plant experience and insufficient information in the areas of fuel cycle performance, reactor safety, safeguards, waste management, and health effects before a commitment would be made to commercialization. Those options involving major delays in the program were likewise deemed unacceptable because of the resulting loss of net economic benefits and of insurance against a potentially inadequate uranium resource and the inefficiencies in the conduct of the program. Finally, I rejected those program options which postu-

lated omitting the Clinch River Breeder Reactor (CRBR) Plant because, in my judgment, the CRBR offers the most timely and cost-effective construction, licensing and operating experience essential to the successful completion of the LMFBR Program.

7. On balance, I find that the issue of plant operation in a utility environment is best addressed by the program plan entitled "reference plan". This plan contemplates construction and operation of the CRBR, a Prototype Large Breeder Reactor (PLBR), and a Commercial Breeder Reactor (CBR-1) on a schedule which calls for operation for three years of a Nuclear Regulatory Commission-licensed CRBR and completion of the design, procurement, component fabrication and testing phases for, and issuance by the Nuclear Regulatory Commission of a construction permit for, the PLBR prior to a commitment to construct the CBR-1. In my judgment, this schedule should provide sufficient experience in design, procurement, component fabrication and testing, licensing and plant construction and operation from CRBR and PLBR taken together to enable ERDA to predict with confidence the successful construction and operation of the CBR-1. This schedule will be periodically re-examined to assure that the experience derived from operation of the CRBR and the pre-operation of the PLBR is sufficient before ERDA commits itself to construction of the CBR-1. Moreover, a separate NEPA review of each of these plants will be undertaken on a site-specific basis to assure that they are environmentally acceptable and are conservatively designed to protect the health and safety of the public and to provide useful information for subsequent environmental, economic, and technical assessments.

8. The base program consists of necessary supporting efforts which proceed relatively independently of the plant demonstration program. These efforts focus on the development of advanced fuels and of a fuel reprocessing system. Key to these efforts is the design, construction and operation of an LMFBR fuel reprocessing hot pilot plant. The FES indicates that completion of the design work for this plant and its equipment would provide an adequate basis upon which to predict with confidence whether a safe, reliable, and economical LMFBR fuel cycle will be developed.

9. The FES also addresses major uncertainties in the areas of reactor safety, safeguards, waste management, health effects, and uranium resource availability. In reviewing the programs in each of these areas, I find that the controlling item currently appears to be the construction of and testing in a large scale safety test facility. While the results of these tests are not required to assure the safety of early demonstration plants, they are required to provide realistic design conservatism for commercial plants. Alternative methods for conducting these tests are being evaluated, and I will separately make a final decision on the conduct of these tests at a later date.

10. On the basis of the material set forth in the FES, I find that if the reference plan and its supporting programmatic efforts are vigorously pursued, sufficient information would be available as early as 1986 to resolve the major uncertainties affecting widepsread LMFBR technology deployment and therefore to permit an ERDA decision on commercialization of that technology. It should be emphaisized

that availability of the necessary decisional data by 1986 requires the successful and timely completion of a large number of interrelated and parallel efforts. Delay in any of the aforementioned controlling elements will result in a delay of the decision date. It should be emphasized also that following an ERDA decision on commercialization the utility industry and the public would have to determine the extent, if any, LMFBR technology would be commercially deployed.

11. To be meaningful, ERDA's decision on commercialization must be made before any commitment to widespread deployment becomes irreversible. In this connection, I do not find that implementation of the LMFBR Program, as structured above, would constitute an irreversible commitment to widespread commercial use in 1986. At that time CRBR would have been in operation three years, construction would have been largely completed on the PLBR, and the CBR would still be in the design stage. The level of program involvement of the industrial sector would be minor compared to the investment required to place LMFBR technology in widespread use. Moreover, if ERDA were to determine that the problems involved in widespread deployment could not be resolved satisfactorily, the Nuclear Regulatory Commission would almost surely refuse to license LMFBR plants.

12. Nor do I find that continuation of the LMFBR Program, as structured above, would inevitably short-change the development of other technology programs for the long term production and conservation of energy. Indeed, these technological alternatives are receiving substantially increased new appropriations and are proceeding as rapidly as possible consistent with prudent management.

13. In conclusion, it must be emphasized that at this stage of LMFBR technology development we do not have all the answers necessary to determine the environmental acceptability, technical feasibility and economic competitiveness of LMFBR technology for widespread commercial deployment. It is to find these answers that ERDA is continuing the research, development, and demonstration program. As the LMFBR Program and its supporting programs continue to evolve and new information is generated, ERDA may decide to reorient the structure or pace of the LMFBR Program or even terminate it altogether. That is why the findings I make today must be periodically re-evaluated in the light of new information. In any event, at least one additional programmatic environmental statement will be prepared and considered prior to any future ERDA decision on the commercialization of LMFBR technology. The current planning schedule calls for the preparation and consideration of such a programmatic statement in 1986.

ROBERT C. SEAMANS, Jr.,
Administrator.

December 31, 1975.

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ADDITIONAL COST-BENEFIT ANALYSIS INFORMATION, SECTION III F OF THE FINAL ENVIRONMENTAL STATEMENT OF THE LMFBR PROGRAM, ERDA-1535*

Section III F.1

INTRODUCTION

The cost-benefit analyses provided in the PFES have received extensive comment by letter (see Section V) and during the Public Hearing held on May 27–28, 1975. The comments were to the effect that the analyses—

(*a*) were too favorable to the LMFBR because they overestimated the potential energy demand; underestimated the capital cost differential; utilized R&D costs that were too low; used introduction dates for the breeder that were too early; and made estimates of uranium resources that were too low and of uranium prices that were too high;

(*b*) were too unfavorable to the LMFBR because they used too high a discount factor; the uranium price and separative work price projections were too low; and estimates of uranium resources were too high; and

(*c*) did not adequately treat the cost-benefits of alternative energy systems such as substantial use of solar energy substitution for electric space heating and cooling; greatly expanded use of geothermal energy and expedited development of fusion power.

These issues were all treated in the PFES (Section II of this document) in Sections 11.1 and 11.2.

The Internal Review Board in its Report to the Administrator [1] reviewed the controversy (see Section IV B, pps. IV B–20 to –27) and stated:

"The Board is wary of facile attempts to resolve these areas of controversy, dependent as they are upon future events which are now more or less speculative. With regard to projections of energy demand, it seems prudent to assume a moderate level of growth for planning purposes. This is so not because ERDA is committed to any particular growth scenario, but simply because the penalties for underestimation are likely to be far more severe than those for overestimation. A program can be scrapped if its need does not become actualized. But the long lead times involved in research and development programs and plant construction make it relatively difficult to accelerate efforts which have been held in abeyance pending an unmistakable confirmation of their need.

*Published December 1975 in ERDA-1535, the "Final Environmental Statement of the LMFBR Program."

"With respect to uranium resources, the Board is impressed with the view of Dr. Stauffer that there is no reliable methodology by which extrapolations can be made from known reserves.* Although significant information can and no doubt will be developed in advance of physical exploration, optimism beyond that reflected in the cost-benefit projections may be unwarranted at this time.

"Due to the vagaries of the manufacturing and construction industries, it seems equally perilous to speculate at this time on the capital cost question. We note that the PFES brackets these areas of uncertainty with sensitivity analyses indicating the influence of various assumptions upon the results. Future events will narrow the bands of uncertainty and permit a more reliable verdict on the LMFBR economics.

"In the interim, the Board finds that the PFES is reasonably complete and sufficient for present decisionmaking.

"The assumptions employed as to energy demand, uranium supply and capital costs may eventually prove to be unrealistic and therefore reduce the calculated benefits. On the other hand, it would be risky to underestimate the advantages of the R D & D Program at this time. Indeed, the value of better information seems undisputed, and, as it becomes available, the record should be supplemented and the course of the Program reevaluated.

"The Board believes that while the final verdict on the economic costs and benefits of a commercial LMFBR industry must be left to the utility industry, ERDA must reserve to itself the judgment as to whether the noninternalized environmental costs, balanced against the net economic benefits of a prospective LMFBR industry warrant a continuation of the Program to the point of commercialization. The present record is not deemed to be ripe for this determination."

Recognizing that input data has changed significantly since the analyses presented in the PFES were performed, Section III F has been prepared to provide up-to-date cost-benefit analyses. Section III F.1 provides additional material on the electric energy cost of substituting alternative energy systems for nuclear power. This Section should provide the reader with a grasp of the economic costs involved in such substitution and should help permit rational estimates to be made as to the relative cost-benefit ratios of such alternatives. In addition, a revised economic cost-benefit analysis of the LMFBR has been prepared. Since the PFES was published, the basic data which affect the conclusions of the cost-benefit analyses have changed substantially. In particular, estimates of future electrical energy requirements, future enrichment costs, future uranium ore costs, future nuclear plant capital costs and future R&D costs have all changed. These updated factors have been used in revised cost-benefit analyses which are presented in III F.2. Despite the fact that updated data was used, uranium prices continue to increase at a rapid rate since the calculations were made for this revised cost-benefit analysis. The increase has been such that even the high price uranium projection is considered conservative. Hence the LMFBR benefits should be considered low even for this reviewed study.

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*Hearing Transcript, pp. 399–401.

11.1S Electric Energy Costs for Alternative Power Supply Scenarios

1. *Introduction and Summary*

This section concerns a cost comparison between the U.S. electric power economy being supplied in large part by a combination of solar, geothermal, organic waste and fusion power sources coupled with fossil and nuclear (LWR and HTGR) power sources and a combination of solely fossil and nuclear power sources referred to as "conventional" with LMFBRs included. The solar, geothermal, organic waste and fusion power sources are referred to as "alternative" (new technology) power sources.

Using the same techniques as in the revised LMFBR cost-benefit study, calculations were made for two energy projections, designated as low and base, for the cost comparisons. The low energy projection, 13.8 trillion Kwhr(e) by the year 2020, corresponds to the projection used by Cochran, et al. in the paper "Bypassing the Breeder" [2] and the low energy projection in the revised LMFBR cost-benefit analysts. The base energy projection, 21.9 trillion Kwhr(e) by the year 2020, is similar to the base energy projection utilized in the revised LMFBR cost-benefit analysis. Hence, four cases were calculated with each energy projection having two cases, one with and another without the alternative power sources. The cases without the alternative power sources included the LMFBR. The cases with alternative power sources included only those nuclear plants that were operating, under construction or on order by January 1, 1975.

In "Bypassing the Breeder" Cochran suggested the following scenario for electric energy generation in the year 2020, consisting mainly of alternative energy sources:

Energy in kilowatt-hour (electrical)

Source:	*Trillions*
Solar	5.5
Geothermal	1.7
Fusion	2.2
Organic wastes	0.6
Other sources (mainly fossil fuels)	3.8
Total	13.8

TABLE III F-1.—CAPACITY PROJECTIONS FOR ALTERNATIVE PLANTS

Year	Operating capacity, GW			
	Geothermal	Solar	Organic waste	Fusion (CTR)
A. Base energy projection:				
1980	10		6	
1990	58	2	29	
2000	228	290	87	
2010	628	731	89	199
2020	783	1,068	89	1,309
2025	783	1,156	89	1,849
B. Low-energy projection (Cochran scenario):				
1980	10		6	
1990	43	2	29	
2000	95	290	88	
2010	164	713	88	177
2020	215	1,068	88	587
2025	149	1,140	88	772

A projection of alternative capacity commitment was developed to correspond approximately to Cochran's energy scenario. A corresponding projection was developed to apply to the basic energy projection. These capacity projections are shown in Table III F–1. It is noted that the capacity projections for alternative plants for both energy projections for solar and fusion and the base energy projection for geothermal are much larger than projected by ERDA in 1975. However, these high projections of Cochran were accepted to examine the cost effect of possible utilization of alternative power sources as a full substitute for nuclear.

In the cost calculations all alternative plants were assumed to be base-loaded. Any additional capacity required to meet projected power demands was assumed to be supplied by fossil plants (base-load and load-following plants) except for those nuclear plants now in operation or committed for operation by 1985.

In all cases the "conventional" plants considered were the nuclear power plants described in the revised LMFBR cost-benefit study and the fossil plants (with costs updated to 1975) described in the LMFBR Program Proposed Final Environmental Statement (PFES) cost-benefit study. The treatment of conventional plant utilization differed from that in the revised LMFBR cost-benefit study in that (1) effects of fossil plants were considered, and (2) both base-load and load-following plants were included in the calculations. In other respects cost data and ground rules were selected to conform as closely as possible to those used in the revised LMFBR cost-benefit study.

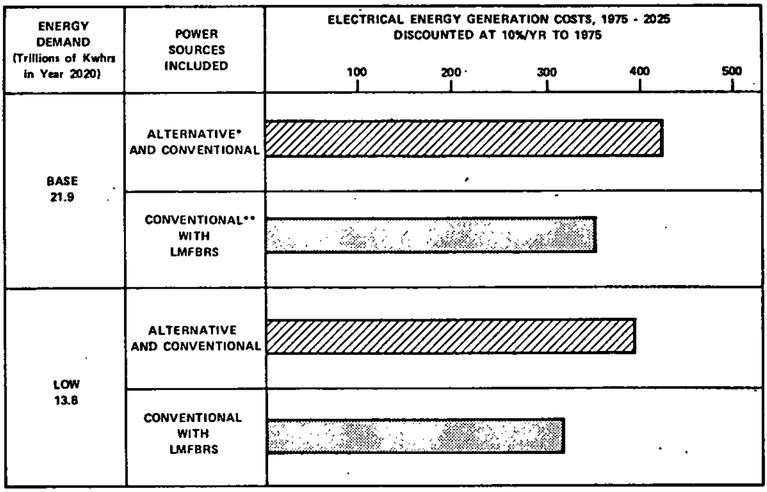
In each case the total cost of U.S. electric energy generation from 1975 through 2025 was calculated and discounted at 10 percent per year to 1975. For the two cases involving alternative energy source scenarios, generation costs were obtained which were considerably higher than the corresponding cases assuming conventional sources with the LMFBR. These costs were also considerably above costs of corresponding cases in the revised LMFBR cost-benefit studies, with or without assumed availability of the LMFBR.

In the case of the Cochran (low energy) scenario, the discounted power cost was calculated to be $389 billion; for the corresponding scenario using the base energy projection, costs were calculated at $432 billion. The corresponding costs assuming use of conventional plants were, respectively, $314 billion and $343 billion. The discounted cost penalty associated with the alternative sources is about $89 billion for the base energy projection and about $75 billion for the low energy projection. The costs are shown in Figure III F–1.

2. *"Alternative" Plants*

Four categories of alternative plants were considered in the study, with characteristics as described below. Plants committed prior to 1990 were assumed to be rated at 1,300 MWe capacity: plants installed in or after 1990 were taken as 2,000 MWe.

Economic data for these plants was for the most part expressed in 1974 dollars. To convert these data to 1975 dollars in conformance with



* Alternatives Include Solar, Geothermal, Organic Waste and Fusion
**Conventional Includes Fossil (Coal) and Nuclear (LWR and HTGR)

POWER COST SUMMARY: ALTERNATIVE VERSUS CONVENTIONAL POWER SYSTEMS

FIGURE III F–1

the revised LMFBR cost-benefit study, escalation factors of 9.5 percent were applied to capital costs, and of 6 percent to operating and maintenance costs.

A. *Geothermal plants* were assumed to be introduced in the late 1970's. For the low energy (Cochran) scenario, they were assumed to increase in capacity to 215 GW in 2020, dropping to 148 GW in 2025. For the case considering the base energy projection, capacity was assumed to increase to about 783 GW in the 2020–2025 period. The projections for the "low" energy scenario are in general agreement with the capacity goals given in "The Nation's Energy Future." [3]

Capital and operating costs of the geothermal plants were based on estimates in the Project Independence Blueprint.[4] A unit capital cost of $712/KWe in 1974 dollars was assumed; this is the mid-range value of $562–862/KWe given in the Blueprint, and assumes the major source of geothermal energy derives from hydrothermal, liquid-dominated reservoirs. No scaling of unit capital costs was assumed for different capacity ratings. Cost scaling does not appear appropriate for these plants because of probable costs of steam collection systems for large units. The capital costs were escalated to $780/kWe for expression in 1975 dollars.

Operating costs were set at 2 mills/kwhr(e), (2.12 mills/kwhr(e) in 1975 dollars) based again on information from the Project Independence Blueprint. Based on plants operating at 100 percent capacity factor, an arbitrary division of 2/3 fixed costs and 1/3 variable costs was assumed. (See Table III F–3 for definitions of fixed and variable costs.)

Technical, economic, and environmental aspects of the use of geothermal energy are discussed in detail in Section 6A.4 of the PFES. The assumptions of capacities and costs used herein are in agreement with the PFES discussion.

B. *Solar energy* converters were assumed to be introduced in the early 1990's, increasing in capacity to about 890 GW in 2020. This penetration is greater than can be inferred from the NSF/NASA Solar Energy Panel Report,[5] but is in line with the Cochran scenario.

The solar energy contribution would presumably consist of a mix of thermal-conversion, photo-voltaic, ocean-thermal, and wind energy systems, but with thermal-conversion and photo-voltaic being the dominant solar conversion systems. Cost estimates for solar-to-electric conversion are highly uncertain because the technology is not well developed. Estimates by Subpanel IX,[6] which provided input data to the report on "The Nation's Energy Future," indicates costs of \$1300–2500/KWe (average) for thermal-conversion and photo-voltaic systems. This estimate does not account for sufficient energy storage to allow solar energy plants to operate as firm power sources. If sufficient energy storage were included, the above estimates would increase by several hundred dollars per kilowatt. Nevertheless, for purposes of this study, the optimistic assumption was made that solar conversion plants with sufficient energy storage to permit base load operation could be constructed for \$1500/KWe (average)—or, in 1975 dollars, \$1643/KWe (average). This cost, derived from the above sources, some of which are relatively old are, however, in the range of new cost estimates under preparation by ERDA.

Annual operating and maintenance costs were taken as 2 percent of the capital investment. These costs agree closely with the 3 mills/kwhr(e) estimated by EPRI[7] as O. & M. costs for solar plants. O. & M. costs were arbitrarily divided as ⅚ fixed costs, ⅙ variable costs (based on 100 percent plant factor).

Aspects of solar energy utilization are discussed in detail in Section 6A.5 of the PFES.

C. *Organic waste* burners were assumed to first come on line in the mid-1970's, to penetrate to a capacity of 78 GW by the year 2000, and to hold at that capacity through the year 2025. The on-line capacity of these plants was assumed to be limited by the availability of collected urban organic wastes, as discussed on pages 6A.6–13 and 11.1–21 of the PFES. No attempt was made to factor in bio-mass contributions from aquacultone and forestry residues. Energy generation from this source agrees with Cochran's proposed value in "Bypassing the Breeder."

Organic waste-burning plants were assumed to have capital and operating costs comparable to those of a coal-burning power plant with no desulfurization equipment. Capital costs were estimated at \$291/KWe (\$319 in 1975) for a 1300 MWe plant, and \$265/KWe (\$290) for a 2000 MWe plant. Fixed O. & M. costs, for 1300 and 2000 MWe plants were estimated at \$6.6 and \$8.8 million per year in 1975 dollars and variable O. & M. costs (100 perent plant factor) were \$10.5 and \$14.1 million per year in 1975 dollars. The capital and O. & M. costs for these plants were furnished by Holifield National Laboratory using the same methods as were used for plant capital and operating costs provided for the PFES.

Organic wastes used as fuel in these plants were assumed to be available free of charge. However, an addition of 10 percent oil as supplemental fuel was assumed to be needed to maintain good combustion. At $11/bbl and an assumed heat rate of 10,000 btu/kwhr(e), this resulted in a net fuel cost of 1.87 mills/kwhr(e).

D. *Fusion* plants were assumed to become available shortly after the year 2000 and to penetrate the power supply rapidly; about 590 GWe were assumed to be on line by the year 2020 for the low energy projection. Energy generation from these plants in the year 2020 is somewhat greater than that suggested by Cochran.

Since the scientific feasibility of fusion reactors has yet to be demonstrated, there is little basis for estimating capital and operating costs. A preliminary estimate by Kulcinski and Conn of the University of Wisconsin [8] indicated that a 1500 MWe CTR might cost $900–1000/KWe. An AEC study (WASH–1239)[9] estimated the cost of a CTR to be about $500/KWe. For purposes of this study, fusion reactors were assumed to produce power at a cost equivalent to the average power cost of nuclear plants over the span from the years 2000 to 2020, calculated for Case 3 (the base LMFBR case) of the PFES cost-benefit study. Capital and operating costs (Tables III F–2 and III F–3) were chosen consistent with those power costs. Net fuel costs were assumed to be zero. It should be noted that the assumed capital cost of $445/KWe is somewhat lower than the estimates cited above. Escalation of capital and O. & M. costs to 1975 dollars resulted in a CTR power cost equivalent to that of the LMFBR.

Consideration of the use of CTR systems is discussed in Section 6A.1.6 of the PFES.

Capital costs assumed for the alternative plants are summarized in Table III F–2, operating and maintenance costs are shown in Table III F–3.

TABLE III F–2.—CAPITAL COSTS ASSUMED FOR CONVENTIONAL AND ALTERNATIVE PLANTS

[Costs in mid-1974 dollars]

Plant type	1,300 megawatts electrical: Per kilowatt electrical	1,300 megawatts electrical: 10^6	2,000 megawatts electrical: Per kilowatt electrical	2,000 megawatts electrical: 10^6
LWR	$460	$598	(*)	(*)
HTGR	460	598	(*)	(*)
LMFBR:				
1993	560	728		
2000			$ 506	$1,012
2006			460	920
Fossil (coal)	380	494	346	692
Geothermal	780	1,014	780	1,560
Solar			1,643	3,286
Organic waste	319	415	290	580
Fusion (CTR)			487	974

*None considered.

TABLE III F-3.—OPERATING AND MAINTENANCE COSTS ASSUMED FOR CONVENTIONAL AND ALTERNATIVE PLANTS

[Costs in millions of mid-1974 dollars per year]

Plant	1,300 megawatts electrical		2,000 megawatts electrical	
	Fixed [1]	Variable [2]	Fixed [1]	Variable
LWR	4.77	2.49	(3)	(3)
HTGR	4.74	2.49	(3)	(3)
LMFBR	5.30	3.0	6.50	3.68
Fossil (coal)	7.51	16.87	10.15	25.99
Geothermal	12.23	7.04	18.72	10.82
Solar			53.19	10.5
Organic waste	6.6		8.83	14.07
Fusion (CTR)			7.45	2.57

[1] Fixed costs for staff, fixed maintenance, fees, and administration.
[2] Variable costs are for variable maintenance, supplies, and miscellaneous. For coal plants they also include limestone, ash, and slurry disposal. Variable O. & M. costs are based on a 100 percent capacity factor.
[3] None considered.

3. *Results of Calculations*

Levelized power costs were calculated for the alternative plants, assuming these plants had the same base-load characteristics assumed for base-loaded plants in the revised LMFBR cost-benefit study. Each individual plant was assumed to reach 72 percent annual capacity factor by the end of the second year following startup, and to remain at 72 percent through its 15th year of life; thereafter the capacity factor decreased linearly to 50 percent at end of its 30-year life. The average lifetime capacity factor with this assumption is 65.9 percent.

A. *Plant power cost comparisons.*—The calculated power costs are shown for post-1990 (2000 MWe) plants, in Figure III F–2. Also shown on the same figure are typical costs for LWRs (using $35/lb uranium), LMFBRs, and coal-fired plants (using 83¢/MBTU fuel). Based on available estimates for costs of building and operating the alternative plants, only the capacity-limited organic waste converters and the advanced CTR system—which are not projected to attain significant on-line capacity until the 2010–2020 area—are seen to be cost-competitive with conventional power plants considered in the PFES cost-benefit study.

B. *Power systems composition: Cases considered.*—Calculations concerned two electrical projections, as previously mentioned: the base and low projections for the revised cost-benefit study, building to 21.9 trillion kwhr(e) and 13.8 trillion kwhr(e) respectively in the year 2020. For each energy projection, two cases with and without alternative power sources were calculated which considered the contributions to electric energy supplied by both base-loaded and load-follower plants. Details of the method of calculation, and the assumptions involved, are provided in Section 11 of the PFES, and in the description of the revised LMFBR cost-benefit study included in this supplement.

Figure III F–3 indicates the mix of plant types for the case involving the alternative power sources with the base energy projection; the corresponding mix for the low energy projection is shown in Figure III F–4.

Results of the alternative case calculations, which were summarized in Figure III F–1, are shown in more detail in Table III F–4, with comparable conventional plant cases.

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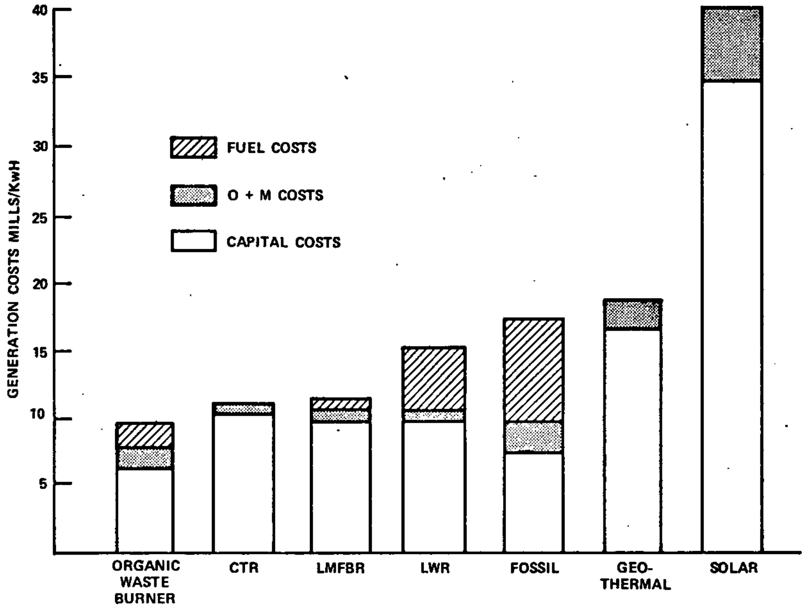


UNIT POWER COST COMPARISON: ALTERNATIVE VERSUS CONVENTIONAL POWER PLANTS

FIGURE III F–2

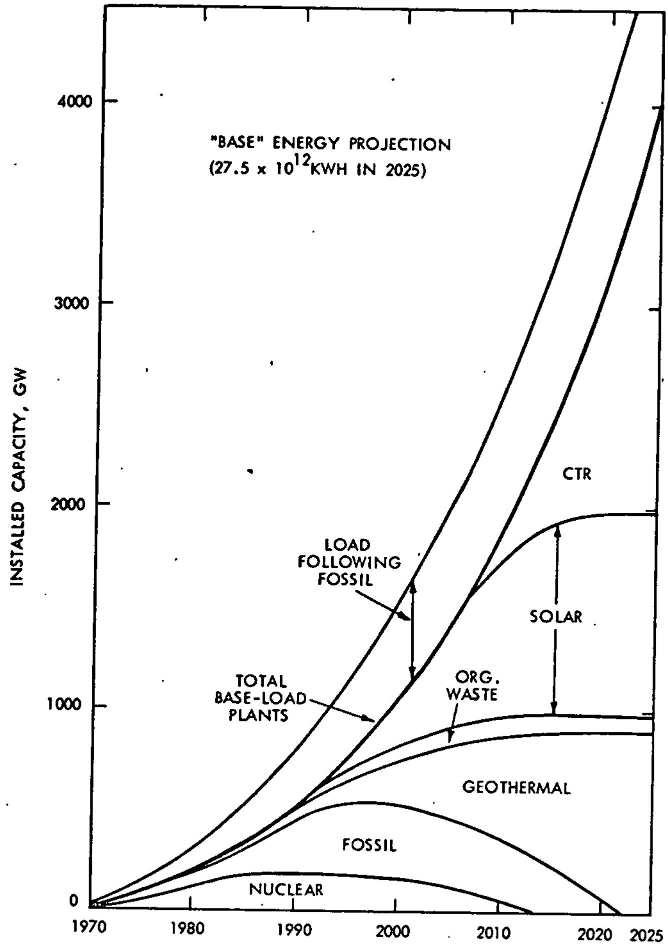
Case X–1, a base-energy alternative power source case considering both base-loaded and load-follower plants, is directly comparable to Case 1, which considered competition among nuclear and fossile plants under similar conditions. Case 1, in turn, is similar to the base case for the revised LMFBR cost-benefit study but includes load-follower plants and allows competition among nuclear and fossil plant types.

Cases X–2 and 2 are the corresponding cases for the low energy projection. Case X–2 is the Cochran scenario.

Cases 3 and 4 were run to check the validity of comparison of the alternative cases with those considering only conventional plants. In these cases, conventional plants were allowed to compete economically with the alternate sources. In these cases, the only alternative plants selected for introduction were the organic waste burner and, late in the study, the CTR generator. Cost differences from all conventional cases were not significant.

The alternative cases, on the other hand, indicated electric power costs 25 percent to 30 percent higher than for the corresponding cases including only conventional plants. These cost increases were consistent for both energy projections, and discounted cost tabulations taken to intermediate years show a continuous divergence of costs from the date of alternative sources introduction.

With "negative benefits" of this magnitude, it is difficult to conceive that the alternative power sources will be incorporated in large quantities into the U.S. electrical power economy unless costs of the developed plants are markedly different than projected in this analysis.



POWER SYSTEM COMPOSITION WITH
ALTERNATIVE POWER SOURCES & BASE ENERGY PROJECTION
(PRE-1970 PLANTS EXCLUDED)

FIGURE III F-3

TABLE III F-4.—POWER COST COMPARISONS: ALTERNATIVE VERSUS CONVENTIONAL SYSTEMS

[Costs in billions of dollars (1975–2025) discounted at 10 percent to 1975]

Case No.	Energy demand	Plants considered	Costs	Compared with case	Cost difference
1	Base	Conventional	343.2		
X1	Base	New technology	432.0	1	88.8
2	Low	Conventional	314.0		
X-2 [1]	Low	New technology	388.6	2	74.6
3	Base	All	339.9	1	−3.3
4	Low	All	311.5	2	−2.5

[1] Case X-2 is the Cochran scenario.

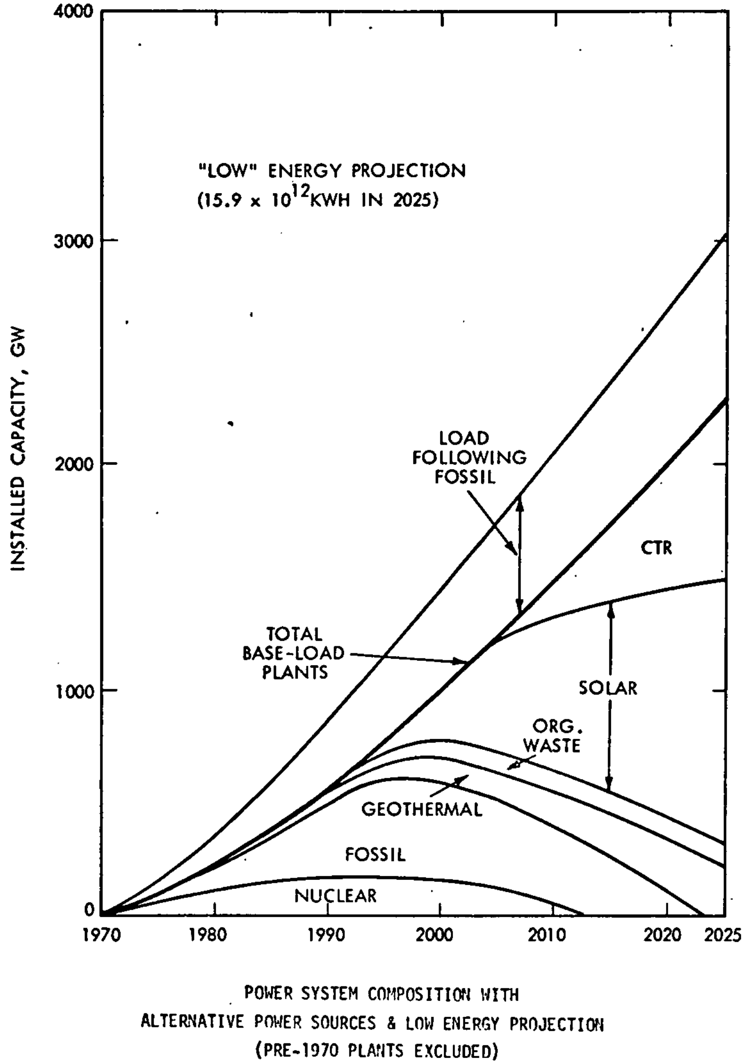


FIGURE III F-4

REFERENCES FOR SECTION III F.1

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Section III F.2

11.2S A Revised Economic Cost-Benefit Analysis of the Liquid Metal Fast Breeder Reactor Program

1. *Introduction*

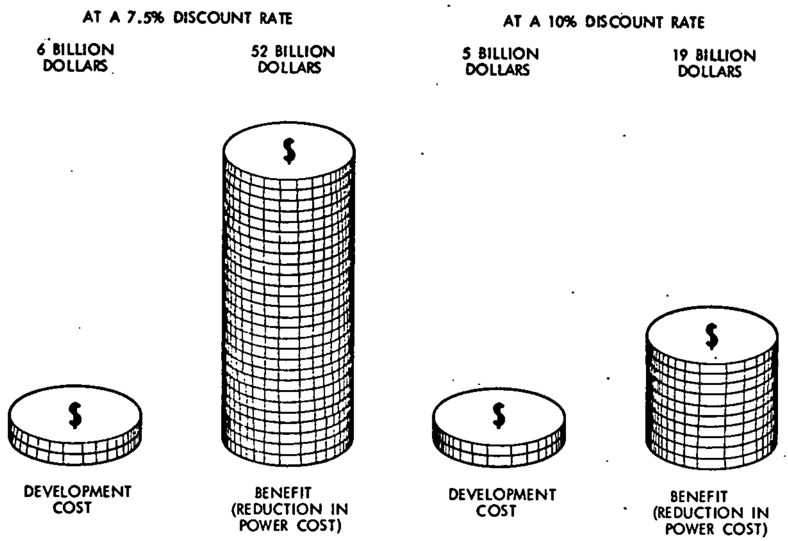
In December 1974, the U.S. Atomic Energy Commission issued the Proposed Final Environmental Statement (PFES) for the Liquid Metal Fast Breeder Reactor (LMFBR) Program.[1] This comprehensive statement, contained an analysis of the probable development of the nuclear power economy to the year 2020 (see Section 11 of the PFES). In the period since that analysis was prepared, the basic data which affect the relative economic competitiveness of the LMFBR have changed. In particular, estimates of future electrical energy requirements, future uranium enrichment costs, future uranium ore costs, future nuclear plant capital costs and future R&D costs have all changed. In view of this, the nuclear energy economy has been reanalyzed to more accurately determine the costs and benefits role of the Liquid Metal Fast Breeder Reactor. The entire analysis was also placed in perspective by viewing the nuclear energy economy in terms of the total U.S. energy situation over the next fifty years.

Numerous studies and statements analyzing and discussing the role of the LMFBR in the nuclear energy economy have been published [2-13] in the past twelve months. It is hoped that a comprehensive analysis utilizing the most recent data will clarify the principal issues regarding the economic feasibility of the LMFBR.

In this study, the new data was utilized in a model of the nuclear power economy based on the linear programming technique in an analogous manner to the analysis performed in the PFES. The objective function of the linear program was designed to minimize the cost of energy over the planning horizon. This method of analysis is capable of providing straightforward conclusions about the economic feasibility of the LMFBR. The analysis showed that society will gain substantially by the development of the LMFBR.

2. *Summary of Results*

The dollar benefit and the development cost associated with the introduction of the LMFBR are shown in Figure III F-5 for a 1993 LMFBR introduction for base assumptions. The benefit is simply the reduction in total power cost over the planning horizon from 1975 to 2025 obtained by introducing the LMFBR, with future costs properly



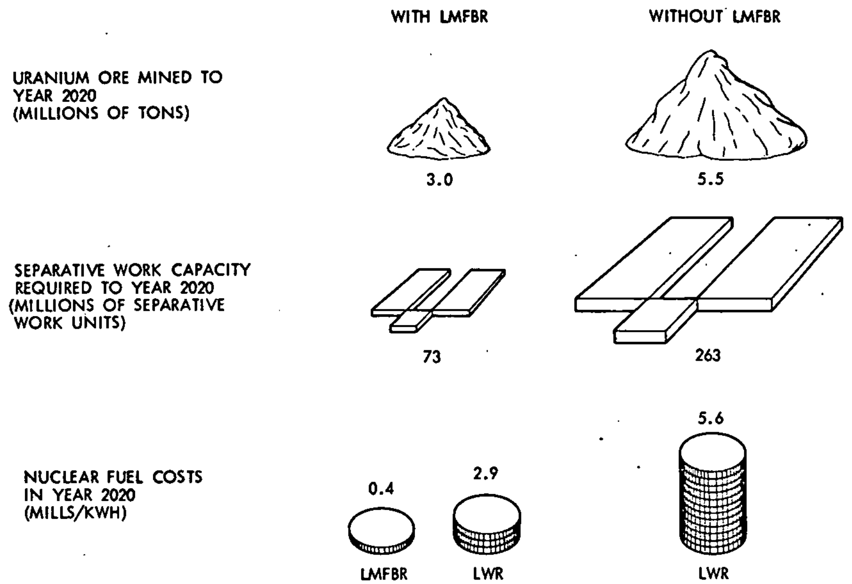
DOLLAR BENEFITS FROM THE LMFBR WITH A 1993 INTRODUCTION

FIGURE III F–5

discounted using present value analysis. With a 1993 LMFBR introduction, the development cost* of the LMFBR program is approximately 6 billion dollars while the benefit is 52 billion dollars, where both values are discounted at a rate of 7.5 percent. When discounted at a rate of 10 percent, the development cost* is approximately 5 billion dollars while the benefit is 19 billion dollars. In either case, the benefit is substantially greater than the development cost. The development cost is relatively insensitive to the discount rate since this cost is incurred early in the planning period. The benefit, on the other hand, is accrued in the latter part of the period, and hence is very sensitive to the discount rate. An indication of the sensitivity of the benefits to the discount rate can be obtained by noting that the benefit would be about one trillion dollars at a zero-discount rate. The undiscounted cost of electric energy is reduced by about 85 billion dollars per year in the year 2020 alone.

The benefit is due primarily to the lower nuclear fuel cost obtained by introducing the LMFBR—in particular, by the reduction in the requirements for uranium ore and separative work. These reductions are illustrated in Figure III F–6. Without the LMFBR, the cumulative U_3O_8 requirements to the year 2025 is 5.5 million tons, while with the LMFBR, the cumulative U_3O_8 requirement is 3.0 million tons. Furthermore, without the LMFBR, U_3O_8 will continue to be mined at an ever increasing rate, while with the LMFBR, the annual ore requirement becomes insignificant after the year 2025.

*The development costs do not include residual construction costs for the early LMFBRs which may be required to bring them into economic parity with LWR's in that time frame. See Section I.3 discussion on capital costs.

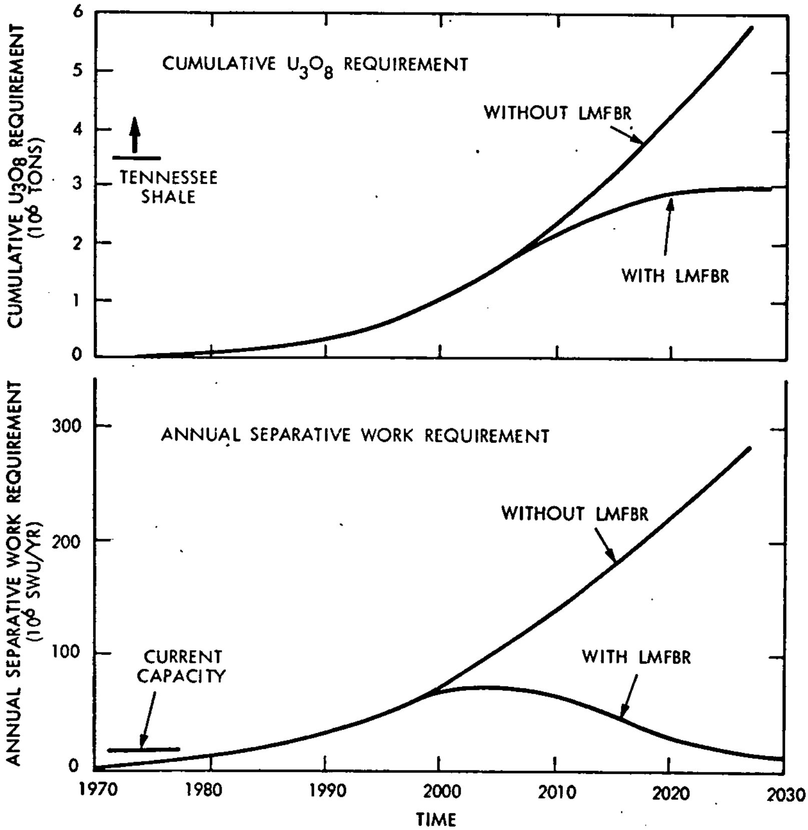


INTERPRETATION OF LMFBR BENEFITS WITH A 1993 INTRODUCTION

FIGURE III F–6

Separative work requirements are also shown in Figure III F–6 Without the LMFBR, an annual separative work capacity of 263 million separative work units (SWU) per year will be required in the year 2025, while with the LMFBR, the maximum separative work requirement will be only 73 million SWU/year. It is wothwhile to mention that the current separative work capacity in the U.S. is only 17 million SWU/year. Without the LMFBR, separative work recuirements continue to increase with time, with the LMFBR, the maximum annual separative work requirement of 73 million SWU/year is obtined in the year 2005, and separative work requirements decrease continuously beyond that time. The time dependence of the annual separative work reouirement and the cumulative U_3O_8 reouirement are shown in Figure III F–7.

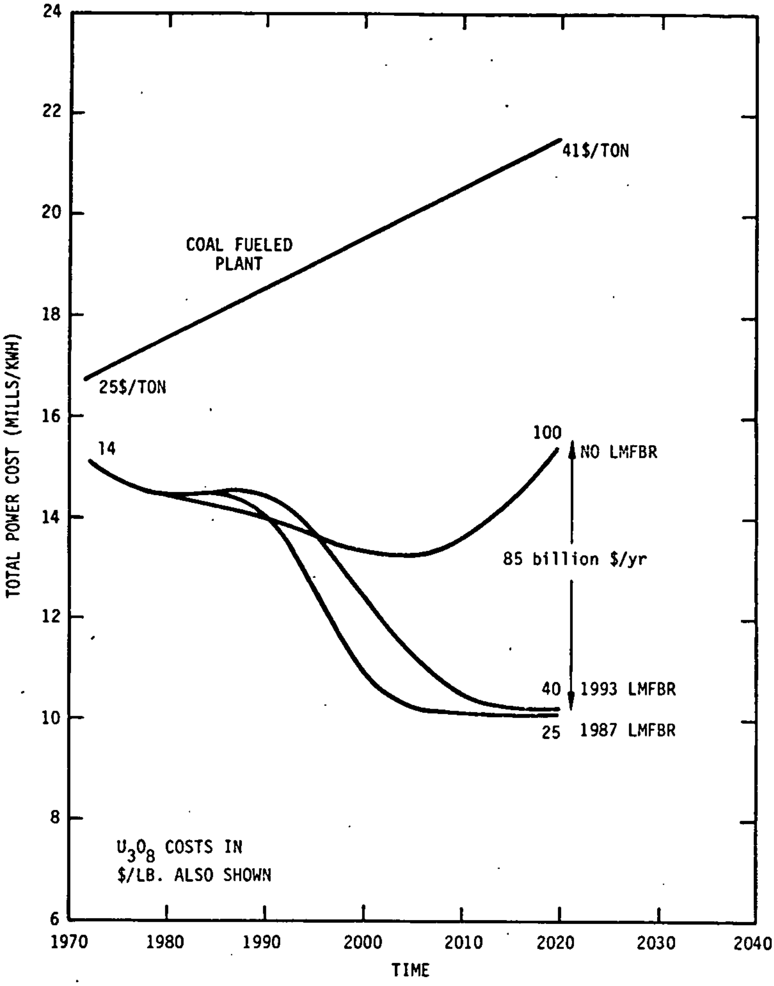
Finally, nuclear fuel costs in the year 2025 are shown in Figure III F–6. Without the LMFBR, the weighted-mean fuel cycle cost for the LWR will increase to 5.6 mills/kwhr(e), while the fuel cycle cost for a uranium-fueled LWR will increase to 8.6 mills/kwhr(e) in 2025. The weighted-mean fuel cycle cost is lower because it includes the effect of plutonium recycle. Throughout this study, plutonium recycle was assumed to be introduced in 1981. Currently, nuclear fuel costs are about 2.8 mills/kwh for a uranium-fueled LWR. Note that the price increases discussed above are real—i.e., exclusive of inflation. With the LMFBR, on the other hand, the weighted mean LWR fuel cycle cost will be stabilized at about 2.9 mills/kwhr(e), while the LMFBR fuel cycle cost will be about 0.4 mills/kwhr(e). Indeed, it is just this difference in fuel cycle costs that is directly responsible for the LMFBR benefits.



TIME DEPENDENCE OF SEPARATIVE WORK AND CUMULATIVE ORE REQUIREMENTS WITH A 1993 LMFBR INTRODUCTION

FIGURE III F–7

The time dependence of the total power costs in the nuclear industry is shown in Figure III F–8. For comparison, the total power cost of a coal-fired plant is also shown. The cost of coal was assumed to be $25/ton in 1975, and coal was assumed to experience a real price increase of 1 percent per year thereafter. As a consequence, the total power cost for a coal-fueled plant is about 17 mills/kwhr(e) in 1975, and this increases to about 22 mills/kwhr(e) in 2025. Nuclear power costs, on the other hand, decrease as the nuclear industry matures, i.e., as plutonium recycle is introduced, and as unit costs for reactor construction, fuel fabrication, and fuel reprocessing decrease. However, without the LMFBR, nuclear power costs ultimately begin to increase as the industry is forced to mine the lower grade uranium ores. In the year 2020, nuclear power costs for an LWR–HTGR economy with plutonium and U^{233} recycle are rising at the real rate



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
REFERENCE CASE

FIGURE III F-8

of 1 mill/kwhr(e) every 5 years. Without plutonium and U^{233} recycle, nuclear power costs in the year 2020 will be several mills/kwh higher and will be rising faster. With the LMFBR, the supply of plutonium increases with time, and as a consequence, nuclear power costs fall quite rapidly around the year 2000 after an initial rise in the 1980s due to rising U_3O_8 prices. Nuclear power costs remain constant thereafter since the basic fuel for the nuclear industry is an increasing supply of plutonium, rather than a diminishing supply of U_3O_8.

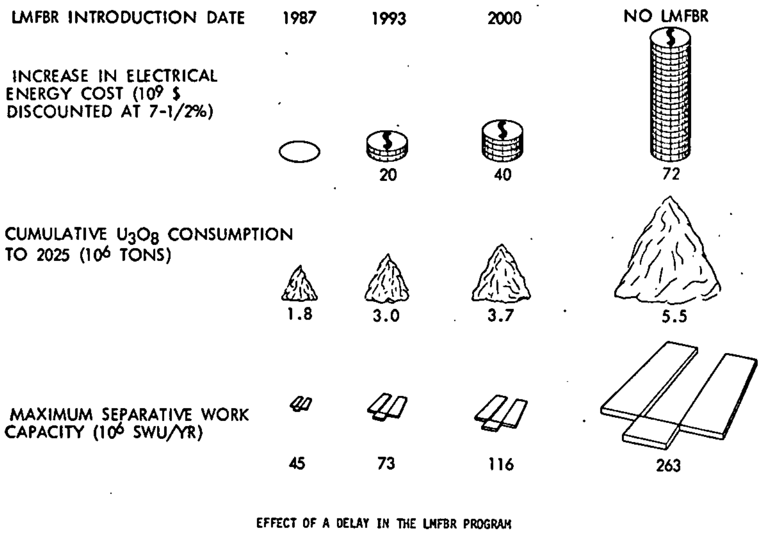
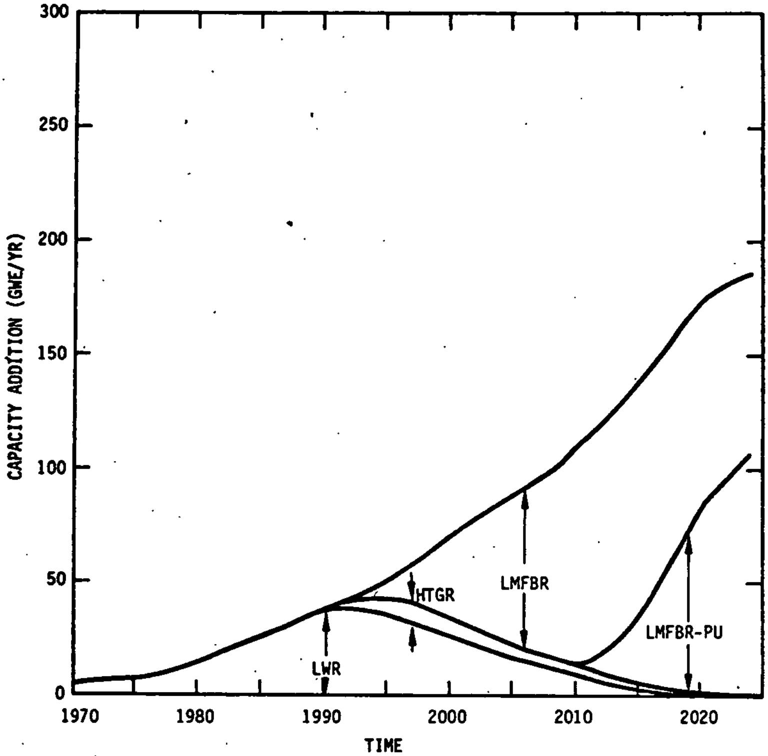


FIGURE III F–9

The effect of a delay in the LMFBR program is shown in Figure III F–9. Note that the discounted (7.5 percent) electrical energy cost to the nation increases at the rate of about 3 billion dollars per year of delay. Note also that a delay in the introduction date for the LMFBR beyond 1993 will require over 3 million tons of U_3O_8 to be mined. As a consequence, a delay substantially past 1993 will require that the low-grade Tennessee shales be mined. Finally, note that separative work requirements increase by about 5 million SWU/year per year of delay. This almost staggering increase in the required enrichment capacity may be the most compelling argument for the early development of the LMFBR.

A nuclear industry growth pattern that might be considered typical of those obtained in this study is shown in Figure III F–10. This figure shows the reactor construction rate as a function of time throughout the planning horizon. Note that the LWR is the primary power plant through the 1980's and into the 1990's. However, the LMFBR is being built at an ever increasing rate in the late 1990's, and it becomes the predominant power plant after the year 2000. An LMFBR without a blanket, i.e., a plutonium burner, emerges in the decade following the year 2010, and consumes the surplus plutonium from the LMFBR's.

The number of LMFBR's constructed prior to the year 2000 as a function of the LMFBR introduction date is shown in Table III F–5. As the table shows, the LMFBR—if introduced early—can contribute significantly toward meeting the demand for energy in the U.S. in the year 2000. If introduced in 1987, the LMFBR could supply 1.9 trillion kwhr of electricity, and could also reduce the rate of consumption of depletable fuel supplies by 16 quads*/year in the year 2000. An energy source, as defined in A National Plan for Energy Research, Development, and Demonstration,[41] will have a moderate



U.S. NUCLEAR POWER GROWTH PATTERN
REFERENCE CASE - 1993 LMFBR

FIGURE III F-10

impact if it can supply between 0 and 4.5 quads/year in the year 2000. Likewise, an energy source will have a substantial impact if it can supply between 4.5 and 9.0 quads/year in the year 2000, and it will have a major impact if it can supply more than 9.0 quads/year. Thus, the LMFBR—if introduced early—would have a major impact on the U.S. energy situation in the year 2000.

TABLE III F-5.—ENERGY CONTRIBUTION OF THE LMFBR IN THE YEAR 2000

	Introduction Date		
	1987	1993	2000
LMFBR installed capacity in 2000—Gigawatt electrical	308	76	0
LMFBR fraction of installed nuclear capacity in 2000	.34	.08	0
Electrical energy production rate by LMFBR's in 2000 (10^{12} kWh)	1.9	.5	0
Thermal energy production rate by LMFBR's in 2000 (quads per year)*	16	4	0

*A quad is equal to 10^{15} Btu's.

Also, as in the PFES LMFBR cost-benefit study, calculations were made to test the combined effects of coincident changing of two or more of the following major parameters; energy demand projection, LMFBR capital cost differential, LMFBR introduction date and uranium price projections.

Introduction of the breeder in year 1987 results in only one case where the discounted benefits are below estimated development costs. This occurs at the 10 percent discount rate when the uranium price projections are low, the energy demand is low, and the LMFBR capital cost is high. The 10 percent discounted benefits for this case are about 1 billion less than the projected discounted development costs. However, at a 7.5 percent discount rate the breeder benefits for this case are about twice the discounted projected breeder development costs. For the combination of high uranium prices, high energy demand projection and base LMFBR costs the breeder benefits are about $150 billion. Breeder benefits are many times breeder development costs for most cases.

When the breeder is introduced in 1993, there are a few cases where the benefits are about equal to the development costs and they are associated with high capital costs and low energy demand, using the 7.5 percent discount rate. The cases with either base assumptions or with conditions that induce greater breeder benefits than with the base assumptions have discounted breeder benefits that are many times the discounted development costs. The discounted breeder benefits range up to about $98 billion. At the 10 percent discount rate the discounted breeder benefits are less than the discounted breeder development costs when the energy demand projection is low and the LMFBR capital cost is high.

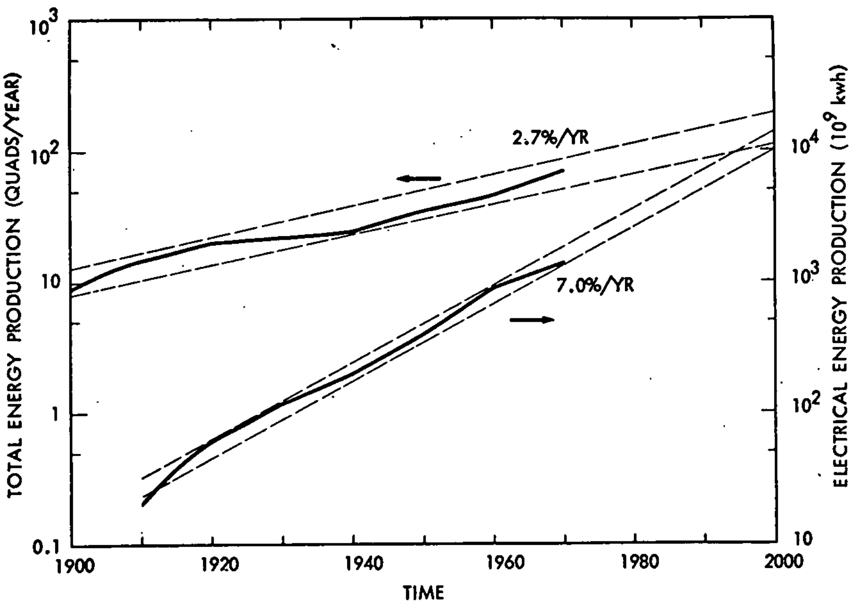
It is only with introduction of the breeder in the year 2000 that there are cases where the breeder benefits are much less than development costs at a discount rate of 7.5 percent. It again requires the energy demand projection to be low and the LMFBR capital costs to be high. The benefits are less than development costs for both the base and low uranium price projections. Due to the late introduction of the breeder the difference in uranium consumption between the breeder and no breeder cases has decreased considerably, hence, the breeder benefits are much less sensitive to uranium price projections. At the 10 percent discount rate the net benefits for year 2000 introduction are negative for five of the eighteen cases reported. One case is associated with base LMFBR capital costs and low energy demand projections. The other cases are all associated with high LMFBR capital costs and either low energy demand and low uranium price projections. Even with a year 2000 LMFBR there are many cases where the discounted benefits are many times the discounted breeder development costs. The benefits range up to about $57 billion and for base assumptions (other than year of introduction) they are $32 billion and $12 billion for 7.5 percent and 10 percent discount rates respectively.

Since the publication of the PFES there has been a large increase in the market place price for uranium and there is no indication of a leveling off in uranium prices. Prices of $25 to $40 per pound of U_3O_8 are the most recent (Oct. 1975) quotes for near term deliveries. These prices are not attained in the base projection of uranium prices in this revised study until after the turn of the century and only shortly before the turn of the century for the high uranium price projection. Hence, if uranium prices were adjusted to more accurately reflect todays uranium prices the benefits would improve for all cases.

3. The U.S. Energy Situation

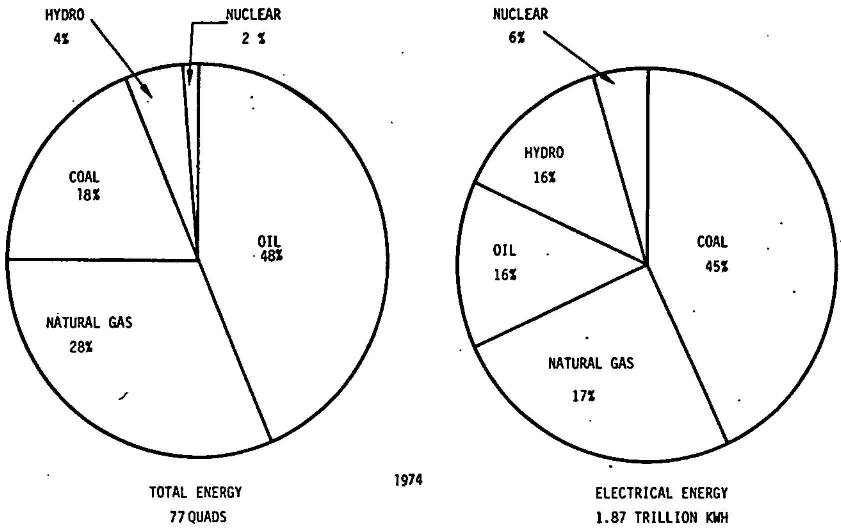
Let us first consider the historical energy production trends in the U.S., as shown in Figure III F–11. It can be seen that total U.S. energy production has grown at the remarkably constant rate of about 2.7 percent per year over the past 75 years. Likewise, electrical energy production has grown at the remarkably constant rate of about 7.0 percent per year over the past 55 years. The fact that electrical enegy is growing at over twice the rate of total energy is due simply to the substitution of one form of energy for another. The means by which this energy was produced, i.e., the production by primary source, is shown in Figure III F–12. As the figure shows, natural gas and oil energy in the U.S. in 1974.

A question of vital importance to the nation is whether the resource base in the U.S. is adequate to maintain this distribution of production in the future. The estimated fuel resource base available in the U.S. for future energy production is shown in Figure III F–13. The resource base, in this case, was defined as the quantity of energy available at three to four times current prices. Since this analysis is oriented toward long-range energy system forecasting, suppose the size of any resource is measured by the following criterion: a resource will be considered large if it is capable of meeting the U.S. energy requirement to the year 2000 by itself; otherwise, it will be considered small. Assuming a continuation of the 2.7 percent per year growth rate for total energy



HISTORICAL ENERGY PRODUCTION RATES IN THE U.S.

FIGURE III F–11



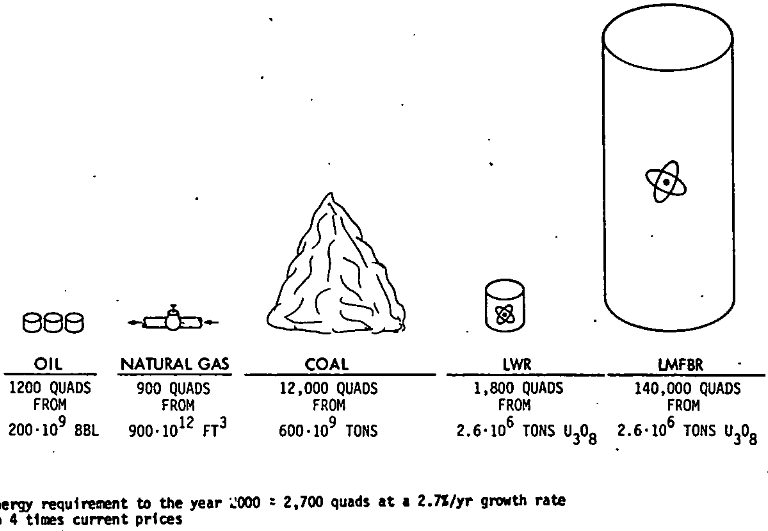
APPROXIMATE U.S. ENERGY PRODUCTION RATES BY PRIMARY SOURCE

FIGURE III F–12

the U.S. will consume 2700 quads between 1975 and the year 2000. If the growth rate were reduced to zero in the next few years, the U.S. would still consume about 1900 quads over the same time span. With either assumption, Figure III F–13 shows that the supply of oil and natural gas is small. The amount of coal is large, provided the coal-bearing regions in the western states are strip-mined. Although the amount of energy available from the Light Water Reactor (LWR) is small, the amount of energy available from the LMFBR is very large. Furthermore, the energy available from the LMFBR exceeds the amount required to take the U.S. to the year 2000 by a factor of about 50.

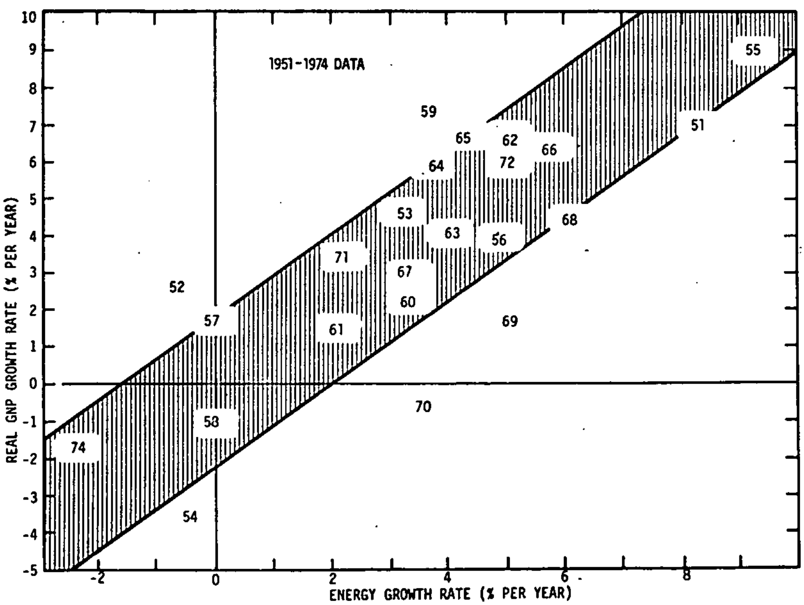
It is important for energy resource planning that the resource base available for the production of electricity, i.e., coal and uranium, is large, while the resource base available for the production of liquid fuel, i.e., oil, is small. As a consequence, oil should be conserved in the future for those applications for which it is uniquely suited, while electrical energy produced by coal and uranium should be substituted for energy produced by oil wherever possible. Thus, the growth rate for electrical energy may not diminish in the future; in fact, it may increase.

The importance of maintaining an adequate supply of energy at a reasonable price should not be underestimated. Energy is as important to an industrial society as any of the classical economic inputs such as land, labor, and capital. In fact, energy production, economic growth, and employment are closely coupled, as Figures III F–14 and III F–15 show. Figure III F–14 shows the relationship which has existed historically between the growth rate of energy and the real growth rate



RESOURCE BASE* AVAILABLE TO U.S.

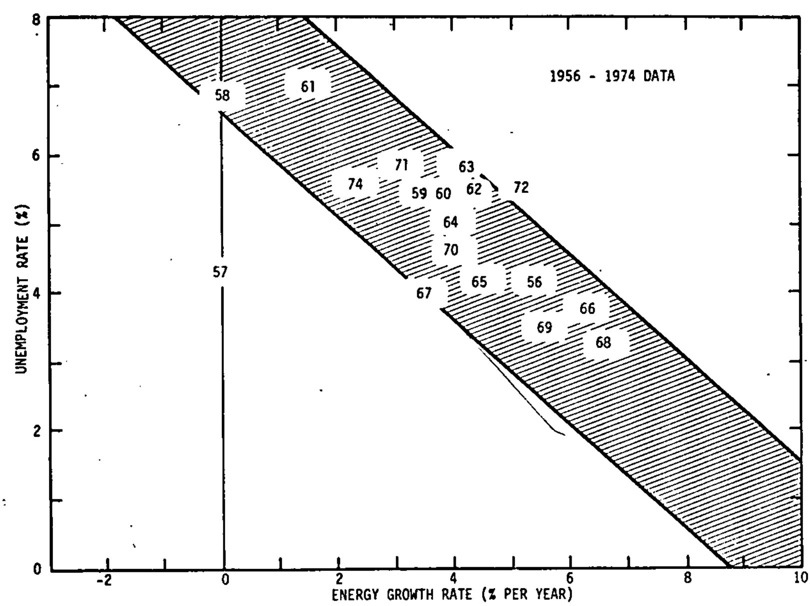
FIGURE III F-13



RELATIONSHIP BETWEEN ANNUAL CHANGES IN ENERGY USE AND GNP

FIGURE III F-14

of the Gross National Product (GNP).[14-16] The growth rate, i.e., the fractional change from year to year, has been plotted rather than the absolute magnitude of either energy consumption or GNP. This is because we are interested in the effect of a change in one variable upon a change in the other, rather than in a series of quasi-equilibrium states. Note that high energy growth rates are correlated with high GNP growth rates, and conversely. Since the rate of unemployment can be related to changes in the GNP, one might expect to find a correlation between the energy growth rate and the unemployment rate. Such a correlation does in fact exist, and it is shown in Figure III F–15.[16, 17] Note that high energy growth rates are correlated with low unemployment rates in this country, and conversely. While the precise cause and effect between energy, GNP, and unemployment changes may not be known, it is also clear that a severe and rapid reduction in the energy growth could imply a severe economic dislocation.



RELATIONSHIP BETWEEN ANNUAL CHANGES IN ENERGY USE AND UNEMPLOYMENT

FIGURE III F–15

4. The Status of the LMFBR

Contrary to the thrust of the arguments of some commentors, the Liquid Metal Fast Breeder Reactor is not an embryonic technology with a high degree of uncertainty. The basic principles were developed in the earliest days of nuclear power. The technical feasibility was first proven in the U.S. nearly 25 years ago with the operation of EBR–I, while EBR–II has been operating successfully for 12 years. Furthermore, large LMFBR power plants are under construction or in varying stages of design in Great Britain, France, Germany, U.S.S.R., Japan, and the U.S.—i.e., in the major industrial nations of the world. The status of the principal LMFBR projects in these countries is shown in Table III F–6. It is evident from this table that technical feasibility is not the problem; the goal of the major industrial nations is obviously to construct and operate large power plants. For this reason, the LMFBR should not be confused with power sources such as solar and fusion, which are in an earlier stage of development.

TABLE III F–6.—STATUS OF MAJOR LMFBR PROJECTS

Country	Name	Approximate power (MWt)	Approximate power (MWe)	Status
U.S.S.R.	BN–350	1,000	[1] 150	Criticality achieved in 1972.
	BN–600	1,470	600	Construction is almost finished.
	BN–1500	3,750	1,500	Currently being designed.
France	Phenix	563	250	Reached full power Mar. 13, 1974.
	Super Phenix	3,000	1,200	Construction scheduled to begin in 1975.
Great Britain	PFR	559	248	Criticality achieved in 1974.
	CFF	2,900	1,160	Construction may begin about 1978.
Germany	SNR–300	736	282	Commercial operation scheduled for 1979.
	SNR–2	3,000	1,200	Early stages of design.
Japan	Monju	714	300	Target criticality date is 1980.
United States	FTR	400		Scheduled for completion in 1978.
	CRBR	975	350	Scheduled for completion in 1983.

[1] Plus process.

5. *Model Characteristics, Input Data, and Assumptions*

The model used to analyze the nuclear energy economy is based on the mathematical technique of linear programming. This is an established technique, and is often used to analyze enconomic [19, 20] and energy system forecasting problems.[2, 12, 21–24] The model functions as follows. Within the model, power plants compete with each other for a share of the market based on their capital cost, fuel cost, and fuel supply. The model utilitizes this competition to select a growth pattern which minimizes the total energy cost over the planning horizon. This technique has the advantage of always producing growth patterns consistent with the cost assumptions. The basic tenet of this model is that the utilities are sufficiently informed so as to always distinguish the power plant with the lowest total power cost, and that the vendors are sufficiently competitive so that the plant with the lowest cost will always sell for the lowest price. Thus, the minimum cost neuclear industry growth pattern is developed, and any deviation from this pattern will result in higher nuclear energy costs.

All analysis in this report was performed in constant dollars. Thus, the calculated changes in energy costs are real—i.e., in addition to general movements in wages and prices.

A. *The discount rate.*—Dollar benefits obtainable from the LMFBR are quoted at two discount rates: 7.5 percent and 10 percent. The discount rate which should be employed in a long-range energ forecasting study has been in dispute. Manne[2] and Stauffer[3] have advocated lower discount rates, while Cochran [5] and Rice [11] have advocated higher discount rates. Since the results of any long range forecasting study are quite sensitive to the discount rate, a discussion of the subject is appropriate.

Some economists [3] are of the opinion that the discount rate employed in energy forecasting studies theoretically should be that rate which measures the time preference of society. That is, it should reflect the degree to which society favors a return today over a return in the future. The use of such a rate would characterize the optimal growth path for the economy, i.e., society would be exactly compensated for the act of saving. Given perfect capital markets, it has been shown that the return on private capital will equal the return on long-term government bonds, and both will equal the rate of social time preference—i.e., the willingness of society to save.[22] However, such things as large government investments in money markets, the inability of economic units to borrow and loan at identical rates, and the corporate income tax, all render capital markets imperfect. Because of this, government bond rates will tend to be lower than the opportunity cost of money, and likewise the return on private capital will tend to be higher.

In spite of the difficulty, there has been some attempt to determine a discount rate for public investments. Stockfish, in an attempt to measure the opportunity cost of government investment, found the before-tax average return on private capital to be 12 percent.[23] After discounting for inflation, he obtained 10.4 percent.

The return on long-term government bonds forms the minimum lower bound for the correct discount rate. This is currently about 6.5 percent, and when discounted for inflation, a value of 4.0 percent is obtained. It has been suggested that public investments be evaluated with a discount rate equal to the average of the government and private returns.[24] Thus, following this suggestion, a discount rate of about 7 percent would be appropriate.

The optimum rate of growth requires that investment be undertaken at a rate such that the increased output, resulting from an additional dollar of investment in productive capacity, precisely equals the willingness of society to invest in such capacity. This is known as the marginal product of capital and is in essence the ideal discount rate. The studies discussed above are attempts to obtain a discount rate from the average product of capital. In general, because of diminishing returns to capital, the marginal product of capital is less than the average product. Hence, a discount rate calculated from the average product of capital will tend to be too high. Considering both the imperfection of capital markets and the difference between the average and marginal product of capital, it should be apparent that the correct discount rate is not truly measurable; it can only be estimated and a range established. The arguments outlined previously suggest a value of 7 percent with a range of 4 percent to 10.4 percent. The use of discount rates on the high side of this range will result in a level of saving less than that which society has revealed it prefers, while the use of rates on the low side would result in an excess of saving. Thus, the use of rates in the center of the range seems most appropriate. In this study, discount rates of 10 percent and 7.5 percent were used.

B. *Basic input data and assumptions.*—A forecasting study which evaluates a long-range energy development strategy requires estimates of future costs, demands, and availabilities. In this study, estimates were required for future electrical energy requirements, future uranium enrichment costs, U_3O_8 cost versus supply estimates, and future nuclear plant capital costs.

1. *Estimated electrical energy requirements.*—The current annual electrical energy demand in the U.S. is about 2.0 trillion kilowatt-hours, and the historical rate of increase has been about 7 percent per year for a period of 55 years. In this study, however, this trend was not assumed to continue—all estimates of future electrical energy requirements were based on a declining growth rate. Thus, the forecasts used in this study are in no way contingent upon a continuation of the long-term historical growth pattern.

The projected electrical energy growth patterns used in this analysis are shown in Tables III F–7 and III F–8. As the tables show, three basic growth patterns were assumed. The small energy growth pattern assumes an electric energy requirement of 7.0 trillion kilowatt-hours in the year 2000. This is based upon an assumed electrical energy growth rate of 5.3 percent per year in the first decade (1975 to 1985) and 2.6 percent per year in the last decade (2015 to 2205), with an average growth rate of 4.1 percent per year over the five decade interval. In the year 2000, nuclear plants supply about 53 percent of the electrical energy requirement, and the installed nuclear capacity is 625 Gwe. The reference energy growth pattern assumes an electrical energy requirement of about 8.1 trillion kilowatt-hours in the year 2000. This is based upon an assumed electrical energy growth rate of 5.9 percent per year in the first decade and 4.6 percent per year in the last decade, with an average growth rate of 5.2 percent per year over the five decade interval. In the year 2000, nuclear plants supply 67 percent of the electrical energy requirement, and the installed nuclear capacity is 900 Gwe. The large electrical energy growth pattern assumes an electrical energy requirement of 9.6 trillion kilowatt-hours in the year 2000. This is based on an assumed electrical energy growth rate of 6.7 percent per year in the first decade and 5.2 percent per year in the last decade, with an average growth rate of 5.9 percent per year over the five decade interval. In the year 2000, nuclear plants supply 79 percent of the electrical energy requirement, and the installed nuclear capacity is 1250 Gwe.

TABLE III F–7.—PROJECTED ELECTRICAL ENERGY REQUIREMENTS

[Energy in 10^{12} kwh, capacity in Gwe]

Energy requirement and production category	1975	1985	2000	2025
Small:				
Total electric energy	2.0	3.4	7.0	15.6
Nuclear electric energy	.2	1.0	3.7	9.8
Installed nuclear capacity	37.0	160.0	625.0	1,730.0
Reference:				
Total electric energy	2.0	3.6	8.1	27.5
Nuclear electric energy	.2	1.2	5.4	21.3
Installed nuclear capacity	39.0	195.0	900.0	3,700.0
Large:				
Total electric energy	2.0	3.9	9.6	37.6
Nuclear electric energy	.2	1.5	7.6	29.5
Installed nuclear capacity	43.0	245.0	1,250.0	5,140.0

TABLE III F-8.—PROJECTED ELECTRICAL ENERGY GROWTH RATES

Energy requirement	Growth rate (percent)		
	Initial, 1975–85	Final, 2015–25	Averzge, 1975–25
Small	5.3	2.6	4.1
Reference	5.9	4.6	5.2
Large	6.7	5.2	5.9

A number of studies in recent years have predicted electrical requirements in the year 2000 which range from a low value of about 2 trillion kilowatt-hours to a high value of about 10 trillion kilowatt-hours.[25–32] Note that the electrical energy requirement in the year 2000 in this study ranged from 7.0 to 9.6 trillion kilowatt-hours, and so our values fall within the established range. However, without exception, the other studies either assumed an increasing electrical energy price, or simply did not include price in their model. The model and some of the assumptions used in each of these studies are indicated in Table III F–9.

TABLE III F-9.—FORECASTS OF ELECTRICAL DEMAND

Source	Type	Annual GNP change (percent)	Annual electricity price change (percent)	Electricity demand in 2000 (trillion kilowatt hours)
1. Ford Foundation [22]:				
a. Historical (continuation of historical trends).	Input-output	+3.45	+0.81	7.96
b. Technical fix (historical, with improved efficiency).	do	+3.30	+4.50	7.60
c. Zero energy growth	do	+3.30	+5.60	3.40
2. Federal Energy Administration [12, 18] (extrapolation of recent trends).	Econometric	NA	NA	5.54
3. Dupree-West [26]	do	+4.1	NA	9.01
4. Chapman, Tyrrell & Mount [27–29]:				
a. Slowly rising energy prices	do	+4.0	+.63	3.45
b. Rapidly rising energy prices	do	+4.0	+3.33	2.01
5. Hudson-Jorgenson [30]	Input-output	+3.85	+3.5	6.98
6. Cornell [31]	Econometric	3.1	NA	10.25
7. HEDL [32]	do	*	**	9.5

NA—Not available.
*3.9 to 1990, 3.4 to thereafter.
**+1.0 to 1990, −1.0 thereafter.

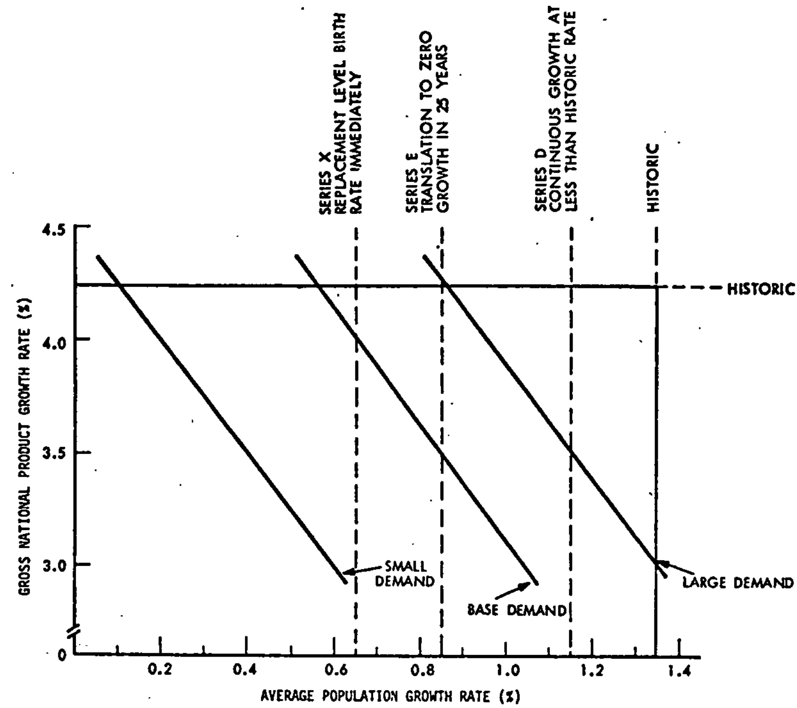
It is important to note that the LMFBR is a technological development which is capable of changing electrical energy production price patterns. This is simply because the LMFBR produces more fuel than it consumes, and so is capable of eliminating the dependence of the electrical energy economy upon depletable fuel supplies. The introduction of the LMFBR ultimately results in an abundant fuel supply and as was shown in Figure III F–8, falling nuclear electric power costs. Thus, the substitution of electric energy for other forms of energy becomes an important consideration in analyzing future electric energy requirements.

Using the nuclear power cost pattern obtained from our forecasting study, we have calculated future electric energy requirements. This was accomplished with an econometric model which estimated future electrical energy requirements by accounting for the real price of electricity, the real price of a substitute fuel, the change in the population, and the change in the GNP.[32] The elasticity of electrical energy demand with respect to each of these variables was computed using data from 1948 to 1974. An analysis of future energy demand was then made based on the following assumptions. First, the GNP will increase at a rate of 3.9 percent per year to 1990 and 3.4 percent per year thereafter, the population will increase at the rate of 1 percent per year to 1990 and 0.7 percent per year thereafter, the real price of a substitute fuel will increase at the rate of 4 percent per year to 1985 and 3 percent per year thereafter, and finally, the real price of electricity will increase at the rate of 1 percent per year to 1990 and will decrease at the rate of 1 percent per year thereafter. With these assumptions, none of which are unreasonable, the demand for electrical energy was found to be 9.5 trillion kilowatt-hours in the year 2000. Note that the 9.5 trillion kilowatt-hours corresponds quite closely to the large energy projection used in this study—implying that the reference energy projection should be considered to be conservative.

As the above discussion indicates, a projected electrical energy demand is inherently associated with a projected rate of change of population and GNP. Thus, the degree of conservatism in an electrical energy requirement can be assessed by comparing the associated population and GNP projections with the historical values. Such a comparison is shown in Figure III F–16. Four population growth rates are considered in this figure—in the nomenclature of the Census Bureau they are: Series X, E, D, and the historic rate.[33] Series X assumes that the birth rate falls to the replacement level immediately and remains there indefinitely. Series E assumes a transition toward a zero growth state in about 25 years. Series D assumes a continuous growth at a rate less than the historic rate. As the figure shows, if the Series X prediction were correct and the GNP were to increase at a rate of 4 percent per year, then the electrical energy requirement would be identical to the reference value used in this study. However, an increase in the GNP of 4 percent per year is less than the historic rate of 4.25 percent per year, and so the reference energy demand should be considered to be conservative.

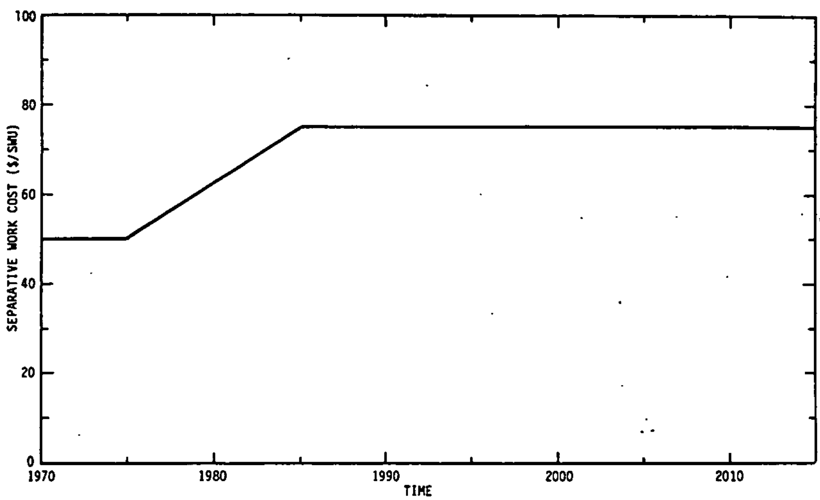
2. *Estimated uranium enrichment costs.*—The uranium enrichment costs used in the study are shown in Figure III F–17. The cost of enrichment was assumed to increase linearly from $50/SWU in 1975 to $75/SWU in 1985, and to remain constant at $75/SWU thereafter.

3. *U_3O_8 cost versus supply estimates.*—The estimates of the cost of U_3O_8 versus the cumulative supply used in this study are shown in Figure III F–18. Three estimates were used: small, reference, and large. The small estimate corresponds to approximately 2 million tons of U_3O_8 available at a cost less than $60 per pound, the reference estimate corresponds to approximately 4 million tons available at a cost less than $60 per pound, while the large estimate corresponds to approximately 6 million tons available at less than $60 per pound. The small estimate corresponds to approximately 2½ million tons of U_3O_8 available before the mining of shale is required, the reference estimate corresponds to approximately 4 million tons of U_3O_8 available prior to the mining of shale, while the large estimate corresponds to approximately 6 million tons of U_3O_8 available before shalle must be mined.



ESTIMATES OF ELECTRICAL ENERGY REQUIREMENT VERSUS POPULATION AND GNP GROWTH RATE

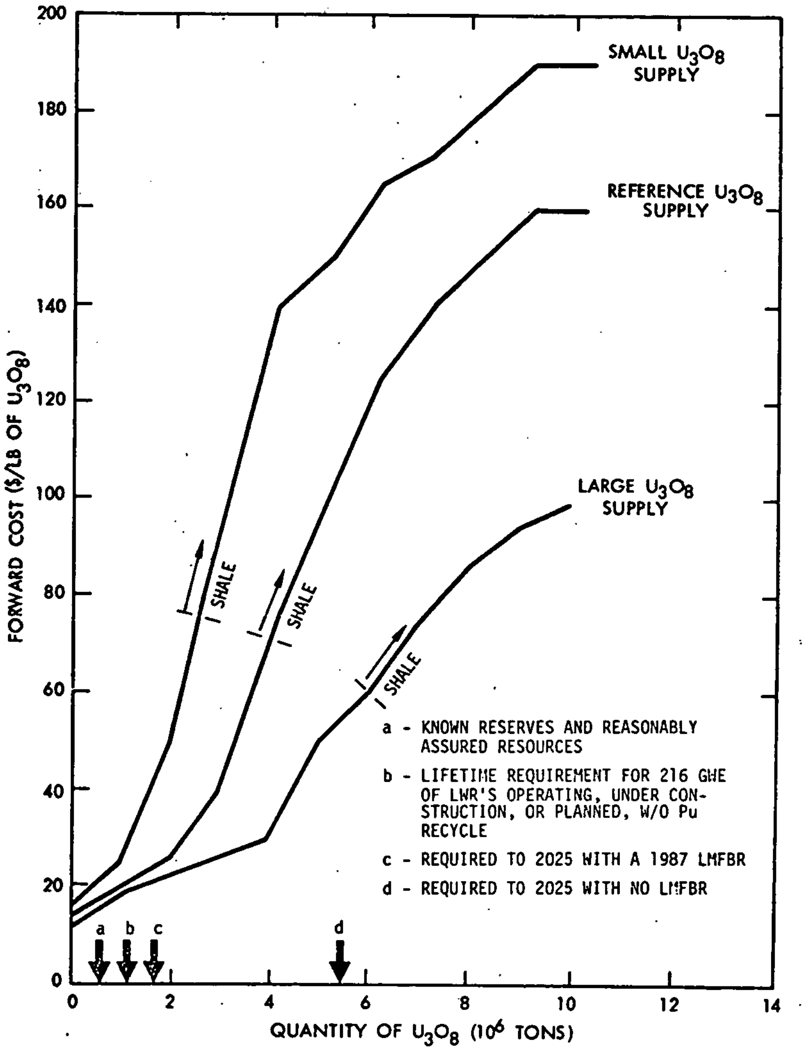
FIGURE III F–16



PROJECTED URANIUM ENRICHMENT COSTS

FIGURE III F–17

It should be noted that the U^3O^8 costs used in this study are substantially less than the prices currently being seen in the marketplace.[34] For example, the Washington Public Power Supply System recently (August 1975) purchased 5.5 million pounds of U_3O_8 at $22 per pound,[35] and other recent purchases have been at higher prices. The reference supply curve used in this study would predict a current price of $14 per pound. It should be also noted that low U_3O_8 price estimates will favor the converter reactors, and thereby induce conservatism into an LMFBR analysis.



U_3O_8 COST VERSUS SUPPLY ESTIMATES

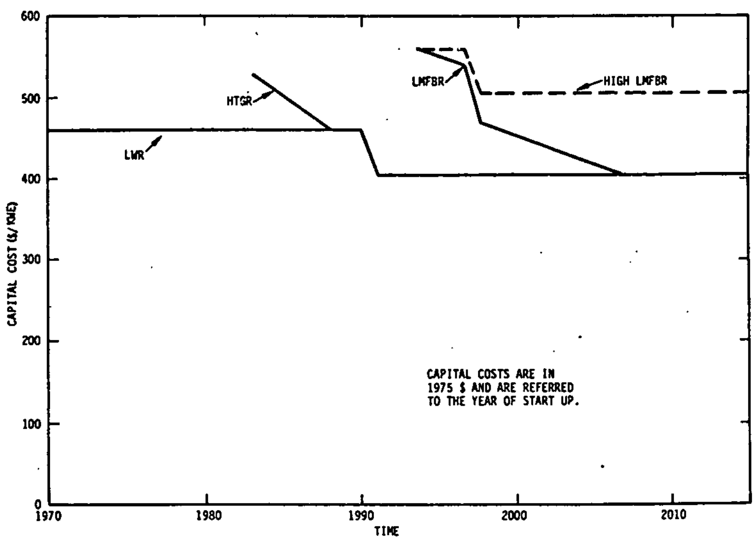
FIGURE III F-18

The adequacy of uranium resources is an important concern in assessing an energy development strategy. In view of this, two points should be noted. First, known reserves and reasonable assured resources, as indicated by point (a) in Figure III F–18, consist of about 0.6 million tons of U_3O_8.[36, 37] Secondly, the LWR's which are currently operating, under construction, or planned, have a total capacity of 216 Gwe, and these reactors will consume about 1.0 million tons of U_3O_8 during their 30-year operating life without plutonium recycle Thus, currently planned consumption without plutonium recycle exceeds known reserves and reasonably assured resources by about a factor of 1.5. Moreover, the U_3O_8 finding rate—expressed in pounds per foot of drilling—declined from 5 lb/ft in 1971 to about 1 lb/ft in 1974. Thus, larger exploration efforts in recent years have resulted in smaller additions to reserves.[37]

In this analysis, it was found that the nuclear industry—without the LMFBR but with plutonium recycle—will require 5.5 million tons of U_3O_8 prior to the year 2025. This assessment included the effect of increasing U_3O_8 prices on the relative competitive position of the LWR and HTGR. Thus, without the LMFBR, 90 percent of the U_3O_8 required to the year 2025 remains to be found. If the LMFBR were introduced in 1987, the nuclear industry would require approximately 1.8 million tons of U_3O_8 prior to 2025, and only negligible quantities after that date. Hence, the LMFBR—when introduced early—substantially reduces the risk associated with an uncertain U_3O_8 supply.

Finally, while the curves of U_3O_8 cost versus quantity may appear to be quite precise, it is important to note that they are simply estimates. Most of the U_3O_8 shown in Figure III F–18 has yet to be discovered.

4. *Nuclear plant capital costs.*—The nuclear power plant capital costs used in this study are shown in Figure III F–19. The costs are in 1975 dollars and are referred to the year of start-up.



PROJECTED NUCLEAR PLANT CAPITAL COSTS

FIGURE III F–19

The capital cost of an LWR was assumed to be $460/kwe prior to 1990, and $405/kwe after that date. A plant size change from 1300 Mwe to 2000 Mwe was assumed to occur in 1990, and the capital cost change was produced simply by this size change.

The LMFBR was introduced in 1993 at a cost of $560/kwe, i.e., $155/kwe above the LWR. Thus, at introduction, the LMFBR was assumed to cost 38 percent more than the LWR. The differential between the two plants was assumed to decrease to zero by the year 2006 via the economies of scale associated with a size change, and also via the classical learning effect. A decrease of $100/kwe was associated with the learning process, i.e., the construction of similar plants in a repetitive manner which increases efficiency and reduces unit costs. A variation in which the LMFBR capital cost was assumed to always be at least $100/kwe above the LWR was also considered.

The HTGR was introduced in 1983 at a capital cost $65/kwe higher than the LWR. This differential was assumed to decrease to zero in 6 years due to the learning effect.

The basis for the capital cost projections, in particular cost differentials between the power plant types, is provided in Section 11.2.3.8.1 of the PFES. However, due to the sensitivity of the benefits to capital cost differentials it was decided it was appropriate to summarize in the following paragraphs the information in this section.

Examination of LWR cost trends indicate that the price of the nuclear steam system has remained relatively constant over the past several years, exclusive of escalation. This has occurred in spite of the cost additions resulting from increased environmental and safety concerns. Thus, it is concluded that the effects of learning and scale of industry operations in the manufacture of nuclear components have led to reductions in some areas of LWR plant costs. These reductions have, unfortunately, been offset by even larger cost increases arising from environmental and safety-related requirements, which increased the scope of work involved in plant construction. In addition, general inflationary cost trends have led to increasing current-dollar costs. The continuation of these LWR trends into the future is uncertain. However, the LWR industry is considered to have reached a relatively mature level. Current LWR cost estimates include all presently implemented environmental and safety requirements and reflect experience gained during the construction of about 37,500 NWe of nuclear capacity as of October 1, 1975. In addition, it is anticipated that future changes required for LWR plants will affect other nuclear plants in a similar manner, and some changes (e.g., thermal discharge limits) would also affect fossil plant costs.

For purposes of the cost-benefit study, it was assumed that any effects from continuing learning or design changes would make little change in the relative cost of LWR plants. It is recognized that the absolute costs of LWR plants may increase or decrease in the future, due to escalation and the changing requirements discussed above. However, this assumption states the belief that those undefined changes will not alter the cost position of the LWR relative to other plant types. Therefore, to provide a reference cost base, the projected LWR capital costs were based on zero learning beyond the plants being ordered for operation in 1981. Capital costs for the other plant types were estimated relative to this reference base.

The estimate of a decrease of about $100/KWe in the differential between LWR and LMFBR capital costs due to learning is considered to represent a conservative viewpoint. This learning takes place over a thirteen year period during which 241 units are placed in operation. The learning curve applicable to the LMFBR in this period results in a learning factor of about 95 percent. Thus, the learning curve assumed for the LMFBR is extremely conservative in comparsion with typical values of 80 to 90 percent learning curves applicable to many industries. This conservative approach is acceptable, since the learning curve being used here applies to reductions in the cost differential for the LMFBR, and not to the total cost change.

In considering all factors and utilizing the expertise in the area of cost estimating developed at HNL/ORNL with some assistance from reactor manufacturers and an architect-engineer, it is the position of ERDA for this study that:

(1) The LWR capital costs (in 1975 dollars) will remain fairly constant in the period 1975 to 2020 for units of equal size and siting conditions.

(2) The HTGR capital costs will be rather close to the LWR costs.

(3) The LMFBR costs will show some reduction due to learning starting with its introduction and at a rate which is reasonable in terms of the number of units produced.

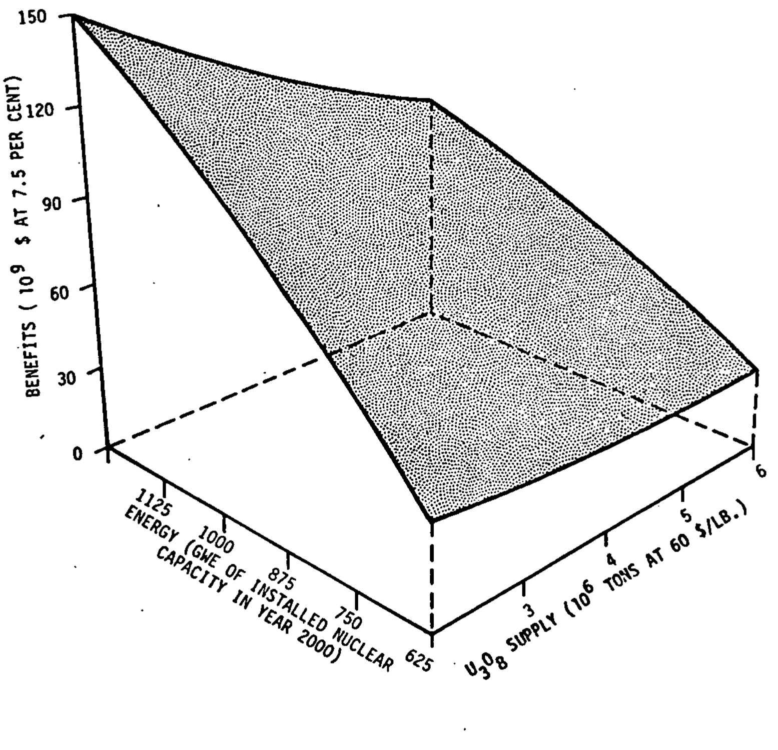
6. Results

The role of the LMFBR in the nuclear energy economy has been extensively studied utilizing an analytical forecasting model. The principal variables in the analysis were: the energy demand, the U_3O_8 price, the LMFBR capital cost, and the LMFBR introduction date. The introduction of an advanced power source with a zero fuel cost, such as a solar or fusion source, might be considered a fifth variable. The effect of changes in each of these five variables will be discussed in turn.

A total of 65 cases were analyzed; the results of 63 of these cases in which the energy demand, U_3O_8 supply, LMFBR introduction date, and LMFBR capital cost were varied, both individually and in combination, are summarized in Table III F–10. The other two cases consider the impact of advanced power sources. In each case, the amount of U_3O_8 consumed to 2025, the U_3O_8 price in 2025, the maximum separative work capacity required prior to 2025, and the dollar benefit associated with the LMFBR are shown.

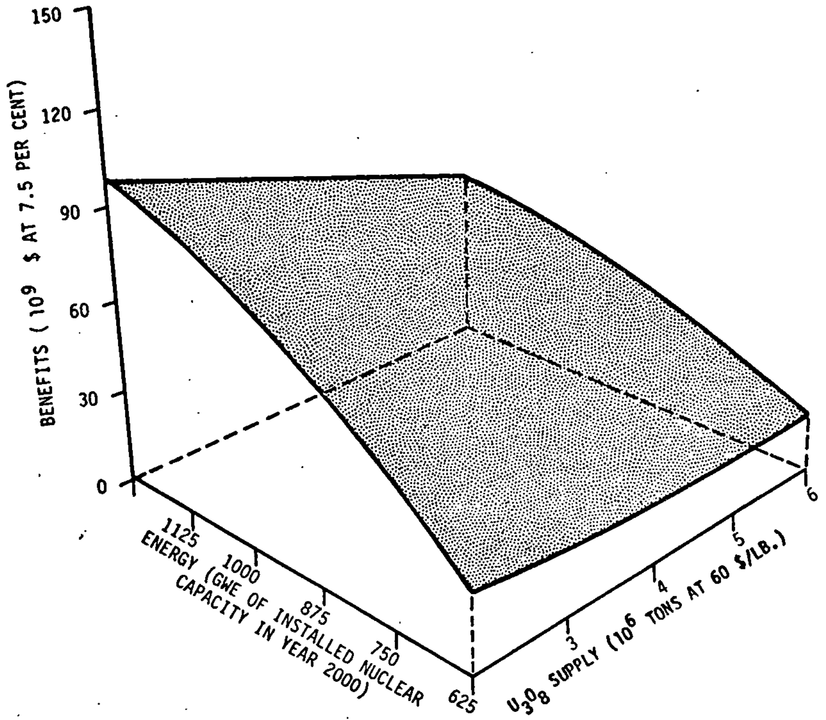
The benefit was calculated at two discount rates: 7.5 percent and 10 percent. The 63 cases tabulated in Table III F–10 are not equally probable. The basic data for the reference case, i.e., 4 million tons of U_3O_8 at $60 per pound, 900 GWe of installed nuclear capacity in the year 2000, an LMFBR capital cost initially at $155/kwe above the LWR and decreasing to parity in 13 years, was developed during the course of an extensive study and should be considered as defining the most probable case. However, since this data is not known with complete certainty, a variation in any one of these variables from the reference value is of definite interest. Multiple variations, i.e., doublet and triplet variations, are also of interest.

The same results are displayed in a more elegant fashion in Figures III F–20 through III F–28. Figure III F–20 shows the benefits as a function of the energy demand and the U_3O_8 supply for a 1987 LMFBR introduction. The benefits range from 150 billion dollars with a large energy demand and small ore supply to 29 billion dollars with a small energy demand and large ore supply. In all cases, the benefits are substantially greater than the development cost. Note that the benefits are not very sensitive to the ore supply when the energy demand is low. This is because the amount of ore consumed with a small energy requirement is small. The benefits are more sensitive to the ore supply when the energy demand is high, but in this case, the sensitivity is inconsequential since the benefits are always large. Figure III F–21 shows the benefit as a function of energy demand and ore supply for a 1993 LMFBR introduction. The benefits range from 98 billion dollars to 19 billion dollars, depending upon the ore supply and energy demand.



LMFBR BENEFITS VERSUS ENERGY DEMAND AND U_3O_8 SUPPLY FOR A 1987 INTRODUCTION

FIGURE III F–20



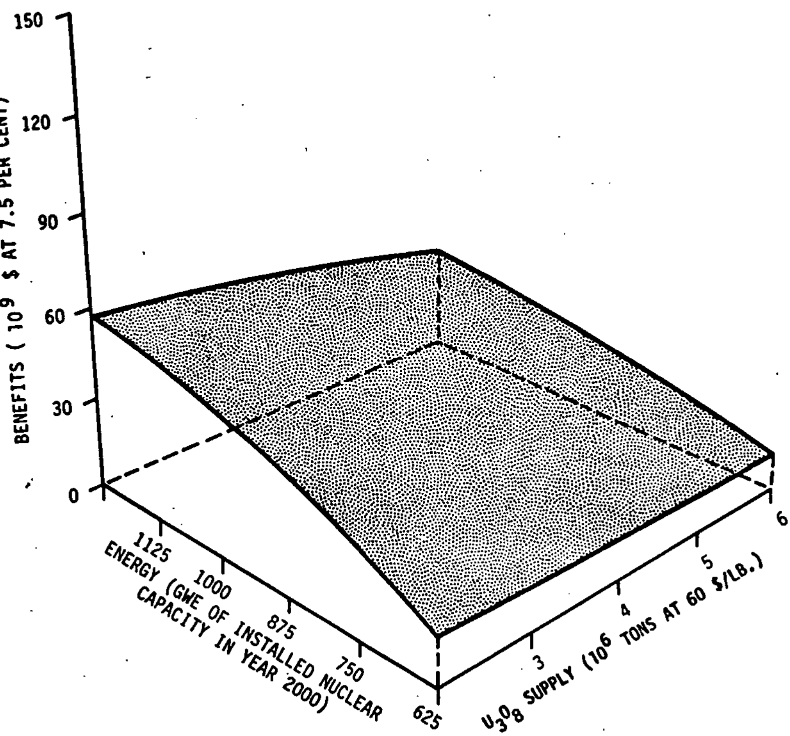
LMFBR BENEFITS VERSUS ENERGY DEMAND AND U_3O_8 SUPPLY FOR A 1993 INTRODUCTION

FIGURE III F–21

TABLE III F-10.—LMFBR FORECASTING RESULTS

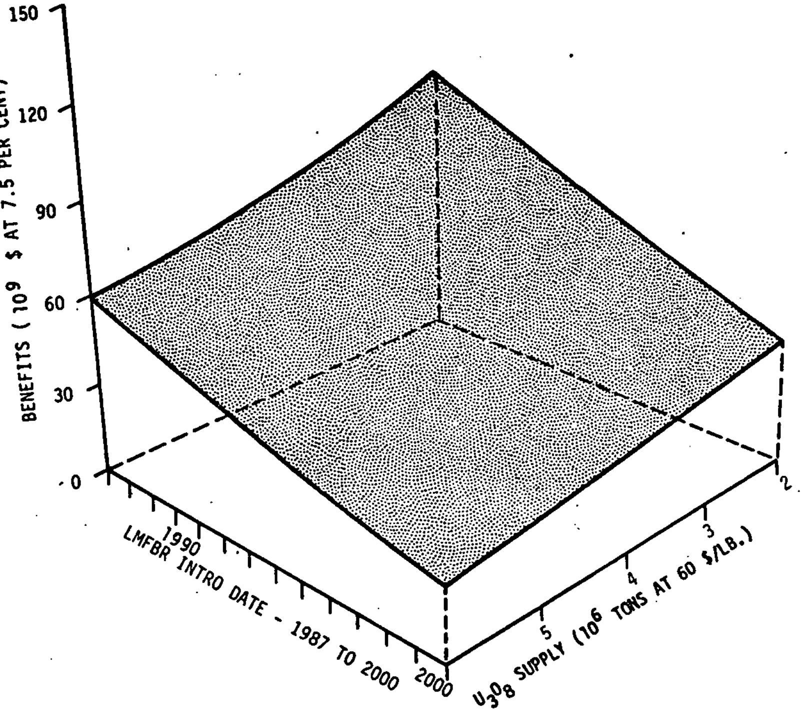
Case	LMBFR introduction date	U_3O_8 supply (10^6 tons of U_3O_8 available at 60 $/#)	Energy demand (Gwe of installed nuclear capacity in year 2000)	LMFBR capital cost	U_3O_8 in 2025		Maximum separative work (10^6 SWU/yr)	Benefit (10^9 $ @ 7.5%)	Benefit (10^9 $ @ 10%)
					Quantity (10^6 tons)	Price ($/#)			
1	None	4	900	Base	5. 5	100	263		
2	1987	4	900	Base	1. 8	25	45	72	28
3	1993	4	900	Base	3. 0	40	73	52	19
4	2000	4	900	Base	3. 7	58	116	32	12
5	None	4	625	Base	3. 0	40	115		
6	1987	4	625	Base	1. 2	20	30	31	13
7	1993	4	625	Base	2. 0	25	48	20	8
8	2000	4	625	Base	2. 3	27	60	13	5
9	None.	4	1, 250	Base	7. 5	140	365		
10	1987	4	1, 250	Base	2. 5	32	63	113	45
11	1993	4	1, 250	Base	4. 0	75	113	78	28
12	2000	4	1, 250	Base	5. 1	100	166	48	16
13	None	2	900	Base	5. 5	150	265		
14	1987	2	900	Base	1. 8	50	45	94	37
15	1993	2	900	Base	2. 5	75	73	68	25
16	2000	2	900	Base	3. 7	120	116	41	15
17	None	2	625	Base	3. 0	98	115		
18	1987	2	625	Base	1. 2	25	30	37	15
19	1993	2	625	Base	2. 0	50	45	25	9
20	2000	2	625	Base	2. 2	50	62	16	5
21	None	2	1, 250	Base	7. 0	170	368		
22	1987	2	1, 250	Base	2. 5	75	63	149	59
23	1993	2	1, 250	Base	4. 0	140	113	98	37
24	2000	2	1, 250	Base	5. 1	150	162	57	19
25	None	6	900	Base	5. 5	50	263		
26	1987	6	900	Base	1. 8	22	45	59	24
27	1993	6	900	Base	3. 0	25	73	41	17
28	2000	6	900	Base	3. 9	30	113	24	9
29	None	6	625	Base	3. 1	25	115		
30	1987	6	625	Base	1. 2	18	30	29	11
31	1993	6	625	Base	2. 0	22	45	19	8
32	2000	6	625	Base	2. 4	24	59	12	4
33	None	6	1. 250	Base	7. 0	74	365		
34	1987	6	1, 250	Base	2. 5	23	63	86	36
35	1993	6	1, 250	Base	4. 0	30	10	58	20
36	2000	6	1, 250	Base	5. 2	50	162	35	12
37	1987	4	900	High	1. 8	25	47	32	13
38	1993	4	900	High	2. 8	40	75	24	9
39	2000	4	900	High	3. 9	73	116	14	5
40	1987	4	625	High	1. 3	22	34	11	5
41	1993	4	625	High	2. 0	25	50	5	2
42	2000	4	625	High	2. 4	32	64	3	1
43	1987	4	1, 250	High	2. 5	32	65	60	24
44	1993	4	1, 250	High	4. 0	75	115	43	17
45	2000	4	1, 250	High	5. 4	100	166	25	9
46	1987	2	900	High	1. 8	50	45	55	22
47	1993	2	900	High	2. 7	75	75	40	15
48	2000	2	900	High	3. 8	130	116	23	8
49	1987	2	625	High	1. 9	22	50	17	7
50	1993	2	625	High	3. 0	25	70	10	4
51	2000	2	625	High	2. 2	50	62	6	2
52	1987	2	1, 250	High	2. 5	75	64	96	38
53	1993	2	1, 250	High	4. 0	140	112	62	23
54	2000	2	1, 250	High	5. 4	150	163	33	12
55	1987	6	900	High	1. 9	22	50	20	9
56	1993	6	900	High	3. 0	25	70	13	6
57	2000	6	900	High	4. 1	30	115	6	3
58	1987	6	625	High	1. 4	20	34	10	4
59	1993	6	625	High	2. 1	22	48	5	2
60	2000	6	625	High	2. 6	23	64	3	1
61	1987	6	1, 250	High	2. 5	23	65	35	14
62	1993	6	1, 250	High	4. 4	30	113	22	9
63	2000	6	1, 250	High	5. 5	50	163	12	5

Again, the benefits are always significantly greater than the development cost. Similar results are shown in Figure III F–22 for a year 2000 introduction. Note that the benefits are very sensitive to the introduction date, and since the benefits are simply the discounted reduction in total power cost, a delay of the LMFBR will substantially increase electrical power costs. Thus, the argument that delaying the LMFBR will not reduce benefits nor increase power costs [5,11] is simply incorrect. The delay effect is illustrated more explicitly in Figures III F–23 and III F–24, where the benefits are plotted first as a function of the introduction date and the ore supply, and secondly as a function of the introduction date and the energy demand. In each case, delaying the LMFBR from 1987 to 2000 reduces the benefits by a factor of two to three.



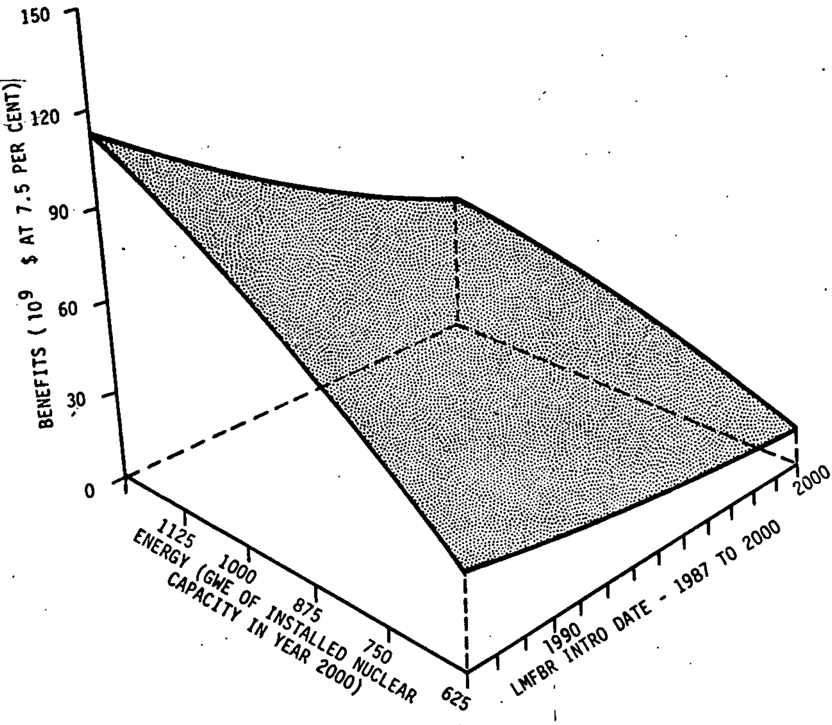
LMFBR BENEFITS VERSUS ENERGY DEMAND AND U_3O_8 SUPPLY FOR A 2000 INTRODUCTION

FIGURE III F–22



LMFBR BENEFITS VERSUS INTRODUCTION DATE AND U_3O_8 SUPPLY
FOR THE REFERENCE ENERGY REQUIREMENT

FIGURE III F–23

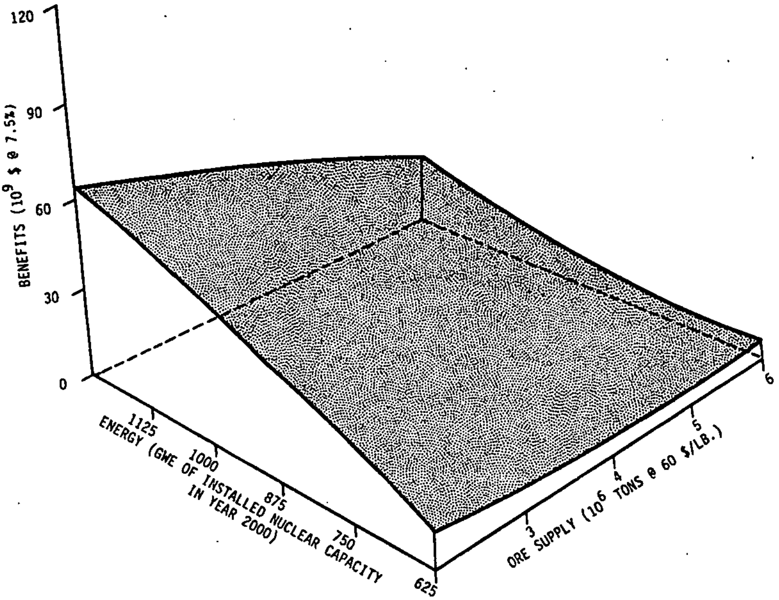


LMFBR BENEFITS VERSUS ENERGY DEMAND AND INTRODUCTION DATE FOR THE REFERENCE ORE SUPPLY

FIGURE III F–24

The effect of a high LMFBR capital cost upon the benefit for a breeder introduced in year 2000 is shown in Figure III F–25. Even with a high capital cost, the LMFBR benefit exceeds the development cost except for situations where the energy demand is low and the uranium supply is based and large. In the case of a large energy demand or a small ore supply, the benefit exceeds the development cost by a substantial margin.

The average nuclear power cost in the U.S. as a function of time and the associated nuclear industry growth pattern is shown for selected cases in Figures III F–26 through III F–31. Recall that Figure III F–8 showed the total power cost with a reference ore supply, energy demand, and capital cost. Also recall that Figure III F–10 showed the growth pattern associated with this case. Note that the LMFBR has the ability to reduce the total nuclear power cost by about 5 mills/kwhr(e) in the year 2020, and nuclear power costs without the LMFBR are 50 percent higher than with the LMFBR. A reduction of 5 mills/kwhr(e) in the total nuclear power cost in the year 2020 corresponds to a reduction in the cost of electricity of 85 billion dollars per year. This cost reduction occurs because the nuclear economy with

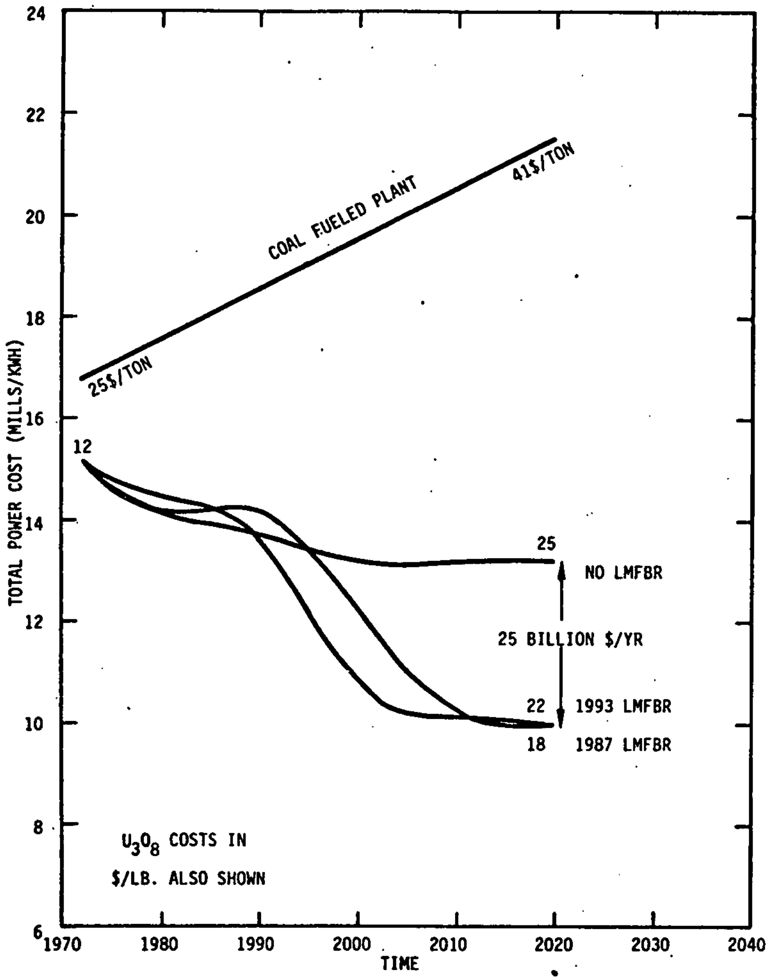


LMFBR BENEFITS IN THE CASE OF A HIGH LMFBR CAPITAL COST

FIGURE III F–25

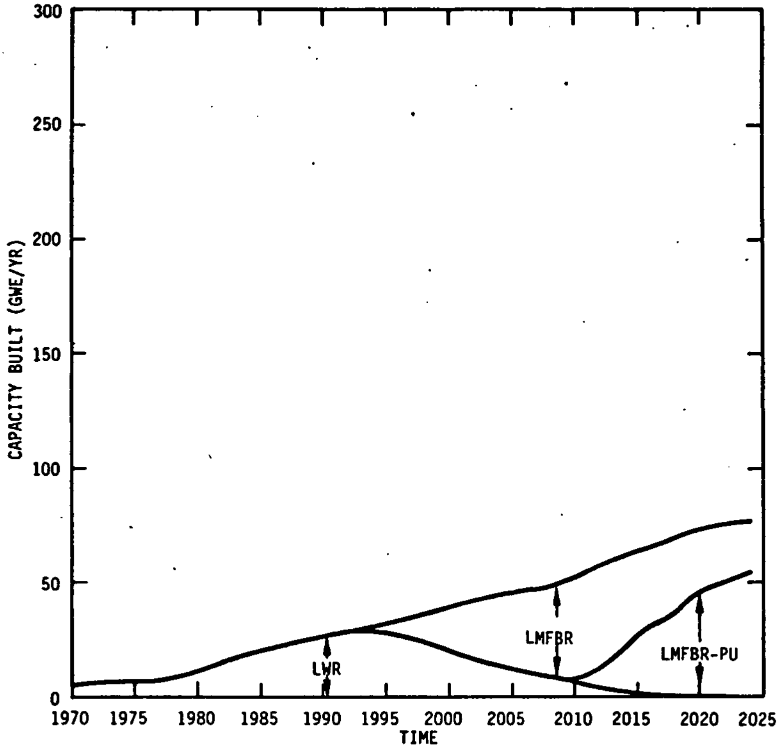
the LMFBR has the benefit of an increasing fuel supply, while the nuclear economy without the LMFBR must depend upon a diminishing fuel supply.

Consider next a case which is pessimistic insofar as the LMFBR is concerned, i.e., the case of a large uranium supply and small energy demand. The time dependence of the total power cost for this case is shown in Figure III F–26 and the associated growth pattern is shown in Figure III F–27. In this event, the LMFBR still has the ability to reduce the tgtal nuclear power cost by about 3 mills/kwhr(e) in the year 2020. This reduction corresponds to a savings of about 25 billion dollars/year in that year. Note that an LWR–HTGR economy is capable of stabilizing the nuclear power cost, whereas the LMFBR with its increasing fuel supply, is capable of reducing it. Thus, even in the case where the LMFBR is not necessarily needed, it still reduces nuclear power costs by a substantial margin.



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
LARGE URANIUM SUPPLY AND SMALL ENERGY DEMAND

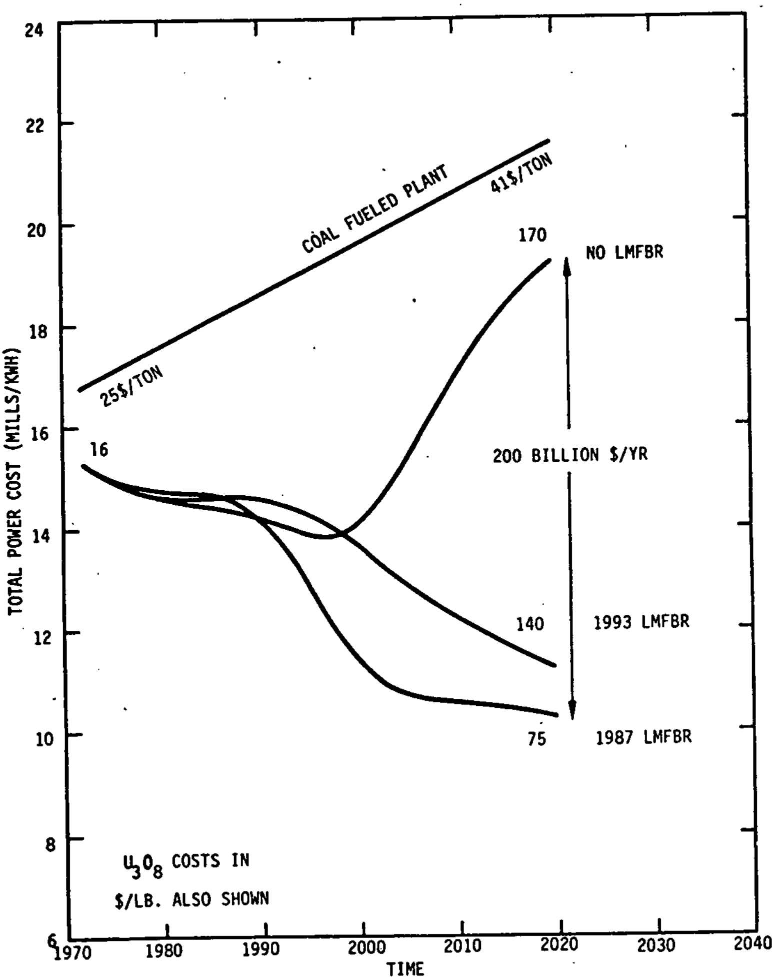
FIGURE III F-26



U.S. NUCLEAR POWER GROWTH PATTERN
LARGE ORE SUPPLY AND SMALL ENERGY DEMAND - 1993 LMFBR

FIGURE III F-27

Consider next a case in which the LMFBR is definitely needed—i.e., the case of a small uranium supply and large energy demand. This is shown in Figures III F–28 and III F–29. The LMFBR then reduces nuclear power costs by about 9 mills/kwhr(e) in 2020, and this corresponds to cost reduction of about 200 billion dollars/year in the same year. Finally, consider the case of an LMFBR with a high capital cost, as shown in Figures III F–30 and III F–31. In this case, the LMFBR reduces nuclear power costs by about 3 mills/kwhr(e) in 2020 and thereby produces a saving of about 50 billion dollars/year.



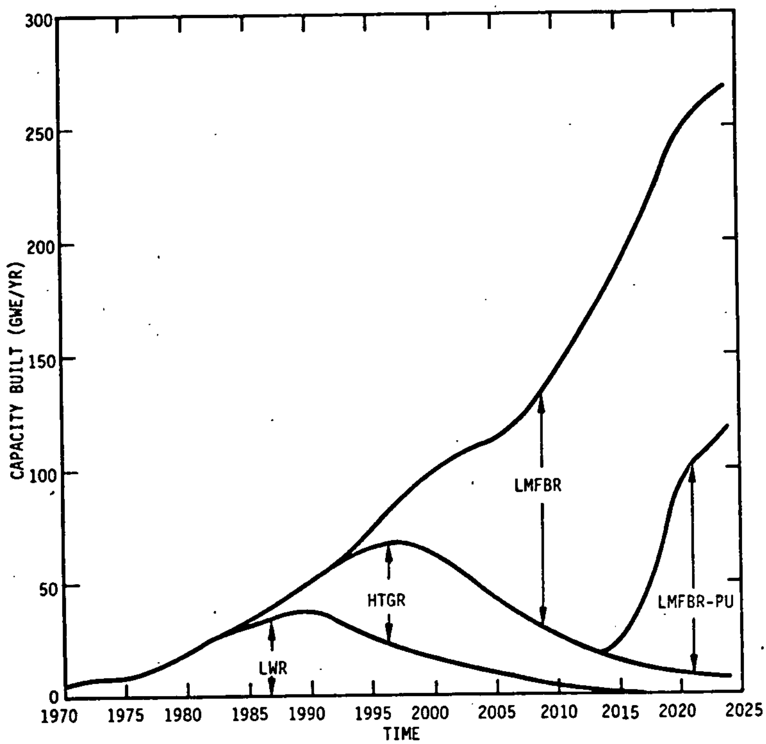
AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
SMALL URANIUM SUPPLY AND LARGE ENERGY DEMAND

FIGURE III F–28

The plutonium-burning LMFBR is not built in the later years in this case. This is because it is more economical to burn the plutonium in a plutonium-loaded LWR, since the capital cost of this reactor is considerably lower.

Average nuclear power costs in 2020 for various combinations of energy demand, ore supply, and LMFBR cost are shown in Table III F–11. In general, nuclear power costs without the LMFBR are about 43 percent higher than with the LMFBR.

Figures III F–32 and III F–33 show the amount of U_3O_8 and separative work required as a function of the energy demand and the LMFBR introduction date. It is clear from these figures that delaying the LMFBR increases the requirements for both items to an excessive degree. In particular, delaying the LMFBR increases the requirement

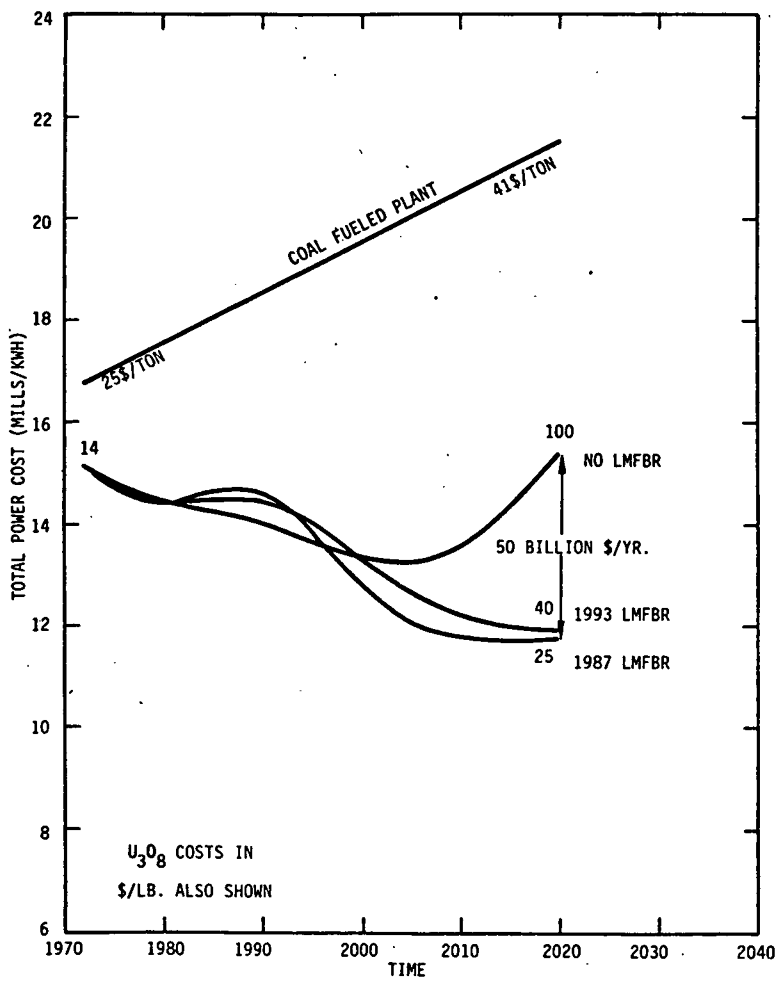


U.S. NUCLEAR POWER GROWTH PATTERN
SMALL ORE SUPPLY AND LARGE ENERGY DEMAND - 1993 LMFBR

FIGURE III F–29

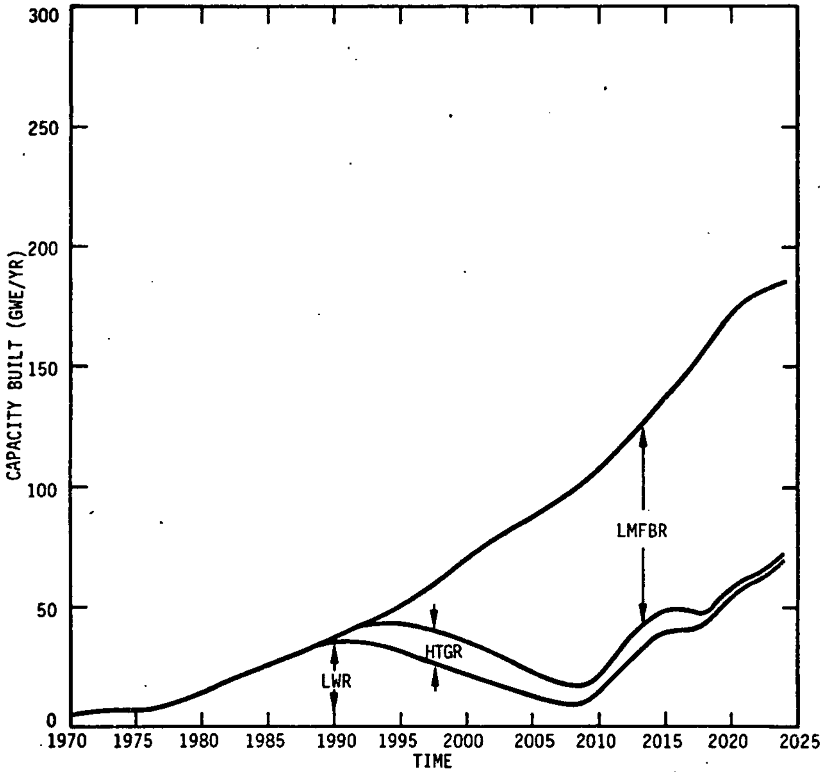
for U_3O_8 by approximately 0.2 million tons of U_3O_8 per year of delay, and similarly increases the requirement for enrichment capacity by almost 5 million SWU/year per year of delay.

Now let us turn our attention to possible advanced power sources. Many critics of the LMFBR view the possible commercialization of an advanced power source during the first decade of the next century as persuasive and even conclusive evidence that the development of the LMFBR is not needed. The miniscule cost for fuel—water for fusion and sunlight for solar—they argue, will more than make up for the higher capital costs of these advanced power sources. As a result of these contentions, a sequence of calculations were made to evaluate



AVERAGE U.S. NUCLEAR POWER COSTS (1975-2025)
HIGH CAPITAL COST

FIGURE III F-30



U.S. NUCLEAR POWER GROWTH PATTERN
HIGH CAPITAL COST - 1993 LMFBR

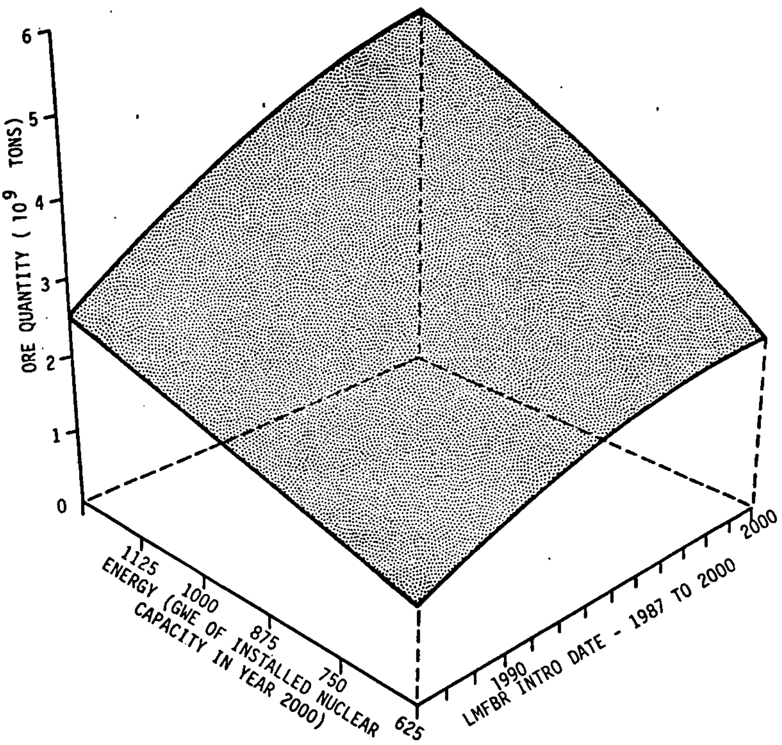
FIGURE III F-31

AVERAGE U.S. NUCLEAR POWER COSTS IN 2020

	LMFBR CAPITAL COST	B									H				
	U_3O_8 SUPPLY	B			S			L			B			S	L
	ENERGY DEMAND	B	S	L	B	S	L	B	S	L	B	S	L	B	B
LMFBR INTRODUCTION DATE	1993	10.2	9.9	10.5	10.5	10.2	11.2	10.1	9.9	10.2	11.9	11.6	12.3	12.2	11.8
	NONE	15.4	13.6	17.1	18.2	15.5	19.2	13.7	13.2	14.6	15.4	13.6	17.1	18.2	13.7

B = BASE   S = SMALL   L = LARGE   H = HIGH

TABLE III F-11

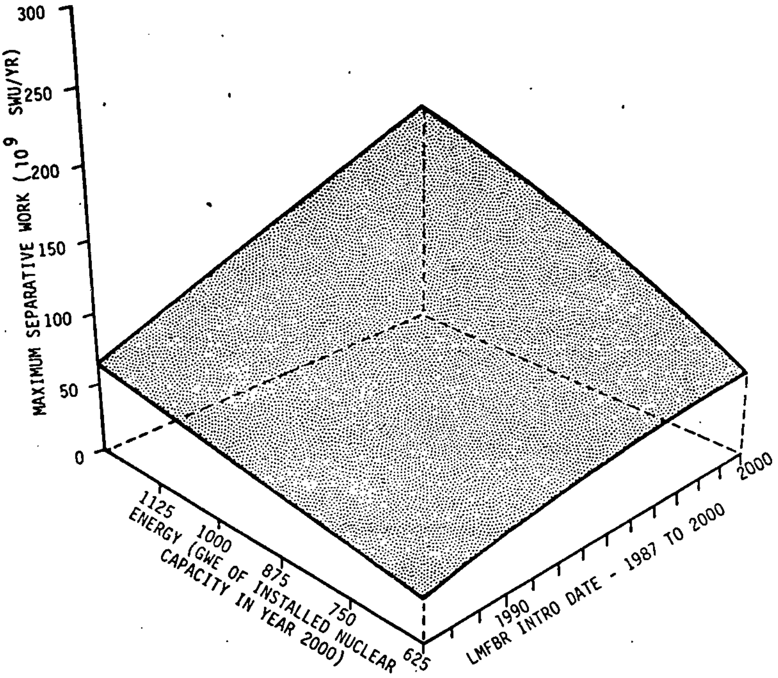


CUMULATIVE U_3O_8 VERSUS ENERGY DEMAND AND LMFBR INTRODUCTION DATE

FIGURE III F–32

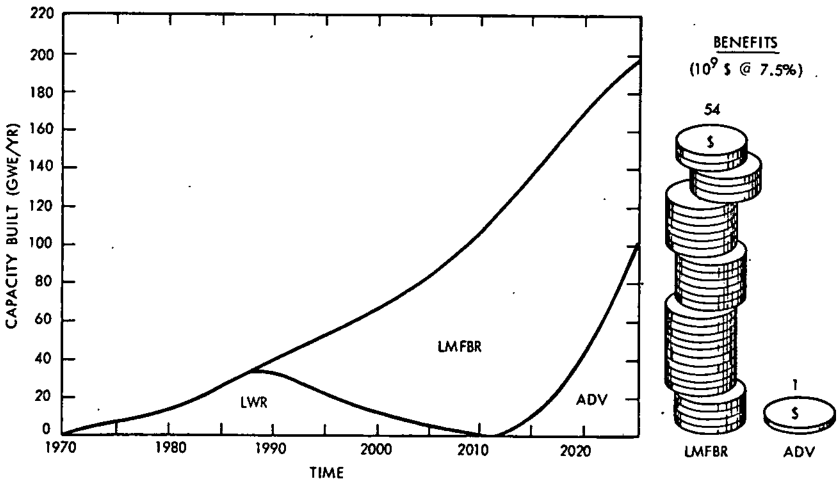
the effect of an advanced power source of the LMFBR benefits stated above.[39] As a by-product, the benefits associated with the advanced power source itself were also obtained. Since design and cost data for solar and fusion sources are quite speculative, the forecasting calculations were performed in a parametric fashion. An advanced power source of arbitrary design was assumed to be introduced in the year 2011 with a zero fuel cost, and with a capital cost of \$50/kwe higher than the LMFBR. An advanced power source with a capital cost \$25/kew higher than the LMFBR was also considered. These asumptions were quite arbitrary, and are definitely not meant to imply that the capital cost of an advanced power source will in fact be this low.

The nuclear industry growth pattern which is obtained when the advanced power source is allowed to compete freely with the LMFBR is shown in Figures III F–34 and III F–35. With a capital cost differential of \$25/kwe, the advanced power source is able to take an ever increasing share of the market from the LMFBR, as shown in Figure III F–34. However, the benefits—from 1975 to 2041—as-



MAXIMUM SEPARATIVE WORK REQUIREMENT VERSUS ENERGY DEMAND AND LMFBR INTRODUCTION DATE

FIGURE III F-33



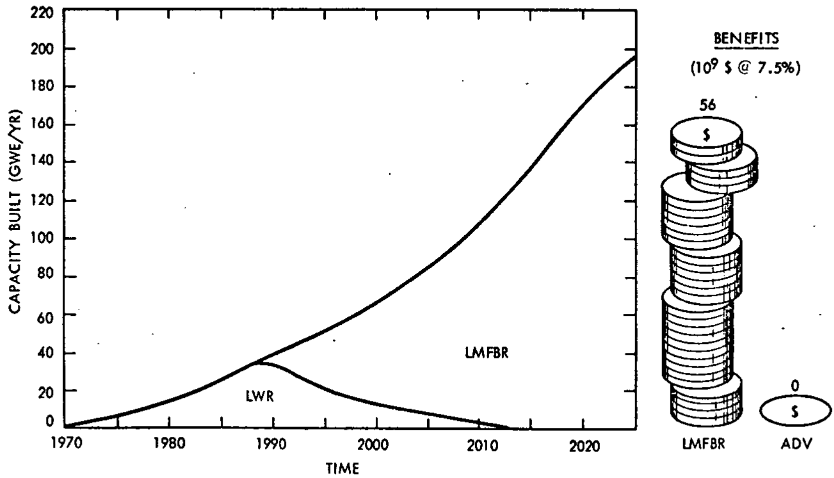
NUCLEAR INDUSTRY GROWTH PATTERN WITH AN ADVANCED POWER SOURCE AT A CAPITAL COST OF LMFBR + 25 $/kwe

FIGURE III F-34

sociated with the advanced power source are about 1 billion dollars, while the benefits associated with the LMFBR over the same time span are about 54 billion dollars. The end of the planning horizon was extended from 2025 to 2041 in order to allow the advanced power source to make a significant market penetration.

The reason that the benefits associated with the advanced power source are small is as follows. The fuel cost of the LMFBR is about 0.4 mills/kwh in 2020, and so the total power cost of the advanced power source is only slightly less than that of the LMFBR. Thus, the advanced power source is providing an insignificant reduction in total power cost in the distant future. The LMFBR, on the other hand, is providing a large reduction in power cost in the near future. With any real time value of money, the benefits obtainable from an advanced power source become inconsequential compared to those obtainable from the LMFBR.

The nuclear industry growth pattern which is obtained with a capital cost differential of $50/kwe between the advanced power source and the LMFBR is shown in Figure III F–35. In this case, the total power cost of the advanced power source is greater than that of the LMFBR, and consequently it is not built. As a result, the benefits associated with the advanced power source are zero, while the benefits associated with the LMFBR are 56 billion dollars. The discounted power cost over the planning horizon and the benefit associated with each power source are shown in Table III F–12. Note that the advanced power source benefits are significant only when the LMFBR does not exist, since the advanced power source was always built in this case. However, even in this case, the advanced power source benefits are substantially smaller than the LMFBR benefits.



NUCLEAR INDUSTRY GROWTH PATTERN WITH AN ADVANCED POWER SOURCE AT A CAPITAL COST OF LMFBR + 50 $/kwe

FIGURE III F–35

TABLE III F-12.—EFFECT OF THE ADVANCED POWER SOURCE DISCOUNTED POWER COSTS—1975-2041

[10^9 dollars at 7.5 percent]

	With LMBFR	Without LMFBR	LMFBR benefit
Advanced power source at LMFBR +25 dollar/kwe	338.7	393.2	54.5
No advanced power source	339.4	419.0	79.6
Advanced power source benefit	.7	25.8	
Advanced power source at LMFBR +50 dollar/kwe	339.4	395.2	55.8
Advanced power source benefit	0	23.8	

7. *Conclusions*

As national reserves of oil and natural gas decline, it becomes apparent that a new energy source will be required or we must be prepared to accept a significant decline in the quality of life. Insofar as electrical power is concerned, coal and nuclear energy are the only two options which meet the dual criteria of an available technology and an adequate fuel supply.

In this Section, we have shown that the LMFBR can have the following effects:

(*a*) Free the electric power industry from a dependence upon depletable fuel supplies, which cannot be restricted by international political concerns.

(*b*) Provide a large decrease in the production cost of electricity from nuclear power plants, primarily by reducing uranium ore and separative work requirements. In terms of undiscounted benefits it will reduce the cost of electrical energy by about one trillion dollars over the next fifty years, and will reduce the cost of electrical energy by 85 billion dollars per year in the year 2020 alone for base case conditions. Also for base case conditions uranium ore requirements are reduced by a factor of two and separative work requirements by a factor of four.

(*c*) Early introduction of the breeder may reduce the capital investment required to develop the nuclear industry, since the investment in uranium mining, milling and uranium enrichment facilities saved by the breeder may be much greater than the added investment for breeder powerplants.

(*d*) The earlier the introduction of the breeder the greater the benefits. Society incurs a positive cost by adopting a wait and see attitude. A delay in the introduction of the LMFBR by seven years to year 2000 will cost 7 billion dollars, discounted at 10 percent. Discounted at 7.5 percent the delay costs 20 billion dollars. This additional cost—produced by higher cost electrical energy—is simply a foregone saving.

(*e*) Provide economic benefits far in excess of the R&D costs required to develop the concept to the commercial stage.

We have shown that these considerations—while changed quantitatively—are not changed qualitatively over those presented in Section 11 of the PFES by changes in the major variables such as U_3O_8 price, energy demand, LMFBR capital cost, or by the introduction of an advanced power source.

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