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STATEMENT OF

DR. THOMAS B. COCHRAN

BEFORE THE

JOINT COMMITTEE ON ATOMIC ENERGY

SUBCOMMITTEE TO REVIEW
THE NATIONAL BREEDER REACTOR PROGRAM

July 10, 1975

Mr. Chairman and members of the Committee, thank you for this invitation to testify at these hearings on the breeder reactor program. My name is Thomas B. Cochran, I am a staff scientist at Natural Resources Defense Council (NRDC), a nonprofit environmental organization with offices in Washington, D. C., New York, and Palo Alto. Prior to joining NRDC in 1973, I was a Senior Research Associate at Resources for the Future (RfF) here in Washington, where I wrote The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique. Since 1971 I have been engaged full time following developments in the civilian nuclear power industry, concentrating principally on the Federal government's Liquid Metal Fast Breeder Reactor (LMFBR) program.

Since 1967, the LMFBR program has been the nation's highest priority reactor development program and since 1971 it has been accorded the highest priority among all the Federal government's energy research and development efforts.

In the Energy Research and Development Administration's (ERDA) June 30, 1975 message to Congress [hereinafter referred to as ERDA's June 30th Energy Plan], if one looks beyond the rhetoric to the proposed changes in the FY-1976 budget, the LMFBR continues to dominate the energy research and development scene. During the coming fiscal year, ERDA proposes to spend roughly a fourth of its budget for energy R&D on this single program, an amount equal to the combined allocations for improvements in coal technology, solar energy development, geothermal energy development, advanced energy research and energy conservation.

The total cost of developing the LMFBR is now estimated to be $10.7 billion; 2.3 billion has been spent to date; 7.3 billion, or 87 percent of the remaining expenditures are projected to be spent in the next twelve years. These estimates, made by proponents of the program, must be judged as conservative. The true costs will probably be more nearly twice these amounts. Already the LMFBR program has experienced tremendous cost overruns. Two years ago total program costs were put at less than half of today's estimate. Since 1967 the program cost has tripled in constant dollars. The principal test facility of the program, the Fast Flux Test Facility (FFTF) was originally planned to cost $87 million, but the latest estimate, including indirect costs, is over $1 billion, more than a ten-fold increase. The Sodium Pump Test Facility, when it was authorized in 1966 was estimated to cost $6.8 million. The total cost is now estimated to be $57.5 million.[1/] Congress was told in 1973 that the proposed

1/ Comptroller General of the United States, "The Liquid Metal Fast Breeder Reactor Program--Past, Present and Future," Report to the Congress, ERDA. RED-75-352. April 28, 1975.

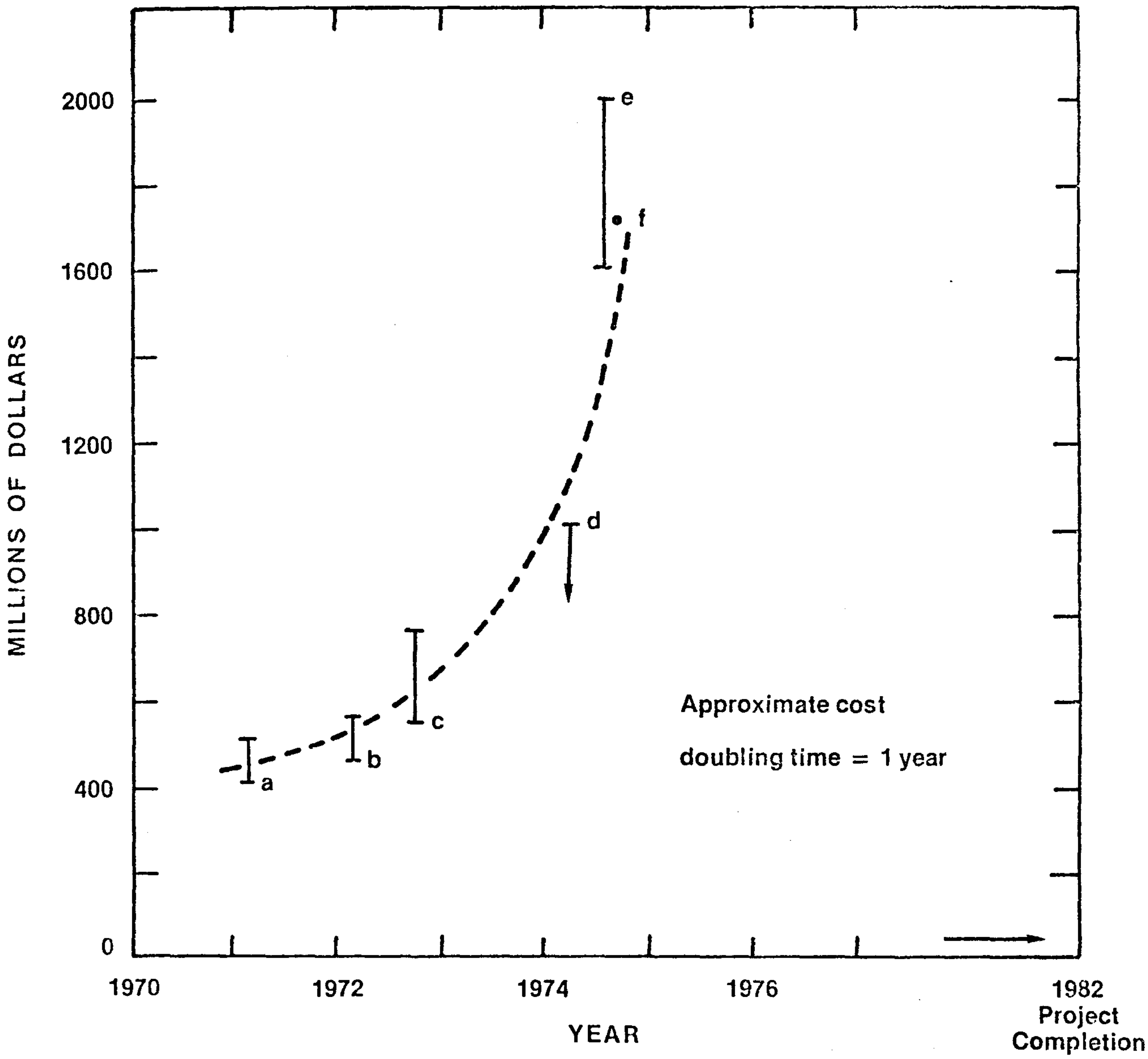
Clinch River Breeder Reactor Plant (CRBR), the first LMFBR demonstration plant if one overlooks Fermi-I, would cost $700 million. As shown in the accompanying figure, its last cost estimate was over $1.7 billion. Since this estimate was made, the CRBR schedule has slipped an additional year which in turn will shove its cost even higher. There is no sound reason to believe these trends will not continue.

And it is not just the overruns. There are still hidden costs in the program. Recognizing that the next generation of plants following the CRBR will not be commercially competitive, ERDA has recently restructured the LMFBR program. All but one of the demonstration plants have been eliminated. These have been replaced by a Plant Component Test Facility to be followed by a commercial-size prototype called Near-Commercial Breeder Reactor (NCBR). What ERDA does not publicize is that it has earmarked only $300 million for the government's share of the NCBR. Yet a subsidy of at least one billion dollars will be required. Can we expect the same utilities who refuse to contribute more than $254 million to the CRBR to subsidize this next plant? Experience suggest that we cannot. The Federal government will be the major source of funding for the project, just as it has to fund the CRBR.

The fundamental question now before the Congress and ERDA is whether the breeder program deserves priority attention

FIGURE 1

BREEDER REACTOR (COST) DOUBLING TIME



AEC Estimates of the Range in the Cost of the Clinch River Breeder Reactor.

Source: (a) JCAE Hearings, AEC Authorizing Legislation - FY 1972, p. 702.
(b) JCAE Hearings, AEC Authorizing Legislation - FY 1973, pp.1156-1159.
(c) JCAE Hearings, LMFBR Demonstration Plant, Hearings, p.44.
(d) Nucleonics Week, 15, March 21, 1974, p.1.
(e) Weekly Energy Report, 30, July 29, 1974, p.1.
(f) Weekly Energy Report, 38, September 23, 1974, p.6.

and great commitment of present and future resources. In my judgment it does not -- not only because of the environmental and safety concerns but also on the basis of economic considerations. My environmental and safety concerns have been documented in NRDC's Comments on the DRAFT and Proposed Final Environmental Impact Statements[2/] on the LMFBR Program [PFEIS-LMFBR]. I incorporate by reference the statement on Plutonium Safeguards submitted to this Committee for the record on June 19, 1975, by J. Gustave Speth, Esquire, of the NRDC staff.[3/] With your permission, Mr. Chairman, I would also like to take this opportunity to submit for the record a statement on the toxicity of plutonium by Dr. Arthur R. Tamplin of the NRDC staff. Dr. Tamplin was invited by this Committee to present this material at a previous hearing but was unable to attend because of his absence from the country.

The present high priority LMFBR program cannot be economically justified at this time. The basis for this view is contained in Bypassing the Breeder: A Report on Misplaced Federal Energy Priorities and reviews of cost-benefit analyses

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2/ Proposed Final Environmental Statement, Liquid Metal Fast Breeder Reactor Program, WASH-1535, Vol.VI, pp.38-1 to 38-328, (NRDC Comments), U.S. Atomic Energy Commission, December, 1974.

3/ Statement of J. G. Speth, Natural Resources Defense Council, submitted to this Subcommittee June 19, 1975.

performed by other organizations and individuals. Bypassing the Breeder was prepared last March by J. Gustave Speth, Dr. Arthur Tamplin, and myself. Mr. Chairman, with your permission, I would like to submit this report and the accompanying Appendix for the record and then take this opportunity to comment on some of the breeder economic issues discussed in this and other reports.

The Atomic Energy Commission has now written and released four cost-benefit analyses of the LMFBR program, if one counts the ERDA staff's "Preliminary Updated LMFBR Cost-Benefit Analysis" prepared in response to NRDC's analysis in Bypassing the Breeder.[4/] Cost-benefit analyses of the breeder program have been performed by other proponents of the breeder as well, with much attention focused on the analysis of Thomas Stauffer of Harvard in collaboration with H. G. Wycoff of Commonwealth Edison and R. S. Palmer of General Electric.[5/] In addition, several cost-

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4/ The first WASH-1126, written in 1968, was released in 1969; WASH-1184, an updated (1970) analysis was released in May, 1972; and the latest (1973) analysis appeared first in the AEC's Draft and then with revisions in the Proposed Final Environmental Impact Statement on the LMFBR Program [PFEIS-LMFBR]. The fourth is contained in "The LMFBR-Its Need & Timing," "A Discussion Of The Need To Continue Timely LMFBR Development, Including Comments on 'Bypassing The Breeder,' By NRDC," Division of Reactor Research & Development, ERDA-38, pp.III-34 to III-37.

5/ Stauffer, T. R., Wyckoff, H. L., and R. S. Palmer, "The Liquid Metal Fast Breeder Reactor, Assessment of Economic Incentives," presented to Breeder Reactor Corporation (Chicago, Illinois), March 7, 1975.

benefit analyses of the LMFBR have been performed by Alan S. Manne of Harvard in collaboration with others. 6/ Using the cost-benefit model developed by Manne and Yu, an economic analysis of the LMFBR timing issue has been prepared by James L. Plummer and Richard G. Richels. 7/ Irvin C. Bupp and Jean-Claude Derian have made an economic evaluation of the breeder program. 8/ Mark Sharefkin at Resources for the Future has prepared a draft paper summarizing most of the existing LMFBR program cost-benefit analyses performed to date and discussed their conceptual and practical limitations. 9/ Donald B. Rice, the President of the RAND Corporation, has prepared an extensive critique of the AEC/ERDA cost-benefit analysis contained in the PFEIS-LMFBR (at the request of Dr. Seamans). 10/ I have attached this as Appendix A to my testimony.

6/ Manne, Alan S., and Oliver S. Yu, "Breeder Benefits and Uranium Availability," Nuclear News, January, 1975, p.46; Manne, Alan S., "Waiting for the Breeder," The Review of Economic Studies Symposium, final version accepted March, 1974; Manne, Alan S., "Electricity Investments under Uncertainty: Waiting for the Breeder," Energy, (Cambridge, Mass.), The MIT Press, 1973.

7/ Richels, Richard, "The LMFBR Timing Issue," [draft], March, 1975. Richels is a graduate student under Manne at Harvard.

8/ Bupp, Irvin C., and Jean-Claude Derian, op.cit., Bupp is in the Center for International Affairs, Grad. School of Business Administration, Harvard, and Derian is at the Center for Policy Alternatives, MIT.

9/ Sharefkin, Mark, "The LMFBR Decision: The Analysis of Limits and the Limits of Analysis," Resources for the Future, [draft], July 1, 1975.

10/ Letter, dated June 4, 1975, to Dr. Robert C. Seamans, Jr., from Donald B. Rice, President, RAND Corporation.

All of the cost-benefit analyses, including ours, depend critically upon the accuracy of assumptions regarding (a) the choice of the discount rate; (b) the cost of the breeder research and development program; (c) the capital cost difference between LMFBR's and conventional nuclear reactors; (d) the future demand for electricity; and (e) the domestic supply of uranium. For example, the favorable LMFBR benefits generated by Stauffer et al., depend critically on their choice of a 6 percent discount rate -- a rate substantially lower than that employed by the other studies, and lower than the rate recommended by EPA, OMB and other organizations.[11/] The argument for the lower discount rate has been put forward in a separate unpublished draft paper circulated by Stauffer. Similarly, the large differences between the best estimates of the net-benefits of the breeder program made by the AEC/ERDA staff and NRDC are based on differences of opinion regarding other key variables, principally (a) the capital cost difference between LMFBR's and conventional nuclear reactors; (b) the future demand for electricity; and (c) the domestic supply of uranium. I will touch on some of these differences subsequently.

11/ U.S. Atomic Energy Commission, Proposed Final Environmental Impact Statement [PFEIS-LMFBR], WASH-1535 (December, 1974), Vol. IV, p.11.2-47; EPA Comments on DRAFT EIS, LMFBR Program. Reproduced in PFEIS, LMFBR Program, Vol.VII, pp.53-35 to 53-38.

It is clear from a review of the economic analyses that have been performed on the breeder that the critical input assumptions can be juggled to come up with widely varying LMFBR cost and benefits. A tempting and too easy way out is to point to these varying conclusions and dismiss economic analysis on that basis. Yet the basic arguments for the current LMFBR program are economic, and it is essential that Congress look critically into these economic analyses to determine whose assumptions are in fact reasonable.

In order to appreciate the degree to which the economic analyses of the LMFBR prepared by the AEC/ERDA staff and the nuclear industry suffer from a fatal promotional bias, one need only look at the electrical energy growth projection used by the AEC in its PFEIS-LMFBR. The steepness of the growth curve, as depicted in the attached graph provided by the AEC, staggers the imagination. The electrical demand growth assumed by Stauffer, _et al._, is consistent with this. The ERDA staff in its latest "Preliminary Updated LMFBR Cost-Benefit Analysis,"[12/] reduced their electrical energy demand projection to a value stated to be equivalent to an installed nuclear capacity of approximately 900 GWe in the year 2000, down by 25 percent from 1200 GWe's used in the PFEIS-LMFBR. Yet the 900 GWe of nuclear capacity assumed in this later analysis is twice the amount

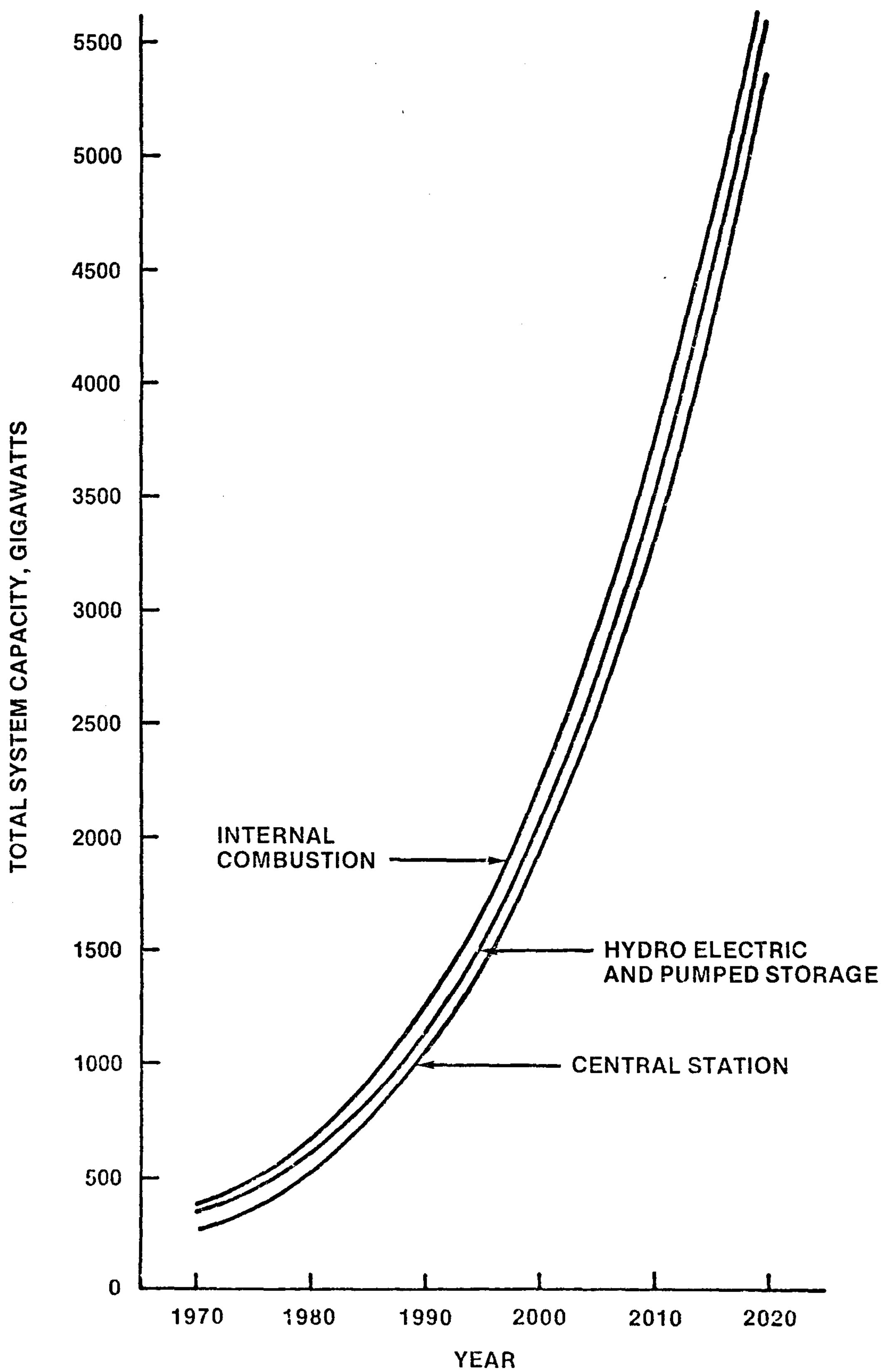
12/ _Id._, at III-35.

assumed in ERDA's June 30th Energy Plan for Scenario V, the strategy for developing all technologies -- the only strategy found acceptable by ERDA.

In this same vein, the cost-benefit analysis in the PFEIS-LMFBR projected 400 GWe of breeder capacity by 2000 as the AEC's best estimate. In the ERDA June 30th Energy Plan two scenarios -- the Intensive Electrification and the Develop All Technologies strategies -- assumed 80 GWe of LMFBR; the remaining three scenarios contained no LMFBR by 2000. At this rate, it won't be long before the ERDA staff and NRDC are in agreement on estimates of LMFBR installed capacity by the year 2000.

A second area where the AEC/ERDA staff resorted to unsupportable assumptions to justify the program is the issue of capital cost differences between LMFBR's and present-day reactors. It is possible to accelerate the date when breeders become economically competitive by arguing that as more breeder reactors are sold the unit price will be reduced. Economists refer to this possibility of decreasing costs with increasing number of units produced as "learning." Hence, a central issue is whether it is appropriate to apply a learning curve to the capital cost of LMFBR.[13/] The AEC in its latest cost-benefit

13/ This learning effect is separate from the subsidies associated with first-of-a-kind or prototype plants. The AEC has simply ignored these first-of-a-kind costs.



PROJECTED DEMAND FOR ELECTRICAL GENERATING CAPACITY 1970-2020

Source: AEC, Proposed Final Environmental Impact Statement for LMFBR Program (December, 1974), Vol. IV, p. 9.1-3.

analysis applied a sharp learning curve to the breeder reducing its capital cost to parity with light water reactors in the short 13 year period following commercial introduction. Remarkably, light water reactors are assumed not to experience any learning at all. There is really no justification for this approach. The AEC has been predicting a learning curve in the cost of present day nuclear plants for the past decade. To the contrary, the cost of commercial nuclear plants has been increasing at an alarming rate, even in constant dollars. So in fact there is no justification for assuming learning for either reactor type. Moreover, if a learning effect is ever experienced, it will be felt by light water reactors before it is felt by breeders. This would increase the capital cost difference between breeders and existing reactors and shift the date of LMFBR commercialization further into the future.

What makes the AEC/ERDA staff's LMFBR learning curve even more unbelievable is that in the same short period, 1987-2000, when LMFBR capital costs are rapidly falling due to learning there is a shift to an advanced LMFBR design in 1991 and again in 1995. Furthermore, in 1990 plant unit sizes increase from 1300 MWe to 2000 MWe with an additional 12 percent decrease in price. The ERDA staff choose not to change this assumption in their latest update of the cost-benefit analysis.

As mentioned earlier, one of the critical input assumptions is the domestic supply of uranium. A number of independent investigators, including Professor John Holdren[14/] at the University of California - Berkeley, Drs. Irvin Bupp and Jean-Claude Derian[15/] at Harvard and MIT respectively, and Milton Searl,[16/] Director of the Energy Supply Studies Program at the Electric Power Research Institute (EPRI), believe the AEC has been overly conservative in estimating the domestic supply of uranium. The Environmental Protection Agency in its review of the AEC analysis stated that, " . . . the uranium supply could be significantly greater than that projected for the [AEC's] base case."[17/] The ERDA staff in its latest "Preliminary Updated LMFBR Cost-Benefit Analysis" adjusted the uranium prices upward from the values assumed in the PFEIS-LMFBR to correct a previous failure to give adequate weight to the

14/ Holdren, John P., "Uranium Availability and the Breeder Decision," Environmental Quality Laboratory, California Institute of Technology, 1973. EQL Memorandum No.8, January, 1974.

15/ Bupp, Irvin C., and Jean-Claude Derian, op.cit.

16/ Searl, Milton F., "Uranium Resources to Meet Long Term Uranium Requirements," Electric Power Research Institute (EPRI), EPRI SR-5 Special Report, November, 1974.

17/ Environmental Protection Agency, "Comments on Proposed Final Environmental Statement, Liquid Metal Fast Breeder Reactor Program," PF-AEC-A00106-00, p.3. April, 1975.

distinction between market price and production cost. ERDA's new base case after this adjustment is consistent with the base case uranium supply curve assumed by Stauffer, et al. In NRDC's cost-benefit analysis we use a uranium supply curve more consistent with the EPRI estimate of Searl. Searl calculated domestic resources below a market price of $100/lb and did take into account the distinction between market price and production cost. In other words, I believe Stauffer and the ERDA staff have made a proper correction but applied it to the wrong base.

There are two important observations in the papers by Manne and collaborators and Sharefkin referenced earlier. First, Sharefkin points out that none of the cost-benefit analyses which compare a world without LMFBRs to one with LMFBRs -- the AEC/ERDA analysis and the analysis by Stauffer, et al., fall in this category -- are structured so as to be able to answer questions about the best strategy an LMFBR program might pursue. Consequently, they uniformly give the same answer to the question of the optional timing of LMFBR commercialization -- the sooner the better. The analyses of Manne and collaborators and Plummer and Richels address the timing issue directly. These analyses share a quite different conclusion. Plummer and Richels, for example, indicate that under quite plausable assumptions " . . . the results do not support ERDA's contention that the breeder should be available as soon as possible." They question ERDA's assumption that R&D costs rise with later LMFBR availability. Their results have been interpreted to show that net discounted benefits are relatively insensitive to LMFBR availability dates over the period from 1988 to 2006 (See, Appendix A, p.14).

The other point I wish to note is that Manne included in his cost-benefit analysis of the breeder an energy demand strategy -- peak load pricing. In an illustrative example, Manne found that the benefits of peak load pricing were roughly an order of magnitude larger than the benefits of early breeder reactor development. Manne's analysis suggests that this country might be better served economically by concentrating on reducing our demand for energy than focusing only on developing a long term source of energy such as the breeder. As Sharefkin notes, demand-side strategies seem well worth exploring, preferably in some framework that makes possible a comparison of the payoff to the strategies with the payoff to supply-side strategies.

In summary, I believe that if the Congress approaches this issue without bias and undertakes a careful analysis of all the available analyses and the critical input assumptions it will come to share our conclusion that the LMFBR will not be commercially competitive with existing energy sources until one or two decades after the turn of the century. Yet the current LMFBR effort is aimed at having the new reactor developed in the early 1990s, more than two decades before it could be economically attractive. In our view, the LMFBR program is thus quite premature and could be delayed substantially without incurring any risks relative to meeting future U.S. energy needs. The sense of urgency and crisis that program supporters have promoted to garner support for the LMFBR has no foundation in fact.

On simple economic grounds, then, the push to develop the LMFBR can and should be postponed. Moreover, such a delay would provide the time needed to show what many experts now believe to be the case -- that environmentally preferable, nonfission energy options can be made available in time to eliminate the need for the LMFBR altogether. What is proposed here is an energy program which should be able to provide an adequate supply of fuels and electric power without the commercial utilization of breeder reactors. This program would include:

- An intensive effort to develop the various forms of solar energy should be undertaken following the recommendations of the expert panels convened under National Science Foundation auspicies, <u>An Assessment of Solar Energy as a National Energy Resource</u> (1972) and <u>Solar and other Energy</u>

Sources: Subpanel IX Report (1973).[18/] In estimates which it believed were not the highest possible, the first of these studies concluded that its recommended R&D program could result by the year 2020 in solar energy providing 35 percent of the nation's total building heating and cooling loan, 30 percent of the nation's gaseous fuel, 10 percent of its liquid fuel, and -- most important for present purposes -- 20 percent of the electrical energy requirements.[19/] I was disappointed that ERDA in its June 30th Energy Plan assigned a lower priority to the so-called "under-used mid-term technologies," namely solar heating and cooling and geothermal resources, than the priority assigned the "inexhaustible sources," particularly the breeder. Although solar heating and cooling is not considered an "inexhaustible" resource because of its limited uses, nevertheless, it can provide more energy in the next 3 decades and do more towards achieving Project Independence than we can hope to gain from the breeder.

- A major R&D effort devoted to exploitation of geothermal resources for electric generation should be launched. The Cornell Workshop on Energy and the Environment (1972) con-

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18/ NSF/NASA Solar Energy Panel, *An Assessment of Solar Energy as a National Energy Resource*, National Science Foundation, Washington, D.C., December, 1972; Alfred J. Eggers, *et al.*, *Subpanel IX Report: Solar and Other Energy Resources*, National Science Foundation, October 27, 1973.

19/ *An Assessment of Solar Energy*, *ibid*.

cluded that "[i]t appears that geothermal energy alone is capable of meeting all American power requirements for several centuries if the hot dry rocks resource proves to be practical."20/ The Cornell Workshop, the National Science Foundation, and others have recommended that a program to establish the feasibility of hot rock geothermal in the next few years be given highest priority. Projections of the electric power available from geothermal resources range from 80 to 400 GWe in the year 2000, depending on assumptions made about the hot rock potential.21/ The AEC recently estimated that geothermal heat could supply 6 percent of our electricity in the year 2020,22/ but it is clear that the percentage could be much higher if hot rock geothermal develops as expected.

- The current effort to develop fusion power should be expanded. The AEC recently stated that "a successful, vigorously supported fusion program would be expected to lead to construction of a demonstration power reactor that would begin operation in the mid-1990's."23/ The agency anticipated

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20/ Cornell Workshop on Energy and the Environment, Summary Report, Committee on Interior and Insular Affairs, U.S. Senate, May, 1972, pp.114-15.

21/ See, e.g., Walter J. Hickel, et al., Geothermal Energy, NSF/RANN-73-003, University of Alaska, 1973, p.7; Dixy Lee Ray, Chairman, AEC, The Nation's Energy Future: A Report Submitted to President Richard M. Nixon (1973).

22/ PFEIS, LMFBR, Vol.IV, p.11.1-20.

23/ Ibid., Vol.III, p.6A.1-191.

"commercial introduction of fusion power plants on a significant scale beginning in the early 21st century."[24/] Thus, it now appears that the demonstration fusion power plant is not far behind the LMFBR demonstration plant and that fusion plants can be available commercially for much of the period during which it was assumed the LMFBR would be critically needed. The AEC's overall estimate is that by the year 2020 about 8 percent of our electricity could come from fusion.[25/]

- Organic wastes provide another source of energy that should be developed. Organic wastes could account for 5 percent of the demand for electricity in the year 2000 but only 2 percent in 2020 due to more efficient practices in the solid wastes area.[26/]

- All of the above year 2020 percentage contributions, e.g., 20 percent for solar, 6 percent for geothermal, etc., are based upon the AEC's year 2020 energy demand forecast which assumes a continuation of extremely rapid growth in electricity demand. Several studies of the future demand for electricity have been carried out using more sophisticated forecasting techniques and taking into account the effects of the increasing price of electricity and other market factors.

24/ Ibid., Vol.III, p.6A.1-179.

25/ Ibid., Vol.IV, p.11.1-22.

26/ Ibid., Vol.IV, p.11.1-21.

These studies suggest that actual future demand will be less than half of that projected by the AEC.[27/] Moreover, as a supplement to market influences, it is apparent that the U.S. is moving towards a national energy conservation policy along the lines recently suggested by the House Committee on Science and Astronautics, the Council on Environmental Quality, the Ford Foundation Energy Policy Project and others.[28/] These groups all suggest that U.S. energy growth can be roughly halved without serious adverse repercussions on the American economy or lifestyle. When both market and policy influences are taken into account, we believe it is reasonable, in fact, conservative, to assume that electricity demand in the year 2020 will not exceed 50 percent of the AEC's astronomical projection.

As summarized in the attached table, these estimates of the potential contribution of solar, geothermal and fusion energy together with energy conservation measures indicate that these sources alone can more than account for the energy expected from the LMFBR in the year 2020, when the reactor is projected to have maximum impact. Indeed, they can account for the energy expected from all fission reactors at that time.

27/ The electricity demand issue is discussed in detail in the Appendix to Bypassing the Breeder, pp.21-28, and in NRDC Comments on Draft LMFBR EIS, Alternative Technology Options, PFEIS, LMFBR, Vol.VI.

28/ Conservation and Efficient Use on Energy, Report of the Committee on Science and Astronautics, U.S. House of Representatives, December 18, 1975; Council on Environmental Quality, "The Half and Half Plan for Energy Conservation," printed in Fifth Annual Report of the Council on Environmental Quality (1974), p.475; Energy Policy Project of the Ford Foundation, A Time To Choose (1974), Chapters 3-6.

Table I

Energy Sources for Electricity Production

in the Year 2020 Without the Breeder

	Trillions of Kilowatt Hours	Percent of AEC Projection	Source
AEC Projection	27.6	100	(1)
New Energy Sources			
Solar	5.5	20	(2)
Geothermal	1.7	6	(3)
Fusion	2.2	8	(4)
Organic Wastes	.6	2	(5)
	10.0	36	
Correction for Market Factors and Energy Conservation	13.8	50	
Total Accounted For	23.8	86	
Remainder for Other Sources (principally fossil fuels)	3.8	14	

Sources:

1. Proposed Final EIS for LMFBR Program, Vol. IV, p. 11.1-25
2. NSF/NASA, Solar Energy as a National Resource (1972), p. 3. Proposed Final EIS for LMFBR Program, Vol. IV, p. 11.1-19
3. Proposed Final EIS for LMFBR Program, Vol. IV, p. 11.1-20
4. Proposed Final EIS for LMFBR Program, Vol. IV, p. 11.1-22
5. Proposed Final EIS for LMFBR Program, Vol. IV, p. 11.1-21

These considerations indicate that a major LMFBR effort is not needed now and probably never will be. And the risks of continuing the present drive to commercialize the LMFBR are great. The most serious danger is that the LMFBR program will proceed as now planned, consuming the $10 billion presently estimated and plenty more besides, cutting deeply into energy R&D funds, and holding back the development of the preferable non-fission technologies. Then, having spent enormous sums the country will find itself with a reactor which must eventually be used only because of the great public and private investments in it and our failure to have developed appropriate alternatives. Our error will be compounded because any attempt to deploy the LMFBR widely would raise the energy-environment confrontation to an unprecedented intensity.

The last refuge of the breeder proponent is the argument that the LMFBR is needed as an "insurance policy." I do not share this view. Ample insurance exists partly in pursuing a variety of non-conventional energy sources and energy conservation and partly in realizing that the AEC would insure us against a non-existent risk -- the risk that our electrical generating capacity will actually grow as that agency projected.

Furthermore, the insurance argument cuts both ways. While proponents of nuclear power wish to insure against the depletion of low cost uranium, opponents wish to insure against catastrophic breeder accidents, nuclear terror and blackmail. We can purchase both policies by continuing much of the LMFBR base program R&D and the LMFBR safety research, gathering operating experience with the Fast Flux Test Facility, but relegating the overall program to a low-priority status by foregoing any expensive push towards demonstration and commercial reactors. At the same time we could accelerate the development of attractive non-fission alternatives such as solar, geothermal, fusion and energy conservation. During the intervening years while the commercial component of the LMFBR program is delayed, much can be learned about uranium availability, future energy demand, and about LMFBR's component development from foreign programs. Furthermore, postponing the commercial component of the LMFBR program one to two decades does not permanently eliminate the LMFBR option. If within about a decade it becomes clear that possible non-fission options are not going to be available, consideration can be given at that time to reinitiating the full program. One could proceed with the CRBR or more probably would proceed with a demonstration plant of another size and a different design, and possibly with a different management and cost sharing structure. There would be no penalty for such postponement.

APPENDIX A

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U.S. ENERGY RESEARCH & DEVELOPMENT ADM. OFC. OF ADMINISTRATOR

1975 JUN 5 PM 4 07

DONALD B. RICE
President

June 4, 1975

The Honorable Robert C. Seamans, Jr.
Administrator
Energy Research and Development Administration
Washington, D.C. 20545

Dear Bob:

This letter responds to your request for an independent review of the cost-benefit analysis of the liquid metal fast breeder reactor (LMFBR) contained in the Proposed Final Environmental Statement (PFES: WASH-1538, Vol. 4). Because no new research could be carried out in the time available, I have depended for the most part on existing studies and publications as well as on past Rand experience with the study of advanced-technology systems.

I have been assisted in my review by Professor Alan Manne and Richard Richels of Harvard University, James Plummer of NSF, and, extensively, by Arthur Alexander of Rand. The conclusions expressed, however, are those I have reached myself; the others do not necessarily subscribe to all of them.

My principal conclusions are summarized below, followed by a more detailed discussion.

Summary of Findings

This review of the cost-benefit analysis of the LMFBR is in three sections, each of which looks at the issue from a somewhat different perspective. The first section examines several of the most important assumptions and detailed projections which underlie the analysis. Section II reviews the role of cost-benefit analysis as a tool for decisionmaking in the LMFBR case, based on the analysis contained in the PFES and on the modifications suggested by our review. Based on a synthesis of these findings, the third section suggests some guides for future policy.

The findings in brief:

- Capital cost differentials between LMFBR and LWRs are likely to be substantially higher than $100/kW, based on learning curves applied to present estimates of the Clinch River Breeder Reactor (CRBR) and and Near Commercial Breeder Reactor (NCBR).

- o R&D costs may go much higher than the PFES estimate of $5 billion (discounted), based on LMFBR program experience to date and evidence from Rand studies of defense R&D.

- o The growth of demand for electrical energy over the next 10-15 years will almost certainly be slower than assumed in the PFES; demand in 2020 could easily be half of that postulated in the base case predictions, based on independent estimates with price effects included.

- o Several circumstances adverse to the LMFBR are likely to occur in concert, substantially reducing net benefits from the PFES "base" case (in contradiction to the study's conclusion [11.3-1]).

- o Net benefits are not very sensitive to the LMFBR availability date (in contradiction to the study's conclusion [11.2-5]).

- o The great uncertainties that characterize both the program and the economic environment in which it is embedded can be effectively met only with an austere, incremental, sequential development program, with adequate time for test and evaluation, and with a plan for resolving uncertainty over time.

- o A slimmed down, sequential program may be acceptable to proponents and opponents if confidence and trust are established through frank and open public program reviews by ERDA.

I. REVIEW OF ASSUMPTIONS AND PROJECTIONS

In a work as detailed, voluminous, and basically well done as the PFES, I could naturally select only a few points to review and comment on. However, two specific areas critically affect the predicted net benefits of the project -- capital cost differentials between the LMFBR and light water reactors, and R&D costs. There is reason to be concerned with their treatment in the PFES. In addition, I propose to comment on the appropriate discount rate and to review a number of estimates of near term electrical energy demand growth that deviate from assumptions in the cost-benefit analysis.

Capital Cost Differentials

The capital cost estimate of $520/kW at "initial commercial introduction" of the LMFBR is not a credible figure and introduces considerable doubt about the early

$100/kW differential of the LMFBR over the light water reactor (LWR). The AEC used an engineering cost model (based on unknown assumptions as to the maturity of the LMFBR technology) to derive this low capital cost, which would be only 24 percent higher than the projected $420/kW costs of a mature LWR in 1987. One relatively firm piece of information is inconsistent with these calculations -- the design costs of the Clinch River Breeder Reactor (CRBR). These costs can be used in conjunction with empirically established learning curves to develop future LMFBR capital costs.[1]

The current construction cost projection for the CRBR is $1.2 billion[2] for 350 megawatts -- giving a capital cost/kW of more than $3400. Similarly, rough estimates for the reactor to follow the CRBR -- the NCBR -- predict capital costs in the region of $2000/kW. But since neither of these plants has been built, both of these figures are conjectural and may, in fact, be too low. Applying a 90 percent learning curve to initial costs of $2000 and $3000/kW suggests that LMFBR costs will be much larger than LWR costs until at least year 2020.[3] If LWR capital costs fall by 1 percent per year as a result of productivity growth and technological change, a 90 percent learning curve applied to $1000, $2000, and $3000/kW initial costs does not bring down future costs far enough to meet the slowly falling LWR costs (see Table 2 and Figure 1).[4] Only for an 80 percent learning curve will LMFBR capital costs become equal to LWR costs -- in 1990, 1999, and 2020 for the $1000, $2000, and $3000 initial cost cases, respectively. Experience suggests that cost reduction at this fast rate is quite unlikely.

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[1]Learning curves are empirically based relationships in widespread use to project the reduction in unit costs associated with each doubling of cumulative quantity produced. A 90 percent curve means that the cost of the last unit produced is reduced by 10 percent when quantity produced is doubled. See Table 1 for examples. Typical learning curve values in other fields are 78-85 percent for airframes, 90-92 percent for aircraft engines and rocket motors, 95-98 percent for electronic systems. See H. Asher, Cost-Quantity Relationships in the Airframe Industry, The Rand Corporation, R-291, July 1956, for a discussion of the theory and application of learning curves.

[2]GAO Report on LMFBR, April 28, 1975.

[3]The cost-benefit analysis uses a 98 percent curve, but claims that a 90 percent relationship was characteristic of LWRs [11.2-84 and ERDA Staff Statement, May 27, 1975, p. 19]. French studies also conclude that learning curves from 87-92 percent have been experienced with LWRs [11.2-91].

[4]In the calculations of Table 2 and Figure 1, we rely on the PFES' highly optimistic assumptions of early introduction date and rapid production rate of commercial LMFBRs. The first few lines of page 11.2-134 indicate that the authors of the PFES may doubt these assumptions.

Table 1

EFFECT OF LEARNING PROCESS ON PRODUCTION COSTS OF LAST UNIT, FOR ALTERNATIVE LEARNING CURVE ASSUMPTIONS.

A DOUBLING OF NUMBER PRODUCED REDUCES UNIT COST OF LAST ITEM TO SPECIFIED PERCENTAGE.

Units Produced	Marginal Cost of Last Unit as Proportion of Cost of First Unit With Learning Curves of:			
	95%	90%	85%	80%
1	1.0	1.0	1.0	1.0
2	.95	.90	.85	.80
4	.90	.81	.72	.64
8	.86	.73	.61	.51
16	.81	.66	.52	.41
32	.77	.59	.44	.33
64	.74	.53	.38	.26
128	.70	.48	.32	.21
256	.66	.43	.27	.17
512	.63	.39	.23	.13
1024	.60	.35	.20	.11

Table 2

CAPITAL COSTS PER kW OVER TIME WITH OPTIMISTIC INTRODUCTION SCHEDULE AND ALTERNATIVE LEARNING CURVES AND FIRST UNIT COSTS

		Capital Cost/kW at Specified Initial Costs and Learning Curves					
	Cumulative Units	$1000/kW Initial Cost		$2000/kW Initial Cost		$3000/kW Initial Cost	
Year	Produced	90%	80%	90%	80%	90%	80%
1986-87	1	1000	1000	2000	2000	3000	3000
1988-89	9	716	494	1432	988	2148	1482
1990-91	22	625	370	1250	740	1875	1110
1992-93	46	559	292	1118	584	1677	875
1994-95	80	514	244	1028	488	1542	732
1996-97	126	480	211	960	422	1437	633
1998-99	186	450	186	900	372	1355	558
2000-01	252	430	169	860	338	1293	507
2002-03	352	410	151	820	302	1230	453
2004-05	462	390	139	780	278	1182	417
2006-07	560	380	130	760	260	1146	390
2008-09	670	370	123	740	246	1116	369
2010-19	1178	340	103	680	206	1023	309

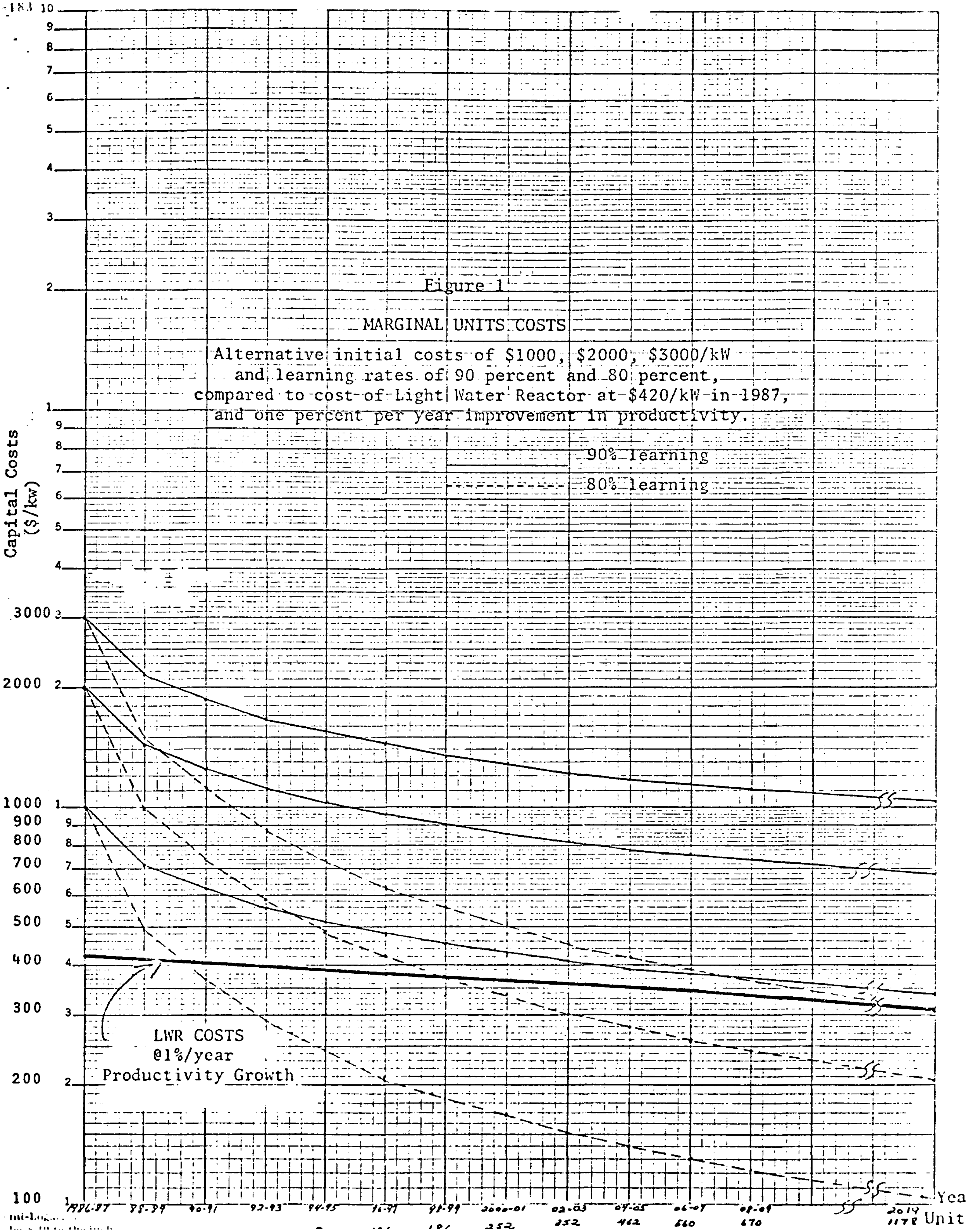

Figure 1

MARGINAL UNITS COSTS

Alternative initial costs of $1000, $2000, $3000/kW and learning rates of 90 percent and 80 percent, compared to cost of Light Water Reactor at $420/kW in 1987, and one percent per year improvement in productivity.

Let me emphasize that so far we have been speaking only of marginal costs -- that is, the cost of the last unit. Average costs will be considerably higher since they are calculated over all the earlier, higher-cost units. The average cost of 1000 units with a 90 percent learning curve and $1000, $2000, and $3000 per kW initial costs would be $410, $820, and $1230. Of course, the assumption of a 1000 unit "production run" may be quite optimistic; average costs would be higher for lower quantities.

The PFES assumed that, except for the more rapid learning effects in the LMFBR because of its relatively less mature status, productivity increases in LWR plants and other shifts in generating costs will parallel those in LMFBR plants. This assumption rules out independent productivity gains by established technologies -- it ignores the steady, non-transferable productivity increases over the years that result from construction and operation of plants of a given type. However, major shifts in costs due to economy-wide forces, such as environmental considerations, would affect generically similar equipment in a parallel fashion, as assumed by the PFES. Several studies of steam-power electrical generating plants show capital costs falling over many decades at a rate that is somewhat faster than average U.S. productivity gains. (This equipment is also more efficient in its use of fuel and labor inputs.)[1] Inflation-adjusted costs of both fossil and nuclear plants, though, began to rise in 1970, the apparent result of economy-wide forces stemming from design changes required by tighter environmental standards and from an overextended construction industry in which prices were rising faster than overall inflation and productivity was deteriorating.[2] The upturn in generating costs is unlikely to continue indefinitely into the future. When design standards for safety and pollution stabilize, the long term historical trend in productivity improvement should resume. This assumption is reflected in the 1 percent annual productivity increase for LWR plants shown in Figure 1.

I conclude from the above that the $520 capital cost figure for initial commercialization of the LMFBR is highly unrealistic -- given what we know about CRBR and NCBR. Capital cost differentials are likely to be considerably higher than even the worst case calculation in the PFES. Since LMFBR capital costs at the base case level of $520 are approximately two-thirds of total bus bar electrical costs, our calculations imply substantially higher electrical costs than assumed in the PFES. LMFBR technology that is not competitive with either LWR or fossil fuel generators is thereby implied.

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[1]See, for example, Yoram Barzel, "The Production Function and Technological Change in the Steam Power Industry," Journal of Political Economy, Vol. 72, April 1964.

[2]See, Irvin C. Bupp, et al., "Trends in Light Water Reactor Capital Costs in the United States," Center for Policy Alternatives, M.I.T., September 1974; McTague, et al., Nuclear News, February 1972; Roe & Young, Power Engineering, June 1972.

R&D Costs

Research and development costs of the LMFBR could well be two to three times higher than those projected in the PFES. This conclusion is based on experience in the LMFBR program itself as well as on past Rand studies of the acquisition of high technology systems in the military and civilian sectors, both in this country and abroad.

The Fast Flux Test Facility has experienced a program cost overrun, over an eight year period, of from 500 to 1000 percent, depending on what is included in the initial and final estimates. Adjustment for inflation would not alter the basic finding that costs were several times greater than first anticipated and that schedules slipped by more than six years.

The Sodium Pump Test Facility, from first estimates in 1966 to actual results in 1974, experienced a cost growth of 300 percent (unadjusted for inflation) for a sodium pump capacity that was only one-third of that originally planned. Modifications to increase pump capacity would increase costs to more than eight times original estimates (unadjusted).

In the three years since 1972, cost estimates for the Clinch River Breeder Reactor have climbed from $700 million to $1.77 billion. This growth factor of 250 percent over a three year period is based on design studies only -- construction of the plant has not yet begun.[1]

General Electric's Midwest Fuel Recovery Plant, intended to extract uranium and plutonium from exhausted nuclear fuel rods, was expected to cost $36 million in 1968 when construction began, with a completion date set for mid-1970. By 1974, costs had risen to $64 million and the plant did not work; current plans are uncertain, but the plant may be abandoned or scrapped. Redesigning and rebuilding the facility would be expected to take four more years with additional expenditures of $90 million to $130 million.[2]

These are perhaps extreme statements of cost growth trends because they extend from very preliminary first estimates -- which are characteristically optimistic -- rather than from estimates based on careful engineering and statistical cost analyses. Nevertheless, studies of major weapon systems indicate that cost overruns are proportional to the degree of technological advance sought in a project.[3] Resolving

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[1]These three cases are summarized in, "The Liquid Metal Fast Breeder Reactor -- Past, Present, and Future," by the Comptroller General of the United States, General Accounting Office, RED-75-352, April 1975.

[2]See, "Nuclear Fuel Reprocessing: GE's Balky Plant Poses Shortage," Science, Vol. 185, 30 August 1974.

[3]Robert L. Perry, et al., System Acquisition Strategies, R-733-PR/ARPA, The Rand Corporation, 1971.

major technological uncertainties is usually more costly than anticipated. The natural optimism of program advocates often tends to obscure the realities of state-of-the-art advances actually required in a program. To project engineers, a technological feature that is conceptually well in hand is often treated as being "on the shelf." The ERDA staff, for example, concludes that "the LMFBR is a well-advanced technology which has reached the demonstration plant stage."[1] This enthusiastic and optimistic attitude, while understandable and often even commendable, makes risky projects seem sure things -- a process that usually increases the probability of project failure. The nuclear plant experience cited above should serve to dampen such confidence.[2]

Cost growth caused by pushing the technology is compounded by the added uncertainty of prediction made over lengthy periods.[3] As information is generated through the construction and testing of a system, cost predictions become more accurate. The length of time between R&D cost predictions and the expected completion of facilities can exceed ten years. The effect is to multiply new technology cost growth by a factor that grows exponentially with the prediction interval.

Given this history, it would not be a unique outcome if LMFBR costs rose to several times the current estimates, given the long time horizon over which they are projected. Indeed, some large increase in program costs should be expected and taken into account by decisionmakers. Section II will examine the sensitivity of benefit-cost calculations to discounted R&D costs at the PFES level of $5 billion and at higher levels of $10 billion and $15 billion. The third section discusses an alternative R&D strategy that treats the technological uncertainties in a more appropriate manner.

As an aside, the PFES treats a wide range of variability in factors affecting the benefit side of benefit-cost calculations, but does no analysis of cost. Variability in costs has great impact on net benefits, as Section II will show. A much more extensive analysis is needed of costs to illuminate the basis for the estimates and identify the sources of uncertainty.

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[1]ERDA Staff Statement, May 27, 1975, p. 4. This statement can be compared to a similar assessment by the Secretary of the Air Force before Congress in 1966 with respect to the development of the C-5A transport aircraft: "The C-5A is within the state of the art and we should have no great trouble in building it." In 1975, the GAO reported: "They [officials of the Military Airlift Command] explained that the C-5's major systems and subsystems, as well as the airframes, are extremely complex and that their designs are at the upper limits of the state of the art."

[2]A specific case of cost underestimation is the NCBR for which the PFES includes $276 million, surely far too low an amount for the government share.

[3]Alvin Harman, A Methodology for Cost Factor Comparison and Prediction, RM-6269-ARPA, The Rand Corporation, 1970.

Discount Rate

We have little to add to the voluminous literature on the appropriate discount rate except to comment on the treatment of the discount rate in the PFES.

The PFES uses discount rates of 10, 7-1/2 and 5 percent. I am persuaded by the literature and by analytical experience that the appropriate rate is at or near the high end of this range. The calculations based on 5 percent should be seen as having only arithmetic interest.

Contrary to the PFES, I do not agree that the conclusions turn heavily on the discount rate. Factors such as technological uncertainty, future electricity demand, capital cost differentials, uranium supply, and others not reviewed here have, in my view, more impact on and relevance to a decision on the LMFBR. It is not discounting that makes it difficult to reach a conclusion in favor of "full speed ahead" on the LMFBR but, rather, the location of the ranges of uncertainty on other key parameters.

Electrical Energy Requirements

Future electrical energy demand in the PFES cost-benefit analysis centers "around a case based on historical projection" [11.2-55], with total energy demand continuing to grow in relation to GNP much the same as in the last 25 years [11.2-53]. In particular, near- term growth over the next decade is expected to maintain past trends at about a 7.8 percent annual growth rate. From that point on, alternative growth paths are assessed until the year 2020. A critical section of the growth path is the early period where the base for future growth is established. A 7.8 percent growth trend over ten years would result in a level of electricity consumption that is 29 percent higher than the level for a five percent growth rate, and 42 percent higher than the level for a four percent rate. Even if projected growth after the first decade is reduced to the same low level for each of the initial alternatives, the differences established in the first decade will persist. Since this near-term future is close to recent experience, uncertainties in prediction should be relatively amenable to detailed analysis, whereas the long-term predictions are appropriately made with cruder tools.

Most of the independent analyses of future electricity demand have estimated early period growth rates considerably below the PFES base case, with consequent low consumption levels projected for future periods. The Environmental Protection Agency (EPA), citing Project Independence projections, calculates electrical energy demand for 2020 to be 28 to 33 percent below the PFES base case. They believe that even a 50 percent lower figure is a reasonable possibility.[1] The Federal

[1] Environmental Protection Agency, "Comments on Proposed Final Environmental Statement," April 1975, pp. 3, 10.

Energy Administration finds the PFES projection out of date and provides an analysis showing a 5 percent growth rate for the next ten years, and a 25 percent lower demand than the PFES estimate through 2000.[1]

Unpublished studies by National Economic Research Associates (NERA) project a ten-year growth rate of 5.5 to 6.5 percent.

Studies performed at Harvard allow energy demand to be determined endogenously within the model through a price elasticity.[2] Initial trials with this enlarged model suggest electrical demand in 2000 to be 50 percent below the PFES base case.

Milton Searle has estimated a range of growth rates through 2020. His high trend through 2000 yields a demand level for that year approximately one-third lower than the PFES base case.[3]

This catalogue of research results could be extended, but the implication is clear. Most independent analyses produce electrical energy growth rates more like the PFES "low" to "very low" estimates. The PFES "base case" should be considered quite high. As suggested above, many of the differences among these estimates can be traced to the near-term projections. Fortunately, the uncertainties of the next ten years can be reduced through better research and time, both of which ERDA ought to be buying.

II. THE COST-BENEFIT ANALYSIS AS A TOOL FOR DECISION

A major theme of the cost-benefit analysis and the PFES as a whole is the great uncertainty in a program as complex and extended through time as the LMFBR. The range of examined alternatives is sweeping. For many of the analyzed cases, there are substantial returns to the possession of a successful breeder technology. On the other hand, many cases exist for which the LMFBR would not be a paying proposition. Incorporating revisions to the analysis as suggested in the preceding section leads me to believe that the cost-benefit analysis in the PFES tends to be strongly biased in favor of the LMFBR.

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[1] Federal Energy Administration, Comment letter 89, May 1, 1975.

[2] Alan S. Manne, "Preliminary Results From Endogenous Demand Model Breeder Commercialization," unpublished paper, April 23, 1975.

[3] Milton Searle, Uranium Resources to Meet Long-Term Uranium Requirements, Electric Power Research Institute, September 1974.

The effects of revising the base assumptions are summarized in Table 3. The Table provides a count of the cases calculated in the PFES with benefits less than \$5, \$10, and \$15 billion. The PFES estimates the discounted R&D costs at \$5 billion. However, our discussion above suggested the \$10 billion, or even \$15 billion, are possible, perhaps likely, outcomes. For the 61 LMFBR cases[1] analyzed in the PFES, 15 (or almost 25 percent) predicted gross benefits below \$5 billion, and 28 (46 percent) fell below \$15 billion. From the total of 61 cases, Table 3 displays selected subsamples that illustrate the impact of the higher capital cost differentials and lower electrical energy growth discussed in Section I. In addition, an optimistic uranium supply condition was also included in Table 3 to illustrate the sensitivity of results to variations in that parameter.

With a capital cost differential of \$100/kW between LMFBR and LWR plants, 15 out of 16 cases have gross benefits smaller than \$15 billion, and 11 cases are smaller than \$5 billion. When this high capital cost differential is combined with low electrical energy demand growth, the results are even more striking -- 7 out of 8 cases show benefits smaller than \$5 billion. Both of these conditions, I believe, are more likely than the base case assumptions in the PFES.

In fact, I must point out that the \$100/kW capital cost differential was used here only because these calculations were available, and not because the differential should be expected to be that small. If the differential were as high as \$200 or \$300/kW (as seems more likely), gross benefits would be commensurably smaller, and perhaps even negative. In the linear programming model used in the cost-benefit analysis, the introduction rate of the LMFBR was dependent on economic factors as the LMFBR competed with other energy sources -- unless constraints were imposed on the model. When a test calculation was made in which only the "early commercial" breeder was available (at, presumably \$520/kW capital cost) and no constraints were imposed, the model "produced a small benefit" [11.2-132].

On this evidence, and on the evidence cited in Table 3, I would guess that, in an unconstrained case, higher cost differentials would make the LMFBR uneconomic. Nevertheless, all of the predictions are probabilistic and detailed predictions beyond 2000 border on the psychic.

Given the wide range of possible net benefits -- from large negative values to even larger positive values -- of what use is a cost-benefit analysis of the kind presented in the PFES? If the net benefit had turned out to be predominantly either positive or negative when future possibilities were assessed over the distribution of probable

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[1]To the 76 cases of Table IV.D-1 in the PFES were added three cases taken from Figure 11.2-11 (page 11.2-19), and three cases from Environmental Protection Agency, Comments on PFES, April 1975, Table 1, p. 18. Of these 82 cases, 21 were base case analyses without LMFBR. Therefore, 61 cases included gross benefits for possessing the breeder.

Table 3

SENSITIVITY OF COST BENEFIT CALCULATIONS
TO CHANGES IN ECONOMIC FACTORS

Case Selection Criteria	Number of Cases	Number of Cases (at 10% discount) with Gross Benefits Less Than: $15 Billion	$10 Billion	$5 Billion
All cases	61	28	23	15
Energy Demand: base case or lower	53	28	23	15
Uranium supply: base case or optimistic	43	20	18	13
Capital cost differential: +$100/kW	16	15	13	11
Energy demand: lower than base case and Uranium supply: base case or optimistic	35	20	18	13
Capital cost differential: +$100/kW and Uranium supply: base case or optimistic	10	10	10	9
Capital cost differential: +$100/kW and Energy demand: lower than base case	8	8	8	7

values, the analysis would provide a signal for a "go" or "no-go" decision. This review suggests that the outcome is much closer to the "no-go" end than does the PFES. Still, there is considerable uncertainty. The outcomes of the analysis do not permit opponents to condemn the project out of hand as uneconomic, or -- for that matter -- a prudent decisionmaker to commit the nation to an LMFBR economy.

The PFES cost-benefit analysis is not primarily a decisionmaking document, although, at least in revised form, it can contribute to the decision process. It reflects, rather, the perceptions and needs of those outside the LMFBR project. The requirements of the environmental impact statement call for the forecasting and evaluation of a highly uncertain future. The AEC tried to cope with these requirements by calculating hundreds of outcomes under varying assumptions. However, each scenario represents the uncertainties as though they were all resolved before any actual decisions have to be taken. To some degree, this approach derives from programmatic Environmental Impact Statement requirements, but it also reflects the actual LMFBR program plans.

The analysis conveys a strong impression throughout that it is important to decide now either to accept or reject an entire development program. For example, delaying LMFBR introduction by a few years is pictured as a case of all loss and no gain. But large positive benefits could result from delaying or extending the program; ongoing ERDA studies, research, and facility development during the period of delay would surely generate information that would lessen the potential for costly mistakes. Analyses performed by James Plummer and Richard Richels for the NSF Office of Energy R&D Policy indicate that the PFES portrayal of losses due to delay are unduly pessimistic. As one scenario, they incorporate a lower electrical growth path (beginning with 5.6 percent through 1985) and assume that total undiscounted R&D costs will remain constant if the program is delayed; however, discounted R&D costs fall as these expenditures are shifted into future years. The Plummer and Richels results can be interpreted to show that net discounted benefits are relatively insensitive to LMFBR availability dates over the period from 1988 to 2006. Thus, even within the restricted scenario structure of the cost-benefit analysis, there is evidence that a go/no-go decision is not necessary at this time.

For decisionmaking purposes, one could perhaps develop a better model of the actual development process through use of a probabilistic decision analysis. However, even a decision-tree analysis that explicitly treats the uncertainties of the program and the multiple potential paths that may be taken, may not be able to deal with the "strong uncertainties" that exist in a major R&D undertaking. That is, one must admit future possibilities that are inconceivable at present, whose probabilities cannot now be estimated. For example, a look back over the past seven years since the first LMFBR cost-benefit analysis was made shows two important, difficult-to-predict events, about which opinions were and continue to be significantly divided -- the large increases in fossil fuel prices stemming mainly from OPEC cartel actions, and the great impact of environmental concerns on the costs and plans for nuclear power. These events have critically affected the course of nuclear power. If over a seven-year period, two major new sources of uncertainty arose, consider the probability of other equally powerful and uncertain events arising over the next 25-40 years covered by the cost-benefit analysis.

In short, the cost-benefit analysis underlines the high degree of uncertainty surrounding the LMFBR and provides some understanding of how a wide range of future events may affect the economics of an LMFBR investment. Incorporating a set of modified assumptions that we believe are more likely than the base-case assumptions yields a high percentage of possible outcomes with low or negative payoff. The work by Plummer and Richels for NSF suggests that net benefits are not substantially reduced by a delayed introduction and commercialization of the LMFBR. All of these conclusions point to a policy that recognizes the uncertainty and is willing to trade time for knowledge. Section III discusses such policy approaches.

III. GUIDES FOR FUTURE POLICY

This section seeks to describe a strategy for decision rather than prescribe a specific course of action. The major features of a sequential development strategy are outlined first. Next, some of the impediments to such a policy are considered. Finally, techniques that may aid in implementing a sequential strategy are discussed.

It can be postulated that the purpose of a federal demonstration project encompassing great uncertainty in many dimensions is to reduce that uncertainty through the generation of validated information. The success of demonstration should therefore be judged by its efficiency in doing this job -- reducing the uncertainty -- and not by whether the technology is ultimately disseminated.

The uncertainties relate to several dimensions of this project -- technology, costs, demands, reliability, safety, licenseability, etc. A current Rand study of federal demonstration projects suggests that if the technological uncertainties are not well in hand, the ability of a demonstration to reduce the other dimensions of uncertainty is likely to be compromised. The first task, therefore, is to prove out the technology before proceeding to the next phases. Though I do not claim specific technical expertise on the LMFBR, the evidence seems to indicate that this first task has not yet been completed.

ERDA is conducting major studies to reduce many of the uncertainties. For example, over the next five years, the Natural Uranium Resources Evaluation Program should substantially increase our knowledge of domestic uranium availability. Even without special studies, new information is continuously becoming available that alters the analysis and outcomes of the LMFBR: "The principal difference between this cost-benefit study and previous cost-benefit studies is that the basic input data have appreciably changed... Because of this, a new study was required for this Environmental Impact Statement." [11.2-1]

Rand studies on technologically advanced systems have shown that austerely developed technical feasibility prototypes are highly desirable both for components and for the entire system before significant work is done to verify the other dimensions of the system.[1] The purpose of austerity is to force developers to use as much off-the-shelf technology as possible, to pursue new designs only where necessary, and to infuse the project with greater creativity and more astute engineering.

Many of the European breeder development programs have proceeded in an incremental, step-like fashion. The French have resisted commitment to a new phase until the reactor of the preceding phase was operating successfully. In Germany, the 20 mW sodium-cooled thermal reactor at Karlsruhe is being modified for operation as a fast reactor. The Soviet Union reworked a 100 kWt (kilowatts thermal) mercury-cooled plutonium reactor into a sodium-cooled plutonium reactor of 5 mWt power. This reactor was later modified for operation at 10 mWt. By changing as few things as possible at each new step, the uncertainties associated with each advance are reduced. Each specific design may not be optimal, but it works, and the sequence can lead to an optimal system design that works.

An essential feature of a sequential strategy is the learning that goes on between phases. Incremental design reduces the amount of testing and learning that must be done at each step. But it is vital that the test and evaluation phase not be ignored. Once again, this takes time; in weapons developments, the costs of not taking this time is measured in billions of dollars and reductions in effective force size. When time is not critical, as in the LMFBR case, it is a cheap commodity; and there have been very few instances where a rush to completion can be justified after the fact. For that matter, there is little hard evidence to support the assumption that incremental, sequential development is slower, in the end, than compressed, concurrent development. It is at least as safe to conclude otherwise.

To summarize, my recommendations for a sequential development strategy include: austere development; incremental design; and time to test. Faced with such a large degree of uncertainty, the prudent decisionmaker will (a) elect not to make decisions that can't be wisely made now (commitment to the currently proposed full develop-

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[1] Robert L. Perry, et al., System Acquisition Strategies, R-733-PR/ARPA, The Rand Corporation, June 1971; Burton H. Klein, et al., Military Research and Development Policies, R-333, The Rand Corporation, December 1958; L. L. Johnson, The Century Series Fighters: A Study in Research and Development, RM-2549-PR, The Rand Corporation, May 1960.

ment program), (b) make today only the decisions that must be made today (for example, key components of CRBR), and (c) plan for the resolution of uncertainty over time (uranium supply, electricity demand, capital costs, R&D costs, etc.). To put it another way, a program that requires a minimum of 12 years to complete is simply beyond human ability to preplan with such confidence that one would want to commit to all of it.

One final point about this strategy: if everything goes well as proponents claim it will, if all the uncertain parameters turn out as estimated in the PFES, and if all the technology is as well in hand as proponents contend, this strategy will result, with very high confidence, in a working, safe and economical breeder only a few years beyond 1987. If the PFES scenario is adopted and proves faulty in any major respect, the least unfavorable result would be significant schedule slippage and cost growth.

Why is such a strategy so difficult to adopt for large, U.S. government programs? Project proponents don't like a sequential process. It implies smaller budgets stretched out over time. It appears to complicate their task by comparison with the illusory alternative of commitment to a fully preplanned course. The project can be perceived as easier to kill if things do not turn out too well -- or even if they do -- because there are no large economic or political consequences linked to cancellation.

Project opponents don't like this kind of low-profile sequential decisionmaking, either. They view it as the camel's nose under the tent. The program can be perceived as hard to kill in the early stages because the major production decision may be years away and no important resource commitments will be up for review until then. The project can develop a constituency and momentum over time that will later roll over its critics.

Politicians may have other reasons for disliking the sequential approach. They may feel short on the expertise needed to evaluate program decisions year after year. Multi-billion dollar decisions are political decisions with high transactions costs to those involved.

Thus, many pressures converge to force a major program review into a take-it or leave-it framework.

Despite the difficulties in running a sequential development program, I believe that ERDA should implement such a strategy. The present situation has grown out of past decisions, promises, and habits that will be hard to change. A shift in direction at this point, however, can be viewed as the result of a frank appraisal of new information and analyses. A stance of openness before the Congress and the public will certainly help to gain their confidence and trust and, perhaps, their grant of authority to manage the program. Further, there is no need to sell the LMFBR now as a billion-dollar program. Rather it can be straightforwardly described as a step toward reducing uncertainty and averting risk for the future. This would require a retrenchment of goals and a slimming down of tasks, but that may be a rational response at the present time.

It must be openly acknowledged that much uncertainty exists in pursuing any new technology -- especially one, like LMFBR, that depends on world-wide events beyond the control of the project. A detailed future cannot and should not be promised; there is always the possibility that the resources spent in advancing LMFBR technology may not have the desired payoff. However, such efforts can be structured to enhance the probability of success and to reduce the cost of failure.

ERDA is of course now more than nuclear. A relative reallocation of resources within the agency, as implied by recommendations to scale down and stretch out the LMFBR, could enhance internal competition and foster more realism in estimates generated by intramural reviews and critiques. It should also be noted that a non-sequential process (which includes the option of cancellation) formally eliminates the possibility of learning, increases uncertainty by straight-jacketing the future, and increases the probability that costs (whether social or project) will be greater than necessary. That is, a truly sequential approach could turn out to cost less and take little, if any, additional time to attain the objective of a reliable, safe, and economical breeder system.

ERDA stands astride many technologies and many possible changes. Its actions today can have a significant impact on the future. Winning approval to carry out an LMFBR project as currently structured could be a Pyrrhic victory. A defeat could carry over to broader issues. A sequential strategy, honestly taken, periodically and critically appraised, with the goal of reducing uncertainty and generating validated information, can perhaps establish a course between these two equally undesirable outcomes.

Sincerely,

Donald B Rice

Donald B. Rice
President

DBR:jy

cc: The Honorable Robert W. Fri,
Deputy Administrator, ERDA