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Bypassing the Breeder

A Report on Misplaced Federal Energy Priorities

By

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March, 1975

At a time of soaring power costs, federal energy officials are giving prime attention to the development of a new nuclear power source which for the next thirty years or longer will not be able to produce electricity as cheaply as existing sources.

At a time when the wisdom of a national commitment to nuclear fission power is increasingly doubted, federal energy policy is according highest priority to the development of a new type of fission reactor which promises to be even more hazardous and problematic than today's reactors.

At a time when new non-fission energy alternatives, including solar, geothermal and fusion energy, are poised for major breakthroughs, federal energy funding is heavily weighted towards a nuclear development program which is experiencing cost overruns of such magnitude that they will severely restrict the funding available for these alternatives.

Such disquieting ironies are the trademark of the federal government's program to develop the Liquid Metal Fast Breeder Reactor (LMFBR). Raised to preeminence by a President who later confessed that "all this business about breeder reactors and nuclear energy is over my head,"[1] the LMFBR has been oversold by its proponents to the point that it is now one of the great white elephants of the day.

The LMFBR's dominance of the energy research and development scene stands out clearly in recent budget estimates. During the coming fiscal year the new Energy Research and Development Agency

(ERDA) plans to spend $1.66 billion on direct energy R&D. Of this amount, over $490 million is to be spent on the LMFBR program. This is roughly a third of ERDA's budget for energy R&D and more than the combined allocations to fossil energy development ($311 million), solar energy development ($57 million), geothermal energy development ($28 million), advanced energy research ($23 million) and energy conservation ($32 million).[2]

The total cost of developing the LMFBR is now estimated to be $10 billion,[3] and this estimate, made by proponents of the program, must be judged as conservative. 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.[4] The principal test facility of the program, the Fast Flux Test Facility (FFTF) was originally planned to cost $87 million, but the latest estimate is $933 million, more than a tenfold increase.[5] Congress was told in 1973 that the proposed Clinch River Breeder Reactor Plant (CRBRP), the first LMFBR demonstration plant if one overlooks Fermi-I,* would cost $700 million. Today, the estimate is over $1.7 billion.[6] There is no sound reason to believe these trends will not continue.

These figures indicate at a minimum that the LMFBR program could cost the American taxpayer a very substantial sum. It would be reassuring if such expenditures could be justified, but they cannot. Unfortunately, the LMFBR program is neither needed nor desirable, for several reasons.

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*/ Fermi-I, the first commercial LMFBR plant, experienced a partial core meltdown and has subsequently been shut down.

First, economic analysis of the potential of the LMFBR[7] indicates that, contrary to Atomic Energy Commission expectations, the new reactor cannot be commercially competitive with existing energy sources until after the year 2010. Yet the current LMFBR effort is aimed at having the new reactor developed by 1990, more than two decades before it could be economically attractive. 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 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, non-fission energy options can be made available in time to eliminate the need for the LMFBR altogether. Recent 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.[8]

These considerations indicate that a major LMFBR effort is not needed now and perhaps 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.

Our recommendation in light of these conclusions is that ERDA take the opportunity it now has to break with the mistakes of the past, that it postpone for a decade or so any push to commercialize the LMFBR, cancelling the CRBRP and relegating the overall program to a relatively low-priority effort, and that it accelerate the development of attractive non-fission alternatives such as solar, geothermal, fusion and energy conservation. Much can be learned during the coming decade -- most likely we will learn that the breeder can be bypassed -- and the delay would impose no penalty on the nation.

Breeder Impacts: Unprecedented Risks

The LMFBR program has proceeded in the face of mounting apprehension within the scientific community concerning the human and societal hazards of nuclear fission reactors, apprehension which would only be increased by the LMFBR. As evidence of this apprehension, scientists from many nations at the 23rd Pugwash Conference on Science and World Affairs in September, 1973, concluded:

> "1. Owing to potentially grave and as yet unresolved problems related to waste management, diversion of fissionable material, and major radioactivity releases arising from accidents, natural disasters, sabotage, or acts of war, the wisdom of a commitment to nuclear fission as a principal energy source for mankind must be seriously questioned at the present time.

"2. Accordingly, research and development of alternative energy sources -- particularly solar, geothermal and fusion energy, and cleaner technologies for fossil fuels -- should be greatly accelerated.

"3. Broadly based studies aimed at the assessment of the relation between genuine and sustainable energy needs, as opposed to projected demands, are required."

Addressing the risks of the LMFBR specifically, the Pugwash scientists concluded that the LMFBR would not eliminate any of the hazards we now associate with nuclear power but in critical respects would actually heighten them. The principal advantage of the LMFBR is its ability to produce or "breed" unprecedented quantities of plutonium. Today's nuclear reactors also produce plutonium, but the LMFBR is designed to produce more of this nuclear fuel than it consumes. By the year 2020, the AEC projected total plutonium generation to exceed 30,000 tons, principally from the LMFBR.[9]

Unfortunately, as events are making us painfully aware, plutonium is probably the most dangerous substance known.[10] It is fiendishly toxic: a millionth of a gram has been shown capable of producing cancer in experimental animals. Plutonium-239, the principal isotope of the element, has a half-life of 24,000 years, so that its radioactivity is undiminished within human time scales.

Plutonium is also the substance from which nuclear weapons are made. An amount the size of a softball is enough for the production of a nuclear explosive capable of mass destruction. Scientists widely recognize that the design and manufacture of a crude atomic bomb is not a technically difficult task,[11] a fact dramatized recently when a Massachusetts Institute of Technology undergraduate successfully designed a nuclear weapon for an educational television program.[12] The only real obstacle to the building of homemade atomic bombs is the availability of plutonium itself, and now, first with the proposed use of plutonium in today's reactors and even more with the introduction of the LMFBR, this final obstacle would be removed. In the "plutonium economy" envisioned by the AEC, a plutonium black market and nuclear theft and terrorism become high probability events -- threats real enough to have spurred nuclear proponents to urge the creation of a federal security system that would meddle with our civil liberties on a vast scale.[13]

In addition, the LMFBR itself is considered even less safe than today's light water reactors. The LMFBR core, where the heat is generated, is far more compact than a light water reactor core, and instead of water the LMFBR uses liquid sodium -- an opaque and highly reactive element -- as coolant. Partial loss of coolant -- "voiding" -- in a breeder increases the nuclear reaction in the core rather than reducing it. The LMFBR's operation is extremely sensitive to fuel motion and loss of coolant from the core in accident situations, leading to the possibility of an explosive nuclear runaway. In the event of a meltdown, the breeder's highly enriched fuel can rearrange itself into a more compact configuration with the possibility of small nuclear explosions of sufficient force to breach the reactor containment. There are major uncertainties in defining the explosive potential of the breeder, which are all the more worrisome considering the several tons of plutonium in it.[14]

For these reasons, a decision to commit this nation to the LMFBR may prove to be the most significant technological decision since the Manhattan Project. The breeder reactor decision is literally a decision for all people and all time. Any action which actually increases the likelihood that the breeder and the plutonium economy will become realities should be taken only with the most compelling justification.

Breeder Economics: Missing Benefits

The stated justification for the LMFBR runs along the following lines. As the nuclear power industry expands the U.S. is slowly depleting its low-cost uranium reserves, with the result that the price of uranium is rising and is expected to continue to do so. The principal substitute for uranium is plutonium, a man-made element produced in nuclear reactors. Since the LMFBR generates about twice as much plutonium as today's reactors, its use would tend to expand greatly the supply of nuclear fuel, perhaps 50-fold, and accordingly hold down its price.

Because of the LMFBR's advantage as a plutonium producer, the AEC in the mid-1960's made achieving its early commercialization the agency's highest priority objective. The current program is geared to achieving commercial introduction in about 12 years, i.e. in about 1987.

How sound is the economic case for the early commercialization of the LMFBR? Not very, we believe. The most useful methodology for pulling together the many variables which determine whether the current LMFBR program can be justified economically is cost-benefit analysis. The AEC performed three cost-benefit analyses of the LMFBR program, the latest appearing first in the Draft and then with revisions in the Proposed Final Environmental Statement for the program. Not surprisingly, constrained to justify its own project, the AEC consistently found that program benefits outweigh the costs. Significantly, the Environmental Protection Agency ruled that the AEC's Draft Environmental Impact Statement was inadequate largely because of deficiencies in the AEC's cost-benefit analysis.

When cost-benefit methodology is applied to the LMFBR program, the results are very sensitive to the assumptions made regarding (1) the capital cost difference between the breeder and conventional reactors; (2) the anticipated supply of uranium; (3) future electrical energy demand; (4) the rate at which conventional reactors penetrate the utility market; (5) the discount rate; (6) the R&D cost of the breeder program; and (7) the reactor performance data for the breeder. The first three of these are extremely important.

The AEC succeeded in making the LMFBR appear attractive by making very favorable, but very unrealistic, assumptions in each of the seven areas listed.* In the Appendix to this report, we have evaluated the economic merits of the LMFBR program using the AEC's cost-benefit methodology but looking outside the AEC to independent opinion as to what assumptions should be made in each critical area. Taking this approach, we demonstrate that the expected economic benefits of the breeder are only a small fraction of the R&D costs. For every $10 spent on developing the breeder, the public will get back

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*/ In the introduction to its recent proposed final impact statement for the LMFBR program, but not in the cost-benefit analysis itself, the AEC was apparently forced by the press of events, including the recent deferrals and cancellations of planned reactors, to abandon its unrealistic assumptions regarding future energy demand and LMFBR introduction date. Using what the AEC now considers more reasonable assumptions in these two areas, but without changing any of the other AEC assumptions, the net benefits of the LMFBR program drop to zero. In other words, by the AEC's own reckoning the present breeder program can no longer be justified economically. See Appendix, pp. 44-48.

only $1 or less in lower energy costs. In sum, when assumptions based on the work of expert authorities outside the AEC are used, the present LMFBR program simply cannot be justified economically. Only when a series of highly unrealistic assumptions are made does the analysis suggest that the LMFBR program will produce net economic benefits.[15]

These results indicate that the commercial introduction date of the breeder can be delayed substantially, probably two decades or more, without economic penalty. The poor performance of the LMFBR in cost-benefit analysis stems from the fact that during much of the period of the analysis (1987-2020) the LMFBR cannot compete economically with alternative sources largely because of its high capital costs, so that only a limited number of LMFBR's are constructed. For example, until the price of uranium rises sufficiently to offset the high capital costs of the LMFBR, utilities will continue to prefer today's reactors. Using the data set out in the Appendix, we have estimated that not until after the year 2010 can it be expected that the LMFBR would gain a competitive edge over present-day reactors.[16] This date is approximately two decades beyond the LMFBR commercial introduction in the current program schedule. Similar conclusions have been reached by others. David Rose, writing in Science, stated recently:

> "I estimate that the breeder will almost surely be attractive when U_3O_8 reaches $50 a pound in 1974 dollars. That will not happen in the first few decades of the 21st century. In the meantime, nuclear power is in no danger of losing out to other fuels, and there does not need to be a crash breeder program. Economic introduction at A.D. 2000 would be a sign of technological good fortune, not of resolving an energy crisis with a time limit."[17]

In sum, the current rush to introduce the breeder is hardly justified. Postponement would impose no penalty, and it would focus attention and effort on the promising non-fission alternatives to the LMFBR.

Alternatives to the Breeder: New Possibilities

A fission-free option to the LMFBR which can provide reasonably priced and environmentally acceptable energy almost certainly exists and can be made available within a suitable timeframe. The claim that the LMFBR or other breeder reactor is in any sense necessary must be rejected -- the breeder is no more necessary than we make it by refraining from developing other technologies. 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. Moreover, as we shall show, heavier reliance upon the various aspects of this program would facilitate phasing-out all fission reactors, leading to a fission-free energy economy.

In brief outline, there are several major efforts the adoption of which is central to an alternative energy program:[18]

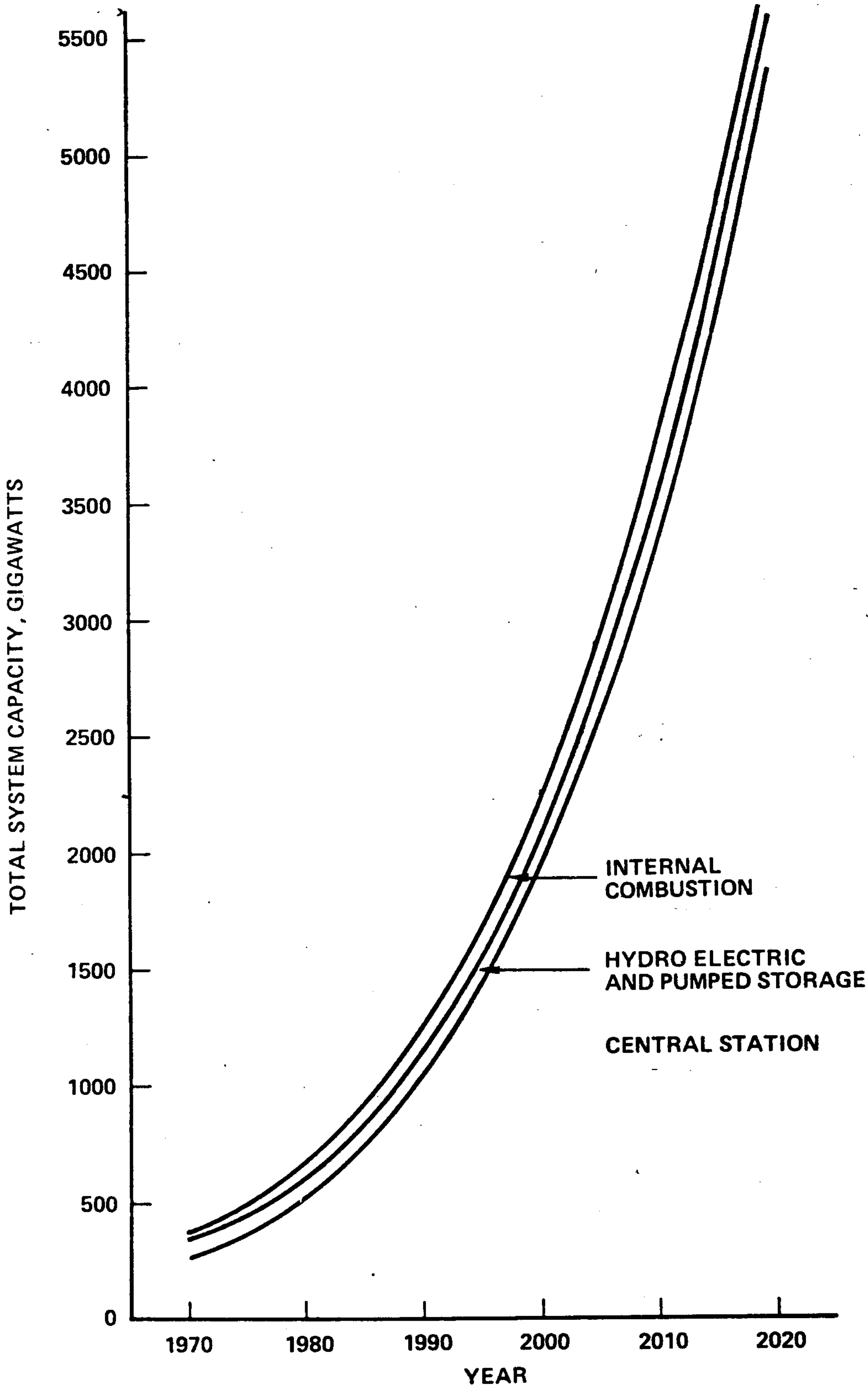
- An intensive effort to develop the various forms of solar energy should be undertaken following the recommendations of the expert panels convened under National Science Foundation auspices, An Assessment of Solar Energy as a National Energy Resource (1972) and Solar and other Energy Sources: Subpanel IX Report (1973).[19] 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% of the nation's total building heating and cooling load, 30% of the nation's gaseous fuel, 10% of its liquid fuel, and -- most important for present purposes -- 20% of the electrical energy requirements.[20]

- 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) concluded 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."[21] 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.[22] The AEC recently estimated that geothermal heat could supply 6% of our electricity in the year 2020,[23] 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."[24] The agency anticipated "commercial introduction of fusion power plants on a significant scale beginning in the early 21st century."[25] 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% of our electricity could come from fusion.[26]

- Organic wastes provide another source of fission-free energy that should be developed. Here the AEC estimates that organic wastes could account for 5% of the demand for electricity in the year 2000 but only 2% in 2020 due to more efficient practices in the solid wastes area.[27]

- All of the above year 2020 percentage contributions, e.g. 20% for solar, 6% for geothermal, etc., are based upon a year 2020 energy demand that assumes a continuation of extremely rapid growth in electricity demand. Such projections can yield an electricity consumption in the year 2020 that is over fifteen times today's, a result widely regarded as completely unrealistic. For illustration, the electricity growth projection used by the AEC to justify the LMFBR program is set out on the following page. The steepness of the curve staggers the imagination. 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. These studies suggest that actual future demand will be less than half of that projected by the AEC.[28] 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.[29] 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



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.

that electricity demand in the year 2020 will not exceed 50% of the AEC's astronomical projection.

Table 1 summarizes some of the data presented in the preceding paragraphs. It shows that it is not unreasonable to expect that over 80% of the electricity demand projected by the AEC for the year 2020 can be accounted for principally by a combination of solar, geothermal, and fusion energy together with more accurate forecasting of energy demand. This percentage is larger by a substantial margin than the contribution expected of the LMFBR by the AEC in 2020(50%) and, indeed, is larger than the contribution the AEC expected from nuclear fission generally (70%). Accordingly, an energy program designed to achieve these objectives could wholly eliminate the need for the LMFBR even if it failed in major respects.

Table 1 indicates that other sources, principally fossil fuels, could be called upon to provide the remaining portion of U.S. electricity needs in 2020. It is likely that our abundant supplies of coal will be relied upon for several decades as a significant power plant fuel. Thus, quite apart from the question of whether the LMFBR is introduced, the development of environmentally responsible means of mining and utilizing coal must be an essential and high priority national objective. The contents of an R&D effort aimed at achieving this objective have been discussed by numerous authors.[30] Elements include strict regulation of surface mining, more efficient and safer technologies for mining deep coal, stack gas cleanup, new combustion technologies and coal gasification and liquification.

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

The funding needed for this alternative energy strategy would not be unacceptably high. It is significant that the last of the AEC's official projections of future LMFBR expenditures, $8 billion to program completion, exceeds a recent Federal Power Commission estimate of the total R&D costs of developing all non-nuclear technologies, including coal gasification, solar (direct and indirect) and geothermal technologies, advanced steam cycles, MHD, fossil fuel effluent controls, and a variety of energy storage systems.[31] The FPC estimate of $6 billion, however, does not include the cost of developing fusion systems, which is expected to be comparable to that of the LMFBR.[32]

The last refuge of the breeder proponent is the argument that the LMFBR is needed as an "insurance policy." The above considerations indicate that this is simply not the case. 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. Moreover, relegating the LMFBR program to a low-priority status and foregoing any expensive push towards demonstration and commercial reactors for from 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 program. The idea that there is a penalty for such a postponement, is, as we have seen, wholly spurious.

What Should Be Done With the LMFBR Program?

Almost everyone, we believe, would prefer to bypass reliance upon the breeder reactor and move directly into using solar, geothermal and fusion energy and energy conservation. The real LMFBR debate centers around whether it is possible to make this leap. We join many experts in believing that it is. Yet, unfortunately, no one will ever know the answer to this question if the present LMFBR program is permitted to continue. By swelling the bureaucratic and industrial forces committed to the LMFBR and by draining away R&D funds that are essential to the timely development of the alternatives that could replace the reactor, the LMFBR program is its own self-fulfilling prophesy.

As a way out of this quandary, we suggest an option to the present program which meets the objections of both optimists and pessimists and therefore should command general support. First, federal energy officials should delay the LMFBR program a decade. We have seen that the program is premature and that there is no penalty in such delay. During this period, the LMFBR effort should be recast as a low-priority program centered on the FFTF, and current plans for going ahead with the costly Clinch River demonstration plant should be cancelled. By greatly reducing the overall costs of the program, funds will be freed for the accelerated development of solar, geothermal, fossil, fusion and conservation technologies, and the tremendous public and private investments which could foreclose the option of ever stopping the LMFBR will be avoided. The 10-year postponement would also provide a period during which several types of data which bear critically upon the desirability of the

LMFBR program could be gathered and assessed. First, more accurate information on uranium availability and future energy demand could be obtained. Second, during the coming decade knowledge regarding the potential of solar, geothermal, and fusion energy should increase dramatically with appropriate funding. And, third, this grace period could also be used to answer critical health and safety questions raised by the LMFBR with far more certainty than now present.

The problems associated with the present reactor program strongly suggest that we are only perpetuating and compounding a bureaucratic blunder by pursuing the current LMFBR program. The alternative strategy suggested here would provide an opportunity to correct that mistake--before it is too late. Construction is scheduled to commence on the Clinch River demonstration plant towards the end of this year, with the necessary approvals coming much sooner. Once these hurdles are cleared, it will be far more difficult to reorient this increasingly massive program.

FOOTNOTES

1. Office of the White House Press Secretary, Remarks of President Nixon at the AEC Reservation, Hanford Works, Hanford, Washington, September 26, 1971.

2. U.S. Energy Research and Development Agency, Summary of Budget Estimates, Fiscal Year 1976, February, 1975.

3. The Atomic Energy Commission's Proposed Final Environmental Impact Statement for Liquid Metal Fast Breeder Reactor Program, WASH-1535 (December, 1974), Vol. IV, p. 11.2-33 (cited herein as "PFEIS, LMFBR"), estimates that an additional $8.1 billion must be spent to develop the LMFBR. Approximately $2 billion has already been spent.

4. In July , 1973, the AEC estimated total program costs at between $4 and $5 billion. AEC, Determination Pending Preparation of NEPA Impact Statement, 38 Fed. Reg. 19855 (July 24, 1973).

5. U.S. General Accounting Office, "Staff Study, Fast Flux Test Facility Program," January, 1975, p. 7.

6. The cost overruns associated with the proposed Clinch River demonstration plant are discussed in detail in the Appendix to this report, at page 9.

7. This economic analysis is contained in the Appendix to this report.

8. The non-fission alternatives to the LMFBR are discussed at pages 10-16 of this report.

9. PFEIS, LMFBR, Vol. IV, p. 9.1-47.

10. J. Gustave Speth, Arthur R. Tamplin and Thomas B. Cochran, "Plutonium Recycle: The Fateful Step," The Bulletin of the Atomic Scientists (November, 1974), p. 15, addresses plutonium related hazards.

11. Mason Willrich and Theodore B. Taylor, Nuclear Theft: Risks and Safeguards (1974); AEC, "The Threat of Nuclear Theft and Sabotage" (Rosenbaum Report), Congressional Record, April 30, 1974, p. S6621.

12. New York Times, February 27, 1975 ("Bill Asks Curb on Plutonium Use To Prevent Building of Homemade Bomb").

13. AEC proposals for a federal security system are discussed in "Plutonium Recycle: The Fateful Step," op. cit., and the sources cited there.

14. Thomas B. Cochran, The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique (1974), Chapter 7.

15. Appendix, pp. 39-44.

16. Appendix, pp. 48-49.

17. David J. Rose, "Nuclear Eclectic Power," Science (April, 1974), p. 357.

18. This program is elaborated and more extensively referenced in Natural Resources Defense Council, Comments on the Draft Environmental Impact Statement for the Liquid Metal Fast Breeder Reactor Program: Alternative Technology Options, printed in PFEIS, LMFBR Vol. VI.

19. 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.

20. An Assessment of Solar Energy, op. cit.

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

22. 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).

23. PFEIS, LMFBR, Vol. IV, p. 11.1-20.

24. PFEIS, LMFBR, Vol. III, P. 6A.1-191.

25. PFEIS, LMFBR, Vol. III, p. 6A.1-179

26. PFEIS, LMFBR, Vol. IV, p. 11.1-22.

27. PFEIS, LMFBR, Vol. IV, p. 11.1-21.

28. The electricity demand issue is discussed in detail in the Appendix, pp. 21-28, and in NRDC Comments on Draft LMFBR EIS, Alternative Technology Options, op. cit.

29. Conservation and Efficient Use of Energy, Report of the Committee on Science and Astronautics, U.S. House of Representatives, December 18, 1974; 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.

30. See, e.g., PFEIS, LMFBR, Vol. III, pp. 6A.2-1 through 6A.2-51, and the references cited there; The Nation's Energy Future, op. cit.; Hammond, et al., Energy and the Future (1973), Part I.

31. Federal Power Commission, Report of the Task Force on Energy Conversion Research to the Technical Advisory Committee on Research and Development, November, 1973, DRAFT.

32. PFEIS, LMFBR, Vol. III, p. 6A.1-189.

The Authors

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J. Gustave Speth has been an attorney on the staff of NRDC since 1970, specializing in nuclear power problems. He was the attorney for the Scientists' Institute for Public Information in Scientists' Institute v. AEC, 481 F.2d 1079 (D.C. Cir. 1973), which required the AEC to prepare an environmental impact statement for its fast breeder reactor development program. He is a former Rhodes Scholar and law clerk to Supreme Court Justice Hugo L. Black and is the author of "The Federal Role in Technology Assessment" in Federal Environmental Law (Environmental Law Institute: 1974).

Arthur R. Tamplin was a biophysicist at the Lawrence Radiation Laboratory in Livermore, California, from 1963 to 1974 and is now on the staff of NRDC. During the period June 1967 to January 1969 he was a member of the AEC's Division of Biology and Medicine Committee on Space Nuclear Systems Radiological Safety. The primary interest of this committee was the hazard of plutonium. Dr. Tamplin holds a Ph.D. degree in biophysics from the University of California at Berkeley. He has published and lectured extensively on the problems of nuclear power. His books include Poisoned Power: The Case Against Nuclear Power Plants (with Gofman).

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APPENDIX

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APPENDIX

Economic Analysis of the LMFBR Program

I. Introduction

The Atomic Energy Commission has now written and released three cost-benefit analyses of the U.S. Liquid Metal Fast Breeder Reactor (LMFBR) Program.1/ Operating under the

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1/ The first, written in 1968, was released in 1969;*/ 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.****/ The basic arguments have not changed in this progression of cost-benefit analyses and the principal differences are in the updating of numbers.

*/ U.S. Atomic Energy Commission, Division of Reactor Development and Technology, Cost-Benefit Analysis of the U.S. Breeder Reactor Program, WASH-1126 (April, 1969).

**/ U.S. Atomic Energy Commission, Division of Reactor Development and Technology, Updated (1970) Cost-Benefit Analysis of the U.S. Breeder Reactor Program, WASH-1184 (January, 1972). This analysis was reviewed in detail by Thomas B. Cochran in _The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique_. Resources for the Future, Inc., Washington, D. C. (March, 1974).

***/ U.S. Atomic Energy Commission, LMFBR Environmental Impact Statement, DRAFT, WASH-1535 (March, 1974). Vol.I, pp.1.11-1 to 1.11-3; Vol.III, pp.11.1-1 to 11.2-21; Vol.III, Appendix III-B, pp.B-1 to 4-41 and Vol.III, Appendix III-B, Annex A, pp.A-1 to A-7.

****/ U.S. Atomic Energy Commission, Proposed Final Environmental Impact Statement [PFEIS], LMFBR, WASH-1535 (December, 1974), Vol.IV, pp.11.2-1 to 11.3-3, Appendix IV- B, C, and D.

familiar with the subject can quickly grasp the key issues that account for the differences of opinion about the breeder's economic merit and more easily form their own opinions. (3) The analysis on our part is greatly simplified since we do not have to construct our own model or research the many less relevant input assumptions. The drawback of this approach is that we are constrained in our choice of input assumption since we are forced to rely on values considered by the AEC.

In each of the AEC's cost-benefit analyses, the gross benefit of the LMFBR program is measured by the difference between the cost of meeting a prescribed demand for electricity between now and 2020 with and without the LMFBR -- the gross benefit being positive when the LMFBR is able to produce electricity more cheaply than other sources. The costs of providing electricity, with and without the breeder, are calculated by means of a computer program which schedules the introduction of power stations to meet the demand in the least costly way. The yearly differences in cost, with and without the breeder, are discounted back to the present and added together to form the AEC measure of gross benefit of the breeder program. In the cost-benefit balance this measure of gross benefit is compared with the include an analysis of the sensitivity of NRDC's base case results to changes in the key assumptions. Our analysis here is extremely limited because we are restricted to sets of assumptions actually considered by the AEC.

II. Basic Assumptions

A) Discount Rate: We use 10 percent/year.

The basis for using a discount rate of at least ten percent per year is presented in NRDC Comments on WASH-1535.[3/] The issue of the appropriate discount rate has largely been laid to rest, as the AEC now uses the 10 percent/year value, "based on the preferences of OMB and other organizations and individuals."[4/] This rate is also consistent with the recommendation of EPA.[5/]

3/ "NRDC's Comments on the DRAFT Environmental Impact Statement of the LMFBR Program." Reproduced in PFEIS, LMFBR, Vol.VI, December, 1974. U.S. Atomic Energy Commission, pp.38-162 to 38-164. See also, Cochran, Thomas B., Op. Cit., pp.23-29.

4/ U.S. Atomic Energy Commission, Proposed Final Environmental Impact Statement [PFEIS], LMFBR, WASH-1535 (December, 1974), Vol.IV, p.11.2-47.

5/ EPA Comments on DRAFT EIS, LMFBR Program. Reproduced in PFEIS, LMFBR Program, Vol.VII, pp.53-35 to 53-38.

Table 1

Estimates of the Undiscounted Breeder Program Expenditures from AEC Cost-Benefit Analyses

	1968[a] Estimate	1970[b] Estimate	late-1973[c] Estimate	late-1974[d] Estimate
Breeders				
LMFBR	2.2	2.5	4.0	6.5
Other Breeders	0.8	0.1	0.2	1.4
Support Technology	1.4	1.2	2.6	1.6
Total Breeders	4.4	3.8	6.8	9.5
Non-Breeders	0.7	0.5	0.5	0.7
General Support	2.6	2.5	(not given)	(not given)

a) U.S.AEC, WASH-1126, Op. Cit., 1970 dollars, assumes 1986 LMFBR commercial introduction.

b) U.S.AEC, WASH-1184, Op. Cit., mid-1971 dollars, assumes 1986 LMFBR commercial introduction.

c) U.S.AEC, WASH-1535, DRAFT EIS, LMFBR Program, Op. Cit., mid-1974 dollars, assumes 1987 LMFBR commercial introduction.

d) U.S.AEC, WASH-1535, PFEIS, LMFBR Program, Op. Cit., mid-1974 dollars, assumes 1987 LMFBR commercial introduction.

The second most significant component of the LMFBR Program is the Clinch River Breeder Reactor (CRBR), the first LMFBR demonstration plant if one overlooks Fermi-I.[10/] The first official estimate of its cost was about $400 million. In a 1972 Memorandum of Understanding its cost was estimated at $700 million, two-thirds coming from the AEC and with the AEC (now ERDA) assuming an open-ended risk (i.e., all the cost overruns). This estimate was $150 ao $200 million higher than an AEC estimate only six months previous. In March 1974, it was reported that CRBR project officials are "focusing on some major steps that they hope will hold the total cost of the plant under $1.0 billion.[11/] In July, it was reported that the CRBR project would cost $1.6 - $2.0 billion,[12/] and in September it was pegged at $1.736 billion.[13/] Unfortunately, the demonstration plant of the federal government's priority energy program has a cost doubling time of one year and a fuel doubling time of 30 to 60 years, instead of the reverse (See Figure 1).

10/ Fermi-I, the first commercial LMFBR plant, experienced a partial core meltdown and has subsequently been shut down.

11/ Nucleonics Week 15, March 21, 1974, p.l.

12/ Weekly Energy Report 30, July 29, 1974, p.l.

13/ Weekly Energy Report, 38, September 23, 1974, p.5. Given the cost trend the last three significant digits are a joke.

C) Capital Cost Differential: LMFBR capital costs remain $100/Kw higher than conventional reactors.

Curves of reactor capital costs versus time are presented in Figure 2. The upper dotted line in the figure labeled $100/Kw DIFFERENTIAL," represents most nearly our base case assumption for LMFBR capital costs. In reality, we believe the cost differential will be even higher. The solid LMFBR line represents the AEC's base case assumption. The AEC assumes that the LMFBR will cost no more than conventional reactors after 2000 -- a zero cost differential.

All costs are in mid-1974 dollars. Other ground rules for the capital cost estimates are given in the PFEIS of the LMFBR Program.[14/] It is important to note that (a) since all costs in the cost-benefit study are in constant dollars, these costs do not include allowances for escalaction during construction, and (b) no first-of-a-kind or prototype costs associated with demonstration reactors or what the AEC refers to as "near-commercial" plants are included.

14/ PFEIS, LMFBR Program, Vol.IV, pp.11.2-78 to 11.2-81.

The central issue here is whether it is appropriate to apply a learning curve to the LMFBR capital costs in addition to the learning associated with the reduction/elimination of first-of-a-kind or prototype costs. We do not apply a learning curve to the LMFBR capital costs. If anything such an effect should be negative (i.e., increasing costs). The AEC, on the other hand, has assumed a sharp positive learning curve with respect to the LMFBR that reduces the present value of LMFBR costs by 21.5% in the short 13 year period between 1987 and 2000. This corresponds to 16 percent per decade. Furthermore, this period of learning is assumed to start immediately upon commercial introduction of the LMFBR.

There are four significant points we wish to make with respect to this difference of opinion. The first concerns the appropriate industry against which the LMFBR learning curve should be compared. The AEC concludes that when examined on a classical basis 15/ their assumed LMFBR learning rate "is extremely conservative in comparison with typical values of 80 to 90% learning curves applicable to many industries." 16/ But the appropriate industry for

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15/ It has been established by a number of empirical studies that as a general rule, the logarithm of the cost of a product is a decreasing linear function of the logarithm of the number of units that have been produced.

16/ PFEIS, LMFBR Program, Vol.IV, p.11.2-84. December, 1974. We calculate a lower learning rate than does the AEC, but that is not the point here.

LMFBR program the capital cost differential was estimated at $85/Kw in mid-1974 dollars, and $100/Kw was actually assumed in the cost-benefit analysis. Thus, we see the LMFBR capital cost differential has been increasing at a rate even faster than 10 percent per year in constant dollars. There is little reason to believe this trend will not continue at this rapid pace.

What makes the AEC'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 MW to 2000 MW with an additional 12 percent decrease in price.

Due to the difficulty of incorporating into the AEC's model a learning effect as a function of the number of units sold the AEC has arbitrarily assumed both the learning rate and the rate of commercial introduction of the LMFBR. With more logic one could assume no learning and no LMFBR's purchased, arguing that no learning is anticipated, therefore, LMFBR will not be competitive, hence no one will purchase them. The AEC must argue that in their collective wisdom, the utilities will anticipate a learning effect, and then purchase some 220 LMFBRs to generate it. The AEC

The third point concerns the inconsistency of the AEC's approach. The AEC does not apply a similar learning curve to the HTGR, even though no commercial size HTGR's are expected in operation before about 1980 to 1983. The AEC argues that since the HTGR is subject to the same environmental and safety regulations as the conventional light water reactor (LWR),

> ". . . a reasonable assumption would be to hold the HTGR and LWR capital costs equal throughout the time span considered. This assumption still gives the HTGR a competitive advantage in power costs, since it is projected to have lower fuel costs than LWRs. Because of this, it might be concluded that there exists no great market-place incentive for HTGR capital costs to ever become substantially lower than LWR capital costs." 22/

The AEC's position is inconsistant in that it does not apply this same argument to the LMFBR even though a) the LMFBR is subject to the same environmental and safety regulations and b) the LMFBR is projected to have a competitive advantage in power costs before its capital cost differential is reduced to zero.

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could be $4 billion which they add to the LMFBR R&D cost (FY75-79). Adding this learning cost to the R&D cost has the effect of subtracting from the R&D advantage. It appears from their estimate of R&D expenditures alone that Manne and Yu have understated the undiscounted cost of the breeder program.

22/ PFEIS, LMFBR Program, Vol.IV, p.11.2-84.

every example here, however, there is a counter example which could lead to higher costs. The LMFBR, unlike the LWR, requires an extensive sodium component and piping system heating system required for preheat, wetting and maintaining sodium in a molten state during shutdown. Remote automatic refueling is required under controlled environmental conditions. Reactor manual and automatic control systems in an LMFBR are more complex due to less inherent control features in the reactor nucleonics. The intermediate coolant loop introduces further complexities. We know from experience with light water reactors that these complex systems of large scale development projects such as LMFBRs can easily encounter subtle and unforeseen interactions that result in costly solutions in terms of commercial designs. Primary sodium pumps for the FFTF, for example, were estimated to cost $1.8 million in 1970 and $10.5 million in 1974.[26/] During the same period the cost of the intermediate heat exchanger for the FFTF doubled.[27/] The more we learn about these complex systems, the more we learn they will cost.

The AEC proposes as one cost savings concept, the elimination of the intermediate heat exchanger. However, "the intermediate loop serves as an important safety feature.

26/ GAO, "Staff study, Fast Flux Test Facility Program," U.S. Atomic Energy Commission, January 1975,p.9.

27/ *Ibid.*, p.9.

D) Electric Energy Demand: We use Curve B in Figure 3, representing a 50% reduction from the AEC's base case (Curve A) in the year 2020.

Before justifying our choice of the energy demand forecast, it is useful to explain how the energy demand projections (Curves A and B in Figure 3) were derived. We begin with the AEC's base case (Curve A).

The AEC's base case is said to be projected with the assistance of an econometric model.[29/] The model is not described in detail and there is insufficient discussion of the model assumptions in the PFEIS or referenced documents to make a detailed critique of the methodology. The AEC's base case electric energy demand projection is thought to be developed along the following lines, or at least is said to be consistent with the following:

1) Real GNP growth is projected on the basis of population and per capita income considerations. Real GNP is assumed to grow at 4%/year between 1970 and 1980; 3.5%/year between 1980 and 2000; and 3.2%/year between 2000 and 2020.[30/]

29/ PFEIS, LMFBR Program, Vol.IV, p.11.2-53.

30/ *Ibid.*, p.11.2-54.

2) Total energy growth is projected assuming energy consumption growth follows real GNP growth for the next 50 years. Total energy is projected to grow from 67 quadrillion Btu in 1970 to 99 quadrillion Btu in 1980; 117 in 1985; 195 in 2000; and 359 in 2020.[31/] This total energy growth rate is comparable to (actually) silghtly higher than the Ford Foundation Energy Policy Project's (Ford-EPP) "Historical Growth" scenario -- 3.5%/year to 2000.[32/]

3) The electric energy demand fraction of the total energy demand is projected assuming the "economy will continue to require a rising share of its energy as electricity because it is a clean and convenient form . . . While the model does not explicitly include electricity prices, implicitly it assumes that at worst the total cost of electricity will not increase faster than the general price level."[33/] The electric energy fraction is assumed to grow from 25 percent in 1970 to 50 percent in 2000,

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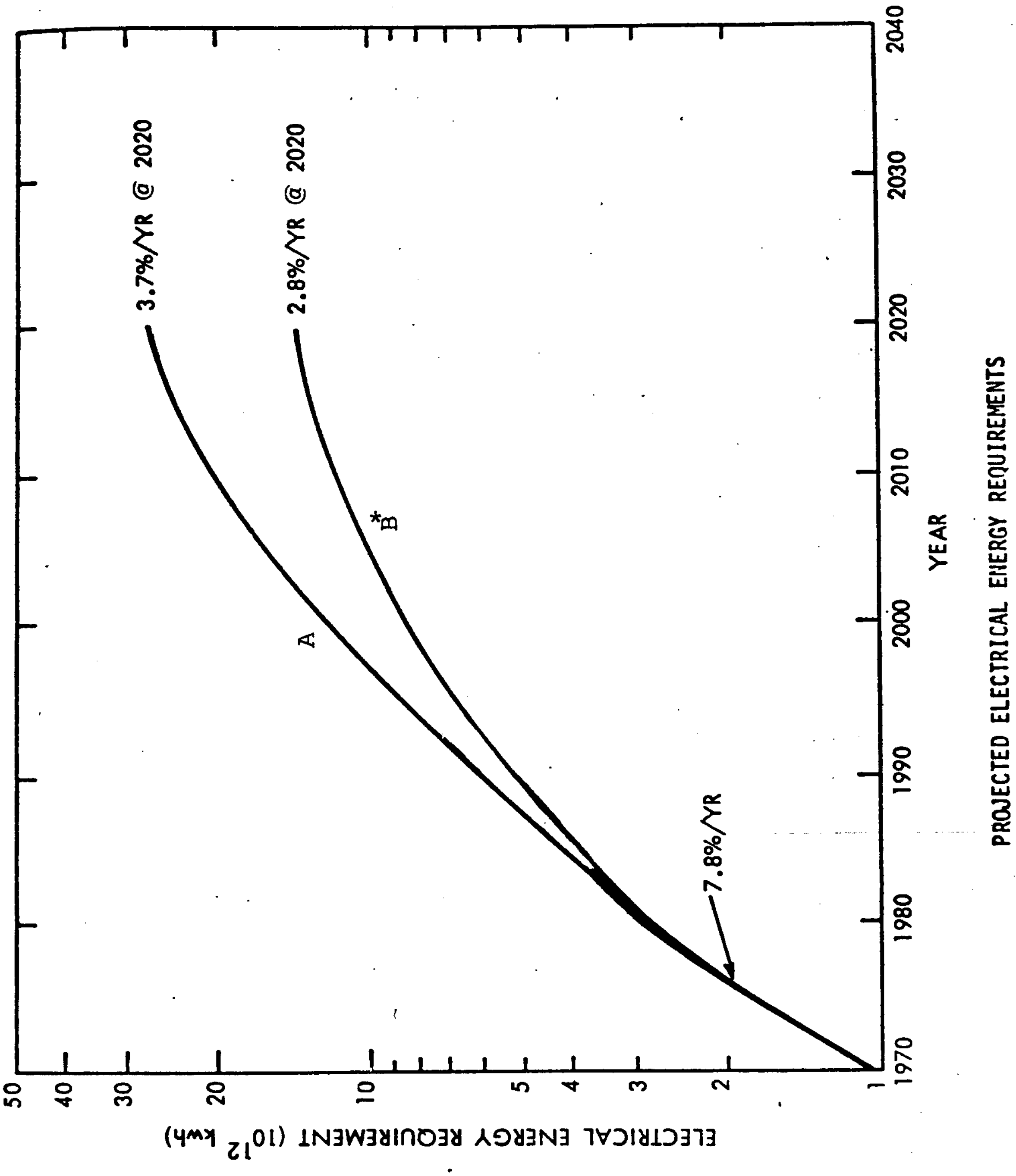
31/ PFEIS, LMFBR Program, p.11.2-53.

32/ Ford Foundation's Energy Policy Project, Exploring Energy Choices, A preliminary report, Washington, D.C. (1974), p.41.

33/ DRAFT, EIS, LMFBR Program, Vol.III, Appendix III-B, p.4-33.

Figure 4



* See footnote 33a on p.24.

Source: PFEIS, LMFBR Program. U.S. Atomic Energy Commission (December, 1974), WASH-1535, Vol.IV, p.11.2-9.

with 7.1 trillion Kwh, NRDC's base case estimate (Curve B) for the same year, and 10.6 trillion Kwh, the AEC's base case estimate (Curve A).

Chapman, Tyrrell and Mount 38/ examined the forecast of the FPC's 1970 National Power Survey on which the AEC has relied, as well as several other similar forecasts, and concluded that these are generally incorrect since their methodologies did not provide quantitative links between energy demand and price and income.

Chapman, et al., 39/ in a report for the 1973 National Power Survey, have updated the electric energy demand forecast using the same model reported by Chapman, Tyrrell and Mount. 40/ Their projected demand for 1980 is 2.2 trillion Kwh, or roughly one-third less than the projected demand using the base case of either NRDC or the AEC. The total electric energy generation in 1973 was 1.85 trillion Kwh. Hence, Chapman, et al.'s forecast of 2.2 trillion Kwh in 1980 represents an average growth rate of about 2.5% compared to the AEC assumption of an average growth rate of about 7.5% over the same period.

The projections of Chapman, Tyrrell and Mount 41/

38/ Duane Chapman, Timothy Tyrrell, and Timothy Mount, "Energy Demand Growth, the Energy Crisis, and R&D," Science, 178 (November 17, 1972).

39/ Chapman, et al., "Power Generation, Conservation, Health and Fuel Supply," Revised Draft.

40/ Ibid.

41/ Ibid.

it is still too early to tell whether this very low growth rate will persist.

We include Searl's forecast because it is a projection of electrical energy demand versus real GNP directly and does not include the arbitrary assumption that energy consumption will grow to 50% of total energy by 2000 and 65% by 2020. Furthermore, the historical correlation between electric energy demand and real GNP is better than the historical correlation between total energy and real GNP.

Using Searl's expression for electrical energy demand versus GNP and extrapolating it to the year 2000 results in an estimated electric energy demand of 6.5 trillion Kwh for 4% growth rate in GNP and 5.5 trillion Kwhr for a 3.5% growth rate. Searl's best estimate is 6.1 trillion Kwh in 2000 and 10.6 trillion Kwh in 2020.[43a/] This latter number is to be compared with 7.1 trillion Kwhr, the NRDC base case estimate and 10.6 Kwh, the AEC's base estimate.

Clearly, NRDC's base case estimate is not "very low" as the AEC would suggest. Rather it is higher than current projections, including those which are based on the most important economic factors influencing energy demand, namely, price of electricity, growth of the population and growth of income. We would, in fact, prefer a lower electrical energy

43a/ *Op. Cit.*, p.12.

> 109,000 MW of previously ordered capacity (both fossil and nuclear) by about 2 years in most cases." 44/

According to the AEC this slippage has not been specifically factored into the various cases examined in the latest cost-benefit study. The AEC concludes:

> "The range of variables explored in the cost-benefit analysis as it now appears in this Statement (e.g. cases which assume a 50% reduction in the base case projection of electrical demand in the year 2020) appear to provide adequate insight into the possible effects of major uncertainties in the assumptions used, including the possibility of a few years' slippage in breeder introduction date."

Here, the AEC is agreeing that our selection of NRDC's base case energy demand (Curve B in Figure 3) is the more appropriate choice of this parameter.

F) Uranium Supply: We use the curve labeled "B" in Figure 5.

This is the supply curve which the AEC considers "optimistic." The AEC base case is Curve A. We choose Curve B as our base case for several reasons.

44/ PFEIS, LMFBR Program, Vol.I, p.1.1-7.

First, it most nearly corresponds to the estimate by the staff of the Energy Supply Studies Program, Electric Power Research Institute (EPRI) under the direction of Milton Searl.[45/] Searl estimated the domestic U_3O_8 resources in conventional deposits that could be recovered at less than $100 per pound. His estimates were presented as a function of his subjective probability that uranium resources will exceed a given value. Searl's best estimate (13.2 million tons at less than $100/lb) is plotted in Figure 5. The horizontal error bar represents his subjective probability at 68% confidence limits. (The high end of this error bar is off the graph to the right at 21 million tons). Searl believes his best estimate is actually conservative because it does not include additional lower grade (down to 0.1 percent) but still conventional ores. Time did not permit calculation of the lower grade resources which could be recovered for less than $100/lb and therefore these material's were not included in Searl's estimate above.[46/] Searl, however, estimates there are 3.8 million tons (at 90% confidence) of these lower grade ores in known producing areas and 14 million

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45/ Electric Power Research Institute, "Uranium Resources to Meet Long Term Uranium Requirements," EPRI SR-5, Special Report (November, 1974), p.12.

46/ Ibid., p.6.

supply and price projections used in the AEC's cost-benefit study, the AEC apparently has identified an additional 1.2 million tons of domestic uranium resources in conventional deposits at less than $30/lb. The new total, 3.45 million tons, is a result of the Preliminary National Uranium Resources Evaluation Program (PNURE), started about 2 years ago. 49/ There is no mention of these data in the PFEIS of the LMFBR Program. 50/ The new total, in fact, is larger than the AEC's base case estimate (Curve A) of the cumulative supply at less than the same $30/lb price. It is almost 50 percent greater than the AEC's estimate of the domestic uranium resources made in January 1974, just over a year ago -- the older estimate forming the basis for the uranium supply projections in the PFEIS.

Third, there appears to be general agreement with the view held by the National Petroleum Council, that

> "Substantially all of the present proved reserves and approximately 85 percent of the potential reserves as determined by AEC are located in the

49/ U.S. Atomic Energy Commission, "Report of LMFBR Program Review Group,"(1974), Fn.5, p.16.

50/ See, for example, Sections 6A.11.2, 6A.1.1.8, 6A.1.1.9, 11.2.1.2, 11.2.3.7., at the PFEIS, LMFBR, U.S. Atomic Energy Commission. December, 1974 (Vols.I through IV).

> have been somewhat fortuitous if the nation's best deposits were so conveniently placed that they were relatively easy to discover early in the history of uranium exploration." 53/

The AEC cites as supporting evidence for its uranium resources estimates the result of an evaluation of the uranium in the San Juan Basin of New Mexico using the Delphi technique. The problem with this analytical technique is that companies wishing to discourage exploration by competitors submit low estimates of the resources in those locations. Where companies are trying to attract developers, high estimates are submitted. A geologist and manager for exploration of one of the largest uranium companies in the San Juan Basin pooh-poohed the whole idea and refused to participate in the AEC's Delphi survey.

The AEC correctly notes, that in the matter of U_3O_8 sales prices versus supply, their base case estimate of price "errs on the low side of reality," and "does not reflect the more recent rapid escalation in prices in the U.S. market." 54/

53/ Electric Power Research Institute, "Uranium Resources to Meet Long Term Uranium Requirements," EPRI SR-5, Special Report (November, 1974), p.28.

54/ PFEIS, LMFBR Program, U.S. Atomic Energy Commission. December, 1974, Vol.Iv, p.11.2-75.

expanded production to meet increased commitments, and the requirement of long-term enrichment contracts appears to have paniced the utility industry. Sales in 1973 shot up 300 percent in a seller's market, increasing commercial uranium deliveries and commitments 45,000 tons over the previous year. This is three times the commercial requirements in 1974 of about 14 thousand tons. Reluctance of uranium producers to overcommit themselves forced sales down to 15,900 tons in 1974, but strong bidding has kept the price up. While prices may not return in 1975 we do not believe recent prices reflect a long-term trend, but rather a shorter term response as the uranium market shifted from the buyer's market of the past several years when prices were deflated, to the seller's market of today. There is little reason to believe that prices will not return, although not to the same low values, as we return to more stable market conditions and a normal profit margin.

III. Results of NRDC's Cost-Benefit Analysis

Table 2 below summarizes the preceeding key input assumptions selected as NRDC's base case and presents for comparison the AEC's base case assumptions. The assumptions selected as NRDC's base case correspond to

Table 3

Summary of Cost-Benefit Study Results Discounted at 10%/Yr. To Mid-1974

Case[a]	Constraints Imposed Until (HTGR)	Constraints Imposed Until (LMFBR)	LMFBR Introduction Date	LMFBR Capital Cost Differential[b]	Electrical Energy Demand Curve[c]	Uranium Supply Curve[d]	Comparison With Case	Energy Costs (Billions of Dollars)	Gross Benefits (Billions of Dollars)	R&D Costs (Billions of Dollars)	Net Benefits (Billions of Dollars)	Benefit/Cost Ratio
5	2020				A	B		201.4				
48	2020				B	B		148.1				
58	2000	2000	1987	$100/Kw	B	B	48	147.7	0.4	4.7	-4.3	0.08
55	2000	2000	1987	$100/Kw	A	B	5	196.6	4.8	4.7	0.1	1.0
52	2000	2000	1987	$ 0/Kw	B	B	48	144.2	3.9	4.7	-0.6	0.8
62	2020			$100/Kw	B	C		157.3				
72	200C	2000	1987	$100/Kw	B	C	62	150.6	6.7	4.7	2.0	1.4

Notes:

a) Numbers refer to AEC identity of cases in the PFEIS.
b) Capital Cost differential after 2000, corresponding to the curves in Figure 2.
c) Letters correspond to curves in Figure 3. Curve B corresponds to NRDC "base case," Curve A corresponds to AEC "base case."
d) Letters correspond to curves in Figure 5. Curve B corresponds to NRDC "base case," Curve A corresponds to AEC "base case."

Source: PFEIS, Appendix IV.D

example, assumed to be available in 1991, are based on a design that optimizes performance at the expense of safety considerations, could not be licensed today and has been shown to be infeasible due to stainless steel swelling of the fuel cladding.

We are now in a position to examine the sensitivity of our base case assumptions to changes in some of the key input assumptions. As noted previously, we are severely constrained in this part of our analysis because we are limited by the cases tested by the AEC. Turning first to energy demand, it can be seen by comparing the results of Case 55 to Case 58 in Table 3, that the electric energy demand would have to grow at the "historical" rate assumed by the AEC to get a break-even benefit/cost ratio of 1.0. Similarly, corresponding to Case 72, one would have to assume a very unrealistic uranium supply curve (Curve C in Figure 5), before the benefits begin to exceed the cost. This unrealistic uranium supply curve was termed "pessimistic" even by the AEC. The AEC's report made this judgment before identification of the additional 1.2 million tons of low cost uranium, at less than $30/lb which was not provide adequate insight into possible effects of major uncertainties in the assumptions used." The AEC has also abandoned the 1987 date of commercial introduction as evidenced by the AEC's statement:

> "Recent evaluations of the LMFBR development program by the AEC taking into consideration cancellations and deferrals of generating capacity by electric utilities that had occurred by the end of September suggest that the commercial LMFBR introduction would probably occur in the early 1990's." 57/

A date of commercial introduction in the 1990's, as opposed to 1987 is also more consistent with the history of slippages in the LMFBR R&D schedule. The effect of these changes on the AEC's results is extremely significant. Figure 6 shows the effect on the gross benefit for changes in the electric energy demand where the energy demand is plotted as a function of the rate of consumption in the year 2020. The two curves are for different assumed dates of commercial introduction of the LMFBR, namely, 1987 and 1991, and have been extrapolated to the electric energy demand corresponding to Curve B (50% reduction in the AEC's

57/ PFEIS, LMFBR Program. U.S. Atomic Energy Commission, December, 1974. Vol.IV, p.11.2-134.

base case projection -- Curve A). All other assumptions correspond to AEC base case assumptions in Table 2.

As can be seen from Figure 6, the gross benefit for 1991 commercial entry is roughly equivalent to the R&D costs, in other words, a breakeven benefit/cost ratio of 1.0. Similar results can be obtained by a slightly different procedure. For most of the cases considered in the benefit-cost analysis the AEC used projections of nuclear capacity by plant type given in the report WASH-1139(72), 58/ a 1972 projection by the AEC's Office of Planning and Analysis. WASH-1139(74) 59/ contains the most recent projections by this Office. Case A energy projection from WASH-1139(74) more nearly corresponds to the current status of the nuclear industry today. Case A assumes that delays in bringing nuclear plants on line continues to plague the industry and forecasts 85,000 MWe of nuclear generating capacity to be on line at the end of 1980. This is slightly higher than current estimates in the range 60,000 - 70,000 MWe. Using

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58/ Forecasting Branch, Office of Planning and Analysis, U.S. Atomic Energy Commission,"Nuclear Power 1973-2000," WASH-1139(72). (December 1, 1972).

59/ Office of Planning and Analysis, U.S. Atomic Energy Commission, "Nuclear Power Growth 1974-2000," WASH-1139(74). February, 1974.

to offset a $100/Kw capital cost differential the price of uranium would have to increase to about $35/Kw.60/ But according to our base case uranium supply curve (Curve B in Figure 5), this price will not be realized until the uranium commitment reaches about 4.5 million tons of U_3O_8. This commitment will not be reached until about 2020 assuming no LMFBRs are built and NRDC base case assumptions. Since it is the levelized cost of power over the lifetime of the plant and not the cost in the year of commercial introduction that determines when a plant is economically competitive, it is reasonable to expect the breeder to be competitive with conventional plants several years prior to 2020. Assuming it is competitive 10 years prior to this date, *i.e.*, in about 2010, it follows that the appropriate LMFBR date is some two decades beyond the date established by the current LMFBR research and development schedule.61/ A better estimate of the commercial entry date is available from the AEC's cost-benefit

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60/ "NRDC Comments on WASH-1535, Re Cost-Benefit Analysis," PFEIS, LMFBR Program. U.S. Atomic Energy Commission (December, 1974), Vol.VI, p.38-192.

61/ Others have reached a similar conclusion. See, *e.g.*, David J. Rose, "Nuclear Eclectic Power," Science (April, 1974), p.357.