Princeton University SCHOOL OF ENGINEERING/APPLIED SCIENCE
CENTER FOR ENERGY AND ENVIRONMENTAL STUDIES
THE ENGINEERING QUADRANGLE
PRINCETON, NEW JERSEY 08544

'82 JAN 22 P4:00

emp

RECEIVED
JAN 27 1982
US NUCLEAR REGULATORY COMMISSION
DOCUMENT MANAGEMENT BR
TIDC

January 13, 1982

DOCKET NUMBER 50-537(E)

Commissioner Nunzio J. Palladino, Chairman
Nuclear Regulatory Commission
1777 H Street, N.W.
Washington, D.C. 20555

Dear Dr. Palladino,

This letter is in response to the NRC's invitation of December 24, 1981 for comments on the request by the Department of Energy that it be allowed to proceed with site preparation for the Clinch River Breeder Reactor plant without first satisfying the usual NRC construction permit procedures.

I would urge that the NRC deny this request because the nation is just now in the midst of a reconsideration of the necessity of this plant. As I will show below, the only logical conclusion which can be drawn from such a reconsideration is that the plant is unnecessary, that its construction will be wasteful of our national resources, and would, in fact, undermine U.S. nonproliferation objectives. Under these circumstances the attempt by the Department of Energy to try to rush the project past some point of no return before it is possible to complete the painful process of cancelling it can hardly be seen as in the national interest.

The LMFBR Demonstration Program is No Longer Necessary

If you refer to the Proposed Final LMFBR Program Environmental Statement which was issued by the AEC in December 1974, you will find an argument there for the breeder that went as follows:

- By the year 2000 U.S. nuclear generating capacity would be approximately 1200 Gw(e) and new capacity would be coming on line at a rate of approximately 100 Gw(e) per year;[1]
- If all nuclear capacity were light water reactors, the associated lifetime U_3O_8 commitments (30 year reactor lifetime) would be 5.5 million tons for 1200 Gw(e) in the year 2000 and 12.7 million tons for 3300 Gw(e) in the year 2020;[2]
- Only between 2.6 and 6 million tons of U_3O_8 could be recovered from U.S. resources before it would be necessary to turn to very costly low grade Chattanooga shale resources;[3] and

DS03
s
1/1

- The capital cost of breeder reactors and the associated plutonium fuel cycle facilities would be so low that LMFBRs and their symbiotic plutonium burning LWRs would generate electricity at a cost 20 percent lower than LWRs operating on a once-through fuel cycle even at a uranium price of $27 per pound U_3O_8 (equivalent to about $50 per pound in January 1982 dollars.)[4]

Contrast this situation with that projected by the Department of Energy today:

- In its most recent (1980) Annual Report to Congress the Department of Energy projects U.S. nuclear capacity in the year 2020 as between 4 and 380 Gw(e).[5] The middle case, 290 Gw(e), is less than one tenth that used by the AEC to justify the breeder in 1974;
- Assuming that this capacity is all LWRs, the same report estimates that the associated cumulative consumption plus 30 year lifetime commitments of uranium as of 2020 will be 2.3 million tons U_3O_8;[6]
- The DOE's estimate of U.S. U_3O_8 available at a forward cost of less than $100 per pound has risen to 4.9 million tons (3.5 million tons at $50 per pound). [The corresponding minimum estimates (95 percent confidence) are only 20 percent lower.[7]]
- The DOE estimated in 1979 that, because of the high cost of the LMFBR and its associated fuel cycle, the cost of U_3O_8 would have to go up to $115-205 per pound before the LMFBR could compete with even a slightly improved (15 percent reduced uranium requirements per kWh) LWR.[8] Other DOE calculations indicate that additional cost-effective uranium efficiency improvements[9] in combination with enrichment tails stripping using advanced isotope separation systems would raise the breakeven range for a mature LMFBR industry to $150-250 per pound U_3O_8.[10] This is two to three times the $78 per pound U_3O_8 which DOE projects for 2020[11] (and still only the equivalent of oil costing $7.5 - 12.5 per barrel[6]).

According to the DOE's own analyses, therefore, the LMFBR will not be economically competitive till far beyond 2020. This suggests that, instead of treating the construction of the CRBR as a critical national priority, the DOE might be looking for more pressing aspects of the nation's energy problems to spotlight. Satayana's statement:

> Fanaticism consists in redoubling your efforts when you have forgotten your aim.

never seemed more appropriate.

Congressional Support for the LMFBR is Weakening

As the effects of the AEC's selling job wear off, Congressional support for the LMFBR program is steadily weakening -- following a pattern reminiscent of what occurred in the case of the U.S. supersonic transport program.[12] Continuation of funding for the LRBR was approved by the Senate in November by only 2 votes,[13] and the most recent vote by the responsible Committee in the House of Representatives was in fact in opposition to continued funding.[14]

The NRC cannot, of course, substitute its judgment for that of Congress on this matter. On the other hand, there is no reason why the NRC shold waive its own rules in order to speed a project of no detectable merit at a time when Congressional support for the project is obviously weakening.

The Breeder Program Complicates Our Nonproliferation Problems

Finally, I would like to remind you that the CRBR became controversial long before the AEC's projected "uranium crisis" faded away. Many of us became concerned that the U.S., by promoting the plutonium fuel cycle, was also promoting the spread of nuclear weapons. Unfortunately, the reasons for our concern have not faded. Indeed it would appear that the NRC has reason to share that concern. According to the NRC's letter of November 27, 1981 to Senator Simpson;

> The NRC is concerned that the IAEA safeguards system will not detect a diversion in at least some types of facilities.

"Some types" of facilities would presumably include the reprocessing and plutonium fuel fabrication plants which would be required by the LMFBR.

The proliferation of nuclear weapons may have critical implications for the public interest well within the DOE's planning horizon of 2020. I assume that, when it is relevant and you have the latitude, you will factor this concern into your decision-making process. You obviously have the occasion and opportunity to do so in this case.

I enclose a recent article, a piece of Congressional testimony, and some comments on the DOE's draft supplement to the LMFBR Program Environmental Impact Statement. They contain additional detail on the way in which the breeder was originally sold and what that case looks like now. Please feel free to contact me if you have any questions on this material.

Sincerely yours,

Frank von Hippel

FvH/zk

Enclosures:

1) Letter comment on the Draft Supplementary Environmental Impact Statement on the Liquid Metal Fast Breeder Reactor Program (DOE/EIS-0085-D).

2) "Uranium, Electricity, and Economics." Invited Statement to the Subcommittee on Energy Conservation and Power of the House Committee on Energy and Commerce, October 5, 1981.

3) "Should Breeder Reactors Be Built in the United States? No!" Public Power, May-June 1981, pp. 19, 21 and 24.

References

1) US AEC, *Proposed Final Environmental Statement, Liquid Metal Fast Breeder Reactor Program* (WASH-1535, December 1974), p. 11.2 - 113.

2) *Ibid*., p. 11.1 - 32.

3) *Ibid*., p. 11.2 - 10.

4) *Ibid*., pp. 11.2 - 4, 11.2 - 10 and 11.2 - 30.

5) US DOE, EIA *Annual Report to Congress, 1980: Vol. 3, Forecasts*, [DOE/EIA-0173(80)/3], p. 158.

6) *Ibid*., p. 177 using 170 million Btu primary energy released in LWRs per pound of U_3O_8 mined.

7) US DOE, *An Assessment Report on Uranium in the United States of America* (GJO-111 (80), 1980), p. 1.

8) US DOE, *Nuclear Proliferation and Civilian Nuclear Power: Report of the Nonproliferation Alternative Systems Assessment Program* (Draft DOE/NE-001, 1979), Figure 11.

9) D.F. Newman *et al*., (PNL) "Assessment of Nonbackfittable Concepts for Improving Uranium Utilization in LWR's," paper presented to the American Nuclear Society, June 10, 1981.

10) Using the curve shown in figure 6 of ref. 9 for the economics of a 30 percent improved LWR and the estimate on p. 9 of ref. 9 that advanced isotope separation systems could strip enrichment tails from 0.2 to 0.05 percent U^{235} at a cost equivalent to \$43 per pound U_3O_8.

11) Ref. 5, p. 177.

12) See e.g., Joel Primack and Frank von Hippel, *Advice and Dissent: Scientists in the Political Arena* (New York; Basic Books, 1974; New American Library, 1975), Chapters 2 and 4.

13. Steven V. Roberts, "Public Works Projects Squeak Through in Senate," *New York Times*, November 5, 1981, p. A20.

14. Robert D. Hershey, Jr., "House Panel Opposes Reactor," *New York Times*, May 8, 1981, p. D3.

Princeton University SCHOOL OF ENGINEERING/APPLIED SCIENCE
CENTER FOR ENERGY AND ENVIRONMENTAL STUDIES
THE ENGINEERING QUADRANGLE
PRINCETON, NEW JERSEY 08544

January 14, 1982

Mr. Wallace R. Kornack, NE-6GTN
Office of Nuclear Reactor Programs
Office of the Assistant Secretary
for Nuclear Energy
U.S. Department of Energy
Washington, D.C. 20545

Dear Mr. Kornack,

This letter is in response to DOE's request for comments on the Draft Supplementary Environmental Impact Statement on the Liquid Metal Fast Breeder Reactor Program (DOE/EIS-0085-D).

I will not comment on the technical details of this draft supplement at this time because it is missing an essential part which is required to make it meaningful -- namely, a cost/benefit analysis of the proposed LMFBR Program.

As I will show below, the DOE has recently completed all the elements of such an analysis, and has concluded both that the U.S. has plenty of low cost uranium to support light water reactors for many decades and that the LMFBR will not be economically competitive with light water reactors for as far in the future as DOE has made projections (40 years). This is quite a different conclusion than that which was arrived at in the original EIS on the LMFBR Program where the AEC and ERDA argued that a uranium shortage was imminent in the U.S. and that the LMFBR would be economically competitive in the 1990's.

The DOE's failure to reveal in the Draft Supplementary EIS the collapse of the basic rationale of the LMFBR demonstration program is, therefore, in effect if not by intention a coverup. For this reason I request that this Draft Supplementary EIS be withdrawn and be replaced by one which contains the updated cost/benefit analysis. Below I will discuss in more detail the essential ingredients of this cost/benefit analysis and why it is critical to the reconsideration of the LMFBR Program at this time. I will also comment on the reasons given by the DOE for not including such a cost/benefit analysis in this Draft Supplement.

The Cost/Benefit Analysis and its Importance to a Reconsideration of the LMFBR Program

As the Draft Supplementary EIS states (p. 3):

> Cost/Benefit Analyses of the LMFBR program were included in WASH-1535 and ERDA-1535.

WASH-1535 and ERDA-1535 are the AEC's proposed and ERDA's final LMFBR Program Environment Statement, respectively. These analyses were published in 1974 and 1975 and provided the basic rationale for the decisions made in that time period to proceed with an LMFBR program aimed at commercialization in the 1990's. The basic argument presented in WASH-1535 was quite straightforward and can be summarized as follows:

- In 1974 WASH-1535 projected U.S. nuclear capacity at 1200 Gw(e) in the year 2000 and 3300 Gw(e) in the year 2020;[1]
- It also estimated that the U.S. resources of low cost uranium could support only about 1000 Gw(e) of LWR capacity;
- The AEC also believed at the time that the breeder would be economically competitive with LWRs fueled by even low cost uranium;[2]
- As a result the AEC concluded that it was necessary and cost-effective to commercialize LMFBRs as soon as possible.

By 1981, however, the picture had completely changed:

- It had become quite clear that the historical decline of real electricity prices had ended and that in fact real prices could be expected to increase for at least a decade.
- As a result it was clear that the period during which U.S. electricity demand doubled every decade had also passed and that in the future U.S. electricity demand would, like the demand for the products of most other mature industries, grow little or no more rapidly than the economy as a whole. Accordingly, by 1981 the DOE's midrange projection for U.S. nuclear capacity had fallen to 175 Gw(e) for the year 2000 and to 290 Gw(e) for the year 2020[3] -- capacities which were respectively one seventh and one eleventh of those which had been projected by the AEC only seven years earlier;
- With these new projections the DOE found that, instead of predicting that the U.S. will be exhausting its uranium resources by about the year 2000, it was now estimating that even by 2020 U.S. LWRs will have consumed only about one quarter of the nation's resource of low cost U_3O_8 (less than $100 per pound forward cost).[4,5]

- During this past seven years the DOE has also concluded that, even a large breeder system fully enjoying all the available economies of scale in the production of reactors and in fuel cycle facilities, will not be able to compete economically with LWRs operating on a once-through fuel cycle until the cost of U_3O_8 rises to extremely high levels. In 1979, in its report on the Nonproliferation Alternative Systems Assessment Program, the DOE estimated that the LMFBR would become competitive with a once-through LWR system with 15 percent improved uranium efficiency only when the cost of U_3O_8 rises to somewhere in the range of \$115-205 per pound.[6] Including nonretrofittable cost-effective improvements in the uranium efficiency to new LWRs and advanced isotope separation technology for enrichment tails stripping would raise this crossover range to \$150-250 per pound of U_3O_8.[7] These numbers are 2-3 times DOE's 1981 estimate of the price of U_3O_8 in 2020: \$78 per pound.[8]

- As a result of this changed situation, a revised cost analysis presented in the Supplementary EIS based on the most recent DOE analyses would show that LMFBRs will not be economic until far beyond the DOE's furthest horizon - 2020.

Of course, the nation could decide to proceed with the program anyway. The purpose of an Environmental Impact Statement, however, is to lay out tradeoffs involved so that they can be subjected to public and peer review.

DOE's Reasons for not Including a Cost/Benefit Analysis in the Draft Supplementary EIS

On p. 3 of the Draft Supplementary EIS it is stated that

> ... no such further [since ERDA-1535] cost/benefit analyses have been performed and none, therefore, are included in this supplement...

As my discussion above demonstrates, however, the DOE has performed all the essential parts of an updated cost/benefit analysis.

The EIS then continued on pages 3 and 4 to give three additional reasons why an updated cost/benefit analysis has not been included in the Draft Supplementary EIS:

> 1) Cost/benefit analyses are not required in an EIS (see CEQ regulations, 40 CFR 1502.23)...

In the light of the description above of the conclusions which can be drawn from the analyses which the DOE has made, this legalistic statement gives the impression that the DOE finds the results of its updated cost/benefit analyses unwelcome and does not wish to bring them to public attention.

2) Cost/benefit information for alternative long-term technologies (fusion and solar electric) has not been developed to a degree that would make cost/benefit analyses of these alternatives meaningful.

This may be true, but it is also irrelevant. If, as it appears from current DOE analyses, the LMFBR cannot even compete for many decades with other fission technologies such as the LWR, why should the nation move ahead now with a demonstration-commercialization program? This question can be answered without any information about the long-term prospects of nonfission technologies.

3) Parameters (e.g., discount rate(s), LMFBR introduction date(s), future nuclear capacity, future cost of coal) used in complex cost/benefit analyses of the LMFBR are so uncertain at present that the value of such analyses would be questionable. It is the goal of the breeder research and development to reduce such uncertainties.

First of all, the principal focus of the LMFBR Program described in the Draft Supplementary EIS is to demonstrate the hardware of LMFBR power plants. This program has very little resemblance to a research program on: the uncertainties in the discount rates used to determine the value of such a program, in the future of U.S. nuclear capacity, or even uncertainties in the future cost of coal!

Secondly, the uncertainties in the parameters which are critical to a cost/benefit analysis of the breeder -- future U.S. nuclear capacity growth, the magnitude of U.S. uranium resources, and the capital and fuel cycle cost differentials between LMFBRs and LWRs -- have been significantly reduced since the AEC-ERDA cost/benefit analysis was published. Indeed, it appears from the DOE's own analyses that they have been reduced enough so that the values of the key parameters used by the AEC and ERDA in their justification of the LMFBR demonstration program are now way outside the remaining uncertainty bonds and that, as a result, it is pointless to go ahead with an LMFBR demonstration program at this time.

On page 43 the Draft Supplementary EIS states that:

> the prudent course is to gear the development program toward possible commercialization of LMFBRs fairly early in the next century.

Yet, at the same time, the DOE has refused to present in this document its own analyses which support by a very wide margin a conclusion that the LMFBR will not be needed early in the next century.

In the past the AEC, ERDA and DOE all accepted the basic assumption which led to the requirements of Environmental Impact Statements: the public has right to expect the government to present the rationale for its proposed programs for public and peer review. This was done in WASH-1535, and ERDA-1535. A number of independent policy analysts took a great deal of trouble to critique these analyses[9] and, as I have demonstrated above, the DOE ultimately changed its own projections drastically. Yet now the DOE, like the tailors in Hans Christian Andersen's fairytale, demands that the public admire the invisible new clothes which it has produced in this Draft Supplementary EIS and accept the bland recommendation that to proceed with the LMFBR demonstration program would be "prudent."

The requirements that governmental agencies prepare Environmental Impact Statements on their major programs was a big step forward toward providing citizens with access to the information and analyses which they require if their rights as citizens are to be meaningful in an increasingly complex society. In this context, acceptance of this Draft Supplementary EIS would be a step backwards. I therefore request, both in the interests of good public policy in this case and in the interests of good government more generally, that the DOE withdraw this Draft Supplementary EIS and publish a new draft which includes the results of DOE's updated cost/benefit analysis.

Sincerely yours,

Frank — Hippel

Frank von Hippel

FvH/zk

References and Footnotes

1) US AEC, Proposed Final Environmental Statement, Liquid Metal Fast Breeder Reactor Program (WASH-1535, December 1974), p. 11.2 - 11.3.

2) ref. 1. pp. 11.2-4, 11.2-10, and 11.2-30.

3) US DOE, EIA, Annual Report to Congress, 1980: Vol. 3 Forecasts, [DOE/EIA-0173 (80)/3], p. 158.

4) Compare Ref. 3, p. 177 (converting primary energy released into pounds of U_3O_8 at the rate of 170 million Btus per pound) with ref. 5.

5) US DOE, An Assessment Report on Uranium in the United States of America [GJO-111(8), 1980], p. 1.

6) US DOE, Nuclear Proliferation and Civilian Nuclear Power: Report of the NonProliferation Alternative Systems Assessment Program (Draft DOE/NE-0001, 1979), Fig. 11.

7) Using the curve shown in ref. 6, fig. 6 for the economics of a 30 percent improved LWR and the estimate in ref. 6 (p. 9)that advanced isotope separation systems could strip enrichment tails from 0.2 to 0.05 percent U^{235} at a cost equivalent to $43 per pound U_3O_8

8) ref. 3, p. 177.

9) See e.g., the report to ERDA by the following members of ERDA's LMFBR Review Stearing Committee; Thomas B. Cochran, Russell E. Train, Frank von Hippel and Robert H. Williams, Proliferation Resistant Nuclear Power Technologies: Preferred Alternatives to the Plutonium Breeder (April 6, 1977) and the subsequent publication by Harold A. Feiveson, Frank von Hippel and Robert H. Williams, "Fission Power: An Evolutionary Strategy," Science, January 29, 1979, p. 330.

Uranium, Electricity and Economics

Frank von Hippel
Center for Energy and Environmental Studies
Princeton University
Princeton, New Jersey 08544

Invited Testimony before the

Subcommittee on Energy Conservation and Power,
of the House Committee on Energy and Commerce.

October 5, 1981

It is my understanding that the purpose of these hearings is to explore one approach by which the utilities might reduce the contribution of uranium costs to the price of nuclear generated electricity. I would like to start, however, by putting this problem in perspective.

Uranium is Cheap

Figure 1 shows the relative costs of the different fuels used by our utilities in 1980 and as projected in the mid-price scenario in the Energy Information Administration's 1980 Annual Report to Congress.[1,2] It shows that uranium is currently about one fifth as costly as coal per kilowatt-hour generated and that, according to the latest DOE projections, it will still be about a fifth the cost of coal in 2020. The reason is quite simple: uranium is such a concentrated source of energy that while it is necessary to mine approximately one thousand pounds of uranium ore to recover one pound of uranium, the uranium in one pound of average uranium ore suffices to generate more electricity in current nuclear power plants than can be generated by the burning of ten pounds of coal.

Why Did the AEC Choose the Breeder?

If uranium is going to stay so cheap, the question naturally arises: Why has this nation for more than a decade been pouring such a large fraction of its energy research and development dollars into the breeder reactor program, a program which has as its only objective the further reduction of the already very small uranium costs being paid by the operators of nuclear power plants?

In order to answer this question it is necessary to go back and look at the assumptions about the future that the AEC was making when it committed the nation to the breeder program. The AEC made many assumptions which have turned out not to be true about the economics of the breeder - assumptions which I will discuss later. The most important mistake that the AEC made, however, was in its assumption concerning the future growth of U.S. electricity consumption. Figure 2 shows the nuclear power growth projections which the AEC made in 1974 when it did its last cost-benefit analysis on the plutonium breeder.[3] The AEC was projecting that by 2020 U.S. nuclear power plants alone would be generating 10 times as much electric power as the entire U.S. electrical generation system did in 1980! Since the AEC thought that the low cost uranium resources of the U.S. could supply the lifetime fuel requirements of only about 1000 Gigawatts of light water reactor capacity and that U.S. nuclear capacity would reach this level by about the year 2000, the Commission concluded that after about the year 2000 all new U.S. nuclear power plants would have to be breeder reactors.

Electricity Prices and the Growth of Electricity Demand

Although the AEC's electricity demand growth projections may seem absurd now, at the time they were made they were simply an extrapolation of the pre-1970 exponential growth of U.S. electricity consumption. During the 40 year period 1930-1970 U.S. electricity consumption had approximately doubled each decade - growing approximately twice as rapidly as the U.S. GNP (6.6% versus 3.2% per year) so that by 1970 the U.S. was consuming four times as much electricity per dollar of GNP as in 1930. (See Figure 3.)

During this same period something else remarkable had been happening as well, however, which we now realize was stimulating the enormous rate of growth in U.S. electricity demand: the real price of electricity had been dropping steadily (except for a brief period in the Depression) so that by 1970 more than 4 kilowatt-hours of electric energy could be bought for the same 15 cents in 1980 dollars which would have bought only one in 1930. (See Figure 4.)

The long period of declining electricity prices was made possible by the dramatic increase of the efficiency with which power plants converted fuel into electricity prior to 1960 and the dramatic increase in the size of central station coal and nuclear power plants between 1960 and 1970.[4] While many in the AEC expected that the introduction of nuclear power plants would make possible a continuing decline in the cost of electricity (some even predicted that nuclear electricity would become so cheap that it would be "too cheap to meter"), these expectations have not been borne out.

After 1970 both thermal efficiencies and the sizes of new central station electrical generating units plateaued and the increase in real fuel and capital costs began to drive electricity prices up. As Figure 3 shows, following the reversal of the price signals to consumers, the growth rate in electricity consumption has slowed to about the same rate as that of the economy.

This does not mean that in the future electricity will not continue to become increasingly important in our economy relative to other energy forms. Indeed, during the past decade the share of U.S. primary energy consumption going to the generation of electricity continued to grow: from 24 percent in 1970 to 33 percent in 1980. The reason for the growing relative importance of electricity in the economy has changed, however, from being due to a very high rate of growth in electricity consumption to being due to a very low (perhaps in the future a negative) rate of growth in the consumption of primary energy for all other purposes.

Future Nuclear Power Growth

The new conventional wisdom is that in the future U.S. electricity consumption will continue to grow at about the same rate as the GNP and the latest projections by both the government and the electrical power industry are roughly consistent with this expectation. Thus, for example, in its most recent projections, the Energy Information Administration assumed that both the size of the U.S. economy and U.S. electricity consumption in 2020 will be 2.5 times greater than today.

The EIA also assumed in its midcase projection that in the year 2020 about 30 percent of this electricity would be generated by nuclear power.[5] In my own view this is a reasonable midrange estimate for the fraction of U.S. electricity which might be generated by nuclear power plants 40 years from now. I believe that, even allowing for lots of electric cars and heat pumps, U.S. electricity consumption need not grow by as large a factor as the EIA projects, however. Indeed, recent analyses show that the U.S. economy would be greatly strengthened if much of the money which would be spent on building new electrical generating capacity in the EIA scenario were invested instead in renovating our buildings and industry. In the course of such a renovation the energy efficiency of these facilities could be increased enough to eliminate the demand which the electricity generating capacity would have been built to serve.[6] From my perspective, therefore, the DOE projection of future U.S. nuclear generating capacity is probably still too high.

In any case I show the 1980 DOE projection on Figure 2 along with the AEC's 1974 projection of U.S. nuclear capacity growth. The essential fact to note is that the 290 Gigawatts, shown there for 2020 are far below the 1000 Gigawatts that the AEC calculated could be supported by U.S. reserves of low cost uranium. This is why the AEC's nightmare about a shortage of cheap uranium has receded into the future by many decades.

Of course, even if the problem of future uranium cost now looks relatively minor for a very long time into the future, there is no reason we shouldn't try to reduce it even further if that can be done in a cost effective manner.

The Cost of the Breeder

The breeder would solve the problem of rising uranium costs because it would ultimately reduce by one hundredfold the uranium requirements per kilowatt of nuclear electricity generated. As a result the contribution of the cost of uranium to the cost of nuclear power could be reduced from about 0.9 cents in 2020 per kilowatt-hour to essentially zero. The breeder would also eliminate the need for enriching uranium which, according to the Department of Energy projection, will cost about 0.25 cents per kilowatt-hour in 2020.[7] Only if the extra costs associated with the breeder amount to less than one cent per kilowatt-hour, therefore, will it be competitive with current unimproved light water reactor technology. (See Figure 5.)

As I will explain below, the breeder fails this test by a large margin. While this technology would have been an effective "brute force" solution to the AEC's concern about the possibility of uranium costs climbing out of sight, it is too expensive to be competitive in a period of rising but still relatively very low uranium costs. The high costs of breeder generated electricity would be due firstly to the high cost of the reactor and secondly to the complexity and difficulty of its fuel cycle.

The Reactor

Six years ago ERDA projected that the first commercial breeder reactor would cost about 20 percent more than a 1980 vintage light water reactor of equivalent size.[8] Such a plant is now nearing completion in France. It is well designed -- indeed many experts think that the French pool-type design is much superior to the loop-type design which has been pursued in the U.S. The development program has been well organized and efficiently run. And no licensing delays have occurred in the commercialization effort since non-governmental critics are excluded from the French nuclear power licensing process. Yet the French now project that the construction cost of the "Super Phenix" will be more than twice that of a light water reactor of equivalent capacity.[9]

Of course, some of the extra cost of this plant stems from the fact that it is a first-of-a-kind plant. In routine production the French Atomic Energy Commissioner estimates that the cost of the Super Phenix could be brought down to only 1.75 times the cost of a light water reactor.[10] It is hoped that the cost may be brought down still further - perhaps to between 1.3 and 1.45 times the LWR cost if the safety margins in the reactor design are somewhat reduced. Even if the cost differential could be reduced to 40 percent, however, the extra capital charge for the breeder would all but eliminate the entire savings associated with the breeder's lower uranium and zero enrichment requirements projected by the DOE.[11] (See Figure 5.)

The Fuel Cycle Services

After a certain time breeder fuel would have to be reprocessed chemically so that the plutonium and uranium could be recycled. (See Figure 6.) Once again, however, the French, who have led the world in commercializing reprocessing technology, have found it to be much more expensive than they and the U.S. AEC had expected. The official French estimates of reprocessing costs increased tenfold in constant francs between 1970 and 1980 and have now reached a level where they would add another 0.45 cents per kilowatt-hour to the cost of the breeder-produced electricity.[12,13] DOE estimates of breeder reprocessing costs based on paper studies are about half this large. (Both numbers are shown on Figure 5.)

There are also extra costs in the breeder fuel cycle when the fuel is being refabricated because of the requirements for extra protections for both workers and materials whenever plutonium is being processed. Taking the 1979 DOE cost estimates and updating them only for general inflation, I find that the extra cost for the fabrication of fuel containing plutonium adds approximately another 0.2-0.4 cents per kilowatt-hour to the cost of breeder generated electricity.[14,15]

The extra fuel cycle costs, of course, increase the margin by which the cost of breeder electricity can be expected to exceed that of light water reactor generated electricity in 2020. (See Figure 5.[16])

There are additional smaller factors which bear on breeder economics and the cost assumptions used by different analysts differ, due to the inherent uncertainties associated with discussions of a technology which is not yet fully commercialized. I am unaware, however, of any recent analysis which shows the plutonium breeder reactor becoming competitive with a light water reactor at a cost of uranium-oxide of less than $90 per pound - the cost which the DOE projects for 2020. The most recent DOE study of breeder economies, for example, showed a crossover point in the range of uranium costs of $150-270 per pound (1981 $).[17]

Considering this background I think that Congress might well ask itself whether the nation should continue to spend over one billion dollars a year "commercializing" a technology which even its advocates don't expect to be commercially viable for at least 40 years. Congress dropped the U.S. supersonic transport commercialization program in 1970 and let the French show the world that it was the right decision. In the case of the breeder the French seem once again to have done us the same favor. Indeed, if we do not move soon, the French may cancel their breeder commercialization program before we cancel ours.

An Alternative Evolutionary Approach

I would now like to return to what I understand is the primary purpose of these hearings: the investigation of an alternative approach to uranium conservation involving evolutionary improvements in the current once-through system. I am very much in favor of such an approach and would like to discuss it in the remainder of my statement.

The current once-through fuel cycle has a number of advantages of which I will mention three:

- It is simple. The contrast with the breeder fuel cycle is striking in this regard. Both reprocessing and plutonium fuel fabrication plants have proven extremely difficult to operate reliably. The reprocessing plants at Windscale, England; La Hague, France; and West Valley, New York all had lengthy shutdowns because of accidents or unsafe working conditions and on average have only worked at a fraction of their design capacities for reprocessing light water reactor fuel. The reprocessing of breeder fuel would be even more difficult. Since each reprocessing plant would recycle the fuel for about 50 reactors, a lengthy breakdown could be economically catastrophic if it shut down the associated reactors. This problem could be mitigated by building extra reprocessing plants or by stockpiling a year or more extra breeder fuel but the large expenses involved would make the economics of the breeder even worse.
- The safeguarding of plutonium in the spent fuel is relatively easy. The highly radioactive fission products in spent fuel are relatively effective in protecting the plutonium from diversion and, because the fuel rods are countable, one can keep track of the plutonium which they

contain with no measurement error. In contrast it has proven impossible in the Department of Energy's weapon's program to verify that plutonium has not been diverted. In 1977 ERDA announced, for example, that the cummulative inventory difference in AEC-ERDA facilities through September 30, 1976 was about 1.5 metric tonnes of plutonium - enough to make about 200 Nagasaki bombs.[18]

- The radioactive waste disposal problem is relatively uncomplicated for the once-through fuel cycle. In the past, various arguments have been raised to the effect that recycling and consuming plutonium significantly reduces the long term hazard of radioactive waste. By now, however, it is generally accepted that this is not the case and that considerations related to radioactive waste disposal do not favor plutonium recycle.[19] Indeed history so far suggests just the opposite. The military reprocessing program has shown reprocessing and plutonium fabrication facilities multiply the number and difficulty of waste forms and greatly increase the volume of contaminated material which requires disposal. The Department of Energy has created horrendous radioactive waste disposal problems at Hanford, Oak Ridge and elsewhere as a result of its reprocessing and plutonium operations. We should, therefore, be in no hurry to break open the metal cladding which today separates from the outside world the even greater quantities of radioactivity contained in our spent power reactor fuel.

The Potential for Uranium Efficiency Improvements in Once-Through Systems

The advantages of the once-through fuel cycle suggest that we should do what we can to increase its viability and longevity.[20] Despite all the concern that has been expressed in the past by the U.S. nuclear industry about the limited U.S. resource of low cost uranium, however, the reality has been that uranium has been extremely cheap and U.S. utilities have not been particularly interested in uranium efficiency. It should not therefore be surprising that, when the reactor manufacturers and national laboratories were asked by the Department of Energy to explore the possibilities for making uranium efficiency improvements in the once-through fuel cycle, they found that the current systems are "uranium guzzlers." Apparently cost-effective retrofittable improvements were identified which could increase the amount of electricity that can be generated from a pound of uranium by a factor 1.25 [21] and additional cost-effective improvements were identified which, if they were incorporated into new reactors, could increase this resource extension factor to 1.5.[22]

Making High Cost Uranium Economic

The payoff from uranium efficiency improvements could be considerably greater than a factor of 1.5 extension in the amount of energy which can be generated by light water reactors, because these improvements, in addition to extending a fixed resource base would make it economical to exploit lower grade ores than before. Consider, for example, the DOE's 1977 estimate of the uranium supply curve shown in Figure 7. Assume also that we are willing to spend up to 1.5 cents per kilowatt-hour on uranium. With current reactors this would make uranium costing up to $180 per pound of oxide affordable. With a one third reduction in uranium requirements per kilowatt-hour, uranium costing 50 percent more or $270 per pound would become affordable on the same basis. In the example shown in Figure 7, at least 1.5 times as much uranium is available at prices of $270 per pound as at $180 per pound.

This extension of the economically exploitable resource base compounds with the improved system's ability to extract 1.5 times much energy out of each pound of uranium so that we can more than double the number of kilowatt-hours that we can economically generate with a once-through fuel cycle (1.5 x 1.5 = 2.25).*

Reducing the Spent Fuel Problem

One of the approaches which would be used to increase the uranium efficiency of the once-through fuel cycle would involve increasing the percentage of the atoms fissioned in the fuel from about 3 to 5 percent. An important side benefit of this would be the reduction of the rate of discharge of spent fuel from the reactor by about 40 percent. This would probably also reduce spent fuel storage and disposal costs by a similar percentage.

A Federal Program to Improve the Once-Through Fuel Cycle

Since the light water reactor improvements being discussed are incremental, the associated research and development costs would be very small in comparison to what would be required to bring on line a whole new reactor and fuel cycle.

A federally funded improvement program for light water reactors would have a number of other advantages as well, including the following:

- It would be of real current interest to the utilities

  A strategy of incremental improvements would therefore be much more effectively disciplined by the "marketplace" than a development program for a whole new reactor-fuel cycle system which may never be deployed commercially.

---

*In this simplified discussion I have assumed that there will not be increased costs associated with light water reactor efficiency improvements which will significantly offset the uranium cost savings. This assumption appears to be approximately valid, however, since, according to the DOE analysis, the efficiency improvements are already economic at the current low uranium cost of about $30 per pound.

- <u>There would be safety and reliability benefits</u>. Shifting some of the nation's nuclear energy R&D talent back to work on light water reactors might help solve the safety and reliability problems which are increasingly plaguing these reactors. Indeed I think that one of the principal reasons for our current troubles was the fact that the AEC diverted its best people to work on breeder R&D just when the safety problems of large light water reactors were beginning to be recognized.
- <u>The U.S. would still have a breeder "option"</u>. Some breeder advocates are concerned that the U.S. may forget everything it ever knew about liquid metal technology and fast neutron reactors and that the time may come - even if it is 100 years from now - when we need more uranium efficiency than can be achieved by light water reactors on a once-through fuel cycle. These people may be reassured to learn that we will still have a breeder option as long as we use light water reactors. Admiral Rickover's group has shown that, if reprocessing is allowed, it is possible to increase the conversion ratio of light water reactors up to any level including that of a "breakeven" breeder reactor.* The cost of electricity from these light water breeders would probably be about the same as that from liquid metal breeders.**

---

*A "break even" breeder would produce about as much "fissile" (chain reacting) material as it consumed. While a true breeder such as the liquid metal fast reactor could produce enough excess fissile material to start up new reactors at a certain rate without any requirements for inputs into the system of the only naturally occurring fissile material, uranium-235, the U.S. resource base is adequate, to start up a system of break even breeders, of any reasonable size. The AEC excluded break even breeders from its program on the basis of unreasonable nuclear power growth projections such as that shown in Figure 2.

**While the capital cost of a light water breeder would be lower than that of a liquid metal breeder, its fuel cycle cost would be higher - principally because the fuel would have to be recycled at least twice as frequently.

A Safer, Less Costly Alternative

In summary, it would appear that:

- With any reasonable nuclear power projection, the U.S. has enough uranium to fuel for generations a system made up exclusively of reactors operating on a once-through fuel cycle;
- This system would produce electricity at lower cost and more reliably than the breeder; and
- The more money that the Department of Energy has put into nuclear R&D - billions for the breeder and millions on once-through systems the wider has the gap between breeder and light water reactor economics become. We have learned that the breeder system will be much more expensive than had been hoped and that the once-through system can be made significantly cheaper and more uranium efficient.

Footnotes and References

1) U.S. DOE Energy Information Administration, Monthly Energy Review, August 1981, p. 86.

2) U.S. DOE Energy Information Administration, 1980 Annual Report to Congress, Vol 3: Forecasts, pp. 126, 177. I assume that one 1979$= 1.2 1981 $. Eleven thousand Btus is approximately the amount of heat required in a steam-electric power plant to generate one kilowatt-hour of electric energy.

3) U.S. AEC, Proposed Final Environmental Statement on The Liquid Metal Fast Breeder Reactor Program, December 1974, p. 11.2-113.

4) Robert H. Williams, "Industrial Cogeneration," Annual Reviews of Energy, 1978, p. 313.

5) Ref. 2, p. 158.

6) See e.g., Marc H. Ross and Robert H. Williams, Our Energy: Regaining Control (McGraw-Hill, 1981), and Solar Energy Research Institute Report on Building a Sustainable Energy Future, U.S. House of Representatives Committee on Energy and Commerce, Committee Print, 1981).

7) Ref. 2, p. 159.

8) U.S. Energy Research and Development Administration, Liquid Metal Fast Breeder Reactor Program: Final Environmental Statement (1975), p. III, F-12.

9) M. Hug, Revue de l'Energie, February 1980, p. 75 (Dr. Hug is a director of Electricité de France, France's electrical utility.)

10) C. Pierre Zaleski:, "Breeder Reactors in France," Science, April 11, 1980, p. 137.

11) According to current Department of Energy estimates, a new U.S. light water reactor will cost about $1500 per kilowatt generating capacity in 1981 dollars (ref. 2, p. 274). Forty percent of $1500 equals $600 which, in constant dollars, would have associated with it an annual capital charge of $60 (compare ref. 2, pp. 262 and 274), which would amount, at a 65 percent average capacity utilization factor, to a capital charge of 1 cent/kilowatt-hour.

12) The official estimates of reprocessing costs are made in France by the PEON Commission, a majority of whose members come from the French Atomic Energy Commission, Electricité de France and the French Treasury. Between 1970 and 1980, PEON Commission estimates for the costs of reprocessing LWR fuel have risen from $100 to approximately $1000 per kilogram of heavy metal in the fuel (1980 $). In most analyses it is assumed that the reprocessing of breeder fuel will cost somewhat more than the reprocessing of light water reactor fuel, but I have assumed $1000 per kilogram. [These numbers were kindly provided by Professor Claude Henry of the Ecole Polytechnique in a letter to my colleague, Robert Williams, dated June 24, 1981. I have assumed that one French Franc = 0.23 $.]

(12 cont.)

A 1000 Megawatt (electric LMFBR with a homogeneous core, operating on a plutonium fuel cycle at a 70 percent average capacity factor, would discharge about 26 metric tonnes of heavy metal per year (ref. 13). This corresponds to a generation of 0.24×10^6 kilowatt-hours per kg. of heavy metal.

13) U.S. DOE, Nuclear Proliferation and Civilian Nuclear Power (Draft report of the Nonproliferation Alternative Systems Assessment Program), Vol. IX, Reactor and Fuel Cycle Descriptions, Tables B.2 and B.6 .

14) The differential estimated in ref. 15, between the costs of fabricating breeder oxide fuel (including axial blankets) for operation on a plutonium fuel cycle and LWR fuel for the current once-through fuel cycle ranges \$540 to \$870 per kilogram of heavy metal in January 1, 1978 dollars. One of these dollars was worth about \$1.35 in 1981 dollars. The differential in overall fabrication costs is reduced somewhat by the fact that the fabrication of the radial blanket in a breeder (which I assume to be 25 percent of the heavy metal flow through the reactor) would cost little more than the fabrication of once-through LWR fuel.

15) U.S. DOE, Nuclear Proliferation and Civilian Nuclear Power, Vol. V: Economics and Systems Analysis, Tables A-5 and A-6.

16) In Figure 5 I have assumed breeder-LWR cost differentials of \$600 and \$1125 per kw(e) capacity corresponding respectively to 40-75% increases over a \$1500 LWR base cost. I have assumed reprocessing costs of \$600 and \$1100 per kilogram heavy metal based respectively on DOE estimates of \$450 - \$800 in ref. 16 and PEON estimates for LWR fuel reprocessing costs (see footnote 12). Finally, I have assumed cost differentials between breeder and LWR fuel fabrication costs of \$400 and \$900 per kilogram heavy metal based on ref. 15. All costs have been converted to 1981 \$. Uranium costs would have to increase to \$120 and \$240 per pound respectively for the breeder savings to equal the two estimates of breeder total incremental costs shown on Figure 5.

17) Ref. 15, p. 44.

18) ERDA Press Release, "ERDA Issues Report on Inventory Differences for Strategic Nuclear Materials," August 4, 1977.

19) Hartmut Krugman and Frank von Hippel, "Radioactive Waste: the Problem of Plutonium," Science October 17, 1980, p. 319.

20) U.S. ERDA, Proliferation Resistant Nuclear Power Technologies: Proposed Alternatives to the Plutonium Breeder, report by Thomas B. Cochran, Russel E. Train, Frank von Hippel and Robert H. Williams, April 6, 1977; Harold A. Feiveson, Frank von Hippel and Robert H. Williams, "Fission Power: An Evolutionary Strategy," Science, January 26, 1979, p. 330.

21) Ref. 13, pp. 13, 14

22) S. Newman, S. Goldsmith, and R.M. Fleischman, "Assessment of Nonbackfittable Concepts for Improving Uranium Utilization in LWR's." Abstract of Paper presented to the American Nuclear Society, June 10, 1981.

Figure 1

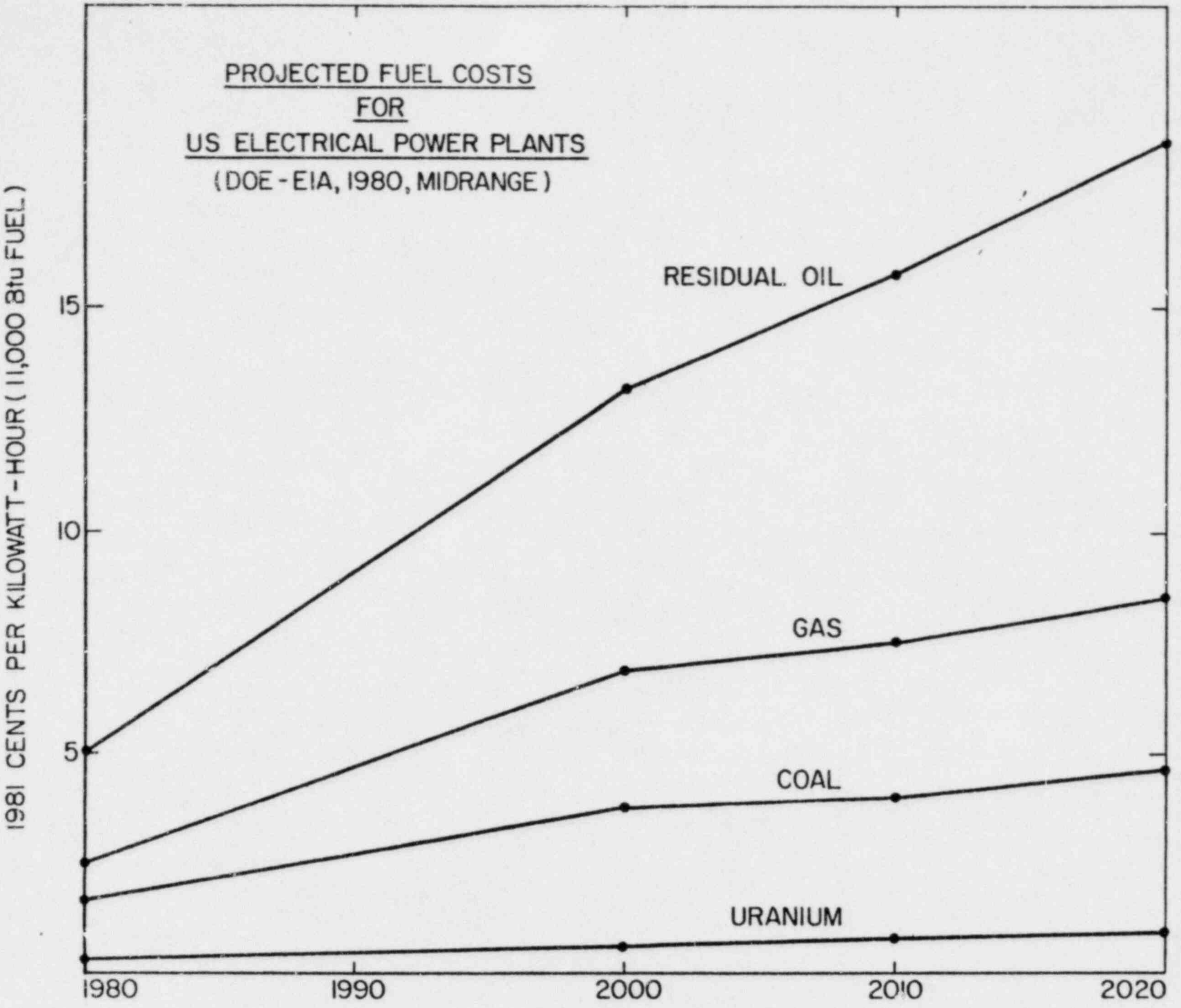
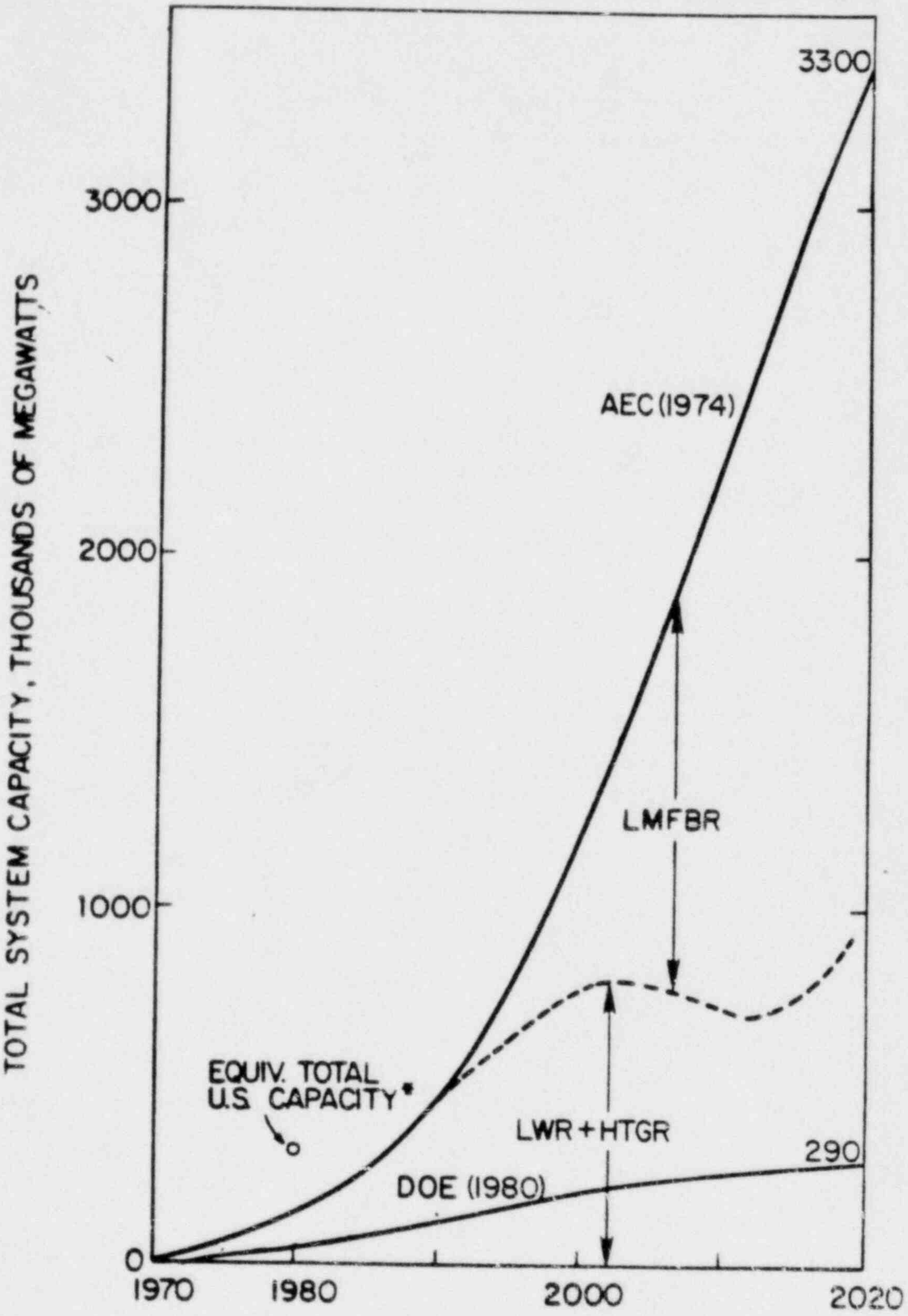

PROJECTED FUEL COSTS
FOR
US ELECTRICAL POWER PLANTS
(DOE-EIA, 1980, MIDRANGE)
1981 CENTS PER KILOWATT-HOUR (11,000 Btu FUEL)
RESIDUAL OIL
GAS
COAL
URANIUM
15
10
5
1980
1990
2000
2010
2020

Figure 2



US NUCLEAR GROWTH PROJECTIONS

*USING THE 80 PERCENT AVERAGE
CAPACITY FACTOR ASSUMED BY
THE AEC IN 1974

Figure 3

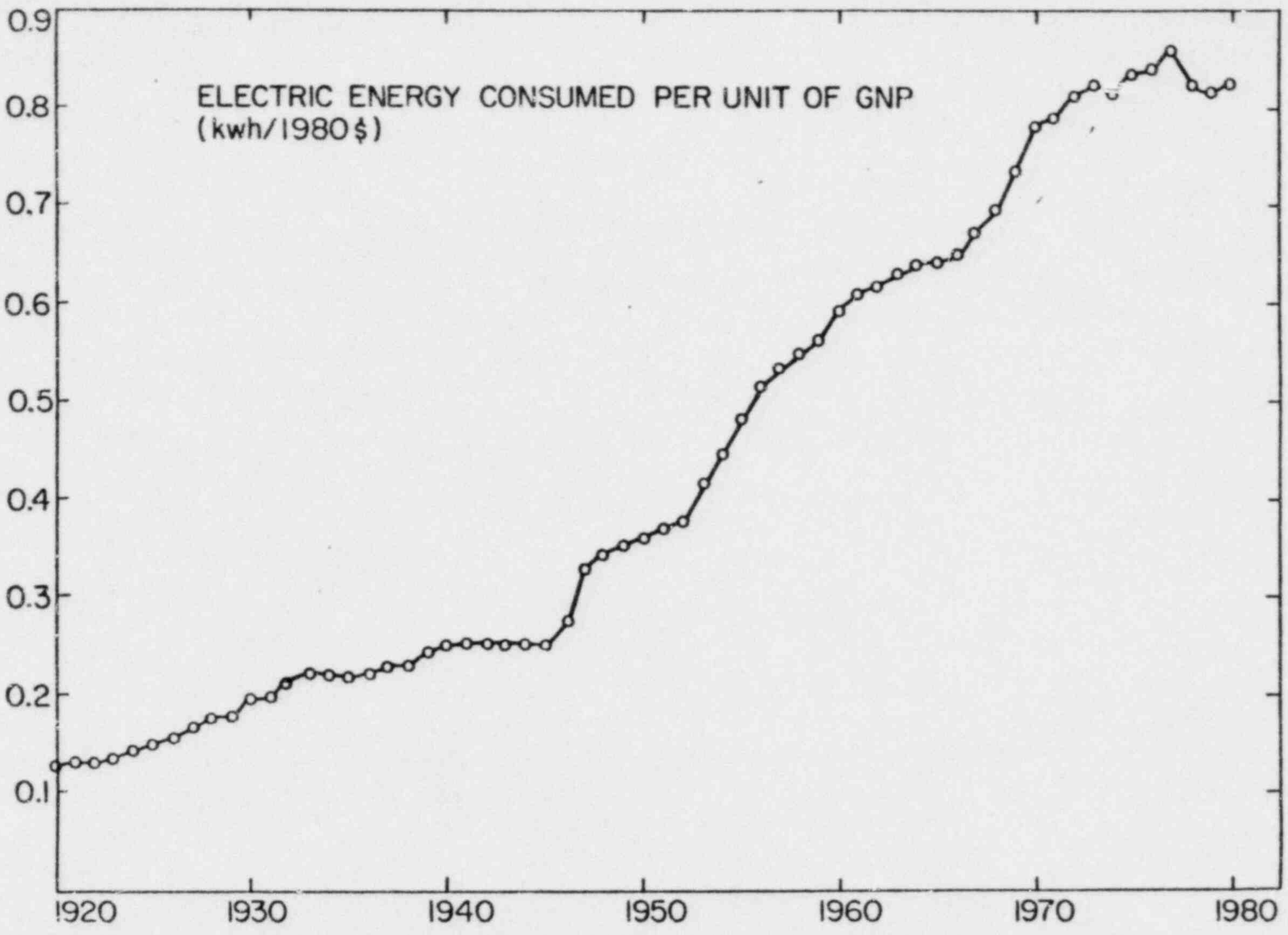
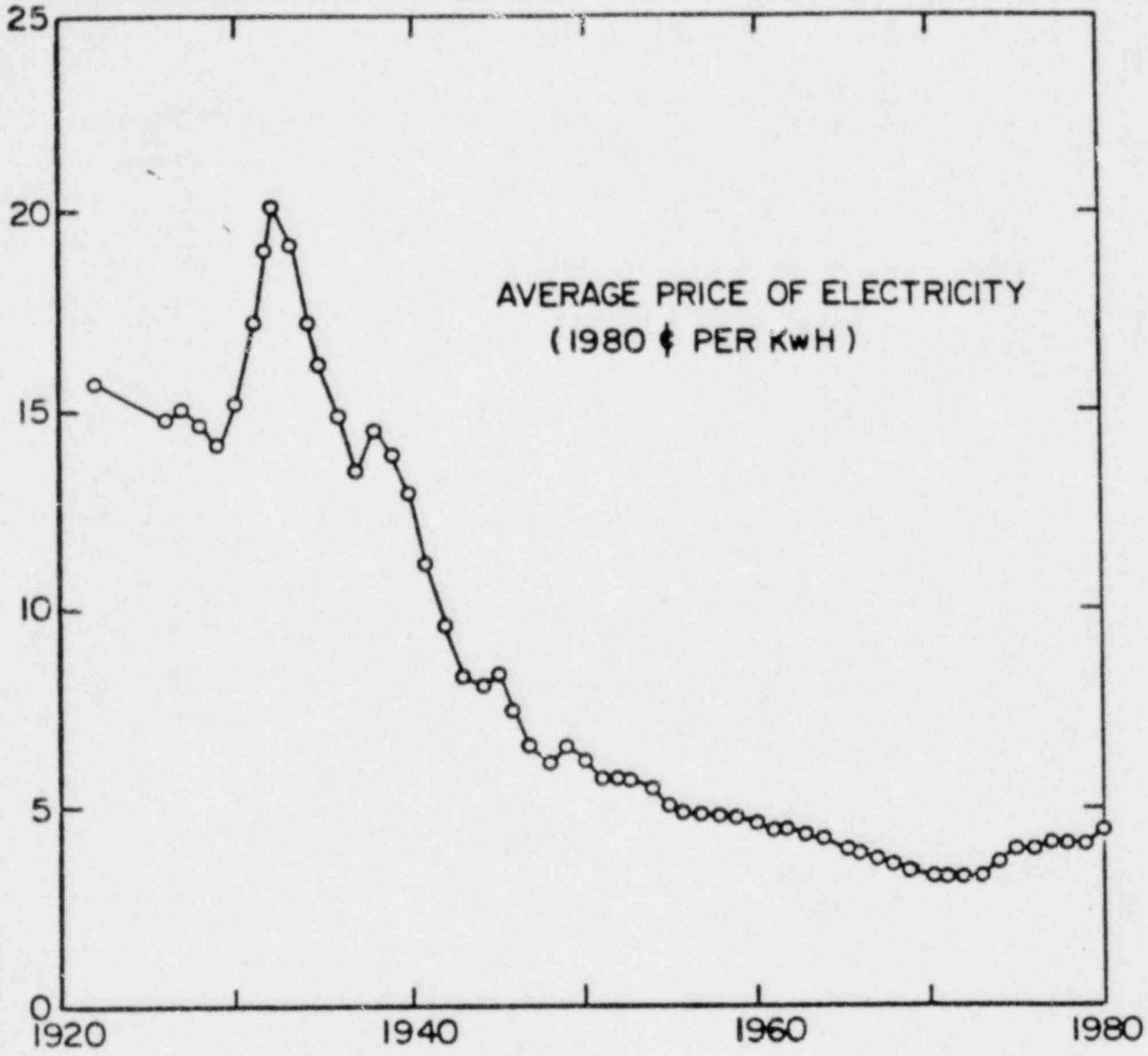
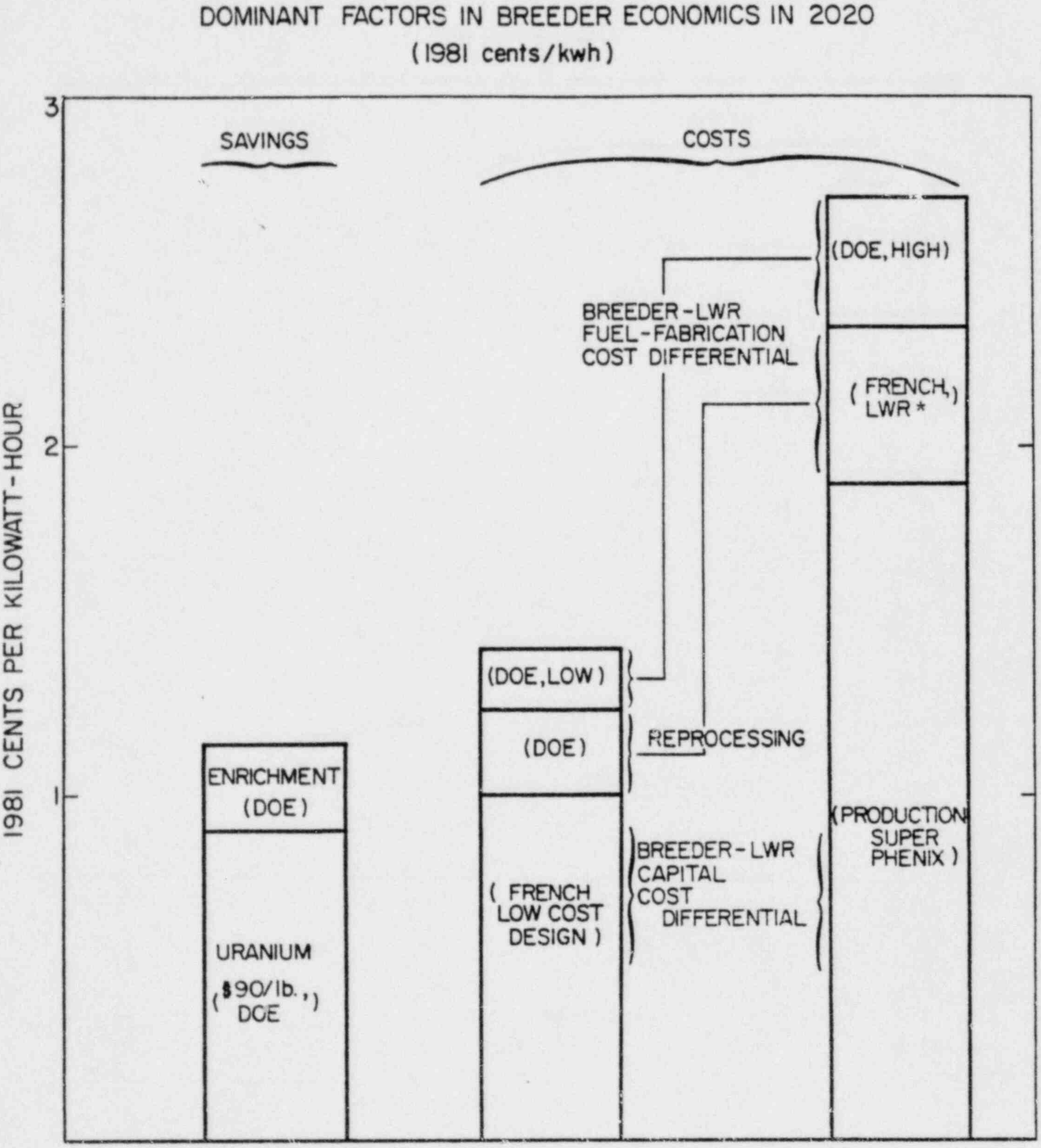

ELECTRIC ENERGY CONSUMED PER UNIT OF GNP
(kwh/1980$)
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
1920
1930
1940
1950
1960
1970
1980

Figure 4



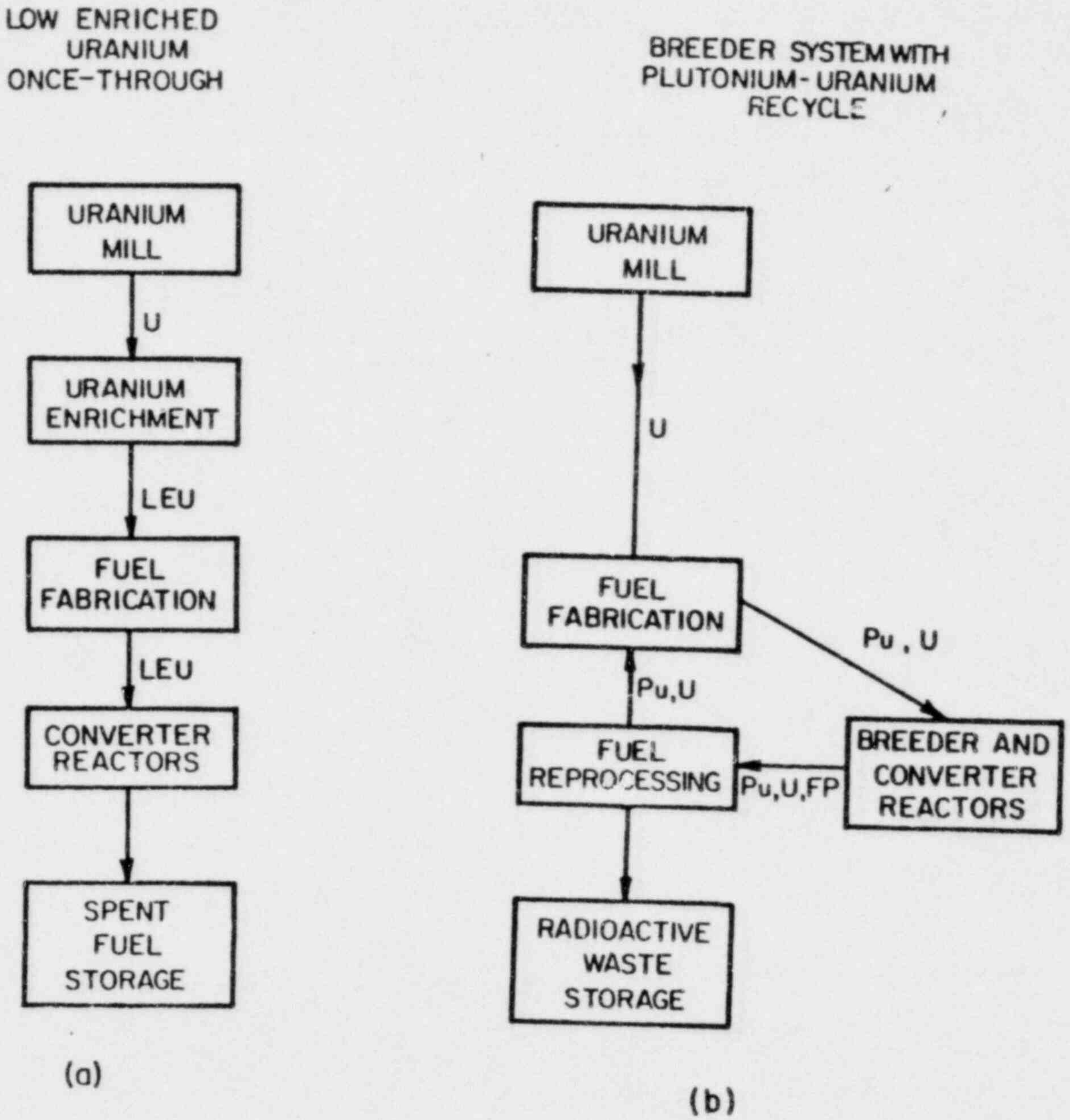
AVERAGE PRICE OF ELECTRICITY
(1980 ¢ PER KwH)
25
20
15
10
5
0
1920
1940
1960
1980

Figure 5



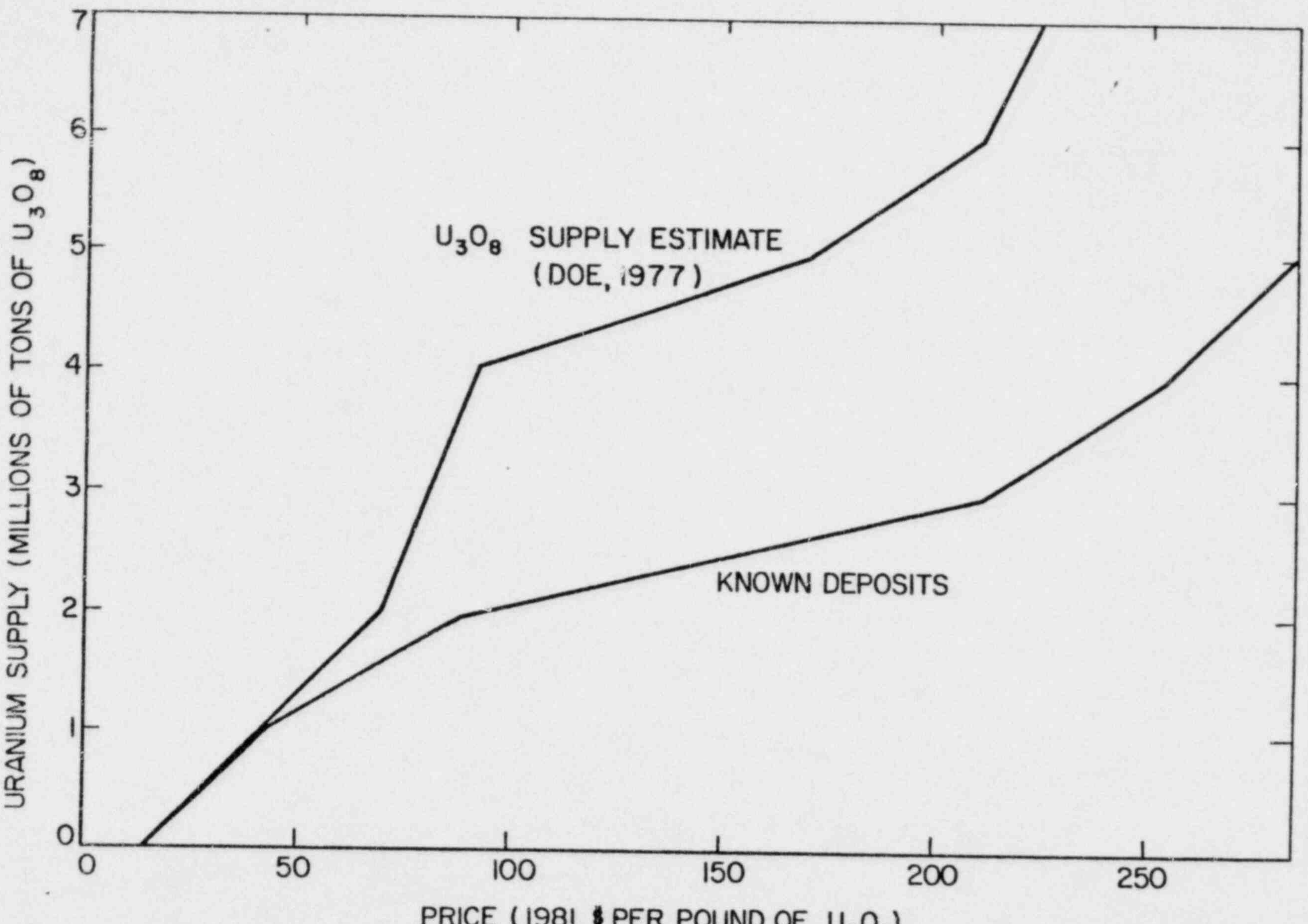
* Based on French experience with reprocessing LWR fuel.

Figure 6



NUCLEAR FUEL CYCLES

Figure 7


U_3O_8 SUPPLY ESTIMATE (DOE, 1977)
KNOWN DEPOSITS
URANIUM SUPPLY (MILLIONS OF TONS OF U_3O_8)
PRICE (1981 $ PER POUND OF U_3O_8)
0
1
2
3
4
5
6
7
0
50
100
150
200
250

public
power

MAY-JUNE 1981
VOLUME 39 NUMBER 3

pp. 19,21,24

Should breeder reactors be built in the United States?

NO!

by **FRANK VON HIPPEL**

Chairman of the Federation of American Scientists and a senior research physicist at Princeton University's Center for Energy and Environmental Studies, von Hippel was a member of breeder review panels established by the National Academy of Science and Energy Research and Development Administration.

"Fanaticism consists in redoubling your efforts when you have forgotten your aim."

—George Santayana, 1905

I BECAME INTERESTED in the proposal to commercialize the plutonium fuel cycle in 1974 when I learned about the enormous flows of materials usable in nuclear weapons which would be involved. The plutonium discharged annually from just 100,000 mw of breeder capacity would be enough for the construction of 10,000 Nagasaki-size nuclear weapons.

In 1974 the U.S. Atomic Energy Commission (AEC), predecessor of the Nuclear Regulatory Commission (NRC), was projecting that the United States would be bringing this much breeder capacity on line *each year* by the year 2000. I knew that a panel of experts set up to advise the State Department had concluded already in 1946 that "in the real world" international safeguards could not be effective in preventing a nation from diverting plutonium or highly enriched uranium from commercial to weapons use. When I inquired whether the situation had changed since 1946 I was told it had: The experts were now worried that it would be impossible to prevent diversions of materials usable for nuclear weapons from a plutonium economy even by terrorist groups.

The problems of a breeder reactor economy seemed to be problems of the next century, however, only a few people had time to worry about them. This state of complacency did not last very long.

In May 1974 India exploded a nuclear bomb using plutonium obtained not from a plutonium breeder reactor but from a research reactor. The Indian nuclear technologists had used the same technique for separating the plutonium from the fuel that we had developed within the U.S. nuclear weapons program. The AEC had trained the nationals of many countries in this technique in the "Atoms for Peace" program because it was advocating the plutonium breeder reactor as the prime mover of future energy systems worldwide.

The Indian bomb woke us up to the fact that the interest of a number of governments in nuclear technology was decidedly ambiguous. Indeed, the ambiguity of the interest of Israel, India, Pakistan, South Korea, Argentina, Brazil, the shah's Iran, Iraq and other nations in purchasing and constructing facilities for the separation of plutonium from nuclear fuels soon became the cause of some of our government's worst foreign policy headaches.

The expectation that a plutonium-fueled future would become a reality was already providing a convenient cover for nations interested in developing a nuclear weapons option. A group of three physicists and a political scientist therefore organized themselves at Princeton University to analyze whether the plutonium breeder reactor was an essential part of the world's energy future.

Demand and the Breeder

At the time we undertook this effort, in 1975, the United States was the world leader in breeder technology. The latest word in U.S. policy analysis with regard to the breeder was contained in the "Proposed Final Environmental Statement on the Liquid Metal Fast Breeder Reactor Program," a statement published in December 1974 by the AEC.

The case for the breeder at that time was the same as it is now: U.S. resources of high-grade uranium ore are large enough only to fuel about one million mw of light-water reactors over their expected 30-year lifetimes. If the United States wishes to build much more nuclear capacity than that it will have to switch to more uranium-efficient reactors.

Over the short run relatively small efficiency improvements could greatly mitigate the uranium supply problem. The nuclear power pioneers were big thinkers, however, and they realized that over a period of millenia a breeder would allow mankind to exploit such low-grade ore that, in principal at least, it would be possible to "burn the rocks" of the earth. Since the breeder reactor was the ultimate solution to the uranium resource problem, no intermediate solution seemed worth the bother.

In 1974 the AEC projected the United States would have 1.2 million mw of nuclear capacity on line in the year 2000 and approximately twice that much by 2010. (See Figure 1, p.21.) Twenty-five years would be a very short time to create a breeder reactor construction industry which could bring on line 100,000 mw of capacity a year. A major government demonstration and commercialization effort therefore appeared to be justified.

At the time the AEC made these nuclear growth projections it was also projecting that total U.S. electricity production would be 10.6 trillion kwh in the year 2000 and 27.6 trillion kwh in the year 2020—up from 1.9 trillion kwh in 1974. About three quarters of all electricity production after the year 2000 was to come from nuclear power plants operating at 80 percent average capacity factors. The overall electricity production growth projections were based on the assumption that use of electricity, which had been doubling every 10 years during the 1920-1970 period, would continue to grow at almost the same rate.

Real Price of kwh Declined

In retrospect it is easy to see that the historically sustained rapid growth of

U.S. electricity consumption prior to 1970 was possible only because the real price of electricity was declining rapidly during the same period. Figure 2 shows that between 1920 and 1970 electricity prices fell in constant dollars at an average annual rate of 3.2 percent—almost the same percentage by which electricity consumption was exceeding gross national product (GNP) growth. Consequently it was possible for the nation to increase its rate of electricity consumption at the rapid historical rate *without increasing the share of the GNP devoted to the purchase of electricity* (about 2.5 percent).

Figure 2 also shows, however, that real electricity prices bottomed out in 1970 and have in fact since risen by about 50 percent. As a result, in order for electricity consumption to grow even as rapidly as the GNP since 1970 it has been necessary for funds to be diverted from other parts of the economy. Naturally, there has been consumer resistance to such a shift and the result has been a dramatically slower growth in electricity consumption.

With the passage of the '70s it has become clear that the causes of slower electrical demand growth are not transient. The projections of long-term future growth trends have therefore also been coming down. The September 1980 ELECTRICAL WORLD forecast for electrical utility generation in the year 2000 was 4.5 trillion kwh—about twice the 1980 level but less than one half the level which the AEC was projecting in 1974.

As projections of future demand growth have fallen, so naturally have projections of future generating capacity—most notably nuclear generating capacity. The most recent ELECTRICAL WORLD projection for nuclear capacity on line in the year 2000 is only 150,000 mw. This is still a very large capability—at 65 percent average capacity factor it would generate about as much electric energy annually as all U.S. coal-fired plants do today—but it is only one-eighth of the 1.2 million mw which the AEC was projecting in 1974. It is also far less than the one million mw of light-water reactor capacity which the AEC was projecting in 1974 as supportable with the U.S. resource base of high-grade uranium ore.

U.S. Uranium Resources

For a brief period in 1977 and 1978 advocates of the breeder reactor argued that, if the AEC's estimates of nuclear growth projections had been unrealistically high, so had its estimates of U.S. uranium resources. Their conclusion was that the effect of the two errors cancelled and that therefore the need for the breeder was as urgent as ever. It appears now however that, if anything, the AEC's uranium resource assessment was pessimistic.

In 1974 the AEC's median estimate of U.S. uranium resources mineable at a marginal cost less than about $50 per pound (in 1980 dollars) was 2.8 million tons of uranium oxide. By 1980, as a result of the Department of Energy (DOE) National Uranium Resource Evaluation program, the estimated probability that U.S. uranium resources in this cost category was less than 2.8 million tons had been reduced from 50 to 5 percent.

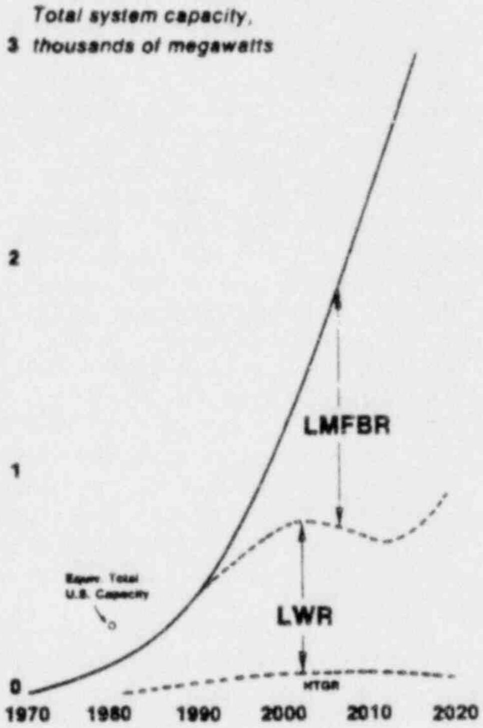
In the same period, it was realized that it would be economic to mine much higher-cost uranium to fuel light-water reactors (LWRs). The Department of Energy published a first estimate that about five million tons of U_3O_8 (uranium oxide) would be mineable in the United States at a marginal cost of less than $100 per pound. (At this price the contribution of uranium per kwh to the cost of electricity generated by light-water is still equivalent to a cost of oil at only $4 per barrel.)

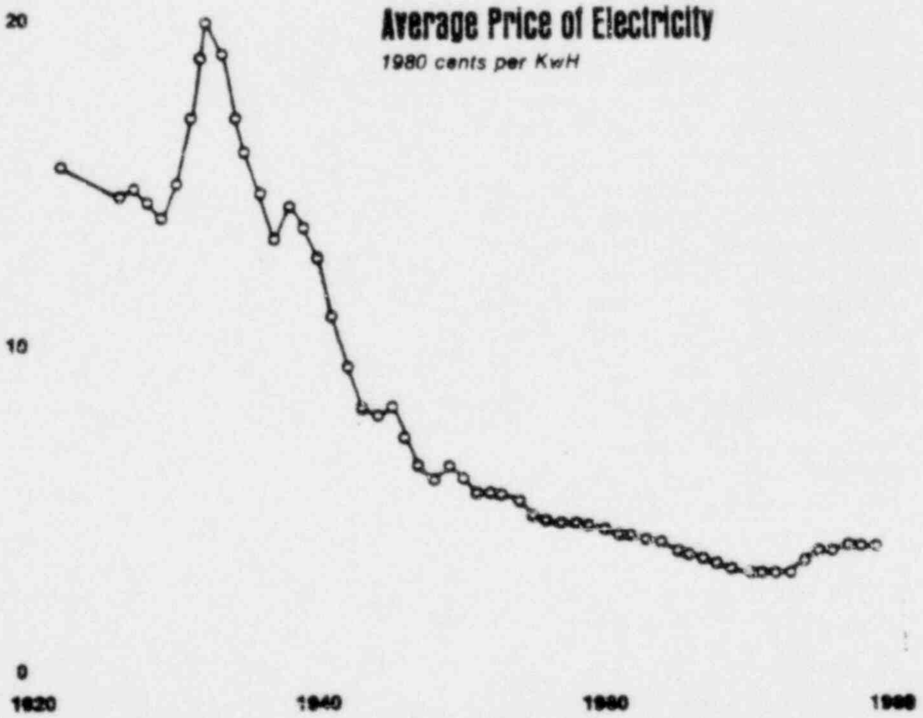
Five million tons of U_3O_8 would amount to about 5,000 tons of U_3O_8 for each of a thousand 1,000-mw

continued on page 24

The AEC's 1974 Nuclear Growth Projection

(80 percent average capacity factor assumed)




Average Price of Electricity

1980 cents per KwH

LWR's—enough even at *current* utilization efficiencies (which according to the Department of Energy, can be increased by 15 to 40 percent) to run each of these reactors for about 30 years at an average capacity factor of 65 percent.

Breeder Economics

In 1974, when the AEC was proposing a breeder reactor commercialization program, the agency's cost figures indicated that U.S. utilities might want a breeder even if the nation had unlimited supplies of high-grade uranium ore. The AEC projected the cost of the first commercial-scale breeder would be only 25 percent greater than that of an LWR of the same capacity, and that thereafter the cost difference would rapidly drop to zero. The cost of the breeder fuel cycle per kwh was projected to be *one-tenth* that of the LWR. Thus, even with uranium costing as little as $30 per pound (today's approximate price) breeder-generated electricity was projected to cost 25 percent less than LWR-generated electricity.

Things have turned out much differently, however. Recently the French revealed that the bus bar cost of electricity from the world's first and only commercial-scale breeder reactor—the much-touted Super-Phenix—is almost twice the cost of electricity from their LWRs. Both the breeder reactor itself and the fuel-reprocessing service which it requires have proven very expensive.

Electricité de France is resisting pressure from the French Atomic Energy Commission to make commitments to purchase further breeders unless the breeder cost can be brought down to within 25 percent of the cost of pressurized water reactors. According to a French news report, Novatome, the builder of Super-Phenix, has proposed as a cost-saving measure the removal of one of the safety barriers—the containment vessel and the dome—in the next generation of French breeder reactors.

The Breeder Reactor Gap

As the need for the breeder reactor has faded into the mists of the future and its economics have come to seem increasingly doubtful, its advocates have been left with one last argument. It was made by Wallace Behnke in the foreword of the 1980 annual report of Project Management Corp., which manages utility interests in the Clinch River breeder reactor. Behnke argued the construction by the U.S. government of a demonstration breeder reactor "is crucial to the nation's ability to keep pace with foreign breeder technology developments."

The implication is that the United States, by not keeping up with the breeder reactor demonstration programs of some other nations, is falling behind in some kind of important race. Unfortunately Behnke does not explain *why* it is important for the United States to keep pace with other nations in what looks increasingly like a race to develop a white elephant.

When I first heard expressions of concern from the U.S. nuclear research and development establishment that the United States was falling behind the French and the Soviets in an important area of technology, the warnings had a familiar ring. Then I remembered the great debate over the U.S. supersonic transport (SST) demonstration program.

President Nixon commissioned two major reviews of this controversial program just after he came into office. When they were completed, both reports expressed doubt that either the U.S. SST or the French-British Concorde would be able to compete economically with subsonic aircraft. Yet the U.S. aircraft industry and the Department of Transportation persuaded the president to go ahead. In his explanation of his decision to the nation the president adopted their principal argument: "I want the United States to continue to lead the world in air transport."

It appears President Reagan has been persuaded by the breeder advocates within the nuclear industry and the DOE that the United States must go ahead with a breeder demonstration program if we are to continue to lead the world in nuclear power technology. The final decision on the breeder, however, will be made by the market. There too the French will ultimately learn the answer to the question asked by LE MONDE, France's leading newspaper, just four years ago: "Is the Super-Phenix a Nuclear Concorde?"

The Breeder Legacy

Perhaps a hundred years from now, just as we today are dusting off the designs of old windmills and are rediscovering how the Greeks proportioned buildings to let in direct sunlight in the winter and exclude it during the summer, our descendants may dust off the plans of today's prototype breeder reactors. I am afraid, however, that long before that time the current burst of enthusiasm for this technology will have helped spread another industry around the earth—the manufacture of the most barbaric weapons ever perfected by man.

It often is argued by breeder proponents that the "genie" of nuclear weapons is already "out of the bottle." If one thing is certain about nuclear weapons, however, it is that things can always get worse. There will always be another country or terrorist group interested in obtaining a nuclear "device."

Our primary responsibility to our descendants must therefore be to contain or at least slow the spread of this dread menace. In this context the promoters of the plutonium economy must be recognized for what they are—the typhoid Marys of the nuclear era.