The Economic Issues of the Fast Breeder Reactor Program

The economic benefits of the fast breeder reactor may not be as definite as its proponents claim.

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The fast breeder reactor (FBR) program in the United States can be traced back to at least 1945, when a project to develop the plutonium-fueled FBR was initiated in the Argonne National Laboratory, Division of the Manhattan District Metallurgical Laboratory. However, major efforts in national and industrial laboratories were focused on light water reactors (LWR's) where the prospect of large-scale commercial application was much nearer at hand. In the mid-1960's, the utility industry began to make heavy commitments to LWR's, and the Atomic Energy Commission (AEC) (*1*) scaled down its involvement in the research and development (R & D) of LWR's and shifted its efforts to FBR's.

Among several types of breeder reactors, the liquid metal fast breeder reactor (LMFBR) program has been receiving a major portion of the financial and personnel support from the government and the industries. Other nations with significant breeder reactor programs, such as the Soviet Union, Great Britain, France, Germany, Italy, and Japan, have made the same choice. The annual budget for the LMFBR program in the United States soared from $0.9 million in 1947 to $34.1 million in 1965 (*2*) and $912.8 million in 1976 (*3*). The Energy Research and Development Administration (ERDA) is requesting $1.23 billion (*3*) for fiscal year 1977, which is 35 percent over the current allotment, 84 percent of the total fission reactor development budget, and approximately twice the total fusion R & D budget, and consistently the largest share of the total energy R & D budget. The support of LMFBR's as the top-priority program can only be justified if their economic and environmental benefits are definite and substantial.

In the past few years, many important environmental and social issues, in case of a mass LMFBR deployment, have been brought to the attention of the public, but only a few remarks about these issues will be made in this article. A substantial amount of research on the safety of reactors, the containment and safeguard of plutonium, and the assessment of accident risks remains to be done. The central concern is the threat posed by plutonium against the lives and health of human beings and other living systems for thousands of years. The core of a typical 1000-Mwe (million watt electric) LMFBR contains roughly 2500 kilograms or 2.5 tons (metric) of plutonium (*4*). With a projected LMFBR capacity of 1000 to 2000 gigawatts by year 2020 (*5*), 2500 to 5000 tons of plutonium will be present in the cores at any given time. Ten to 20 kg of plutonium is sufficient to make a nuclear bomb in the kiloton range, and it is much easier to extract bomb materials from the LMFBR fuel assemblies than from those of currently available converter-type nuclear reactors. In addition, plutonium is one of the few most toxic elements ever known, is completely man-made, and has a half-life of 24,000 years. Some studies indicate that inhalation of a mere milligram of plutonium can cause death from fibrosis of the lungs within a few weeks and even a microgram may be sufficient to eventually cause lung cancer.

These figures may be debatable, but if they were raised by one or two orders of magnitude, few would doubt the consequences. The maximum permissible dose over a lifetime has been established by medical authorities to be 0.6 microgram. Thus, only a small quantity of plutonium is sufficient in the construction of a bomb or a dispersal device capable of mass destruction. The unsettling question is: How effectively can thousands of tons of plutonium be properly confined in thousands of reactors and other sectors of the fuel cycle, and be safeguarded against reactor accidents, sabotage, and theft? The impact of LMFBR's on nuclear weapon proliferation is also a serious issue. However, we should realize that alternative electric generating systems, such as coal-fired, converter-type nuclear, and the still unproved solar and fusion power plants are not without environmental and health hazards. Future debates should be centered around the probability and magnitude of risk associated with LMFBR's and their risk-benefit trade-off in comparison with those of natural phenomena and other man-made systems, particularly the alternative electric generating systems. Based on present information, we have no reason to believe that LMFBR's are and will be better than any of the aforementioned alternative electric systems on environmental grounds. Consequently, breeder advocates have been emphasizing the economic benefits of LMFBR's, which I will review in this article.

Cost-Benefit Analyses

The major advantage of FBR's is their ability to unlock more than 60 percent of the energy in uranium in contrast to only about 1 to 2 percent by LWR's and 4 to 5 percent by high-temperature gas reactors (HTGR's). Even such an efficient utilization of uranium does not guarantee a lower electric generation cost because the savings in fuel cost may or may not outweigh the expected higher plant capital cost of LMFBR's, at least during the introductory years, and the R & D costs of the program. For an LWR in operation by 1982 and producing 1000 Mwe, the fuel cost is estimated at 25 percent, the capital cost at 69 percent, and the operating and maintenance cost at 6 percent of the electric generation cost of 22.6 mills per kilowatt-hour (*6*).

The proponents' claim of an economic benefit for LMFBR's is based on the cost-benefit analyses of the U.S. breeder reactor program by the AEC over the past decade. The first cost-benefit analysis was available in 1968 and was published in 1969 (CB-68) (*7*). It was updated in 1970 and published in 1972 (CB-70) (*8*). Another updated draft appeared in the *Draft Environmental Statement, Liquid Metal Fast Breeder Reactor Program*, in March 1974 (CB-74D) (*9*). In December 1974, the draft was slightly modified and expanded and appeared in the *Proposed Final Environmental State-*

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ment (CB-74P) (*10*). In December 1975, the report was published as the *Final Environmental Statement* (CB-74F) (*11*). The assumptions in these analyses changed quite substantially but the methodology and the conclusions were essentially unchanged. Both ERDA and the former AEC claim that the LMFBR program will produce substantial economic benefit to the nation. The benefits for the reference cases (most-probable cases) are summarized in Table 1.

All of the cost-benefit analyses start with a projection of electrical energy demand. Costs and benefits are measured in constant dollars which are corrected for general inflation. The costs of electricity with and without the integration of LMFBR's into the national electric generating system are then calculated by employing the linear programming technique to minimize the total electric cost over a planning horizon of 50 years. The difference between the two energy costs, with cost of the LMFBR program subtracted, is called the net gross benefit. The net discounted benefit is the present worth of the net gross benefit. If the net discounted benefit is positive, it means that the program will produce an economic benefit subject to the validity of the input projections and data.

In addition to the most-probable case, ERDA presented more than 60 cases based on different combinations and variations of major projections. The cases are neither equally probable nor weighted. The economic benefit or loss of the LMFBR program thus depends on the selection of a subset of cases and on which cases are considered to be more important than others. I suggest that, in addition to what was done in the cost-benefit analyses, ERDA should estimate and assign a probability coefficient to each variation of the major projections, and perform a risk analysis similar to those frequently used for capital investments (*12*). The results could be represented by a curve showing the probability of any rate of return as well as the variances, and could be compared with curves for alternative and competing programs. With such an approach, the debate over economic issues would be transferred from the selection of favorable cases to that of probability coefficients. I recognize the difficulty and arbitrariness in the determination of these coefficients, especially when they are for projections that extend 50 years into the future. But, quantification can narrow and focus the issues in debate and in their resolution. It is better to make rough estimates of these coefficients and to adjust them according to new information than not to attempt any estimate. The major assumptions and projections in the cost-benefit analyses that are under the strongest dispute are the discount rate, uranium supply, electrical energy demand, plant capital costs, and program costs. I review them individually below.

Discount Rate

The costs and benefits of a program are often incurred in different time and quantity streams. They must be discounted to the present at a rate to reflect time-preference and time-productivity. The AEC considered a discount rate of 7 percent to be most appropriate in the early cost-benefit analyses, CB-68 and CB-70 (*7, 8*). The rate was raised to 7.5 percent in CB-74D (*9*). In CB-74P and CB-74F, a rate of 10 percent was reluctantly chosen, but a 7.5 percent or lower rate was still considered to be more appropriate (*10, 11*). The net discounted benefit is highly sensitive to the discount rate, which is apparent from Table 1. The net discounted benefit drops from $46 billion to $14 billion when the rate is changed from 7.5 percent to 10 percent. In recent economic analyses supportive of the LMFBR program, a low rate was generally used. A 6 percent rate was adopted in the study of Stauffer *et al.* (*13*) and a 5 percent rate was favored in that of Auer *et al.* (*14*), though the results of the latter authors were also given for 7.5 and 10 percent. Contrarily, breeder critics consider that the rate should be at least 10 percent. In other economic studies (*15, 16*) a 10 percent rate has been used. Discount rates favored by the AEC were derived from the after-tax return of utilities. Such a philosophy remained unchanged in all the cost-benefit analyses and was clearly stated in the earliest analysis, CB-68 (*7*, p. 38):

> The LMFBR program can be identified with the utility sector of the U.S. economy, and the rate of return applicable to that sector has been considered as the criterion rate for evaluation of public investments in this area. The discount rates applicable to the electric utility industry would most nearly comply with this criterion.

This argument is invalid because the government should invest in programs which best benefit society, not any particular industry. The AEC's philosophy would lead the government to favor the less efficient industries which tend to have a lower rate of return. Society would, hence, suffer from the reduction of overall rate of return of all government projects. Also, the rate of return of the electric utility industry is a regulated rate which tends to be lower than unregulated rates. The use of an after-tax figure is inappropriate because taxes paid by the utilities represent a portion of the benefit returned to society. Discount rates should be based on the opportunity cost of utilized resources, which would otherwise be provided for in the private sector (*17*), or on the opportunity cost of public borrowing (*18*). Calculations based on these theories led to a discount rate of around 10 percent or higher (*16*, pp. 22–26). However, the debate on discount rate will probably subside. In March 1972, George P. Shultz, then director of the Office of Management and Budget, instructed all agencies of the Executive Branch of the federal government (except the U.S. Postal Service) to adopt a 10 percent discount rate before tax and after inflation for the analysis of program proposals submitted to his office. While other government projects are being evaluated at a 10 percent rate, it is unlikely that ERDA will be able to justify a lower rate.

Uranium Supply

The economic benefit of LMFBR's depends to a large degree on the uranium supply and price schedules. It is the most debated issue related to breeder economics. Relatively speaking, it is easier to settle the debate on discount rate than on uranium supply because the former deals with the choice of economic theories while the latter with an uncertain future of at least 50 years. Breeder advocates use lower supply curves which lead to larger benefits for the breeder. For uranium ores (U_3O_8) available at a cutoff price of $60 per pound (*19*), ERDA assumed 3.6 million tons in CB-74F (*11*), Manne and Yu, 4 million tons (*20*), and Stauffer *et al.*, 2.2 million tons (*13*). By contrast, breeder critics favored a figure between 7 to 10 million tons. In CB-74P (*10*), the net discounted benefit for the reference case would be lowered from $14.7 billion to $7.3 billion (in 1974 dollars) if the uranium supply at a $60 cutoff price was increased from 4 to 7 million tons.

The uranium supply schedules used in the AEC's cost-benefit analyses are shown in Table 2. Comparing the figures used in the recent analyses with those in the earlier ones, one can see that the projected uranium prices for the first 3 million tons have been reduced while the prices for uranium beyond the first 3 million tons have been drastically increased. The 3 million figure happens to be the amount of uranium ore needed to sustain an electric generating system with LMFBR participation (*11*, p. IIIF-24). In other words, higher prices for the first 3 million tons would not materially strengthen the case for LMFBR's as people generally perceive, but would tend to reduce the nuclear installed capacity and share in the electric generating system, and thus may even weaken the case for LMFBR's. It is because 3 million tons will be needed regardless of whether or not LMFBR's are introduced into the electric generating system (*11*, p. IIIF-24). Rather than claiming to "induce conservatism into the LMFBR analysis" (*11*, p. IIIF-50), ERDA would not underestimate the benefit by using lower prices for the first 3 million tons. However, as the prices for uranium beyond the first 3 million tons are adjusted upward substantially over the years, as shown in Table 2, the competitiveness of LWR's and HTGR's against LMFBR's is significantly reduced, and this has a substantial positive effect on the LMFBR benefit. Are these price revisions justified?

Reasonably assured and potential uranium resources in the United States, which were estimated when the cost-benefit analyses were performed, are shown in Table 3. The meaning of forward cost used by ERDA for uranium resource estimation should be clarified. Forward costs (*21*)

> . . . represent the calculated maximum amount of uranium that could be produced from a deposit at specific cost. Sunk costs, such as property acquisition, exploration, and other past capital costs and return on investment, are not included.

One should not equate forward cost with price, which is determined in the market by supply and demand. The method and theory of price determination are never explicit in any of the AEC's cost-benefit analyses. Past prospecting activities have been concentrated on ore with a forward cost at less than $15 per pound. But the uranium resources most relevant to the cost-benefit analysis of the LMFBR program are at a cost higher than $15 because low cost uranium will have been consumed before LMFBR's can contribute significantly to the reduction of uranium demand. The national uranium resource evaluation (NURE) program, initiated by the AEC in 1973, is the first comprehensive project to estimate the uranium resources in the entire United States, including Alaska. Unfortunately, the first comprehensive NURE report will not be available until early 1980. Evaluations of such importance to the choice and timing of our future energy systems should have been started a decade ago. The preliminary results of NURE indicate U.S. uranium supplies to be reasonably assured and potential uranium resources to be 3.52 million tons at a forward cost of $30 per pound. These estimates are based on the projected areas for which surveys were completed as of the end of 1975. It was stated by ERDA that (*11*, p. IIIE-40):

> . . . these areas constitute the most favorable known areas in the United States. However, a number of areas in the West and most of the East remain to be assessed.

As shown in Table 3, total uranium resources at a forward cost of $30 per pound have more than doubled since 1968. Yet, as shown in Table 2, ERDA did not assume a corresponding rise in uranium supply at a price of $60 per pound (*22*). In addition, uranium available at the cutoff price of $75 per pound has been reduced from 10 million tons in CB-68 and CB-70 (*7, 8*) to 4 million tons in CB-74F (*11*), while uranium resources, shown in Table 3, are either revised upward or are still under evaluation by NURE. An explanation by ERDA is warranted.

As well as ERDA, many other observers have pointed out the surge in uranium market price from $10 to $40 or $50 per pound in the past 3 years. Uranium production has a long lead time of approximately 8 years. The short-run price does not reflect the long-run price, which is the only relevant one in a cost-benefit analysis covering 50 years. The recent soaring price of uranium has already led to intensive exploration for this metal. The previous record for drilling was 29.9 million feet (*19*) in 1969 (*23*, p. 14). Uranium drilling in 1975 showed a 34 percent increase over the previous year, and drilling in 1976 was expected to be 30.8 million feet, which would have been even

Table 1. LMFBR benefits according to the AEC analyses (*7–11*). Benefits are expressed as billions of current dollars.

Analysis	Net discounted benefits	
	Discount rate at 7.5 percent	Discount rate at 10 percent
CB-68	6.6*	0.0
CB-70	19.1*	4.3
CB-74D	55.5	18.2
CB-74P	48.6	14.7
CB-74F	46.0	14.0

*At 7 percent discount rate.

Table 2. Uranium supply versus price schedules in the AEC's cost-benefit analyses (*7–11*). Prices are expressed in dollars (1975) per pound of U_3O_8.

Price ($)	Uranium supply (million tons of U_3O_8)			
	CB-68	CB-70	CB-74D and CB-74P	CB-74F
30	1.3	2.1	2.8	2.3
50	1.8	2.7	3.6	3.3
60	2.5	5.2	3.8	3.6
75	9.7	>10.0	4.5	4.1
100			5.6	5.1

Table 3. Reasonably assured (RA), potential (P), and total [T (the sum of RA and P)] uranium resources in the United States (*7, 10, 11, 30*). Forward costs are expressed in dollars (1975) per pound of U_3O_8.

Forward cost ($)	Resource	Uranium (cumulative million tons of U_3O_8)			
		CB-68	1971	CB-74D and CB-74P	CB-74F
30	RA	0.53	0.67	0.67	0.60
	P	0.97	1.37	1.59	2.92
	T	1.50	2.04	2.26	3.52
50	RA	1.44	2.42		
	P	1.74	2.50		
	T	3.18	4.92		
75	RA	5.59	5.35		
	P	4.23	4.41		
	T	9.82	9.76		
100	RA	7.63	6.89		
	P	7.23	6.33		
	T	14.86	13.22		

higher were there not a shortage of drilling equipment. The producers were to spend $157 million on uranium exploration in 1976, while the average was around $54 million a year in the past decade.

As mentioned earlier, the uranium prices relevant to the LMFBR cost-benefit analyses are not those of the first 3 million tons but those beyond the first 3 million tons. In other words, the cumulative uranium consumption for an electric generating system even without the participation of LMFBR's will not reach the 3-million-ton mark until around year 2014, or 37 years from now. Therefore, the projection of the uranium prices relevant to the analyses must be based on long-run instead of on short-run demand and supply.

In 1972, a National Petroleum Council Task Force with representation from both industry and the AEC reported that (*24*):

> Substantially all of the present proved reserves and approximately 85 percent of the potential reserves as determined by AEC are located in the presently producing areas, yet these areas make up less than 10 percent of the total region in which uranium occurrences are found—and even the producing areas in many cases are not completely explored.

Uranium is by no means a rare metal. Its exploration history extends back to only 1950, while oil exploration in the United States can be dated back to at least 1859. From our experiences with the exploration of other energy resources and minerals, early estimates of uranium resources are likely to be well below actual resources. We realize the danger of generalization and the danger to a nation should it run out of energy resources. But ERDA seems to be more interested in making very conservative estimates of our uranium resources than in estimating the most probable amount. The most probable figures should be used for the most probable case in the cost-benefit analysis. If the economic benefit turns out to be negative and we still want to pursue the program, we know, at least, what the insurance premium will be for what kind of risk protection. Again, a risk analysis as recommended earlier, in addition to the cost-benefit analysis, would be very valuable.

Electrical Energy Demand

The AEC projected the electric energy demand in the year 2000 to be 8×10^{12} kwh in CB-68 (*7*), 10.0×10^{12} kwh in CB-70 (*8*), 10.6×10^{12} kwh in CB-74P (*10*), and 8.1×10^{12} kwh in CB-74F (*11*). The total installed nuclear capacity by year 2000 was projected at 645 to 823 Gwe (gigawatt electric) in CB-68 (*7*), 1380 Gwe in CB-70 (*8*), 1200 Gwe in CB-74P (*10*), and 900 Gwe in CB-74F (*11*). In the last 3 years, there have been about ten studies on future electric energy demand. In CB-74F, ERDA mentioned seven major studies which were sponsored or authored by the Ford Foundation, Federal Energy Administration, U.S. Department of the Interior, Oak Ridge National Laboratory (ORNL), Hudson-Jorgenson, Cornell Workshops, and Hanford Engineering Development Laboratory. Their projections of electrical energy demand in 2000 ranged from a low of 2×10^{12} kwh to a high of 10×10^{12} kwh, with an average of 6.6×10^{12} kwh (*11*, p. IIIF-46). If this average can be considered to be from an unbiased sample and a better estimate than ERDA's, then the consequence is very significant. If ERDA were to use a consumption rate of 7.0×10^{12} kwh instead of 8.1×10^{12} kwh, the LMFBR net discounted benefit would drop to only $3 billion from $14 billion (*11*, pp. IIIF-44 and 57). Thus, at 6.6×10^{12} kwh, this factor alone would wipe out all the LMFBR benefit. One can now see that the LMFBR benefit claimed by ERDA is very sensitive to some projections.

It was projected by ERDA that there would be an average annual growth rate in electrical energy consumption of 5.9 percent in the first decade (1975 to 1985), 4.6 percent in the fifth decade (2015 to 2025), and 5.2 percent over the five-decade interval (1975 to 2025) (*11*, p. IIIF-43). Its figure of 8.1×10^{12} kwh by the year 2000 is about four times the 1975 consumption rate of 1.9×10^{12} kwh. Growth rate for the last 60 years has been 7.0 percent. But, with the exception of the last few years, electricity has been inexpensive.

The electricity consumption in 1974 was 0.56 percent below the 1973 level. The consumption during 1975 was only 2.0 percent above that of 1974 (*25*). One major cause of the lower growth rate of consumption was, no doubt, the higher prices of electric energy as well as other forms of energy in the past 3 years. However, one should not forget that the economic decline which lasted until March or April of 1975 also contributed to the slower growth rate. Future consumption will depend to a large degree on future prices of energy; thus, debates on electrical energy demand will be focused on these prices and on elasticity of demand, energy efficiency improvement, and the desirability, feasibility, and significance of energy conservation.

Cost Projections and Program Slippages

In CB-74F (*11*), it was assumed that the LMFBR would be introduced commercially in 1993 at a cost of $560 per kwe or at a capital-cost differential of $155 per kwe above the LWR's. It was assumed that the differential would vanish in 13 years because there would be a change in reactor size (about $55/kwe) and because of the learning effect (about $100/kwe). The value of the learning effect is much larger than that recommended by the capital cost evaluation group at ORNL, which has studied nuclear and fossil power plant costs extensively for a number of years. The AEC relied principally on ORNL staff to provide cost data, but took exception to following their recommended 95 percent learning curve (5 percent improvement per decade) commencing 10 years after commercial introduction (*26*). If this were followed, it would take about 50 years instead of 13 years to eliminate the cost differential with LWR's.

The AEC's overoptimism is also reflected in its estimate of the most probable date of the commercial introduction of LMFBR's. The date has been slipping consistently from the year 1984 in CB-68, to the year 1986 in CB-70, 1987 in CB-74D and P, and 1993 in CB-74F (*7–11*). On the other hand, cost overruns have plagued various projects and the program as a whole. The two projects that account for the largest share of the LMFBR program costs are the fast flux test facility (FFTF) and the Clinch River breeder reactor (CRBR). The FFTF construction is about two-thirds complete and is scheduled for completion in August 1978 (*27*, p. 24). The construction cost was initially estimated at $87.5 million (1968 dollars) in 1968; the estimate increased to about $200 million (1973 dollars) in 1973, and was estimated at $206 million (1974 dollars) in CB-74P (*10*). The CRBR is now scheduled to become critical in October 1983, even though groundbreaking would not occur in 1976 (*23*). The cost of the CRBR has also soared alarmingly. The first official estimate of its total cost was about $400 million. In 1972, the cost was predicted to be $699 million, but it was raised to $1.736 billion last March (*28*). Inflation can only account for a small fraction of the rise.

With regard to the LMFBR's total program costs, I chose a common reference date for comparison and eliminated the inflationary effects by discounting all costs to that reference date. As a result, the discounted LMFBR program costs from fiscal year 1970 till completion were estimated at \$2.96 billion in CB-68, \$3.59 billion in CB-70, and \$7.20 billion in CB-74D, P, and F (*7–11*). The AEC, however, does not lack experience in cost overruns. MacAvoy (*29*) studied the forecast and the realized costs for the 1958 10-year program of civilian nuclear power R & D, and reported that all projects failed to stay within the estimated costs, and that the average ratio of realized to forecast costs was above 1.5 for all projects. The AEC defended itself in CB-74P (*10*, p. 11.2):

> Cost overruns and schedule slippages are, by their nature, impossible to predict accurately. Part of good program planning is to establish reasonable cost and schedule goals and to attempt to meet them.

But, in a cost-benefit analysis, unlike a pep talk, one should make and use realistic estimates based on past experience and future expectation. It is possible to keep a program alive by continually underestimating it and revising its costs upward, because past costs are ignored in a cost-benefit analysis. For example, a discounted past cost of \$3.3 billion prior to fiscal year 1975 was never shown or included in the CB-74 analyses (*16*, p. 68).

A Cost-Benefit Analysis Based on Equally Reasonable Projections

In 1975 and based on CB-74P (*10*), I studied the net discounted benefit of the LMFBR program under some equally, if not more, reasonable projections. For example, the program produces no benefit with the following set of projections (*16*, p. 19): (i) a discount rate of 10 percent; (ii) availability of 7 million tons of U_3O_8 at a cutoff price of \$60 per pound, instead of the 4 million tons assumed by ERDA; (iii) restriction of the initial capacities of both HTGR's and LMFBR's for 13 years instead of indefinite restriction of only the HTGR capacity; (iv) an electrical energy demand of 10.6×10^{12} kwh by the year 2000; (v) imposition of a constant capital-cost differential of \$50/kwe 13 years after the commercial introduction of LMFBR's, instead of a zero differential; and (vi) a future discounted LMFBR program cost of \$4.7 billion.

After completion of my study, ERDA published the final cost-benefit results in CB-74F (*11*), with some changes. The electrical energy demand by the year 2000 dropped from 10.6×10^{12} to 8.1×10^{12} kwh, but the enrichment cost was raised from \$36 to \$75 per separative work unit. The aforementioned changes together would not materially change the results of the study. With recent breakthroughs in laser enrichment, the risk of obsolescence of gas diffusion and centrifuge plants should not be ignored. Laser enrichment could save as much as half the cost and 10 to 40 percent of natural uranium demand. However, it should be emphasized that I have considered only a small number of cases. Many cases based on more pessimistic and optimistic projections have not been quantified. But, it is apparent to me that the benefit of LMFBR's under the most probable projections can be either positive or negative. A risk analysis as recommended earlier would be very valuable in quantifying and focusing attention on the disputable issues.

Recommendations and Closing Remarks

Within a year or two, there will be several studies on nuclear energy that will include recommendations on the future of the LMFBR program. Three major ones are being independently conducted by the National Academy of Sciences, the Mitre Corporation, and the Center for Environmental Studies of Princeton University. The economic benefit of the LMFBR program claimed by the AEC cannot be accepted at face value. Doubts raised here and elsewhere should be examined in detail.

By honestly disclosing the benefits as well as the risks and losses of its programs, ERDA could gain the public's faith and trust. For example, rather than following the AEC's tradition of selecting projections to assure a positive economic benefit in the reference case of the cost-benefit analysis, ERDA could use the most probable projections, even at the risk of producing an economic loss for the LMFBR program. Weights could be estimated and listed for all cases in its sensitivity analysis, and a risk analysis performed. The debate would then be in quantitative terms. If, after such an analysis, the decision was made to support the LMFBR program at a certain level, the insurance premium that we would be paying in terms of the type of risk involved and its magnitude would be known. Political, social, and other considerations should also play significant roles in the adoption and the level of support of a particular program. In the case of LMFBR's, their development and mass deployment will have far-reaching implications in international politics and the future of mankind in the whole world.

I suggest that ERDA should internalize (include) the environmental and social costs of the LMFBR program in their cost-benefit analyses and to compare the results with those of alternative energy options. Otherwise, advocates and critics will continue their dialogue on different grounds and, frequently, in a subjective, ambiguous, and qualitative manner. I also recommend that ERDA support some studies that are critical of the LMFBR program. Such support should not only be financial, but should include ERDA's making accessible its computer programs, personnel, and facilities, so that the costs and benefits of various energy scenarios under the critics' investigations can be examined.

More serious consideration should be given to the possibility of optimizing the benefit or minimizing the cost of the LMFBR program by varying its timing and funding. Also, the optimal mix of energy programs should be determined under a capital rationing situation. In attempting to promote and support as many programs at as high a level as possible, ERDA may generate waste, suboptimization, and public distrust.

The ERDA is urged to assess seriously a strategy in which more emphasis is put on energy conservation and efficiency improvement, on the improvement of safety and performance of LWR's and HTGR's, and on the pollution abatement of coal-fired power plants. More support should also be given to fusion and solar power programs and less to the fast breeder program. We should adopt a sequential approach to the LMFBR program based on future developments in uranium resource assessment, laser enrichment, fusion feasibility, plutonium risk assessment, and other relevant factors.

The development of an economically, environmentally, and socially acceptable energy generating system is vital not only to our nation but to the rest of the world, and not only to our generation but to many future generations.

References and Notes

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NEWS AND COMMENT

Kennedy, GAO Criticize NSF; Grant Renewal Is Rejected

Senator Edward M. Kennedy (D–Mass.) has landed a haymaker on a George Washington University professor and bloodied the nose of the National Science Foundation (NSF) in an unusual case of senatorial second-guessing of the foundation's grant-awarding process.

Several months ago Kennedy challenged the propriety of two NSF grants that had supported energy policy studies by William A. Johnson, a research professor at George Washington who had previously served in senior posts with the RAND Corporation, the Council of Economic Advisers, the Treasury Department, and the Federal Energy Office (*Science*, 10 September 1976). He was particularly disturbed that Johnson's work was supported—in addition to the NSF grants—by funds from oil marketing groups with special-interest views on some energy issues.

Late last month the results of that challenge indicated that Kennedy had emerged a clear winner. In rapid succession, the General Accounting Office (GAO), which had investigated the situation at Kennedy's request, reported that there were indeed deficiencies in NSF's handling of the grants; Kennedy issued a strong statement criticizing the foundation for failing to require policy papers "to meet even the most basic test of independence, objectivity, and merit"; and NSF rejected Johnson's long-pending application for continued funding.

The rejection added to the accumulating woes of Johnson's policy analysis team. Johnson says that, as a result of the fracas with Kennedy, he has lost other potential sources of funding and has been forced to cut back drastically on his research.

NSF officials insist that they rejected Johnson's latest application on the merits, without paying heed to the political flap surrounding Johnson's work. "We tried to set aside political considerations in his case and look at his proposal," said Thomas Ubois, acting director of NSF's division of policy research and analysis, the unit responsible for monitoring Johnson's grant.

But the affair left Johnson grumbling that he had been the victim of a "book burning, American style." He complained that he had been singled out for attack by Kennedy's staff because he advocated energy policies that differed with Kennedy's. And he accused NSF of rejecting his proposal in an effort to appease Kennedy, who exerts tremendous power over NSF's fortunes because he chairs the Senate subcommittee that considers the NSF budget authorization. "It's very clear what happened," Johnson told *Science*. "The NSF has to live with Senator Kennedy as chairman of the subcommittee that reviews the budget. They don't have to live with Johnson. It's as simple as that."

Johnson had sought an additional $35,000 to support preparation of a book that would consolidate the work he had done under his first two grants and would include substantial amounts of new material as well. His proposal was rejected on the grounds that the old material was already available and that the proposal lacked "specificity" concerning the nature of the new material. Johnson acknowledges that the foundation might conceivably have rejected his application, even if Kennedy had never raised any questions. But he finds this hard to believe because supporters within the foundation have told him that the book project got "highly favorable" marks from six of seven reviewers and was strongly endorsed by NSF's own program manager for the project as well. Foundation officials declined to discuss the results of the review process other than to note that such reviews are purely advisory to those agency officials who make the granting decisions.

The struggle over Johnson's grants first reached public attention late last summer when Kennedy asked the GAO, the investigative arm of Congress, to review NSF's handling of two awards to Johnson, who was both a research professor at George Washington and head of the university's Energy Policy Research Project. The two grants—which totaled a hefty $130,000 for a 2-year period—were made by the Office of Energy R & D Policy, a unit of NSF that no longer exists. That office was created in 1973 to