JUNE 1975

ENVIRONMENT

VOLUME 17, NUMBER 4, ONE DOLLAR

DOUBLE, DOUBLE TOIL AND TROUBLE!

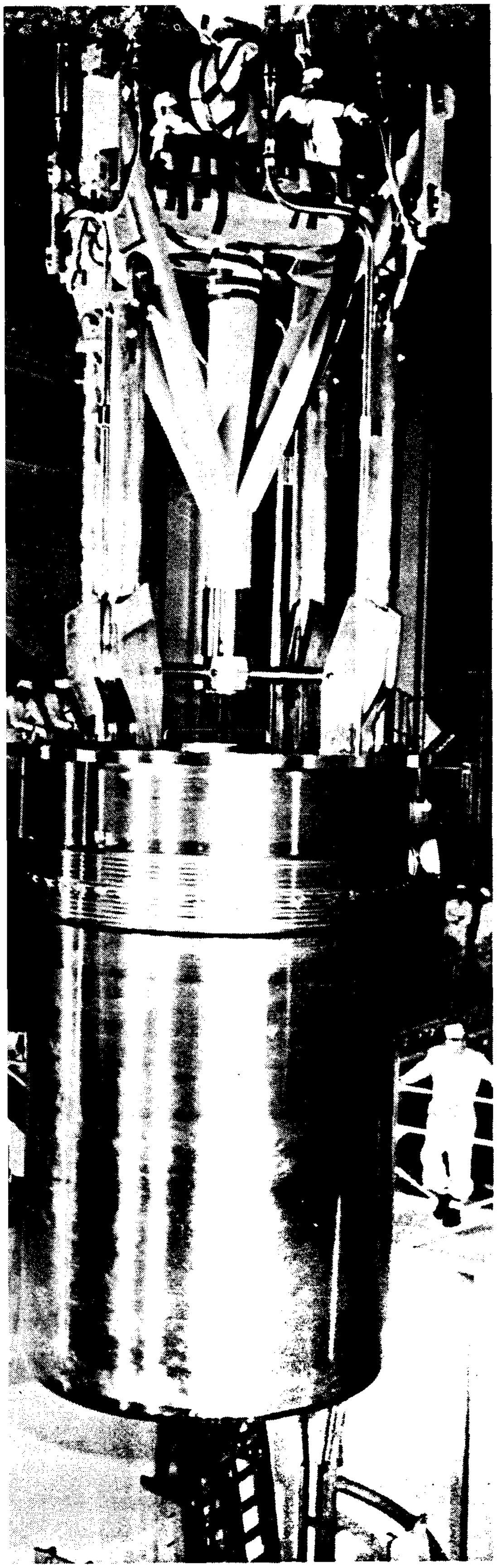
The Nuclear Pot Does Bubble (Page 8)

New Pesticide Poisonings

Puerto Rico

A POOR

How our money goes



Westinghouse Electric Corporation

The 58-ton nuclear core, containing natural and enriched uranium, as it is lowered into a pressurized-water reactor. It was thought by AEC officials that the price of electricity could be held down if the breeder reactor, which produces fuel during operation, were built instead of today's reactors.

AT A TIME of soaring power costs, federal energy officials are giving prime attention to the development of a new nuclear power source, the liquid metal fast breeder reactor (LMFBR), which for the next 35 years or more will not be able to produce electricity as cheaply as existing sources. The LMFBR produces nuclear fuel, as well as electricity, and therefore would appear to have advantages over today's nuclear reactors, the light water reactors, which depend on an available supply of uranium. A close look at the assumptions employed by the Atomic Energy Commission (AEC) in its cost-benefit analysis of the breeder program, however, shows that the benefits are illusory. When more realistic assumptions are considered, it can be shown that the costs clearly outweigh the benefits. The sense of urgency and crisis that program supporters have promoted to show that the LMFBR is needed to meet future U.S. energy requirements has no foundation in fact.

The economic arguments surrounding further development of the breeder must be considered in light of the breeder's potential hazards. Plutonium, the fuel for the breeder, is one of the most toxic substances known. Plutonium is also the material from which nuclear weapons are made, and illegal nuclear weapons could be made from reactor fuel. In addition, there is the chance that a breeder reactor could explode. Overall, the LMFBR promises to be even more hazardous and problematic than today's reactors.

Possible alternative sources of energy must also be considered in any cost-benefit analysis of the LMFBR program. Solar, geothermal, and fusion energy are now considered realistic possibilities. Despite the potential of these alternatives, however, of the $1.66 billion the Energy Research and Development Agency (ERDA) plans to spend directly on energy research and development in the coming year, over $490 million is to be spent on the LMFBR program – more than the combined allocations for fossil fuel ($311 million), solar ($57 million), geothermal ($28 million), and advanced energy research ($23 million), and energy conservation ($32 million).[1]

The total cost of developing the LMFBR is now estimated to be $10 billion,[2] and this estimate, made by proponents of the program, must be judged as conservative. Already, the LMFBR program has

BUY

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BY THOMAS B. COCHRAN, J. GUSTAVE SPETH, AND ARTHUR R. TAMPLIN

experienced tremendous cost overruns. Two years ago, total program costs were put at less than one-half of today's estimate.[3] The principal test facility of the program, the Fast Flux Test Facility (near Richland, Washington), originally planned to cost $87 million, but the latest estimate is $933 million, more than a tenfold increase.[4] Congress was told in 1973 that the proposed Clinch River Breeder Reactor Plant (to be built in Tennessee), the first LMFBR demonstration plant if one overlooks Fermi-I, would cost $700 million. (Fermi-I, the first commercial LMFBR plant, experienced a partial core meltdown and has subsequently been shut down.) Today the estimate is over $1.7 billion.[5] There is no sound reason to believe these trends will not continue.

These figures indicate that, at a minimum, the LMFBR program could cost the American taxpayer a very substantial sum. Such expenditures can be justified only if it can be shown that the LMFBR program is needed or desirable, but such justification is lacking for several reasons.

First, economic analysis of the potential of the LMFBR indicates that, contrary to AEC expectations, the new reactor cannot be commercially competitive with existing energy sources until after the year 2010. Yet the current LMFBR effort is aimed at having the new reactor developed by 1990, more than two decades before it could be economically attractive. The LMFBR program is thus quite premature and could be delayed substantially without incurring any risks relative to meeting future U.S. energy needs.

On simple economic grounds, then, the push to develop the LMFBR should be postponed. Moreover, such a delay would provide the time needed to show what many experts now believe to be the case that environmentally preferable, nonfission energy options can be made available in time to eliminate the need for the LMFBR altogether. Recent estimates of the potential contribution of solar, geothermal, and fusion energy together with energy conservation measures indicate that these sources alone can more than account for the energy expected from the LMFBR in the year 2020, when the reactor is projected to have maximum impact. Indeed, they can account for the energy expected from all fission reactors at that time.

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

For the next 35 years or more the LMFBR will not be able to produce electricity as cheaply as existing sources.

Our recommendation in light of those conclusions is that ERDA take the opportunity it now has to break with the mistakes of the past. ERDA should postpone for a decade or so any push to commercialize the LMFBR, canceling the Clinch River Breeder Reactor Plant, and relegating the overall program to a relatively low-priority effort. ERDA should at the same time accelerate the development of attractive nonfission alternatives such as solar, geothermal, and fusion power, and energy conservation. Much can be learned during the coming decade, and the delay would impose no penalty on the nation. If it is learned that the breeder can be bypassed, as seems likely, the period of delay would provide a substantial benefit.

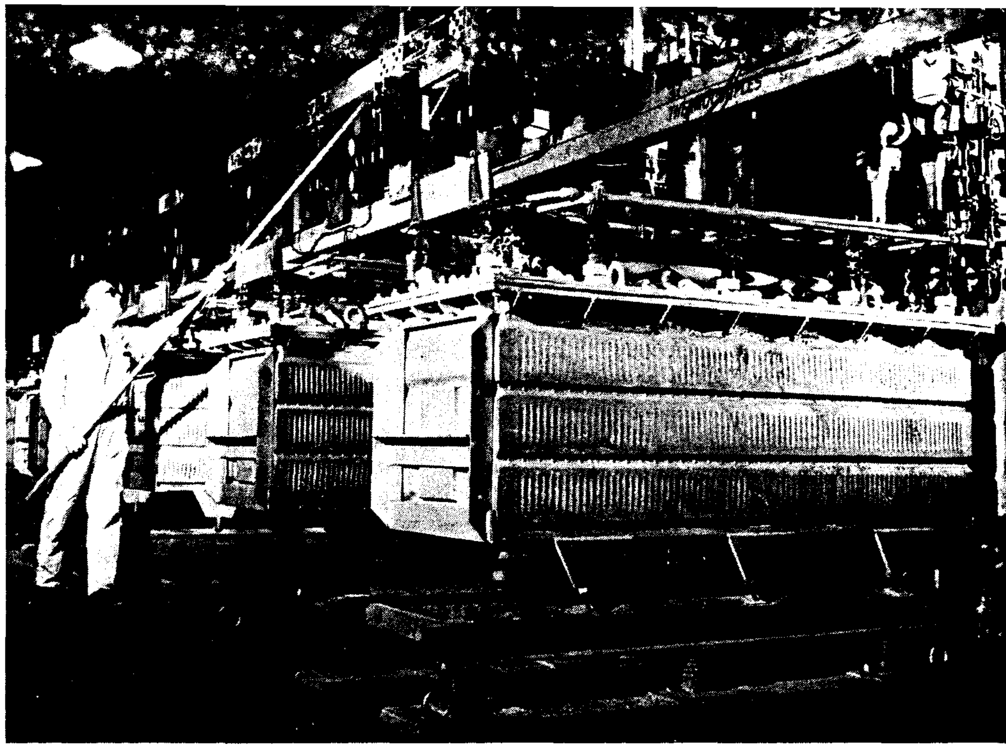
Hazards

Unfortunately, as events are making us painfully aware, plutonium is probably the most dangerous substance known.[6] It is fiendishly toxic: a millionth of a gram has been shown capable of producing cancer in experimental animals. Plutonium-239, the principal isotope of the element, has a half-life of 24,000 years, so that its radioactivity is undiminished within human time scales.

Plutonium is also the substance from which nuclear weapons are made. An amount the size of a softball is enough for the production of a nuclear explosive capable of mass destruction. Scientists widely recognize that the design and manufacture of a crude atomic bomb is not a technically difficult task,[7] a fact dramatized recently when a Massachusetts Institute of Technology undergraduate successfully designed a nuclear weapon for an educational television program.[8] The only real obstacle to the building of homemade atomic bombs is the availability of plutonium itself, and now, first with the proposed use of plutonium in today's reactors, and even more with the introduction of the LMFBR, this final obstacle would be removed. In the "plutonium economy" envisioned by the AEC, the development of a plutonium black market and nuclear theft and terrorism become high probability events – threats that have spurred nuclear proponents to urge the creation of a federal security system that could meddle with our civil liberties on a vast scale.[9]

In addition, the LMFBR itself is considered even less safe than today's light water reactors. The LMFBR core, where the heat is generated, is far more compact than the core of a light water reactor and instead of water, the LMFBR uses liquid sodium – an opaque and highly reactive element – as coolant. Partial loss of coolant, or "voiding," increases, rather than reduces, the nuclear reaction in the core of a breeder. The LMFBR's operation is extremely sensitive to fuel motion and loss of coolant from the core in accident situations leading to the possibility of an explosive nuclear runaway. In the event of a meltdown, the breeder's highly enriched fuel can rearrange itself into a more compact configuration with the possibility of small nuclear explosions of sufficient force to breach the reactor containment. There are major uncertainties in defining the explosive potential of the breeder, which are all the more worrisome considering that the reactor will have several tons of plutonium in it.[10]

On balance, the breeder reactor is probably the most unrelenting and hazardous technology ever considered for widespread commercial application. A decision to commit this nation to the LMFBR may prove to be the most significant technological decision since the Manhattan Project – a decision which is literally a decision for all people and all time.



U.S. Atomic Energy Commission

Breeder Economics

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

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

How sound is the economic case for this early commercialization of the LMFBR? The most useful way to pull together the many variables which determine whether the current LMFBR program can be justified economically is to make a cost-benefit analysis. The AEC performed three cost-benefit analyses of the LMFBR program, the latest appearing first in the draft, and then with revisions, in the *Proposed Final Environmental Impact Statement for the Liquid Metal Fast Breeder Reactor Program.* Not surprisingly, constrained to justify its own project, the AEC consistently found that program benefits outweigh the costs. Significantly, the Environmental Protection Agency (EPA) ruled that the AEC's draft environmental impact statement was inadequate largely because of deficiencies in the AEC's cost-benefit analysis.

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

The AEC succeeded in making the LMFBR appear economically attractive by making very favorable, but very unrealistic, assumptions in each of these seven areas.[11] Fortunately, as a result of criticism by the EPA, the Natural Resources Defense Council (NRDC), and others, the AEC was forced in its most recent analysis to present the results of a more realistic combination of input assumptions.

These more realistic assumptions enable us to reevaluate the economic merits of the LMFBR program using the AEC's cost-benefit methodology. The assumptions we have made correspond to those made in case 58 (shown in Table 1) of the cases tested by the AEC in its latest cost-benefit analysis. In each of the seven areas mentioned above, the assumptions used in our analysis are as follows:

Discount Rate. A discount rate of 10 percent per year is used. The issue of the appropriate discount rate has largely been laid to rest, as the AEC now uses the 10 percent per year value "based on the preference of the OMB [Office of Management and Budget] and other organizations and individuals,"[12] including the EPA.[13]

LMFBR Research and Development

One operation at the Paducah (Kentucky) Gaseous Diffusion Plant where uranium is processed. Because uranium is a nonrenewable resource, the AEC has made development of the liquid metal fast breeder reactor its highest priority objective.

Costs. Assuming LMFBR commercial introduction in 1987, $8.4 billion is considered the cost to completion. Discounted at 10 percent per year this is equivalent to $4.7 billion in mid-1974 dollars. These are values assumed by the AEC. Here we are being very generous to the LMFBR for in reality the research and development costs of the LMFBR program will probably be substantially higher. As noted previously, the program and its major facilities are experiencing enormous cost overruns and these trends are likely to continue.

Capital Cost Difference Between LMFBRs and Conventional LWRs. Here it is assumed that the LMFBRs will remain $100 per kilowatt more expensive than the LWRs. In reality, the capital cost differential will be even higher, but $100 per kilowatt is the largest differential tested by the AEC in its analysis.

The AEC's assumption is that LMFBRs will cost $100 per kilowatt more than LWRs initially, but that LMFBR costs will fall. As a result, by the year 2000 the cost differential will drop to zero. Thus, the central issue is whether it can be assumed that the LMFBR will experience "learning" (cost reductions with increasing experience) particularly when it is assumed that LWRs will not. We believe it is impermissible to apply a learning curve to LMFBR capital costs.

First, there is no evidence that today's nuclear power plants are on a learning curve. A learning curve is indicated when the cost of a product decreases with increased production. Actually, the cost of commercial nuclear plants has been increasing at an alarming rate, even in constant dollars. Bupp and Derian estimate that the capital cost of the LWRs is increasing, from $30 per kilowatt to $50 per kilowatt per year in constant (1973) dollars.[14]

Moreover, if learning effects are to be experienced they will be experienced first with light water reactors and high-temperature gas-cooled reactors, a development which would penalize the LMFBR. Certainly, there is no basis for the AEC's assumption that only the LMFBR will experience learning. In this regard, the AEC's approach stands in stark contrast to the assumptions of independent investigators. Bupp and Derian, for example, observe:[15]

"[Because of learning effects] Breeders will not be competitive with LWRs when only ten to twenty of the former have been installed as opposed to several hundred of the latter. Consequently, an added cost will be incurred by breeders until their manufacturing costs have decreased enough to compensate for the initial LWR advantage due to fabrication experience. These learning-curve costs must be taken into account even if it is assumed that breeder capital costs will turn out to be below the allowable threshold for previous uranium oxide prices and other variables. In such circumstances, learning curve costs have to be subtracted from the breeder advantage in order to determine the real benefits of their introduction.... Any claim of definitive economic advantage from breeder introduction must therefore take account of costs due to learning effects which could quite easily turn out to be a substantial multiple of research and development costs."

Finally, we find no valid basis for the view that improvements in the design and construction of selected LMFBR components will lead to a substantial reduction in the costs of LMFBRs relative to other plants. On the contrary, experience indicates that complex systems such as the LMFBR can easily encounter subtle and unforeseen interactions that require costly solutions. Primary sodium pumps for the Fast Flux Test Facility, for example, estimated by AEC contractors to cost $1.8 million in 1970, were estimated by the AEC[16] to cost $10.5 million in 1974. During the same period, the cost of the intermediate heat exchanger for this test facility doubled.[16] As more is learned about these complex systems, then, the more apparent do the costs become.

In summary, a constant $100 per kilowatt represents a conservative estimate of the capital cost difference between the LWR and the LMFBR. Based on historical experience, the capital cost differential will probably go even higher. There is no sign that it will level off.

Electrical Energy Demand. Curve B, in Figure 1, is our assumption for electricity demand. Curve B represents a 50 percent reduction from the AEC's assumed electrical energy consumption (curve A) in the year 2020. Curve B is the lowest electrical energy growth projection tested by the AEC in its analysis. Our selection is based principally on the forecasts of Chapman and his colleagues,[17] and Searl,[18] which are also plotted in Figure 1.

The most important economic factors influencing electrical energy demand are: (1) the price of electricity, (2) the growth of the population, (3) the growth of income, and (4) the prices of substitute fuels and appliances. Using these parameters, it has been estimated that electrical energy demand in 1980 will be 2.2 trillion kilowatt-hours,[19] or roughly one-third less than the projected demand assumed by us. This forecast of 2.2 trillion kilowatt-hours in 1980 represents an average growth rate of about 2.5 percent compared to the AEC assumption of an average growth rate of about 7.5 percent over the same period.

Searl's forecast of electricity growth is based on the direct relationship between electricity consumption and the Gross National Product. He avoids the AEC's approach of projecting total energy demand versus GNP and then making the arbitrary assumption that electrical energy consumption will grow to 50 percent of total energy by 2000 and 65 percent by 2020. The historical correlation between electric energy use and GNP is better than the historical correlation between total energy use and GNP.

Extrapolating Searl's work to the year 2000 results in an estimated elec-

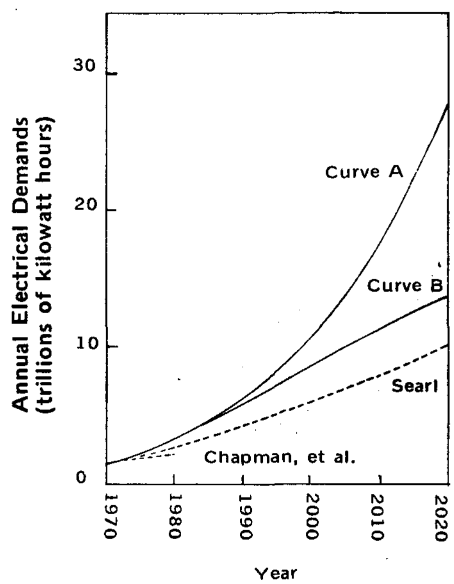


FIGURE 1
PROJECTED ELECTRICAL ENERGY DEMAND

Source: PFEIS, LMFBR, vol. IV, p. 11.2-107. Chapman, et al., "Power Generation: Conservation, Health and Fuel Supply — A report to the Task Force on Conservation and Fuel Supply, Technical Advisory Committee on Conservation of Energy, 1973, National Power Survey, USFPC," revised draft; Chapman, et al., "Energy Demand Growth, the Energy Crisis, and R&D," Science, 178:703-708, Nov. 17, 1972. Electric Power Research Institute, "Uranium Resources to Meet Long Term Uranium Requirements," EPRI SR-5, Nov. 1974, p. 12.

-trical energy demand of 6.5 trillion kilowatt-hours if GNP is assumed to grow at 4 percent annually, or 5.5 trillion kilowatt-hours if GNP increases at 3.5 percent. Searl's best estimate is 6.1 trillion kilowatt-hours in 2000 and 10.6 trillion kilowatt-hours in 2020,[20] well below the assumption we used.

Clearly, then, our estimate (curve B) is not "very low" as the AEC suggests. Rather, it is higher than current projections based on the more important economic factors influencing energy demand.

Rate of Penetration into Utility Market. Here we are forced to use the AEC's estimate of the fraction of the total electrical energy demand supplied by nuclear reactors because more realistic nuclear capacity fractions were not considered in the AEC analysis. This estimate is based on AEC projections made in 1972.[21] A much lower rate of market penetration, much less favorable to the LMFBR, would be more consistent with the recently experienced reactor cancellations and schedule delays. In fact, the AEC recognizes this and states in its proposed final environmental impact statement on the LMFBR program:[22]

"This general schedule slippage suggests that the assumed timing of commercial breeder introduction should also be slipped, presumably into the early 1990s. . . . The range of variables explored in the cost-benefit analysis as it now appears in this Statement (for example, cases which assume a 50 percent reduction in the base case projection of electrical demand in the year 2020) appear to provide adequate insight into the possible effects of major uncertainties in the assumptions used, including the possibility of a few years' slippage in breeder introduction date."

Here, the AEC is in agreement with our selection of the electrical energy demand (curve B in Figure 1) as the more appropriate choice for this parameter.

Uranium Supply. We use curve B, in Figure 2, a uranium supply curve the AEC considered "optimistic" in its latest cost-benefit analysis. The AEC's assumed supply curve is shown as curve A. We choose curve B primarily for two reasons:

First, it most nearly corresponds to the estimate by the staff of the Energy Supply Studies Program, Electric Power Research Institute (EPRI).[20] The EPRI staff estimated the domestic uranium oxide resources in conventional deposits that could be recovered at less than $100 per pound. Its best estimate (13.2 million tons at less than $100 per pound) is plotted in Figure 2. Milton Searl, the director of the EPRI study, believes this best estimate is actually conservative because it does not include additional lower-grade, but still conventional, ores.

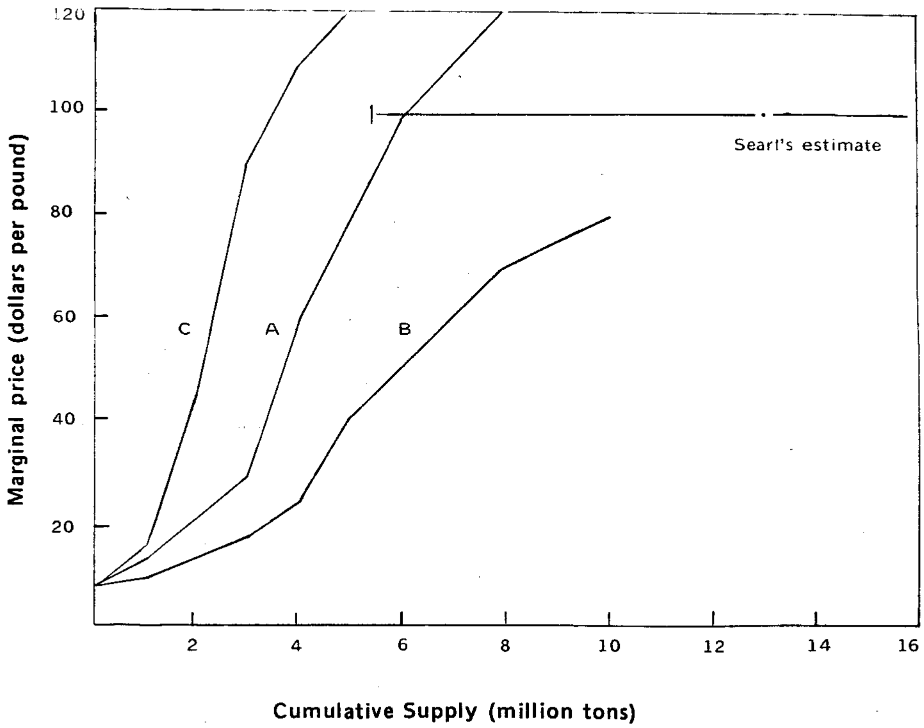


FIGURE 2
MARGINAL PRICE OF URANIUM OXIDE VERSUS CUMULATIVE SUPPLY

Source: PFEIS, LMFBR, vol. IV, pp. 11.2-72. Searl's estimate is from Electric Power Research Institute, "Uranium Resources to Meet Long Term Uranium Requirements," EPRI SR-5, Nov. 1974, p. 12.

We share Searl's view that his estimates are most likely conservative. There are numerous instances in which conservative assumptions were made in deriving the EPRI estimates. For example, although the eastern U.S. and Alaska have potential sources of uranium, no credit is given to these areas.

Searl's estimate of 13.2 million tons plus an additional several million tons in lower-grade ores is to be compared with the estimate of only 4 million tons of uranium in conventional deposits in the AEC's "most likely" case (curve A) and only 6 million tons in the agency's "optimistic" case (curve B).

The second reason we choose curve B is that subsequent to the preparation of the uranium supply and price projections used in the AEC's cost-benefit study, the AEC apparently has identified an additional 1.2 million tons of domestic uranium resources in conventional deposits at less than $30 per pound.[23] The new total is larger than the AEC's base case estimate (curve A) of the cumulative supply at less than the same $30 per pound.

A New Timetable

The key assumptions we have made correspond to those made in case 58 of the cases tested by the AEC in its latest cost-benefit analysis. The results for this case are reproduced in Table 1, together with additional cases which show the effect of varying the more sensitive input assumptions. The benefit-cost ratios for these cases are shown in the last column. (A ratio of less than one indicates that costs outweigh benefits; a ratio of more than one means that benefits outweigh costs.)

As seen from case 58 in Table 1, the discounted costs of the LMFBR program are ten times the discounted benefits. For every $10 spent on development of the LMFBR, the public will get back only $1 or less in lower energy costs. The breeder program is thus hardly what one would term a worthwhile investment. We arrive at this result even though our analysis contains a number of assumptions that are highly favorable to the LMFBR — more favorable to the LMFBR than realities justify.

In examining the sensitivity of our results to changes in some of the key input assumptions, we are severely constrained because of the limited number of cases tested by the AEC. Turning first to energy demand, it can be seen by comparing the results of case 55 to case 58 in Table 1, that electrical energy demand would have to grow at the tremendous rate assumed by the AEC to get a breakeven benefit-cost ratio of one (that is, costs and benefits balance). Similarly, in examining case 72, one would have to assume a very unrealistic uranium supply curve (curve C in Figure 2), before the benefits begin to exceed the cost. This uranium supply curve was termed "pessimistic" by the AEC even before identification of the additional 1.2 million tons of low-cost uranium. Finally, as evidenced by case 52, reducing the capital cost differential to zero by 2000, other assumptions remaining unchanged, still leaves the benefit-cost ratio less than one.

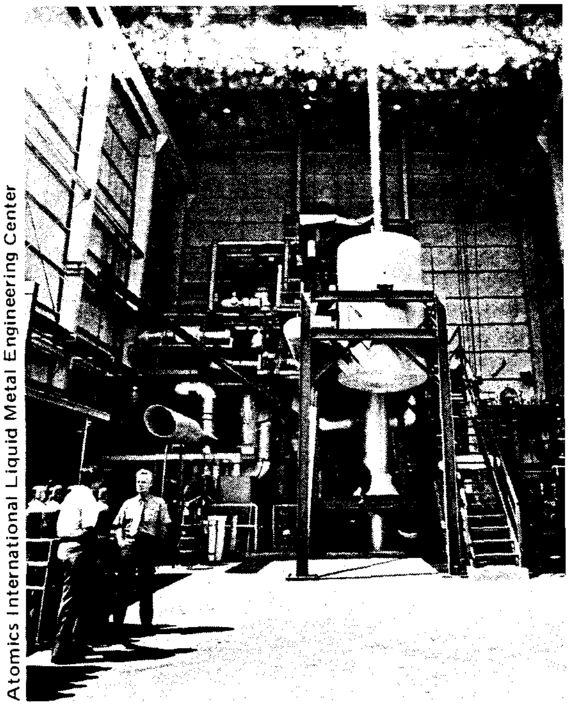
In sum, when more reasonable assumptions based on the work of expert authorities outside the AEC are used, the LMFBR program simply cannot be justified economically. Only when a series of highly unrealistic assumptions are made does the analysis suggest that the LMFBR program will produce net economic benefits.

These results indicate that the commercial introduction of the LMFBR can be delayed substantially – for two decades or longer – without economic penalty. The poor performance of the LMFBR in cost-benefit analysis stems from the fact that during much of the period of the analysis (1987 to 2020) the LMFBR cannot compete economically with alternative sources largely because of its high capital costs, so that only a limited number of LMFBRs are constructed. Until the price of uranium rises sufficiently to offset the high capital costs of the LMFBR, consumer-minded utilities will continue to prefer today's reactors and other energy sources. We estimate that not until after the year 2010 is it possible for the LMFBR to gain a competitive edge over the LWRs.

Moreover, an estimate of when the LMFBR becomes commercially competitive under case 58 assumptions is available from the AEC's cost-benefit computer model. While this information for case 58 was not provided in the proposed final impact statement for the LMFBR program, we have been advised by the AEC that after the constraint on LMFBR construction (through the year 2000) is lifted, the computer model projects that no LMFBRs are constructed until 2019. This date is almost three decades beyond the date for LMFBR commercial introduction proposed in the current program schedule.

Similar conclusions have been reached by others. David Rose, professor of nuclear engineering at the Massachusetts Institute of Technology, writing in *Science,* stated recently:[24]

"I estimate that the breeder will almost surely be attractive when uranium oxide reaches $50 a pound in 1974 dollars. That will not happen in the first few decades of the twenty-first century. In the meantime, nuclear power is in no danger of losing out to other fuels, and there does not need to be a crash breeder program. Economic introduction in 2000 would be a sign of technological good fortune, not of



Atomics International Liquid Metal Engineering Center

Valves and pumps for the liquid metal fast breeder reactor being tested at the Atomics International Liquid Metal Engineering Center Facility near Los Angeles.

TABLE 1

SUMMARY OF COST-BENEFIT STUDY RESULTS DISCOUNTED AT 10 PERCENT PER YEAR TO MID-1974

	CASES*						
	5	48	58	55	52	62	72
Constraints imposed until							
(HTGR)	2020	2020	2000	2000	2000	2020	2000
(LMFBR)			2000	2000	2000		2000
LMFBR introduction date			1987	1987	1987		1987
LMFBR capital cost differential**			$100/kw	$100/kw	$0/kw	$100/kw	$100/kw
Electrical energy demand curve†	A	B	B	A	B	B	B
Uranium supply curve††	B	B	B	B	B	C	C
Comparison with case			48	5	48		62
Costs in $ billions							
Energy costs	201.4	148.1	147.7	196.6	144.2	157.3	150.6
Gross benefits			0.4	4.8	3.9		6.7
R&D costs			4.7	4.7	4.7		4.7
Net benefits			−4.3	0.1	−0.6		2.0
Benefit/cost ratio			0.08	1.0	0.8		1.4

*Numbers refer to AEC identity of cases in the **PFEIS**.
**Capital cost differential after 2000.
†Letters correspond to curves in Figure 1. Curve B corresponds to "base case"; Curve A corresponds to AEC "base case."
††Letters correspond to curves in Figure 2. Curve B corresponds to our "base case"; Curve A corresponds to AEC "base case."

Source: PFEIS LMFBR, Appendix IV.D.

resolving an energy crisis with a time limit."

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

Alternatives

A fission-free option to the LMFBR which can provide reasonably priced, and potentially more environmentally acceptable energy, almost certainly exists and can be made available within a suitable time period. The claim that the LMFBR or other breeder reactor is in any sense necessary must be rejected. The breeder is no more necessary than we make it by refraining from developing other technologies. What is proposed here is an energy program which should be able to provide an adequate supply of fuels and electric power without the commercial utilization of breeder reactors. Moreover, as will be shown, heavier reliance upon the various aspects of such a program would facilitate the phasing out of all fission reactors, leading to a fission-free energy economy.

In brief outline, there are several major efforts, some, or all, of which could comprise the core of an alternative energy program:[25]

■ An intensive effort to develop the various forms of solar energy should be undertaken following the recommendations of the expert panels convened under National Science Foundation auspices, *An Assessment of Solar Energy as a National Energy Resource* (1972) and *Solar and other Energy Sources: Subpanel IX Report* (1973).[26] Based on estimates which the authors of the first of these studies believed were not the highest possible, it was concluded in that study that its recommended research and development program could result by the year 2020 in solar energy providing 35 percent of the nation's total building heating and cooling load, 30 percent of the nation's gaseous fuel, 10 percent of its liquid fuel, and – most important for the present argument – 20 percent of the electrical energy requirements.[27]

■ A major effort devoted to exploitation of geothermal resources for electric generation should be launched. The Cornell Workshop on Energy and the Environment (1972) concluded that:

"... [it] appears that geothermal energy alone is capable of meeting all American power requirements for several centuries if the hot dry rocks resource proves to be practical."[28]

The Cornell Workship, the National Science Foundation, and other groups have recommended that a program to establish the feasibility of hot rock geothermal energy in the next few years be given highest priority. (Presently at the research stage, hot dry rock systems are made up of impermeable rocks overlying a local heat source, such as a magma chamber. Water would be introduced into the system, where it would be converted into steam. These sources are for the most part very deep, beyond the ability of today's drilling technology. A shallow hot rock system, however, is under study in Montana.) Projections of the electric power available from geothermal resources range from 8,000 to 400,000 megawatts (electrical) in the year 2000, depending on assumptions made about the hot rock potential.[29] The AEC recently estimated that geothermal heat could supply 6 percent of our electricity in the year 2020,[30] but it is clear that the percentage could be much higher if hot rock geothermal systems are developed as expected.

■ The current effort to develop fusion power should be expanded. Officials of the AEC recently stated that "a successful, vigorously supported fusion program would be expected to lead to construction of a demonstration power reactor that would begin operation in the mid-1990s."[31] The agency anticipated "commercial introduction of fusion power plants on a significant scale beginning in the early twenty-first century."[32] Thus, according to the AEC, the demonstration fusion power plant is not far behind the LMFBR demonstration plant, and fusion plants can be available commercially for much of the period during which it was assumed the LMFBR would be critically needed. The AEC's overall estimate is that by the year 2020 about 8 percent of our electricity could come from fusion.[33]

■ Organic wastes provide another source of fission-free energy. Here the AEC estimates that organic wastes could account for 5 percent of the demand for electricity in the year 2000, but only 2 percent in 2020 due to more efficient practices in the solid wastes area.[34]

■ All of the above year 2020 percentage contributions, for example, 20 percent for solar, 6 percent for geothermal, and so on, are based on a year 2020 energy demand that assumes a continuation of extremely rapid

MITRE Corporation

A photovoltaic solar cell panel being installed atop a building in McLean, Virginia. The breeder reactor will not be needed if alternative sources of energy, such as solar, geothermal, and fusion energy, are developed soon.

growth for electricity demand. Such projections can yield an electricity consumption in the year 2020 that is over *fifteen times* today's, a result widely regarded as completely unrealistic. For example, the electricity growth projection used by the AEC to justify the LMFBR program is depicted as curve A in Figure 1. The steepness of the curve staggers the imagination. Several studies of the future demand for electricity (including those discussed earlier) have been carried out using more sophisticated forecasting techniques and taking into account the effects of the increasing price of electricity and other market factors. These studies suggest that actual future demand will be less than one-half of that projected by the AEC. Moreover, as a supplement to market influences, it is apparent that the U.S. is moving towards a national energy conservation policy along the lines recently suggested by the U.S. House of Representatives Committee on Science and Astronautics, the Council on Environmental Quality, the Ford Foundation Energy Policy Project, and others.[35] These groups all suggest that U.S. energy growth can be roughly halved without serious adverse repercussions on the economy or on life-style. When both market and policy influences are taken into account it is reasonable, in fact, conservative, to assume that electricity demand in the year 2020 will not exceed 50 percent of the AEC's astronomical projection.

TABLE 2

ENERGY SOURCES FOR ELECTRICITY PRODUCTION IN THE YEAR 2020 WITHOUT THE BREEDER

	Trillions of Kilowatt-Hours	Percent of AEC Projection
AEC projection for electrical energy demand*	27.6	100
New energy sources		
Solar**	5.5	20
Geothermal†	1.7	6
Fusion††	2.2	8
Organic wastes‡	0.6	2
Total	10.0	36
Correction for market factors and energy conservation	13.8	50
Total accounted for	23.8	86
Remainder for other sources (principally fossil fuels)	3.8	14
TOTAL	**27.6**	**100**

*From **PFEIS, LMFBR Program**, vol. IV, pp. 11.1-25.
From NSF/NASA, **Solar Energy as a National Resource, 1972, p. 3.
PFEIS, LMFBR Program, vol. IV, pp. 11.1-19.
†From **PFEIS, LMFBR Program**, vol. IV, pp. 11.1-20.
††From **PFEIS, LMFBR Program**, vol. IV, pp. 11.1-22.
‡From **PFEIS, LMFBR Program**, vol. IV, pp. 11.1-21.

Table 2 summarizes some of the data presented above. It shows that it is not unreasonable to expect that over 80 percent of the electricity demand projected by the AEC for the year 2020 can be accounted for principally by a combination of solar, geothermal, and fusion energy together with more accurate forecasting of energy demand. This percentage is larger by a substantial margin than the contribution expected of the LMFBR by the AEC in 2020 (50 percent) and, indeed, is larger than the contribution the AEC expected from nuclear fission generally (70 percent). Accordingly, an energy program designed to achieve these objectives could wholly eliminate the need for the LMFBR even if it failed in major respects.

Table 2 indicates that other sources, principally fossil fuels, could be called upon to provide the remaining portion of U.S. electricity needs in 2020. It is likely that our abundant supplies of coal will be relied on for several decades as a significant power plant fuel. Thus, quite apart from the question of whether the LMFBR is introduced, the development of environmentally responsible means of mining and utilizing coal must be an essential and high priority national objective. Such a research and development effort, aimed at achieving this objective, has been discussed by numerous authors.[36] Strict regulation of surface mining, more efficient and safer technologies for mining deep coal, stack gas cleanup, new combustion technologies, and coal gasification and liquification would be a necessary part of such an effort.

The funding needed for this alternative energy strategy would be high, but not unacceptably so. It is significant that the last of the AEC's official projections of future LMFBR expenditures, $8 billion to program completion, exceeds a recent Federal Power Commission estimate of the total research and development costs of developing all nonnuclear technologies, including coal gasification, solar (direct and indirect), and geothermal technologies, advanced steam cycles, magnetohydrodynamics, fossil fuel effluent controls, and a variety of energy storage system.[37] The Federal Power Commission estimate of $6 billion, however, does not include the cost of developing fusion systems, which is expected to be comparable to that of the LMFBR.[38]

The last refuge of the breeder proponent is the argument that the LMFBR is needed as an "insurance policy." The above considerations indicate that this is simply not the case. Ample insurance exists partly in pursuing a variety of nonconventional energy sources and energy conservation and partly in realizing the the "insurance" proposed by the AEC would insure us against a nonexistent risk – the risk that our electrical generating capacity will actually grow as that agency projected. Moreover, relegating the LMFBR program to a low-priority status and foregoing any expensive push towards demonstration and commercial reactors for from one to two decades does not permanently eliminate the LMFBR option. If within about a decade it becomes clear that possible nonfission options are not going to be available, consideration can be given at that time to reinitiating the program. The idea that there is a penalty for such a postponement, is, as we have seen, wholly spurious.

What Should Be Done

Many would prefer to bypass the breeder reactor and move directly into using solar, geothermal, and fusion energy and a program of energy conservation. The real LMFBR debate, however, centers around whether it is possible to make this leap. Unfortunately, no one will ever know the answer to this question if the present LMFBR program is permitted to continue. By swelling the bureaucratic and industrial forces committed to the

LMFBR, and by draining away research and development funds that are essential to the timely development of the alternatives that could replace the reactor, the LMFBR program is its own self-fulfilling prophesy.

However, there is an option to the present program which meets the objections of both optimists and pessimists and therefore should command general support. First, delay the LMFBR program for one decade. We have seen that the program is premature and that there is no penalty in such delay. During this period, recast the LMFBR effort as a low-priority program centered on the Fast Flux Text Facility and cancel current plans for going ahead with the costly Clinch River demonstration plant. By greatly reducing the overall costs of the program, funds will be freed for the accelerated development of solar, geothermal, fossil fuel, fusion, and conservation technologies, and the tremendous public and private investments which could foreclose the option of ever stopping the LMFBR will be avoided.

The ten-year postponement would also provide a period during which several types of data which bear critically upon the desirability of the LMFBR program could be gathered and assessed. First, more accurate information on uranium availability and future energy demand could be obtained. Second, during the coming decade knowledge regarding the potential of solar, geothermal, and fusion energy should increase dramatically with appropriate funding. And, third, this grace period could also be used to answer critical health and safety questions raised by the LMFBR with far more certainty than now exists.

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

The title of this article as originally submitted was "Bypassing the Breeder: A Report on Misplaced Federal Energy Priorities." The Publisher and Editors of Environment are responsible for the published titles and subtitles, selection of photographs and lead-in excerpts, photo captions, and preparation of most graphs and illustrations which appear in Environment articles.

NOTES

1. U.S. Energy Research and Development Agency, **Summary of Budget Estimates, Fiscal Year 1976**, Feb. 1975.

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

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

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

5. The cost overruns associated with the proposed Clinch River demonstration plant are discussed by Thomas Nemzek, director of ERDA's reactor development division, in his prepared statement before the Joint Committee on Atomic Energy, March 11, 1975.

6. Speth, J. Gustave, Arthur R. Tamplin, and Thomas B. Cochran, "Plutonium Recycle: The Fateful Step," **Bulletin of the Atomic Scientists**, Nov. 1974, p. 15.

7. Willrich, Mason, and Theodore B. Taylor, **Nuclear Theft: Risks and Safeguards**, Ballinger, Cambridge, Mass., 1974. AEC, "The Threat of Nuclear Theft and Sabotage" (Rosenbaum Report), **Congressional Record**, Apr. 30, 1974, p. S6621.

8. "Bill Asks Curb on Plutonium Use To Prevent Building of Homemade Bomb," **New York Times**, Feb. 27, 1975.

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

10. Cochran, Thomas B., **The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique**, Resources for the Future, 1974, Ch. 7.

11. **In the introduction to its recent (Dec. 1974) proposed final impact statement for the LMFBR program, but not in the cost-benefit analysis itself, the AEC was apparently forced by the press of events, including the recent deferrals and cancellations of planned reactors, to abandon its unrealistic assumptions regarding future energy demand and LMFBR introduction date.** Using what the AEC now considers more reasonable assumptions in these two areas, but without changing any of the other AEC assumptions, the net benefits of the LMFBR program drop to zero. In other words, by the AEC's own reckoning, the present breeder program can no longer be justified economically.

12. **PFEIS, LMFBR**, op. cit., vol. IV, pp. 11.2-47.

13. EPA comments on the draft environmental impact statement, LMFBR Program are reproduced in **PFEIS, LMFBR**, op. cit., vol. VII, pp. 53. 35-38.

14. Bupp, I. C., J. C. Derian, Marie-Paule Donsimoni, and Robert Trietel, "The Economics of Nuclear Power," **Technology Review**, 77:15-25, Feb. 1975.

15. Bupp, Irvin C., and Jean-Claude Derian, "The Breeder Reactor in the U.S.: A New Economic Analysis," **Technology Review**, July/Aug. 1974, p. 34.

16. U.S. General Accounting Office, op. cit., p. 9.

17. Chapman, Duane, G. G. Akland, John F. Finkler, Ralph L. Larsen, Timothy Mount, William C. Nelson, Dan C. Quigley, and William C. Wilson, "Power Generation: Conservation, Health and Fuel Supply A Report to the Task Force on Conservation and Fuel Supply, Technical Advisory Committee on Conservation of Energy, 1973, National Power Survey, USFPC," revised draft. See also, Chapman, Duane, Timothy Tyrrell, and Timothy Mount, "Energy Demand Growth, the Energy Crisis, and R&D," **Science**, 178:703-708, Nov. 17, 1972.

18. Electric Power Research Institute, "Uranium Resources to Meet Long Term Uranium Requirements," EPRI SR-5, Special Report, Nov. 1974, p. 12. Cochran, Thomas B., op. cit., p. 110.

19. Chapman, et al., "Power Generation, Conservation, Health and Fuel Supply," loc. cit.

20. Electric Power Research Institute, loc. cit.

21. Forecasting Branch, Office of Planning and Analysis, U.S. Atomic Energy Commission, "Nuclear Power 1973-2000," WASH-1139, Dec. 1, 1972.

22. **PFEIS, LMFBR**, op. cit., vol. I, pp. 1.1-7.

23. U.S. Energy Research and Development Administration, "Report of the Liquid Metal Fast Breeder Reactor Program Review Group," ERDA-1, Jan. 1975, Fn. 5, p. 16.

24. Rose, David J., "Nuclear Electric Power," **Science**, 184:357, Apr. 19, 1974.

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

26. NSF/NASA Solar Energy Panel, **An Assessment of Solar Energy as a National Energy Resource**, National Science Foundation, Washington, D.C., Dec. 1972. Eggers, Alfred J. (panel chairman), et al., **Subpanel IX Report: Solar and Other Energy Resources**, National Science Foundation, Oct. 27, 1973.

27. NSF/NASA, ibid., p. 5.

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

29. See, for example, Hickel, Walter J., et al., **Geothermal Energy**, NSF/Rann-73-003, Univ. of Alaska, 1973, p. 7. Ray, Dixy Lee, chairman, AEC, **The Nation's Energy Future: A Report Submitted to President Richard M. Nixon**, 1973.

30. **PFEIS, LMFBR**, op. cit., vol. IV, pp. 11.1-20.

31. **PFEIS, LMFBR**, op. cit., vol. III, pp. 6A.1-191.

32. **PFEIS, LMFBR**, op. cit., vol. III, pp. 6A.1-179.

33. **PFEIS, LMFBR**, op. cit., vol. IV, pp. 11.1-22.

34. **PFEIS, LMFBR**, op. cit., vol. IV, pp. 11.1-21.

35. "Conservation and Efficient Use of Energy," Report of the Committee on Science and Astronautics, U.S. House of Representatives, Dec. 18, 1974. Council on Environmental Quality, "The Half and Half Plan for Energy Conservation," in **Fifth Annual Report of the Council on Environmental Quality**, 1974. p. 475. Energy Policy Project of the Ford Foundation, **A Time to Choose**, 1974, Ch. 3-6.

36. See, for example, **PFEIS, LMFBR**, vol. III, pp. 6A.2-1 to 6A.2-51, and the references cited there. The **Nation's Energy Future**, op. cit. Hammond, Allen L., William D. Metz, and Thomas A. Maugh, II, **Energy and the Future**, AAAS, Washington, D.C., 1973, Part I.

37. Federal Power Commission, "Report of the Task Force on Energy Conversion Research to the Technical Advisory Committee on Research and Development," Nov. 1973, Draft.

38. **PFEIS, LMFBR**, op. cit., vol. III, pp. 6A.1-189.