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ISSUE PAPER TO THE CONGRESS

BY THE COMPTROLLER GENERAL OF THE UNITED STATES

The Liquid Metal Fast Breeder Reactor: Promises And Uncertainties

Energy Research and Development Administration

OSP-76-1

COMPTROLLER GENERAL OF THE UNITED STATES
WASHINGTON, D.C. 20548

B-164105

To the President of the Senate and the
Speaker of the House of Representatives

This is the sixth General Accounting Office study issued since December 1974 concerning the Federal program to develop a Liquid Metal Fast Breeder Reactor (LMFBR) for use in electrical power generating plants. The earlier studies addressed the history, status, plans, and potential problems of the program.

This study identifies and assesses the issues relevant to the Federal Government's role in the development of the LMFBR. The study looks beyond the managerial and technical aspects of the LMFBR program to assay its economic, environmental, and social implications. It contains conclusions regarding the program and recommendations concerning actions that can be taken on the part of responsible Federal agencies and the Congress to clarify and help resolve key uncertainties.

Our review was made pursuant to the Budget and Accounting Act, 1921 (31 U.S.C. 53), and the Accounting and Auditing Act of 1950 (31 U.S.C. 67).

We are sending copies of this issue paper to the Director, Office of Management and Budget; the Administrator, Energy Research and Development Administration; the Chairman, Nuclear Regulatory Commission; the Administrator, Federal Energy Administration; the Administrator, Environmental Protection Agency; and the Director, Office of Technology Assessment.

Elmer B. Staats

Comptroller General
of the United States

Contents

ABBREVIATIONS

AEC Atomic Energy Commission

CRBR Clinch River Breeder Reactor

EBR Experimental Breeder Reactor

EPA Environmental Protection Agency

EPRI Electric Power Research Institute

ERDA Energy Research and Development Administration

FFTF Fast Flux Test Facility

GAO General Accounting Office

GCFBR gas-cooled fast breeder reactor

GESMO Generic Environmental Statement Mixed Oxide Fuel (Recycle Plutonium in Light Water-Cooled Reactors)

HCDA hypothetical core disruptive accident

HTGR high temperature gas-cooled reactor

HWR heavy water reactor

IAEA International Atomic Energy Agency

LMFBR liquid metal fast breeder reactor

LWBR light water breeder reactor

LWR light water reactor

MSBR molten salt breeder reactor

NCBR Near Commercial Breeder Reactor

NEA	Nuclear Energy Agency
NPC	National Petroleum Council
NRC	Nuclear Regulatory Commission
NURE	National Uranium Resource Evaluation Program
OMB	Office of Management and Budget
Q	1 quadrillion
R&D	research and development
TVA	Tennessee Valley Authority

COMPTROLLER GENERAL'S ISSUE PAPER

THE LIQUID METAL FAST BREEDER REACTOR: PROMISES AND UNCERTAINTIES
Energy Research and Development Administration

D I G E S T

Estimated to cost $10.7 billion in current dollars, the Liquid Metal Fast Breeder Reactor (LMFBR) is one of the Nation's high priority energy research and development projects. It is also highly controversial.

GAO identified and assessed the issues relevant to key questions facing LMFBR decision-makers.

--Does the United States need an LMFBR and, if so, when?

--Should the Federal Government continue to develop the LMFBR?

--What are the benefits, costs, and risks?

--What are the options?

Because LMFBRs will breed from natural uranium more nuclear fuel than they consume, they offer the promise of substantially extending the life of the Nation's uranium resources and are a key future option for generation of central station electric power.

The LMFBR is controversial because

--it is the most likely vehicle by which nuclear fission may become an assured energy source through the 21st century and beyond,

--key uncertainties persist with respect to the need for and the economics and safety of LMFBRs, and

--research and development to resolve the uncertainties is an expensive, and often time consuming, matter.

Some uncertainties and problems are unique to the LMFBR. However, problems of safeguarding nuclear materials and problems of radioactive waste disposal are already present with existing reactors.

Thus, the LMFBR is intimately interwined with the benefits and risks to society from continued use of nuclear fission in any form.

KEY CONCLUSIONS

LMFBR uncertainties argue against extreme actions to either expand and accelerate or abandon the program.

Given the uncertainties, GAO reached five general conclusions.

--The United States clearly should not abandon the nuclear fission option at this time, nor should it abandon the LMFBR research and development effort.

Uncertainties regarding the scientific, technical, or economic feasibility of potential alternative energy sources; the problems of increased reliance on fossil fuels; and uncertainties regarding the ability and willingness of the Nation to conserve fuel--all make these unrealistic courses of action.

--The LMFBR program should be clearly identified and recognized for what it is: a research and development program. There has been premature concern and emphasis on commercializing the LMFBR at a time when the Nation is years away from demonstrating that commercial-size LMFBR plants can be operated reliably, economically, and safely. It is unlikely that utilities will make major financial commitments in advance of such proof, which may not be available until the mid-1980s.

--Given the history of slippage in this program and the likelihood that future experience will be similar, it does not appear reasonable to attempt to accelerate the research and development schedule. It will be difficult to maintain the current schedule.

--Whatever action is taken by the United States on nuclear power and the LMFBR, the problems of nuclear safety and safegrards will not go away. Many foreign governments appear likely to rely significantly on nuclear fission power in the future, including LMFBRs. These governments are not concerning themselves initially with commercialization problems but are attempting to demonstrate that LMFBRs can operate reliably, economically, and safely.

A unilateral descision on the part of the United States to abandon nuclear power or the development of the LMFBR will not change this situation.

--The most logical course of action is to pursue the LMFBR program on a schedule which recognizes that the program still is in a research and development stage. Not until some point in the future, perhaps 7 to 10 years from now, need a firm decision be made as to whether the Nation will commit itself to the LMFBR as a basic central station energy source. At that time, many of the uncertainties of today should be reduced or eliminated, particularly if priority efforts are made to resolve as many as possible between now and then. (See pp. 92 and 93.)

RECOMMENDATIONS

GAO recommended actions by the heads of the responsible Federal agencies and the Congress to obtain adequate information on domestic uranium resources, resolve environmental and safety questions, improve the Nation's understanding of and cooperation with foreign LMFBR efforts, and improve projections of demand for electrical energy. GAO specifically recommended that:

--The Energy Research and Development Administration (ERDA) expedite its National Uranium Resource Evaluation Program currently scheduled for completion in 1980.

--The Congress explore with ERDA, the Geological Survey, and the Federal Energy

Administration the feasibility of establishing a program to thoroughly appraise the U.S. uranium resource base by having the Federal Government conduct or sponsor extensive exploratory drilling.

--ERDA and the Nuclear Regulatory Commission give higher priority to developing adequate systems to safeguard nuclear materials, particularly at the vulnerable points of transport.

--ERDA and the Nuclear Regulatory Commission decide how to deal with the possibility of LMFBR core disruptive accidents, including recriticality, and whether to include a "core catcher" or some greater structural integrity in the reactor containment system.

--ERDA and the Nuclear Regulatory Commission proceed now to establish a relatively permanent underground storage system so designed that wastes are retrievable if necessary sometime in the future. They must make decisions on the management of radioactive wastes and implement a program soon if we are to proceed with expanding nuclear power in any form.

--ERDA work with the Environmental Protection Agency in developing an accelerated program of research in the environmental and health aspects of coal mining and use to better enable the Nation to know whether coal is an alternative to fission power or only a complement to it.

--ERDA take the lead in examining the feasibility of information exchange arrangements with foreign governments and consider carefully obtaining franchises to use foreign LMFBR technology for domestic production of LMFBR systems and components. Also, purchasing total LMFBR systems and components from foreign sources should be closely examined.

--The Nuclear Regulatory Commission and ERDA intensify efforts to identify and resolve problems in licensing the French LMFBR system and components for use in the United States, since France may be the most advanced in large LMFBR plant experience.

--ERDA, working with the Federal Energy Administration, extend and improve projections of demand for electrical energy.

GAO recommended also that, as better information becomes available in the years ahead and the Nation strives for a balanced energy research and development program, the Congress periodically and systemically reassess the Nation's major energy options. Reassessments should consider the Nation's ability and willingness to conserve energy as well as the changing status of all energy supply options. (See pp. 93 to 95.)

LMFBR UNCERTAINTIES

In the analysis which led to its conclusions and recommendations, GAO identified critical LMFBR uncertainties.

--The rate of growth in the use of electricity in the years ahead. (See pp. 4 and 5.)

--The extent to which nuclear fission power will be required to meet the future demand for electrical energy. (See pp. 5 to 8.)

--The amount of recoverable uranium resources at current and anticipated future prices and the resultant implications for when LMFBRs would be needed. (See pp. 34 to 43.)

--The economic feasibility of LMFBRs. (See pp. 55 to 62.)

--The ability to deal adequately with environmental, safety, and safeguards concerns, including diversion of nuclear materials and disposal of radioactive waste. Special problems are licensing by the Nuclear Regulatory Commission of plutonium recycling, a process essential to economically viable LMFBRs, and a decision whether LMFBRs need "core catchers" or other additional containment to guard against core disruptive accidents, including recriticality. (See pp. 63 to 84.)

--The status of development of foreign LMFBR programs and their implications for our domestic efforts. (See pp. 26 to 31.)

In addition, serious questions exist regarding:

--The level of Federal Government support necessary to encourage the use of LMFBR technology beyond the building of a demonstration plant on the Clinch River in Tennessee. ERDA estimates such support at $300 million, but it recognizes the amount could go much higher if utilities and the nuclear industry are unwilling to provide the bulk of financial support for its development.

--When utilities will commit to the purchase of commercial LMFBRs given the fact that safety and reliability demonstration and test results will not be available before the mid-1980s. (See pp. 18 to 24.)

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In developing the issue paper, GAO was fortunate to have had the expert advice of a number of extremely knowledgeable consultants with a wide range of backgrounds and viewpoints. The consultants were not asked to comment on the conclusions and recommendations.

Comments on a draft of this issue paper, including the conclusions and recommendations, were obtained from the Energy Research and Development Administration, Nuclear Regulatory Commission, Federal Energy Administration, and Environmental Protection Agency.

Although GAO believes there is substantial support for its conclusions and recommendations, they are GAO's and do not necessarily reflect the views of any of the consultants or the agencies.

PART 1

INTRODUCTION

This is our sixth report, staff study, or issue paper since December 1974 1/ concerning the Federal program to develop a Liquid Metal Fast Breeder Reactor (LMFBR)* for use in electrical power-generating plants. In our earlier documents we addressed the history, status, plans, and potential problems of the program--one of the Nation's high priority energy research and development (R&D) efforts.

This paper seeks to identify and assess the issues relevant to key questions facing LMFBR decisionmakers:

--Does the United States need an LMFBR and, if so, when?

--Should the Federal Government continue to develop the LMFBR?

--What are the benefits, costs, and risks?

--What are the options?

The paper looks beyond the managerial and technical aspects of the LMFBR program to assay the economic, environmental, and social implications of the LMFBR.

Like all existing nuclear power reactors, the LMFBR is a fission reactor and most of its social and environmental problems are similar to those of nuclear plants as they are operated today or as they are expected to be operated in the future. Although the paper concentrates on LMFBR R&D, demonstration, and commercialization, it also examines a number of issues, such as what to do with radioactive waste and the social acceptability of plutonium recycling which must be resolved for the nuclear fission option in general.

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*Liquid metal refers to the liquid sodium used as the coolant to carry off the heat of the reactor fuel. A fast reactor is a reactor in which the chain reaction is sustained primarily by fast neutrons rather than by the slower speed neutrons found in present-generation commercial nuclear power reactors.

Note: Numbered footnote references to part 1 are on p. 3.

Determining which LMFBR program course is best is a dynamic process requiring continual reassessment of program goals against available information on such factors as uranium resources, electrical energy demand projections, LMFBR economics, and LMFBR technical risks.

This paper synthesizes existing literature and information on the LMFBR, the nuclear option, and the U.S. energy situation. It is intended to assist congressional and other decisionmakers as they deal with the LMFBR issues and with the controversy that surrounds them.

In developing this paper, we had the benefit of comments by a varied group of consultants knowledgable about LMFBR issues. The consultants were not asked to review or take a position on the conclusions and recommendations developed by us as a result of our analysis.

The Energy Research and Development Administration, Nuclear Regulatory Commission, Federal Energy Administration, and Environmental Protection Agency reviewed a draft of the issue paper and provided us with formal comments which were recognized in finalizing the paper. (See app. IV through VII, respectively.)

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PART 2

PERSPECTIVE

The U.S. energy situation is serious and will be for many years. There are no cheap or fast or easy solutions, but there are options. Whether this country chooses to depend essentially on domestic fossil fuels or on fossil plus nuclear fuels--or any other possible combination of energy sources--it will be expensive and time consuming to bring into being the actual production facilities required to

--ensure an adequate supply of energy at reasonable prices to satisfy the basic human needs of our country;

--keep adverse economic, social, and environmental impacts of that production and use of energy to a minimum; and

--avoid excessive dependence on foreign sources of supply.

FUTURE ENERGY DEMAND

Total energy consumption grew at an average annual rate of 3.9 percent during the period 1954-73. 1/ Electrical energy consumption grew at an even faster rate--6.5 percent annually--during the same period. 2/ In contrast, preliminary data indicates that total energy use in 1974 actually declined by 2.2 percent, and electrical consumption declined by 0.9 percent. 3/ These declines apparently were due to a combination of the country's general economic problems, the oil embargo, rising energy prices, energy conservation actions, and consumer fears and apprehensions.

Most forecasters agree that future growth in both total energy and electrical energy consumption will slow from historical trends, but they disagree on how much they will slow and on possible growth rates in the various energy sectors: coal, oil, gas, solar, etc. Whatever the chosen level of expected growth, there is considerable agreement that historical trends in overall energy consumption cannot continue. For example, future total energy growth rates of about 2 to 3 percent were seen as likely in some major energy policy studies completed in the last year. 4/

Note: Numbered footnote references to part 2 are on pp. 12 to 14.

In the remainder of this section, we discuss only the electrical sector of energy because it is critical to nuclear energy and to the LMFBR. Nuclear energy is being used almost exclusively to produce electricity and will continue to be so used well into the future.

Some forecasters, including many within the electricity utility industry, believe the negative growth rate for electricity in 1974 was an aberation and not indicative of the future; 5/ others believe that the 1974 experience was a harbinger of lower growth of electricity demand. 6/ These assumptions, therefore, yield widely differing estimates of future electrical growth--ranging from about 2 to 7 percent per year. 5/, 6/

Extrapolating a growth rate of 2 percent per annum to the year 2000 yields about 33 quadrillion* British thermal units** of energy input which would be needed to meet electrical demand; a growth rate of 4.5 percent yields 62 Q; and 7 percent yields 115 Q. Obviously the additional generating capacity that would be needed under any of the above assumptions is considerable. However, as one assumes higher, more traditional, growth rates, the additional capacity needed grows from large to prodigious; for example, the amount of capacity which would be required in the year 2000 to meet the 7-percent demand growth rate is about six times the Nation's total electrical capacity in 1974, assuming the capacity to demand ratio remains fixed. One can speculate on the Nation's ability to produce the sheer magnitude of resources required to achieve such a scenario, given the most favorable of circumstances.

FUTURE ENERGY SUPPLIES

Exactly how the various energy supplies will or should fit into a national energy policy is uncertain and the subject of much controversy. In considering the major current sources of electrical energy, we can see serious problems with each one. The world price of oil, for example, is currently set by the Organization of Petroleum Exporting Countries whose recent actions have affected international economic stability. Coal has many environmental drawbacks, including air pollution, strip mining restoration, and acid pollution of streams and rivers. (See pp. 78 to 80.) In

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*1 quadrillion (Q) is equal to a thousand trillion (10^{15}).

**1 British thermal unit (Btu) is the amount of heat required to raise the temperature of 1 pound of water 1 degree Fahrenheit.

the longer term, some scientists argue that, if we burn enough coal or other fossil fuels, we may add enough carbon dioxide and small particles to the atmosphere to change climates and disrupt world agriculture. 7/ These effects may have far-reaching climatic consequences. Natural gas, the country's cleanest and least environmentally damaging source of energy, is in short and dwindling supply. Its continued use as fuel to produce steam to generate electricity seems increasingly wasteful and shortsighted. Nuclear energy, like the others, has many problems associated with its development, not the least of which are the isolation of radioactive waste products from the environment and the potential for diverting nuclear materials used in manufacturing nuclear weapons.

ENERGY CONSERVATION

We do have one attractive available energy option to which more lip service than action has been paid--energy conservation. We waste more than half of our potential energy, but it is technically feasible to eliminate much of the waste. 8/ Rising prices, environmental problems, and the Nation's drive to energy self-sufficiency have made it economically feasible and otherwise necessary to save more and more energy.

Studies have recently described both the problems and the opportunities for energy conservation. 4/

FUTURE ELECTRICAL DEMAND AND SUPPLIES

Oil and natural gas presently produce about 7 Q of electrical energy in the United States. 9/ Domestic supplies of these resources appear to have reached their peak and their use for electrical generation could be measurably reduced by the year 2000. 10/ Forecasts for solar and geothermal indicate that together, in the year 2000, they may produce roughly what is expected to be lost in electrical production from oil and natural gas. 11/ Fusion is not expected to make a significant energy contribution until after the year 2000. 12/ Hydroelectric power is generally expected to produce 4 Q, 13/ bringing the total in the year 2000 to about 11 Q for the above energy sources.

The only other developed sources of supply are nuclear fission and coal. These would have to provide an annual British thermal unit input into the electrical sector of 22 Q at 2 percent average annual electrical demand growth, 51 Q at 4.5 percent, or 104 Q at 7 percent. Both nuclear power and coal will obviously have to play important roles in this Nation's energy future, regardless of the electrical growth rate. What is not obvious is how much of each will be used and at what cost. Also not obvious is how long into the next century coal and nuclear would be expected to carry the load, as other, now unconventional, sources come into operation. But, in any case, nuclear and coal are expected to be major sources of electricity in this century. For example, the Council on Environmental Quality's Half and Half Plan indicates that 35 Q of nuclear power and 10 Q of coal would be used to produce electricity in the year 2000. 14/ That plan indicates also that 23.4 Q of coal would be required to produce additional energy in other forms, for example, coal gasification and liquification and direct industrial use.

Coal production (bituminous and lignite) has slowly risen by an average 1.6 percent a year since 1960. 15/ If coal alone were used to meet the additional electricity demand in the year 2000

--under the 2-percent growth rate, average annual coal production would have to increase 3.9 percent annually (2.7 times present production);

--under the 4.5-percent growth rate, coal would have to increase 6.3 percent (4.8 times present production); and

--under the 7-percent growth rate, it would have to increase 8.8 percent (9 times present production). 16/

Because coal will also be used for other purposes, such as coal gasification and liquification, total increases in coal production would have to be larger. Increasing coal production by such amounts, particularly to the higher assumptions, would raise numerous problems, but, if it were a national decision to do so, adequate coal resources are available to supply the demand. The issue is--At what cost?

Nuclear power, which we discuss in detail in this paper, could also meet these additional demands. The most likely scenario, of course, is that neither coal nor nuclear power will alone supply the electrical generating needs. The country's future energy supplies will depend on which energy sources are most attractive economically and are most compatible with our social, environmental, and foreign policy goals.

As of September 1974 installed electric generating capacity totaled 331,000 MWe* for conventional steamplants (coal, oil, and gas) and 34,000 MWe for nuclear plants. 17/ Table 1 shows statistics compiled by the Atomic Industrial Forum (as of March 1975) and the Edison Electric Institute (as of January 1975) on recent commitments, cancellations, and deferrals for these plant categories.

Table 1

Recent Commitments, Cancellations, and Deferrals for Conventional Steamplants and Nuclear Plants

	Conventional steamplants	Nuclear powerplants
Total commitments	132,000 MWe	196,000 MWe
Cancellations	5,700 MWe	8,400 MWe
Percent of total MWe canceled	4.3%	4.3%
Deferrals	27,000 MWe	92,000 MWe
Percent of total MWe deferred	20%	47%

WHY NUCLEAR POWER?

There are potential significant economic, fuel resource, and environmental benefits to be derived from the increased use of nuclear power. Some believe that reliance on providing our energy needs without nuclear power is imprudent and could lead to distastrous consequences to our economy and our strength internationally.

The annual national savings, based on an Atomic Energy Commission (AEC)** "reasonable" projection of nuclear capacity additions, could be: 18/

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*1 MWe is equal to 1 million watts.

**On January 19, 1975, legislation abolishing AEC and establishing the Energy Research and Development Administration (ERDA) and the Nuclear Regulatory Commission (NRC)--AEC's successor agencies--became effective. Accordingly, this paper refers to AEC for programs and activities carried out before that date and to either ERDA or NRC for programs and activities on and after that date.

	1980	1985	1990
Nuclear capacity (megawatts electric)	102,000	260,000	500,000
Generation cost savings* (millions of dollars per year)	1,560	3,990	7,670
Oil consumption displaced** (millions of barrels per day)	2.4	6.2	11.9

In addition, nuclear power systems can offer certain environmental benefits over fossil-fired plants, including very low releases of wastes to the air and water environs and considerably less mining (coal v. uranium ore) per unit of contained energy. 18/

On the other hand, some experts believe that sufficient assurance has not been obtained that the public is being adequately protected against the risks of nuclear power. They see a need for better safety control systems, including institutional changes, but doubt that the desired levels of public protection can be reached before the control systems--e.g., police intelligence to thwart possible incidents--would become socially and politically unacceptable. Last, they point out that one major incident could sour the Nation on the use of nuclear power and that to place heavy reliance on a technology that one day may be unacceptable is, in their opinion, imprudent. 19/

In any case, the issue of nuclear fission in the context of alternative future supplies must turn on analyses and understanding of nuclear power's relative merits and actual ability to achieve potential benefits compared to the principal alternatives, particularly coal. (See pp. 78 to 80 for a discussion of the costs to society of nuclear power systems and coal power systems.)

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*At a current differential of 2.5 mills per kilowatt-hour in favor of nuclear power and 70 percent plant capacity factor. The savings could be larger in the future if fossil fuel prices continue to escalate relative to nuclear fuel cycle costs. 18/

**At an 8,500 Btu per kilowatt-hour fossil plant heat rate and at 6 million Btu's per barrel. 18/

WHY THE LMFBR?

Current nuclear reactors can use only 1 to 2 percent of the potential energy in uranium. If they were the only types to be used in the future, the number of these reactors to be constructed by the end of the century could possibly consume, over their lifetimes, all the presently estimated economically recoverable uranium resources in the United States. 20/

The unused portion of uranium from today's nuclear powerplants is not necessarily wasted. The hope of nuclear proponents is to use these "wastes" (called tails in the industry) in a nuclear reactor known as a breeder. Breeder reactions are remarkable inventions. They can produce from natural uranium more usable nuclear fuel then they consume. They can extract more than 60 percent* of the energy in uranium. For these reasons, development of large-scale electricity generation plants powered by fast breeder reactors would extend the useful life of available economically recoverable uranium sufficiently to provide a large fraction of the Nation's growing electric energy needs for many hundreds of years.

Because of the breeder's exceptional promise, interest in developing this type of reactor to commercial feasibility arose very early in the nuclear energy program. From the mid-1940s, various research projects have been undertaken to develop breeder reactor technology and, in 1951, the first nuclear electricity ever produced was made in an experimental LMFBR. Despite this early interest, the less resource-efficient light water reactor (LWR) technology was developed more rapidly and was brought into early commercial use, in part, because it was selected and developed at an early date for naval nuclear propulsion, and it represented a somewhat smaller departure for U.S. industry from the familiar technology of fossil fuel steam electric plants than breeder reactors would have entailed. 21/

After development and commercial adoption of LWR technology, however, the focus of the AEC reactor development

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*In principle, they can extract nearly 100 percent of the energy, but there are inevitable losses of uranium to scrap and waste streams during fuel reprocessing and fabrication. After many recyclings, these losses could accumulate from 30 to 40 percent of an initial uranium loading. Improved process efficiencies could reduce these anticipated losses. 21/

program shifted toward breeder reactor technology in the mid-1960s. After considering its ongoing reactor programs and the results of research up to that time, AEC selected the LMFBR as its highest priority breeder reactor development program. The LMFBR was given priority over other breeder concepts because of its predicted performance, existing industrial support, technological experience, and proven basic feasibility. 22/ Other major industrial nations have also chosen the LMFBR in their own national breeder reactor program.(See pp. 26 to 31.)

From this brief overview, it can be seen that the issues of the LMFBR evolve from a hierarchy of policy considerations. Given any assumption about future demand in energy, certain assumptions must be made about electrical energy demand. In turn, we must understand the mix of supplies available for filling that demand and the benefits and risks associated with their use. Over the long haul, the Nation's energy problems may all be solved by widespread use of solar power and nuclear fusion, but this in now uncertain. Although these uncertainties remain unresolved and as oil and natural gas become less available for use to generate electricity, nuclear fission and coal are the primary options. The nuclear fission option, however, is constrained by the availability of economically recoverable uranium which is inefficiently used in today's LWRs. Either more uranium must be found or what is available must be used more efficiently. The concern over the latter has produced the quest for a breeder reactor, and that quest has led this Nation and several others to invest heavily in R&D on the LMFBR. Obviously any or all of the above assumptions can, and should be, analyzed and challenged where faulty. We hope this paper provides some of that analysis.

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"A National Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future," vol. 1, p. VIII-3.

12/"A National Energy Plan for Energy Research, Development, and Demonstration: Creating Energy Choices for the Future," vol. 1, pp. VIII-3 and 4.

13/"A Time to Choose America's Energy Future," pp. 28, 76, and 111.

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15/GAO calculated on the basis of:

"United States Energy Through the Year 2000," p. 43.

"U.S. Energy Use Down in 1974 After Two Decades of Increases," Table 3.

16/Based on GAO calculations.

17/"The Nuclear Industry 1974," WASH-1174-74, pp. 7 and 16.

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19/"Statement of the Executive Committee of the Scientists' Institute for Public Information--Comment on the Breeder Reactor," Environment, vol. 17, Number 4, June 1975.

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20/"ERDA Staff Statement for the Public Hearing on the LMFBR Proposed Final Environmental Statement," U.S. Energy Research and Development Administration, May 27, 1975.

21/"Proposed Final Environmental Statement--Liquid Metal Fast Breeder Reactor Program," vol. 1, p. 1.1-1.

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PART 3

U.S. LMFBR PROGRAM

Since 1967 the LMFBR has been accorded the highest priority in the U.S. civilian reactor development program.* Total program funding through fiscal year 1974 was about $1.8 billion. Recent estimates show that an additional $8.9 billion** will be needed to carry the program through to planned completion in the year 2020. 1/ Of the $10.7 billion total costs, over $7 billion is planned to be spent from 1975 through 1987--the target date for operation of the first commercial plant. 2/ Federal funding for developing the LMFBR is estimated to be $444 million in fiscal year 1976, or about 22 percent of the total $2 billion Federal energy R&D funding. 3/

PROGRAM OBJECTIVES

The basic objective of the LMFBR program is to develop a broad technological and engineering base with extensive utility and industrial involvement which will lead to a strong, competitive, commercial breeder industry. 4/

The program is proceeding along two lines of effort--the base technology program and the demonstration plant program. Under the base technology program, emphasis is placed on developing key technical areas: engineering, manufacturing, and proof testing. These efforts are performed in cooperation with private industry and are directed at developing realistic technical and economic bases for the LMFBR demonstration program. 5/

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*On June 30, 1975, ERDA released "A National Plan for Energy Research, Development, & Demonstration: Creating Energy Choices for the Future." The highest priority for the long term (past the year 2000) is to pursue nuclear breeders (primarily the LMFBR), fusion, and solar electric, which will permit the use of essentially inexhaustible energy resources. The plan points out that none of these technologies is assured of large-scale application. All have unique unresolved questions in one or more areas: technical, economic, enviromental, or social. The benefits to be gained in achieving success in one or more of these approaches require that vigorous development efforts proceed now on all three, according to the plan.

**In fiscal year 1975-76 dollars.

Note: Numbered footnotes to part 3 are on p. 25.

The demonstration plant program is to serve as the key to the program's transition from the technology development phase to large-scale commercial use. Plans for building the Nation's first LMFBR demonstration plant--the Clinch River Breeder Reactor (CRBR) near Oak Ridge, Tennessee--are now in the preliminary design stage. This facility is to be a 350-MWe* powerplant and is presently scheduled to be operational by mid-1983. It is a cooperative Government-industry effort, with industry providing about $250 million and the Government the remainder of the project costs estimated at $1.7 billion, including R&D, construction, and operating costs for 5 years. CRBR's primary objectives are to

--demonstrate the safe, clean, and reliable operation of an LMFBR closely resembling a commercial-size plant while showing a high availability factor for power production in a utility environment;

--serve as the focal point for the development of systems and components;

--develop industrial and utility capabilities to design, construct, and operate LMFBRs; and

--demonstrate the commercial licensability of LMFBRs. 7/

According to ERDA, constructing and operating an LMFBR demonstration plant is the only means by which these objectives can be realized. The guidelines issued in establishing CRBR as it presently exists were based, in part, on utility recommendations. 7/

AEC considered other approaches to realizing these same objectives, including trying to encourage industry to undertake the demonstration of LMFBR technology on its own, relying on foreign experience to demonstrate the concept, and purchasing foreign LMFBR technology and adopting it to the prevailing U.S. regulatory requirements. According to AEC, however, none of the alternatives met the objectives satisfactorily. 8/

Until mid-1974 AEC stressed the progressive development of successively larger demonstration and "early commercial"

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*In the United States, commercial nuclear powerplants being built generally have capacities in excess of 1,000 MWe. Commercial LMFBRs are, at this early date, anticipated to be somewhat larger--about 1,500 MWe. 6/

plants.* These plants were to be used as test beds for component development. AEC projected that two more demonstration plants and three early commercial plants would be built after CRBR is built. These plants were expected to show the reliability, safety, licensability, and environmental acceptability of the LMFBR concept and were to provide private industry with a reliable basis on which to build an LMFBR energy economy. 8/

As a result of an assessment of the LMFBR program made in mid-1974, AEC--along with industry, AEC national laboratories, and utility executives--identified what it judged to be a severe program imbalance. AEC concluded that building several successively larger demonstration plants placed too much emphasis on developing components for each successive plant--a costly and time-consuming process. 8/

Consequently, in July 1974, AEC redirected its LMFBR program. AEC terminated its plans for multiple demonstration plants and called for only a single demonstration plant--CRBR. Instead of follow-on demonstration and early commercial plants, a large component test facility--Plant Component Test Facility--is now planned to test full commercial-size components. One Near Commercial Breeder Reactor (NCBR) plant** is planned to cover any further needs in the plant experience area. The NCBR is expected to be about 1,000 to 1,500 MWe in size and to consist of the large commercial-size components to be developed and tested under the component development portion of the LMFBR program. 9/

Under this revised program, CRBR is placed in an even more important position--it alone will have to demonstrate the reliability, safety, licensability, and environmental acceptability for the LMFBR concept. Also CRBR should provide major input to the large component development programs and the testing requirements which must be factored into the design of the Plant Component Test Facility. This facility is scheduled to begin operation in the early 1980s. 10/

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*Operating LMFBR plants smaller in size and in power-generating capacity than future commercial LMFBR plants are anticipated to be. 8/

**One which has full-size commercial plant components and features; it may be at a lower power level than a commercial plant. 9/

According to ERDA, the availability of the Plant Component Test Facility should allow industry to construct large commercial-size components much sooner than previously contemplated. ERDA stated that this adjusted LMFBR plan should further enhance the ability of industry to design and build a number of large commercial plants for operation by the late 1980s or early 1990s. 10/

With respect to program objectives, two vital unresolved issues are: What is the role of the Federal Government in the commercial application of the LMFBR technology if the R&D and demonstration efforts succeed? When will Federal funding and other support (direct and indirect subsidies) of LMFBR plants terminate? According to ERDA, the burden of commercial application will fall to the private sector, starting with NCBR and continuing through commercial plants. Both the plant designs used and the pace of LMFBR introduction will be determined by the private sector. ERDA officials told us that the Government neither wanted to design nor build the NCBR or later reactors, that it wanted industry to take the lead, and that the Federal role was simply that of making a promising technology available for the Nation.

On the other hand, ERDA officials recognize that, to commercialize the LMFBR technology, the Federal role may have to be more extensive, both in time and in funding. The uncertainty arises in connection with the number of commercial LMFBR plants needed for LMFBR electricity costs to become competitive with electricity from other types of powerplants. 11/

The current LMFBR program cost estimate of $10.7 billion includes $300 million for a Government subsidy of the NCBR. ERDA officials said that there was a great deal of uncertainty regarding the amount of subsidy that would be necessary for that plant and the question of whether subsidees would be necessary for additional plants to encourage utilities to build LMFBRs for commercial use. The officials explained that much of this uncertainty stems from whether design and construction improvements can be realized after CRBR is built. The estimate that only one plant after CRBR would require a subsidy of $300 million is based on the assumption that such design and construction improvements would be major. 11/

ERDA officials told us that, on the basis of other analyses ERDA and its contractors have made, this amount could run as high as $2 billion for several plants if the program did not attain its development goals and resulting improvements and if more conservative assumptions were made. 11/ The officials noted that, for the present generation of reactors, AEC's approach was to subsidize follow-on plants until their power costs become competitive with the available power sources. 12/

The LMFBR program is unlike some other major Federal R&D efforts--such as the Manhattan project or the Apollo program--in that its end product is destined for the marketplace. If the LMFBR R&D and demonstration succeed and if the utilities do not buy LMFBRs--because equally or more attractive options are available--then, at least in terms of energy supply, the program will have failed and the Nation may be unable to recoup its investment of several billion dollars. What, then, are the program expectations in terms of numbers and timing of LMFBRs to be built, and what is the current position of the utility and reactor equipment-manufacturing industries on building LMFBRs?

PROGRAM EXPECTATIONS

ERDA anticipates that during the early 1990s a viable and competitive commercial industry can be developed. A viable industry would include reactor manufacturers and architect-engineers from whom interested utilities can solicit bids and select a powerplant. A competitive industry would include several qualified and experienced vendors from whom selections can be made for furnishing major equipment items. 13/

In March 1975 ERDA projected that by the year 1998 about 128 commercial-size LMFBRs will be built and operating.* This projection was derived from a statement by ERDA before the Joint Committee on Atomic Energy on March 11, 1975, that:

> "* * * the first breeder becomes operational in 1987, and the aggregate capacity doubles annually until about 1990 and every 2 years thereafter until 1998." 14/

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*The LMFBR objective in ERDA's June 30, 1975, national plan for energy R&D and demonstration is to make possible an initial contribution before the year 2000 and a very major contribution after then. No specific number of LMFBRs was projected for any particular year.

Our discussions with representatives of the utility and reactor equipment manufacturing industries, indicate that, although they expect a need and a market for a successful LMFBR, they also believe that ERDA's March 1975 projections for the number of LMFBRs in the late 1980s and early 1990s were optimistic and probably unrealistic. These representatives said that few utilities would be willing to commit large amounts of capital until they were fairly certain that LMFBRs would be technically and economically viable.

Table 2, page 21, shows estimates of capital requirements for building LMFBRs at the rate projected by ERDA in March 1975 and the estimated capital requirements to provide equal generating capacity using LWRs and coal-fired plants. These are preliminary GAO estimates based on our continuing examination into what would be involved in going from the LMFBR R&D program to commercializing the LMFBR. (See p. 52.)

Building reactors in the United States from time of commitment to operation presently requires about 8 to 10 years. 15/ To meet ERDA's March 1975 projections, utilities would be required to commit hundreds of millions of dollars in the early 1980s, which is several years before ERDA expects to have developed and tested the major components required for commercial-size LMFBRs. It is also about 5 years before the projected 1987 operation of the first commercial-size LMFBR, which ERDA believes will establish the economic viability of commercial-size LMFBRs.

Assuming that the CRBR operates successfully and that NCBR is completed on time, the utility and reactor

'ECTIVE*

NOLOGIES
ї INTRODUCTION

93	94	95	96	97	98	99	2000	TOTAL THROUGH YEAR 2000
8	8	13	19	27	37	24	24	24
24	32	45	64	91	128	152	176	176
8.88	10.59	11.69	11.51	10.84	10.34	10.09	10.08	$109.5
8.44	10.17	11.35	11.28	10.73	10.30	10.08	10.08	$105.6
5.76	7.67	9.28	9.78	9.05	8.62	8.30	8.30	$81.3

plant capital costs
ı 1000 MWe plant.

ıgn and finance each
construction, start-up,
ɔn as a base load plant.

ıl investment, in percent,
345)

ɔtal Investment

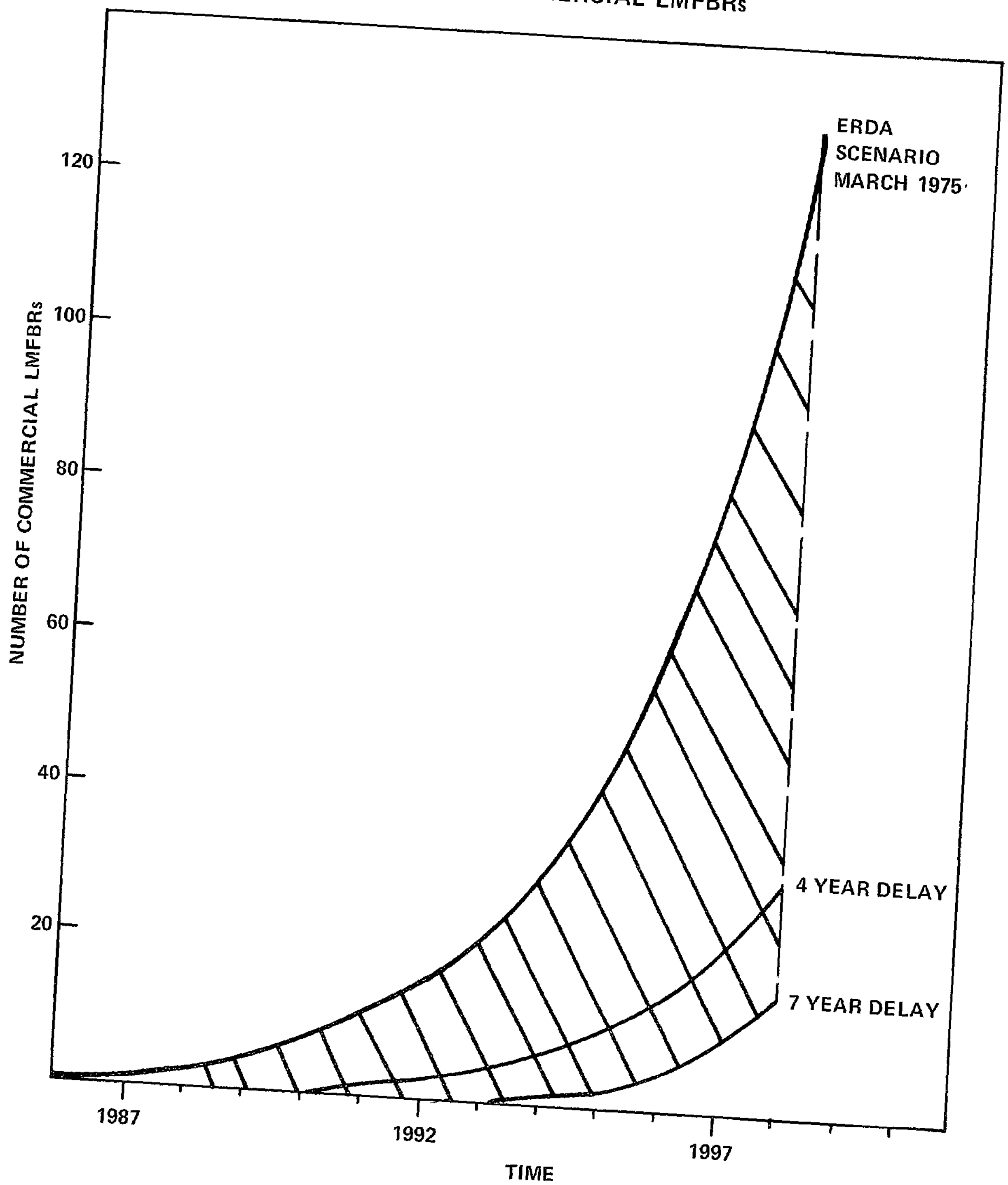
?
ł.5
3.5
5
?
5
7
)%

COMMENTS

1. Fuel costs per kWh for the LWRs are presently much smaller than fuel costs for a fossil-fueled plant.
2. The assumption that LMFBR, LWR, or coal power plant capital costs per kWe will decrease or remain constant in 1974 dollars is optimistic and perhaps unrealistic. A recent study[1] suggests that LWR costs per kWe in 1974 dollars for large (> 450 MWe) nonturnkey commercial plants have risen over the last four years at an average rate of about $30/kW per year. This increase explicitly takes into account such factors as reactor size, cooling system, and geographic area. Fossil-fueled plant capital costs have risen at roughly similar rates. If this trend were to continue, a reactor costing $420/kW today would cost $1,170/kW in the year 2000 in 1974 dollars.

   One of the important considerations is the relative costs between these systems. At the present time, not enough is known to convincingly determine which system can produce electricity at the lowest cost per kWh.
3. There is increasing competition for capital and an early requirement for large amounts of capital for base load electric generating capacity. These imminent capital requirements may warrant early consideration of what the appropriate role of Government should be; i.e., alternative Government policies -- various interventions including subsidies -- and their implications.

FIGURE 1:
ALTERNATIVE INTRODUCTION
RATES FOR COMMERCIAL LMFBRs



Also, in a May 21, 1975, letter to the Chairman, Joint Committee on Atomic Energy, the Administrator of the Environmental Protection Agency (EPA) stated that:

> "* * * if one were to substitute the more recent and lower Project Independence projections of energy demand growth in place of the base demand growth used in the environmental statement, considerable flexibility appears to be available in the projected date of commercialization. Specifically, our analysis showed that a delay of four to twelve years for commercial introduction of the technology may be possible without losing the uranium conservation value of the breeder. By this we mean that the date selected by the AEC as the base case date for commercial entry of the LMFBR (1987) could be delayed until 1991 to 1999 under the Project Independence energy demand forecast. Such a delay, according to our analysis, would still allow optimum extraction of energy from the Nation's uranium reserves."

The Administrator added, however, that EPA favored early demonstration of breeder technology and was in no sense asking for a stretch out but indicating that such flexibility in timing could provide a more solid knowledge base at each decision point in the developmental program up to the time commercialization was to be introduced.

FOOTNOTE REFERENCES

1/"The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future," U.S. General Accounting Office, RED-75-352, April 28, 1975, p. 10.

2/*Ibid*., Appendix I.

3/Energy Branch, Office of the Controller, ERDA, July 18, 1975. Science and Energy Technology Branch, Office of Management and Budget, July 18, 1975.

4/*Ibid*., p. 6.

5/*Ibid*., p. 7.

6/"Westinghouse Recommendations for a National Plan for Commercial Introduction of the Breeder Reactor in the Late 1980s," Westinghouse submission to the U.S. Atomic Energy Commission's LMFBR "Commercialization Study," p. 19.

7/"The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future," p. 7.

8/*Ibid*., p. 8.

9/*Ibid*., pp. 8 and 9.

10/*Ibid*., p. 9.

11/*Ibid*., p. 11.

12/*Ibid*., pp. 23 and 24.

13/*Ibid*., p. 2.

14/Thomas A. Nemzek, Director, Division of Reactor Research and Development, ERDA, statement before the Joint Committee on Atomic Energy, ERDA authorization hearings for FY 1976, March 11, 1975, p. 11.

15/Warren H. Donnelly, "Nuclear Power Plants: Expediting of Licensing," Library of Congress: Congressional Research Service, Issue Briefing Number IB74055, January 31, 1975, p. CRS-1.

PART 4

FOREIGN LMFBR PROGRAMS

The United States is not the only Nation in the world with an LMFBR R&D program, and U.S. utility industry decisions on the readiness of LMFBR technology for commercial power generation will not be based solely on the results of the U.S. program. Utility and reactor manufacturer representatives told us that, if there was a success among the foreign programs, the confidence of U.S. utilities in the LMFBR concept should increase and that they might order commercial LMFBRs of U.S. design earlier than would be warranted by developments in the U.S. program alone.

The LMFBR is perhaps the highest priority national energy development program in the United Kingdom, France, Japan, the Federal Republic of Germany (with the Benelux countries), and the Soviet Union. These programs are independent of the U.S. effort and appear likely to continue regardless of what the United States decides to do about its LMFBR program.

Although there are some differences in approach and emphasis, all of the foreign programs either contain or plan to contain many of the same elements that are in the long-range U.S. program. Table 3, page 27, taken from AEC-ERDA documents, lists the LMFBR demonstration and commercial plants throughout the world which are operating, under construction, or planned.

The United Kingdom, France, and the Soviet Union already have demonstration-size breeders in operation; West Germany and Japan have demonstration plants scheduled for operation by 1980.

Why, then, doesn't the United States simply obtain a license to install foreign designed LMFBRs? Part of the answer is that proven commercial LMFBRs do not exist anywhere in the world at this time.1/ Only France has offered to sell commercial LMFBRs. The model marketed is a scaleup version of France's 250-MWe Phenix demonstration plant,2/ a model which France does not plan to use for its own commercial power generation facilities.3/ The first commercial LMFBR in France is planned to be the 1,200-MWe Super-Phenix LMFBR to be constructed and operated jointly with utilities of West Germany and Italy and scheduled for operation in 1981, as shown in table 3, page 27. 4/

Note: Numbered footnote references to part 4 are on p. 31.

Table 3

Worldwide LMFBR Demonstration and

Commercial Plants Operating, Under Construction, or Planned

DEMONSTRATION PLANTS

Country (plant)	MWe	Initial operation
Soviet Union (BN-350)	a/350	1972
France (Phenix)	250	1973
United Kingdom (PFR)	250	1974
West Germany and the Benelux countries (SNR-300)	300	1980
Japan (Monju)	300	1980
United States (CRBR)	350	1983

a/This plant generates steam equivalent to 350 MWe. Its output is used to generate 150 MW of electricity and 200 MW equivalent for desalination of water.

COMMERCIAL PLANTS

Country (plant)	MWe	Operation planning dates
Soviet Union (BN-600)	600	1977
France, West Germany, and Italy (Super-Phenix)	1,200	1981 (in France)
United Kingdom (CFR)	1,300	1981
West Germany, France, and Italy (SNR-2)	2,000	1984 (in West Germany)
United States (NCBR)	1,000 to 1,500	1987

This does not mean, however, that the United States cannot or should not learn from the experience of foreign programs or that it would not ultimately find the purchase of foreign LMFBRs advantageous. As the U.S. program has slipped behind its original schedules and foreign programs have appeared to advance closer to commercialization, questions have been raised on the advisability of using foreign LMFBR technology in addition to or instead of U.S. technology.

Since France may be the furthest advanced in large plant experience, these questions have focused on the use of the French LMFBR in the American commercial power system. Such questions are of value, but they must be addressed with full recognition of the fundamental differences between the French and American programs.

The French program is primarily directed to the goal of showing that a breeder can be built and reliably integrated into a commercial power system.5/ After this goal is accomplished satisfactorily, the French program intends to concentrate on commercial considerations, including the development of better fuels.6/ The French method trades off a slower rate of commercial expansion for a faster proof of operational reliability.

The American program seeks to develop the industrial infrastructure simultaneously with the development of a commercially-reliable LMFBR demonstration plant and the development of better fuels. The American technique sacrifices speed of building demonstration plants for the ability to rapidly exploit the concept once it is successfully proved.

Both the French and the American methods have strengths and weaknesses; but, because of their fundamentally different approaches, the evaluation of their relative successes at any point in time is extraordinarily difficult.

Unless the French program could be redirected to build for the Amercian market, utilities would not know whether the French breeder is licensable. Thus, although the French LMFBR might prove commerically reliable long before the United States LMFBR, the French LMFBR may not be what will be ordered by the U.S. utilities. The utilities must be confident of licensability before they buy a reactor.

There are many examples of successful importation of foreign technology and hardware ranging from large electric transformers to Volkswagens. However, these are imports of proven technology, either as products or as licensed processes. As we have seen, LMFBRs, whether American or foreign, have yet to reach this stage. Because the first nation to develop a commercially-viable LMFBR may gain advantage in a multibillion-dollar international market, competition could inhibit free exchanges of information between the various parties.

Although relationships and arrangements for mutually beneficial exchanges of information and technology at this time should certainly be explored, U.S. expectations of what may be learned from the foreign programs should be realistic. It should be recognized that we know little about how much could be saved, if anything, in either the Clinch River project or the LMFBR program as a whole, by greater interaction with the foreign programs.

As suggested by an AEC LMFBR review group in December 1974, several options are open to the United States.7/

1. Cooperate with foreign countries to the extent of obtaining technological information from their programs.

2. Purchase LMFBR components that have been developed in foreign programs for testing and use in U.S. plants.

3. Negotiate with one or more of the countries planning an intermediate-size LMFBR powerplant for a cooperative program to design and construct such a plant, either in the United States or abroad.

4. Rely on obtaining information from a foreign plant instead of building an intermediate-size plant in the United States and proceed to domestic construction of a full-size plant.

5. Depend entirely on foreign sources for LMFBR technology and powerplants.

The first two options appear to be immediately available. The United States currently has formal or informal cooperative exchanges with all the LMFBR countries and these could be expanded, where appropriate, to include paying for foreign data or for the use of test facilities.8/ As a practical matter, industrial design and construction projects in the United States normally purchase and use foreign components whenever they promise to meet the necessary requirements and can be purchased at reasonable prices.9/ The LMFBR program could do likewise. In fact, the AEC LMFBR review group recommended that:

> "An active program to obtain and make use of foreign data and experience should be pursued and, if suitable LMFBR components are developed in foreign programs, their procurement should be considered."10/

More extensive use of foreign technology would be subject to greater uncertainty. Selecting one of the last three options assumes that a foreign nation would be willing to share proprietary LMFBR technology with the United States, or that it would agree to participate in a joint venture, or that this approach would result in cost savings over the current program. Since NRC has not evaluated any foreign designs, these options would also require an assumption that foreign design can economically be modified to meet U.S. licensing requirements.

Total suspension of the United States LMFBR program and dependence on foreign programs for their still developing breeder technology would have to be based on the assumption that the foreign R&D and demonstration programs will indeed produce, on a timely basis, successful commercial LMFBRs that are licensable in the United States.

Several international trade considerations affect the desirability and feasibility of foreign procurements of powerplant equipment. The Buy American Act (41 U.S.C. 10) and Executive Order No. 10582 require Federal agencies to purchase American-made products unless their costs are unreasonable or their purchase would not serve the public interest. Agency heads may determine what constitutes an unreasonable domestic price; however, the price must generally exceed the delivered cost of the foreign product, including duty, by 6 percent or more to be excessive.

Other considerations relating to the potential for substantial increases in purchases of foreign-made power equipment include the effect on the U.S. balance of payments, the impact on domestic suppliers and manufacturers, and the uncertainties regarding foreign and domestic inflation and currency reevaluations.

At the request of the Chairman, Joint Economic Committee, our Office is taking a more comprehensive look at the status of foreign breeder programs, as well as the feasibility of cooperative development and technology sharing and purchasing. This review is scheduled for completion in the spring of 1976.

FOOTNOTE REFERENCES

1/Thomas A. Nemzek, Director, Division of Reactor Research and Development, ERDA, statement before the Joint Committee on Atomic Energy, ERDA authorization hearings for FY 1976, March 11, 1975, pp. 132-133 of supplemental information submitted for the record.

2/*Ibid*., p. 137.

3/*Ibid*., pp. 135 and 137.

4/*Ibid*., p. 135.

5/F.C. Olds, "Phenix Fast Reactor: Big Boost for the Breeders," *Power Engineering*, September 1974, p. 66.

6/Georges Vendryes, "Phenix: On the path to its objectives," *Nuclear News*, vol. 18, No. 5 (April 1975), pp. 84 and 88.

7/"Report of the Liquid Metal Fast Breeder Reactor Program Review Group," U.S. Energy Research and Development Administration, ERDA-1, January 1975, p. 42.

8/*Ibid*., pp. 43 and 46.

9/*Ibid*., p. 43.

10/*Ibid*., p. 8.

PART 5

NUCLEAR REACTOR ALTERNATIVES

There are other breeder concepts in R&D besides the LMFBR. Of these, the light water breeder reactor (LWBR)* is probably the most advanced, although its breeding capability is expected to be marginal. This reactor might combine the well-developed LWR technology and efficient fuel use by retrofitting LWR cores with LWBR cores. However, the actual breeding as well as the economics of its uranium-thorium fuel cycle and of retrofitting existing LWRs remain to be demonstrated. A technical and economic evaluation of the LWBR is being pursued in an ERDA-owned small reactor plant at Shippingport, Pennsylvania.

The molten salt breeder reactor (MSBR) appears to offer several distinct advantages and disadvantages in comparison to other fission concepts. Use of fluid fuel and online processing would avoid the necessity and problems of solid fuel fabrication and handling and fabrication of spent fuel elements associated with all other reactor types. Deterring factors include a marginal breeding ratio and serious structural materials problems. In addition, MSBR still requires considerable research and development.

Gas-cooled fast breeder reactor (GCFBR) proponents claim that this concept has the potential for a higher breeding ratio than does the LMFBR; however, it is in a relatively early state of development. In December 1974 AEC said that it believed the GCFBR might not be ready for commercial introduction much before the end of this century even if a full-scale, successful R&D program were carried out.

There are nonbreeder concepts as well that offer considerable uranium savings over LWRs, although not as great as LMFBRs. These reactors might extend the time before a breeder is needed in the United States by lengthening the life of the Nation's economically recoverable uranium resources. One such concept is the heavy water reactor (HWR), which was developed and commercially demonstrated in Canada. A second concept is the high temperature gas-cooled reactor (HTGR) being developed in the United States.

Last, there is nuclear fusion which requires no uranium at all. Although sustained controlled nuclear fusion promises an unlimited fuel supply and might provide safety and environmental advantages over fission reactors, it has not yet been

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*It is not yet clear whether this reactor is, in fact, a breeder or whether it is an advanced converter. (See pp. 117 to 119.)

proven scientifically feasible. Until the present uncertainty about the feasibility of its basic processes is resolved, relying on fusion instead of the LMFBR or any alternative energy supply source seems to be a precarious energy course.

When considering the advantages and disadvantages of nuclear alternatives, it should be remembered that only the LWR and HWR have been proven commercially viable, and only the LWR in the United States. Each of the other concepts is either in R&D or involved in demonstration programs. Thus they still face many of the uncertainties associated with the LMFBR. Also, with the exception of the LWR, none has received the scrutinized public review given to the LMFBR. With the possible exception of fusion, alternative reactors would each, in varying degrees, share with the LMFBR problems with respect to safeguards, waste management, and most environmental and safety considerations. (See app. III for details on these and other nuclear alternatives.)

PART 6

URANIUM RESOURCES

As noted earlier, the Nation's current generation of fission reactors, the LWRs, use only about 1 to 2 percent of the potential energy content of natural uranium. The LMFBR could potentially use about 60 percent of the potential energy in uranium and thereby stretch the usefulness of this finite resource from a few decades to centuries. The LMFBR could be, in effect, the next best thing to a renewable resource.

If the Nation continues to plan to use nuclear fission to generate a major share of its electricity far into the future, a breeder reactor, such as the LMFBR, will inevitably be needed. The issue is when. At what point in time will the Nation's supply of economically recoverable uranium become insufficient to meet demand? ERDA says the 1990s. Others say the year 2040 or later. The answer will depend, of course, on our electricity consumption growth rate, the share of that electricity generated by nuclear fission, and how much economically recoverable uranium actually exists, each of which is also subject to a great deal of uncertainty.

Today the cost of generating electricity with existing LWRs is only minimally dependent on the price of uranium. Even a doubling of the average 1974 price of $8 a pound* would increase the cost of producing electricity less than 1 mill per kilowatt-hour, a relatively small amount, compared to the average 1974 electricity costs to all consumers of 23 mills per kilowatt-hour. 1/ However, if the cost of uranium were to rise to $100 a pound or more, the price of uranium would be an important economic factor. Such a price rise would be likely, as we discuss below, if the Nation is forced to rely on its low-grade uranium resources. The cost of generating electricity with LMFBRs, however, is expected to be virtually independent of the price of uranium because LMFBRs will require little, if any, additional uranium after a few years' operation.

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*The price of uranium has gone up recently. The current price depends on many factors, including the amount ordered and the time of delivery. Prices generally range between $20 and $30 a pound of U_3O_8 which is the end product of the uranium mining-milling process.

Note: Numbered footnote references to part 6 are on p. 43.

The United States would need LMFBRs in operation well before depletion of economically recoverable uranium so that the LMFBRs could produce fuel needed to replace the natural uranium. In LMFBR jargon this translates into a number of LMFBRs in operation at least one "doubling time" before depletion. A doubling time is the period required for a breeder reactor to produce enough nuclear fuel to refuel itself, to fuel another reactor consuming fuel at a comparable rate, to compensate for fuel tied up outside reactors in the fuel cycle, and to replace the fuel lost as wastes during processing.

The amount of uranium to be found in the United States is uncertain. Proven reserves of uranium--that is, those in known ore deposits which can, within a stated cost, be recovered with current mining and processing techniques--are not at issue here. Disagreement arises on how the available geological data is interpreted to estimate potential uranium resources. Hence, differing uranium estimates are termed "pessimistic" or "optimistic" rather than right or wrong. It is important to remember that estimated resources become proven reserves only after their presence has been physically verified.

Mining industry officials have told us that many high-grade and low-grade uranium deposits near the earth's surface have been detected during exploration but have not found their way into the statistics because they were not of commercial interest at then-existing market prices. At current and future higher prices, these deposits may be economically recoverable. ERDA officials believe that their uranium estimates reasonably account for most of these deposits.

In addition, exploration of even high-grade deposits near the surface has been limited outside the known producing areas in the western part of the country, although other portions of the United States are believed by some to be promising.

Total U.S. nuclear capacity by the year 2000 is forecast in the range of 625,000 to 1,250,000 MWe. A projection of 1,000,000 MWe, which assumes an electrical growth rate of about 6.2 percent, is being used in ERDA for planning purposes. Plant lifetime uranium requirements for this installed capacity would be about 4 million tons, roughly 2 million tons before the year 2000 and 2 million tons after the year 2000. 2/ Lifetime uranium requirements would be about 2.5 million tons for 625,000 MWe and about 5 million tons for 1,250,000 MWe. ERDA estimates that there are about 3.5 million tons of high-grade domestic uranium resources, including 600,000 tons of reserves. (See table 4, p. 36.)

ERDA's URANIUM RESOURCE ESTIMATES

AEC estimated U.S. resources only in and around uranium producing areas; it did not attempt to estimate uranium deposits in areas where only limited data was available, such as Alaska, the western Great Lakes areas, the western Great Plains, and parts of the Appalachians, even though these areas were thought by some to have had considerable potential for uranium. As discussed on pages 39 and 40, AEC initiated and ERDA is continuing a program to assess uranium resources for the entire United States.

ERDA's estimates are made in two categories of reliability--uranium reserves and potential uranium resources. "Uranium reserves" are defined as ore contained in known deposits and delineated by drilling data. Estimated additional resources or potential resources are listed in three classes. Generally, "probable" potential is in favorable trends in existing mining districts and productive formations; "possible" potential is in productive provinces and productive formations; and "speculative" potential is in new provinces or formations.

A preliminary ERDA estimate of uranium resources for the entire United States, as of July 1975, is given in table 4. The cost categories refer to future expenditures ("forward costs") required to develop, mine, transport, and process the ore to recover the uranium. Other costs, such as return on investment and cost already incurred in property acquisition and exploration, are not included. Therefore, the selling price of uranium will be higher (perhaps 200 percent or more) than the costs shown here, depending also on the demand and supply market.

Table 4

ERDA Estimate of Uranium Resources
in Thousand of Tons of U308 For Various Forward Costs

	$8	$8 to $10	$10 to $15	$15 to $30	Total
Reserves					
Potential:	200	115	105	180	600
Probable	300	160	220	460	1,140
Possible	200	190	250	700	1,340
Speculative	30	80	100	200	410
	730	545	675	1,540	3,490

ERDA also prepares estimates of uranium in low-grade resources ($100 and more a pound) as shown in table 5. These resources generally are considered adequate to satisfy almost any future requirements; however, they generally are not considered practicable sources because they can be recovered only at high costs and with considerable industrial and environmental problems. For example, with uranium content of 60 to 80 parts per million, if used in a LWR, 1 ton of shale contains about the same amount of extractable energy as 1 ton of coal.

Table 5

ERDA Estimate of Low-Grade Uranium Resources

Type. of deposit	Tons U3O8	Parts per million	Forward cost per pound
Shale	5 million	60 to 80	$100
Shale	8 million	25 to 60	150
Granite	8 million	10 to 20	200
Shale	200 million	10 to 25	+200
Granite	1.8 billion	4 to 10	+200
Seawater	4 billion	0.003	+500

Because resources containing uranium between 100 and 800 parts per million have not been identified in the United States, ERDA does not report estimates of intermediate-grade uranium; that is, uranium which falls into the $30 to $100 a pound range.

The International Atomic Energy Agency (IAEA)-Nuclear Energy Agency (NEA) estimate of the world (noncommunist) supply of low-cost uranium is shown in table 6, page 38. It is noteworthy that the United States is estimated to possess 62 percent of $10 potential resources and 37 percent of $10 to $15 potential resources. No world resource estimates have been prepared for forward costs above $15 a pound. IAEA and NEA are preparing world resource estimates for forward costs of $15 to $30 a pound.

Table 6

IAEA-NEA Estimate of World (Noncommunist)Supply of Low-Cost Uranium in Thousands of Tons U308 for Various Forward Costs

Country	$10 Reserves	$10 Potential	$10 to $15 Reserves	$10 to $15 Potential	Total
Australia	210	510	80	40	840
Canada	240	250	160	280	930
France, Niger, and Gabon	130	60	--	50	240
South and Southwest Africa	260	--	80	--	340
Sweden	--	--	350	50	400
United States	340	700	180	300	1,520
Other	60	70	70	100	300
Total	1,240	1,130	920	820	4,570

ERDA will permit utilities to use imported uranium in 1977 to satisfy up to 10 percent of their uranium requirements. The allowable percentage will increase each year until 1984 when 100 percent of a utility's requirement may be imported. It is unclear at this time how much uranium will be available for import because the foreign demand for uranium is very high in relation to foreign supply. The exporting policies of leading uranium exporting nations may further limit the uranium available for import. Canada, for example, will not permit the exporting of uranium until the lifetime uranium requirements for its reactors have been provided for.

OTHER URANIUM STUDIES

Several studies,3/ to 6/in recent years, have suggested that there is more uranium in the United States than ERDA estimated. Summaries of two studies follow.

The National Petroleum Council (NPC), an advisory board established by the Secretary of the Interior, issued a report in December 1972 to the Secretary on the U.S. energy outlook. In it NPC said that about 95 percent of known uranium reserves were located in the western United States and that present producing areas comprised less than 10 percent of the areas in the United States favorable for uranium deposits and even these areas were not completely explored. Because of these large, unexplored regions, NPC concluded that the U.S. uranium resource base is presumed adequate to meet uranium requirements until the breeder becomes the major reactor type ordered in the 1990s. The report did not address whether enough uranium exists to enable delay of the breeder past the 1990s. 3/ As noted earlier, ERDA's NURE program is continuing to assess uranium resources for the entire United States.

The Electric Power Research Institute (EPRI), in November 1974, issued a statistical extrapolation of reported uranium resource data. EPRI estimated remaining uranium resources to a cutoff cost of $100 a pound as of January 1, 1973, and the probability of whether there is more uranium than it estimated. EPRI concluded that its "low" estimate for known producing areas would require the early introduction of the LMFBR or an equivalent alternative and that its "high" estimate for known producing areas would allow continued expansion of LWRs well beyond the turn of the century without the LMFBR but with rising fuel cycle and electrical power costs. 4/ EPRI's estimates are summarized in table 7.

Table 7

EPRI's Estimated Remaining Uranium Resources in Intermediate- and High-Grade Deposits to a Cutoff Cost of $100 per Pound as of Jan. 1, 1973

(Numbers in parentheses are the probabilities that the true quantity is greater than that given)

	Million of tons	
	Low	High
Known producing areas	3.5 (90%)	7.7 (10%)
Total United States	13.2 (50%)	28.9 (5%)

NATIONAL URANIUM RESOURCE EVALUATION PROGRAM

AEC initiated in the spring of 1973 and ERDA is continuing the National Uranium Resource Evaluation Program (NURE) to extend its uranium resource estimates to include an assessment of our total domestic uranium resources. A deadline of January 1976 has been set for a preliminary evaluation report on domestic uranium resources with the final report due January 1980. ERDA has not yet established the total cost of the program but has spent about $7 million in fiscal years 1974 and 1975 and expects to spend about $14 million in fiscal year 1976.

The final NURE report will include new data based on widespread geological, geophysical, and geochemical investigations, and the investigation of economic and production factors affecting exploitation.

ERDA's preliminary estimate as of July 1975 indicates that the United States possesses more extensive uranium resources than previously estimated by AEC. As a result of its preliminary work, ERDA has increased AEC's January 1974 resources estimate of 2.4 million tons to 3.5 million tons, an increase of about 46 percent. ERDA's NURE program will involve extensive geophysical and geologic investigations but is expecting private industry to do most of the exploratory drilling for uranium.

In June 1974 the U.S Geological Survey, Department of the Interior, estimated that to thoroughly appraise the U.S. uranium resource base would probably cost about $523 million and about 5 to 10 years of effort. Virtually all of the cost--$500 million--would be for exploratory drilling and supporting services. Because much of this work would not yield a direct dollar return in a short time, the Geological Survey noted that it probably would have to be done by the Federal Government.

URANIUM DEMAND VERSUS SUPPLY

In its Proposed Final Environmental Statement for the LMFBR, AEC projected the cumulative demand for uranium ore with and without the breeder as presented in table 8. These numbers assume a 1987 introduction date for the breeder, an average annual electrical growth rate of 6.2 percent, and plutonium recycle for LWRs. AEC's estimates approach the historical growth rate for electrical energy and do not reflect the recent slowdown in electrical and nuclear growth.

Table 8

AEC's Projected Cumulative Demand for Uranium

Year	With breeder	Without breeder
	(millions of tons U3O8)	
2000	1.8	2.0
2020	2.45	6.3

This data implies that, without LMFBRs, given ERDA's electricity demand assumptions and ERDA's estimate of uranium resources of about 3.5 million tons, the demand for uranium in the United States would exceed the estimated resources of $8 to $30 a pound uranium sometime betweeen the years 2000 and 2020. On the other hand, EPRI's assumptions for growth in electricity demand and its high estimate of 28.9 million tons (5 percent probability) for total U.S. uranium resources up to $100 a pound suggest the demand for uranium without the LMFBR would not exceed the economically recoverable supply until sometime after the year 2040.

It should be emphasized that all of these numbers are highly speculative and that estimated resources can only be made available if uranium mining and milling production can be expanded fast enough to meet the demand. Estimated resources become proven reserves only after their presence has been verified. Also, demand projections are changeable quantities which are sensitive to the complex and not well understood interaction of such factors as electricity prices, technological changes in how energy is consumed, and the general level of economic activity. The introduction date of the LMFBR is also obviously a factor in uranium demand. AEC estimated that a 4-year delay in LMFBR introduction could cause the cumulative demand for uranium to increase from 2.45 million tons to 3.3 million tons by the year 2020. However, if a new and more efficient enrichment technology--such as laser isotope separation--could be developed, the demand for uranium could be reduced, 7/ possibly by 30 to 40 percent.

The demand for uranium could also be reduced if HTGRs or LWBRs penetrate the market in large numbers. These reactors operate on the uranium-thorium fuel cycle* which requires less uranium than the current LWRs. (See app. III.) ERDA's estimate of the cumulative demand for thorium through the year 2000 represents only a small fraction of its estimate of thorium resources in the United States.

Expanding uranium production to meet rising demand will be a formidable task if increasing reliance on nuclear fission for electricity generation continues. According to ERDA, it may be necessary to drill 3 billion or more feet of holes between now and 1990; the mining and milling capacity may have to be increased three times within 10 years and five times in 15 years; and an investment of about $20 billion to $30 billion between now and 1992 may be needed. This task will be made more difficult by an 8-year leadtime, from exploratory drilling to production.

Because LMFBRs create nuclear fuel out of the 99.3 percent of natural uranium not burnable in the present generation of LWRs, they would be much less sensitive to a reduction in uranium supply. Once operating, LMFBRs would require less than 2 percent as much mining of uranium ore as do LWRs of comparable size. In addition, once in production, LMFBRs could draw replacement uranium from the stockpile of over 250,000 tons of uranium tails presently stored as wastes at uranium enrichment plants.

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*This fuel cycle uses naturally occurring thorium which, when exposed to neutrons in a reactor, breeds uranium-233 that can be processed into nuclear fuel.

Unfortunately, attempts to compare the supply of uranium to the demand yield one general conclusion: both are so sensitive to the assumptions which are chosen that almost any desired result can be achieved. On the demand side, the key assumptions are the demand for electrical power and the proportion of it which will be generated by nuclear plants.

The supply side is sensitive to differing estimates of the Nation's uranium resources based on limited geological data. For example, ERDA stated that, if uranium resources were to double to 7 million tons, enough uranium would exist without breeders to meet lifetime requirements of all conventional reactors built through about the year 2022, assuming a 4.6-percent electrical growth rate. If an electrical growth rate of 6.2 percent were assumed, 7 million tons would be adequate only until the year 2004. 8/

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How much economically recoverable uranium the United States possesses is one of the key issues in determining when the LMFBR would be needed. However, the uranium resources issue cannot be resolved at this time due to data limitations. Therefore, from the standpoint of uranium resources, it is impossible to say whether the urgency reflected in the present LMFBR program is or is not warranted.

Optimistic projections for uranium discoveries coupled with lower projections of growth in electricity demand and nuclear fission would allow the continued expansion of LWRs for sometime into the next century without the LMFBR but with some increase in the cost of electricity. Pessimistic projections for uranium discoveries coupled with higher projections of growth in electricity demand and nuclear fission would require commercial operation of LMFBRs in less than 20 years.

GAO believes that an aggressive, accelerated effort is needed to define the likely availability of economically recoverable U.S. uranium resources. The pace of the LMFBR program should be reassessed as additional resource data come available. Consideration should be given to expediting the work and final report of ERDA's NURE program and to the Geological Survey's alternative approach to thoroughly appraise the U.S. uranium resource base through extensive exploratory drilling by the Federal Government. The Federal Energy Administration told us that it planned to consider policy initiatives and to monitor program activity with regard to Federal uranium drilling.

FOOTNOTE REFERENCES

1/Edison Electric Institute, "Statistical Year Book of the Electric Utility Industry for 1973," November 1974, p. 53; and unpublished data prepared by the Edison Electric Institute's New York Office.

2/Robert D. Nininger, Assistant Director for Raw Materials, ERDA, statement before the Subcommittee on Energy and Environment, Committee on Interior and Insular Affairs, House of Representatives, June 5, 1975, p. 3.

3/"U.S. Energy Outlook: Nuclear Energy Availability," National Petroleum Council, 1972.

4/Electric Power Research Institute, "Uranium Resources to Meet Long-Term Uranium Requirements," EPRI SR-5, Special Report (Palo Alto, California, November 1974).

5/Battelle Pacific Northwest Laboratories, "Assessment of Uranium and Thorium Resources in the U.S. and the Effect of Policy Alternatives" (Richland, Washington, December 1974).

6/Richard E. Graves, "Uranium Resources in the U.S.: An Overview" (Cambridge, Mass., MIT Energy Laboratory, September 27, 1974), Working paper MIT-EL-74-002 WP.

7/"Efforts to Develop Two Nuclear Concepts That Could Greatly Improve This Country's Future Energy Situation," U.S. General Accounting Office, RED-75-356, May 22, 1975.

8/"Report of the Liquid Metal Fast Breeder Reactor Review Group," U.S. Energy Research and Development Administration, ERDA-1, January 1975, pp. 35 and 36.

PART 7

PROGRAM COSTS AND SCHEDULES

In considering the expansion of any energy supply option, it is well to recall that it takes a long time to make things happen in the energy world. Building an oil refinery takes at least 3 years. Locating an offshore oil field and bringing it to production takes 3 to 5 years.1/ Developing other energy sources takes even longer. It takes about 8 to 10 years to plan and build a nuclear plant2/ and about as long to bring a geothermal plant into production after a heat source is found.3/

Energy R&D is inherently ponderous. It takes about 20 years to go from early testing to commercial application and 7 to 10 years from demonstration of the technology to an impact on the energy supply.4/ Over 20 years elapsed from proof of scientific feasibility until operation of the first commercial nuclear fission reactor; and that effort used technology developed in a high-priority defense project for submarine propulsion.5/ In April 1975, over 30 years after proof of scientific feasibility, commercial reactors still supplied only 8 percent of the Nation's domestically generated electricity and about 2 percent of the Nation's total energy.6/

No course of energy development is without technical risk. New technologies must pass through three thresholds--scientific feasibility, technical and industrial feasibility, and economic feasibility--before achieving widespread acceptance. Success in passing one threshold does not guarantee success in succeeding steps. Some of the difficulties remaining after 24 years of moving from the first operational LMFBR in 1951 to a still unattained commercial LMFBR are discussed below. Problems in passing through the thresholds are not unique to reactors. For example, fusion has yet to pass the first threshold; solar energy for central power stations, the second; and solar energy for the direct heating and cooling of buildings, the third.

It is also well to recall that whatever options are chosen to increase energy supply, R&D can be expected to be both costly and to require some degree of Federal funding. In nuclear programs, past Federal funding support has been persistent and crucial. Future support is expected to be much greater in the form of support for the LMFBR, as we have seen, and perhaps as much as $10 billion for fusion R&D.7/ In the case of solar, geothermal, coal gasification,

Note: Numbered footnote references to part 7 are on p. 53 and 54.

coal liquification, and other advanced energy sources, the Federal Government has taken on the responsibility of encouraging and conducting demonstration of economical production systems and components; the demonstration of practical use; and, for geothermal, loan guarantees for publically owned or privately owned development projects.8/

LMFBR R&D AND DEMONSTRATION

As reported in the recent GAO staff studies and reports, cost estimates for the overall program have risen sharply--from $3.9 billion in 1969 to $10.7 billion in 1975 9/--including the capital cost estimates for the program's major components, such as the Fast Flux Test Facility (FFTF)10/ and the CRBR.11/ FFTF and CRBR are discussed in appendix I. Cost increases have been accompanied by slippages in the overall LMFBR schedule. The program milestone date for the first commercial plant has slipped from a 1969 estimate of 1984 to the present estimate of 1987,12/ but it is still optimistic. (See pp. 49 to 52.)

AEC's total LMFBR program funding through fiscal years 1948-74 was about $1.8 billion. The following table summarizes the LMFBR program costs through fiscal year 1974 and ERDA's projections through fiscal year 2020. A detailed chart showing projected program costs for fiscal years 1975 to 2020 is included in our report "The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future."9/

Table 9

Summary of LMFBR Program Costs 13/

	Through FY 1974 (actual)	FY 1975 (FY 1975 dollars)	FY 1975 to 2020 (FY 1975-76 dollars)	Total
	(000,000 omitted)			
Operating:				
Reactor physics	$ 119	$ 11	$ 162	$ 281
Fuels and materials	619	114	1,816	2,435
Fuel recycle	15	6	507	522
Safety	97	36	1,023	1,120
Components	470	88	2,021	2,491
Plant experience	30	56	1,489	1,510
Total	1,350	311	7,018	8,368
Capital equipment	66	23	424	490
Construction	379	147	1,431	1,810
Total	$1,795	$481	$8,873	$10,668

Figure 2, page 47, shows that most of the program costs are expected to be incurred for R&D and operating expenses of test, experimental, examination, and demonstration facilities. Next largest in estimated costs are construction of support facilities activities--including the FFTF; costs for constructing CRBR and NCBR; and, last, capital equipment costs for all parts of the LMFBR program. Looking more closely at the R&D and operating cost estimates, figure 3, page 48, shows that the major portion of these are earmarked for research in the base technology areas (physics, fuels, materials, fuel recycle, and chemistry); engineering development (components and systems); and LMFBR safety.14/

In a 1969 AEC study entitled "Cost-Benefit Analysis of the U.S. Breeder Program," AEC projected for the first time the expected R&D costs for the LMFBR program. The costs through the year 2020 were estimated to be about $3.9 billion in 1968 dollars. Thus, since 1968, the expected costs of the LMFBR program through the year 2020 have increased by about $6.8 billion.13/

According to an ERDA study comparing the two estimates, $3.3 billion of this estimated increase was due to changes in the scope of the program, including increased projections for the FFTF project ($660 million), CRBR project ($670 million), large component development program ($1,120 million), fuel development program ($450 million), safety program ($140 million), and capital equipment and miscellaneous ($220 million).13/

The remaining $3.5 billion of the increased estimate represents the effect of inflation on both the 1969 estimate and the program scope changes which need to be considered in 1976 dollars to express the overall program cost in 1976 dollars.13/

These cost estimates do not include the amounts spent by AEC's regulatory organization or the amounts to be spent by the successor agency--NRC--to meet their licensing and related responsibilities pertaining to the LMFBR program. AEC's regulatory organization spent about $2.2 million in fiscal year 1973 and 1974 and NRC expects to spend $22.7 million during fiscal years 1975-80 on LMFBR related work.13/

Pertinent to the program cost issue is whether the Congress, as discussed in our staff study on the FFTF,10/ wishes to:

FIGURE 2:
LMFBR PROGRAM PROJECTIONS OF CUMULATIVE COSTS THROUGH 2020

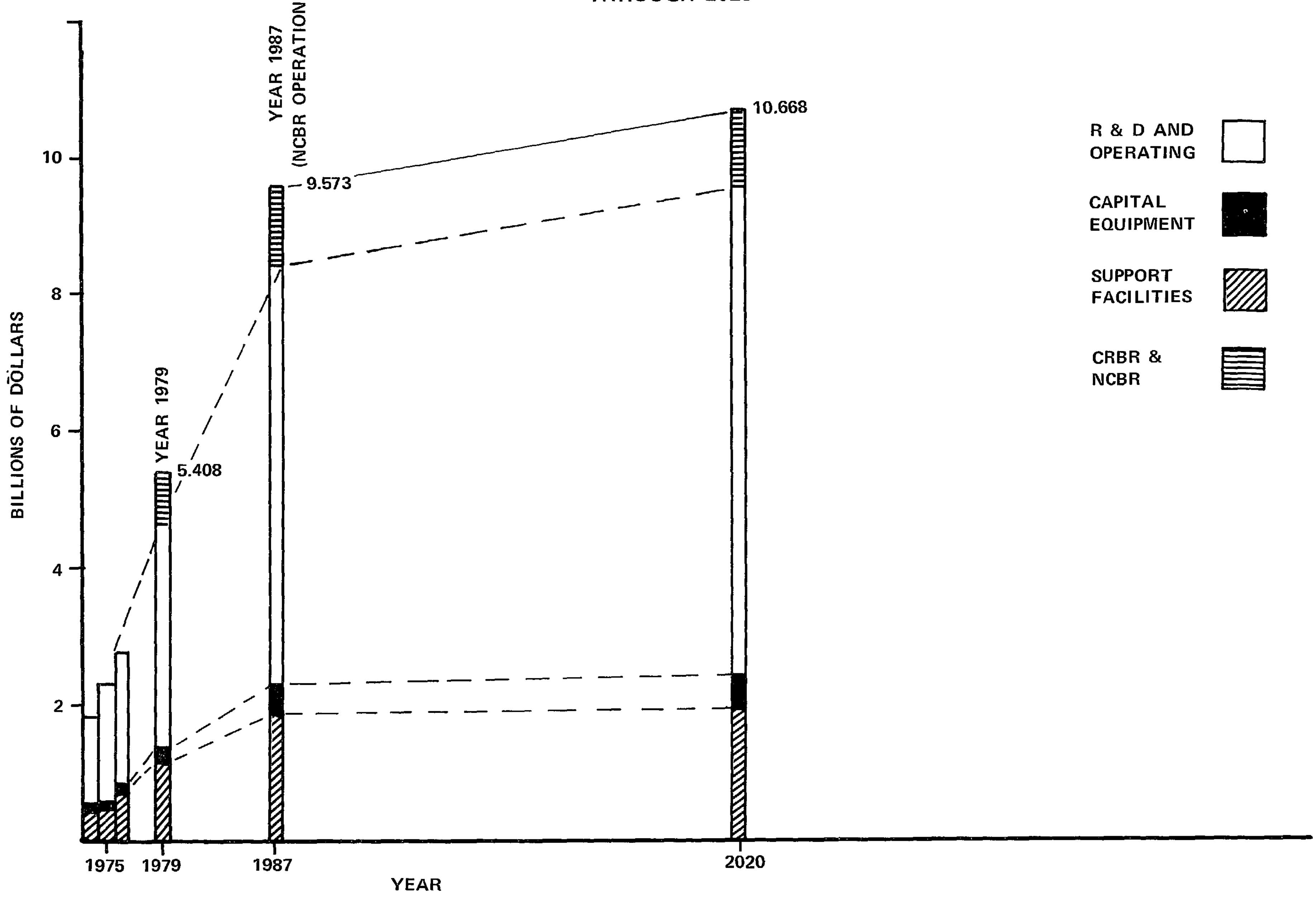
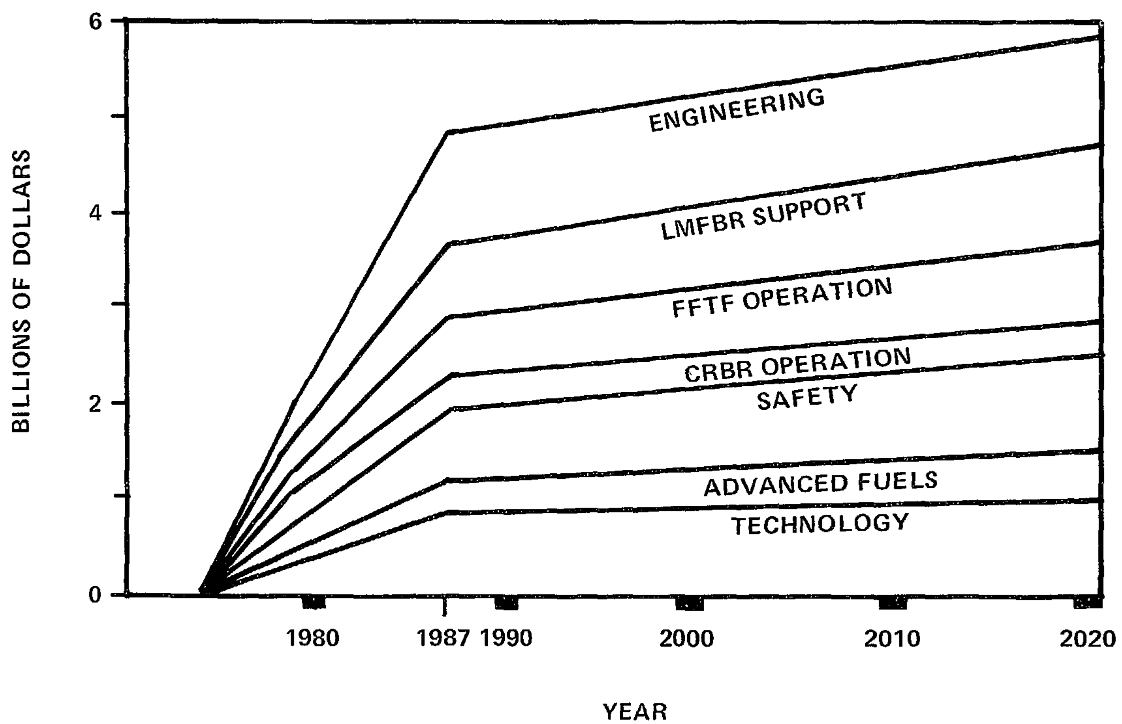


FIGURE 3:
LMFBR CUMULATIVE R&D AND OPERATING COSTS
THROUGH THE YEAR 2020



--Require that cost and schedule estimates be complete as to the inclusion of all major associated project costs and be based upon relatively firm designs.

--Require prompt submission of such data to preclude incurring considerable project costs before enough data is available for informed decisions.

--Require notification of anticipated cost increases and changed, or redefined, critical milestones.

These points are worth equal consideration for other projects within the overall LMFBR program.

Meeting current R&D program costs and schedules will require prompt and successful completion of each of the six major program areas. Five of these--plant experience, fuels and materials, fuel recycle, component development, and reactor physics--are discussed in appendix I. The sixth area--safety--is discussed on pages 65 to 69 and in appendix II.

Potential trouble spots

A number of factors with the potential of adversely affecting current cost and schedule estimates have been identified; most concern the CRBR--delays in the licensing process, timely delivery of long leadtime materials and components, unavailability of craftsmen, major design changes,11/ and a complex and potentially cumbersome management arrangement.15/ With respect to matters other than CRBR, a potentially critical problem is the lack of decision on the acceptability of plutonium recycle (see p. 69), which could affect the program's ability to carry out fuel recycle and fuels and materials testing.

Licensing

One CRBR project objective is to demonstrate that breeder reactor powerplants are licensable. Accordingly, NRC's licensing review is a key factor in the project schedule. Two important project milestones were obtaining a limited work authorization by September 1, 1975, and obtaining a construction permit by August 1, 1976.11/

A limited work authorization allows the applicant to prepare the project site for construction work, whereas NRC completes its review of the construction permit application. Major construction work, however, cannot begin until the permit is issued.

Delays have already occurred in the licensing process.11/ NRC officials told us that neither the limited work authorization milestone nor the construction permit milestone would be met. A delay of at least 10 months--to July or August 1976--is expected in obtaining the limited work authorization which, because it is on the critical path for completion of the CRBR, will delay CRBR operations until mid-1983 at the earliest.

It is also possible for the licensing process to stretch out even further. On the basis of past LWR experience, 5 months have been scheduled for public hearings on the limited work authorization application. Since development of the breeder reactor concept is controversial and organized opposition already exists, the 5 months scheduled by the participants for hearings might not be enough. NRC officials told us that certain events could lengthen the hearing period. First, possible litigation could occur over the acceptability of NRC's guidelines for allowable accidential exposures to plutonium--the breeder's radioactive fuel. Second, the CRBR hearings could be used as a forum for challenging the need for the breeder reactor program and for CRBR. NRC believes that such intervention could extend the hearings considerably.

NRC officials told us also that potential problems in the granting of a construction permit for CRBR might have a major impact on their review schedule, which they cannot presently predict.

Materials and components

According to ERDA and the Project Management Corporation,* there was uncertainty in the timely delivery of long leadtime materials and components. In the spring of 1974, the delivery time for certain materials was 16 to 57 weeks longer than it was only 6 months earlier. There is also a limited number of suppliers for certain CRBR major components.11/

In March 1975 project participants said economic conditions had changed and this was no longer a problem. Delivery times have improved, and the number of available suppliers has increased. This is one area of the CRBR project, however, that is subject to changes in economic conditions. As the project progresses and economic conditions change, there could be problems again. The CRBR schedule, however, has allowed for some slippage in this area.11/

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*A nonprofit organization having overall management and contracting responsibility for the CRBR project.

Craftsmen

A shortage of craftsmen qualified to build the CRBR, particularly welders, could affect the timely completion of the project. The Tennessee Valley Authority (TVA), has experienced difficulty in obtaining enough construction personnel to build an LWR in the CRBR area. In November 1974 TVA informed NRC that there had been a 4-month slippage in completing a nuclear powerplant because of a shortage of qualified steamfitters and welders.11/

During the period 1975-82, construction activity will occur at 14 nuclear powerplant units and a fuel reprocessing plant within a 150-mile radius of the CRBR site. TVA has projected that an additional 700 welders will be needed in the next 4 years for the planned construction.11/

The craftsmen shortage is not a problem unique to the area near the CRBR site. Of the 69 nuclear powerplants under construction as of August 23, 1974, 11 had incurred schedule delays because of the unavailability of craftsmen.11/

The potential problem of getting craftsmen was recognized by project participants when developing the preliminary cost estimate, and estimates for training programs have been included in it.11/

Design

Several CRBR design features are conceptual and several design decisions still are to be made.11/ Also NRC has to be convinced by the project participants on one major safety issue--whether the plant should be designed to accommodate a core disruptive accident. This issue must be resolved before NRC issues a construction permit. (See pp. 65 to 69.)

The schedule for completing engineering design and procurement contains a small allowance for changes as a result of the licensing review process. According to ERDA, this allowance might not be enough because of the highly developmental nature of the plant and because of possible differing opinions on incorporating certain design features.11/

Management

The present organizational arrangement for the CRBR is complex and potentially cumbersome; it is managed by a committee drawn from ERDA, TVA, and the Commonwealth Edison Company, with the Project Management Corporation directing operations. Although we found no evidence of problems thus far resulting directly from organization complexity, we recently reported that the existing arrangement was not conducive to efficient conduct of the CRBR project.15/

Because of this and the large increase in the financial contribution needed from the Government, ERDA has proposed changes in the CRBR arrangement which would enable ERDA, instead of the Project Management Corporation, to direct and manage the project with a single, integrated Government-utility staffed organization. The requested changes are contained in the pending fiscal year 1976 authorization legislation for ERDA.

On April 4, 1975, we reported to the Joint Committee on Atomic Energy that the proposed changes would allow the utility participants to terminate their role and financial contributions if they disagreed with major changes in the currently approved reference design of the CRBR. In the same report, we noted that there are very strong indications that the utility participants might be strongly enough opposed to some safety design changes being contemplated by NRC to begin termination proceedings. ERDA could continue with the project without the utilities, but, if ERDA did not, the viability of the LMFBR concept would not be demonstrated in this country.16/

LMFBR COMMERCIALIZATION

As discussed on pages 18 and 19, two important unresolved issues are: What is the role of the Federal Government in the commercial application of the LMFBR technology if the R&D and demonstration efforts succeed? When will Federal funding and other support (direct and indirect subsidies) of LMFBR plants terminate? Obviously, their resolution will have an impact on program costs and schedules.

Plutonium recycle is also critical and the issue must be resolved if the commercial success of the LMFBR is to be achieved. (See p. 69.)

We are continuing to examine into what would be involved in going from the LMFBR R&D program to commercializing the LMFBR. That work will identify and assess key technical, cost, and schedule matters pertinent to commercialization and proliferation of LMFBRs.

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3/Peter G. Miller, "Is There Steam in Our Future?", The Washington Post (Sunday, January 12, 1975), p. B2.

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7/James E. Connor, Director of the Office of Planning and Analysis, U.S. Atomic Energy Commission, quoted in National Journal Reports, Vol. 5, No. 41 (October 13, 1973), p. 1536.

8/"Geothermal Energy Research, Development, and Demonstration Act of 1974," Public Law 93-410, September 3, 1974.

"Solar Heating and Cooling Demonstration Act of 1974," Public Law 93-409, September 3, 1974.

"Energy Reorganization Act of 1974," Public Law 93-438, October 11, 1974.

9/"The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future," U.S. General Accounting Office, RED-75-352, April 28, 1975.

10/"Fast Flux Test Facility Program," U.S. General Accounting Office, January 1975.

11/"Costs and Schedule Estimates For The Nation's First Liquid Metal Fast Breeder Reactor Demonstration Power Plant," U.S. General Accounting Office, RED-75-358, May 22, 1975, pp. 26 to 32.

12/"The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future," p. 3.

13/*Ibid.*, p. 10.

14/*Ibid.*, p.45.

15/*Ibid.*, pp. 31 and 32.

16/"Comments on Energy Research and Development Administration's Proposed Arrangement for the Clinch River Breeder Reactor Demonstration Plant Project," U.S. General Accounting Office, RED-75-361, April 4, 1975, pp. 8 and and 9.

PART 8

ECONOMIC PROMISE OF THE LMFBR

The economic promise of the LMFBR is that it would supply the United States with electricity at an economical cost sometime in the future when generating plants powered by fossil fuels, other nuclear fission reactors, and unconventional sources--such as solar, geothermal, and organic waste--may not be sufficient to meet the full demand for electricity.

In terms of American consumers, this promise could mean energy when they need it and at a price they can afford.

LMFBR COST-BENEFIT ANALYSES

The United States LMFBR program has undergone several cost-benefit analyses. Although they provide some insight into economic prospects, cost-benefit analyses tend to emphasize issues which lend themselves to dollar costs and dollar benefits and do not adequately consider qualitative issues--social, political, and ethical--which do not. For example, the LMFBR is an energy alternative which would help free the United States from reliance on insecure energy sources abroad. But what dollar figure should be affixed to the resulting qualitative benefits--e.g., a more independent foreign policy? Similarly, what dollar figure should be assigned to the risk to society of nuclear material being stolen from somewhere in the LMFBR fuel cycle by terrorists or criminals?

The most comprehensive of the LMFBR cost-benefit analyses and the one which has attracted the most public debate is AEC's, which was part of its Proposed Final Environmental Statement for the LMFBR, released for public comment in January 1975. AEC estimated the costs of meeting a prescribed demand for electricity through the year 2020 with and without the LMFBR under varying assumptions. AEC's base case projected gross LMFBR benefits to the United States of $19 billion* through the year 2020 discounted at 10 percent to 1974. Gross future costs, discounted to 1974, were estimated to be $4.7 billion.

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*An ERDA update of the AEC cost-benefit analysis in the Proposed Final Environmental Statement is in progress and preliminary results were published on May 20, 1975, in "The LMFBR-Its Need & Timing" (ERDA-38). These results indicate base case benefits of $28 billion through 2025 discounted at 10 percent to 1975.

Note: Numbered footnote references to part 8 are on p. 62.

Projected benefits for the LMFBR are sensitive to the availability and price of uranium ore, future demand for electricity, the choice of a discount rate, and capital costs of the LMFBR. The effect of these key variables are considered here.

Savings in uranium ore costs account for 86 percent of AEC's projected $19 billion base-case benefits. Projections used were based on an AEC 1974 estimate of U.S. uranium resources of 3 million tons at forward costs up to $30 a pound. AEC estimated that benefits would vary widely--$30 billion to $12 billion--if ore availability varied from 1.5 million tons to 4.3 million tons, respectively. ERDA now estimates these resources at 3.5 million tons.

In the base case AEC assumed that the demand for electricity would grow 7.8 percent a year during 1974-80. After 1980 the rate of growth was assumed to decline linearly until it reached a rate of 3.7 percent in the year 2020. This represented an average annual growth rate of 6.2 percent over the period 1974-2020. For a higher rate of 6.7 percent, AEC estimated benefits of $26 billion; a lower electrical growth rate of 4.6 percent yields benefits of $5.6 billion.

AEC used several different discount rates* in its analysis. A 10-percent discount rate was used to arrive at AEC's $19 billion base-case benefits. Benefits would be $54 billion at a discount rate of 7.5 percent. At a rate of about 12 percent, program benefits would be about $4.7 billion and would equal gross discounted future costs.

There has been much debate regarding the choice of an appropriate discount rate. The Natural Resources Defense

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*Costs incurred over the life of project alternatives cannot be merely summed in an arithmetic fashion and compared. The time value of money for future expenditures must be considered. For example, a $10,000 expenditure made 12 years from now is not equivalent to a $10,000 expenditure made today or even 5 years from now. All costs must therefore be compared by restating them to the same point in time or their present value. Discounting is the technique most frequently used.

Council, which opposes continued high-priority development of the LMFBR, suggests that the rate should possibly be as high as 15 to 20 percent (before taxes) to show the return from other investments the breeder might replace. On the other hand, a March 1975 LMFBR cost-benefit analysis done by General Electric, Commonwealth Edison Company, and Mr. T. R. Stauffer of Harvard University indicated that a rate of 6 percent or less (after taxes) should be used. (See p. 59.) In previous analyses AEC used 7.5 percent since this rate corresponded to the average rate of return on utility company bonds and stocks, but AEC used 10 percent in the base case of the study discussed here, as suggested by EPA and the Office of Management and Budget (OMB). OMB Circular No. A-94, Revised, states that 10 percent represents an estimate of the average rate of return on private investment, before taxes and without recognition of inflation.

AEC's treatment of the capital cost differential between LMFBRs and LWRs has been criticized. 1/ The base case assumes that LMFBRs will be introduced in 1987 with capital costs of $100 a kilowatt greater than those of LWRs and that this differential decreases linearly until LMFBR costs attain parity with LWR costs in the year 2000. This treatment of capital costs assumes that LMFBR costs will decrease relative to LWR costs as more LMFBRs are built. As applied in AEC's cost-benefit analysis, this assumption favors the LMFBR in that it presupposes an effect for the LMFBR that critics believe has not been demonstrated to exist for the LWR program, the only reactor program which has enough data for comparison. If the effect is not allowed for the LMFBR, base-case benefits would be reduced to $12.6 billion. ERDA maintains that, because most of an LMFBR plant is expected to be similar to a LWR plant, a relative cost-reduction effect can be demonstrated.

Figure 4, page 58, shows the synergistic effects--that is, the impact of changing two or more variables simultaneously--of different assumptions about key LMFBR variables. This figure shows that there are combinations of plausible assumptions which would result in gross discounted benefits that fall below gross discounted future costs of $4.7 billion.

FIGURE 4:
SYNERGISTIC EFFECTS OF ASSUMPTIONS ABOUT KEY LMFBR VARIABLES

	CAPITAL COST AFTER YEAR 2000	DEMAND FOR ELECTRICITY	GROSS BENEFITS* (BILLIONS 74 DOLLARS)
OPTIMISTIC (4.3 MILLION TONS UP TO $30/LB.)	$100/kW HIGHER	LOWER (AVERAGE ANNUAL GROWTH RATE OF 4.6%)	0.4
		BASE (AVERAGE ANNUAL GROWTH RATE OF 6.2%)	4.8
	BASE	LOWER	3.9
		BASE	12.0
BASE CASE (3.0 MILLION TONS UP TO $30/LB.)	$100/kW HIGHER	LOWER	0.9
		BASE	12.6
	BASE	LOWER	5.6
		BASE	19.4

*GROSS DISCOUNTED FUTURE COSTS ARE ESTIMATED TO BE $4.7 BILLION.

Note, for example, that the combination of optimistic uranium supply estimates plus $100 a kilowatt higher LMFBR capital costs would not be expected to yield benefits which exceed estimated program costs, except under the higher electrical growth rate of 6.2 percent. In addition, note that the LMFBR benefits would not be expected to exceed program costs under an electrical growth rate of 4.6 percent, except in the second case from the bottom where base case uranium supply estimates, and optimistic capital costs reductions are assumed.

On the other hand, different assumptions could result in benefits much greater than the $19 billion in AEC's base case. For example, ERDA officials told us that using a uranium supply estimate of 1.5 million tons, a discount rate of 7.5 percent, and the rest of AEC's base case assumptions results in benefits of $78 billion.

The March 1975 LMFBR cost-benefit analysis made by General Electric, Commonwealth Edison, and T. R. Stauffer of Harvard University shows gross LMFBR benefits of about $76 billion discounted at 6 percent to 1974 dollars. The major difference between the AEC study and the General Electric-Commonwealth Edison study is the choice of a discount rate. The 6-percent discount rate chosen in the latter study is based on the concept of a social rate of time preference, a different approach to discounting from that used by AEC. The social time preference rate attempts to measure the price a society puts on deferring immediate consumption. It expresses a concern for future generations and thereby assumes a collective willingness to transfer more income from current to future generations than is implied by the 10-percent rate.

Use of the lower discount rate would always predict higher benefits for the program. As pointed out on page 56, the AEC found that lowering the discount rate from 10 to 7.5 percent would roughly triple its projected base-case benefits from $19 billion to $54 billion (both in 1974 dollars).

LMFBR CAPITAL COSTS

The LMFBR's capital costs have been the subject of considerable controversy. These costs could be higher than those for LWRs, and the total investment for the two types of plants could still be competitive. 2/ This is because LMFBR fuel cycle costs are expected to be lower than LWR fuel cycle costs. The question is: Can the differential between LMFBR and LWR capital costs be kept sufficiently small for the LMFBR to be economical?

Unfortunately, it is still too early in the LMFBR R&D program to state just what the difference in capital costs between the two types of reactors would have to be. Several important factors--for example, the cost of LMFBR fuel reprocessing--have not yet been identified. Estimates of how much LMFBR-LWR capital costs could differ, while remaining competitive, range from $60* a kilowatt to $300* a kilowatt in 1976 dollars. 3/ to 6/ The LMFBR experience in the United States over the next few years is not expected to provide firm answers to the capital cost issue.

CRBR's capital costs will be over $3,000 per kilowatt of capacity--about five times the expected $600 per kilowatt price of commercial LWR plants--but CRBR is a first-of-a-kind demonstration plant and to compare it with a commercial powerplant is misleading. ERDA estimates the capital costs for the NCBR--not including research and development costs--could be as high as $1,000 per kilowatt of capacity. This, too, is not an accurate guide to eventual LMFBR capital costs because it is possible that, on the basis of the experience gained from CRBR and NCBR, those costs could be reduced to a level where the fuel cycle cost advantage expected from the LMFBR would make its electricity competitive with electricity from the LWR.

Whether this will, in fact, happen is uncertain. Proponents and opponents disagree. For example, a recent report by Resources for the Future, Inc., a nonprofit research group, states that:

> "* * * the best present projections of the capital-cost differential between light-water and breeder reactors are so unfavorable to the breeder that even pessimistic uranium price assumptions would not make the breeder the cheaper technology." 7/

On the other hand, ERDA and the manufacturing industry believe that the cost-differential gap can be made small enough. 8/

It is certain that the LMFBR cannot fulfill its economic promise as long as the LWR produces electricity at a more economical cost. Ultimately, the future price of uranium *and* the LMFBR's future capital costs will determine the LMFBR's competitiveness compared to the LWR's.

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*Escalated at 10 percent from 1974 dollars.

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The studies reviewed here lead to the realization that determining the future economic feasibility of LMFBRs is fraught with uncertainty. As we have seen, the LMFBR's economic feasibility turns on several assumptions about future electrical demand, uranium supply, discount rates, and capital costs. These assumptions can be changed to come up with plausible but widely different answers to the same crucial question: Will the current LMFBR program result in an economically viable energy alternative for the Nation?

FOOTNOTE REFERENCES

1/Thomas B. Cochran, "The Liquid Metal Fast Breeder Reactor: An Environmental and Economic Critique" (Washington, D.C., Resources for the Future, Inc., 1974), p. 40.

2/"The Liquid Metal Fast Breeder Reactor--Past, Present, and Future," U.S. General Accounting Office, RED-75-352, April 28, 1975, p. 24.

3/Irvin C. Bupp and Jean-Claude Derian, "The Breeder Reactor in the U.S.: A New Economic Analysis," Technology Review, July/August 1974, pp. 26-34.

4/R.S. Palmer and K.M. Horst, "Cost Targets for Commercial Breeder Reactor," Public Utilities Fortnightly, July 18, 1974, pp. 17-23.

5/"Westinghouse Recommendations for a National Plan for Commercial Introduction of the Breeder Reactor in the late 1980s," June 30, 1974, Westinghouse submission to the U.S. Atomic Energy Commission's LMFBR "Commercialization Study," p. 18.

6/"Commercialization of the LMFBR," July 1, 1974, General Electric Company submission to the U.S. Atomic Energy Commission's LMFBR "Commercialization Study," p. 9.

7/"A Matter of Breeding," Resources, Some Highlights of 1974 (Washington, D.C., Resources For The Future, Inc., 1975), p. 9.

8/"Westinghouse Recommendations for a National Plan for Commercial Introduction of the Breeder Reactor in the Late 1980."

"Commercialization of the LMFBR."

"Proposed Final Environmental Statement Liquid Metal Fast Breeder Reactor Program," vol. IV, U.S. Atomic Energy Commission, WASH-1535, December, 1974, pp. 11.2-88 to 11.2-93.

PART 9

LMFBR ENVIRONMENTAL AND SAFETY ISSUES

The LMFBR has been heralded by its promoters as a clean, environmentally sound, and safe energy alternative for the future. Like all nuclear power, it avoids the byproducts from fossil-fired powerplants.

In normal operations, the LMFBR releases somewhat less thermal pollution at the reactor site and requires much less uranium mining to meet fuel requirements than the current LWRs. Radiation releases during normal operations should not be a major issue in the LMFBR debate.

There are, however, environmental and safety uncertainties regarding the LMFBR that remain to be resolved. These include hypothetical core disruptive accidents which may lead to an event termed "recriticality,"* plutonium recycle, safeguarding nuclear materials, and management of radioactive waste. Only the recriticality issue is unique to the LMFBR and other fast reactors. The other issues are common to nuclear fission power in general, but their resolution is critical because the LMFBR would exacerbate the problems.

In its April 1975 comments to ERDA on the Proposed Final Environmental Statement for the LMFBR, EPA said that program development through CRBR could probably be conducted without any unacceptable environmental impact but that there was uncertainty surrounding the safety aspects of CRBR since there was a lack of detailed design information. EPA expected that some of this information would be developed during the necessary planning and design work and could be evaluated when the specific environmental statement and other documents are issued by NRC in conjunction with CRBR licensing. EPA concluded that the planned approach to use

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*The reassembly of the molten fuel during a core disruptive accident into a mass capable of releasing potentially large amounts of energy.

Note: Numbered footnote references to part 9 are on pp. 81 to 84.

conservative design and siting practices to minimize safety risks could probably provide an adequate basic level of safety at CRBR.

With respect to the commercialization aspects of the LMFBR, EPA said that its review indicated that current information was inadequate to predict the ultimate environmental impacts with any certainty but that much of the information needed to make such predictions would come from ongoing and planned R&D.

We did not find any information which might contradict the substance of EPA's conclusions. However, successful commercialization of the LMFBR would undoubtedly increase the rate of expansion in the number of nuclear powerplants and lead to the presence in industry and in interstate commerce of increasing quantities of dangerous nuclear materials, including strontium-90, cesium-137, and plutonium-239

It is generally recognized that the radioactivity produced by these materials can damage or destroy living cells, causing cancer or death, depending on the quantity and length of time involved. If ingested, most of the cesium will be excreted within a few months; however, strontium deposits itself in bone cells where it will continue to emit radiation to surrounding tissue for a number of years. Plutonium, although relatively easy to shield against, is also extremely dangerous in small quantities if inhaled or absorbed into the body.

These radioactive materials cannot be neutralized. It will take hundreds of years before they dacay to innocuous levels of radioactivity. For plutonium-239, it takes hundreds of thousands of years.

These radioactive materials can reach man by several means if released to the environment. Water supplies can be contaminated by accidental leaks of this material which can percolate through the soil to the water table. Vegetation may be contaminated directly by using contaminated irrigation water or indirectly through contaminated soil. Man can receive this contamination by eating the plants, eating animals that have eaten the plants, or using products (milk, cheese, etc.) from such animals. Radioactive materials can also be inhaled or absorbed into the body through open wounds or sores.

Because of these hazards, it is important that radioactive nuclear materials be permanently isolated from the general environment. Additionally, some nuclear materials have the potential of being the energy source for a nuclear explosive device--whether a carefully designed weapon or a crude, homemade bomb. In the case of the LMFBR, the potential bomb material would be plutonium.

With the increased amount and movement of nuclear materials in industry, the possibility increases that some group--whether terrorists, criminals, or agents of foreign countries--may attempt to get such materials by theft or armed robbery. While recognizing this possibility, NRC and ERDA believe that beyond a threshold quantity consistent with a moderate nuclear industry, the rate of attempts could more likely be dependent mainly on the prevalence of anti-social behavior rather than the quantity of nuclear material in the fuel cycle.

As could be expected, nuclear proponents and critics have suggested different approaches for resolving nuclear environmental and safety issues. The proponents have suggested that they should be studied and resolved as nuclear power continues to grow, as has been done in the past with this and other new technologies. 1/ The critics point to the possibility that these problems may never be resolved and suggest a more cautious approach, that is, slow or completely halt nuclear power's expansion until more is learned about controlling them. 2/

CORE DISRUPTIVE ACCIDENTS

A major safety objective in the design of all nuclear reactors is keeping the fuel intact within the reactor vessel that surrounds it. If the reactor core becomes disrupted because the nuclear fuel overheats, melts, and ejects the coolant from the center of the reactor, and the protective barriers surrounding the reactor also fail, potentially large amounts of radioactivity could be released to the environment. Although the potential for a catastrophic accident is a risk common to all reactors, the theoretical possibility of recriticality, leading to an explosion and an additional disruption of the reactor core is unique to the LMFBR and other fast reactors. Such an explosion would not be comparable to a nuclear bomb explosion, although the release of large amounts of radioactivity into the environment could result.

Great care is taken in designing, constructing, and operating nuclear powerplants to protect against a serious malfunction and to ensure that, if there is a malfunction, radioactivity is not released.

The safety record of LWRs to date has been excellent in that there has been no major release of radioactivity. 3/

Nevertheless, it is impossible to guarantee that a catastrophic accident will never occur. Although scientists and engineers might, in time, reduce the probability of an accident to the smallest possible value, some risk will always remain.

A highly improbable, but conceivable, LWR accident could lead to the following consequences: 4/, 5/

--Hundreds to thousands of deaths from acute exposure to radiation and from resultant cancers.

--Thousands to hundreds of thousands of cases of non-fatal cancer.

--Hundreds to thousands of genetic defects.

--Contamination of hundreds of acres of land.

No such analysis has been made for breeder reactors, including the LMFBR.

About $97 million has been spent to date on LMFBR safety R&D. ERDA estimates that it will spend over $1.3 billion in the LMFBR safety R&D program operating and construction costs from fiscal year 1975 through fiscal year 2020. 6/ (Discussed in app. II are the safety programs, as well as ERDA's work regarding LMFBR sodium accidents; the LMFBR emergency shutdown system; and LMFBR accident initiators.) The aim of ERDA's LMFBR safety program is to develop enough technology to prove that LMFBRs do not represent an undue hazard to the health and safety of the public.

Fuel melting is of particular concern in LMFBRs because of the theoretical potential for recriticality. Nuclear fuel in LMFBRs would be more highly enriched with fissionable material than the fuel used in LWRs; only about 3 percent of the material in LWR fuel is fissionable, 7/ whereas about 12 to 15 percent of the material in LMFBR fuel would be fissionable. 8/ Furthermore, LWRs are at or near their most reactive configuration during normal operating conditions. Theoretically, molten LMFBR fuel could reorganize itself into a more reactive configuration during a core disruptive accident and result in additional structural failures of the reactor system containing the nuclear fuel.

The so-called hypothetical core disruptive accidents (HCDAs) in LMFBRs do not necessarily pose a threat to the public safety. The postulated spectrum of core disruptive accidents ranges from relatively mild accidents involving the distortion of the inside of the reactor; to the melting, perking, or boiling of the nuclear fuel causing very low energy releases; to serious accidents involving violent energy releases. 9/ Although there are great uncertainties surrounding HCDAs, the probability of a serious core disruptive accident is generally considered to be low by nuclear experts. As the LMFBR plants become larger, so could some of the potential consequences of such an accident. A point could be reached where design options to maintain safety margins are not economically feasible. Failure to resolve the HCDA question in a satisfactory manner might limit the size of commercial plants.

A major LMFBR design safety issue is whether a HCDA should be included as a Design Basis Accident* in LMFBRs. On the basis of the current state of technology and experience, NRC safety experts told us that such an accident, although unlikely, was within the realm of possibility and should be provided for in the design of the first LMFBR demonstration plant on the Clinch River in Tennessee until a better understanding of the HCDA phenomenon is achieved.

ERDA and the reactor manufacturers, however, believe that safety design is best provided by emphasis on accident prevention systems. They believe that adequately designed accident prevention systems would make the probability of an HCDA of a magnitude which could lead to uncontrolled amounts of radioactive debris so low that they need not be included as a Design Basis Accident. They have expressed confidence that ongoing R&D efforts will adequately support this contention. If they are unable to provide this support, safety features, such as a core catcher** and/or additional containment against release of radioactive material, may be required in the CRBR. ERDA is also confident that ongoing R&D efforts will prove that extra safety features are not needed in the reactor. However, in the event that ongoing R&D should fail to show that a core catcher and/or the additional containment are not needed, ERDA recently started work on an alternative CRBR design which includes both.

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*Design Basis Accidents are hypothetical accidents selected as a basis for the design. They require incorporation in the plant of features and equipment to protect public health and safety should such events occur, however unlikely.

**A device located within or below the vessel surrounding the nuclear fuel. In the event of a core disruptive accident, the core catcher would spread out and cool the radioactive debris to prevent it from reforming into a mass capable of sustaining a nuclear reaction.

Industry spokesmen told us that a requirement for a core catcher, estimated to cost between $20 million and $60 million, 10/ would make LMFBRs less commercially attractive to the utilities. For example, in addition to the added costs, there is concern that inclusion of core catchers in the reactors would be viewed as an admission that LMFBRs are inherently unsafe and as such would discourage utilities from buying and operating them. Others have said that the inclusion of a core catcher in the CRBR would not necessarily be a commitment to the need for core catchers in all future LMFBRs.

Some LMFBR proponents believe there is no feasible way of proving the reliability of a core catcher. If a core disruptive accident with a magnitude and characteristics capable of severely damaging the primary reactor system's integrity must be provided for in the design of LMFBRs, some proponents of the program told us they feared that it would be difficult to prove that extra safety devices, such as a core catcher, would provide sufficient assurance that such accidents would be harmless.

Critics of the LMFBR program have said that they believe severe core disruptive accidents are low-probability events but the probability has not been and probably cannot be demonstrated to be sufficiently low. Therefore, they believe that construction of the first LMFBR demonstration plant and introduction of a commercial LMFBR should be delayed until more is known about HCDAs and until the upper limits of their potential destructive force are defined.

Two HCDA-related questions being studied are: What will be the characteristics of a fuel melt? After melting and motion of the fuel, can recriticality occur and, even if it does, would it impose an acceptable risk?

ERDA has a number of R&D efforts underway to examine the movement of molten fuel under accident conditions. Approximately $15 million has been budgeted for this effort during fiscal year 1975, 11/ and ERDA is giving resolution of the recriticality problem a high priority. About $2 million has been budgeted for this effort during fiscal year 1975. 11/ ERDA is currently planning to build a large $230 million Safety Research Experiment Facility 6/ and plans to devote part of this facility to making tests to determine the potential for recriticality and associated energy releases. Also in the early discussion stage is the possibility of building a test reactor located on a remote site specifically designed to make tests involving core disruptive accidents, including recriticality.

It is possible that the probability of a core disruptive accident will not be quantified before the first LMFBR demonstration plant goes into operation. ERDA believes that the LMFBR emergency shutdown system and the current safety margins being designed for the plant make it unnecessary to provide for HCDAs in the design basis of the first demonstration plant. Nevertheless, even if core disruptive accidents are not provided for in the initial LMFBR plants, it must be demonstrated to NRC, before large commercial plants can be built, that the probability of such accidents is sufficiently low that they become unimportant or that such accidents do not have serious public consequences.

Ultimately, if the LMFBR program continues, NRC will decide whether each LMFBR is safe enough to be licensed for commercial operations, as it does with each nuclear power-plant.

PLUTONIUM RECYCLE

The commercial success of the breeder depends on an efficient fuel cycle whereby fuel burned in the reactor can be reprocessed to recover the newly bred material (plutonium), as well as the remains of the spent material. This process of fuel recycle requires shipping the spent usable fuel, reprocessing it to recover any reusable material, and refabricating the recovered material into new LMFBR fuel. The efficiency of these processes will have a strong effect on fuel doubling time and hence economics of LMFBR. According to ERDA, the LMFBR will not be viable without the recycling of plutonium.

NRC is presently considering the question of allowing the recycling of plutonium in LWRs. In considering this question, NRC is studying the issues surrounding the safety, environmental, and safeguard impacts of using plutonium.

In August 1974 the AEC regulatory organization issued a draft entitled "Generic Environmental Statement Mixed Oxide Fuel (Recycle Plutonium in Light Water-Cooled Reactors)" (GESMO). In May 1975 NRC decided not to take a final position on the acceptability of plutonium recycle in LWRs until ERDA and NRC complete a number of safeguard studies and the public was given time to comment on them. A NRC official told us that another draft environmental statement may be issued and that, depending on the length of public hearings, a final decision might take 2 to 3 years. A decision not to approve plutonium recycle for LWRs for health, safety, or safeguard reasons would almost certainly preclude recycling of plutonium for the LMFBR since the health, safety, and safeguard impacts of using plutonium are essentially the same for both.

SAFEGUARDING NUCLEAR MATERIALS

U.S. domestic safeguard measures are designed to prevent, detect, and respond to theft and diversion of major quantities of nuclear materials and to the sabotage of nuclear facilities.

A special safeguard study 12/ for the AEC Director of Licensing stated that the potential harm to the public from the explosion of an illegally made nuclear bomb was greater than that from any plausible powerplant accident and that, because of the widespread availability of information for making a nuclear weapon, obtaining plutonium remains the only substantial problem facing groups desiring to have such weapons. According to the study, the seriousness of the problem demands a clear commitment by the Federal Government to bring the risk to the public from safeguard problems down to the level of public risk associated with the operation of nuclear powerplants. The matter of safeguards is now under study in ERDA and NRC.

Under conceivable circumstances a few persons, perhaps one person working alone, who possessed about 20 pounds of plutonium and a substantial amount of high explosives could build a crude fission bomb which could explode with a force of at least 100 tons of TNT and which could be carried in an automobile. 13/ To obtain 20 pounds of plutonium would require the theft of 50 to 300 pounds of LMFBR fuel materials. 14/ If the theft were attempted during transport--now thought to be the most vulnerable link of the reactor fuel cycle--shipping containers could add from several hundred to several thousand pounds to the weight of material to be stolen. 15/

Plutonium need not be made into a bomb to pose a threat to human life. It has been argued that a quantity of plutonium placed in the air circulation system of a building, for example, could be hazardous. 16/ (See pp. 64 and 65.) Another potential problem might arise when relatively large quantities of plutonium are in circulation at different locations around the country and it becomes difficult to verify whether a blackmailer who claims to possess some is, in fact, telling the truth or not. A person could learn the fundamentals of making a nuclear weapon in public library books, including the "Encyclopedia Americana". If this person repeated this information convincingly when the blackmail threat was made and claimed to have enough plutonium for a bomb, society would have a dilemma, even though no plutonium may actually be in his possession. 17/

Safeguard measures have not been adequate in all cases to either prevent or quickly detect a diversion attempt. In a November 1973 report, 18/ GAO recommended that AEC strengthen the physical protection over nuclear materials, both in plants and in shipments, and provide a better basis for assessing the adequacy of the protection.

NRC has assumed from AEC the authority and responsibility to ensure public protection against the effects of potential illegal use of special nuclear materials and other radioactive substances. In response to both internal and external concerns, the Regulatory Branch of the AEC, NRC's predecessor, increased the physical protection and materials accountability practices at licensed facilities and in the transportation of dangerous materials. The adequacy of these safeguard measures, however, has been questioned. 19/

Some believe that current safeguards are inadequate and that future safeguards can never sufficiently protect society against nuclear theft or diversion unless the Nation resorts to police-state practices, such as extra-legal intelligence-gathering operations, surveillance, and behaviorial controls. These critics urge a moratorium on further use of nuclear energy, particularly the LMFBR. 2/

Others 20/ believe that the threat of diversion is virtually nonexistent and neither the effort nor the cost of avoidance is worth the price. Still others 1/ believe that safeguards need to be improved and can be made to work if certain measures are taken. These measures could mean a greater role of the Government in the nuclear industry, a small incremental increase in the total cost of nuclear power, and the possible creation of a Federal guard force to protect nuclear materials.

Several suggested means of minimizing the risks of diversion are being studied. They include spiking the plutonium with lethal amounts of radioactivity, which would make it dangerous to handle without elaborate procedures, 21/ and the nuclear park concept which could include a fuel fabrication plant, a reprocessing plant, a waste management facility, and perhaps one or more reactors together in one locale to minimize plutonium transportation. Whether the benefits of these and other proposals outweigh the costs is yet to be determined.

On November 6, 1974, AEC issued, for comment, revised safeguard regulations 22/ which were intended to tighten requirements for materials control and accountability, armed guard forces, inspection and enforcement, and reporting requirements in case of an incident. NRC is now considering those comments.

The Proposed Final Environmental Statement for the LMFBR Program and the draft GESMO 23/(see p. 69)suggested the following future safeguards improvements: further tightening of personnel security clearance procedures; improved physical security; increased liaison with police intelligence organizations to detect potential acts; increased use of armed guards, with the possible creation of a Federal security force of a mixed Federal-private guard force; and the development of Federal contingency plans to deal with nuclear incidents.

Some of these measures, especially the last three, concern some observers 2/ who see them as first steps of an inevitable sequence leading to police-state practices previously mentioned. Whether these measures would, in fact, threaten civil liberties has been raised as an important issue in the LMFBR debate. Resolution of this question may be a long process involving public hearings and possibly a court suit.

There is concern also over industry involvement in safeguarding nuclear materials and the measures industry may take to protect materials from possible theft. Recent events at a Kerr-McGee fuel fabrication plant have resulted in that plant's requiring its employees to take polygraph tests and to submit to questioning about their personal habits. 24/

AEC contended that the security precautions required to prevent theft of nuclear materials would normally have very little public impact. 25/ According to AEC, these precautions will be in effect at relatively few locations in very specialized industries so that, under normal conditions, their effect on personal freedom and liberties would be minimal. The most obvious effects would be the presence of armed guards required during the transport of plutonium fuel among the reprocessing facility, fuel fabrication plant, and reactor, and possibly during transport of high-level wastes. According to AEC, the function of these armed guards would likely be limited to safeguarding these materials in sealed containers during transit.

According to AEC, safeguarding the shipment of hazardous material for LMFBRs can be accomplished by organizing a security force of a few thousand carefully selected and well-trained individuals, and the numbers involved and the nature of the impact do not justify significant concern at this time. The responsibility entrusted to this force might be comparable to the responsibilities routinely entrusted to police or members of the armed forces; therefore, a security force to safeguard shipments of special nuclear materials could be expected to function reliably and not pose a threat to society, AEC argued. AEC said that, if a quasi-independent nuclear security force were established, its responsibilities could be circumscribed to ensure that the force did not assume illegal authority. 26/

AEC contended that the nature of any credible nuclear diversion attempt would inherently limit the impact of countermeasures on personal freedoms and privacy, because the fraction of society that might conceivably be interested in, or capable of, stealing nuclear material is very small. AEC argued further that, because of the small number of people potentially interested in and able to divert nuclear materials, successful diversions would be expected to occur rarely, if ever. AEC also contended that material recovery activities after a serious threat might conceivably be obtrusive and stringent but that such events would likely be localized and of short duration and recovery activities would be taken in the public interest. Last, AEC believed that concern about loss of constitutional rights as a result of organized action in infrequent emergency situations would not seem to be a realistic possibility because of immediate public reactions in the past when basic freedoms were threatened.

AEC's conclusion was that the social and political impacts of safeguards required serious attention but that they were manageable.

According to AEC estimates, 27/ although the characteristics of future safeguard systems are not established, the cost of reasonably effective safeguards systems should not constitute a major fraction of the total cost of LMFBR electricity. These estimates indicate that safeguard costs for an LMFBR economy would constitute less than 2 percent of total operating costs and less than 1 percent of fuel cycle capital costs. The potential cost of ineffective safeguards, in terms of potential property damage and destruction of human life, are, of course, enormous.

ERDA officials told us that they reviewed the AEC position on LMFBR safeguards and did not intend to modify that position substantively.

Some of the safeguards policy issues remaining to be resolved include:

--The social costs of a safeguards program, including political freedoms and civil liberties.

--The impact of a more intensive program for security for nuclear explosive materials on the prices paid by users of nuclear power.

--The implications of establishment of a national protective force authorized and equipped to use armed force in protection of nuclear materials.

--The implications of a national intelligence operation to anticipate or discover planned attempts to seize such materials.

International safeguards and physical security

Unlike U.S. domestic safeguards, international safeguards are not designed to provide physical security against theft or sabotage by subnational or terroists groups. Physical protection measures against such acts are a national responsibility. International safeguards, which consist primarily of accountability measures and inspection procedures, are only intended to detect, and deter by risk of detection, the diversion of materials by national governments.

Much of the safeguards related risks associated with nuclear power will exist whether or not the United States continues to develop the LMFBR. The risks will continue to exist as long as foreign nuclear power programs continue. It could be argued that a major reduction in the U.S. nuclear program and in U.S. export of nuclear reactors and enriched uranium would reduce the extent of the risks. On the other hand, by retreating from the world market, the United States might lose its ability to influence the development and strengthening of international safeguards and physical security, and by failing to fulfill the assurances of its Treaty on the Non-Proliferation of Nuclear Weapons to assist countries in the peaceful applications of nuclear energy, the United States could cause many nonnuclear weapons states to question their commitment to the Treaty.

Historically, guns used in terrorist attacks often come from countries other than those in which they are used. There is no reason to believe it would be otherwise for a potential attack involving nuclear materials. Although plutonium will be produced faster in the LMFBR, any reactor containing uranium or thorium in its core--and most reactors contain these materials--can be used to produce plutonium or uranium-233 suitable for weapon use. Moreover, several other nations are developing fast breeder reactors. (See pp. 26 to 31.)

Although the International Atomic Energy Agency--an autonomous, intergovernmental organization, sponsored by the United Nations--is responsible for establishing and administering international safeguards to detect and deter the national diversion of nuclear materials for nonpeaceful purposes, its application of safeguards is limited. For example, at least eight IAEA member nonnuclear weapon states have nuclear facilities which are not subject to IAEA safeguards. Also, problems have been encountered in the application of safeguards and more can be expected in the future. The only "teeth" IAEA has when material is found to have been diverted or unaccounted for is notification to IAEA members and the United Nations Security Council and General Assembly, recall of IAEA sponsored material and technical assistance, and suspension of membership rights and privileges. By the time disclosure is made, the nation or terrorist group involved may already have built its nuclear bomb. 28/

Adequate safeguards on a worldwide basis is, therefore, a complex problem. To devise methods of protection against not only the illegal diversion of weapons material but also attacks on reactors, shipments of radioactive wastes, fuel-reprocessing facilities, and waste repositories as well, while ensuring national sovereignty, will be a monumental task. A successful LMFBR program which led to widespread commercial use of LMFBRs would certainly heighten the urgency for developing an effective international safeguards program and for strengthening physical security measures worldwide.

MANAGEMENT OF RADIOACTIVE WASTES

The management of nuclear wastes--the high-level wastes, such as strontium-90 and cesium-137, as well as the transuranic wastes, such as plutonium-239 (see pp. 64 and 65)--raises important social and political issues. These wastes relate to nuclear power in general; they are not unique to the LMFBR. They would increase in magnitude as the use of any form of nuclear energy grew.

Operation of a 1,000-MWe LMFBR for 1 year would produce about the same amount of high-level wastes--about 55 cubic feet--as an LWR using recycled plutonium. 29/ High-level wastes are both highly radioactive and a major heat source. In addition, a 1,000-MWe LMFBR would be expected to produce annually about 165 cubic feet of transuranium-contaminated fuel-cladding material versus about 60 cubic feet for a comparably sized LWR using recycled plutonium. 29/ These are not a major heat source and are less radioactive than high-level wastes.

Both types of reactors would produce comparable amounts of other wastes of about 20,000 to 45,000 cubic feet a year, some of which are contaminated with transuranics. 29/ These wastes--formerly called low-level wastes--are neither heat sources nor highly radioactive. The amounts of plutonium in them are significant, although in very low concentrations, making their use for weaponsmaking impossible. Because of their much larger volume, they are expected to receive special consideration in future Federal waste management regulations. 30/

The social questions about radioactive wastes revolve around the very long time periods--centuries to millenia--required for these materials to be isolated from man and from other living species. These are time scales longer than the lifetime of existing and previous civilizations.

Two important social questions arise.

--Is it possible to structure social and political institutions capable of watching over additional nuclear wastes for the long periods of time it would require for these materials to decay to safe levels?

--Would management of additional nuclear wastes impose an unreasonable burden on future generations?

The answers to these questions depend on what is ultimately done to remove or isolate the long-lived, radiologically hazardous by-products of fission energy. If, as ERDA contends, it is possible to find safe permanent sites for isolating these materials, the first question will become moot in due time. Until, and unless, such permanent sites are found, however, stored wastes will require continued surveillance and maintenance.

The accumulating, storing, and disposing of high-level radioactive waste has been of concern to the public, the Congress, AEC, ERDA, and NRC for some time. This concern recently received increased public attention because of leaks, in 1973, from underground tanks of AEC-stored high-level waste from the nuclear weapons production program as well as because of growing recognition that additional high-level waste will be created by the nuclear power industry over the next 20 to 30 years. Over 205 million gallons (27 million cubic feet) of liquid wastes have been created by the weapons program and about 7.5 million additional gallons are being created annually. By solidification, AEC reduced the weapons waste volume to about 81 million gallons, or about 11 million cubic feet. 31/

Civilian nuclear reactors of all types have already produced 600,000 gallons (70,000 cubic feet) of liquid high-level wastes 32/ and are projected to produce about an additional 500,000 cubic feet of solid high-level wastes by the year 2000. 33/ Under current Federal regulations (10 CFR 50, appendix F), civilian liquid high-level wastes must be solidified within 5 years of their generation and, within 10 years, must be shipped to a Federal repository.

Nuclear wastes in the United States are in temporary storage pending development of a permanent disposal scheme. Disposal, as distinct from storage, entails relinquishing control over the wastes and abandoning the ability to retrieve them.

Some years ago, AEC began a rather extensive program to identify, evaluate, and possibly demonstrate feasible disposal techniques. Its first attempts to establish a permanent disposal area in bedded-salt formations in Kansas were canceled in 1972 because of adverse public reaction and because of uncertainties concerning the integrity of the overlying formations which protect the salts from water. 34/

More recently, in 1974, AEC proposed storing high-level wastes in retrievable form in above-ground storage facilities. 35/ ERDA has deferred action on this proposal pending completion of a study of all the environmentally significant aspects of the overall Federal strategy for disposition of spent nuclear fuel from commercial reactors, including the steps from fuel reprocessing through permanent disposal of radioactive wastes. 36/ In the interim, however, ERDA officials told us they would continue to pursue permanent disposal technologies, including a pilot disposal site in the salt beds of southeast New Mexico.

There is, of course, no guarantee that a satisfactory permanent storage scheme can be found. As the search for permanent storage of radioactive wastes continues, ERDA, NRC, and the nuclear power industry are moving forward under the assumption that successful resolution of this problem will ultimately be found. At present, there is no fixed time by which a permanent storage scheme must be developed, nor are there established statutory review procedures to ensure that expanding of nuclear power and resolving of waste management issues are linked.

The question of whether this generation should pass responsibility for managing additional nuclear wastes to future generations hinges on value judgments about contemporary society's responsibility to those generations and about the extent of the risks posed by these wastes. If the Nation should be abandoning or avoiding all activities which cannot be guaranteed free from any adverse effects in the future, creating and storing additional nuclear wastes--and thus, nuclear power--would be unacceptable. However, if we are willing to pass on to future generations both the benefits and the risks of nuclear power, then radioactive waste disposal problems would not preclude its continued use.

NUCLEAR ENERGY VERSUS COAL ENERGY

There are no risk-free energy sources, and our ability to measure their total cost is quite limited. Thus there is no unequivocal answer to the question: Which source of electrical energy can provide power with the least total cost per kilowatt-hour to society? To a certain extent, it depends on a person's values and perceptions. For example, how does one compare the "routine" deaths and injuries in coal mining with the potential for "nonroutine" deaths from a catastrophic accident at a nuclear powerplant?

In the following discussion, we examine the concept of total cost of an energy supply system, the limitations of our ability to make objective comparisons between the alternatives, and some of the trade-offs that can be reasonably established. The discussion centers on the comparison of coal-fired systems versus nuclear systems, because these are generally believed to be the two major sources of electrical energy for at least the next several decades. In this context a power system includes all aspects of energy production, including fuel recovery and processing; the construction, operation, and maintenance of plants and other system facilities; and the disposal of waste materials.

Ideally, we would like to determine the total cost per kilowatt-hour for the production of electricity from each available electrical energy system. The total cost per kilowatt-hour would include the costs associated with routine impacts--including accidents whose frequency can be established from historical data--and nonroutine impacts whose costs must be based on more theoretical and generally more uncertain studies.

More specifically, the production of a quantity of useful energy involves several dimensions of cost.

--The diversion of conventional labor, materials, and capital resources, all of which should normally be reflected in the market price of energy.

--The consumption of a quantity of a nonrenewable resource, thus precluding its use in the future.

--Degradation of natural and manmade environments, including disruption of natural materials, energy, and biological balances, and damage to manmade structures and materials.

--Impacts on human health and safety in routine operations.

--Environmental and human risks associated with large-scale, low-probability, nonroutine events (e.g., major accidents, successful sabotage, large abnormal releases of harmful substances, and potential climatic changes associated with atmospheric pollution).

Unfortunately, it is currently impossible to carry this type of analysis to a definitive conclusion, although some efforts have been made at this type of analysis. 37/ Some of the major areas of difficulty include the lack of adequate data to translate specific emissions of air pollutants (measured in tons per year) and ambient concentrations (measured in mass of pollutants per unit volume) into health, environmental, and material damage. In addition, considerable uncertainty exists concerning the magnitude of the risks associated with:

--The potential for global climatic change due to the combustion of fossil fuels.

--The probability of an accident at a nuclear powerplant which results in the release of large amounts of radioactivity into the biosphere.

--The management and disposal of nuclear waste.

--The possible theft or diversion from somewhere in the fuel cycle of nuclear material for a bomb.

Even though it is impossible to make an adequate analysis of the trade-offs between coal-fired systems and nuclear systems, the following qualitative conclusions were reached in an AEC study. 37/

Although coal is the most abundant domestic fossil fuel resource, it is the most severe offender (from a human health, safety, and environmental standpoint) when the routine impacts are considered. The comparison for nonroutine impacts between coal and nuclear is uncertain. It is also uncertain whether the comparison of nonroutine risks is a critical issue or not. 37/

Electricity costs borne by the consumer (including capital expenditures for powerplants, fuel cycle, and operation and maintenance) are roughly similar for coal and nuclear. 37/

In terms of occupational health and safety, nuclear appears to be far better than coal with about one-tenth the fatalities and man-days lost per kilowatt-hour.* 37/

In terms of public health, it is impossible to make an accurate comparison at this time. In terms of public safety relating to transportation injuries, coal has more than 10 times more deaths and injuries per kilowatt-hour than nuclear. (This is mainly due to the much larger volumes of fuel that must be transported to the coal plants.) 37/

For a given unit of electricity supplied to the Nation:

--the land area required for the coal system is more 20 times that required for the nuclear system;

--the release of oxides of sulfur, oxides of nitrogen, particulates, and trace metals for the nuclear system are small or negligible compared to the coal system, even with pollution controls (the amount of such pollutants associated with the nuclear system is dependent on the assumption of what source is used to supply the power for the uranium enrichment facility);

--routine radioactive releases to the atmosphere and to water for nuclear systems are several orders of magnitude greater than for coal systems (these are very small, however, and should not be an issue in the LMFBR debate); and

--thermal discharges LWR nuclear systems are about one-third greater than for coal systems (because of their higher operating temperatures, LMFBR systems would be roughly comparable to coal systems in terms of thermal discharge). 37/

The human, environmental, and conventional costs associated with all present forms of electrical energy production, including coal and nuclear, emphasize the benefits to be gained through energy conservation and the efficient use of energy. They also suggest the importance and urgency in developing the technology for developing solar electric and other nonnuclear, nonfossil sources of power for the Nation.

*It is important to remember that even "routine" health and safety impacts per kilowatt-hour are not fixed for either coal or nuclear. For example, the injury rate for underground coal mines per million man-hours has typically varied by over a factor of 10 among even the major coal companies.

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PART 10

ALTERNATIVE LMFBR PROGRAM COURSES

There are many development courses open to LMFBR decisionmakers. Determining which is best is a dynamic process requiring continual reassessment of program goals against available information on such factors as uranium resources, electrical energy demand projections, LMFBR economics, and LMFBR technology risks.

In considering future alternatives, it is important to recognize that to continue the LMFBR program is a decision to provide additional Government resources for the next step in a complex multistep process; it is not an irreversible commitment by the United States to the widespread commercial use of LMFBRs. It must also be noted, however, that there has been substantial Federal and private investment in the program, and, with each additional committed dollar, a decision to abandon the program will become increasingly difficult.

At present, commitment to this program translates into continuing R&D and to the building of a plant to demonstrate that an LMFBR can satisfactorily operate in a utility power system, although at higher than competitive costs per kilowatt. Widespread use of the LMFBR will require that the present R&D effort prove successful, that NRC finds each plant to be safe, and that utilities decide that the LMFBR is economically competitive with other options such as coal, oil, and LWRs.

The LMFBR is not a short-term energy supply option for the United States. Assuming everything in the current high-priority program goes as scheduled, commercial LMFBRs would not begin to operate in large numbers until the 1990s or, if current construction and licensing schedules do not improve, the early years of the 21st century.

Until the benefits of the LMFBR efforts are realized, that is, until LMFBRs are generating substantial amounts of economical electricity, some claim that the program would compete for and divert limited Federal funds and industry resources which otherwise might be invested in energy conservation measures and in implementing other energy sources, such as solar power for heating and cooling buildings.

Decisions on issues general to U.S. nuclear power will also affect the LMFBR's development. Unfavorable resolution, for example, of the safeguards or waste management issues would raise serious doubts about the future of the LMFBR, as well as the nuclear option as a whole. An unfavorable decision on one issue in particular--plutonium recycling with its associated safety and safeguards requirements--would probably make selecting of future LMFBR program alternatives irrelevant, because recycling is essential to the entire viability of the concept.

Potential LMFBR program courses range from accelerating the present effort to abandoning the entire program. Within this spectrum are a number of alternatives, including continuation of the present course and slowdown. Each course involves trade-offs of various advantages and disadvantages. Therefore, any decision concerning the LMFBR program must involve a careful weighing of the risks and benefits associated with each alternative strategy. As a practical matter and as noted earlier, decisionmakers must recognize that the Nation would be hard pressed to develop and demonstrate the LMFBR concept as currently scheduled by ERDA--CRBR in mid-1983 and NCBR in 1987. Our discussions with representatives of the utility and reactor equipment manufacturing industries indicate that large numbers of LMFBRs would not begin to come into operation from 4 to 7 years later than projected by ERDA--even if the R&D and demonstration program were successful and carried out on schedule.

The following brief discussion does not purport to list all the LMFBR alternatives--any one or combination of which the LMFBR program course could follow--nor to cite all their various advantages and disadvantages. Rather, it is intended to provide illustrative examples of basic alternatives which can provide a perspective on the options open to the Nation.

ACCELERATE THE PROGRAM

Accelerating the program offers several possible advantages. It might increase the probability of bringing commercial LMFBRs into operation before the serious impacts of an electrical energy shortage, reduce the chances of foreign manufacturers' dominating the world LMFBR market, and provide for increased testing and verifying of fuels and components before commercialization.

A major disadvantage is that this alternative increases the risk that LMFBRs will reach the marketplace before it is economic for utilities to buy them, possibly requiring further Government subsidy if early commercialization is desired. Also,accelerating the program may not provide the plant operating experience desired by utilities before investment. It also pumps increasing amounts of resources into an energy option which might never achieve commercial use.

CONTINUE THE PRESENT COURSE

Continuing the present program runs the same risks as the acceleration option but to a lesser extent. If high growth in electrical energy consumption does not materialize and if our economically recoverable uranium proves to be more plentiful than estimated by ERDA, the present course might lead to introducing the LMFBR sooner than needed to preclude the exhausting of economically recoverable uranium or before it is an economically viable technology.

If, however, there is high growth in electricity consumption and if ERDA's uranium estimates are accurate, the successful continuation of the present course could produce a viable energy option when it was needed by the Nation to prevent an electrical energy shortage.

SLOW THE PROGRAM

That the LMFBR will not be ready when the Nation needs it is the most important possible disadvantage in slowing the present program. This course also runs the risk that foreign manufacturers might have the advantage of reaching the marketplace first, that total R&D costs might end up being higher, and that industry might be reluctant to continue to commit its resources.

The possible advantages of slowing the present program follow. It allows additional time for resolving problems, for developing better information on technical and economic uncertainties, and for reassessing the Government's funding priorities; it might free funds for other purposes, such as implementing energy conservation activities; and it gives decisionmakers further opportunity to debate and consider the desirability of the LMFBR as a major energy option.

ABANDON THE PROGRAM

The most obvious advantage of abandoning the LMFBR program is that it would free limited Government funds for other priority programs or for trimming the Federal budget. The major disadvantage is that, by abandoning the LMFBR, the United States might be foreclosing on the long-term future of one of its major energy options--nuclear fission--and, as a consequence, might have to depend more heavily on coal or foreign oil despite their economic, environmental, and political costs. For those who believe that such problems as safeguards and waste management are not resolvable, the foreclosing of nuclear fission's future might not be seen as a disadvantage.

To restart the program after a decision to abandon would be possible, but it would be costly and time consuming, and the nuclear industry might be skeptical of reinvolvement. If the LMFBR program were abandoned and had to be restarted, few advantages would accrue. This course of action would be prudent only if we concluded that the LMFBR or nuclear fission is neither needed nor desirable.

SOME MORE SPECIFIC STRATEGIES

Within the broad alternative program courses there are strategies which can be pursued either individually or in combinations.

Narrow the program scope

Within the acceleration alternative, there could be a strategy to narrow the scope of the program. Under such a strategy, LMFBR resources could be refocused to attain only one of the program's present goals--the rapid demonstration of a large LMFBR. If reports on the success of the French demonstration plant are accurate, this strategy might produce a reliable operating LMFBR much quicker and at lower cost than the current program.

Translated into program actions, this strategy might reduce the emphasis on the FFTF, fuels and materials, and the fuel recycle areas. Increased attention would be paid to funding demonstration plants and proceeding to commercial-size plants as rapidly as possible. As in France, early United States LMFBRs could be fueled with uranium rather than plutonium. Emphasis on plant construction as a trade-off against developing better fuel doubling times in FFTF would be expected to aggravate the pressure on uranium supplies and, over a long term, dictate the construction of a larger number of LMFBR plants than now planned.

Additional funds and personnel

Another example of a strategy which could be pursued within the acceleration alternative would be to inject additional funds and personnel into the program. This strategy could permit increased testing and perhaps could reduce the risk of failure in demonstration and early commercial plants. However, the present program has received such priority emphasis that it may have reached a funding limit beyond which it would be difficult to use additional support efficiently.

Reassess timing factors

Within the alternative of slowing the program, an effort could be made to obtain more definitive information on those factors which influence LMFBR timing. Execution of this strategy could include expediting action to identify the extent of our economically recoverable uranium resources and to reduce uranium demand through conservation. This strategy might also require the use of other energy sources for generating electricity, recycling of plutonium, building more uranium enrichment plants, and building reactors, such as the high temperature gas-cooled reactor or the heavy water reactor, if they prove commercially viable, which makes more efficient use of uranium than LWRs. At the same time the LMFBR program could still be pursued toward a goal of commercialization--but it would come later than is now planned. This strategy would provide more information upon which to resolve the other LMFBR uncertainties.

Resolve technological uncertainties

Another strategy within the slowdown alternative which could be pursued would be to try to resolve technological uncertainties in the program before building demonstration plants. By revising the current program pace to allow more time to resolve the uncertainties surrounding critical design problems, higher confidence levels in designs might be gained and the probability of success might be increased. It could allow time to reassess the LMFBR more completely and provide further opportunities to ensure public acceptance through a broader base of knowledge on the safety and reliability features of the reactor. However, the program may have already reached a stage where the major remaining technological uncertainties relate to the interplay of all the components in a plant, so that resolution of these uncertainties requires building a complete plant, such as the CRBR demonstration plant.

Specific actions to implement this strategy could include steps to defer the licensing, constructing, and operating of CRBR until at least the early results of FFTF can be evaluated. This would permit CRBR to incorporate design considerations and improvements dictated by the extensive fuel and safety tests run in FFTF. Implied in this strategy is a delay in the commercial introduction of LMFBRs and increased costs for CRBR.

Reduce Federal funding

Yet another strategy within the slowdown option would be to make a major cut in the Federal funding for demonstration of LMFBR feasibility. This strategy would subject the LMFBR program to the acid test of the marketplace by shifting to industry more of the burden of implementing the concept. However, in the light of the current capital problems being experienced by the U.S. utility industry, continuing LMFBR plant development without heavy Government subsidies seems unlikely at present. The high capital costs, the degree of technical risk, and the long delay before expected profits (about 20 years) might make the LMFBR's continued development at present an unacceptable risk to private developers. It is doubtful that an industry which is canceling capacity additions to proven technologies--coal, oil, and LWRs--would, under current conditions, venture very far into the exploitation of an unproven alternative. Inherent in this strategy would be a decision to retain the possibility of using the LMFBR to extend uranium supplies by purchasing and operating foreign LMFBRs. (See pp. 26 to 31.)

PART 11

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

Our purpose was to identify and assess the issues relevant to key questions facing LMFBR decisionmakers:

--Does the United States need an LMFBR and, if so, when?

--Should the Federal Government continue to develop the LMFBR?

--What are the benefits, costs, and risks?

--What are the options?

Both the LMFBR issues and the solutions are not clear cut; they are complex and riddled with uncertainties. In our judgment, these uncertainties argue against extreme actions which, on the one hand, would expand and accelerate or, on the other hand, abandon the LMFBR program.

The LMFBR is controversial because it is the most likely vehicle by which nuclear fission may become an assured energy source through the 21st century and beyond. The LMFBR is controversial because decisions must be made in the face of uncertainties with respect to need, economics, and safety. Lastly, it is controversial because research and development to resolve these uncertainties is an expensive, and often time consuming, matter.

Some of the uncertainties and problems are unique to the LMFBR. However, the problems of safeguarding nuclear materials and the problems of radioactive waste disposal often cited by LMFBR critics are already present with existing reactors. With an LMFBR economy, these problems would become quantitatively worse. Without the LMFBR, however, uranium resources might be depleted while there is still a need for fission-generated power. In the broader context, therefore, the LMFBR is intimately intertwined with the benefits and risks to society from continued use of nuclear fission in any form.

As set forth in this paper, critical uncertainties concerning the LMFBR include:

--The rate of growth in the use of electricity in the years ahead.

--The extent to which nuclear fission power will be required to meet the future demand for electrical energy.

--The amount of recoverable uranium resources at current and anticipated future prices and the resultant implications for when LMFBRs would be needed.

--The economic feasibility of LMFBRs.

--The ability to deal adequately with environmental, safety, and safeguards concerns, including diversion of nuclear materials and disposal of radioactive waste. Special problems are licensing by NRC of plutonium recycling, a process essential to economicially viable LMFBRs, and a decision whether LMFBRs need core catchers or other additional containment to guard against core disruptive accidents, including recriticality.

--The status of development of foreign LMFBR programs and their implications for our domestic efforts.

If these uncertainties are resolved, two important management issues will require decisions also.

--The level of Federal Government support necessary to build the NCBR which is to follow the Clinch River demonstration plant. At present, ERDA contemplates a Government subsidy of $300 million, but it recognizes the amount could go much higher if utilities and the nuclear industry are unwilling to provide the bulk of financial support for its development.

--The extent to which utilities will commit themselves in the 1970s and early 1980s to purchasing commercial LMFBRs for delivery in the late 1980s and early 1990s, before the availability of results from the CRBR demonstration or from nuclear fuels testing in FFTF.

In the face of the uncertainties, we believe the following general conclusions are appropriate.

First, the United States clearly should not abandon the nuclear fission option at this time, nor should it abandon the LMFBR R&D effort. Uncertainties regarding the scientific, technical, or economic feasibility of potential alternative energy sources; the problems of increased reliance on fossil fuel; and uncertainties regarding the ability and willingness of the Nation to conserve fuel--all make these unrealistic courses of action.

Second, the LMFBR program should be clearly identified and recognized for what it is: an R&D program. There has been premature concern and emphasis on commercializing the LMFBR at a time when the Nation is years away from demonstrating that commercial-size LMFBR plants can be operated reliably, economically, and safely. It is unlikely that utilities will make major financial commitments in advance of such proof, which may not be available until the mid-1980s.

Third, given the history of slippage in this program and the likelihood that future experience will be similar, it does not appear reasonable to attempt to accelerate the R&D schedule. It will be difficult to maintain the current schedule.

Fourth, whatever action is taken by the United States on nuclear power and the LMFBR, the problems of nuclear safety and safeguards will not go away. Many foreign governments appear likely to rely significantly on nuclear fission power in the future, including LMFBRs. These governments are not concerning themselves initially with commercialization problems, but are attempting to demonstrate that LMFBRs can operate reliably, economically, and safely. A unilateral decision on the part of the United States to abandon nuclear power or the development of the LMFBR will not change this situation.

Fifth, the most logical course of action is to pursue the LMFBR program on a schedule which recognizes that the program still is in an R&D stage. Not until some point in the future, perhaps 7 to 10 years from now, need a firm decision be made as to whether the Nation will commit itself to the LMFBR as a basic central station energy source. At that time, many of the uncertainties of today should be reduced or eliminated, particularly if priority efforts are made to resolve as many as possible between now and then.

RECOMMENDATIONS

We recommend that, to help resolve existing uncertainties, the heads of the responsible Federal agencies and the Congress take the following actions to:

1. Obtain adequate information on domestic uranium resources at current and anticipated future prices.

   --We recommend that ERDA expedite the work and final report of its National Uranium Resource Evaluation Program currently scheduled for completion in 1980.

--We recommend that the Congress explore with ERDA, the Geological Survey, and the Federal Energy Administration the feasibility of establishing a program to thoroughly appraise the U.S. uranium resource base by having the Federal Government conduct or sponsor extensive exploratory drilling, including such program and funding authorizations as may by needed.

2. Explore the development of policies and mechanisms which are acceptable to society to deal with the outstanding environmental and safety questions.

--We recommend that ERDA and NRC give higher priority to developing adequate systems to safeguard nuclear materials, particularly at the vulnerable points of transport.

--We recommend that ERDA and NRC decide how to deal with the possibility of LMFBR core disruptive accidents, including recriticality, and whether to include a core catcher or some greater structural integrity in the overall containment system.

--We recommend that ERDA and NRC proceed now to establish a relatively permanent underground storage system so designed that wastes are retrievable if necessary sometime in the future. ERDA and NRC must make decisions on the management of radioactive wastes and implement a program soon if we are to proceed with expanding nuclear power in any form.

--We recommend that ERDA work with EPA in developing an accelerated program of research in the environmental and health aspects of coal mining and use to better enable the Nation to know whether coal is an alternative to fission power or only a complement to it.

3. Improve the Nation's understanding of and cooperation with foreign government efforts to develop LMFBRs.

--We recommend that ERDA take the lead in examining the feasibility of information exchange arrangements with foreign governments and consider carefully obtaining franchises to use foreign technology for domestic production of LMFBR systems and components. Also, purchasing total LMFBR systems and components from foreign sources should be closely examined.

--We recommend that NRC and ERDA intensify efforts to identify and resolve the problems in NRC's licensing the French LMFBR system and components for use in the United States, since France may be the most advanced in large plant LMFBR experience.

4. Extend and improve projections of demand for electrical energy as more information becomes available.

   --We recommend that ERDA, working with the Federal Energy Administration, analyze the extent to which recent trends are the result of increased energy conservation and indicative of reduced growth rates in years ahead or are simply aberrations from normal growth curves which can be expected to resume under more favorable economic conditions.

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As better information become available in the years ahead and the Nation strives for a balanced energy R&D program, we recommend also that the Congress periodically and systematically reassess, with appropriate inputs from the agencies concerned, the Nation's major energy options. Such reassessment should consider the Nation's ability and willingness to conserve energy as well as the changing status of all energy supply options.

We support ERDA's recent decision to ask the National Academy of Sciences to review the LMFBR program. Such a review from a technical viewpoint can help provide a broader base for considering the current status of the LMFBR, as well as other nuclear and nonnuclear energy alternatives.

DESCRIPTION OF THE LMFBR PROGRAM

The LMFBR program consists of six major program areas, each of which contributes an important element of technology. Each area must be successfully completed in order to meet the overall objective of commercializing the LMFBR.

According to ERDA, none of these areas has been sufficiently developed to support a commercial plant at this time. The six areas are plant experience, fuels and materials, fuel recycle, component development, reactor physics, and safety.

Each program area has at least one major test or demonstration facility which is expected to provide a major contribution to the LMFBR commercialization objective. The relationship between these facilities and program areas is shown in figure 5. (See page 97.) For the most part, these are Government-owned and contractor-operated facilities. They have been built over time and represent large capital investment by the Government. Many of the facilities are at the various national laboratories but some are at other contractor locations.1/

Each program area is discussed here, except safety, which is discussed in appendix II.

PLANT EXPERIENCE

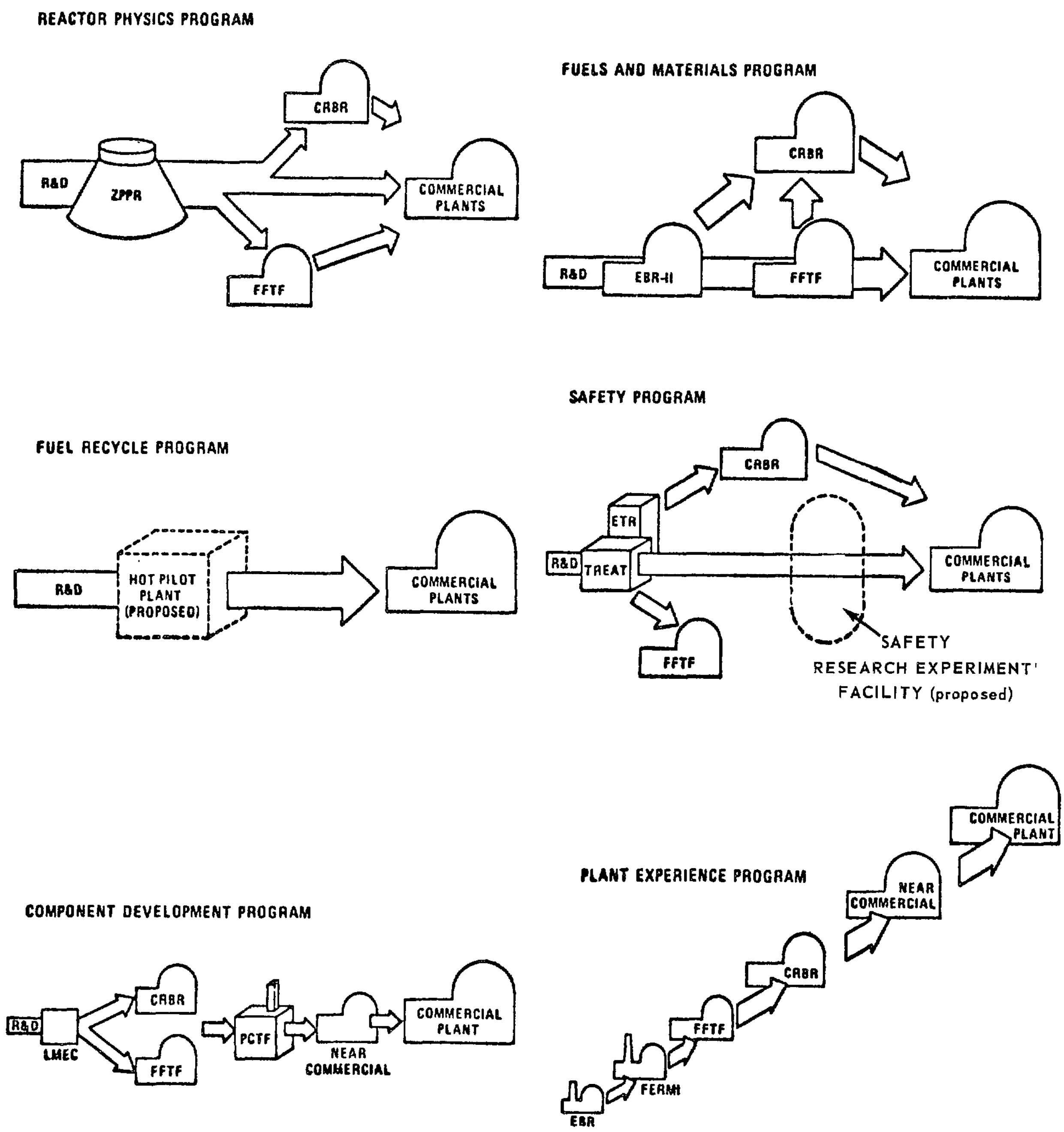
Plant experience is where technology developments are integrated into operating reactors to demonstrate the feasibility of the total concept. To meet its objectives, this program area must demonstrate--through its planned operation of a demonstration plant, or plants--the existence of a high probability that the following conditions can be met:

--LMFBRs can operate reliably, safely, and in an environmentally acceptable manner under practical utility conditions.

--Capital costs for LMFBRs are not so much greater than competing systems that the fuel cycle cost advantage is wiped out or exceeded.

Note: Numbered footnote references to appendix I are on pp. 106 and 107.

FIGURE 5:
RELATIONSHIP OF LMFBR PROGRAM AREAS
TO TEST OR DEMONSTRATION FACILITIES



--An LMFBR plant is licensable and can be licensed on a schedule on which utilities an depend.

--That LMFBRs can be operated and maintained using utility personnel.2/,3/

ERDA believes that U.S. success in this area, using CRBR and NCBR, together with experience gained in the foreign LMFBR programs, should provide adequate experience for a United States LMFBR industry.2/

According to ERDA, plant experience is acquired by designing, constructing, and operating a succession of plants--progressing in size through reasonable extrapolations of technology--until the commercial plant is reached. Limited experience has been achieved from operating several U.S. reactors, and more is expected from FFTF.

The Fast Flux Test Facility

One of FFTF's roles is to demonstrate the effective performance of plant systems and components that are forerunners to commercial fast breeder reactors.4/ When it is completed, FFTF will be the largest U.S. demonstration of LMFBR reactor components and high-temperature sodium-cooling components. However, since it will not be equipped with steam- and electrical-generating components and facilities, the FFTF will not be a prototype electrical-generating plant. FFTF is being built to serve as an irradiation and testing facility for LMFBR fuels and materials.4/

FFTF is being built because the Experimental Breeder Reactor-II (EBR-II) cannot duplicate the nuclear environment expected in larger LMFBRs and, in most cases, exposure in the EBR-II test environment falls short of expected or design exposure. Without FFTF, prediction of the ultimate incore performance of fuels and core materials will require much extrapolation of data 5/ which, in turn, would probably lead to less economical design of these items. If necessary, many of the functions of FFTF could be performed in an operating LMFBR demonstration plant. However, FFTF will be equipped to perform tests and experiments more quickly and efficiently.

According to the Proposed Final Environmental Statement on the LMFBR Program, failure to develop advanced LMFBR fuels would reduce the economic benefits expected from LMFBR use by about 65 percent; would, in turn, result in greater pressure on uranium resources; and would greatly slow down the potential rate of breeder introduction into the economy.6/

In July 1967 the Congress authorized construction of FFTF which, at that time, was estimated to cost $87.5 million and scheduled to begin full-power operation in early 1974. Since congressional authorization, FFTF has experienced considerable cost growth and schedule slippage. The FFTF cost and schedule estimate has been revised several times. The latest official cost estimate (February 1974) for the construction of the facility is $420 million.* At this same time, the construction completion schedule had slipped to November 1977; no estimate was made for the full-power operation milestone.7/

The FFTF contractor is presently forecasting that an additional $92 million will be needed to construct the FFTF. Also, as of December 31, 1974, the latest field estimate for construction completion was August 1978, with full-power operation expected to occur 18 months later.7/

The Clinch River Breeder Reactor

The CRBR demonstration plant is planned to serve as the key bridge of the program, linking the technology development phase to large-scale commercial use. Plans to build a 350-MWe demonstration plant** near Oak Ridge, Tennessee, are now in the early design stages. This facility is currently scheduled to be operational by mid-1983. It is a cooperative Government-industry project. CRBR's primary objectives are to

--demonstrate the safe, clean, and reliable operation of an LMFBR closely resembling a commercial-sized plant while showing a high availability factor for power production in a utility environment;

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*This estimate is only for constructing the facility. An additional $505 million was estimated for equipment, R&D, and other supporting costs for a total program cost of $925 million. A complete estimate for these costs was not prepared when the initial $87.5 million estimate was prepared.

**About 2-1/2 times the heat-generating capacity of the FFTF.

--serve as the focal point for the development of systems and components;

--develop industrial and utility capabilities to design, construct, and operate LMFBRs; and

--demonstrate the commercial licensability of LMFBRs.

According to ERDA, constructing and operating an LMFBR demonstration plant is the only means by which these objectives can be realized. The guidelines issued in establishing CRBR as it presently exists were based on utility recommendations.

There are certain tasks which CRBR is not intended to accomplish. It will not, for example:

--Determine optimum design choices for full commercial LMFBRs.

--Demonstrate the ultimate performance of LMFBRs.

--Result in an economically viable reactor system.8/

In September 1972, during hearings before the Joint Committee on Atomic Energy, AEC presented its estimate of what the demonstration plant would cost--$699 million; the Federal Government would provide $422 million through AEC and industry would provide the balance. The project was scheduled to achieve initial operation in 1979.9/

Since then, CRBR has incurred considerable schedule delay and cost growth. ERDA now estimates that the project will cost $1.736 billion and will not start operation until mid-1983--an increase of more than $1 billion and a delay of about 4 years.

The Near Commercial Breeder Reactor

Until November 1974, ERDA had stressed the progressive development of successively larger demonstration and "early commercial" plants, using these plants as test beds for component development. After the CRBR, the commercialization program called for two more demonstration plants and then for three "early commercial" plants.10/ These plants were to show the reliability, safety, licensability, and environmental acceptability of the LMFBR concept and were to provide private industry with a reliable basis on which to build an LMFBR energy economy.1/

As the result of an assessment of the AEC civilian nuclear power program during 1974, AEC revised its LMFBR program plan. Instead of the follow-on demonstration and early commercial plants, a large component test facility (see pp. 17 and 18) and only one "near commercial plant" are now planned.11/

According to ERDA, the NCBR would provide the large-scale plant experience necessary to initiate full industrial participation in the commercialization of the LMFBR. The experience of ERDA and private industry with this facility would determine how much more work on the LMFBR concept is necessary before it becomes economically viable and can be integrated into utilities' power production systems.

NCBR is not well defined, except that it is expected to be a large, commercial-size LMFBR (in the 1,000 to 1,500 MWe power range) which uses commercial-size components. At the higher power level it would generate about four times as much power as CRBR.12/

ERDA, in partnership with EPRI, plans to fund work on designs of large plants which must begin before detailed design and construction of the NCBR. A previous design effort ended in 1968. The upcoming designs--known as LMFBR Target Plant Designs--will also provide essential technical input to ERDA's full-size component development and testing program, as well as to the rest of the LMFBR development effort. Work on these LMFBR Target Plant Designs is expected to begin in mid-1975 with the participation of two or more reactor manufacturers and the utility industry.

ERDA expects that NCBR will be a cooperative project between the Government and the nuclear utility industry and that the Government's assistance to the project will be substantially less than that required for the CRBR. As pointed out earlier, the cost estimate, schedule, and degree of industry participation have not yet been determined. ERDA anticipates that the nuclear utility industry will commit funds to the project beginning in 1977 and that the project will be operating in 1987.

ERDA officials told us that they had no sound basis for predicting the extent of cost sharing on the initial NCBR. ERDA's estimates of LMFBR program costs through the year 2020 specify that ERDA's contribution for the NCBR will be $300 million but that there is a significant amount of uncertainty related to this $300 million subsidy and it might be as high as $2 billion.

Additional federally supported LMFBRs

Although not certain, ERDA officials told us that more than one NCBR may be needed and that ERDA might also provide funds to supplement industry investment for any additional NCBRs. That is, Government subsidies might have to be added to private industry investment for NCBRs until such time as the cost per kilowatt of breeder generated electricity is about the same as for LWRs (or other competing sources) of the same generating capacity.13/

ERDA estimates the capital costs for the initial NCBR--not including R&D costs--could be as high as $1,000 per kilowatt of capacity. The same costs for an LWR are now about $600 per installed kilowatt. Because LMFBR fuel cycle costs are expected to be lower than those for LWRs, LMFBR capital costs can be higher than those for LWRs and the total costs of electricity for the two types of plants could be competitive.14/

FUELS AND MATERIALS

The goal of this area is to develop a reliable, safe, and economic fuel system design. Efforts are being made to improve fuels and materials for near-term needs and to develop advanced fuels and materials which would be necessary for the LMFBR to reach its full potential for uranium conservation and to have sufficiently low fuel cycle costs to permit economic viability. A mixed-oxide fuel design will be used as the fuel for the FFTF and CRBR and could also be used in a commercial plant. Improved and advanced fuels and materials are being developed, primarily to increase the reactor's breeding capability.15/

EBR-II and its associated Hot Fuel Examination Facility, located in Idaho,are the primary facilities used in this area. When FFTF is completed, it also will have a major role in carrying out experiments for developing fuels and materials.

FUEL RECYCLE

The objective of the fuel recycle program area is to develop technology in the areas of reprocessing, fabrication, and shipping of spent LMFBR fuels to permit an economically competitive LMFBR and to attain a doubling time of less than 10 years. The fuel recycle area is currently centered in the laboratory and, according to ERDA, is probably the least technologically advanced area at this time.16/

Yet, commercial success of any breeder* will depend on an efficient fuel cycle whereby fuel burned in the reactor can be reprocessed to recover the newly bred material (plutonium), as well as the remains of the spent material. This requires shipping the spent fuel, reprocessing it to recover any reusable material, and fabricating the recovered material into new LMFBR fuel. The efficiency of these processes would have a strong effect on fuel doubling time (see p. 35) and, hence, the economics of the LMFBR. According to ERDA, LMFBRs will not be economically viable without an efficient fuel cycle.

The long-term goal for fuel fabrication is the startup of large commercial fuel fabrication facilities in 1988 or 1989. For fuel reprocessing, the goals are to commit funds for the first commercial reprocessing plant in 1987 and to start full-scale commercial fuel reprocessing by 1997.17/

To advance the fuel cycle to the potential of rapid reprocessing for fast reactor fuels, two facilities are planned: a High Performance Fuel Laboratory and an LMFBR Fuels Reprocessing Hot Pilot Plant. The High Performance Fuel Laboratory is projected to cost $54 million to build and is planned to become operational in late 1981 or early 1982. Its purpose would be to demonstrate fabrication of LMFBR fuel using plutonium from LWRs and to provide the technological base for designing and operating economic high-production licensable commercial fabrication plants.

The LMFBR Fuels Reprocessing Hot Pilot Plant, consisting of a storage and receiving facility and an experimental reprocessing facility, is being proposed to demonstrate the technology of receiving, handling, storing, and reprocessing spent LMFBR fuel (initially FFTF and CRBR fuels) with full-scale equipment. The storing and receiving facility is presently estimated to cost $100 million and is planned to begin operation in mid-1981. The experimental reprocessing facility is estimated to cost $200 million and is planned to begin operating in fiscal year 1985.17/

COMPONENT DEVELOPMENT

The objective of this area is to insure the availability of plant components and systems with demonstrated capability

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*Fuel recycle is also imperative for successful commercial application of reactors, such as HTGRs and LWBRs which use a thorium-uranium fuel cycle. (See pp. 32 and 33.) However, these reactors will recycle uranium-233 rather than plutonium.

of meeting the exacting performance requirements of commercial LMFBRs, including reliability, safety, economy, operability, and ease of maintenance. This area is in transition from focusing on near-term needs (FFTF and CRBR) to focusing on component sizes of interest to commercial plants. According to ERDA, progress to date in developing components, particularly those to be used in FFTF, has not been satisfactory.18/

Without these components, which convert the heat of the nuclear reaction into steam to drive the electric turbine-generator, economics of scale expected in the 1,000 to 2,000-MWe LMFBRs necessary to make them competitive with existing electrical powerplants will be unattainable. In fact, the lack of a technological base for the design of large sodium components--heat exchangers, pumps, and steam generators--and the consequent unwillingness of vendors to supply this equipment on warranty bases have been cited as the principal remaining technical obstacle to the construction of a commercial-size LMFBR.19/

Sodium Pump Test Facility

The construction of the Sodium Pump Test Facility was authorized in the fiscal year 1966 budget. The estimate presented to the Congress for approval at that time was $6.8 million. In 1969 a review of the project by a private architect-engineering firm revealed that the project, with its then-current scope, would cost $25.2 million.20/

To reduce estimated costs, the project scope was then revised to test sodium pumps having a capacity of about one-third the size of those initially anticipated to be tested. The reduced project scope resulted in a cost estimate of $12.5 million for the facility. This estimate was presented to and approved by the Congress as part of AEC's fiscal year 1972 budget request. In fiscal year 1974, this $12.5 million estimate was again revised up to $17.5 million. At that time, AEC said that the reduced capability of the facility would not adversely affect the capability to test pumps up to the sizes needed for use in the foreseeable future of the LMFBR program.21/

ERDA is presently planning modifications to this facility so it can test CRBR-size pumps, which are larger than the pumps for which the facility is presently designed. These modifications are presently estimated to cost $40 million, increasing the project's total cost to $57.5 million.21/

Additional facilities

According to ERDA, many component features are being developed which are applicable to large plants, and it will be necessary to test the full-size components to provide assurance that they will operate reliably under conditions typical of powerplant services. Facilities currently available within the program are inadequate for testing the large-size components. Consequently, the Plant Component Test Facility, which is intended to serve as a test bed for commercial-size components, has been added to the LMFBR program plan. This facility is estimated to cost about $200 million and is planned for operation in the early 1980s. ERDA expects that testing components for the near commercial plant will be completed by 1984.22/

In addition to constructing the Plant Component Test Facility, ERDA plans to construct a Radiation and Repair Engineering Facility--estimated to cost $36 million--for maintaining and repairing large, radioactive sodium-contaminated components.23/

Present emphasis in the component development area is on the CRBR component development. Fabrication of prototype components is scheduled to begin in 1975 with testing to follow. The critical components--the pump and steam generator--are scheduled for testing in 1977. According to ERDA, this will be early enough to allow rework, if necessary, based on the test results, before installing similar components in CRBR.23/

REACTOR PHYSICS

The objective of this program area is to develop design data, experimental procedures, and analytical methods adequate to ensure the safe and economic performance of commercial LMFBRs. The Zero Power Plutonium Reactor, located in Idaho, is the principal experimental facility for this area. This facility is presently being modified so it will be able to handle experiments for reactor cores in the commercial-size range. According to ERDA, this is the most technologically advanced area in the LMFBR program.24/

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10 "The Currently Planned LMFBR Program," presentation of the Division of Reactor Research and Development to the Klein/Culler Committee, U.S. Atomic Energy Commission, November 4, 1974, p. 14.

11 *Ibid*., pp. 16-17.

12 "The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future," p. 22.

13 *Ibid*., pp. 23-24.

14 *Ibid*., p. 24.

15 *Ibid*., p. 16.

16 *Ibid*., p. 18.

17 *Ibid*., p. 19.

18 *Ibid*., p. 21.

19 "Westinghouse Recommendations for a National Plan for Commercial Introduction of the Breeder Reactor in the Late 1980s," June 30, 1974, Westinghouse Submission to the U.S. Atomic Energy Commission's LMFBR "Commercialization Study," p. 8.

20 "The Liquid Metal Fast Breeder Reactor--Past, Present, and Future," p. 25.

21 *Ibid*., p. 26.

22 *Ibid*., p. 21.

23 *Ibid*., p. 22.

24 *Ibid*., p. 15.

LMFBR SAFETY PROGRAM

THE LMFBR safety program objective is to investigate and develop the technology necessary to resolve safety concerns related to the LMFBR concept. The program aims to develop sufficient technology to prove that LMFBRs do not represent an undue hazard to the health and safety of the public. The program is intended to demonstrate that

--accidents leading to major core disruption will be of very low likelihood;

--even if accidents do happen, the system can be designed to preclude serious damage; and

--even if the system were seriously damaged by an accident, the consequences would not harm the public.1/

According to ERDA, the safety area has received considerable emphasis, many basic safety questions have been answered, and a large amount of technology is available. ERDA anticipates that safety work will be completed in the 1990s but that funding will continue to be provided for safety R&D for as long as LMFBRs are being built.

Several major facilities are now used in the safety program. Another major facility is planned--the Safety Research Experiment Facility. This facility is presently estimated to cost $230 million and is expected to begin operations in the mid-1980s. The facility will provide a fast-flux zone for testing up to seven full-scale LMFBR fuel assemblies through total loss of fuel element integrity. It will enable data to be developed to address outstanding safety issues--such as the question of core disruptive accidents, including recriticality--and will provide input into the design evaluation process of commercial LMFBR designs and data to respond to concerns of licensing bodies and citizen groups. It will also provide the capability of conducting prototypic tests under conditions of hypothesized LMFBR accidents.

According to ERDA, this planned facility is not needed to provide safety data before the scheduled mid-1983 operation of the CRBR demonstration plant because conservative

Note: Numbered footnote references to app. II are on p. 114.

design features and margins are included in the present CRBR design. However, it is needed to provide data for the design of larger plants because these same conservative design features and margins impose substantial economic penalties on the costs of electricity.

In addition to HCDAs, discussed on pages 65 to 69, the ERDA safety program is also addressing LMFBR sodium accidents, the LMFBR emergency shutdown system, and LMFBR accident initiators.

SODIUM ACCIDENTS

There are a number of advantages to the use of liquid sodium as a reactor coolant. Liquid sodium--which is used in the LMFBR--is a superior heat transfer fluid with a high heat capacity and good thermal conductivity. Furthermore, sodium has a high boiling point and system pressures in sodium-cooled reactors are low and thereby reduces the danger of a loss-of-coolant accident. However, there are dangers involved in the use of liquid sodium because it can react violently when brought into contact with air, water, and concrete. In addition, burning sodium gives off caustic fumes.

The primary coolant system in LMFBRs is surrounded with inert gas to avoid the possibility of a violent sodium-air reaction in the event of a primary system break. A sodium fire would more probably occur in the secondary cooling system, the system that transports heat from the primary cooling system to the water which produces the steam. The secondary cooling system contains essentially no radioactivity; therefore, this system is not contained in an inerted atmosphere.

A sodium-water reaction is also a possibility in LMFBRs. Such an accident recently occurred in a Soviet LMFBR, the BN-350. A tube in the sodium-to-water steam generator broke, causing a large scale and violent reaction. Although the explosion caused internal damage to the steam generators, it apparently did not result in damage to any other parts of the system.

ERDA has been experimenting with sodium fires for many years, and some good experimental data and analytical models are available. ERDA had budgeted approximately $500,000 2/ during fiscal year 1975 to study the effects of sodium on different types of materials, such as concrete and steel, and to study sodium fires in a pipe burst situation.

Some LMFBR critics have cited the potential for sodium fires as an LMFBR safety problem and have also pointed out that steam generator leaks are common in LWRs.3/ ERDA and NRC officials, however, agree that sodium fires and sodium-water reactions are not a major public safety problem in LMFBRs. However, these phenomena constitute a potential economic problem because a sodium fire would cause a reactor shutdown while repairs are being made.

SCRAM RELIABILITY

The first LMFBR demonstration plant will contain two redundant scram (emergency shutdown) systems, one controlled electrically and the other pneumatically. The scram systems are designed to be triggered by sensors scattered throughout the reactor to detect abnormal occurrences. In the event of an abnormal occurrence, the scram systems are designed to shut the reactor down by inserting safety rods into the core. The rods contain materials that would stop the reactor operation by absorbing the neutrons which produce the nuclear reaction.

Experts have told us that failure to shut down an LMFBR in some emergencies could cause the reactor to suffer a core disruptive accident. Two major questions to be answered are: What degree of reliability should be set as a goal for the scram systems? What degree of reliability has, in fact, been achieved? The first question will undoubtedly involve judgmental factors weighing the magnitude of consequences of failure to shut down the reactor in an emergency. Setting a target reliability will also involve assessing all the other major aspects of LMFBR safety. If very high targets of reliability are set, it may be very difficult, or impossible, to demonstrate that they have been achieved in practice. In essence these questions involve both policy matters (how much safety is enough?) and technical matters (what is the reliability of the system?)

NRC has established a "what is reliable enough" criterion for LWRs. If failure to shut down an LWR is shown to be no more probable than 1 in 10 million for each reactor each year, the consequences of such failure need not be considered in the design of the reactor.4/

Some critics of the LMFBR claim that the scram systems in LMFBRs must be faster acting than the safety control systems in other types of reactors. According to these critics, under an accident situation, the power level in LMFBRs might rise so rapidly that the ordinary safety controls could not have time to operate before the reactor was seriously damaged.5/ However, NRC told us that this claim was based on a technical misconception and that LMFBR scram systems do not have to be faster acting. In addition, ERDA told us it is not physically possible to achieve the rapid increases in power level hypothesized by the critics. ERDA and NRC experts contend that reliability of the system is what has to be shown.

Critics of the program also claim that ERDA may never be able to demonstrate that the scram systems are reliable enough to prevent serious LMFBR accidents.5/ ERDA, however, holds the position that it can adequately demonstrate through test and analysis that the LMFBR emergency shutdown systems are reliable enough to prevent serious accidents in the reactor.

In determining the licensability of LMFBRs, NRC will determine whether there is sufficient analytical and experimental data available to make an engineering judgment that the scram systems are reliable enough.

ERDA has started an effort to develop success criteria for scram reliability. ERDA schedules call for the initial definition of shutdown reliability requirements by June 1976.6/ After a scram criterion has been established, the current state of the art will be reviewed to determine what experiments and analysis are needed.

NRC has expressed the opinion that significant design and construction decisions will have to be made on the Clinch River plant before this information is available.

ACCIDENT INITIATORS

According to ERDA nuclear safety experts, there are four principal initiators which could lead to a fuel meltdown and subsequently to a core disruptive accident.

Pump failure

In the case of a pump failure and loss or decrease of coolant flow, the nuclear fuel could overheat if the emergency shutdown system also fails. The overheated fuel could cause any remaining coolant in the system to boil. The vaporization of the coolant by boiling could, in turn, cause further overheating and melting of the fuel. Although backup power sources are provided to prevent pump failures, it is expected that such failures will occur on very rare occasions. The LMFBR developers believe that action of the two independent and diverse emergency shut down systems will prevent fuel melting in the event of such an accident. According to the developers, the emergency shutdown systems are so designed that relatively little additional heating of the fuel would occur.

Insertion of large amounts of reactivity

In the event of a continuous insertion of large amounts of reactivity in conjunction with failure of the emergency shutdown system, the fuel would overheat beyond the cooling capability of the sodium coolant and melt. However, ERDA safety experts consider the continuous insertion of large amounts of reactivity to be physically impossible since no source of this type of reactivity has been identified.

Tests are being made to study fuel melting caused by pump failure and reactivity insertion, both of which are similar in that they could cause a powerflow mismatch--a situation where either there is not enough coolant flowing past a fuel element at normal power to keep it at its normal temperature or the normal flow of coolant past an overheated fuel element is not sufficient to cool it.

Current test emphasis on these two initiators is to develop input data to be used in computer models simulating powerflow mismatch. The fiscal year 1975 budget for the test and analysis in this area is approximately $4 million.2/

A break in the sodium cooling system

Loss of cooling to the fuel elements as a result of a break in the sodium cooling system may cause the elements to melt. However, the liquid sodium coolant is maintained under relatively low pressure and would not be prone to rapid expulsion in case of a breach in the system.

Both ERDA and NRC consider catastrophic breaks in the LMFBR sodium coolant systems to be unlikely. NRC believes, however, that such a break could possibly occur and the potential consequences are great enough to warrant providing for such an event in the design of the LMFBR. Although ERDA officials agree that small leaks may occur in LMFBRs, they consider it extremely unlikely that a serious break would occur. In the event that NRC requires that protection against the consequences of a serious break be provided for in the LMFBR design, ERDA believes it can do so without any major problems.

ERDA is spending approximately $4 million during fiscal year 1975 2/ in R&D efforts to determine the probability of breaks in the LMFBR coolant system and to determine at which points in the system they are most likely to occur. ERDA has also budgeted about $1 million during fiscal year 1975 2/ to both update current codes and develop new codes for computer simulation of accidents involving breaks in the sodium system. In addition, as part of its CRBR design effort, ERDA is studying design features which could accommodate such accidents.

Channel blockage

Blockage of the channels through which the sodium coolant circulates between the fuel elements in the core occurred in an LMFBR in 1966. A loose component in the Enrico Fermi Reactor produced almost total blockage of one of the channels in the reactor's core and partial blockage of another. The blockage caused the melting of two fuel subassemblies. Fuel melting, however, did not spread to other portions of the core.7/

At one time a major concern among experts was that small blockage of the channels in the core could cause individual fuel pins to melt, which could, in turn, cause adjacent fuel pins to melt and that such melting could spread rapidly and result in the failure of the entire core.

However, ERDA and NRC nuclear safety experts have told us that this problem is of lesser concern to them that it was at one time. Tests to date indicate that the rapid spreading (seconds or less) of fuel melting among the fuel pins in the core should not pose a major problem in LMFBRs. ERDA is currently studying the effects of a slow buildup of blockage (minutes or longer) and the likelihood of fuel melting spreading under these conditions. ERDA has budgeted approximately $2 million during fiscal year 1975 2/ to study this safety area.

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6/"LMFBR Shutdown System Reliability, U.S. Atomic Energy Commission Goals," Program and Budget Proposal (Form 189a) No. 13972., September 13, 1974, pp. 1, 3, 4.

7/R. Crawford, et. al., "Sub-assembly Boundary Integrity: An Interim Report," U.S. Atomic Energy Commission, Argonne National Laboratories, ANL/RAS 73-13, May 1973, pp. 5-6.

NUCLEAR REACTOR ALTERNATIVES

Assessing the relative merits of various nuclear options is not a novel idea. In 1962 a report to the President on civilian nuclear power was prepared by the AEC. 1/ AEC concluded that the development and exploitation of nuclear power should be vigorously pursued with added emphasis on stimulating industrial participation, including (1) the demonstration of economic nuclear power by constructing LWRs, (2) the early establishment of a self-sufficient nuclear power industry that would assume an increasing share of development costs, (3) the development of improved converter reactors (more efficient users of uranium than LWRs) and later breeder reactors to improve the use of nuclear fuels, and (4) maintenance of U.S. technological leadership in the world by means of a vigorous nuclear program and appropriate cooperation and assistance from foreign countries.

During the intervening years, AEC narrowed its study of potential reactors to those shown in table 10, which are now being studied by ERDA. By far the greatest amount of emphasis has been given to the LWR and LMFBR concepts. During the past few years, increasing attention has gone to fusion.

TABLE 10

Reactor Concepts Being Studied by ERDA

- LWRs
- Breeder reactors:
  - LMFBR
  - LWBR
  - MSBR
  - Gas-cooled* fast breeder reactor
- Advanced converter reactors:
  - Heavy water moderated** and cooled reactor
  - HTGR
- Fusion reactors:
  - Magnetic confinement reactors
  - Inertial confinement reactors

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*The coolant is the medium circulated through a nuclear reactor to remove or transfer heat. This heat eventually serves to produce steam which drives the plant generators. Common coolants are water, helium, and liquid sodium.

**A moderator is a material--such as ordinary water or heavy water, or graphite--used in a reactor to slow high-energy neutrons, thus increasing the likelihood of further fission.

Note: Numbered footnote references to app. III are on pp. 125 and 126.

Only the LWR and HWR reactor concepts are proven commercially viable, and only the LWR in the United States. Each of the other concepts are either under R&D or involved in demonstration programs. Thus they still face many of the uncertainties associated with the LMFBR.

When looking at the advantages and disadvantages of these concepts, it should be remembered that, except for the LWR, none has received the scrutinized public review given to the LMFBR. With the possible exception of fusion, alternative reactors would not greatly differ with respect to safeguards, waste management, and most environmental and safety considerations.

LIGHT WATER REACTORS

LWRs are widely recognized as the most developed of the world's nuclear technologies. As of September 30, 1974, U.S. utilities had built, ordered, or announced plans for about 222 LWRs; 12 additional LWRs were ordered or announced and than canceled. About 55 LWR plants were in operation as of that date. Only nine other nuclear plants have been built, ordered, or announced--all HTGRs. 2/

A major obstacle to continued reliance on LWRs is the recognition that their poor use of nuclear fuel is hastening depletion of economically recoverable uranium resources. Even with the recycling of plutonium by-products, which has not yet been approved by NRC, LWRs would still use less than 2 percent of the energy potential of uranium. By hastening the depletion of uranium resources, continued proliferation of LWRs would favor introduction of an LMFBR or some other type of breeder.

LWR capital costs will at least initially be lower than those of the LMFBR, 3/ but proponents expect that the fuel cost savings possible with LMFBRs would eventually offset this advantage. LMFBR-LWR fuel cost differentials are discussed on pages 59 and 60.

With respect to environmental impacts, LWRs discharge about 25 to 40 percent more waste heat than current fossil and projected LMFBR plants, owing to a thermal efficiency of about 33 percent versus efficiencies of about 40 percent 4/ for these other plants. This results in greater needs for cooling water.

LWRs require many times as much land for mining uranium as do LMFBRs of equal size. 5/ Other environmental impacts are expected to be comparable for LWRs and LMFBRs.

BREEDER REACTORS

There are other breeder concepts in R&D besides the LMFBR. Probably the most advanced breeder concept--except the LMFBR--is the LWBR. Application of the other breeder concepts--the MSBR and the GCFBR--appears to be further in the future.

Light water breeder reactor

This reactor might combine the well-developed LWR technology with efficient fuel use by retrofitting pressurized* LWR cores with LWBR cores. It is hoped that retrofitting can be accomplished without extensive costs and changes, although the power output of retrofitted plants may be reduced. This could eliminate some of the uncertainties and costs of developing and implementing a new kind of powerplant as is the case for the other breeder concepts. Utilities, however, may be reluctant to retrofit LWR cores unless the projected fuel savings compensate for the retrofitting costs and possible reduced power output. Proponents expect the LWBR to have approximately the same operating costs as the LWR 6/, hence, at least initially lower than LMFBR costs.

LWBRs would use both uranium and thorium resources as fuel. For initial operation, large quantities of highly enriched uranium would be required. Eventually, it is expected that only thorium need be added as fuel. Proponents hope that over its lifetime this reactor will use two-thirds less uranium than current LWRs. By so doing, LWBRs would conserve uranium while hopefully extracting approximately 50 percent of the energy potential of thorium. 7/ ERDA's estimate of the cumulative demand for thorium through the year 2000 represents only a small fraction of its estimated thorium resources in the United States.

Principal uncertainties include the question of whether or not this reactor will be a breeder or an advanced converter, along with the overall plant economics of the thorium-uranium fuel cycle. For economical operation, it is imperative that a thorium-uranium-233 reprocessing capability be developed. This is further in the future than plutonium

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*A pressurized LWR is one of two types of LWR. The other is a boiling water reactor.

reprocessing. Most of the basic thorium reprocessing R&D is expected to be conducted in connection with the HTGR.

Development of the LWBR concept has been under the technical direction of AEC's Naval Reactors Division (now a part of ERDA). Technical and economic review outside this organization has been negligible and the potential utility commitment is uncertain, although utility spokesmen have expressed interest in learning more about the LWBR.*

A 50-MWe LWBR core is being installed in an ERDA-owned small reactor plant at Shippingport, Pennsylvania, and is expected to begin operation in 1976. Analysis will be undertaken after about 3 years of operation to evaluate performance and to determine the rate of breeding. Successful operation of this LWBR core would prove the technical feasibility of installing breeder cores in pressurized LWRs; however, scale-up problems would still have to be overcome. Thus, if economics permit, commercial introduction of the LWBR might be more rapid than for any of the other breeders which require totally new plants.

Difficulties associated with the handling of uranium-233 from this reactor are similar to plutonium-239 problems with the LMFBR, including nuclear weapons implications.

Environmental impacts are similar to those of LWRs, although, over a period of time, improved fuel utilization should reduce mining requirements.

The LWBR must demonstrate technical and economic feasibility before utility interest can be determined. Even if the LWBR breeds more nuclear fuel than it consumes--the ratio will be marginal. This means that the LWBR would be self-sustaining but could not be expected to produce fuel for additional reactors. In comparison, it is hoped that the first commercial LMFBRs will generate enough nuclear fuel, perhaps every 15 years, 8/ to fuel a new reactor in addition to sustaining its own capacity. Advanced LMFBR fuels being developed are hoped to eventually bring the time for LMFBRs to under 10 years. 9/

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*"The Report of the Cornell Workshop on the Major Issues of a National Energy R&D Program," December 1973, p. 144, urged that LWBR characteristics be described much more openly than has been the case so that utility managements can learn more about it for their planning.

Consequently, the ultimate potential of the LWBR must be viewed from the context of the expected nuclear role in meeting energy demand. LWBRs alone might suffice if a limit is placed on nuclear electrical generation. If, on the other hand, nuclear energy would have to meet a rapidly increasing share of the Nation's electrical generating load, a higher gain breeder, such as the LMFBR, would ultimately be necessary.

Molten Salt Breeder Reactor

The MSBR concept is based on use of a fluid fuel coupled with continuous online fuel processing in which additional fuel can be added at any time without shutting down the reactor. As presently envisioned, the MSBR would utilize a thorium-uranium fuel cycle and thereby offers potential for broadened use of our nuclear resources.

Although the breeding ratio of an MSBR is likely to be considerably smaller than the breeding ratio of the LMFBR, it requires less than half as much nuclear fuel to produce the same amount of power as an LMFBR. As a result, the MSBR's doubling time is expected to be about 20 years. 10/

Use of fluid fuel and online processing would avoid the necessity and problems of solid fuel fabrication, and handling and reprocessing of spent fuel elements associated with all other reactor types. By eliminating transportation of processed fissionable material, online fuel processing would reduce nuclear safeguards problems.

Elimination of fuel fabrication and the need for a small fuel inventory could result in favorable MSBR fuel cycle costs. Refueling without shutting down the reactor could provide a relatively high plant capacity factor in comparison to the LWR and LMFBR. However, demonstration of these savings in contingent on development of an economical, continuous fuel-processing capability.

Although exploration of the MSBR concept has been in process since the 1950s, MSBR technology is still essentially in the initial R&D stage. The concept has yet to demonstrate technical as well as economic feasibility, and its commercialization would be further in the future than that scheduled for the LMFBR. Proponents believe that development costs are lower than those projected for the LMFBR.

MSBR safety characteristics are anticipated to be generally better than those of solid-fueled reactors in terms of potential major accidents. The liquid fuel would operate at low pressure but would retain iodine and strontium, two of the most hazardous fission products. Additionally, very high radioactivity would be present throughout the MSBR system and containing radioactive trititum gas poses a major difficulty. In an experimental molten salt reactor, the corrosive properties of the fluid fuel created serious structural material problems and the need for special maintenance techniques.

The thermal efficiency of MSBRs is projected to be 44 percent. 10/ Thus the amount of waste heat released would be relatively small compared to that of other nuclear and non-nuclear powerplants.

Gas-cooled fast breeder reactor

The GCFBR would use helium gas--rather than water or liquid matal--as the reactor coolant. As presently evisioned, it would operate on the uranium-plutonium fuel cycle, the same as that used for the LMFBR.

The GCFBR is not a new concept. The relative advantages and disadvantages of the GCFBR and LMFBR received considerable study by AEC before the decision was made to emphasize the sodium technology and the LMFBR, based largely on extensive sodium reactor experience.

The GCFBR is expected to breed more nuclear fuel in a shorter time period than the LMFBR. Proponents hope that GCFBR can double its nuclear fuel inventory every 8 to 10 years, 11/ compared to about 15 years hoped for with early commercial LMFBRs. Development of advanced fuels could reduce the times for both reactors. Also, helium does not become radioactive, and unlike sodium, cannot react with air and water should a leak occur. Maintenance of GCFBRs is expected to be easier.

GCFBR's capital costs might be lower than those of the LMFBR and could make possible lower power costs, if certain questions involving design can be resolved favorably. Two unanswered design questions are: How would the core be cooled if power to the helium fans were to fail? Is it possible to economically obtain structural materials strong enough to construct a prestressed concrete reactor vessel massive enough to contain the entire primary coolant system? In any case, because of its early developmental state, GCFBR costs are difficult to predict.

In terms of environmental impacts and safeguarding of nuclear materials GCFBR would be expected to differ little from LMFBRs.

Private interest in the GCFBR is evident and the system developers expect to utilize much of the already developed high temperature gas-cooled reactor technology. In December 1974, AEC said that it believed the GCFBR might not be ready for commercial introduction much before the end of this century even if a full-scale, successful R&D program were carried out.

ADVANCED CONVERTER REACTOR CONCEPTS

There are nonbreeder reactor concepts that offer considerable uranium savings over LWRs, although not as substantial as LMFBRs. These reactors might greatly extend the time before a breeder is needed in the United States by lengthening the life of our low-cost uranium resources.

Heavy water moderated and cooled reactor

Canada has successfully operated an HWR (sometimes referred to as the CANDU) on natural unenriched uranium since 1971 and has demonstrated the basis technology and commercial viability of the HWR system. However, if used in the United States, some anticipate that operation with slightly enriched uranium would be an economic probability. 12/ Although much further in the future, proponents anticipate that these reactors can be economically adapted to the thorium-uranium fuel cycle, thus broadening the nuclear resource base. It is also anticipated that HWRs could operate on recycled plutonium.

With plutonium recycle, the CANDU reactor may be considered about 170 percent more efficient with respect to uranium requirements than LWRs and about 40 percent more efficient than the HTGR assuming thorium recycle. 13/

Four 540-MWe HWRs are currently operating in Canada. These reactors had reportedly achieved capacity factors* averaging in excess of 80 percent, 14/ considerably higher than those of LWRs and fossil plants). Recently, however, problems at one of these plants temporarily forced its shutdown. Unlike LWRs, additional fuel can be added to HWRs without shutting down the reactor.

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*The ratio of the amount of electricity produced to the amount that could have been produced had the plant been running at full power during the period being measured.

Although CANDU power costs have been reported to be low, the economics of application in the United States has been questioned. Capital costs for an HWR plant would probably be higher than LWR costs, although some of this would be expected to be offset by lower fuel cycle costs.

The use of natural uranium in this reactor would avoid the necessity for enrichment. However, as previously mentioned, using enriched uranium might be more economical in the United States where uranium enrichment facilities already exist. But there is a lack of heavy-water separation facilities here. The relatively high cost of these facilities, plus an apparent lack of U.S. industrial and utility interest, seems to deter use of HWRs in this country.

In terms of safety, HWRs are somewhat different than LWRs and LMFBRs. The Canadian reactor employs hundreds of pressure tubes containing heavy-water coolant. Proponents believe that these tubes eliminate the need for a large pressure vessel and render the reactor less vulnerable to complete loss of coolant and core meltdown accidents.

In contract with other fission reactors, HWRs produce large quantities of tritium gas 15/--a radioactive isotope of hydrogen--and containment of this gas is a major safety concern. HWRs also generate large quantities of plutonium. An environmental consideration is the large amount of waste heat generated by HWRs. Their thermal efficiency is about 30 percent, 16/ compared to the expected 40 percent for LMFBRs. In all, a number of uncertainties remain about the licensability of HWRs in the United States, and there has been no NRC licensing review of an HWR concept.

Currently, the U.S. Government does not support any R&D on this concept, but because of a U.S.-Canadian Cooperative Program Agreement, the United States has access to the existing technology. ERDA recently initiated a study of the potential for HWRs in this country.

HTGR

The HTGR operates on the thorium-uranium fuel cycle. The predicted lifetime uranium requirement for an HTGR with recycle is about 25 to 50 percent less than that of an LWR with recycle 16/ but is much greater than that of a breeder reactor. A recent AEC study estimated that, if all reactors built between the years 1985 and 2000 were HTGRs (with recycle of the uranium-233 produced in the HTGR), uranium demand during this period might be reduced from that of LWRs with plutonium recycle by about 15 percent. 17/ Thorium availability is not expected to be a limiting factor. However, operation of the thorium-uranium fuel cycle would require the development of an economic thorium recycle technology.

The HTGR system should permit thermal efficiencies of about 39 percent, 4/ compared to the 33 and 40 percent efficiencies for LWRs and LMFBRs, respectively.

Increasingly discussed as an advantage of the HTGR is its potential for direct cycle gas turbine and high-temperature-process heat applications. A direct cycle gas turbine would make the HTGR more easily independent of water sources for cooling than other types of reactors. And, because of its higher operating temperature, HTGR process heat might be employed for coal gasification, steelmaking, or other industrial processes.

Proponents claim that HTGR costs will approximate those of the LWR. However, recent changes in HTGR pricing policy and an interim evaluation by a private architect and engineering firm indicate that LWRs will have a capital cost advantage. 18/

A 40-MWe HTGR was commercially operated at Peach Bottom, Pennsylvania, from 1967 until November 1974. A 330-MWe demonstration plant began low-power testing in January 1974 at Fort St. Vrain, Colorado, but full-power operation has been delayed until late 1975. Eight HTGRs have been ordered or announced by utilities, including six 1,140 to 1,200-MWe plants. Two additional HTGRs were ordered and subsequently canceled. 2/

HTGR safety and environmental concerns are similar to those of most fission reactors. Their high thermal efficiencies should result in considerably less waste heat than LWRs. Thorium mining has many of the hazards of uranium mining and, because the HTGR is not a breeder, considerably more uranium and thorium mining will be necessary, compared to the LMFBR.

FUSION REACTOR CONCEPTS

All of the reactor concepts discussed above involve fission-type reactors. Fission involves splitting a heavy atom, such as uranium, with the attendant release of energy.

Thermonuclear fusion--or simply, fusion--is the joining of two light atoms to form a heavier one. It occurs constantly on the surface of the sun and results in the release of tremendous quantities of energy.

Fusion holds the promise of an energy source with a virtually inexhaustable source of fuel. In addition, a preliminary analysis of catastrophic accident risks and safeguards problems indicates a relative safety advantage for fusion over fission, although waste disposal problems for fusion might approximate those of fission.

To date principal research efforts have been focused on attempts to prove the scientific and technical feasibility of various theoretical approaches to the concept. Federal efforts to develop these approaches are discussed in our report to the Congress dated May 22, 1975, and entitled "Efforts to Develop Two Nuclear Concepts that Could Greatly Improve This Country's Future Energy Situation."

Although scientists have not yet proven the controllability of sustained fusion reactions, fusion proponents speculate that a fusion demonstration plant might go into operation by the mid-1990s. But even if they are right and considering present uncertainties as well as time requirements for gaining operating experience and commercialization once a demonstration plant is built, it would probably be about the year 2020 before fusion reactors could make a major contribution to our energy supplies. As with LMFBRs, capital investment, rather than fuel costs, is expected to be the major cost of producing power from fusion reactors.

Despite its many promises and because of its early state of development and corresponding uncertainties, relying on fusion instead of the LMFBR or any other energy supply source appears to be a precarious energy course for the Nation at this time.

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18/ United Engineers and Constructors, Inc., "Interim Evaluation of the Economic Relationship Between HTGR and LWR Plants," April 1, 1975, submitted to the U.S. Energy Research and Development Administration.

UNITED STATES
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION
WASHINGTON, D.C. 20545

July 22, 1975

Honorable Elmer B. Staats
Comptroller General of
the United States
General Accounting Office

Dear Mr. Staats:

We consider "The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties" to be a very important report. We appreciate the opportunity to work with members of your staff during its preparation and review. It appears that our problems with the draft were considered in a constructive fashion during the staff level meetings. However, we are concerned that parts of the report present information that would tend to decrease the urgency of the breeder program without presenting other readily available information that would be helpful for a more balanced understanding of the need for the LMFBR.

We recognize the pressures on GAO to release the report as early as possible. However, we strongly request an opportunity to review the final text before submitting final ERDA comments. For your information we are enclosing preliminary comments based on the draft report and the discussions with your staff. We would like to have such comments included in the report, but need to confirm or revise them after reviewing the final text. Please be assured that a review of the final text will be given a very high priority and will be accomplished within a few days.

Overall, we think GAO has done very well on a very difficult and complex assignment. We find the conclusions of the report to be reasonable and we are in general agreement with the recommendations.

Sincerely,

Robert C. Seamans, Jr.
Administrator

Enclosure:
As stated

Energy Research and Development Administration (ERDA) Comments on Recommendations and Conclusions of the GAO Report "The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties"

Recommendation A

Obtain Adequate Information on Domestic Uranium Resources at Current and Anticipated Future Prices

The National Uranium Resource Evaluation (NURE) Program is already a vigorous program that was started by the AEC in FY 1974 and continued and expanded by ERDA. The program receives continuing management attention to assure that it is performed as expeditiously as possible.

We believe that the NURE program and continued aggressive exploration, together with supporting geologic studies and mapping by the Geological Survey, will add to our uranium resource base. However, we caution against over optimism or over simplified approaches to a difficult problem. The data developed on uranium resources over the past 30 years is probably more extensive than for any other mineral commodity. It should also be noted that the "more optimistic" non-ERDA resource assessments are statistical extrapolations and interpretations of data developed by ERDA and are not based on additional geologic investigations.

With regard to the size of the resource base needed, it should be recognized that identification of resources equivalent to the fuel requirement to a given date is not sufficient to supply the annual demand to that date because the number of production operations and their capacity begin to decline unless resources continue to expand. The rate of production possible from a given resource begins to decline long before those resources are finally depleted as in the present situation with oil. This is particularly true for uranium for which the demand is projected steadily to increase. Thus, resources much larger than the actual demand to a given date are needed to support the production rates required.

Recommendation B

Explore Development of Policies and Mechanisms Which Are Acceptable to Society to Deal With the Outstanding Environmental and Safety Questions

The priority ERDA attaches to this subject is illustrated by the fact that we have an Assistant Administrator for Environment and Safety. Under the Assistant Administrator there are four Headquarters divisions specifically responsible for developing policies and mechanisms and otherwise dealing with environmental and safety matters. The Assistant Administrators for Nuclear Energy and for National Security as well as the entire agency are very concerned with these issues. Further, the priority given to these matters was emphasized by the establishment last year of the Division of Safeguards and Security to serve as the focal-point for safeguards efforts.

Each of our programs is required to give careful consideration to environmental and safety matters. The report discusses the recriticality accident at some length as one of the major factors being considered in LMFBR design. This discussion is reflective of the attention being given to this area by ERDA, but does not reflect the progress being made. The question of whether a "core catcher" should be included in the final design will be resolved with NRC. Similarly, we plan to continue to work with the Environmental Protection Agency on many matters, including researching thoroughly the environmental and health aspects of coal.

Transportation of nuclear materials and the management of radioactive wastes are both subjects that receive careful management attention within ERDA. The subject of waste management is, as you know, particularly sensitive and we are working vigorously to develop a program of permanent storage while maintaining an interim retrievable storage capability.

The question of acceptance by society is very important. This issue paper should be helpful in informing the public that there are no "risk-free" alternatives for supplying power to the nation. It is also important for the public to understand that most of the issues have relative answers - not absolute ones.

- Virtually all of the safeguards related risk associated with nuclear power will exist whether the United States continues or abandons its nuclear programs as long as foreign nuclear power programs continue. U. S. actions will, of course, help to determine the extent of the risks. ERDA is taking a lead role in the development of international safeguards.

- The potential for clandestine groups operating in opposition to society already exists, and materials of lethal potential equivalent to or greater than plutonium (nerve gas, botulism, etc.) will exist even if breeder reactors are not developed.

- Safeguards measures against theft and diversion of significant quantities of nuclear materials are mainly internal to operations where the materials are used. The number of guards for all LMFBR activities has been estimated and reported in the December 1974 Proposed Final Environmental Statement on the LMFBR Program. The number does not significantly increase the total number of guards and police needed by society for all purposes. We are not aware of anything that indicates a substantial loss of political freedoms, civil liberties, or personal mobility related to an effective safeguards program.

Recommendation C

Improve Our Understanding of And Cooperation With Foreign Government Efforts to Develop LMFBRS.

We are continuing our efforts in this area, and will cooperate with the NRC with respect to identifying the problems in NRC's licensing the French LMFBR or components for use in the United States. It should be recognized however, that such an effort is very dependent on the attitudes of the foreign countries towards disclosing their technology, their judgment with respect to the potential for commercial competitiveness within the U. S., and their assessment of the licensing problems that might be encountered.

It should be noted that our efforts in this area will be supplemental to our development effort. Conceptually it might be possible for the U. S. to be totally dependent on

APPENDIX IV

foreign LMFBR programs for breeder technology. However, there is a substantial risk in such a course because it would involve dependence on foreign sources for an incompletely developed technology. For so important a commodity as energy, a strong U. S. capability is essential.

Recommendation D

Extend and Improve Our Projections of Demand For Electrical Energy as More Information Becomes Available

We plan to continue to work with the Federal Energy Administration and with other groups and to continue our own efforts in this area.

With respect to the conclusions of the report, we agree that it will be some years into the future before a firm decision is needed "as to whether the Nation will commit itself to LMFBR economy." However, in view of the very long lead-time in establishing a new, widely used energy supply, it is necessary to make firm decisions now on the demonstration phases of the LMFBR program. These include interim decisions related ultimately to commercialization efforts. In view of the urgency of the world energy situation we consider it imperative to conduct a balanced program with reasonable overlap rather than follow a fully sequential development and implementation strategy.

We would also like to emphasize a point made in the report - without breeder reactors the nuclear fission option for generating power is constrained by the availability of economically recoverable uranium, and this is inefficiently used in today's LWR's. The use of breeder reactors could extend the usefulness of our uranium resources from a few decades to centuries.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

July 16, 1975

Mr. Henry Eschwege, Director
Resources and Economic Development Division
United States General Accounting Office
Washington, D. C. 20548

Dear Mr. Eschwege:

This is in reply to your letter of June 25, 1975 requesting comments on the proposed GAO issue paper entitled "The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties".

Our review of the topics covered in this report indicates that the majority of them are related to the responsibilities of the other Federal agencies to which you have sent copies. Therefore, we have focused our comments on only those sections which pertain to NRC responsibilities in connection with the LMFBR. Enclosed are comments prepared by the NRC staff.

I hope that these comments are helpful to you. Please let me know if we may provide any further assistance.

Sincerely,

Lee V. Gossick
Executive Director
for Operations

Enclosure:
Comments by NRC staff

NRC STAFF COMMENTS ON DRAFT GAO ISSUE PAPER
"THE LIQUID METAL FAST BREEDER REACTOR:
PROMISES AND UNCERTAINTIES"

Overall Comment

In general this report reflects an accurate picture of the status of safety and licensing of LMFBR's. Only a modest number of comments have been made to make the report more precise.

[See GAO note, p. 135.]

Part 7 - Program Costs and Schedule

Page 55, Paragraph 1: Suggest first paragraph be rewritten as follows: Delays in the CRBR project have already resulted in delays in the licensing process. The September 1, 1975 milestone for obtaining a limited work authorization was based on submitting an acceptable Environmental Report (ER) in October 1974, and an acceptable Preliminary Safety Analysis Report (PSAR) in November 1974. The ER was not sufficiently complete to be acceptable until April 1975, and a partial PSAR was not submitted until April 1975. In addition, the PSAR submitted in April 1975 is not judged by either PMC or NRC staff to be complete, and a major amendment is scheduled for October 1975 to correct these deficiencies. NRC staff officials told us that neither the limited work authorization milestone nor the construction permit milestone can, therefore, be met. A delay in obtaining the limited work authorization of at least 10 months has resulted, which, because it is on the critical path for completion of the CRBR, will delay CRBR operations until late 1983 at the earliest. This assumes that the results of the NRC staff environmental and general site suitability reviews are favorable. If they are not favorable, and/or a favorable clearance on the LWA is not reached by the atomic safety and licensing board after public hearings, which are likely to be contested, there could be further delay.

[See GAO note, p. 135.]

Part 9 - LMFBR Environmental and Safety Issues

Page 72, lines 1-4: The relationship stated in the GAO report between quantity of material and probability of theft attempts is only assumed and has not been established; further, it is regarded by some experts as incorrect. Beyond a threshold quantity consistent with a moderate nuclear industry, the rate of attempts could more likely be dependent mainly on the prevalence of anti-social behavior rather than the quantity of nuclear material in the fuel cycle.

Page 72, lines 17-20: Change to read: "... could be released to the environment. Additionally, while the potential for a catastrophic accident is a risk common to all large power reactors, there is some theoretical possibility of recriticality, which could lead to a significant energy release. This is unique to fast reactors such as the LMFBR. Such an energy release would not be ..."

Page 73, line 18: Substitute "subassembly" for "sodium".

Page 76, line 6: Suggest adding the following sentence at the end of this paragraph: "Others have said that the provision of a core catcher in the CRBR would not necessarily be a commitment to the need for core catchers in all future LMFBR's."

Page 76, line 8: Change to read: If a core disruptive accident with a magnitude and characteristics capable of severely damaging the primary reactor system integrity must be provided for in the design...

Page 78, line 16: Change "safety" to "safeguards".

Page 79, paragraph 2: Add sentence at end: "This objective was not accepted by the AEC, and the matter of safeguards needs is now under study in NRC.

Page 85, line 6: NRC has not proposed, and are not aware that AEC or ERDA have proposed, a "national intelligence operation" as suggested here, but rather increased liaison with police intelligence organizations in order to be informed concerning potential adversary acts.

Page 89, paragraph 1: Suggest deleting first sentence and change rest of paragraph to read: "Under current Federal regulations (10 CFR 50, Appendix F), civilian liquid high-level wastes must be solidified into a physically and chemically stable form that is essentially insoluble in water within 5 years of their generation and, within 10 years, must be shipped to a Federal repository. Thus it appears that the experience with leaks that have occurred in connection with AEC high level wastes will not be applicable to commerical wastes."

Part 11 - Conclusions and Recommendations

Page 104, line 14: Change "a recriticality accident" to "molten fuel".

Page 105c, last 4 lines: The information needed to identify potential licensing issues in connection with French LMFBRs could not be obtained by the NRC unless a plant proposed for use in the U.S. were put into the NRC licensing process. This recommendation should be modified accordingly.

Appendix 2 - LMFBR Safety Program

[See GAO note.]

Page 121, line 10: Substitute "subassembly" for "sodium".

Page 124, lines 6-15: The claim that LMFBR scram systems must be faster acting than those in other reactors is incorrect and is based on a technical misconception. While it is true that the prompt neutron lifetime is shorter in an LMFBR, this does not govern the behavior of the reactor below prompt critical. It is in the regime below prompt critical when the reactor behavior is governed by delayed neutrons that the scram system must be called upon to protect the reactor. Above prompt critical the power is increasing so fast that no scram system can operate fast enough to prevent some damage.

Page 140, line 20: Add to the last sentence "however, there has been no NRC licensing review of an HWR concept."

Page 141, line 16: Change sentence to read: "A direct cycle gas turbine would make the HTGR more easily independent of water sources for cooling than other types of reactors."

GAO note: Material deleted no longer pertains to this paper.

FEDERAL ENERGY ADMINISTRATION
WASHINGTON, D.C. 20461

JUL 18 1975

OFFICE OF THE ASSISTANT ADMINISTRATOR

Mr. Monte Canfield, Jr.
Director
Office of Special Programs
United States General Accounting Office
Washington, D.C. 20548

Dear Mr. Canfield:

This responds to your letter, of June 25, 1975, to Frank Zarb on your proposed issue paper entitled "The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties."

We have reviewed the draft document, and our comments are enclosed. Mr. Edwin (Al) Kuhn, Acting Associate Assistant Administrator for Energy Conversion (telephone 961-6037) has informally been in touch with Mike McCloskey as requested in your letter.

Thank you for the opportunity to provide our comments, and please let us know if we can be of further assistance.

Sincerely,

Donald B. Craven

Donald B. Craven
Acting Assistant Administrator
Energy Resource Development

Enclosure

FEA Comments on Draft GAO Issue Paper

"The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties"

(Comments are limited to GAO conclusions and recommendations.)

1. GAO Conclusion #1: Don't abandon the fission option.

   FEA Comment: Agree. In addition to the reasons given by GAO, there is the tremendous cost in jobs, pollution from alternate energy sources, and increased costs of electricity that would result.

2. GAO Conclusion #2: Continue to treat the LMFBR program as a development effort, deemphasize concern with commercialization as it is not relevant at this time.

   FEA Comment: Agree

3. GAO Conclusion #3: It is not reasonable to attempt to accelerate the schedule.

   FEA Comment: Agree regarding commercialization. Disagree with regard to Clinch River Demonstration Plant (CRBR.) The most recent startup date projected by ERDA, 1987, will add many millions of dollars to this program. We believe by striving for a tight but achievable schedule such as 1982, the program will be tightened up with decreased opportunity for excursions into peripheral areas, and with no loss of essential information. Six years of actual construction time is enough time to build a nuclear power plant, even one with some unique characteristics, such as the CRBR.

4. GAO Conclusion #4: Presence of foreign LMFBR programs would render a U.S. decision to withdraw meaningless from standpoint of safeguards.

   FEA Comment: Agree.

5. GAO Conclusion #5 Proper approach is to pursue the existing LMFBR program. "Not till some point in future, perhaps 7 to 10 years fron now, need a firm decision be made as to whether the Nation will commit itself to an LMFBR economy."

FEA Comment: We do not anticipate there ever being a "national" decision to commit the Country to an LMFBR economy. If the demonstration plant proves reliable, individual utilities will make local decisions as economic, fuel availability and demand conditions warrant. These decisions will, of course, be subject to NRC licensing actions.

6. GAO Recommendation A-1:
ERDA should expedite its National Uranium Resource Evaluation Program.

FEA Comment: Agree.

7. GAO Recommendation A-2:
Congress explore with ERDA and Geological Survey the feasibility of thorough appraisal of U.S. uranium resource base, including test drilling.

FEA Comment: Agree. FEA plans to consider policy initiatives and to monitor program activity in this area, since it primarily involves energy production rather than research and development.

8. GAO Recommendation B-1:
ERDA and NRC give high priority to developing systems to safeguard nuclear materials....

FEA Comment: In addition to emphasizing the priority of development, we feel there is a need for a series of prompt interim decisions which would enable industrial ventures to go forward in parallel with further development of safeguards systems.

[See GAO note, p. 139.]

[See GAO note.]

10. GAO Recommendation B-3:
Prompt decisions needed on radioactive waste management.

FEA Comment: Agree. Suggest equal emphasis be given to need for a prompt decision on criteria and standards for waste solidification, so private industry can get on with installing and operating such facilities.

11. GAO Recommendation C:
Improve our understanding of and cooperation with foreign governments to develop LMFBR's.

FEA Comment: Agree

12. GAO Recommendation D:
Extend and improve our projections of demand for electrical energy as more information becomes available.

FEA Comment: Agree. FEA has efforts underway to develop more comprehensive projections of electricity growth and will work closely with both ERDA and FPC in carrying out these efforts.

GAO note: Material deleted no longer pertains to this paper.

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
WASHINGTON, D.C. 20460

July 25, 1975

OFFICE OF
PLANNING AND MANAGEMENT

Mr. Henry Eschwege
Director
Resources and Economic Development Division
U.S. General Accounting Office
Washington, DC 20548

Dear Mr. Eschwege:

Your letter of June 25, 1975, transmitted the draft issue paper entitled "The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties."

We have had the paper reviewed by our technical offices and they offer the attached specific comments for your consideration. The substantive content of the paper is well constructed and informative, and we appreciate the opportunity to review it in its draft stage.

Sincerely yours,

Alvin L. Alm
Assistant Administrator
for Planning and Management

Enclosure

COMMENTS ON DRAFT LMFBR ISSUE PAPER:
LMFBR: Promises and Uncertainties

As a general comment, there is some concern over the use of non-specific terms throughout the report; e.g., sufficient safety, adequately protected, extremely dangerous. It would be helpful to have such terms elucidated, i.e., what criteria are there to evaluate the content in these general descriptive phrases?

Page 2, second full paragraph, the question: "What are the risks?" should be expanded to include costs, risks, and benefits in the broad social sense, not necessarily restricted to economics.

Page 9, middle paragraph - Of the wastes released to the air and water environs, waste heat is a major one, and conventional (LWR) nuclear plants release some 60% more waste heat than do fossil fired plants.

[See GAO note, p. 143.]

The statement about less mining per unit of contained energy depends critically on existence of a widely-developed and smoothly-functioning breeder reactor system. In the absence of such a breeder system uranium mining impacts will be comparable to those from coal mining by the turn of the century, if current estimates of uranium resources prove accurate or high, and non-breeder reactors come into wide use.

Page 18, second full paragraph - The economic risk (the probability of some acceptable return on research money invested) should be calculated as part of the evaluation of the LMFBR program. This would seem to be a central issue in the broad assessment of the program.

On Table 2, after page 19 - (1) It seems that the assumption of capital costs associated with the LWR yields costs that are too low, given recent information; (2) the differential between the LWR and the LMFBR also seems too low.

[See GAO note, p. 143.]

cycle appear to be missing, along with their uncertainties, i.e., reprocessing costs and the economies of scale of handling the plutonium fuel.

Part 6 provides a good discussion of the availability of uranium. Some of the conclusions from this section (as well as from elsewhere in the report) should perhaps be presented in the front of the paper.

[See GAO note, p. 143.]

Page 46, second full paragraph - There seems to be a basic inconsistency in the estimated time requirements to bring new technology "on line" between this and ERDA's projections on the development of a commercial LMFBR.

Page 68 - Again, the appropriate question seems to be: What is the economic risk of investing capital in the LMFBR research program? How much capital is irretrievable (capital from which there will be no payoff if the LMFBR does not succeed)?

Page 71 - The statement that radioactive materials cannot be neutralized should perhaps acknowledge that research is underway to investigate the possibility that transmutation of certain troublesome waste products might be possible by intense neutron irradiation, as in a nuclear reactor.

[See GAO note, p. 143.]

Pages 90-94 - A study recently completed for EPA should be of help to GAO in this section. A final report was submitted to EPA by Teknekron, Incorporated of Berkeley, California, and is entitled: "Fuel Cycles for Electrical Power Generation, Parts I and II. Towards Comprehensive Standards: The Electric Power Case, Phase I." This study is available for your review if you feel it would be helpful.

Page 86 - The reference to "high level wastes such as ^{90}Sr and ^{137}Cs" is misleading. High level wastes are defined in terms of concentrations, or origin, rather than specific nuclides.

Page 103, line 14 - The safety problem of diversion of nuclear materials (to construct an illicit nuclear explosive device) does not exist with the LWR unless the spent fuel is reprocessed to recover (recycle) the plutonium. Hence, there is a qualitative difference between LWR's without plutonium recycle and commercial LMFBR's which require recycle. As you know, the LWR recycle question has not yet been decided.

[See GAO note.]

Page 133 - The explanation of thorium utilization in LWBR and thorium reserves gives a very misleading picture of the potential of the LWBR. The "50%" figure represents the fraction of energy that will eventually be extracted from the thorium added to the LWBR, and not from the extensive thorium resources. Actually, using the same reference (AEC's PFES) it appears that both domestic and world thorium resources are, at least at reasonably low price, less than uranium resources (cf. Tables 6A.1-2, 6A.1-15, 6A.1-16 and Figure 6A.1-5).

[See GAO note.]

Page 144 - The definition for "Breeder" should reflect that it requires fissions which produce more than two neutrons per fissioned nucleus (not more than one), since a reactor using fuel which produces between one or two neutrons per average fission could never be a breeder. One neutron is needed to be absorbed to replace the fuel burned.

Page 145 - The definition for "Enrichment" should be broadened to include any elements, with uranium as an example.

[See GAO note.]

GAO note: Material deleted no longer pertains to this paper.

PRINCIPAL OFFICIALS OF AEC AND ERDA RESPONSIBLE FOR ADMINISTERING THE ACTIVITIES DISCUSSED IN THIS ISSUE PAPER

	Tenure of office From	To
AEC		
CHAIRMAN:		
Dixy Lee Ray	Feb. 1973	Jan. 1975
James R. Schlesinger	Aug. 1971	Feb. 1973
Glenn T. Seaborg	Mar. 1961	Aug. 1971
GENERAL MANAGER:		
Robert D. Thorne (acting)	Jan. 1975	Jan. 1975
John A. Erlewine	Jan. 1974	Dec. 1974
Robert E. Hollingsworth	Aug. 1964	Jan. 1974
ERDA		
ADMINISTRATOR:		
Robert C. Seamans, Jr.	Jan. 1975	Present
ASSISTANT ADMINISTRATOR FOR NUCLEAR ENERGY:		
Richard W. Roberts	June 1975	Present
Robert D. Thorne (acting deputy)	Jan. 1975	June 1975

GLOSSARY

Breeder — A nuclear reactor that produces more fuel than it consumes. Breeding is possible because of two facts of nuclear physics.

1. Fission of some atomic nuclei produces more than one neutron for each nucleus undergoing reaction. Hence, one neutron can be used to sustain the fission chain reaction and the excess neutrons can be used to create--breed--more fuel.

2. Some nonfissionable nuclei can be converted into fissionable nuclei as a result of capture of a neutron. Nonfissionable uranium-238, for example, can thus be bred into fissionable plutonium-239.

Breeder reactors are divided into two types: fast breeders, which use high energy neutrons, and thermal breeders, which use neutrons of lower energy.

Breeding ratio — A measure of the efficiency of a breeder reactor. Defined as the number of new fissionable atoms produced per atom of fissionable material consumed.

British thermal unit (Btu) — The amount of energy necessary to raise the temperature of 1 pound of water by 1 degree Fahrenheit. A kilowatt-hour is equivalent to 3,413 Btu's; a barrel of crude oil, 5.6 million Btu's; a ton of bituminous coal, 26.2 million Btu's; a gallon of gasoline, 125,000 Btu's.

Converter — A nuclear reactor that consumes more fuel than it produces.

Coolant — In a nuclear reactor, it is the medium which picks up heat from the reactor core where fission occurs. This heat eventually serves to produce steam which drives the plant generators. In the Liquid Metal Fast Breeder Reactor, the coolant is liquid sodium.

Critical mass — The minimum amount of fissionable material, such as uranium-235 or plutonium-239, that is required to produce a self-sustaining nuclear chain reaction, once it has been initiated by an external source of neutrons.

Deuterium	An isotope of hydrogen having about twice the mass of ordinary hydrogen. It is expected to be the primary fuel for fusion power plants. Deuterium is generally obtained through electrolysis of deuterium oxide (heavy water).
Discount rate	An accounting device used so that a project's future costs also reflect the loss of those benefits which would have been realized if the same funds had been invested elsewhere during the same period.
Doubling time	The time required for a breeder reactor to produce as much fissionable material as the amount normally contained in its core, plus the amount tied up in its fuel cycle--fabrication, cooling, processing, and transporting--and thus to be able to support the operation of an additional reactor of the same kind.
Enrichment	The process of increasing the concentration of uranium-235 in uranium from the naturally occurring level of about 0.7 percent to a higher concentration. The principal process of enrichment is gas diffusion. A second process, the gas centrifuge, is also receiving much commercial attention, especially in Europe. Uranium enrichment requires complex and expensive facilities and large quantities of electricity.
Fertile	Those atoms that can be converted into nuclear fuel (fissionable atoms) in a breeder reactor. For example, uranium-238, plutonium-240 or thorium 232 are fertile materials.
Fissile	Fissionable, capable of fission or of being a nuclear fuel.
Fission	The splitting of atomic nuclei into two or more nuclei of lower atomic weight and whose aggregate mass is less than that of the original nucleus. The process is initiated by the capture of a neutron by the nucleus of the fissionable atom and is accompanied by the emission of one to about three neutrons. The lost mass becomes energy (E) in the amount $E=Mc^2$, where M is the change in mass and c is the speed of light (about 186,000 miles per second). Since

fission produces neutrons, the reaction can be made self-perpetuating. Self-perpetuation, the initiation of fission in adjacent nuclei by neutrons from a nucleus that has undergone fission is known as a chain reaction. If the chain reaction is controlled it can be used to produce heat that can be used for production of steam to generate electricity. When the chain reaction is uncontrolled, it can produce an explosion of tremendous force.

Fuel reprocessing The chemical or metallurgical treatment of used fuel from a nuclear reactor for recovering and decontaminating fissionable materials. The principal operations involved in reprocessing follow.

1. Decay cooling, in which the spent fuel is stored for 3 to about 6 months, often underwater, to allow for decay of short-lived fission products.

2. Removal of the fuel element cladding and dissolution of the fuel and its support material.

3. Chemical separation of the fissionable and fertile constituents.

4. Recovery of the fissionable constituents for reuse.

5. Disposal of radioactive wastes. Because of the intense radioactivity of the spent fuel, most of the operations of a reprocessing plant must be performed behind massive shielding and by remote control. Fuel reprocessing plants are thus much more expensive than conventional chemical plants of comparable size and complexity.

Fusion The combination of two atomic nuclei to yield one larger nucleus whose mass is less than the aggregate mass of the original nuclei; the lost mass appears as energy in the same manner as in fission.

Electrical charges and atomic forces make it very difficult to bring the nuclei close enough together for fusion to occur. Initiation of the reaction therefore requires a combination of very high temperatures and pressures, much higher than have ever been produced under controlled conditions. Because of this requirement for heat, fusion is often referred to as thermonuclear reaction. The hydrogen or thermonuclear bomb is an uncontrolled explosive fusion reaction in which the necessary conditions are achieved by detonation of an atomic bomb.

Isotope — Any of two or more forms of a chemical element having the same atomic number (i.e., the same number of protons) but with different atomic masses because of differing numbers of neutrons in the nucleus. All isotopes of an element have the same number of orbital electrons and thus the same chemical properties, but the differing atomic masses produce slightly different physical properties. Since the atomic mass governs the stability of the nucleus, one or more isotopes of an element may be radioactive or fissionable while other isotopes of the same element are stable.

Kilowatt — The unit of power equal to 1,000 watts. Roughly, equivalent to 57 Btu's per minute.

Laser fusion — A proposed concept in which high temperature and pressure required for initiating fusion are produced by bombarding <u>fuel pellets</u> (frozen deuterium and tritium) with intense bursts of electromagnetic radiation from one or more lasers.

Megawatt — A unit of power equal to 1,000 kilowatts, or 1 million watts.

Moderator — A substance used to slow neutrons to a speed at which there is a higher probability of initiating fission in a nuclear reactor. The neutrons lose energy by colliding with the nuclei of the moderator. The most commonly used moderators include graphite, water, heavy water (deuterim oxide), and beryllium.

Neutron — An uncharged (neutral) elementary particle with a mass slightly larger than that of a proton. Because it has no electrical charge, the neutron is able to penetrate the dense negatively charged electron cloud on an atom and interact with the positively charged nucleus.

Quadrillion	A thousand trillion, or the number 1 followed by 15 zeros.
Radioactivity	The spontaneous disintegration of the nucleus of an atom with the emission of corpuscular or electromagnetic radiation. These emissions are of three principal types, called alpha, beta, and gamma. Alpha radiation is composed of positively charged helium nuclei (two protons and two neutrons) ejected with a velocity 5 to 7 percent that of light. Beta radiation is composed of negative electrons ejected with velocities which may approach the speed of light. Gamma radiation is uncharged electromagnetic radiation similar to x-rays. Although gamma radiation is approximately 100 times more penetrating than that of beta radiation and about 1,000 times more penetrating than that of alpha radiation, it is not necessarily the most dangerous since ingestion must be considered.
Reactor	An assembly of nuclear fuel capable of sustaining a fission chain reaction.
Turbine	A rotary engine turned by the impulse from a current of fluid under pressure. A turbine is usually made with a series of curved vanes on a central rotating spindle. Simple examples of a turbine are a windmill and a waterwheel.

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