REPORT TO THE
JOINT ECONOMIC COMMITTEE
CONGRESS OF THE UNITED STATES

BY THE COMPTROLLER GENERAL
OF THE UNITED STATES

Can The U.S. Breeder Reactor Development Program Be Accelerated By Using Foreign Technology?

For years the United States, Britain, France, the Federal Republic of Germany, the Soviet Union, and Japan have been conducting extensive fast breeder reactor research and development programs. Except for the Soviet Union, these countries lack the energy resources--coal, oil, natural gas, and uranium--that the U.S. possesses and have more urgent needs and shorter time frames for developing commercial fast breeder reactors than does the U.S.

This report addresses the question: can the U.S. save time and/or money by making more extensive use of foreign technology?

Although the Energy Research and Development Administration's efforts to develop areas of exchange are worthwhile and should be continued, it is unrealistic to expect that the U.S. program could be greatly accelerated or that large amounts of money could be saved through quid pro quo exhanges with other nations.

RED-76-93 MAY 6, 1976

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

B-164105

The Honorable Hubert H. Humphrey
Chairman, Joint Economic Committee
Congress of the United States

Dear Mr. Chairman:

In response to your May 2, 1975, request, we are reporting on foreign fast breeder reactor programs and the feasibility of cooperative exchanges of fast breeder reactor technology between the United States and foreign countries developing this type of reactor. Most of the report deals with the status of foreign programs and the benefits from and impediments to exchanging breeder reactor technology.

Officials of the Energy Research and Development Administration and the Nuclear Regulatory Commission and fast breeder reactor program officials of the United Kingdom, France, Federal Republic of Germany, and Japan commented on this report. We revised the report in response to their comments and believe that there are no residual differences in fact. The Energy Research and Development Administration concurs with our recommendation. The Nuclear Regulatory Commission agrees with those aspects falling within its responsibilities.

This report contains a recommendation to the Administrator of the Energy Research and Development Administration which is set forth on page 45. As you know, section 236 of the Legislative Reorganizarion Act of 1970 requires the head of a Federal agency to submit a written statement on actions taken on our recommendations to the House and Senate Committees on Government Operations not later than 60 days after the date of the report and to the House and Senate Committees on Appropriations with the agency's first request for appropriations made more than 60 days after the date of the report.

We will be in touch with your office in the near future to arrange for release of the report so that the requirements of section 236 can be set in motion and so that copies can be provided to other congressional committees and to interested Members of Congress.

Sincerely yours,

Elmer B. Staats

Comptroller General
of the United States

Contents

ABBREVIATIONS

AEC	Atomic Energy Commission
CEA	Commissariat à l'Energie Atomique
CFR	Commercial Fast Reactor
CBR	Commercial Breeder Reactor
CRBR	Clinch River Breeder Reactor
EBR	Experimental Breeder Reactor
EdF	Electricité de France
ERDA	Energy Research and Development Administration
EURATOM	European Atomic Energy Community
FFTF	Fast Flux Test Facility
GAO	General Accounting Office
NRC	Nuclear Regulatory Commission
PLBR	Prototype Large Breeder Reactor
PNC	Power Reactor and Nuclear Fuel Development Corporation
SEFOR	Southwest Experimental Fast Oxide Reactor
UKAEA	United Kingdom Atomic Energy Authority

COMPTROLLER GENERAL'S REPORT TO THE JOINT ECONOMIC COMMITTEE

CAN THE U.S. BREEDER REACTOR DEVELOPMENT PROGRAM BE ACCELERATED BY USING FOREIGN TECHNOLOGY?

DIGEST

The liquid metal fast breeder reactor is the highest priority reactor concept being developed in industrially advanced countries. This reactor can create more nuclear fuel than it uses.

The United States, Britain, France, the Federal Republic of Germany, the Soviet Union, and Japan have been conducting extensive fast breeder reactor research and development programs for years. Each country's breeder reactor program differs in approach and emphasis. All contain or plan to contain many of the same aspects of the U.S. long-range program. (See p. 1.)

Are other countries' programs ahead of the U.S. program? If so, can the United States save time and/or money by using foreign technology? (See p. 1.)

It is impossible to accurately predict which country will be the first to develop a successful commercial fast breeder reactor. However, if development of an intermediate-size demonstration reactor is used to measure program progress, then it appears, at this time, that the French program has advanced the furthest and is progressing the fastest.

The relative status of the other programs cannot be readily determined; with the exception of Japan, they all have or plan to have a demonstration reactor operating before the U.S. Clinch River Breeder Reactor demonstration plant is scheduled to become operational in mid-1983. (See p. 41.)

Except for the Soviet Union, the other countries developing fast breeder reactors lack the energy resources--coal, natural gas, oil, and uranium--that the United States possesses, and they have established more urgent needs and tighter schedules for developing a commercial fast breeder reactor than has the United States. (See p. 14.)

Fast breeder reactor development programs in other countries involve close coordination of government research and development agencies, electric utilities, and industry. Little or no attention is given to developing internal competitive fast breeder reactor industries.

The foreign approach contrasts sharply with the Energy Research and Development Administration's philosophy of developing a broad technological and engineering base to establish the capability for competitive industry.

The philosophy of other countries toward breeder reactor development programs is to learn by building plants. This indicates a willingness to accept greater risks of failure than does the United States approach of developing a strong technological background for building breeder reactors so that, once a decision is made to build, the risk of failure or serious problems is sharply reduced.

Thus, other programs are focused more on earliest possible operation of demonstration breeder reactors with less emphasis on developing the broad array of base technology and component testing programs that characterize the U.S. program. (See p. 14.)

Cooperative fast breeder reactor exchange agreements offer the United States opportunities to save time and/or money because they have the potential for

--broadening the U.S. data base,

--identifying problems in other programs which may help the U.S. program avoid similar problems,

--confirming findings developed by the U.S. program,

--reducing duplicative research and development work, and

--obtaining information on the construction and operational experience of breeder reactors. (See p. 33.)

Various factors impede the Energy Research and Development Administration's efforts to exchange fast breeder reactor technology with other countries, such as

--foreign reluctance to furnish data of possible commercial value,

--foreign views that the U.S. program has little commercially valuable information to offer in future exchanges,

--adverse effects on U.S. balance of payments,

--possible dependence on foreign sources for an important energy system, and

--potential licensing problems in the United States. (See pp. 35 to 40.)

However, the Energy Research and Development Administration, the Nuclear Regulatory Commission, national laboratories, U.S. industrial concerns, and program managers in other countries agree that extensive fast breeder reactor information has been exchanged and the opportunities exist for more beneficial exchanges in the future. (See p. 42.)

GAO concludes that impediments to cooperative exchanges of fast breeder reactor technology with other industrially developed countries become increasingly difficult to overcome as their programs approach commercial status. Therefore, the U.S. breeder reactor development program could not realistically be expected to significantly accelerate or save significant amounts of money through quid pro quo exchanges with other countries. (See p. 42.)

Some governments are concerned that technical data furnished to the Energy Research and Development Administration would be made available to U.S. industrial firms and others under the requirements of the Freedom of Information Act. GAO recommends that the Administrator of the Energy Research and Development Administration seek legislation specifically exempting data acquired through international technology agreements from the disclosure provisions of the act. The Energy Research and Development Administration concurs with this recommendation. The Nuclear Regulatory Commission agrees with those aspects falling within its responsibilities.

Foreign concern about the Freedom of Information Act is clearly subordinate to the reluctance of some foreign governments to exchange commercially valuable information for research and development technology. (See pp. 42 to 43 and 45.)

Benefits derived from international exchanges of breeder technology have not been and probably will not be great enough to appreciably reduce the time and/or money required for the United States to develop a commercial fast breeder reactor. But the past and potential future benefits from cooperative exchange agreements are important enough for the Energy Research and Development Administration to continue to develop new and broadened areas of exchanges.

The learn-by-doing approach of some of the other countries' programs appears to complement the in-depth-technology approach of the U.S. program, thereby offering opportunities for all parties to benefit from future exchange agreements. (See p. 43.)

Areas offering the most potential for cooperative exchange agreements include:

--Equal exchanges of basic research and technology development data and safety-related data.

--Agreements permitting component testing in reactors and test facilities of other countries.

--Participation in joint component development programs.

--Purchase of technical information, reactor components, and/or entire reactors. (See pp. 43 to 44.)

This report was reviewed by the Energy Research and Development Administration, the Nuclear Regulatory Commission, and fast breeder reactor program officials of the United Kingdom, France, Federal Republic of Germany, and Japan to make sure the factual material was correct. (See p. 47.)

CHAPTER 1

INTRODUCTION

The liquid metal fast breeder reactor is the principal advanced nuclear reactor concept being developed in the industrially advanced countries of the world. A breeder reactor can create, for the future, more nuclear fuel (plutonium) than it uses and is considered a priority energy program in the United States and in other countries. There have been extensive fast breeder reactor programs in the United States, United Kingdom, France, and the Union of Soviet Socialist Republics since the early 1950s and in Japan and the Federal Republic of Germany since the early 1960s. While all the programs have some differences in approach and emphasis, they all contain or plan to contain many of the same elements that are in the U.S. long-range program.

Our April 28, 1975, report to the Congress entitled "The Liquid Metal Fast Breeder Reactor Program--Past, Present, and Future" pointed out that an analysis is needed of the advantages and disadvantages of using foreign fast-breeder reactor technology to determine whether the United States can rely more on such technology. After this report, the Chairman of the Joint Economic Committee asked us to make such an analysis. The Chairman asked a series of specific questions on the status of the foreign programs and the possibility of the United States saving time and/or money by using foreign technology.

NEED FOR THE BREEDER REACTOR

Fossil fuels are in limited supply in the United States, Japan, and many European countries. Future energy security may depend on these countries' ability to decrease their energy dependence on coal, oil, and natural gas. Nuclear power is considered a logical alternative. However, present generation light water (thermal) reactors can use only 1 to 2 percent of the energy content of the uranium fuel. (Natural uranium consists of two kinds of uranium--0.7 percent is uranium-235 and 99.3 percent is uranium-238. Uranium whose uranium-235 content has been increased (enriched) to about 3.0 percent is used as fuel in light water reactors.) If light water reactors were the only types to be used in the future, these reactors, to be constructed by the end of the century, could possibly consume over their lifetimes all the uranium resources currently estimated to be economically recoverable in the world.

The abundant uranium-238, which cannot be used directly as a nuclear fuel, can be used in what is known as a fast breeder reactor and be converted into a usable fuel, plutonium-239. Fast breeder reactors can produce more usable fuel (plutonium) than they consume and can use 60 percent or more of the energy content of uranium. For these reasons, developing large-scale electricity generating plants powered by fast breeder reactors would extend the useful life of available uranium sufficiently to provide electric energy for many hundreds of years.

In reactors being developed as a part of all major fast breeder reactor programs, a liquid metal (sodium) is used as the coolant to remove heat (which is used to produce electricity) from the reactor core. Liquid sodium is used because it is an excellent heat transfer fluid and does not significantly slow down the speed of the fast (high energy) neutrons, which sustain the chain reaction in fast reactors. This use of fast neutrons results in more efficient, and thus higher, conversion of uranium-238 to plutonium than does the use of slow (thermal) neutrons (resulting from using water as the core coolant) in most present generation reactors. Therefore, this type of reactor is called the liquid metal fast breeder reactor.

CHAPTER 2

THE U.S. BREEDER REACTOR PROGRAM

GAO has previously issued six reports, staff studies, and issue papers on various breeder reactor topics.[1] These reports discussed in detail the status, history, structure, and objectives of the U.S. breeder reactor program.

The Energy Research and Development Administration (ERDA) projects that the U.S. electrical energy demand will increase fourfold between 1975 and the year 2000. The United States has more fossil fuel resources than most other developed countries, but these resources--in particular, oil and natural gas--are in limited supply. Nuclear power accounts for over 8 percent of the total installed U.S. electrical generating capacity, and ERDA expects that it will account for about 67 percent by the year 2000. Because of a limited supply of low-cost uranium ore available for fuel for light water reactors, many believe that the full potential of nuclear energy can be realized only by developing the fast breeder reactor.

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1 "The Liquid Metal Fast Breeder Reactor: Promises and Uncertainties," U.S. General Accounting Office, OSP-76-1, July 31, 1975.

"Cost and Schedule Estimates for the Nation's First Liquid Metal Fast Breeder Reactor Demonstration Powerplant," U.S. General Accounting Office, RED-75-358, May 22, 1975.

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

"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.

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

"Problem Areas Which Could Affect the Development Schedule for the Clinch River Breeder Reactor," U.S. General Accounting Office, December 1974.

PROGRAM OBJECTIVES

ERDA's breeder reactor program seeks to develop a broad technological and engineering base with extensive utility and reactor industry involvement. The objective is to develop a strong, competitive, commercial breeder industry.

ERDA expects to be able to decide on the commercial acceptability of the breeder reactor by as early as 1986. By this time ERDA expects that sufficient information will be available to resolve major uncertainties affecting widespread use of breeder reactor technology.

DEVELOPMENT APPROACH

The U.S. breeder reactor program has two major aspects--the base technology program and the demonstration plant program. The base technology program consists of developing test facilities and programs necessary to understand the full range of technology associated with the design, construction, and operation of commercial fast breeder reactor powerplants. The philosophy has been to develop as much basic design information as possible so that a design could be created with a high degree of confidence in successful performance of the plant components and systems. Basic research and testing on fuels, materials, components, subcomponents, and calculational codes are included in the program. The U.S. program has emphasized quality control resulting in the development of an extensive set of design, manufacture, construction, and operating codes and standards. The program includes many experimental and test facilities, the largest and one of the most important being the Fast Flux Test Facility (FFTF). There has been an underlying effort to develop not only a technology base but an industrial base for building fast breeder reactor powerplants. The U.S. program is a low-risk, high-cost, and time-consuming approach.

The demonstration plant program is to serve as the transition from the technology development phase to large-scale commercial use. The first[1] U.S. large-scale fast breeder reactor demonstration plant--the Clinch River Breeder Reactor (CRBR)--is being designed and is also undergoing licensing review by the Nuclear Regulatory Commission

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[1] The Enrico Fermi Atomic Power Plant was an earlier fast breeder reactor demonstration plant but of a lower power level than current demonstration plants in the United States and other countries.

(NRC). Site preparation is planned for November 1976 and construction is scheduled to start in early 1978.

The U.S. development approach differs considerably from that of foreign countries. Other nations have not emphasized developing a broad base of technology as much as operating demonstration plants as early as possible; that is, they have taken a learn-by-doing approach. They have, particularly in the United Kingdom and France, assumed more risks than the United States by limiting the research and development options pursued. The emphasis in Europe has been to gain system design, construction, and operational experience through the building of plants. They have built or are building their demonstration plants as soon as possible after gaining experience from operating small experimental breeder reactors. Also, with the exception of Japan, they have or are scheduled to have demonstration plants operating before the United States does.

On the other hand, the United States, because of its emphasis on developing a broad base of technology, is building a large test reactor (FFTF) after building and successfully operating an experimental breeder reactor (Experimental Breeder Reactor II) and before building its first large-scale demonstration reactor (CRBR).

HISTORY AND STATUS

The U.S. interest in liquid metal fast breeder reactors began in the 1940s. From 1946 to 1953, the Atomic Energy Commission (AEC), predecessor agency of ERDA, operated the Clementine reactor at the Los Alamos Scientific Laboratory in New Mexico to explore the possibility of operating a fast reactor using a liquid metal coolant. In 1951 Argonne National Laboratory began operating the Experimental Breeder Reactor I (EBR-I) in Idaho. This facility was the first nuclear reactor to produce electricity and also proved the feasibility of the breeding concept.

The success of EBR-I led to construction of two larger fast breeder reactors, the Experimental Breeder Reactor II (EBR-II)--18.5 megawatt electric[1]--and the Enrico Fermi

[1] A measure of electric power; a megawatt thermal is a measure of heat. For present generation nuclear powerplants, about 3 megawatt thermal are required for each megawatt electric produced. For breeder reactors, about 2.5 megawatt thermal will be required for each megawatt electric produced.

Atomic Power Plant--60.9 megawatt electric. EBR-II, which began operation in 1963 at Argonne National Laboratory's test site in Idaho, was constructed to determine the feasibility of (1) using a breeder reactor as a central station powerplant and (2) developing a fuel recycle capability. EBR-II still operates as a test reactor.

The Fermi reactor, located in Michigan, also began operations in 1963 and was the United States' and the world's first privately owned fast breeder reactor. A series of operating problems were experienced during operation of the Fermi reactor. It was shut down in 1972 because full funding could not be secured for a 6-year program which included developing and procuring a new oxide core. The plant had operated successfully at the full power limit of the first core during 1971.

The Southwest Experimental Fast Oxide Reactor (SEFOR), located in Arkansas, was a sodium-cooled experimental fast reactor constructed and operated through an international cooperative program involving Southwest Atomic Energy Associates (a group of U.S. electrical utilities), General Electric Company, the German Karlsruhe Nuclear Research Center, and AEC. Design of the reactor began in 1964, and its construction was completed in 1968. The operational program, which began in April 1969, was successfully completed in early 1972. The SEFOR experiments were directed toward demonstrating the safety of sodium-cooled fast breeder reactors and also provided practical experience in the design, construction, licensing, and operation of a sodium-cooled fast reactor.

The next major step in the breeder reactor program will be operating the FFTF at the Hanford Engineering Development Laboratory, Richland, Washington. The FFTF is basically a sodium-cooled fast reactor designed to test high performance fast breeder reactor fuels and materials. It is not designed to generate electricity but will provide experience in design, construction, operation, and maintenance of liquid metal-cooled fast reactors. The FFTF is under construction and is scheduled for full power operation in 1980.

The CRBR will be the first U.S. large-scale fast breeder reactor demonstration plant. It will be built near Oak Ridge, Tennessee, and is designed to operate at 350 megawatt electric. Construction is expected to start in 1978 and initial operation is scheduled for late 1983. The objective of the CRBR is to demonstrate the environmental advantages and economic potential of fast breeder reactors as a major electrical energy resource. CRBR will also serve as a focal point for system and component development, will demonstrate the commercial licensability of fast breeder reactors, and will aid in developing industrial and utility capability to design, construct, and operate breeder reactors.

AEC originally intended to build two more demonstration plants and three early commercial plants after CRBR. In 1974 AEC, to save time and money, largely redirected its breeder program. Instead of follow-on demonstration and early commercial plants, the program was changed to include constructing a large component test facility--scheduled to begin operation in the early 1980s--and a Prototype Large Breeder Reactor (PLBR) to provide further plant experience data. This reactor is expected to be about 1,000 to 1,500 megawatt electric and to consist of commercial-size components. ERDA and the Electric Power Research Institute are jointly funding work by three reactor manufacturer/architect-engineer teams on the conceptual design of the PLBR. Construction is expected to begin in 1981 with criticality[1] scheduled for 1988.

Design work on the next large breeder reactor--designated Commercial Breeder Reactor 1 (CBR-1)--would start about 2 years (1983) after construction of the PLBR. Before constructing this plant, ERDA will decide (probably in 1986) on the acceptability of widespread commercial fast breeder reactor development. Construction is expected to start in 1986 with criticality scheduled for 1993. CBR-1 would be about the same size or perhaps a little bigger than the PLBR. ERDA expects that this project will be the first project initiated by reactor vendors and utilities, with possible Government financial assistance. ERDA assumes that successive commercial plants will rapidly follow the CBR-1, with some possibly receiving Government assistance but evolving into a solely commercial industry.

STRENGTHS AND WEAKNESSES

Discussions held with representatives of ERDA, national laboratories, U.S. industrial firms, and foreign breeder reactor programs indicate that the basic strength of the U.S. breeder reactor program is in its base technology work. In breeder reactor physics, the United States is felt to have excellent test facilities (such as the Zero Power Plutonium Reactor, which gives the United States full-scale reactor

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[1]The state of a nuclear reactor when it is sustaining a chain reaction.

core-mockup capability) and effective means to evaluate and measure nuclear data. ERDA's breeder reactor safety program is considered well advanced. Other areas mentioned as strengths of the program were sodium-coolant technology, high temperature design capability for structural materials, and fuel cladding (the sheath containing the fuel), testing, and evaluation.

Large-scale plant operating experience and component development (in particular, steam generator development) were generally agreed to be the weakest areas of the U.S. program. This is the direct result of ERDA's approach of building and operating a demonstration breeder reactor at a later point in the program.

A discussion of program strengths and weaknesses is necessarily a subjective analysis. The differences in the approach and emphasis among various program areas which are perceived to be major strengths or weaknesses in one country's program may be felt by another country to be of minor consequence in developing a commercial breeder reactor.

LICENSING PROCEDURES AND CRITERIA

NRC is responsible for licensing commercial nuclear reactors in the United States. Basic NRC licensing procedures for fast breeder reactors are the same as those for light water reactors. NRC requires submission of a preliminary safety analysis report and an environmental report. The NRC staff documents its review in its safety evaluation report and in a draft and final environmental impact statement. Public hearings on site suitability and environmental impact must be held before site excavation and other limited work can begin. Before initiation of safety-related construction, the NRC staff must approve the preliminary design and proposed principal design criteria.

The Commission's Advisory Committee on Reactor Safeguards reviews the safety portion of the applications and further public hearings must be held. While construction is underway, the applicant must submit a final safety analysis report covering the final design and proposed operation for NRC staff review. Review by the Advisory Committee on Reactor Safeguards is also required at the operating license stage and opportunities for public hearings are afforded persons who might wish to intervene in the proceedings. On completion of construction in accordance with the application, if all is satisfactory and all licensing requirements are met (including completion of the public hearing, if held), an operating license is issued.

NRC's general safety objective is to insure that the risk involved in the normal operations of a nuclear reactor and from accidents for which the reactor is designed is reduced to an acceptable level and to insure that the likelihood for more severe accidents is extremely small. In implementing this safety philosophy, NRC has established criteria and guides for the design, construction, and operation of nuclear reactors. These criteria and guides were established specifically for light water reactors, but many can be applied directly to breeder reactors. The differences between breeder reactors and light water reactors, however, require some modifications, which NRC has issued for the CRBR. Criteria will periodically be modified on the basis of the results of ongoing and planned safety research and development work.

DESCRIPTION OF BREEDER REACTOR EXCHANGE AGREEMENTS BETWEEN THE UNITED STATES AND FOREIGN COUNTRIES

The United States has had agreements to exchange fast breeder technology with foreign countries since the mid-1950s. Active agreements exist between the United States and the Union of Soviet Socialist Republics, the United Kingdom, the Federal Republic of Germany, and Japan. ERDA is currently trying to negotiate an agreement with France and Italy, to renew and broaden the existing agreement with the United Kingdom, and to broaden the existing agreements with Japan and the Federal Republic of Germany. The following is a summary of the breeder reactor exchange agreements which are or have been in effect and the type of exchanges which have taken place under the agreements. A quantitative analysis of the results of these exchange agreements is presented in appendix V.

United Kingdom

The original breeder reactor exchange arrangement between AEC and the United Kingdom Atomic Energy Authority (UKAEA) was started by an exchange of letters in February 1956. This arrangement was superseded by the present agreement signed on February 11, 1965, and is effective until July 21, 1976. The current agreement provides for the exchange of information for fast reactor development except for

--detailed design drawings and manufacturing specifications for FFTF and Prototype Fast Reactor;

- --process specifications for the manufacture of fuel elements and materials; and

- --information on the development, design, construction, and operation of fast reactors subsequent to FFTF and Prototype Test Reactor.

The current arrangement provides for implementation by exchange of visits and technical reports. Numerous technical reports have been exchanged. U.S. breeder reactor officials have toured the United Kingdom's facilities, attended the UKAEA's fast reactor training courses, and have held discussions with UKAEA officials concerning fast reactor safety, core materials, and irradiation (exposure to nuclear radiation in a reactor) effects. ERDA has a representative stationed in the United Kingdom to monitor irradiation tests of U.S.-provided materials in the Prototype Fast Reactor. The United Kingdom has, in the past, sent representatives to tour U.S. breeder reactor facilities and has assigned personnel to work in the U.S. program.

France

Although negotiations for a fast reactor agreement are taking place between ERDA and the French atomic energy agency, the Commissariat à l'Energie Atomique (CEA), there is currently no agreement and all exchanges are negotiated on a case-by-case basis.

Before 1963 technical information exchanges were made pursuant to the terms of an agreement on the civilian uses of atomic energy. In 1963 a letter exchange established an exchange agreement for fast reactor technology, reactor safety and shielding, gas-cooled reactors, reactor physics, fuel reprocessing, waste management, test reactors, and transuranium elements. This arrangement was in effect until 1972; however, the exchange produced no appreciable results other than a few visits, personnel assignments, and an exchange of operating reports of the EBR-II and Rapsodie reactors from 1970 to 1972. The exchange of these reports was discontinued by AEC due to the imbalance of information exchanged and the erratic delivery of the Rapsodie reports.

Federal Republic of Germany

AEC and ERDA have exchanged breeder reactor information with West German organizations since the 1960s. These exchanges have been conducted under relatively informal arrangements without benefit of an overall bilateral arrangement.

Exchanges have included reports, visits, and long-term personnel assignments. These exchanges appear to have been highly successful, particularly the cooperative program which led to the design, construction, and operation of the SEFOR reactor safety project.

Negotiations for an overall bilateral agreement are in progress and are expected to be concluded in the near future. The German Ministry for Research and Technology has assisted AEC-ERDA in their contacts with the major laboratory centers and the industrial nuclear development organization, Interatom.

Union of Soviet Socialist Republics

From 1959 until 1973, five 2-year Memorandums for Cooperation were in effect between the United States and the Soviet Union. These provided for exchanges of information in various technical areas, including fast reactors.

On June 21, 1973, the current agreement on cooperation was signed. It is to remain in effect for 10 years and provides for cooperation in controlled thermonuclear fusion, fast breeder reactors, and research on the fundamental properties of matter. Cooperation in the fast breeder area is defined as including finding solutions to mutually agreed upon basic and applied problems in the design, development, construction, and operation of fast breeder reactors. On October 9, 1974, a protocol was signed by representatives of AEC and the Soviet Union which defined the scope of the fast breeder reactor exchange to include the following areas:

--Research and development of materials and engineering technology for component and systems development.

--Design, research, development, construction, and operation of nonnuclear test facilities supporting the fast breeder reactor program.

--Research, development, and testing of components and systems for experimental reactor plants and power reactor demonstration plants, including quality assurance practices.

--Research, development, design, construction, operation, and maintenance of experimental reactor plants and power reactor demonstration plants.

--Economic, environmental, and safety considerations in the research and development of fast breeder reactors.

Cooperation is to be implemented through joint consultations; seminars; personnel assignments; tests of samples, instruments, and components at the other country's facilities; and through exchange of reports.

Numerous technical reports have been exchanged and visits to breeder reactor facilities have been made by representatives of both countries. In addition, formal seminars have been held on steam generators, construction and operation of fast breeder reactors, and on safety of fast breeder reactors. During 1976-77, seminars are scheduled on reliability and safety of steam generators, fast reactor physics, and cladding material.

Japan

On March 4, 1969, AEC and the Power Reactor and Nuclear Fuel Development Corporation (PNC) signed a 10-year fast breeder reactor exchange agreement. The agreement provided for an exchange of information which has resulted from base technology program work in reactor physics, nuclear safety, fuels and materials, and sodium technology.

The agreement is implemented by exchanging reports, letters, drawings, specifications, visits, meetings, and personnel assignments.

The Japanese have visited U.S. breeder reactor facilities many times, whereas U.S. personnel have made only few visits to Japan. One person from each country is currently on a long-term assignment working in the other country's program. Numerous technical reports have been exchanged.

Other breeder reactor agreements

In addition to the agreements mentioned above, ERDA has or has had breeder reactor agreements or arrangements with the Netherlands, Switzerland, and the European Atomic Energy Community (EURATOM), which is comprised of Belgium, the Federal Republic of Germany, France, Italy, Luxembourg, Netherlands, Denmark, Ireland, and the United Kingdom. ERDA is also a member of the International Atomic Energy Agency.

A formal agreement was reached in October 1970 between AEC and the Organization for Industrial Research of the Netherlands that provided for exchange of information between Netherlands Sodium Component Test Facility at Hengelo and the Sodium Component Test Installation at the Liquid Metal Engineering Center, Santa Susana, California. Reports are exchanged on the operation of the two facilities and visits and short-term assignments have taken place.

A technical exchange arrangement with Switzerland for fast reactor physics became effective March 20, 1970. A few reports were exchanged before the agreement was terminated on March 20, 1975.

EURATOM does not have a breeder reactor research and development program and does not sponsor any breeder reactor seminars. However, in the past, AEC-ERDA was able to obtain reports on breeder reactor base technology from EURATOM.

The International Atomic Energy Agency was established in 1957 and includes 106 countries. The United States provides approximately 27 percent of the total budget. In 1967 the International Working Group on Fast Reactors was established. Members of this group include representatives from France, Italy, Japan, the Federal Republic of Germany, the United Kingdom, the United States, and the Soviet Union. Annual meetings are held to review member nations' fast reactor programs, to coordinate meetings concerning fast reactor research and development, and to arrange for specialist meetings. Specialist meetings provide particularly valuable opportunities for very detailed and informal exchanges between the working-level experts in highly specialized areas in the fast reactor field. All countries, including France and the Soviet Union, having major fast reactor programs are active participants in these specialist meetings, which have been regarded as valuable avenues for mutually beneficial information exchanges. Specialist meetings have been held in such areas as fuel failure mechanisms, fission and corrosions product behavior in primary breeder reactor circuits, and core and primary circuit construction. The International Working Group on Fast Reactors does not sponsor fast breeder reactor research.

CHAPTER 3

DESCRIPTION AND STATUS

OF FOREIGN BREEDER REACTOR PROGRAMS

The United Kingdom, France, the Federal Republic of Germany, the Union of Soviet Socialist Republics, and Japan are all developing sodium-cooled fast breeder reactors. The United Kingdom, France, and the Soviet Union have demonstration-size breeder reactors operating with varying degrees of success. West Germany and Japan are currently constructing demonstration-size plants. In addition, Belgium and the Netherlands are participating with Germany in their fast reactor program, and Italy has an interest in the large commercial breeder reactors to be built in France and Germany.

Except for the Soviet Union, the foreign countries have a more urgent need and a shorter time frame for developing commercial fast breeder reactors than does the United States because, individually or collectively, they do not have the coal, oil, natural gas, or uranium resources the United States possesses. Other factors prompting development of the breeder include the relatively limited worldwide uranium resources and the desire to use the plutonium produced by thermal reactors.

The foreign fast breeder reactor development programs involve the close coordination of government research and development agencies, electric utilities, and reactor manufacturers in each country. Little or no attention is given to developing internal competitive breeder reactor industries. This approach contrasts sharply with ERDA's philosophy of fostering competition by developing broad industrial capability. Also, the learn-by-doing approach of the foreign programs emphasizes operating demonstration fast breeder reactors as early as possible rather than developing a broad technology base and testing programs that characterize the U.S. approach to the program. Many foreign programs are structured to accept greater risk of failure than the U.S. approach of developing a strong technological background for building breeder reactors so that, once a decision is made to build, the risk of failure or serious problems is sharply reduced.

Foreign programs are relying on the experience obtained from prototype plants to provide the design basis for larger commercial plants. Much of the concept and technology used in developing these foreign prototype fast breeder reactors may have originally been obtained by monitoring U.S.

construction and operation of EBR-II and Fermi. In an article in the August 1974 Nuclear News, L. J. Koch (formerly project manager for EBR-II) wrote

> "In August 1964, the U.S. LMFBR[1] program was the most advanced in the world, and the nation had an operating experimental LMFBR power station to obtain experience and to provide the vehicle for evolutionary improvement. Nevertheless, the United States did not proceed with the next logical step in the development of commercial LMFBR's. The Europeans did, and they did it by exploiting and extending our technology."

UNITED KINGDOM

Although the United Kingdom is relatively well-endowed with fossil resources (coal, oil, and natural gas), it still faces a gap between the supply and prospective demand for energy, which it anticipates filling through nuclear power. The United Kingdom has no large uranium resources and is therefore developing the fast breeder reactor to more efficiently use uranium and to achieve a degree of energy independence. Fast breeder reactors will reduce the impact of uranium price increases and will reduce the possibility of not being able to meet the uranium demand from the world market. Further, the ability of fast reactors to use plutonium more efficiently than thermal reactors make them a suitable complement for the United Kingdom program of gas-cooled thermal reactors from which substantial quantities of plutonium have been and are being produced.

The discovery and development of North Sea oil has given the United Kingdom a breathing space in which to reassess its energy options. However, this oil supply is seen only as an intermediate answer to the United Kingdom's energy problems, and the United Kingdom may again possibly be a net importer of oil in the late 1990s.

History and status of the program

The fast reactor development program began in the late 1940s with a study of liquid metal coolant technology. There have been three stages so far in the development of the fast reactor in the United Kingdom. In the first stage, physics studies were carried out, culminating in work on a plutonium-fueled zero power reactor (ZEPHYR) in the mid-1950s.

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[1] Liquid metal fast breeder reactor.

The second stage involved the construction of an experimental power reactor at Dounreay in Northern Scotland, the 14-megawatt-electric Dounreay Fast Reactor. This reactor was built to establish the engineering feasibility of the system. It has been operating since 1959 and has supplied electricity to the Scottish supply system for more than 12 years. Its prime task has been to provide information on fast reactor operational behavior, with special emphasis on a detailed understanding of fuel behavior. The Dounreay reactor is due to be shut down at the end of this year after completing its required work program.

The third stage involves the 250-megawatt-electric Prototype Fast Reactor. In 1966 construction began on this reactor, which is to demonstrate all the key engineering, technical, economic, and safety features of large plants. The reactor began operations in 1974. It has not yet reached full power, mainly due to problems with the steam generators[1], pump, and turbine, but it is expected to do so in 1976.

The United Kingdom's development approach has been to focus development work on the needs of specific reactor plants, and to thereby gain an increasing understanding of the system.

The next major step in the program is a full-scale demonstration unit--the 1,320 megawatt electric commercial fast reactor (CFR 1)--on which design and development work are underway. This plant could be ordered around 1978, with construction beginning in 1979 and operation beginning about 1984 or 1985. The United Kingdom does not expect a large-scale program of orders on a fully commercial basis before the late 1980s at the earliest.

The United Kingdom's Royal Commission on Environmental Pollution recently said it would prefer the government not to decide on a demonstration commercial-scale breeder until the Commission completes a report on radiological safety for an expanded British nuclear power program. The Commission made a clear distinction between the environmental implications of a large, ongoing program and a demonstration

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[1]Steam generators transfer heat from the intermediate (nonradioactive) sodium system to the water-steam system that generates steam from the turbine generator. These components must have high integrity because of the potentially violent reaction between water and sodium in the event of a leak.

breeder plant. The Commission noted the arguments for a demonstration plant and recognized that the fast breeder reactor is an important component of the United Kingdom's energy program. But the Commission is not yet convinced that the United Kingdom's energy needs in the next 30 to 50 years require the deployment of breeder reactors on a large scale. The Commission also noted that in its view there are serious fundamental difficulties with the current status of breeder reactors, such as managing radioactive waste, reactor stability, and plutonium safeguards. The Commission's report is not expected to be issued for several months.

Management and organization structure

The United Kingdom's fast reactor program is managed by UKAEA, which is part of its Department of Energy. The UKAEA has overall responsibility for the experimental and prototype stages of the program and specific responsibility for the generic research and development required. The work to date has been wholly funded by the government through the UKAEA. The research and development program is centered within the UKAEA, is maintained by a development committee chaired by the UKAEA, and has representatives from the British nuclear industry (Nuclear Power Company Ltd. and British Nuclear Fuels Ltd.) and the Central Electricity Generating Board, the principal utility in the United Kingdom. The required research and development is carried out at various UKAEA research establishments.

The British are not concerned with developing competitive nuclear industrial companies. From 1957 to 1970 the number of nuclear design and construction consortia were reduced from five to two (to some extent through government-prompted amalgamations and consolidations). However, two firms did not provide meaningful competition. In 1973 the industry was reorganized with government encouragement into a single company, the National Nuclear Corporation Ltd. This company is Britain's single authority for the design-construction sector of the nuclear energy industry. It is a holding company owned by the UKAEA (35 percent), General Electric Company Ltd. (30 percent--no connection with the General Electric Company in the United States), and British Nuclear Associates Ltd. (35 percent--comprised of seven firms). It exercises its operating capacity through its wholly owned subsidiary, the Nuclear Power Company Ltd. Under contract to the UKAEA, the Nuclear Power Company Ltd. is responsible for design and component development work on the CFR 1.

In 1971 British Nuclear Fuels Ltd. was formed to assume responsibility for the UKAEA's nuclear fuel services. Since then it has manufactured, for the UKAEA, Prototype Fast Reactor fuel and has developed fuel processes. UKAEA project staff provide overall coordination.

Safety philosophy and licensing procedures

The general safety philosophy is to design for high integrity against faults, to provide inherent control, and to provide engineered systems to make the risk associated with possible accidents as low as for thermal systems. The British feel that requiring containment[1] for a fast reactor assumes that a severe core disruptive accident could occur, and other engineered safety systems, such as a core catcher[2], must therefore be considered necessary. The current commercial fast reactor design includes a core catcher, but it has not yet been determined if it will be positioned inside or outside the reactor core vessel.

Responsibility for establishing safety standards and licensing commercial nuclear powerplants in the United Kingdom belongs to the Nuclear Installations Inspectorate of the Health and Safety Executive. Before the formation of the Health and Safety Executive in 1974, the Nuclear Installations Inspectorate was a division of the Department of Energy and, earlier, of other government departments. Since it was set up in 1959, the Inspectorate has performed the licensing function independently of the development organization.

Insuring the safety of UKAEA-sponsored reactors, such as the Dounreay Fast Reactor and the Prototype Fast Reactor, is the responsibility of the UKAEA's Directorate of Safety and Reliability. The CFR 1 will almost certainly be subject to commercial licensing review by the Nuclear Installations Inspectorate.

NRC officials said that their analysis of the United Kingdom's safety criteria and licensing requirements for

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[1]A gastight shell or other enclosure provided around a reactor to limit the release of radioactivity.

[2]A device located below or at the bottom of the reactor vessel which, in the event of a core disruptive accident, will spread out and cool the core debris. This would prevent material from reforming into a mass capable of a chain reaction and would prevent core residue from melting through the bottom of the reactor.

commercial thermal plants revealed that the British requirements are nearly identical to the current French criteria but are not as specific in detail as NRC's criteria. The French and British have general criteria which is applied specifically on a case-by-case basis. NRC officials said that although NRC and British requirements differ in detail, the end result is the same for basic reactor safety features.

The United Kingdom's licensing procedure begins with the applicant's submission of the preliminary design and a safety analysis report. An environmental impact report is not required although some environmental factors are included in the safety analysis report. A nuclear site license, which allows construction to begin, is issued by the Health and Safety Executive. The Inspectorate has power to impose and enforce license conditions in the interests of safety. These conditions are attached to the license and give the Inspectorate the necessary control over design and construction of the plant and over its operation. A final safety analysis report is submitted during the construction and commissioning phases when design details have been settled. The safety analysis report is not made public.

A public hearing on siting proposals may be held at the time of the initial license application in the event of an objection of the local authority concerned or otherwise under the direction of the government minister responsible for energy matters. Public hearings are not held on safety issues.

British fast reactors are similar to the French reactors, according to NRC officials; therefore, potential modifications for U.S. licensing of French reactors, discussed on page 23, could also apply to the British reactors.

FRANCE

The fast breeder reactor program is the highest priority energy development program in France. The goal of the French nuclear program is to develop the breeder reactor as soon as possible. The breeder reactor program uses 60 percent of the funds of the CEA electronuclear development programs. France has limited fossil fuels--some coal and little oil or natural gas--but does control about 10 percent of the world's uranium supply with indigenous resources in France and interest in mines in Gabon and Niger. France considers it imperative to develop and use fast breeder reactors to reduce uranium consumption and its price. Additionally, breeder reactors can use the plutonium produced in thermal reactors as fuel. French officials believe that breeder reactors will be introduced commercially in France between 1985 and 1990 and that France will possibly have 30 breeder reactors operating by the year 2000.

History and status of the program

France started fundamental research on liquid metals in 1953, but it was not until the late 1950s that a significant research and development program was begun. Large investments in experimental installations were made from 1960, parallel with the beginning of the experimental reactor project, Rapsodie, which France built in association with EURATOM. Construction of Rapsodie, a 20-megawatt-thermal fast reactor, started in 1962 and began operating in 1967. Rapsodie's power was increased to 40 megawatt thermal in 1970 and is currently being used to test fuels. Like FFTF it does not generate electricity as it has no electrical power-generating equipment.

Rapsodie's performance gave the French confidence in their capability to build an intermediate-size fast reactor. Construction of Phenix, a 250-megawatt-electric fast reactor prototype, was started in late 1968 and completed in 1973. Phenix began operations in 1973 and reached full power in March 1974. Since then it has successfully been generating electricity while encountering only relatively minor problems. Phenix was designed to demonstrate that a 250-megawatt-electric breeder reactor could operate successfully without much concern as to whether it would be economically feasible in a commercial environment. Like the other European countries and in contrast to the United States, France has not emphasized breeding ratio[1] or doubling time[2] to enhance economics.

Studies for the next project in the French program--the 1,200-megawatt-electric Super Phenix--began in 1972. France expects to begin constructing Super Phenix in mid-1976, after about 2 years of satisfactorily operating Phenix. Super Phenix represents a major extrapolation in existing technology from Phenix. Many aspects of the Phenix concept are being used in Super Phenix. An essential difference is in the design for the steam generators. A completely different

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[1]The ratio of the fuel produced to fuel consumed--which is greater than 1.0 for a breeder reactor.

[2]The time it takes to double the amount of plutonium fuel.

design will be used for this critical component in Super Phenix because the Phenix steam generator would be too costly to put in commercial plants. Although more attention is being given to economics on Super Phenix, it will still cost about 50 percent more than a comparable size light water reactor.

The next phase of the French breeder reactor program, after Super Phenix, is the construction of twin commercial reactors the size of Super Phenix or even larger. Design work is planned to begin on this project at the time construction starts on Super Phenix. France hopes that the twin reactors will be a strictly commercial venture.

One of the most important features of the French program is the planned sequence of constructing progressively larger reactors, with each reactor project more closely approaching commerciality and, at the same time, maintaining a continuity of engineering, fabrication and construction, and management personnel. For example, while Rapsodie was being constructed, the Phenix reactor was being designed. After a year of successful operation of Rapsodie, construction was started on Phenix. Super Phenix was being designed while Phenix was being built and construction is expected to start shortly on Super Phenix. Design work is planned to begin on the twin commercial reactors at the same time.

The French research and development program on the breeder is presently oriented toward (1) testing selected large components for Super Phenix, (2) research for better core and fuel performance, and (3) simplifying certain components as well as using materials that will permit better performance or savings.

Management and organization structure

The French breeder reactor program is managed by CEA, which was created in 1945. It has been responsible for developing nuclear reactors for (1) research, (2) production of materials for nuclear weapons, (3) submarine propulsion, and (4) electric power generation.

Nuclear powerplants are generally designed by CEA but are operated by Electricité de France (EdF), the French national electric utility company. EdF will be the client for the breeder reactor power stations and has worked together with CEA on the breeder reactor program since the Rapsodie stage. EdF is responsible for part of the research and development program and provided 20 percent of the financing for the construction of Phenix, with CEA providing the balance. Complete ownership of Phenix is to be transferred to EdF after 5 years.

Technicatome, a commercial subsidiary of CEA, was formed in 1972 to commercialize some of the government operations and is responsible for marketing reactor technology (both water and fast breeder reactors). Technicatome is owned by CEA (90 percent) and EdF (10 percent).

The French nuclear industry has worked closely with CEA since the beginning of the program. It is linked with CEA by collaboration agreements for developing components. The engineering firm that specializes in reactors is a common subsidiary of CEA and of industry.

The Super Phenix project is a multinational undertaking. It will be financed by a consortium of electric utilities representing France, Italy, Federal Republic of Germany; providing 51, 33, and 16 percent of the cost, respectively. The Italians will participate with the French in designing Super Phenix. The German technical role will be confined to supplying components. Each participant will receive electric power from France proportionate to their investment. The trilateral agreement calls for a second commercial-size fast breeder reactor (SNR-2) to be built in Germany, using German breeder technology, to start after Super Phenix is completed. For this second reactor, the funding breakdown is 16 percent France, 33 percent Italy, and 51 percent Germany.

<u>Safety philosophy and licensing procedures</u>

The French nuclear regulatory group is the Service Central de Sûreté des Installations Nucléaires (Central Service for the Safety of Nuclear Reactors) and is independent from CEA. However, both report to the same cabinet minister, the Ministry of Industry and Research. In matters of safety, fast breeder reactors are subject to the same requirements and criteria as those applied to any other kind of nuclear reactor. CEA and Central Service work closely together from the early design stages of a reactor project in establishing the design and the specific safety criteria for the plant. These criteria can vary depending upon the local characteristics of the plant site.

The operator (EdF) prepares the preliminary safety analysis report and CEA prepares an independent safety evaluation report on reactors. The Central Service evaluates these and decides whether the mutually agreed upon safety criteria have been met. The Ministry of Industry and Research issues a decree of authorization (similar to NRC's construction permit) after (1) a permanent group of experts examines the reports and gives opinions on the safety of the installation and (2) the Ministry of Health provides a favorable opinion on the plant. Similar procedures are followed at other stages.

An environmental report is not required although environmental concerns are discussed in the safety analysis report. A cost-benefit analysis is not required. Public hearings on the safety of a plant are not held. The public is involved only at the time of site selection. This is independent of the study of the plant's safety.

NRC and the Central Service have recently concluded a joint review of the French safety criteria and licensing requirements. As a result of the NRC and Central Service review, the French and U.S. standards were found to be similar except that the French criteria are not as detailed as NRC's. This is the same difference between NRC and United Kingdom criteria (see pp. 18 and 19.)

Discussions with NRC officials indicated that a breeder reactor of the same design as Phenix would probably not be licensable in the United States. According to NRC, the major identifiable aspects subject to change to meet U.S. licensing criteria are (1) containment structure, (2) separation of steam and sodium piping, (3) design for seismic loads, (4) reactor protection and control rod systems,[1] and (5) systems for removal of heat generated by the decay of fission products after reactor shutdown. The French believe that these changes would require only minor modifications.

French criteria has changed since Phenix was licensed in 1968. In all probability, Phenix could not be licensed in France under current criteria. For example, a containment building rather than a confinement building would now be required.

Super Phenix is being designed to resolve all of the licensing problems identified with Phenix, and according to the French, it should satisfy the U.S. licensing requirements. NRC officials anticipate the leakage rate of the containment building is a potential major problem with the

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[1]Mechanisms to insert neutron-absorbing material into a reactor core to control the power output.

Super Phenix design. They expect that constructing a low leakage containment structure could increase total cost of the reactor installation by approximately 1 percent. In commenting on our report, the French said that the containment building was the second radiation leakage barrier in Super Phenix and that a primary containment structure surrounding the reactor had a much lower leakage rate than did the containment building.

Bechtel Nuclear Corporation of San Francisco is making a 2-year study for the French to determine what, in their best judgment, would have to be done to the Super Phenix design to make it conform to U.S. licensing requirements and codes and to estimate the effect of these changes on cost and schedule.

FEDERAL REPUBLIC OF GERMANY

The Federal Republic of Germany's energy supplies are based over 95 percent on fossil fuels (oil, natural gas, and coal), of which they are heavily dependent on oil (55 percent) and natural gas (9 percent). Germany has some coal but no uranium reserves and depends almost entirely on imports for its oil supplies.

German officials said the fast breeder reactor is needed because of (1) limited resources of fossil fuels and uranium, especially in Western Europe, (2) the need for independence from uranium ore import and prices, (3) the ability of fast breeder reactors to use plutonium from light water reactors, and (4) long-term cost benefits made possible from reduced fuel cycle costs. Germany expects the breeder reactor to be introduced commercially by about 1990 and estimates that in the year 2000 about 15 breeder reactors of up to 2,000 megawatt electric each could be on line and producing about 20 percent of projected electrical energy demand.

History and status of the program

Germany began developing the breeder reactor later than the other European countries. The German fast breeder project started in 1960 at the Karlsruhe Nuclear Research Center, and, after initial studies, Germany undertook a 5-year research and development program with EURATOM from 1963 to 1967. Construction of a sodium-cooled thermal reactor (KNK) started at Karlsruhe in 1966. This 20-megawatt-electric reactor produced electric power for the first time in August 1972. Modification of the reactor for operation with a fast core (KNK-II) was started in 1975 and is expected to begin operating in 1976. Germany participated with AEC and others in the SEFOR program in the late 1960s and early 1970s.

The German program is currently centered around the construction of a 300-megawatt-electric prototype fast reactor, the SNR-300, which is jointly financed with Belgium and the Netherlands (15 percent each). Construction of this reactor started in early 1973 and is expected to be completed in 1980. Full power operation is expected in 1981. The construction of this plant has been slower than originally scheduled because of numerous licensing difficulties.

German officials believe that, although the fast breeder reactor programs of the United Kingdom and especially of France may be more advanced than their program at this time, the gap will close in the future, because the SNR-300 is being developed in a commercial environment and is being subjected to stringent licensing procedures (equivalent to those in use for commercial light water reactors). The German approach is to solve licensing problems on early prototype reactors before designing a near commercial fast reactor.

Germany, like France, plans to sustain momentum in its breeder reactor development program by designing and constructing progressively larger reactors in such a sequence that design work on the next larger reactor project is done at the same time the existing reactor project is being constructed. For example, Germany is planning its second demonstration breeder reactor (1,200-2,000 megawatt electric), the SNR-2, with construction scheduled to start about 1 year after completing construction of the SNR-300. As discussed on page 22, the SNR-2 is a jointly financed project with France and Italy.

Management and organization structure

Germany does not have a national atomic energy agency. The Federal Ministry of Research and Technology and the State governments provided funds to private industry, research centers, and universities for nuclear research and development, including development of the breeder reactor. The Ministry only has three to four employees assigned to its fast breeder reactor program and their responsibilities generally involve awarding grants and monitoring the effectiveness of fast-breeder-reactor-related research and development sponsored by these grants. Planning, constructing, and operating nuclear power facilities are responsibilities of the utilities and industry. Sodium component development for the breeder reactor is done mainly by industry while basic research and development is done by research centers.

The industrial organization, Interatom, is the major company in Germany involved in fast breeder reactor work with two-thirds of its 1,500 personnel and work devoted to the breeder. Interatom operates a sodium technology center and is responsible for design, component development, manufacturing, and construction. It designed, constructed, and is modifying Germany's 20-megawatt electric reactor for a fast core. The Karlsruhe Nuclear Research Center is the principal center for fast breeder research and development. The principal utility in Germany, Rheinisch-Westfälisches Elektrizitätswerk AG, is involved in the breeder reactor program by its participation in the SNR-300, Super Phenix, and SNR-2 projects.

The SNR-300 project is a trilateral project--for both manufacturers and electric utilities--among Germany, Belgium, and the Netherlands. The project structure is given in appendix III. The SNR-300 cost is financed by the three governments (90 percent) and a consortium of electric utilities (10 percent--comprised of the three national utilities from each country). The plant is being built by a consortium of industrial firms from the three countries. The owner and operator will be the utility consortium. Research centers in the three countries provide supporting research and development.

The SNR-2 project is a multinational undertaking among the electric utilities of Germany (51 percent), France (16 percent), and Italy (33 percent). The German share of the SNR-2 cost will be divided among the German-Netherlands-Belgian utility consortium and governments. The utility consortium share will be the amount it would pay for a comparably sized light water reactor plus an undefined extra amount to compensate the governments for technology acquired. In addition, the governments will make loans to the utility consortium to cover part of the consortium's share of the construction cost and to cover the higher than normal initial operating costs for the reactor. The terms of the loans call for gradual payback once profits are realized from the SNR-2.

Safety philosophy and licensing procedures

Licensing authorities of each individual German State, acting on behalf of the federal government, are responsible for granting licenses to construct and operate nuclear powerplants, including breeder reactors within their State boundaries. Safety analysis and environmental reports and a final design are required before a construction license is granted. Partial construction licenses are granted at various stages during construction. Public hearings are held before granting the first partial construction license. Further partial licenses for both construction and operation are granted without additional public hearings. The German State licensing authorities use various safety expert groups to prepare detailed studies and to carry out technical checks and inspections on all important plant items.

The Federal Ministry of the Interior is responsible for legal and technical supervision of the State licensing authorities and also examines the license application. The Ministry is assisted in an advisory function by an independent body of experts called the Advisory Committee on Reactor Safeguards. The State licensing authority must comply with instructions resulting from the Ministry's checks of an application. Other Federal agencies also provide comments. The State licensing authority is responsible for either granting the license or rejecting the application.

According to NRC officials, German safety standards and regulations are nearly identical to NRC's. NRC has not, however, reviewed the specific breeder reactor criteria or their design implementation and has not reached any conclusions on licensing German designs in the United States.

UNION OF SOVIET SOCIALIST REPUBLICS

Information on the breeder reactor program of the Union of Soviet Socialist Republics was not available directly from the Soviet Union, as we were not able to arrange a visit there to meet with Soviet officials. The following information on the status and organization of the breeder reactor program in the Soviet Union is based on data (including some Soviet Union documents) supplied by ERDA or other sources and in part is based on a discussion we had with members of a fast breeder reactor delegation visiting the United States for meetings with U.S. officials on U.S.-Soviet Union fast reactor cooperation.

Although the Soviet Union consumes less than half the electricity which is consumed in the United States, its annual rate of increase for 1974 (8 percent) was higher than that of the United States (6 percent). Nuclear power is expected to play an increasing role in achieving needed new generating capacity. The objective of their fast reactor program is to meet long-range power needs.

History and status of the program

The Soviet Union's fast breeder reactor program started in 1955 with the operation of a small plutonium-fueled reactor (BR-1), which was used to obtain physics information. In 1956 a small mercury-cooled, plutonium-fueled reactor (BR-2) was built for physics experiments and materials testing. This facility was reworked into a sodium-cooled, plutonium-fueled reactor of 5 megawatt thermal (BR-5), which went into operation in 1959. This reactor was modified for operation at 10 megawatt thermal in 1973 (BR-10) and is used principally for irradiation testing of fuel and structural material. In 1970 a 60-megawatt-thermal experimental fast breeder reactor, the BOR-60, was first operated. It is used for testing fuels, materials, and components (in particular, steam generators for the BN-600) for larger fast breeder reactors.

BN-350 was the Soviet Union's first demonstration-size fast breeder reactor when it first produced energy in July 1973. This 350-megawatt-electric equivalent reactor is designed to produce electric power (150 megawatt electric) and to desalinize drinking water (200-megawatt-electric equivalent steam power). Operation of the BN-350 has been severely hampered by serious steam generator leaks. It has been operating for the past 2 to 3 years at about 30 percent of design power. At the end of 1975, it was reported to be running at 55 percent of nominal power.

Construction of BN-600, a 600-megawatt-electric plant, was started in late 1968; initial operation is expected in 1978. The BN-600 will be the world's largest operating fast breeder reactor when completed.

Like the French, the Soviet Union has emphasized learning by building plants rather than devoting as much of its resources to a base technology program as does the United States. Its emphasis has been to build a reactor and to test it as a whole rather than to perform a lot of individual tests. Its program has also been directed toward constructing reactors and major components of different design. The BR-5/BR-10, BOR-60, and BN-350 reactors have been loop designs, while the BN-600 is a pool design. Pool- and loop-type reactors are described in appendix II. The Soviet Union has operated and/or is designing five different designs of steam generators and is interested in installing an American-designed unit on the BN-350. (See pp. 39 and 40.)

The Soviet Union's next plant is expected to be about 1,600 megawatt electric. Design studies are underway which include both the pool and loop concepts. The Soviets have not yet decided when this larger plant will be built or which concept will be used.

Management and organization structure

With the exception of the BN-600, the State Committee for the Utilization of Atomic Energy directs the Soviet Union's breeder reactor program. The design, construction, and operation of the BN-600 is under the Ministry for Power and Electrification. To support its reactor building program discussed above, the Soviet Union has institutes, laboratories, and test facilities at Obninsk, Dimitrovgrad, and Kurchatov to do basic design, base technology, and test programs.

Safety philosophy and licensing procedures

The safety philosophy of the Soviet Union is to design nuclear plants so that accidents potentially disastrous to the area surrounding the plant are highly unlikely. The Soviet Union assumes that loss-of-coolant and fuel-failure accidents are not possible. The program is aggressive, operating under the theory that any deficiencies in plant design, fabrication practices, or technologies can be corrected after construction is completed.

The Soviet Union believes in taking precautions to insure the reliable operation of the cooling and safety systems of its reactors instead of designing a core catcher for them. They do not believe it reasonable to use a "maximum credible accident" as a basis for the design of a reactor plant.

A breeder reactor plant of the current Soviet Union design would not likely be licensed for operation in the United States. However, adequate design information is not available for NRC to reach any licensing conclusions or to identify any appropriate changes.

JAPAN

To meet the increasing energy requirement vitally needed for its national economy, Japan is developing nuclear power as a cheap, stable, and clean energy source. Japan has few natural resources (essentially no coal or oil and only limited amounts of uranium) and therefore attaches a high priority to developing nuclear energy and, in particular, to developing the fast breeder reactor. The share of nuclear-generated electricity in the total supply of electricity has grown rapidly in recent years and is projected to be as high as 30 percent by 1985. Much of the anticipated growth in nuclear power generation for the immediate future will be supplied by conventional light water reactors. However, to keep a stable fuel supply and to effectively use nuclear fuel, Japan is developing advanced reactors--the fast breeder reactor and the heavy water reactor. The advanced power reactor development porgram for these national projects calls for introducing commercial types of the fast breeder reactor in the late 1980s and the heavy water reactor in the 1970s.

History and status of the program

The Japanese program, which started in the early 1960s, consists of broad technology development and component proof-testing along with constructing a progression of breeder reactor plants. The first plant is an experimental fast reactor (JOYO), followed by a prototype fast breeder reactor (MONJU), and perhaps a 1,500-megawatt-electric commercial plant.

The construction of JOYO was started in 1970 and the installation of its components and equipment was completed in 1974. Nonnuclear systems tests are now being carried out. The reactor is expected to reach criticality in 1976. The reactor power of JOYO is initially 50 megawatt thermal but will be increased to 100 megawatt thermal after gaining sufficient operational experience and after redesigning the reactor core. Like FFTF it will not generate electricity because it has no turbine-electric system. Its purpose is to provide design, fabrication, construction, and operating experience necessary for developing the MONJU reactor and future commercial reactors. After necessary tests and experiments have been carried out, it will be used as an irradiation facility for fast breeder reactor fuels and materials.

The design of the 300-megawatt-electric prototype reactor, MONJU, has been in progress since 1967. Its design has been repeatedly refined and is being reviewed for final adjustments while a siting problem is resolved. The safety evaluation of the plant is expected to start in 1977 and construction is expected to begin in 1976, aiming for first criticality in 1983. MONJU's purpose is to demonstrate in the performance, reliability, and economy of fast breeder reactor powerplants as well as to gain experience for larger commercial units.

A conceptual design has been completed for a 1,500-megawatt-electric commercial breeder reactor. Construction of such a plant is expected to begin around 1985.

Management organization and structure

PNC is responsible for developing the fast breeder reactor. PNC is a semigovernmental organization created under a special legislative act in 1967 to develop technology for advanced power reactors (fast breeders and heavy water) and the nuclear fuel cycle. PNC receives its basic policy, program and development funds from the Science and Technology Agency. The Science and Technology Agency, which reports directly to the Prime Minister, has overall responsibility for planning and developing science and technology. The Japan Atomic Energy Commission, an advisory body to the Prime Minister, is responsible for formulating atomic energy policies and programs.

Research and development work is carried out through contract with PNC by the Japan Atomic Energy Research Institute, universities, national laboratories and institutions, electric utility companies, and industry. PNC operates an engineering center with extensive facilities large enough for testing full-scale components. PNC obtains industrial involvement and develops industrial experience by awarding contracts to industrial contractors for the design, construction, and initial operation of facilities, components, and reactor plants. Four nuclear industry groups were involved in the construction of JOYO. Five nuclear industry groups, including the four working on JOYO, are involved in the MONJU design.

PNC personnel come for various participants in the program. Industry and electric utilities will share in funding the prototype reactors.

Safety philosophy and licensing procedures

Japan's goal of nuclear safety is to insure that a reactor, either under normal operating conditions or in the event of a postulated serious accident, will not have any substantial radiation effect on the general public nor on the operational workers.

Licensing nuclear reactors requires granting two licenses by different regulatory bodies. An advisory body to the Japan Atomic Energy Commission considers factors affecting the location, structural design, and the social and environmental aspects of proposed nuclear powerplants before granting a permit to proceed with construction. The other advisory body, under the Ministry of International Trade and Industry, gives advice on design details and conducts component-by-component evaluations before licensing the operation of nuclear reactors for powerplants.

According to NRC officials, Japanese safety standards and regulations are nearly identical to NRC's. NRC has not, however, reviewed the specific breeder reactor criteria or their design implementation and has not reached any conclusions on licensing Japanese designs in the United States.

ITALY

The breeder reactor program in Italy started in the early 1960s and consists mainly of research and development to support a fuels and materials irradiation test reactor, Prova Elementi di Combustible, which is currently being constructed. This reactor will be used to provide research and development support to the French Super Phenix program. In June 1974 France and Italy completed agreements whereby France would assist Italy in carrying out this program. As noted previously, Italy has a tripartite interest in the large commercial breeder reactors (Super Phenix and SNR-2) to be built in France and Germany.

CHAPTER 4

BENEFITS FROM AND IMPEDIMENTS TO EXCHANGING FAST BREEDER REACTOR TECHNOLOGIES

The six countries conducting large fast breeder reactor research and development programs are at different stages of development and are progressing at different rates because of differences in starting dates, national philosophies, and program approaches. This situation might be conducive to more meaningful international information exchanges and cooperative agreements except that these six nations are competing for breeder reactor leadership in the world market. This and other factors create impediments to attaining international information exchanges.

BENEFITS FROM INTERNATIONAL EXCHANGES OF FAST BREEDER REACTOR INFORMATION

Fast breeder reactor technical information exchange arrangements can benefit the U.S. program in one or more aspects.

--Foreign fast breeder reactor information, including information on construction and operational experience, can broaden the U.S. data base and may provide additional input to future projects or program decisions.

--Information on problems encountered in foreign programs may help the U.S. program avoid similar problems or mistakes.

--Foreign information or data which confirms findings already developed as part of the U.S. program may increase the degree of confidence placed on such data (on which future developments or decisions may be based).

--U.S. participation with other countries in experiments, use of foreign test facilities, or receipt of information concerning experiments, calculations, or construction not yet underway in the United States may enable the United States to eliminate duplicative research and development work.

Examples of fast breeder reactor exchanges that government and industry officials consider to have been beneficial are summarized below.

Exchange of materials
for irradiation experiments

During 1973 French CEA and Hanford Engineering Development Laboratory officials agreed to exchange fuel cladding materials for irradiation in the EBR-II and Rapsodie.

Westinghouse Hanford Company, which is the ERDA contractor operating the Hanford Engineering Development Laboratory, and UKAEA agreed, in 1975, to irradiate in the Prototype Fast Reactor certain core structural materials supplied by Hanford Laboratory.

In 1970 officials from AEC and Karlsruhe Nuclear Research Center agreed to exchange fuel assembly specifications and material for irradiation in EBR-II and KNK-II, a German reactor. Operating data and postirradiation examination data was also to be exchanged. The irradiation in the German reactor, KNK-II, has not yet taken place.

Seminar on steam generator development

From December 2 to 4, 1974, representatives of ERDA and the Soviet Union met in Los Angeles for a seminar on developing sodium-cooled fast breeder reactor steam generators. The seminar included the presentation of prepared papers on and discussions of such topics as the status of steam generator development in the United States; testing the CRBR steam generator; and testing, operation, and leaks in the BN-350 steam generator.

SEFOR project

SEFOR consisted of tests on a privately owned 20-megawatt-thermal sodium-cooled fast reactor located in Fayetteville, Arkansas. The reactor was owned by Southwest Atomic Energy Associates, a group of 17 electrical utilities, and operated by the General Electric Company. In 1969 the reactor began operations to

--demonstrate the operational safety of fast breeder reactors,

--obtain physics and engineering data under operating conditions, and

--verify theoretical predictions of fuel behavior.

AEC, the Federal Republic of Germany, and EURATOM supported this project financially in exchange for full operating data. Operation of SEFOR, which terminated in 1972, verified the theoretic calculations on fuel behavior. Participants reported they were highly satisfied with the cooperative arrangement and the project results.

IMPEDIMENTS TO EXCHANGING FAST BREEDER REACTOR TECHNOLOGIES

Various factors hamper the effective exchange of fast breeder reactor information between the United States and foreign countries. These factors include the commerciality of the program, the Freedom of Information Act, the tighter time frames imposed in foreign programs, potential licensing problems, certain inherent difficulties in exchanging information, lack of travel funds, and national pride. In addition, certain undesirable situations may result if the United States depends heavily on foreign breeder reactor programs.

Commerciality of information

Generally, when the results of a research and development program become commercially valuable, it is more difficult to attain meaningful exchanges of information. Countries are reluctant to give information to another country, because the exchanges may result in the loss of a competitive advantage. Foreign breeder reactor programs are now entering this phase, particularly the French program.

The French feel that the information they possess has immediate commercial value and are unwilling to release it to other countries unless royalty arrangements are negotiated. The type of agreement the French are interested in is a long-term (25 years) licensing agreement with one U.S. reactor manufacturer under which the U.S. manufacturer would construct Super Phenix-type plants and, in return, compensate the French. France is not willing to sell just one reactor and does not view a lump-sum payment or some arrangement to buy into the Super Phenix design as desirable.

The British have the same general attitude as the French on the commercial value of some of their information and are therefore unwilling to release such information without receiving something (for example, equivalent information) in return. They recognize that the information they give ERDA will be passed on to U.S. industry involved in the fast breeder reactor program.

The Germans are willing to provide some commercially valuable technology data to ERDA. However, they would want some of their data protected from disclosure to U.S. industry because of possible future commercial competition between U.S. and German firms for sales of breeder reactor components, subsystems, or entire reactors.

The Freedom of Infomation Act

The Freedom of Information Act (5 U.S.C. 552) requires that ERDA, NRC, and other Government agencies release to the public on request, any unclassified records developed by the agency whether in the possession of the agency, its contractors, subcontractors, or others. The term "record" refers to any documentary material such as reports, pictures, designs, and books. The Department of Justice and several court decisions indicate that the term "public" means anyone regardless of nationality, residence, or official status.

The problems ERDA and NRC face with the Freedom of Information Act are that (1) unclassified information developed by ERDA and NRC is readily available under the act to foreign governments upon request, thereby diminishing the need for foreign governments to enter into exchange arrangements with the United States and possibly reducing U.S. effectiveness in negotiating for similar information from foreign governments and (2) foreign governments fear that data which they have supplied in confidence to ERDA and NRC may be released to others without their approval.

ERDA officials said that in their recent and continuing negotiations on breeder reactor exchange agreements, European program officials doubted ERDA's ability to protect data which may be given to ERDA as part of an exchange. ERDA informed these countries that an exemption to the Freedom of Information Act affords ERDA a method to protect foreign proprietary data. However, ERDA said the countries are still concerned about ERDA's ability to protect their proprietary information.

Commenting on our report, an ERDA official said that ERDA believes it cannot protect nonproprietary data, whether foreign or domestic, and thus there is a genuine basis for the foreign concern over the Freedom of Information Act. ERDA believes this will be a continuing concern difficult to alleviate.

Foreign concern over the Freedom of Information Act varies by country. The United Kingdom believes that information provided in confidence to ERDA and ERDA's contractors could be released to others without the approval of the United Kingdom. Such disclosure could damage the United

Kingdom's position for exchanging the same information with other foreign countries as well as make available to the U.S. public and others information that is not publicly available in the United Kingdom. In the United Kingdom, information developed by government organizations is not normally made public. Also, breeder reactor technology is made available to British industry on commercial terms.

The Germans believe that the Freedom of Information Act could impede the transfer of important information that would otherwise be exchanged on a government-to-government basis. They are concerned that some commercially valuable information provided to ERDA may not be adequately protected from disclosure to U.S. firms which may, in the future, be competing with German firms for sales of breeder reactor components, subsystems, or entire reactors.

However, we do not feel that the Freedom of Information Act is the real problem inhibiting exchanges with the French. It appears that, even if ERDA is able to protect proprietary data, the French would not exchange information having commercial value unless they were suitably compensated.

Tighter time frame in foreign programs

The United Kingdom, France, the Federal Republic of Germany, and Japan have tighter time frames for developing commercial fast breeder reactors than does the United States because they do not have the fossil fuel or uranium resources that the United States possesses. Foreign officials describe their programs as being more urgent, taking higher risks, and progressing faster than the U.S. program. Foreign program managers expressed concern that future exchanges of information with the United States may not provide data which can be readily used in their more advanced programs. However, the United States could be in a favorable position if any of the foreign plants encounters a problem for which the U.S. base technology data can provide a solution.

Undesirable results from relying on foreign breeder reactor programs

If the United States relies too heavily on foreign development of commercial breeder reactors, several long-term problems will almost certainly result. The immediate result may be the lack of a domestically controlled breeder reactor industry. The United States would then be forced to purchase foreign-designed reactors which would have an unfavorable effect on the U.S. balance of payment. This could also place the United States in the position of relying on foreign sources for an important energy system, which is contrary to the U.S. goal of energy independence.

Potential licensing problems in the United States

NRC officials view the licensing of foreign design breeder reactors as introducing additional complications and problems of undefined magnitude.

To license a nuclear reactor in the United States, NRC requires detailed technical data and development information including design information, experiment and testing results, research information, and safety data. Unless the developing country provides this type of information to the U.S. applicant (and thus to NRC) to adequately establish the safety of the design, a foreign-designed reactor would not be licensable in the United States irrespective of the design's quality. A foreign country would probably not be willing to make public such information.

Inherent difficulties in international exchange

Attempts to exchange breeder reactor information have met with difficulties which are probably encountered in all international technology exchanges. There is a general tendency for countries possessing information to think of their data as having more value than it is thought to have by other countries. Also, negotiations for exchanges are often time consuming.

An example of the difficulties involved in an international exchange is the Soviet Union's proposal, made in February 1974, to test the planned CRBR steam generator in the Soviet Union's BN-350 reactor. The Soviet Union offered to ship, install, and test the steam generator. ERDA was to fund the construction of the unit and was to receive complete test data. Before accepting the proposal, ERDA said that certain conditions would have to be agreed to. For example, the steam generator would be returned to ERDA after testing; ERDA personnel would supervise installation and testing; and the United States would retain all proprietary rights to the steam generator design.

Although the Soviet Union agreed to these conditions, ERDA said a study group would have to be formed to review the proposal. Nevertheless ERDA did not act before the fall of 1975, when they began studying the proposal. During the intervening period, the Soviet Union inquired about ERDA's response through diplomatic channels. In November 1975 ERDA submitted a counterproposal to the Soviet Union which stated that ERDA would be interested in testing the steam generator if CRBR operating conditions could be simulated on the BN-350 reactor. The Soviet Union, in December 1975, responded that simulating CRBR conditions may be possible and requested that ERDA supply further details. In January 1976 these details were supplied, and as of March 1976, ERDA was waiting for a response from the Soviet Union. This example illustrates the time-consuming nature and the problems involved in negotiating an international exchange.

Lack of travel funds
and other considerations

The most effective information transfer in many areas is achieved through one-on-one personal contact and by temporary assignments to other programs. Currently, ERDA and its contractors have only three representatives assigned to foreign breeder reactor facilities--one in the United Kingdom, one in the Federal Republic of Germany, and one in Japan. Budget restrictions on the amount of international travel funds have prevented ERDA and its contractors from fully benefiting from developments in foreign breeder reactor programs. ERDA officials said that foreign travel is limited by Office of Management and Budget policy and a ceiling agreement with two congressional committees. The number of Government-funded trips made by ERDA and its contractors to visit foreign breeder reactor officials and facilities and the cost of these trips is shown in the following table.

	Cost of foreign breeder reactor-related travel		People visiting foreign breeder reactors	
	FY 1974	FY 1975	FY 1974	FY 1975
ERDA headquarters	$11,661	a/$28,250	9	17
General Electric	2,851	3,717	2	2
General Atomic	1,154	0	1	0
Atomics International	0	1,545	0	1
Hanford Engineering Development Laboratory	11,480	18,642	9	13
Argonne National Laboratory	18,079	22,655	22	25
Aerojet Nuclear	1,000	1,200	1	1
Oak Ridge National Laboratory	2,000	8,442	2	7
Total	$48,225	$84,451	46	66

a/ Approximate cost.

Impediments, other than cost, to exchanges of personnel are (1) the reluctance of management to allow their most qualified people to be assigned to a foreign program, thereby losing their services for the duration of the assignment, (2) willingness of people to relocate, and (3) language problems. Other problems arise concerning where the U.S. representatives should be stationed. For instance, the United Kingdom will not permit a U.S. representative to be assigned to its breeder reactor facility because of the potential opportunity to learn information of commercial value.

National pride

On the basis of our discussion with U.S. breeder reactor program officials, we believe that national pride may impede effective international information exchanges. Various parties involved in the U.S. program--and this may also be true in foreign countries--may be unwilling to accept foreign technology as being more advanced or useful than that developed in the United States. For this reason, the most beneficial use may not be made of foreign breeder reactor information or exchange agreements.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATION

The United States and five other countries are conducting large fast breeder reactor research and development programs. These programs are expected to begin developing commercial fast breeder reactors in the early to mid-1980s. Because of the variations in (1) national philosophies, (2) government-industry relationships, (3) program approach and emphasis, and (4) normal technical uncertainties associated with large, complex research and development programs, it is impossible to accurately predict which country will be the first to successfully develop a commercial fast breeder reactor.

However, if development of an intermediate-size (250 to 350 megawatt electric) demonstration fast breeder reactor is used to measure program progress, then the French are clearly in the lead with Phenix operating and generating power for about 2 years. The relative status of the other programs cannot readily be determined. With the exception of Japan, they all have or plan to have a demonstration breeder reactor operational before the CRBR is scheduled to become operational. The British and the Russians have each completed construction of intermediate-size demonstration reactors, although both reactors are experiencing operating difficulties. The British anticipate resolving their difficulties and reaching full power in 1976. The Russian reactor is reported to be running at better than 50 percent of full power. German officials anticipate completing construction of the SNR-300 in 1980. Construction of the U.S. CRBR is scheduled to be completed in late 1982 with initial operation planned for 1983. The Japanese MONJU reactor is also scheduled for initial operation in mid-1983. However, because of technological uncertainties and differences in approach, it remains to be seen whether the United States or another country will first develop a truly commercial fast breeder reactor.

Except for the Soviet Union, the other countries developing fast breeder reactors lack the energy resources--coal, oil, gas, and uranium--that the United States possess. They have more urgent needs and tighter time frames for developing a commercial fast breeder reactor than does the United States.

To varying degrees, the foreign fast breeder reactor development programs involve the close coordination of government research and development agencies, electric utilities, and reactor manufacturers in each country. Little or no attention is given to developing internal competitive fast breeder reactor industries. This contrasts sharply with ERDA's philosophy of developing a broad technological and engineering base on which to establish the capability for competitive industry. Also, the learn-by-doing approach of the foreign programs emphasizes operating demonstration fast breeder reactors as early as possible rather than developing a broad technology base and testing programs that characterize the U.S. approach to the program. The foreign approach indicates a willingness on the part of the foreign programs to accept greater risk of failure than the U.S. approach of developing a strong technological background for building fast breeder reactors so that once a decision is made to build, the risk of failure or serious problems is sharply reduced.

The desirability of fast breeder reactor exchange agreements has been long recognized by the United States and by the other countries conducting large fast breeder reactor research and development programs. Since the February 1956 U.S. breeder reactor exchange agreement with the United Kingdom, ERDA has engaged in formal or informal exchanges with the countries developing breeder reactors. ERDA, NRC, national laboratories, industry, and others contacted and foreign program managers generally agree that extensive information has been exchanged and that opportunities exist for more beneficial exchanges in the future.

CONCLUSIONS

We conclude that:

--The issues impeding cooperative exchanges of breeder reactor technology with other industrially developed countries become increasingly more difficult to overcome as their programs approach commercial status. Therefore, the U.S. fast breeder reactor development program could not realistically be expected to significantly accelerate or save significant amounts of money through quid-pro-quo exchanges with other countries.

--Some foreign governments are concerned that technical data furnished to ERDA would be made available to U.S. industrial firms and others under the requirements of the Freedom of Information Act. However, this concern is clearly subordinate to the reluctance of some foreign governments to exchange commercially valuable technology for research and development technology. For example, France appears unwilling to exchange what it considers commercially valuable fast breeder reactor technology even if such data were specifically exempted from the Freedom of Information Act.

--The benefits derived from international exchanges of fast breeder technology have not been and probably will not be great enough to significantly reduce the time and/or money required for the United States to develop a commercial fast breeder reactor. However, the past and potential future benefits from cooperative exchange agreements are important enough for ERDA to continue to develop new and broadened areas of exchange. The learn-by-doing approach of some of the foreign programs appears to complement the in-depth technology approach of the U.S. program, thereby offering opportunities for all parties to benefit from future exchange agreements. Cooperative exchange agreements are most effective when they involve the exchange of qualified technical personnel. Accordingly, an important element of future exchange agreements should be the exchange of carefully selected and technically qualified personnel. It would be advantageous to the United States for U.S. engineering personnel to be involved in the design, construction, and operation of foreign fast breeder reactor programs. The areas that offer the most potential for cooperative exchange agreements include:

1. <u>Equal exchanges of basic research and technology development data and safety related data</u>. We believe ERDA should continue to exchange these types of data. The scientific and technical community in all countries with fast breeder reactor development programs appear eager to exchange basic research and technology development data and general breeder reactor safety data (some countries are not willing to exchange safety data for specific plants because of the Freedom of Information Act problems). Such data is readily exchanged because it enhances development work without jeopardizing the commercially sensitive aspects of breeder reactor development programs. The exchange of safety information, data, and methods is mutually

beneficial to all countries developing breeder reactors because safety problems in one country could severely hinder breeder reactor development programs of all countries.

2. Agreements permitting component testing in reactors and test facilities of other countries. A limited amount of fuel irradiation testing and testing of reactor components has taken place at facilities in other countries; however, additional agreements of this nature offer the potential for savings resulting from eliminating duplicative tests.

3. Participation in joint component development programs. Another type of cooperative agreement worth exploring by ERDA involves participation with another country or countries in joint component development programs. Opportunities for agreements in this area occur when different countries are at relatively identical stages in their research and development of common breeder reactor components and/or subassemblies.

4. Puchase of technical information, reactor components, and/or entire reactors. ERDA's efforts to acquire foreign technology have consisted of cooperative exchanges on an equal basis. Because this is becoming increasingly more difficult as the foreign programs approach commercial status, ERDA should consider purchasing information, components, and/or reactors from other countries. While fair value may be difficult to agree on, puchasing commercially valuable information seems to be a logical approach for ERDA to explore. Although it is difficult to predict the extent foreign program managers would be receptive to selling breeder reactor technology, French officials appear interested in capitalizing on their lead, and therefore the price of French technology will most likely be high. The French said they would prefer negotiating some arrangement calling for long-term payments in return for licensing a U.S. reactor manufacturer to build the French-designed breeder reactor in the United States rather than a lump-sum payment. ERDA and U.S. industrial firms will have to determine whether the cost of purchasing technical information, components, and/or reactors from other countries is worth the

investment. Although U.S. industry has held some discussions with the French, firmer actions should be taken to explore the terms under which foreign countries would be willing to sell technical information, reactor components, and/or entire reactors. This should enable ERDA to better evaluate alternatives to its own energy development programs--both nuclear and nonnuclear.

RECOMMENDATION TO THE ADMINISTRATOR, ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

Foreign breeder reactor program officials said they are concerned over ERDA's ability to protect data given to ERDA from the disclosure provisions of the Freedom of Information Act. ERDA believes that there is a genuine basis for this concern and that it will be continuing and difficult to alleviate. We recommend that ERDA seek legislation specifically exempting data acquired through international technology agreements from the disclosure provisions of the act.

ERDA officials concur with our recommendation. NRC also agrees with those aspects falling within its responsibilities.

CHAPTER 6

SCOPE

We gathered the following information, indicative of each country's ability, need, and willingness to exchange breeder reactor data, to find out how the United States may benefit from obtaining foreign breeder reactor technical information.

--The history, status, and future of the United States and foreign breeder reactor programs.

--Identification and evaluation of current exchange agreements.

--Feasibility of international exchange.

--Licensability of foreign reactors in the United States.

We obtained this information from officials at the Energy Research and Development Administration; Nuclear Regulatory Commission; Westinghouse Electric Corporation; General Electric Company; Atomics International (Division of Rockwell International); Combustion Engineering, Inc.; Stone and Webster Engineering Corporation; Bechtel Power Corporation; Burns and Roe, Inc.; Commonwealth Edison Company, Chicago; Tennessee Valley Authority; Electric Power Research Institute; American Nuclear Society; Atomic Industrial Forum; University of Tennessee; Hanford Engineering Development Laboratory; Argonne National Laboratory; and Oak Ridge National Laboratory.

We toured breeder reactor facilities in the United Kingdom, France, the Federal Republic of Germany, and Japan and talked with breeder reactor program officials in each of these countries. We were unable to arrange a tour of the breeder reactor facilities in the Soviet Union; however, we discussed the Soviet program with science and technology officials of the Soviet Embassy in Washington, D.C., and with members of a fast reactor delegation visiting the United States for meetings with U.S. fast breeder reactor program officials.

We contracted with two technical consultants--Dr. Donald T. Eggen from Northwestern University and Mr. Eldon L. Alexanderson from the Power Reactor Development Company--to assist us in analyzing the issues affecting the use of foreign fast breeder reactor technology in the United States. We considered their comments in preparing this report. Complete texts of their reports to us are contained in appendixes VI and VII.

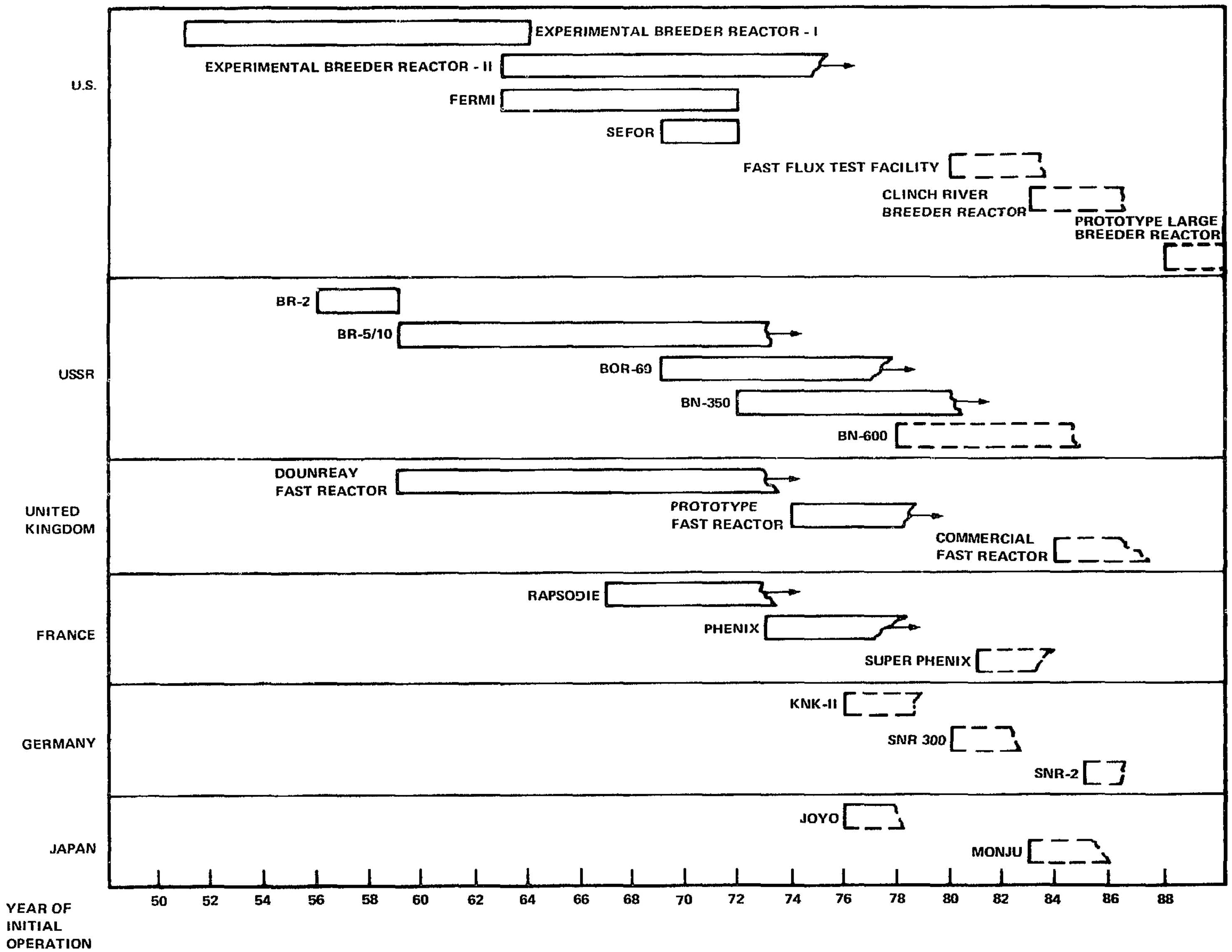
ERDA and NRC officials and fast breeder reactor program officials of the United Kingdom, France, Federal Republic of Germany, and Japan commented on this report. We made some revisions to the report in response to their comments and believe that there are no residual differences in fact.

WORLD-WIDE FAST BREEDER REACTOR PLANTS

Name	Country	Power Megawatts thermal	Power Megawatts electric	Pool or Loop	Initial Operation
Decommissioned					
Clementine	USA	0.025	--	Loop	1946
Experimental Breeder Reactor-1	USA	1	.02	Loop	1951
BR-1/BR-2	USSR	0.1	--	Loop	1956
LAMPRE	USA	1	--	Loop	1961
Fermi	USA	200	60.9	Loop	1963
SEFOR	USA	20	--	Loop	1969
Operable					
BR-5/BR-10[a]	USSR	5/10[a]	--	Loop	1959[a]
Dounreay Fast Reactor	UK	72	14	Loop	1959
Experimental Breeder Reactor-II	USA	62.5	18.5	Pool	1963
Rapsodie	France	20/40[b]	--	Loop	1966[b]
BOR-60	USSR	60	12	Loop	1969
BN-350	USSR	1000	150[c]	Loop	1972
Phenix	France	567	250	Pool	1973
Prototype Fast Reactor	UK	600	250	Pool	1974
Under Constr.					
Joyo	Japan	100[d]	--	Loop	1976
BN-600	USSR	1470	600	Pool	1978
Fast Flux Test Facility	USA	400	--	Loop	1979
Planned					
KNK-II[e]	W. Germany	58	20	Loop	1976[e]
Prova Elementi di Combustibile	Italy	140	--	Modified Pool	1978
SNR-300	W. Germany[f]	770	312	Loop	1980
Super-Phenix	France[g]	2900	1200	Pool	1982
Monju	Japan	714	300	Loop	1983
Clinch River Breeder Reactor	USA	975	350	Loop	1983
Commercial Fast Reactor	UK	3230	1320	Pool	1984-5
SNR-2	W. Germany[g]	5000	1200-2000	Loop	1985-6
Prototype Large Breeder Reactor	USA	2500	1000	Not Decided	1988

[a]Initially operated at 5 megawatt thermal as BR-5; upgraded to BR-10 (10 megawatt thermal) in 1973.
[b]Initially operated at 20 megawatt thermal; power increased to 40 megawatt thermal in 1970 with "Fortissimo" core.
[c]Also produces the equivalent of 200 megawatt electric as process steam for desalination.
[d]To be operated initially at 50 megawatt thermal.
[e]Operated 1971 through 1974 as a thermal reactor, KNK-I.
[f]In cooperation with Belgium and the Netherlands.
[g]Tripartite effort of French, German and Italian electric utilities.

WORLDWIDE FAST BREEDER REACTOR PLANTS



APPENDIX I

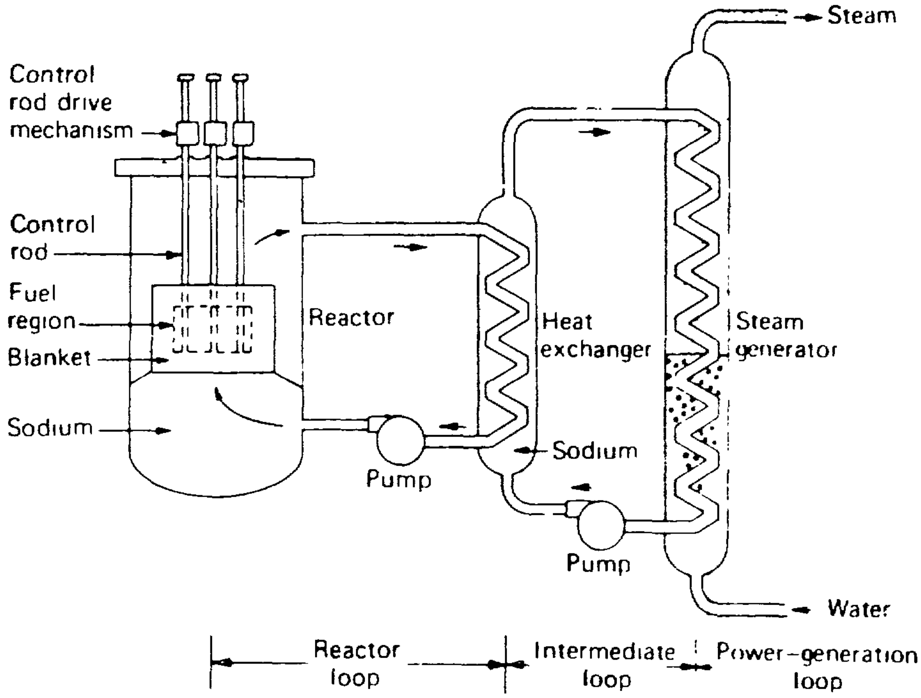
DESCRIPTION OF POOL AND LOOP TYPE FAST BREEDER REACTORS

A pool type reactor contains the reactor and the complete radioactive system, including primary pumps, intermediate heat exchanger, and connecting piping within a large primary tank filled with the sodium coolant.

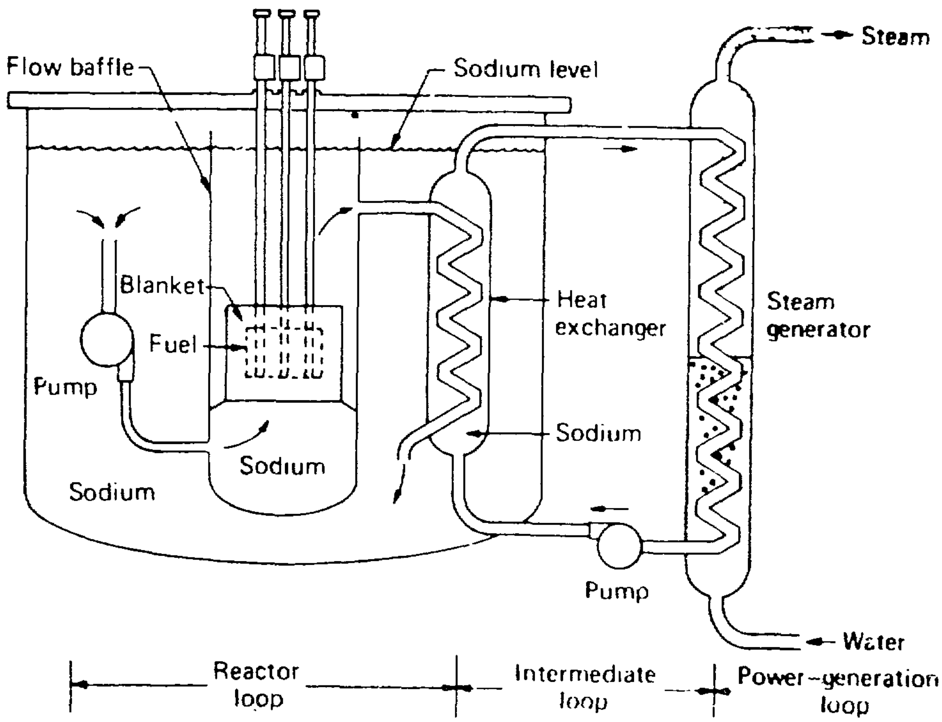
A loop type reactor has separate containers for the reactor, the pumps, and the heat exchanger which are all interconnected by very large piping, up to five feet in diameter in 1200 megawatt electric size plants.

There is no consensus as to the best choice. Safety, operational, and maintenance advantages are claimed for each system design.

LOOP AND POOL TYPE LIQUID METAL FAST BREEDER REACTORS



LOOP TYPE



POOL TYPE

ORGANIZATION CHARTS OF FOREIGN FAST BREEDER REACTOR PROGRAMS

UNITED KINGDOM

Fast Reactor Organization
Structure of Nuclear Industry

FRANCE

Super Phenix Organization

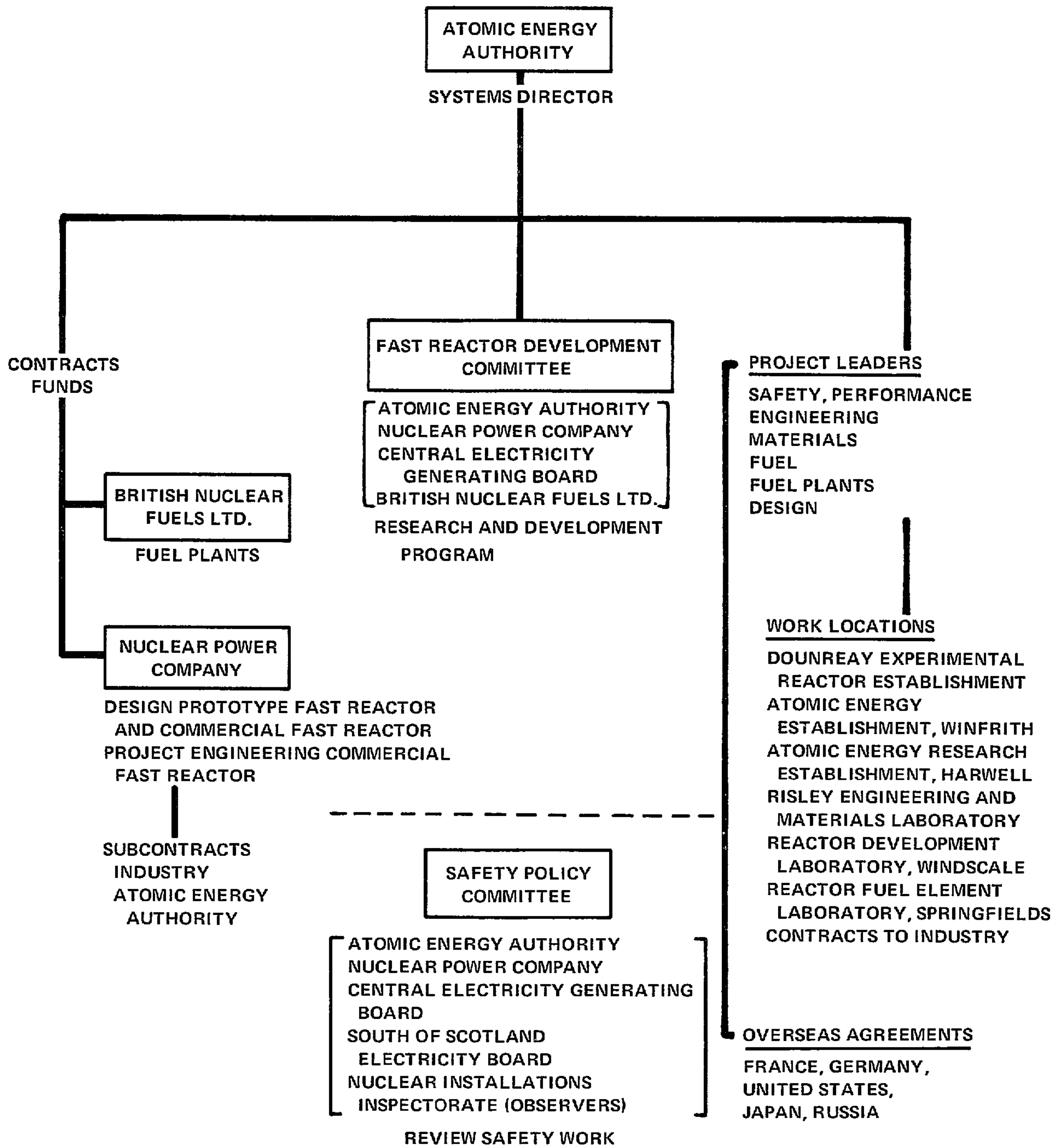
FEDERAL REPUBLIC OF GERMANY

SNR-300 Organization
SNR-2 Organization

JAPAN

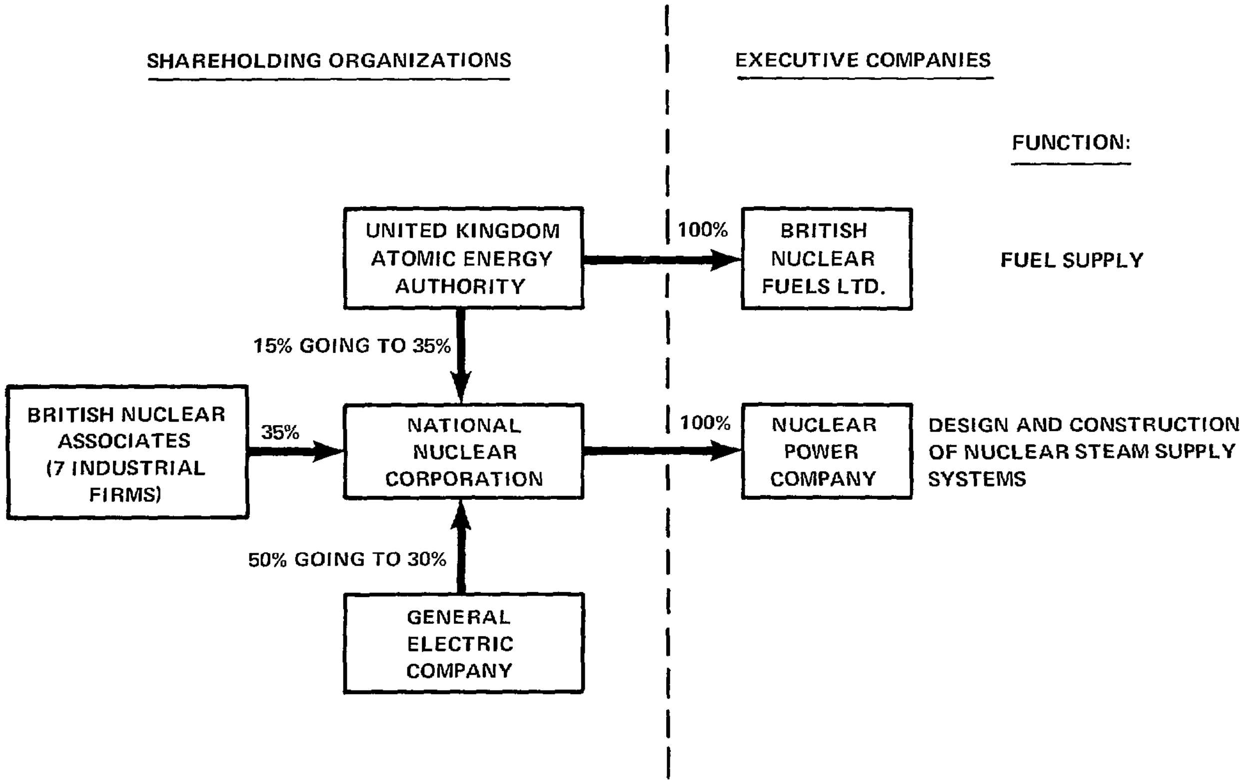
Organization for Power Reactor Development

UNITED KINGDOM FAST REACTOR ORGANIZATION

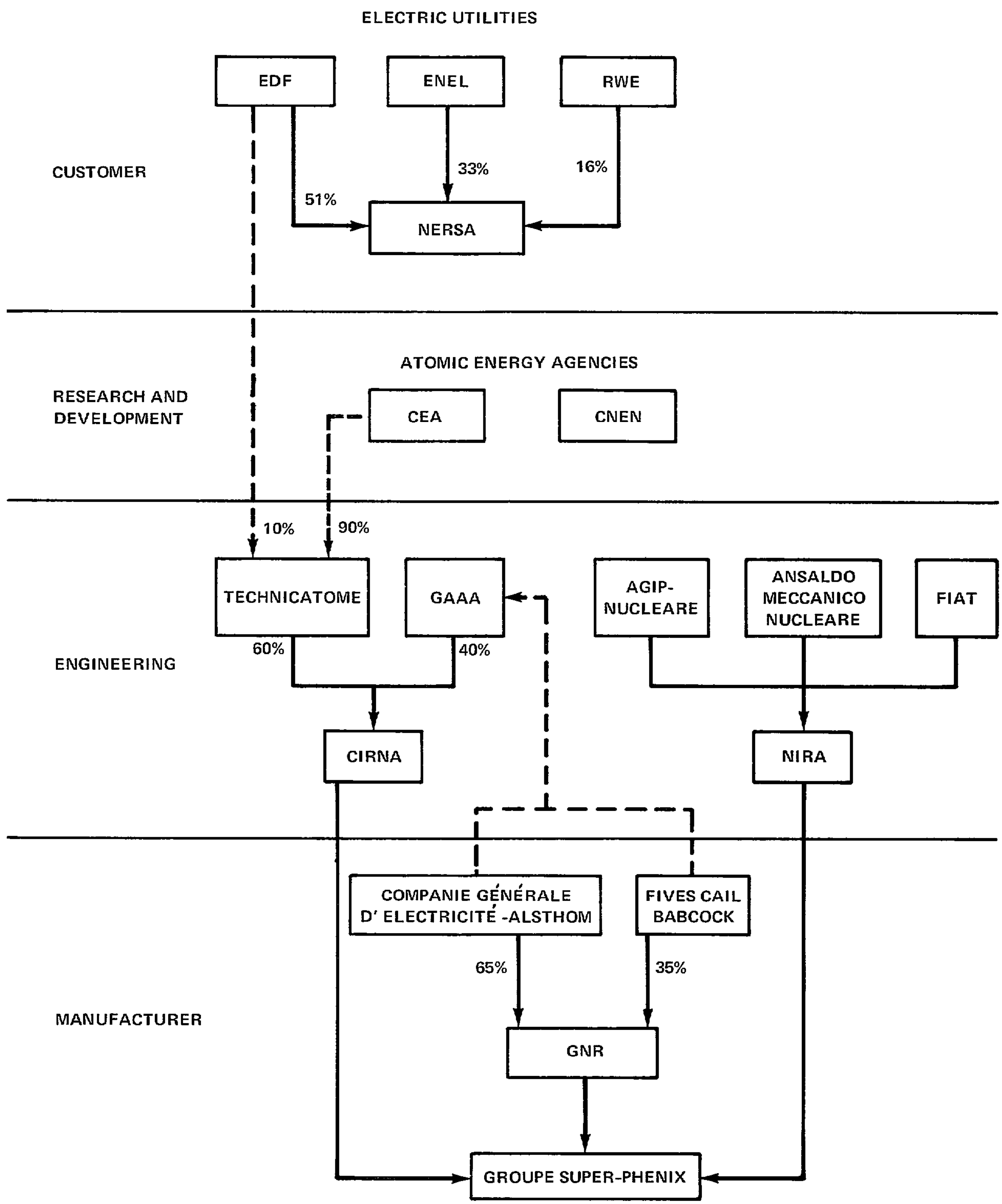


APPENDIX III

UNITED KINGDOM
STRUCTURE OF NUCLEAR INDUSTRY



FRANCE
SUPER PHENIX ORGANIZATION

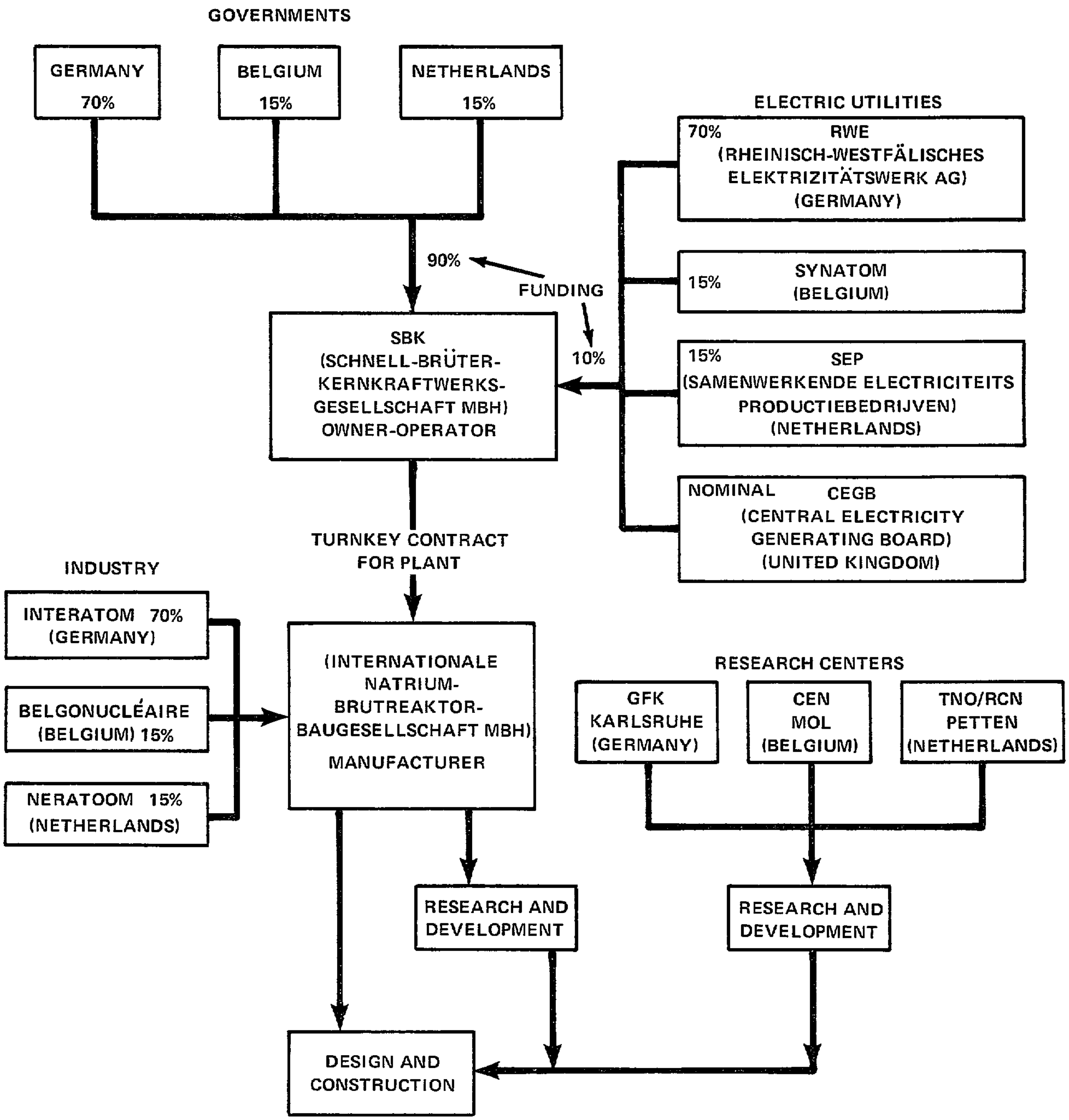


APPENDIX III

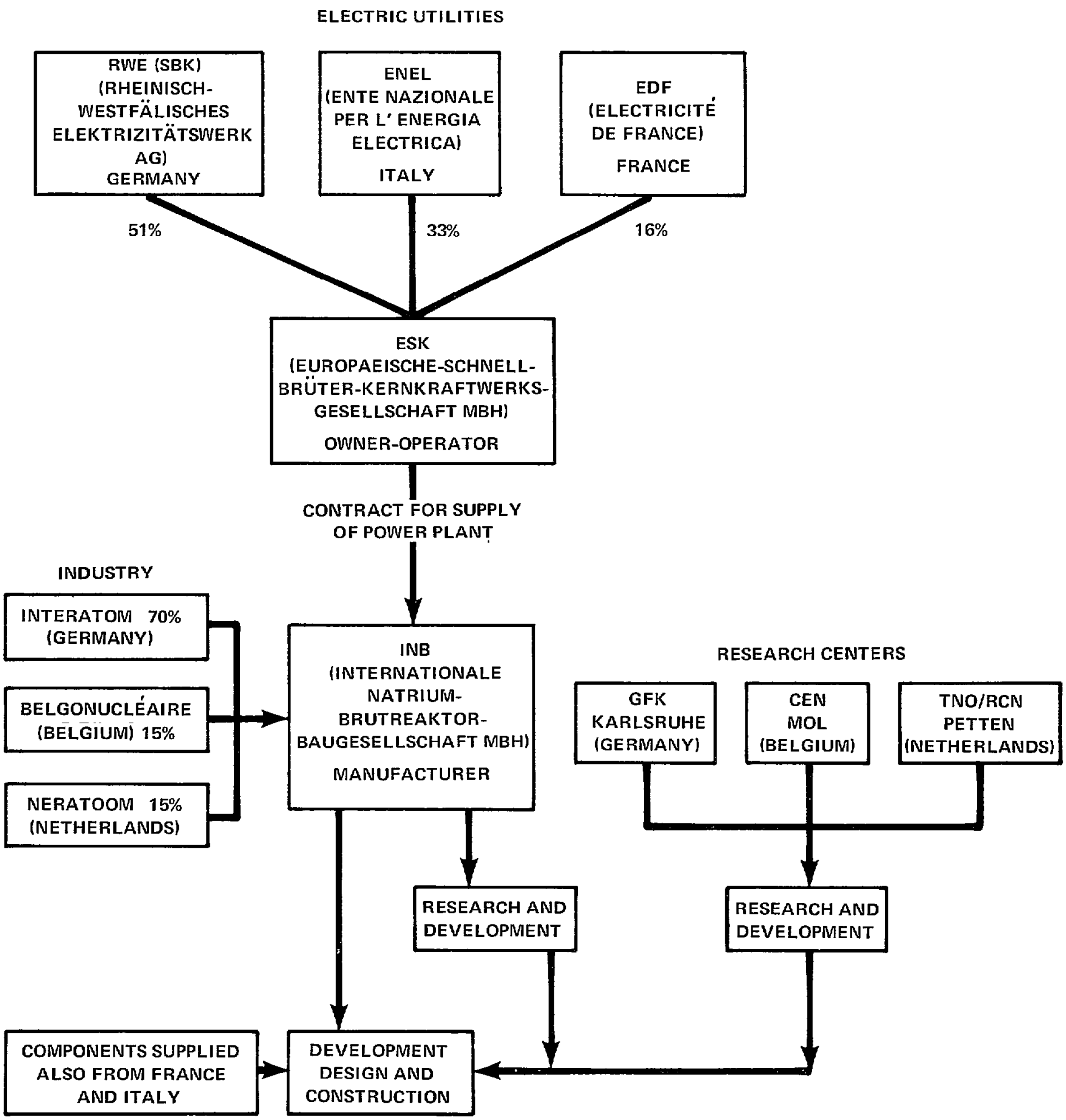
FRANCE
SUPER PHENIX ORGANIZATION

EDF	ELECTRICITÉ DE FRANCE, FRANCE
ENEL	ENTE NAZIONALE PER L'ENERGIA ELECTRICA, ITALY
RWE	RHEINISCH - WESTFÄLISCHES ELEKRIZITÄTSWERK AG, FEDERAL REPUBLIC OF GERMANY
NERSA	NEUTRONS RAPIDES SOCIETÉ ANONYME
CEA	COMMISSARIAT À L'ENERGIE ATOMIQUE, FRANCE
CNEN	COMITATO NAZIONALE ENERGIA NUCLEARE, ITALY
GAAA	GROUPEMENT POUR LES ACTIVITÉS ATOMIQUES ET AVANCÉES, FRANCE
CIRNA	COMPAGNIE D'INGÉNIÉRIE POUR LES REACTEURS RAPIDES AU SODIUM, FRANCE
NIRA	NUCLEARE ITALIANA PER I REATTORI AVANZATI, ITALY
GNR	GROUPEMENT NEUTRONS RAPIDES, FRANCE

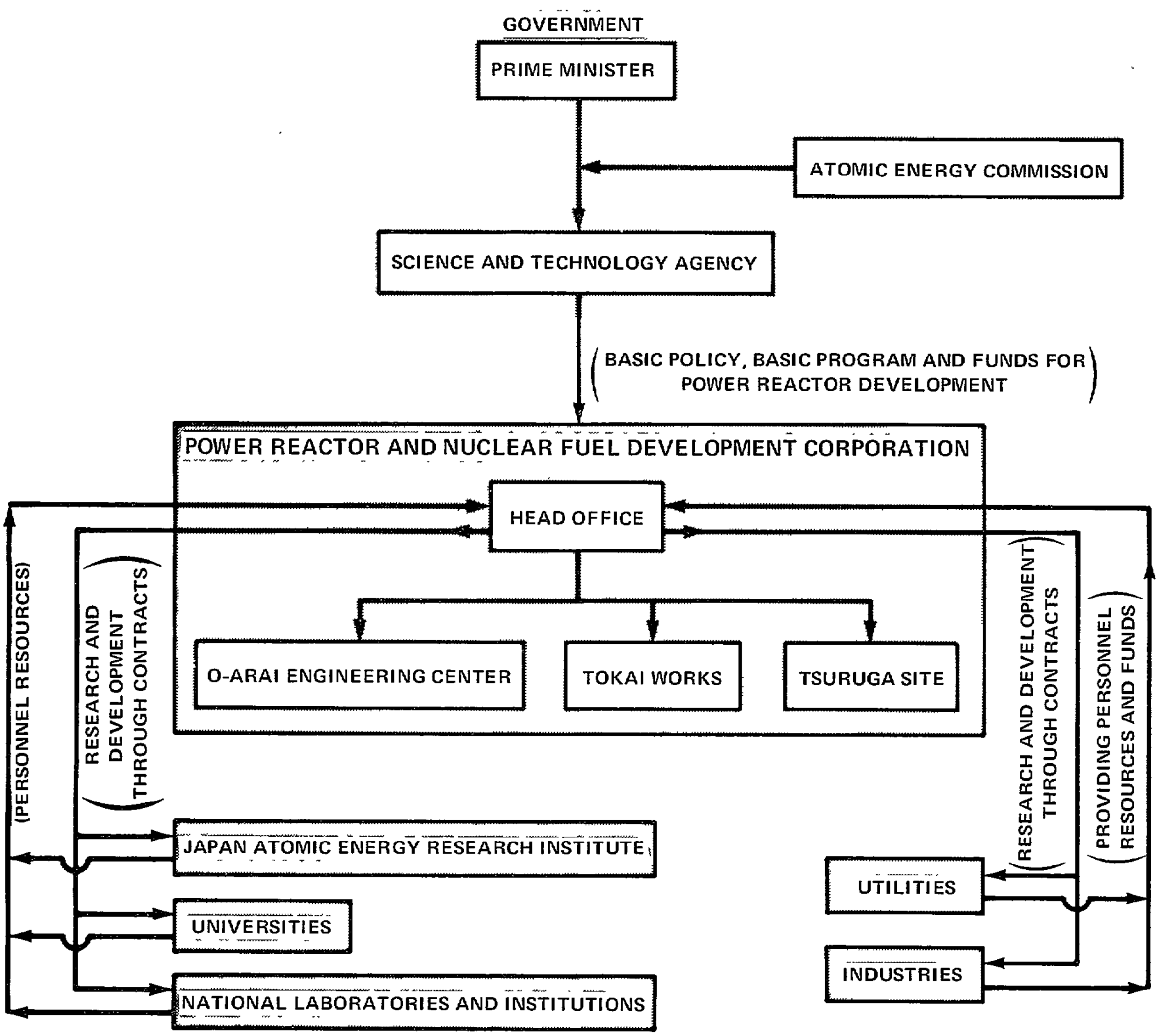
FEDERAL REPUBLIC OF GERMANY
SNR-300 ORGANIZATION



FEDERAL REPUBLIC OF GERMANY
SNR-2 ORGANIZATION



JAPAN
ORGANIZATION FOR POWER REACTOR DEVELOPMENT



APPENDIX IV

SUMMARY OF NUCLEAR POWER PLANTS CURRENTLY OPERATING OR PLANNED
FOR FUTURE OPERATION IN THE SIX NATIONS WITH MAJOR FAST BREEDER REACTOR PROGRAMS

Type of Reactor	Federal Republic of Germany		France		Japan		United Kingdom		United States		U.S.S.R.	
	Operating	Planned	Operating	Planned	Operating	Planned	Operating	Planned	Operating	Planned	Operating	Planned
Pressurized water reactor	3	13	1	22	3	7	0	0	32	109	6	5
Boiling water reactor	4	6	0	8	5	12	0	0	24	47	1	0
Gas cooled reactor	1	1	8	0	1	0	28	10	1	2	0	0
Fast breeder reactor	0	3	1	1	0	1	2	1	0	1	2	1
Heavy water reactors	1	0	0	0	0	1	1	6	0	0	0	0
Graphite moderated, light water cooled	0	0	0	0	0	0	0	0	1	0	14	7

APPENDIX IV

QUANTITATIVE LISTING OF RESULTS OF FAST BREEDER REACTOR EXCHANGE AGREEMENTS

Fast Reactor Reports Exchanged Between the United States and Foreign Countries

Number and Length of Fast Reactor Related Long-term Personnel Assignments (1967-75)

Personnel Meeting with Foreign Fast Reactor Officials or Visiting Foreign Fast Reactor Facilities

Fast Reactor Reports Exchanged Between the United States and Foreign Countries

Country	Reports received by AEC-ERDA 1973	Reports received by AEC-ERDA 1974	Reports sent by AEC-ERDA 1973	Reports sent by AEC-ERDA 1974
United Kingdom	77	133	361	271
France	0	0		
Federal Republic of Germany	70	59	361	271
INBFR (note a)	5	29		
Netherlands	2	6		
Italy	0	1		
U.S.S.R.	4	1	1	0
Japan	53	44	127	85
	211	273	850	627

a/Interatom of Germany, Belgonucléaire of Belgium, and Neratoom of the Netherlands.

Number and Length of Fast Reactor Related Long-Term Personnel Assignments (1967-75)

Country AEC-ERDA personnel assigned to	Number of assignments	Total length of assignments (years)
United Kingdom	3	5
France	1	2
Federal Republic of Germany	5	9.5
Japan	1	1
	10	17.5

Foreign personnel assigned to work in the United States program (note a)	Number of assignments	Total length of assignments
		(years)
United Kingdom	3	6
Federal Republic of Germany	6	7.5
Japan	1	1
	10	14.5

a/Does not include the many people (nearly 100) from foreign countries assigned to work at the privately owned Fermi plant.

Personnel Meeting With Foreign Fast Reactor Officials or Visiting Foreign Fast Reactor Facilities

Countries visited by U.S. personnel	Number of personnel making visits	
	FY 1974	FY 1975
United Kingdom	48	92
Federal Republic of Germany	12	32
France	12	35
U.S.S.R.	1	11
Japan	8	1
Belgium	7	3
Netherlands	5	7
Italy	5	7
Norway	0	1
Spain	0	2
Austria	3	3
Republic of China	0	2
Australia	0	1
India	1	0
	102	197

Countries sending fast reactor personnel to visit the United States	Number of personnel making visits	
	FY 1974	FY 1975
United Kingdom	11	5
France	15	6
Federal Republic of Germany	28	23
U.S.S.R.	0	17
Japan	28	34
	82	85

CONSULTANT REPORT TO THE GENERAL ACCOUNTING OFFICE ON U.S. AND FOREIGN FAST BREEDER REACTOR PROGRAMS, DONALD T. EGGEN, DECEMBER 31, 1975

Donald T. Eggen is a professor, the Chairman of the Nuclear Engineering Program, and Acting Chairman of the Engineering Science Department at Northwestern University in Evanston, Illinois. Dr. Eggen also consults for Argonne National Laboratory on fast reactor core materials and served as a program section manager at Argonne from 1966 to 1968 with responsibility for research and development of fast reactor core designs and safety research.

 APPENDIX VI

U.S. and Foreign Fast Breeder Reactor Programs and Potential Cooperative Programs

A report submitted

by

Donald T. Eggen

Evanston, Illinois

to the

U.S. General Accounting Office

Washington, D.C.

December 31, 1975

Preface

The consultant was engaged by the U.S. GAO to provide technical and programic advice relative to the liquid metal cooled fast breeder reactor (LMFBR) program as it is being conducted in the United States and other developed countries of the world. The particular assignment is in regard to a request by Senator Humphrey, Chairman, Joint Economics Committee of Congress, to assess the possibilities, potential advantages and economic value of cooperative programs of technological and experience exchange between the U.S. and England, France, Germany, the Soviet Union, and Japan (those having LMFBR programs).

The following report is in two parts. The first is directly responsive to specific questions posed by the GAO staff. The second part is broader in scope and presents generalities and observations made by the author. The source material has been derived primarily from notes taken during meetings with representatives of various national laboratories in the U.S., UK, France and Germany, and national directors in the various countries. In addition, brochures, technical data, annual reports, written responses to specific questions, interviews with scientific personnel in Paris and Brussels connected with U.S. missions, and other information have been used. Appendix A is a list of specific items on which the first part of this report is based. A listing of visits, dates, and contacts are provided in Appendix B. Appendix C gives a list of abbreviations used in the text and defines certain "jargon".

Donald T. Eggen
Evanston, Illinois

Part I - Discussion of Specific Items Related to U.S.-Foreign Cooperation in the LMFBR Program

Summary

The principal strength in the U.S. fast breeder program is the breadth of technology being developed under the ERDA program in its national laboratories and the industry. The principal weakness is its performance in design and building fast reactors. The areas of greatest accomplishment are fast reactor physics, safety, fuel and materials technology, high temperature piping and tanks, and sodium technology and instrumentation. In fuel fabrication, heat transport components, core structure, and reactor and system control, the U.S. is on par with other countries. Processing technology is not well developed in any country. The U.S. has more extensive and advanced test facilities than any other country or group of countries.

The principal strengths of the fast breeder programs are: in France, single mindedness of purpose and the program continuity and success at each phase to date; in Germany, the development of an apparently prototypic reactor system capable of reasonable scale up and designed to meet licensing criteria over the longer term; in the UK, the reactor is prototypic, fuel development is well characterized, and the safety criteria are based on experience and probabilistic analysis. The principal weaknesses in the European programs are generically, lack of general breadth in technology and fall back alternatives to components which have been developed. There seems to be a common cause feeling in Europe.

The U.S. would benefit from closer (personal) interactions with any foreign manufacturing, construction, and operation of fast breeder plants and/or facilities. This does not infer that the U.S. industry will not have to involve itself in the same activities. It does mean that if such arrangements could be made there is every possibility that some experiences with foreign plants will reduce the potential for problems in design, construction and operations. Involvement of senior engineering personnel in foreign design, development and operational teams would be advantageous to the program. The Germans and probably the Japanese appear amenable to arrangements for exchange of engineering personnel between design and operational groups. The British and French find difficulty due to their "advanced state" and the proprietary interests of their industry.

The second area of information exchange is in the area of basic research and technology development. The two most straightforward areas are physics and safety. In the areas of fuel and component design, sodium components and instrumentation, these fall in the category between proprietary interests and fundamental development and technology exchange arrangements will be more difficult.

The value of the U.S. base technology program is long range. The net economic value is questioned by those who point to the success of the French program. However, the problems experienced by the Russians and to some extent the UK can be used to illustrate the value of a more thorough understanding of basic phenomenon and a quality assurance program. The answer will come as the commercial market develops. The base technology program of the U.S. will probably support the commercialization of fast breeder reactors in this country. It will also be a benefit to other countries of the world if they develop problems in their larger sized plants. The U.S. could have built a fast breeder reactor demo plant much earlier if there had been a need, a direction, or there had been less emphasis on base technology. There would have been a higher risk.

Based on discussions with representatives in the UK, France and Germany, it appears there is good possibility for joint programs and exchange of information in the areas of fast breeder reactor safety and physics. In the areas bordering on commercial application, there seems to be less interest. These areas in this category include: fuel and material technology, sodium components and instrument technology (sodium physical chemistry, large sodium components, and steam generators), and fuel handling and core restraint. On overall plant design, construction and operation, there appears to be little opportunity with France and the UK. The French want to develop license agreements with U.S. industry. There would appear to be a genuine interest on the part of Germany to exchange personnel in design, development and operational sectors. They also seem interested in the use of test facilities in the USA. The British seem to feel they would prefer to join with their European partners to build facilities for the next size plant testing.

The impediments to international exchanges of LMFBR information, joint projects, or programs are pride, success, and easy access to most that they want. The only impediment to joint projects with Germany seems to be monetary or the availability of comparable or adequate facilities in Europe. The British are trying very hard to be Europeans. They are also in an economic squeeze. The French CEA has proprietary interest in the fast breeder reactor design and most of the systems associated with it.

There are several opportunities for the U.S. to use foreign facilities. The value, economics, and arrangements are questionable in some cases. It would be valuable to test prototypic fuel elements in PFR or Phenix and to test a prototypic steam generator unit on the USSR-BN350 to get actual operating experience.

The licensing procedures are quite general between the U.S. and European countries except for some specifics. The German safety philosophy is quite parallel to the USA. The UK uses a probabilistic evaluation. The French safety philosophy is to evaluate any initiating event that can be postulated mechanistically.

The Phenix reactor could not be licensed in the USA. The Super Phenix appears to be designed in a manner that it could probably be licensed in the U.S.

LMFBR power plants are designed with either a loop or pool layout. Examples of loop designs are the U.S., Japan, USSR, and German demonstration designs. Examples of pool designs are the French and United Kingdom demonstration plants, and the French, UK and USSR first commercial designs. Firm decisions have not been made for the U.S. or German first commercial design.

1. United States Program Strengths and Weaknesses

The principal strength in the U.S. fast breeder program is the breadth of technology being developed under the ERDA program in its national laboratories and the industry. The principal weakness is its performance in design and building fast reactors. The areas of greatest accomplishment are fast reactor physics, safety, fuel and materials technology, high temperature piping and tanks, and sodium technology and instrumentation. In these areas, the U.S. is still ahead of the rest of the world. In fuel fabrication, heat transport components (pumps, valves, heat exchangers, service systems), core structure, and reactor system control, the U.S. is on par with other countries. In the area of structural response to explosive loads, the U.S. is strong on calculational methods and the Europeans (especially UK) are stronger on experimental technology. Processing technology is not well developed in any country.

The U.S. program exmphasis on quality control and the development of industrial capability has been costly and time consuming. The U.S. program has developed an extensive set of design, manufacturing, constructing and operating codes and standards. It is yet to be proven how much of this will be needed or how timely it is.

The philosophy has been to develop as much basic design information as possible so that a design could be created with a high degree of confidence in successful performance of the components and systems. A considerable amount of basic research and testing on materials (fuels, cladding, structural bearing), components, sub components (e.g., seals, bearings, moving parts in sodium) and phenomena (corrosion, sodium interactions with fuel) and calculational codes (physics, safety, structural response) is included in the program. There has been an underlying effort to develop not only a technology base but an industrial base for building fast reactor power plants.

The result has been that while the U.S. has the knowledge, it has not produced a product and the rest of the industrial world appears to be ahead of the U.S. in the ability to build plants. The wisdom of the U.S. approach is subject to conjecture. Surely, the Russian steam generator leaks are at least partly due to lack of adequate quality assurance and control, material technology, and prior testing. The French have relied heavily in the past on the U.S. physics, safety, and sodium technology, and are currently ordering fuel cladding from U.S. supplier - presumably to U.S. specifications. The real test of success for the U.S. program of a multipronged, broad-based technology in providing alternates where problems arise will come when commercialization is needed.

The U.S. has more extensive and advanced test facilities than any other country or group of countries with few exceptions (steam generator test facilities in Holland are larger than LMEC, but LMEC is upgrading the LCTI to 70 Mwt; explosion test facilities in the UK are better; fuel testing in Rapsodie are better than EBR-II, however FFTF will be the best in the world). Comparable facilities are TREAT/CABRI; ZPR-V/SNEAK (Gr), MASURCA (Fr), and ZEBRA (UK) (ZPPR is more versatile and can test larger cores than any), sodium-water interaction at LMEC/Cadarache and Interatom; and hot cells at EBR-II/Dounreay, Phenix.

In addition to the basic technology program, the U.S. program includes an extensive test program for virtually all components, subsystems and systems designed for the FFTF and CRBR (and probably the NCBR). These include first production units of pumps, valves, heat exchangers and cold traps at LMEC. Full prototype tests of the FFTF fuel handling, core restraint, control rods are conducted in out-of-pile facilities at HEDL. Modifications to the design are made as required (and there are instances - sodium-to-air HX for FFTF). All components will of course be tested in preoperational tests in the plants. These tests are as or more extensive than those conducted in foreign countries.

There is currently no proven, commercially acceptable, steam generator in the world. A 30 Mwt has been tested in the U.S., 50 Mwt units have been tested by Germany (in Holland) and France which potential could be scaled to commercial units. The U.S. program includes the development of advanced fuels (for higher burnup and breeding ratio). Only minor efforts exist in foreign countries.

In support of the U.S. programmatic philosophy, one can make the following observations.

1. The need for developing a breeder reactor is not as critical (in the sense of urgency) as in Europe or Japan. The U.S. has a relatively large supply of uranium and fossil fuels.

2. The breeder must compete economically with alternate energy sources. Whereas, in Europe and Japan limited uranium supplies and the production of Pu in thermal reactors put a larger premium on optimizing their use, in spite of short term economic disadvantages.

3. If a reactor, or system, or component encounters a technical problem, the base technology can better provide an alternate solution.

4. The U. S. Policy against monopolistic industry is being fostered by the development of capability in the equipment supply and service industries.

5. Since commercial breeders will not be needed until about the 1990's, it is possible a good policy to space the development, design, construction and operation over a period in order to maintain an industrial continuity and competence. (It is important that the design, development, and construction proceed in a regular and adequate frequency so that the cadre of competent engineers and suppliers are not diverted to other activities or that the orders are so small and infrequent that suppliers can't afford to maintain a product line.)

Distracting from the program's value are the following:

1. There was a long period between the design and construction and development of the EBR-II and Fermi reactors and the start of the next generation.

2. Many of the developed components were "reinvented". Designs of several components incorporate mistakes made previously and forgotten.

3. Delays in the program resulted in loss of talented and trained engineers and suppliers. (Program directors point to problems made in design, construction, and operation of plants like Fermi and Hallam as justification to starting over. Cognizance was not given to the limited budgets and support provided these projects and the risks recognized and accepted.)

4. Codes and standards for design, fabrication, and construction were "set" too early without the benefit of experience. Compliance to these resulted in delays (time spent in engineering them and time spent in trying to comply). Codes and standards traditionally evolve from experience in the industry. The policy of inventing codes and standards appears untimely (as evident by the decision not to follow certain RDT codes and standards on non-critical systems in CRBR).

5. No outstanding management organization or scheme has evolved to build reactors. The system has tended toward mediocrity and lack of purpose or focus.

2. European Program(s) Strengths and Weaknesses

The principal strengths of the European fast breeder programs vary from country to country. In France, they are: single mindedness of purpose and the program continuity and success at each phase to date. In Germany, the development of an apparently prototypic reactor system capable of reasonable scale up and designed to meet licensing criteria over the long term. In the UK, the reactor is prototypic, fuel development is well characterized, and the safety criteria are based on experience and probabilistic analysis.

The principal weakness in the European programs are generically, lack of general breadth in technology and fall back alternatives to components which have developed. Fixes on components experiencing problems have been accomplished by add on work and/or accepted periodic maintenance. These troubles provide insight and have led to redesign and further testing for the larger units required in the next generation of plants.

Generally speaking, no major problems have occurred in the reactor part of the plants. Fuel technology appears to be adequate (not proven yet for Germany). Evolutionary improvement and continuing testing in the demonstration plants will probably provide economic fuel at least in the plant (that is the useful life (burnup) expectancy will be attained). There is still the recycle and refabrication to be established for an economical fuel cycle.

Generically the programs in France and the UK, and to a lesser extent in Germany, have emphasized development and testing of components identified to have a high risk potential (operationally). All programs have had a significant safety component although the emphasis has varied to some extent. All programs have had physics included. Fuel development has varied from fundamental development, principally in the UK, to extensive testing, principally in France. In component development for heat transport and core applications (structure, fuel handling, and reactor control), the emphasis has been on testing equipment designed for plants. Modifications and improvements were made based on limited general development programs, specific development, and U. S. technology; to provide a design with a limited risk. In most cases, prototypic sized and designs were used for tests using water and later sodium atmospheres. In some cases, models or segments of total systems were used for tests. This is similar to practices in the U.S. and for other reactor systems when they have progressed to the design/fabrication stage. The differences lie primarily in the degree of available base technology and risk acceptable.

It should be noted that the amount of funds spent on fast reactor safety in all of Europe is about equal to that spent in the U.S. There is a certain amount of cooperative effort in this area. However, there is a significant amount of duplication. The same is true in the physics area. Fuel development has been basically independent efforts in each of the countries, although the Germans have used UK test facilities. Fuel development and sodium system development are considered proprietary and therefore less easily subject to joint programs.

There seems to be a common cause feeling in Europe. This is manifest in joint use of some facilities (e.g., Germans pooling Pu for critical with UK, German and UK safety test with French in CABRI, possible tests of UK units in Hengelo, master caluclational codes for safety and structural dynamics). On the other hand, each country has the individuality of a reactor design like companies in the U.S. Joint plant construction projects like Super Phenix and SNR-2 which involve French (EdF), German (RWE) and Italian (ENEL) utility groups is another instance of commonality.

3. Areas of Information Exchange

The U.S. would benefit from closer (personal) interactions with any foreign manufacturing, construction, and operation of fast breeder plants and/or facilities. This does not infer that the U.S. industry will not have to involve itself in the same activities. It does mean, however, that if such arrangements could be made, there is every possibility that some experiences with foreign plants will reduce the potential for problems in design, construction and operations.

This would be reflected in lowering costs (mistakes and problems are costly in time and money) and time in attaining a commercial industry. It is virtually impossible to build a large complex system without some problems.

One of the unfortunate facts of industry is that reports on problems in manufacture, construction, and operation are not well reported. Either the organization involved suppresses such information or it is lost in the maze of paper constituting operational, construction, and maintenance logs. A good observer involved in these functions (but not handicapped by the responsibilities) can digest and highlight significant information. If then, he provides expert advice to another organization, correct design and other functions can be accomplished with minimal problems.

At the present time the U.S. has the opportunity to make use of its own facilities at EBR-II, the LMEC and HEDL test facilities, the construction of the FFTF and new facilities at LMEC. The use of engineers and managers working at these facilities and the assignment of design and management personnel at these facilities could provide a substantial insight-into design and operational expertise.

In addition, involvement of senior engineering personnel in foreign design, development and operational teams would be advantageous to the program. Other teams have different approaches and solutions to problems. These increase the breadth of alternatives.

The Germans and probably the Japanese appear amenable to arrangements for exchange of engineering personnel between design and operational groups. The British and French find difficulty due to their "advanced state" and the proprietary interests of their industry. Such arrangements are of value mostly between design, construction and operation groups. Therefore it might be expected that U.S. industrial groups would also find difficulty in releasing their best engineers and accepting outsiders into their organizations and company secrets. This area is probably most amenable to interindustrial agreements (licenses).

The second area of information exchange is in the area of basic research and technology development. The two most straightforward areas are physics and safety. In both of these the U.S. is supreme and therefore the rest of the world is eager to develop communications. Inasmuch as most of the U.S. work is unclassified, non-proprietary, is published in the open literature and/or is available through reports publicly available within short times after discovery, it would be advantageous to the U.S. to develop multilateral (or many bilateral) agreements for free exchange of reports and personnel.

In addition, the advantage of free and total exchange of safety information, data and methods is paramount to a sucussful commercialization of fast breeders. The industry is dependent on convincing the public of the safety of the fast breeder system. A safety occurrence in any country's program will be reflected in all programs. Many of the safety studies of importance to adequate design analysis are statistical in nature or require expensive facilities. The joint coordinated program in all nations can provide the statistics needed, the cross checks required, and spread the costs.

In the area of physics, the free exchange of cross section data is important. The U.S. has an extensive data file. The Europeans appear to have good adjusted cross sections which have been successful in core physics calculations for current reactors. They will need experimental data to prepare suitable adjustments for larger systems. The U.S. can gain from their methods. Both groups are developing advance synthesis techniques for reactor criticality and kinetics calculation. Inter-comparisons are vital to continued progress and accuracy.

In the area of fuel and component design, these fall in the category between proprietary interests and fundamental development. The line is hard to distinguish and has led to various interpretations in the several countries. Areas possible for exchange are basic fuel and cladding material properties. Another area of potential exchange is in design and performance calculational codes and models. This area is basic research with guidance and verification from experiments. The large body of irradiated elements under various test conditions which have been performed in EBR-II, DFR, Rapsodie, BN-300, and Phenix would be of tremendous value to the fuel performance modelers both in the U.S. and abroad. The U.S. and UK have the most advanced models. The French are more empirical in nature. These models are currently used to predict the "safe" lifetime of fuel; ultimately they will be useful in the design of more economical fuel, and as a part of safety analysis.

Sodium components and instruments are potential commercial products and therefore subject to proprietary interests. However the state of the art is not so advanced or the design optimized to the extent that interchange of basic and operational data would not be possible. Seals and bearings, material selection, weldments, etc. are still fraught with frustrating occurrences. Components operate, but little things like seal leakage (in Phenix), stripped bearing surfaces and warped shafts (in PFR) still plague operation efficiency. A freer exchange of experiences could solve some of these irritations.

Codes and standards for high-temperature, long-term applications in LMFBR vessels and piping systems would be of interest in Europe. Advanced alloys for systems which have been developed in Germany or those under study in the UK could be of interest in the U.S. Quality assurance methods are expected to be recognized as being of greater importantce and exchanges are possible to mutual benefit.

4. Value of Base Technology Program

It is difficult to give a direct answer to the question of the value of a base technology program. Some advocate that it is better to have assessed the risks and carried out development and test projects on the high risk area. They attest that one learns by doing. They point to the French successes as illustrations.

Others claim that good engineering studies which identify all the uncertainties in the engineering and technology and the missing data are the first step to successful commercialization. Then a plan of developing this base technology and a program to carry out the plan is developed. When all (or almost all) the foreseen lacks of technology are in hand, then one may proceed with engineering the reactor system. Prototypic components and systems are tested for progressively larger plants. A demonstration plant is built to assure that the synthesis of all this technology has been correctly applied. The demo plant is the last in the development train. That does not mean that all research and development is complete. There are still the matter of scale up, process and design improvement, and improved assurance of safety.

A well planned program of developing base technology provides assurance that if a problem appears in the synthesis of design, alternative methods of solution are near at hand and the project will not be unduly delayed.

The U.S. has followed the second method to a large degree. The French and English have followed the first, basically.

The U.S. has included in its program the design and construction of a relatively large test reactor, the FFTF. This could have served a purpose of maintaining and further developing a qualified cadre of engineers, managers, and vendors. Its main purpose may have been to provide a desirable test facility. The project was used for many purposes and suffered many redirections and management changes. Its advent took place during a period of reorganization in the Reactor Development Division (AEC) and was authorized to an organization without prior experience in sodium technology, fast reactor design, or major project responsibility. It was an R & D group not a reactor designer and builder. The location was chosen to support a manpower pool.

Not only has the U.S. program emphasized a base technology, but it has also developed in parallel a management program. This program has included the development of procedures and methods of management control and decision making, quality assurance and control, and a set of codes and standards for everything. These are good and proper but may be carried to excess and may be premature.

Another argument for the U.S. program may be that the the need for breeder reactors is not imminent. Commercialization will not evolve until there is a market based on economic considerations which will not occur until the years 1990 to 2000. Therefore, it is better to build a base technology which will support any eventuality and not worry about building demonstration plants until a few yea before commercial need.

It is seemingly true that once there is a commitment for a reactor plant there is a need that another project should follow on its heels rather closely, say three years (estimated time of design, construction, or early operation). This provides continuity in management, engineering personnel, component vendor capability and interest. The U.S. faces a problem only paralleled by the total of the European effort in this respect. The U.S. has two or three reactor designers. How are all these vendors to be developed concurrently? In Germany and France, the ministry pointed out that the potential internal need for fast breeders would only utilize a half of the industrial capacity (needed to maintain a viable organization) and they only have one reactor design organization each. The British have reduced their industry to one supplier which also is responsible for thermal reactor design. The French are seeking a licensee in the U.S., the Germans are anticipating sales in South America and elsewhere.

In summary, the base technology program of the U.S. will probably support the commercialization of fast breeder reactors in this country. It will also be a benefit to other countries of the world if they develop problems in their larger sized plants. The U.S. could have built a fast breeder reactor demo plant much earlier if there had been a need, a direction, or there had been less emphasis on base technology. There would have been a higher risk. (However, a present worth analysis might have shown that the costs of the risks would be less than the cost of escalation experience in the last 10 years.)

5. Potential for U.S.-Foreign Joint Programs and Projects

Based on discussions with representatives in the UK, France and Germany, it appears there is good possibility for joint programs and exchange of information in the areas of fast breeder reactor safety and physics. These are fields of mutual interest, base technology or research in character, and not of direct significant commercial value. A parallel area, already of agreed cooperation, is that of licensing criteria and related safety research.

In the areas bordering on commercial application, there seems to be less interest although the German spokesmen seemed to consider these areas of potential interest. These areas in this category include:

A. Fuel and material technology

   1. Design and performance of prototypic fuel are excluded by France and UK.

B. Sodium Components and Instrument Technology

   1. Sodium physical chemistry is of interest in most countries and may be an area of possible cooperation.

   2. Large sodium components are quite often peculiar to a specific design and therefore not interchangeable.

   3. Steam generators are a nemesis. There is no consensus as to the best design. A totally successful design which is economical will be important internationally. However, little cooperative effort is potential.

   4. Generally, components developed which work and are economical will be incorporated into designs and bought from vendors independent of national lines.

C. Fuel Handling and Core Restraint

   1. Particular to a design like fuel and steam generators.

2. If a national design has trouble they will adopt the design of another nation (through purchase or agreement) and develop and test it for their use.

3. Exchange of technology is premature except with Germany. The French and English haven't experienced problems, yet.

On overall plant design, construction and operation, there appears to be little opportunity with France and the UK. The French want to develop license agreements with U.S. industry. The British are not sure what their future marketing plans are and do not want to jeopardize potential commercial interests. (Also they do not want anyone in their plant while they are fixing their problems.)

There would appear a genuine interest on the part of Germany to exchange personnel in design, development and operational sectors. They also seem interested in the use (either by exchange of comparable services) of test facilities in the USA. For example: large critical experiments in ZPPR (they are currently compromising size by cooperating with the UK in a modification of ZEBRA), the Treat (they currently have a joint program with France on the CABRI which also involves UK and Japan), and FFTF (their KNK is small and they use some space in PFR for fast fuel irradiation development and testing). They also said they might be interested in a safety test facility (SEREF) or a very large component test facility (PCTL) if they are built, but probably not to the extent of contributing to the capital cost.

The British seem to feel they would prefer to join with their European partners to build facilities for the next size plant testing. They prefer to join with their European colleagues in the development of large complex calculational codes, such as for safety analysis, structural dynamics response, physics, and cross sections. They would be interested to have access to U.S. codes for cross comparison of results. France asks and offers nothing in the way of facilities.

6. Impediments to International Exchanges

The impediments to international exchanges of LMFBR information, joint projects, or programs are pride, success, and easy access to most that they want. There appears little if any impediment to exchange of almost any information or technology with Germany; with Germany it seems to be monetary or the availability of comparable or adequate facilities in Europe. Also they expressed the desire to be involved in the project definition phase and planning rather than, 'will you join us now that we have such a great idea'.

The British are trying very hard to be Europeans. They are also in an economic squeeze. They claim the U.S. is too far to cooperate on projects or use of facilities (after all, the U.S. facilities are 8,000 miles away - west coast), On technology programs, they sell technology to their industry when it is developed and cannot therefore give it to the U.S. which gives it to U.S. industry to compete with British industry.

The French CEA has a proprietary interest in the fast breeder reactor design and most of the systems associated with it. French industry has proprietary interest in many of the component parts. The French consider that they have something to sell and hope to recoup, through licenses, some of their cost to develop the fast breeder. (Not all of their national projects have been successful including the Gas-Cooled-Reactor. They have had to buy U.S. knowhow on PWR's. This smarts and they want to get it back.)

(Although I did not talk with the Russians, I think the following is a problem.) The Russian program is progressing reasonably well. However they have had problems with their steam generator and possibly other parts of the system tankage ang piping. This is partly due to quality control and materials development. They seem interested in information exchange in certain areas, maybe personnel exchanges and equipment (steam generators). The main impediment is the lack of centralization of authority, interest, and technical knowledge. There is also a communication problem only partly language. More contact might open lines and cooperative work.

7. Feasibility of U.S. Using Foreign Facilities.

There are several opportunities for the U.S. to use foreign facilities. The value, economics, and arrangements are questionable in some cases. It would be valuable to test prototypic fuel elements in PFR or Phenix as well as to do materials tests also because there are specific test vehicles and the "right" environment (neutron flux and energy, and flowing sodium). It would be more valuable if an engineer were stationed at PFR. It would be worthwhile to test a prototypic steam generator unit on the USSR-BN350 to get actual operating experience if personnel from the manufacturers (and the reactor designers) organization could help plan the test program and participate. An alternative would be to use test facilities at Hengelo (Holland - 50 Mwt or Les Renardières France - 50 Mwt). However, these have less capability than the 70 Mwt modular size (also LMEC is increasing the capability of the LCTI from 30 Mwt to 70 Mwt). The tests on BN350 have value even with tests in LMEC which has controlled test conditions.

Consideration might be made to design some tests with multi-pin assemblies under reactivity transient and/or loss of flow conditions in a joint program with the UK, France, Germany in the DFR (and maybe later in EBR-II when it is decommissioned). Such tests might provide insight into core meltdown, fuel coolant ineraction, accident propagation, and post accident heat removal planned for the safety test facility (SEREF).

8. Safety Philosophy, Licensing in Europe and America

The licensing procedures are quite general between the U.S. and European countries except for some specifics. In each country there are licensing authorities which are separate from the developmental or promotional groups to various degrees. In the U.S. this separation is the greatest (almost to the point of the ridiculous - they hardly will talk with each other). In the UK, the Inspectorate does independent evaluation of the safety report but may call on the AEA for supplementary analysis, information, or research. In France, the CEA prepares the safety reports, the safety evaluation, and the SCSIN* evaluates and decides whether the criteria established by mutual agreement have been met. The Ministry of Industry and Research (MIR) then issues a permit. He has veto power. Permits are required at several stages: construction, preoperational tests, fuel loading, reloading. The public is involved only at the site selection stage. This has been done en masse last year and sites for some 20 power stations have been dedicated even though it has not been decided what type of station will be located on each (fossil, PWR or LMFBR).

The German licensing authority is complex. There is a federal approval and also a state approval. The state's approval rests on the TÜV, a guild which has cognizance over all safety matters. They are somewhat between a technical society that sets standards (like ASME) and a state inspector. Their membership is composed of professional engineers, many professors. They contract research and evaluation work to their members, universities or research labs (e.g. Karlsruhe or Jülich).

The German safety philosophy is quite parallel to the USA. The UK uses a probabilistic evaluation and has specified that the probability of an 'initiating' event which could lead to a serious consequence must be lower than that for a thermal reactor. They admit that the consequence of a fuel meltdown is more serious in an LMFBR but that the heat removal capabilities after such an event are orders of magnitude better for a pool type LMFBR. Their development program is aimed at verifying that core damage does not propagate to whole core accidents and that less than 10% of the theoretical energy release is in the form of work energy. They also

*Service Central de Sûreté des Installations Nucléaires.

state that if one assumes that containment is required, he is assuming a whole core accident (hypothetically) and therefore must provide a core catcher.

The French safety philosophy is to evaluate any initiating event that can be postulated mechanistically. They then analyze these events up to the point where they are non-mechanistic. If protection is required it is provided. If it becomes hypothetical they "rationally" say that it is of no importance. Phenix does not have a containment building over the reactor (there is a confinement building). Therefore there is no provision for major sodium fires, radioactivity release from the primary containment (3 concentric vessels), or external missile protection.

The Phenix reactor could not be licensed in the USA. It does not provide for earthquakes, tornadoes, or external missiles. It is doubtful whether the confinement provisions are adequate for fires, radioactive releases, etc. The primary pumps, intermediate heat exchangers, and steam generators are not designed for seismic loads. Quality assurance and inspection requirements were not followed. Some of these deficiencies could be incorporated into a design for U.S. applications - but not all in a reasonable fashion.

The Super Phenix appears to be designed in a manner that it could probably be licensed in the U.S. The French claim that they have done so to meet their own criteria but they have also engaged the Bechtel Corporation, San Francisco, to assess their design and give them an opinion on its probable licensability in the USA. (Only the U.S.-NRC can make that determination. However, the report of the recent ACRS team indicated that they were favorably impressed by their "first look" at the design.)

9. A discussion of Loop and Pool Fast Reactors.

In fast reactors the reaction takes place in a core about 3 feet high and 5 to 8 feet in diameter. One to two and a half (1 to 2.5) million watts of power is produced in this small volume. To remove the heat, liquid sodium is pumped (upward) through the core. This sodium becomes radioactive in the core. The heat (power) is transferred from the radioactive fluid (primary) to a non-radioactive liquid sodium (secondary) in a heat exchanger (IHX). The secondary sodium is pumped to a steam generator. Steam (as in a conventional power plant) drives the turbine which generates electricity.

In a loop type fast reactor the core is located in a tank. Pipes in the upper section of the tank transport the sodium from an upper plenum above the core. The core tank and IHX's (3 or 4) are connected with pipes in loops. In current designs (FFTF and CRBR), the pump is located between the core tank and each IHX (hot leg) in each loop. All of the primary sodium loops, including the IHX's, are located in shielded vaults. The secondary sodium is transported out of the vaults in pipes to the steam generators and then is pumped back to the IHX's.

In the pool type reactor system, a large tank is located in a shielding vault. A thick shielded roof covers the tank. The core is normally located in the center of the tank under a rotating shield plug used for fuel handling (a similar plug is located in the top of the tank in a loop design - basically no differences in the plug size). The primary pumps and the IHX's are located around the core in the pool tank and supported from the roof structure. Ducts direct the sodium from the region above the core into the IHX's. The pumps take suction from the outer cool (750F) pool and the pump discharges through ducts to the region (plenum) below the core (cold leg pump). A core barrel and skirts separate the hot upper pool from the cool outer pool. The secondary sodium circulates through the IHX and then out of the roof. The secondary loops, steam generators, and steam/turbine loops are basically the same as for a loop system.

There is no consensus as to the best choice. Safety, operational, and maintenance advantages are claimed for each system design.

Proponents for the loop design claim: (1) emergency cooling is accomplished easier with heads for natural convection; (2) maintenance and inspection of components are easier to do; (3) fabrication of smaller tanks can be done in a shop under better quality control; (4) pumps and IHX can be tested easier.

Proponents of the pool design claim: (1) a large volume of sodium provides emergency cooling in the event of pump failure; (2) there are no primary pipes to break and small leakages in the ducts only reduce the efficiency; (3) it is easier to locate a core catcher inside the pool tank where it can be cooled by the existing pool sodium; (4) fabrication of the tank is done in place and reduces handling and construction costs.

Opponents of the loop design claim: (1) a pipe break could reduce the sodium level and cooling capability; (2) the long length to diameter of the tank is less stable under earthquake loading.

The French and UK demo plants are pool designs. The U.S., German and USSR demo plants are loop designs. The first commercial plants are pool designs for France, UK, USSR. Germany and the U.S. have not committed design although both tend toward loop designs. One U.S. group (GE and Bechtel) may propose a pool design. The Germans say their reason for the joint venture on Super Phenix is to gain experience and compare the values of loop and pool.

10. Security and Reactor Fuel Processing

During recent years, there has been a public concern developed regarding the security of fissile fuels (U-235 and Pu-239). The concern stems from the hypothetical case of diversion of Pu-239 from the controlled use in peaceful applications for electrical power to illegal use by criminal elements, either domestic or foreign.

Concern is primarily with respect to plutonium which can be separated chemically from nuclear fuel which has been irradiated (used) in power plants. U-235 can only be separated from fuel by very complex and expensive physical processes and is normally found in earth minerals in concentrations of 0.7% and in thermal reactor fuels (fresh) at about 3%, which are significantly lower than that useful in bombs.

Plutonium is produced in reactor fuels. In thermal (PWR or BWR) reactors it may reach a concentration of 1.5 to 2% and is present with highly radioactive fission products with about twice that concentration. As used fuel elements, the Pu is probably not vulnerable to diversion because of the high radioactivity and heat generation. Reclamation of the Pu from this fuel by other than a well developed facility would be impractical. Transportation of such used fuel is therefore not of particular concern from a diversion standpoint.

At a processing plant, the radioactive fission product wastes are removed and the Pu is separated from the uranium. The Pu is stored for future use - probably in fast reactors, although Pu recycle into PWR's has been proposed. The wastes are concentrated and will be disposed of by the government. The uranium may be recycled through a diffusion enrichment plant, or it may be mixed with higher enriched uranium for use in fabrication of new fuel elements.

The purified Pu may be stored at the processing plant or shipped to a storage site or fabrication plant. This Pu is vulnerable to diversion either within the processing plant, by invasion by outside forces, or during transit to the next site. At the next site the same opportunites for diversion exist.

If the Pu is fabricated into new fuel elements, it is still subject to diversion since now it is relatively clean (of fission products). Even low concentrations of Pu (2 to 3% in uranium) in thermal recycle fuel elements could be separated, chemically, by a well equipped laboratory without undue hazard to the operators. Of course, higher concentrations of Pu (15-20% Pu in uranium) used in fast reactor fuels, would be more advantageous to the illegal group. For these reasons, fabricated fuel containing Pu must be safeguarded with the same vigor as separated Pu in the processing, storage, of fabrication plant or during shipments against covert or overt division.

It has been suggested that fuel should not be processed until the plutonium is required. That is, it should be stored as irradiated fuel not as separated Pu. A second suggestion (Levenson of EPRI) is to leave enough fission products with the Pu during processing to "denature" the Pu. P. Zaleski (France-EdF) suggested that the pyroprocessing system developed for EBR-II could be used rather than aqueous processing (currently used method for thermal reactor fuels and proposed for LMFBR fuels with modifications). The pyroprocessing system leaves certain fission products (refractory metals which do not poison the fuel neutronically) with th uel. This gives a natural "denaturing". The pyroprocessi g scheme was developed for metal fuels and may be applicable to carbide fuels. No scheme has been developed for oxide fuels.

It should be noted that this question of Pu security has not been as much of public note in Europe. However, it was recently announced (Nucleonics Week, Vol. 16, No. 46, Nov. 13, 1975) that guns have been issued to guards at four UKAEA sites (Windscale - reprocessing plant, Winfirth, Dounreay - fast reactor plants, and Harwell - fuel fabrication plant). Plants handling nuclear fuels in the U.S. have had armed guards since the beginning. Last year all nuclear power stations and sites where nuclear fuel is present have been under high security with armed guard. Security check of personnel and exclusion areas lighted, fenced and patrolled (10CFR73) have been instituted.

Part II - Evaluation of Possible Fast Reactor Technology Exchange Between U.S. and Foreign Governments

The questions of principal pertinence to this project seem to be:

1. What is the status of fast reactor development in the USA?
2. Why hasn't a fast reactor been built in the USA?
3. What is the status of fast reactors in foreign countries?
4. On what basis have reactors been built in foreign countries?
5. Can the USA use the fast reactor technology developed in foreign countries?
6. If so, how can the USA obtain this technology and what will it pay for it?

To assess these questions one must look at the past, the history and philosophy and the management and motivation. Then we must explore the current events - what is being done, why is it being done in that way - and finally we must postulate what the future holds, assuming different options and alternatives.

The following sections discuss in general terms the development of the fast reactor industry in the U.S., UK, France, and Germany. Included in each discussion is an overview of the current programs, organizational sturctures, technology strengths and weaknesses, and appraisal of potential exchange possibilities.

A. General Discussion About the U.S. Fast Reactor Program

The history of fast reactors starts in the USA. Early experiments at Los Alamos in the late forties demonstrated that a reactor operating with a fast neutron spectrum could be controlled. The EBR-I reactor or Argonne - built in Idaho during the early fifties - demonstrated that a fast reactor could breed more fuel than it used, be cooled with a liquid metal (NaK), and produce power. During transient testing of the reactor, an accident occurred which led to a meltdown of the core. Subsequent analysis and testing has established the importantance of a mechanically stable core. The EBR-I reactor was "cleaned up" and put back into operation with a fuel configuration which allowed testing and verification of the analysis. In the mid-fifties two fast reactors were designed, one by Argonne (ANL) and one by the Atomic Power Development Association (APDA). The ANL reactor (EBR-II) was to demonstrate the reliability and system's features of a larger liquid metal cooled reactor to produce electrical power. Another important aspect of the original objectives of the EBR-II was to demonstrate a closed fuel cycle where fuel used in the production of power was remotely handled and transported to a reprocessing facility built in conjunction with the reactor plant. The fuel was reprocessed and refabricated and then recycled into the EBR-II. An advanced reprocessing scheme using high temperature metallurgical techniques partially removed fission products from the spent fuel and produced a metallurgically stable uranium-plutonium alloy (fissium) which was vacuum cast into fuel pins and clad in stainless steel for assembly into fuel assemblies. These experiments were successful but were discontinued in 1966 due to a redefinition of the mission for the EBR-II and a change in objectives of the national program. The mission of the EBR-II was changed from a demonstration power plant to an irradiation test facility.

There were certain delays in attaining the full capabilities of EBR-II as a test facility. These resulted mostly from the fact that a test facility is designed differently than a power facility. There was of course also the reorientation of the staff and operations. Nevertheless, the EBR-II has given yeoman service as an irradiation test facility for the past eight years. It and the Dounreay Fast Reactor in England have provided more and better characterized data on the effects of high energy neutron irradiation on fuel and cladding materials than any other reactors in the world. (Others including the Rapsodie and Phenix have irradiated more elements, but they are not as well characterized and the resulting data is not as readily extrapolated to improving the fuel capabilities.) One serious disadvantage of the EBR-II as an irradiation facility is the fact that the neutron energy is faster than currently planned demonstration and commercial reactors. Also, due to its small size, the fuel is more highly enriched than for proposed systems. This latter results in a lower irradiation effect on the cladding for the same fuel burnup. Nevertheless, EBR-II has produced significant data on the irradiation effects (radiation swelling, irradiation creep and stress relaxation) which are of utmost importance in the design of fuel cladding and core structure.

The APDA (Fermi) reactor which was designed, built and operated by private industry was unfortunately ill fated. It was built as a prototypical demonstration reactor using metal alloy fuel. One of the objectives of the project was to build a practical system. To this end, several innovative systems were included, such as the single-walled steam generator, and undershield fuel handling. The project suffered a series of delays and occurrences which proved to be too costly to justify its continued operation, especially when the technology indicated that large reactors using ceramic fuels were more practical than alloyed fueled systems.

It is of interest to note that the Fermi project has served another very important function during its existence. Due to the private nature of its corporate structure several international arrangements were made. Scientists and engineers from Belgium and France worked with the design and development personnel on the project. After the reactor was recovered from the fuel assembly meltdown accident in 1965 a cooperative agreement was made with Japan to train engineers for fast reactor design and study was carried out to install an oxide fueled core. Hereby we see one approach to the exchange of technology between a U.S. organization and foreign programs. Several of the top engineers on the French fast reactor program were involved.

In 1963, the USAEC sponsored designs of commercial sized (1000 Mwe) fast breeder reactors. The purpose of these design studies was to explore the various options in system designs with the principal aim of defining the state of technology and establishing a basis for a technology development program. These studies focused the U.S. program on an oxide fueled, liquid metal cooled reactor. The questions of a pot-type or loop-type design, hot cell vs. undershield handling, and modular or large steam generators was not resolved - and still aren't today either in the USA or abroad. It was evident, however, as a result of these studies that an extensive development program was needed to assure the required performance of fuel, steam generator and other system components, and reactor safety. For economical and predictable design and operational performance, improved reactor physics data was needed. Of more immediate urgency was the requirement for test facilities. In 1966-67 a comprehensive program plan was developed. Existing facilities were inventoried and modifications were made where possible and nearly practical. Design was started on a physics facility (ZPPR) capable of testing large plutonium fuel cores and developing design data. A fuel and materials irradiation test facility (FFTF) was authorized in 1966 and EBR-II was modified to provide interim testing capability. The TREAT facility in Idaho was dedicated to fast reactor transient testing to provide insight and preliminary understanding into fast reactor safety analysis. A need for a fast reactor safety test facility has been defined, but not implemented. Steam generator testing on a small scale was provided at the Liquid Metal Engineering Center (LMEC) which was established in 1965 and dedicated to the testing of sodium system components. A very large pump test facility was authorized and is nearing completion. Other sodium test facilities were installed at

Hanford in conjucntion with the development of the FFTF. Private facilities are available at GE-Sunnyvale and Westinghouse-Monroeville.

Basic technology into the chemistry of liquid metals has been done at Argonne. An outstanding capability to analyze the operational safety performance of fast reactors has been developed for currently proposed systems, although continued development is required to analyze commercial-sized system. Proof and verification tests of these methods have not been accomplished.

The emphasis in the USA has been on the development of a base technology and the provision of facilities in which the base technology can be verified and prototypic components or systems tested. In contrast, the emphasis in Europe has been to gain system design, construction, and operational experience.

The organization for developing a fast reactor program in the U.S. is complex and based on government support of a nationally needed technology while at the same time providing the development of a non-monopolistic industry in line with its policy of free enterprise. The U.S. government is providing about 90% of all the financing for the program currently. There are basically eight (8) national laboratories, of which seven (7) are directly involved in the LMFBR program. There are three (or four) major companies involved in the design and development of nuclear steam supply systems (NSSS) for fast reactors. The utility industry is involved by a direct commitment of 250 million dollars for a demonstration plant as well as through a research institute, EPRI, which supports research in fast reactor technology. When taken as a whole this compares with the total effort in Europe.

There have been cooperative arrangements between the UK, France, Germany, Euratom and the USA. During the design, development and construction of the Fermi and EBR-II reactors, there were several engineers and scientists working with the staff at APDA (Fermi designers) and ANL (EBR-II designers). These visitors worked with the American staff persons, learning and contributing to the decision making. They returned to their home countries and have been involved in the programs there. In addition, there were many visits by the French, Germans and British to all of the U.S. development and design facilities including Atomics International where many German engineers received training in sodium technology and engineering design, fast reactor physics analysis and experiments, and instrumentation and control. The KNK reactor uses (U-Zr) hydride fuel which was developed at A.I. for the SNAP reactors. The British had scientists assigned at ANL-West on the ZPR-III critical reactor and cooperated in a safety test in TREAT by supplying fuels irradiated in DFR.

The project of greatest international significance was the SEFOR project (jointly sponsored by SAEA, General Electric, Karlsruhe and the AEC). This project, which included building a test fast reactor in Arkansas, involved the verification of the mechanism that the doppler effect in (U-Pu) oxide fuel would provide an inherent control on the run-away reactivity in a fast reactor core. This was a highly successful project, organized by GE, both from the standpoint of technical significance and international cooperation. The use of the SEFOR reactor for other experiments was discontinued by lack of continued support in the U.S. although the Germans had proposed to continue their support.

The Fermi reactor program also constituted a degree of international cooperation between APDA and the Japanese. After the recovery, it was proposed to install an oxide core in Fermi. The Japanese sent engineers to work with the APDA staff and gain experience with sodium systems. Due to lack of funding the program was terminated last year (1974) and Fermi has been decommissioned (Nov. 1975).

The U.S. provided a reasonably large quantity of Pu for use in the Euratom fast reactor physics program. The original concept was to build <u>one</u> Euratom critical facility. Due to nationalistic reasons, both the French (Masurca at Cadarache) and Germans (SNEAK at Karlsruhe) built criticals. There was some cooperation in the exchange of Pu fuel elements between the two facilities. However, since the elements designs differed this was not entirely practical. Now there is not enough at either facility to do a prototype sized (3000 liter) critical experiment. The Germans are pooling their Pu with the British for use in a modified ZEBRA experiment. Apparently the U.S. has indicated that European experiments cannot be accommodated in the enlarged ZPPR facility.

The Germans indicated that they had received negative responses to their proposals to use TREAT and later the FFTF facilities. They have been approached, with the other fast reactor nations, to consider a joint venture on a U.S. designed fast reactor safety test facility and program (SEREF). They feel that they should be involved in the program definition phase rather than after the fact when the design of a facility has been firmed up.

All in all there has been a period in U.S. policy where cooperative programs flourished with foreign groups. There has also been a period where non-cooperation was the policy of the day. It behooves the U.S. to reconstitute good relations again and to gain the economic and timely advantages of others who appear to be successfully carrying out their programs.

The following are some observations which characterize some of the reasons why the U.S. program has not progressed to the point of building a fast reactor demonstraction plant.

1. U.S. had the leadership in fast reactor technology in 1960-65.
2. U.S. had more operating and construction experience in fast reactors and sodium technology until 1965.
3. If the decision had been made to design and build a demonstration plant in 1963 instead of, or in parallel with, pursuing the base technology and development/test facility route, the U.S. would presumable have been first to have a demonstration plant.
4. The U.S. delays in building the FFTF have resulted from some or all of the following conditions:

    a. The criteria for awarding the original contract was at least partially motivated by political and available manpower considerations, not technical excellence or practical design.

    b. The original design concept was not generally accepted as practical.

    c. Three corporate managements have been in charge of FFTF (GE, Battelle Northwest, Westinghouse).

    d. The project was not single purposed:

        i. it was used to develop industrial capability to be used for the demo and future commercialization,

        ii. it was used to develop basic codes, standard, practices and specifications to be used in the industry,

iii. it was used to develop management, engineering and construction methods and procedures - notable quality assurance.

e. A change in the role of the AEC staff on large projects was introduced.

i. Programic control was maintained in Washington

ii. Technical decisions were reviewed and varified (or restated) by the staff in Washington.

iii. Work was not allowed until the contractors had satisfied the current dictates of Washington.

f. An upsurge in public involvement in the licensing of reactors.

i. Realization of certain advocates that the atomic energy act provided a podium on which to advocate that there existed public mismanagement of the environment and resources by large industry.

ii. A quasilegal objection to the use of public funds to develop an industry.

iii. A quasiscientific objection to the building of nuclear reactor power plants from the standpoint of potential hazard of a catastrophic nuclear accident.

g. There has been a reluctance and reticence on the part of certain vendors to become involved in providing goods and services for a fast reactor project.

i. Several were fully involved in producing goods and services for the water reactor industry which was booming and showed a good future.

ii. There was no assurance of continuity and possibility of follow-on orders was questionable. It is important in an industry that volume be expected. First of a kind is always expensive and companies expect to make up their losses on repeated orders after the processes are developed.

iii. Liquid metal technology is not state-of-the-art for most companies.

iv. Tight tolerances and manufacturing control, quality assurance programs, and documentation are new and frightening to small organizations. Some of this was overcome by award of cost plus and developmental contracts.

h. The project costs were significantly underestimated.

i. The original scoping of the proje. was not adequate.

ii. The project definition phase only identified the technical scope of the project.

iii. A great reliance was made on base technology not under the direct control of the project management.

iv. The mission was extended to (a) develop a methodology for projects, (b) develop an industrial capability, (c) develop and verify industrial codes and standards, (d) develop a quality assurance methodology.

v. Inflation and delays.

vi. Transfer of funds from base technology interrupted and cutrailed projects which influenced the FFTF project.

5. The U.S. has more extensive test facilities than Western Europe for physics, pumps and other sodium components - there is a superior steam generator test facility in the Netherlands (joint Benelux

and German). There are critical facilities (physics) in France, Germany, Russia and England.

6. France, England and Russia have superior operating and possibly construction experience. However the U.S. codes and standards on vessels and piping are probably equal or better.

7. The U.S. has manufacturing and fabrication capability with good quality control.

8. Research and base technology is transferable via reports and communication. Construction, fabrication, manufacturing, and operational experience is transferable basically on a personal basis.

9. There have been personnel exchanges between U.S. and France, Germany, Italy, and Euratom. There has been technology transfer agreements with England (Crockoff Libby - due to expire), France before 1970, Germany. There now exists a limited exchange with Russia.

10. French and English reactors are not licensed to the same (less) standards and criteria as US-NRC. What change in cost would occur is not known. Some foreign manufacturers manufacture to NRC and ASME standards.

    a. German licensing is very demanding and requires approval of both federal and state boards. (They haven't built a fast reactor.)

    b. England uses a risk/consequence probability criteria - not accepted in U.S. (yet).

    c. France has no formal licensing system. The systems are designed to meet the criteria of "adequate" regard to the protection of the public. (This may have changed.)

    d. Russia used remoteness and good engineering design. They do not provide secondary containment. Protection of the operational staff is provided. It is said that their safety assurance rests on the fact that the facility director lives on the site.

B. General Discussion of the United Kingdom Program

The UK program has included basic studies in physics, safety, and sodium technology. Their fuel development program started with metal alloy fuels and now concentrates on mixed (U-Pu) oxides with stainless steel (316M) cold worked cladding. They identified the S.S. swelling phenomenon in 1967. The DFR was built and started operations in 1961. It has been used for fuel and core material irradiations. Although it produces electrical power it may be classified as a test reactor. It, with the associated development programs, has provided a significant sodium system operating experience. Component development was carried out on pumps, valves, and handling equipment for the DFR. Significant work was done on sodium-water interactions and structural integrity of vessels under explosive loads.

The PFR was designed as a prototype reactor with all the major design features designed in such a way that they could be scaled up. Some components and systems were developed and tested during the construction of the reactor. Identified critical components and systems were subject to intensive development. However, the main objective was not basic technology but rather the commercial design, fabrication, installation, construction, and operation of the Prototype Fast Reactor. The philosophy has been to perceive problem areas and attack them with vigor for solution. When new or unforeseen problems such as steam generator leaks, pump shaft bowing, pump bearing seizures, and inadquate top shield cooling have occurred during pre-operational and operational testing and since operational startup these have been dealt with and fixed. Redesign of the steam generator and modifications to the pumps are believed to provide adequate design basis for the Commercial Fast Reactor 1 (CFR 1) currently under design.

Because of sizes they apparently will not test large components such as steam generators and pumps for the CFR 1. Although they probably will test critical parts in smaller scale (modular). These may include the tube-to-tube sheet welds and interfacial gas space, pump bearings and convective spaces and valves. Control drive mechanism will also be tested.

Significant quantities of fuel will be run in PFR during its regular operation. Modifications to fuel design which are expected to be only nominal can be tested in special assemblies in PFR. The UK has a very good fuel program when PFR is operational.

Major factors in bringing about the CFR 1 (first prototype large reactor) will be: (1) the successful operation of PFR and development and testing of components and/or component parts which have experienced trouble for PFR. (2) Scale up of system components (generally only 3-4 times for sodium and steam system units and nomially for core components). (3) Larger pool tank and associated roof and plugs. (The current plans include prestressed concrete for the roof.) (4) Improved top shield (roof and plugs) cooling and insulation. (5) Core catcher (current design includes both an internal and out of pool units). (6) Seismic and natural hazards designs.

Major areas of continued technology development include physics mockups (critical experiments), safety for HCDA (hypothetical core disruptive accidents) and LOF (loss of flow), primary containment and design against energetic core and vessel distortions. Materials (316M, RP548, and Nimonic-P16 stainless steels for cladding and 9 Cr-Mo steel and 316 stainless steel for steam generators) are under extensive test.

The general safety philosophy is to design for high integrity against faults, to provide inherent control, and provide engineered safety systems to make the probability of accidents as low as for thermal systems which are acceptable. Analyses are made on the borderline of credible and hypothetical. They consider if containment is necessary then one is assuming a HCDA and other engineered safety systems such as the core catcher must be considered as necessary. Energetic releases from an accident are lower than for a thermal reactor system and the large mass of sodium in the pool provides large heat capacity. They feel comfortable that a sub-assembly accident will not propagate to a HCDA if the FCI (fuel coolant interaction) is not too large. Their development emphasizes the definition of this phenomenon and is to show that it does not occur. Tests in CABRI and SCARABE (French safety test reactors) investigate this. They consider that if the work energy from an FCI is less than 10% of the theoretical energy release there will be no sub-assemby to sub-assembly propagation. They are trying to demonstrate less than 10% energy conversion.

Licensing procedures are similar to those in the USA. The Installation Inspectorate serves the role of our NRC. Firm criteria have not been set (but then they don't even exist for AGR either).

The organization for the fast breeder program in the United Kingdom includs the UKAEA which is responsible for research and development, the CEGB which owns and operates the power stations, the NNC which through its subsidiary NPC is responsible for the design and component development work (NSSS supplier). Fuel services are under another government controlled organization, BNFL. The AEA has been responsible for the experimental (DFR) and prototype (PFR) phases of the fast reactor program. They will continue to be responsible for safety, physics and basic engineering development and also play a strong hand in the NNC design coordination. They currently own 15% of NNC and 100% of BNFL. They plan to acquire an additional 20% (to 35%) of NNC from the General Electric Company (now the major - 50% owner of NNC). The other 35% of NNC is owned by the British Nuclear Associates which include suppliers of nuclear equipment. The British industry has been merged from originally five NSSS companies in England, later to three, then two and now only one in which the AEA has a strong control.

The areas of possible bilateral cooperation include:

1. Fuels and materials data (UK strong)

    a. They have experimental locations for outside experiments.
    b. Post irradiation examination facilities.
    c. Test locations for coolant system materials
    d. Personnel assigned at Risley with visits to PFR (no assignments at PFR).

2. Codes and Standards - high temperature conditions (U.S. strong)

3. Comparative analysis between U.S. and European developed codes

    a. Safety
    b. Structural dynamics

4. Test rigs (U.S. strong), but only if not available in UK or Europe, and if there were commercial agreements.

Under existing agreements it has been difficult to establish a quid pro quo arrangement. They feel agreements need looseness, regular meetings, and specific correspondents in area of mutual interest to provide for timely interchange. Exchange of personnel must be contingent on proper qualification, a need (place or position) for that talent in their organization, and it must not jeopardize commercial interests. The policy of the UKAEA is to sell technology developed in their facilities to the industry when it becomes commercial. Therefore it is unthinkable to give it to a foreign organization which could then compete with their industry. Operating experience arrangements would have to be made with NPC - their industry. Such arrangements might require licensing deals between industries. Industrial exchanges or systems components may be areas of mutual interest.

At Risley I got a definite feeling that if they need test facilities they will build them or use European ones before coming to the USA. Also they are cooperating with their European colleagues to develop analytical codes for safety and structural dynamics. They say they would welcome independent calculations for check confirmations of their methods. I get the strong feeling that they are going way out to become a full partner in the European community. I also get the feeling that they are very brusk about their PFR experiences to cover any disappointment or in any way allow that it is not a great success. They often stated how the problems they had encountered have taught them how to make a perfect product in the future. How each error was a worthwhile experience (methinks they protesteth too loudly). I'm sure they would have been happier to start up on schedule. They still have organizational problems ahead and they have tried other organizational schemes in the past.

c. A General Discussion of the French Program

The French fast reactor program got started in 1958. A thorough plan was developed to progress step by step in developing a national fast breeder industry. They acquired basic technology through the U.S. and UK program and through building and testing components and systems. Industry (GAAA) was brought into the program in 1960 and was responsible for much of the hardware development (Fontenay-aux-Roses).

The Rapsodie reactor was designed and all components were tested in full scale in both water and sodium. The tank, inlet plenum and reactor structural arrangements, control and handling were also tested in full scale in water and sodium. The original reactor core was designed for metal fuel. However, when it became internationally recognized that oxide fuel was the preferred system, the plan was changed. The development of oxide fuel fabrication had been carried on from the first at Cadarache. It may be noted that the Rapsodie was at that time in the design/ development phase where a change could be accomodated and was the only national program at that stage.

A national laboratory was located at Cadarache and is the location of major fast reactor development, the Rapsodie, and test reactors, such as the Masurca (fast critical facility), Harmonie (neutron source reactor, Cabri (safety test) and Sarabée (safety test). Fuel fabrication for the Rapsodie, Masurca and Phenix is carried out at Cadarache in excellent facilities.

Rapsodie has a loop type heat transport system and does not generate steam (air dump like FFTF). When it was started up in 1967 various anomalous reactivity effects were observed. These were slow changes and not directly related to power or temperature level. They have been identified as fuel restructuring effects. Rapsodie has been used to gain reactor operating and sodium system experience and as a fuel test facility for oxide fuels. Over 20,000 fuel elements have been irradiated to levels as high as 200,000 Mwd/T (50% to greater than 12% and 5% to 19%) to prototypic neutron flux levels and energies (slightly faster than Phenix but less than EBR-II).

By the time the Rapsodie reactor had entered the construction phase (1963) design was started on the Phenix, a 250 Mwe (650 Mwt) demonstration reactor. After Rapsodie had operated a year, construction of Phenix was started. Development and testing of a modular type steam generator was started at Grand Quevilly in 1963 and testing of prototypic heat transfer components was started at Cadarache. The fuel handling and transfer machines were tested at Cadarache. Control mechanism were tested. Vented boron carbide control elements were developed and used for Phenix. Phenix has a pool type heat transport system - that is all the primary system components, pumps and intermediate heat exchangers are located around the core in the same tank. The steam generator is a simple design but bulky and expensive. It would not be economical or practical to scale it up or use it as a modular unit for large plants. The major philosophy in the design of the Phenix was to make all systems simple and to test to minimize potential problems in operation. This seems to have to be done at the expense of compactness. Fabrication facilities for large components were constructed at the site. The guard vessel, reactor tank and core structure as well as all the piping spools (shop fabricated sections of large sizes - as large as could be handled into location in the plant to minimize field weld which are harder to control, accomplish and inspect) were fabricated and machined in this facility. The facility is currently used for maintenance shop and storage.

Extensive hot cell facilities are located near the reactor hall (not as large as the HFEF at EBR-II). These facilities are used for fuel disassembly and post irradiation examination. Such facilities would not be as complex or extensive in an operating production plant. In the case of Phenix, the facility is used in conjunction with a statistical fuel development and testing program to improve the capabilities of Phenix and prepare for Super Phenix. Provision is also made in this section of the plant for primary system component decontamination, inspection and maintenance. Such facilities are probably required in Super Phenix. They will be larger but no more complex.

Criticism has been leveled at the Phenix from a public safety standpoint. Phenix was not licensed in the sense that a U.S. reactor is licensed. In particular, reactor containment is not provided, the plant is not designed for seismic, tornado, or missile conditions. Criticism also has been cited that the design is not suitable for scale up and it is not economically designed. This is true in several cases. In particular, the steam generator is modular to the extreme (seven tube, zigzag, tube and shell). The plant is layed out in an open arrangement. This simplified the construction phase and enhances the inspectability and maintenance. However, it is costly and has not addressed various engineering economical and operating problems.

Phenix was designed by CEA; components, systems, and construction were done by GAAA; civil work was by EdF. The CEA was the project manager and the strong hand of the old school (Polytechnic Institute) engineers is evident in the management, decision making, and safety evaluation and approval. Phenix is owned and operated by CEA (80%) and EdF (20%). EdF buys the power. After five years of initial operation (during which tests and fuel development will be carried out) the operation and management transfers to EdF. The French make the point that Phenix was built and started operation on schedule (a very good schedule of only 4 years from start of construction to critical) and within budget (again at an official cost which is quite reasonable). However, unofficial costs, government enforced prices on the industry for goods and services, and developmental and testing costs which are included in U.S. figures are hard to evaluate to get comparable costs. It is also noted that Phenix was built during the period prior to spiraling escalation of costs and under cost conditions enforced by the government. Be that as it may, the French Phenix is an example of single and dedicated mindedness to build an operating fast breeder reactor. They did not try to solve all their problems of licensing and plant economics in one step. They have demonstrated the stability of their reactor; the practicability of a tank-type, heat transport system; reliable operation; and a confidence with design, testing, and operating large sodium systems.

The Super Phenix poses new challenges for the French. They still have a good team of managers in CEA and the suppliers are still available. However, due to the new international nature (part ownership by ENEL (Italian utility - 30%) and RWE (German utility - 19%) which also exten to the supply of certain components and sub systems) there e management complications. The tight national contrc on prices and schedules will be more difficult. In addition, the CEA is flexing its muscle and acquiring a larger part in the management and controls. French industry represented by GAAA (a consortia of French industry including CGEN formed to design and market BWRs and develop and supply fast reactor systems) has 40% interest (with Technicatome owned by CEA - 90% and Edf - 10%) in a company - CIRNA - formed to design and build the Nuclear Steam Supply System (NSSS) CEA "owns" the patents on the fast reactor in France.

The present French development program is oriented toward testing of large components for Super Phenix, fuel and core performance, materials testing and safety (about 70MF/yr to 100 MF/yr by 1980). They have not developed an integrated calculational code for safety analysis. They do separate calculations of various initiating events, core phenomena (fuel melting, fuel coolant interaction, coolant boiling, etc.). They are trying to verify these models experimentally in CABRI and out of pile. They do not presently plan on conducting full scale critical experiments for Super Phenix. Apparently, they have confidence in their calculational methods (which predicted Phenix pretty well after adjusting cross sections based on Masurca experiments). However, as the time approaches to order the fuel for Super Phenix, they may welcome an invitation to do a "core" in ZPPR and/or evaluate the data taken on large core systems being planned by ANL-West.

It is my opinion that the French have done very well and that the probabilities are that they will do alright on Super Phenix. However, their move to an unproven steam generator of very large size and the complications of the international nature of their management pose major uncertainties along with all the little items of cleaning up the design and making the plant economical. I am sure that their current stance on bilateral agreements with the U.S. stems from their success on Phenix, national pride, and opportunism in exploiting the Phenix success. There is also the possibility that it is a reaction to the closed shop policy of the AEC between 1965 and 1973. I am reasonably sure that the French are counting on the broad based technology program in the U.S. to bail them out if they get into trouble. They appear to be willing to exchange base technology in the areas of physics and safety. They indicated that they would like to get some technology in the area of sodium physical-chemistry and instrumentation.

D. General Discussion of the German Program

There are many similarities between the German program and that in the U.S. These similarities exist in the government/industry relationships, licensing procedures and criteria, and reactor plant concepts for the demonstration plants (loop heat transport system). Neither country has built a demonstration plant yet, although the Germans are in the construction phase.

The German fast reactor program started in the late 1950's with studies at Karlsruhe on liquid metal, steam, and gas-cooled fast systems. At Interatom (then partially owned by Atomics International) development and design was started on a compact sodium cooled thermal reactor, KNK. Facilities to test sodium components, conduct critical experiments, and do safety testing were provided. The concept of a compact core using uranium hydride/zirconium hydride for a fuel/moderator in a sodium cooled system was developed to gain early experience with sodium as a coolant without the licensing problems of a fast system. Also it was possible to design a fast core to replace the thermal core. This is currently being installed in the KNK (as KNK-II) and will be used for fuel testing at Karlsruhe. (Licensing review and approval has not been completed as yet.) All components and mechanisms were tested in full scale for KNK.

In 1966 design was started on the SNR-300, a demonstration reactor to be built at Kalkar. The SNR-300 is a loop reactor. It uses three pantagraph undershield fuel handling and mixed (U-Pu) oxide fuel. Larger diameter fuel pins are planned than are being used in other reactor concepts. This is expected to improve fuel economy. The reactor also incorporates a "core catcher" (or "floor cooling device" as they call it) - the first in the world. All of the system components - heat transport, fuel handling, control mechanisms, core and steam generator modules have been tested in full size. Extensive tests have been done on sodium/water interactions and sodium physical/chemical interactions with materials at Interatom and Neratoom. Safety and physics research and testing has been done primarily at Karlsruhe. Fuel development has been done at Karlsruhe and Belgonucléaire and CEN-MOL in Belgium. Licensing has been done on the basis of full criteria for fast reactors. This procedure which included a lot of learning on the part of the TÜV and negotiations between the TÜV, Interatom, and RWE delayed the project about three years and resulted in the requirement for the core catcher. It is expected however that the licensing of the next generation of reactor will be more straightforward. Licensing is complicated by several factors. One is that the plant must be approved by the state where it is built and the federal government. The first is done under the direction of the TÜV which is a professional group that develops criteria, evaluates design, and does research. A second set of complications is the high population density, environmental intervention, and limited availability of cooling water and open space. Construction is progressing and startup is scheduled for 1980.

The Germans have started design work on the next generation referred to as SNR-2. It may be as large as 2000 Mwe but this isn't set. It will probably be a loop type but they are involved through NERSA in the Super Phenix project and may change to a pool type reactor. The design again is under the direction of INB for the NSSS and SBK for the civil work.

The German fast reactor program is sponscred by the Ministry for Research and Technology. Karlsruhe is a national laboratory where most of the research is done. Interatom located in Bensberg near Cologne is a division of Kraftwerk-Union in charge of design, component development, manufacturing and construction. RWE is a major utility which will operate the first fast reactors and is responsible for civil design and construction and fuel processing. The German program is linked and in partnership with efforts in Belgium and the Netherlands (each own 15% of SBK, the owner/operator, and INB, the manufacturer and developer of SNR-300).

The financing plan in Germany is divided between the government and the industry. Most of the basic research such as physics, safety, and fuels and materials is subsidised by the government and conducted in the national laboratories (GFK, CEN, TNO/RCN). Development is conducted by the industry with grants from the government. For the SNR-300 about 10% of the cost was borne by the utility groups and the government provided 90% plus a certain amount for risk sharing in the operation. The ministry expects that for the next phase, which they refer to as a full size demonstration plant (SNR-2), the utilities will pay 70 to 90% of the price they would pay for a comparable light water plant; the government will make up the difference plus carry part of the risk for operation. When SNR's become commercial the utilities will pay the price.

There is an interesting concept on grants by the government to the industry regarding patents. The industry owns the patents, but the government receives royalties until t e grant is repaid. Also, patents must be licensed without fee for nonprofit use in the interest of the people.

The German interest in fast reactors is similar to France and England. They have a shortage of energy natural resources. They have developed an LWR industry and one producing Pu which they do not consider economically or technically optimum to use in Pu recycle. They have limited storage (of Pu) capabilities and want LMFBR's to use the Pu. They have no oil, limited gas, limited and expensive coal, and are acquiring a stockpile of depleted uranium from their LWR industry. They feel that an industry needs to sell about six (6) units a year to be viable. They project to need about three (3) per year. They don't expect to sell to the U.S. so hope to develop a market in South America. (They are developing an LWR market there now.) They have a small effort in gas cooled fast reactors along with an interest in high temperature gas reactors in cooperation with General Atomic in the U.S.

They don't consider the delays in building the SNR-300 or getting into the LMFBR business as too serious. The real test is who attains commercialization and develops the industry first.

The Germans have conducted a program balanced between base technology, component development and construction. They have faced the problems of licensing. Their strengths are on well developed system components and hardware. They have had a vigorous safety and physics program. They have developed advanced analytical techniques and conducted verification experiments using the SNEAK, fast critical, and laboratory and inpile safety tests. They are working with the French on new safety tests in CABRI. Their sodium/water and sodium/materials tests are very advanced. The KNK and test facilities have given them sodium systems operational experience.

The weakest part of their program has been in regard to fuels. Most of their testing has been in thermal reactors although they have done some irradiations in DFR and have plans for PFR. They have a limited advanced fuel program. Analysis indicates that advanced fuels such as carbide are important only in how soon they will be able to stop buying uranium and that 20-30 years is a reasonable goal to find an advanced fuel. The emphasis is more on optimum use of resources (Pu and depleted uranium) rather than the best cost. (Energy Independence.)

The possibilities for exchange of technology seems to be high. They have had joint programs in the U.S. before. They have commercial ties with U.S. industry. Karlsruhe-General Electric-SAEA-AEC conducted a joint study - SEFOR - on the doppler effects on fast reactor safety in the 1960's. They tried to extend the program on SEFOR but the AEC dropped it from their program. The AEC would not consider their request to use the TREAT, FFTF, or ZPPR. All of these are still potnetial areas which the Germans would like to gain access to and exchange technology. In exchange the Germans are developing some rather advanced physics and safety analytical methods which could complement those in the U.S. Operating experience on the SNR-300 and the use and assignment of personnel to sodium and other test facilities appear to be possible in Germany, whereas such opportunities seem limited or impossible in France or England.

In summary, the German program seems compatible with that of the U.S. although not as advanced (in construction and operation) as the French and English. Cooperative arrangements appear to be easier to consummate and there are areas of value to the U.S. program. However, the value will not be so much in providing information that will accelerate or save money in the U.S. program as much as providing complementary technology and independent verification of our program elements.

Appendix A

Items for discussion in Part I of report

1. A discussion of the strengths and weaknesses of the United States' LMFBR program, including reasons for the strengths and weaknesses.

2. A discussion of the strengths and weaknesses of the LMFBR program in each country visited, including reasons for the strengths and weaknesses.

3. Areas in which the United States' LMFBR program could benefit from foreign information; what could the United States offer in exchange?

4. Has the United States spent too much effort developing base technology? Why or why not?

5. Based on the discussions held with foreign representatives, what is the potential for ERDA participating with foreign governments in joint LMFBR programs or projects?

6. What are the impediments to international exchange of LMFBR information, joint projects, or joint programs?

7. Would it be feasible for the United States to test its LMFBR components in foreign facilities (i.e., testing our steam generator in the Soviet Union's BN-350 as proposed by the Soviets)?

8. Based on the discussions held with foreign representatives, summarize their safety philosophy, licensing procedures, and the problems of safety and licensing foreign LMFBR's in the U.S.

9. Describe the main differences between the "pool" and "loop" designs and the significance of such differences.

10. Safeguard in reprocessing.

Appendix B

Visits and Contacts

Sept. 15, 1975: Westinghouse Atomic Power Division, Pittsburgh, Pa. Meetings were held in the division conference room to discuss the areas of possible international co-operation. Those present: Westinghouse-John Taylor, John Yasinsky, Carl Anderson; GAO-Washington - Ralph Carlone, William McGee; GAO-Philadelphia - Edward Herron, Frank Fee; GAO-consultant - Donald Eggen.

Oct. 8, 1975: Argonne West, Idaho. These meetings were held at the EBR-II conference room and included a tour of EBR-II, HFEF, and ZPPR. ANL presented their views on cooperative programs with foreign countries and pointed out areas where they could be of help to the U.S. and foreign programs. Those present: ANL - Robert Laney (Ill), Robert Staker (West), Fred Thalgooth (West), Art Goldman (Ill), Bryd (Aerojet Nuclear Corp.), others; GAO-Washington - Phillip S. Hughes, Ralph Carlone, William McGee; GAO-Denver - Albert Braddock, Larry Peters; GAO-consultants - Eldon Alexanderson, Donald Eggen, ERDA-Washington - Fred Hiser, John Yevick.

Oct. 8, 1975: LOFT Facility, Idaho - not germane to this assignment.

Oct. 9, 1975: FFTF Facility, Hanford, Washington. Meetings were held in ERDA conference room during the morning and included tours and briefings at the High Temperature Sodium Facility, FFTF, and Fuels Laboratory. Those present: ERDA-HAN - R. L. Ferguson (and others) Westinghouse-HEDL - Al Squire, S. A. Weber, Ersel Evans, B. H. Noordhoff, William Roake, Tom Claudson; GAO-Washington - Hughes, Carlone, McGee; GAO-Seattle - Joseph Kegel, Donald Cortright; GAO-consultants - Alexanderson, Eggen; ERDA-Washington - Hiser, Yevick.

<u>Oct. 10, 1975</u>: Atomics International, Canoga Park, Calif. The morning meetings were held in the headquarters conference room and discussed AI's contributions to the fast reactor program and suggestions concerning foreign cooperation. The afternoon was devoted to a tour of the ERDA sodium test facilities at the Liquid Metal Engg. Center (LMEC). Those present: AI-Sam Iacobellis, Ralph Balent, Jim Cochran, Wayne Meyers and others; GAO-LA - James Hall, William Parsons, Richard Gannon; GAO-other - Hughes, Carlone, McGee, Alexanderson, Eggen; ERDA - Hiser, Yevick.

<u>Oct. 15, 1975</u>: Argonne National Laboratory, Ill. Discussions were held with A. Amorosi concerning studies being conducted at ANL on pool type designs. Discussions were held with R. Laney concerning possible areas of cooperation with Europeans and to get the insight of his trip to Europe and the USSR. Those present: ANL - Robert Laney, Al Amorosi; GAO-consultants - Eldon Alexanderson, Don Eggen.

<u>Oct. 20-31, 1975</u>: European Tour. Generally meetings were held with the directors of national programs at the capital location. Breifings into specific areas of programs, research and development, design, operations were given at national laboratories and reactor sites. Tours of facilities were also included. The following will give specific details to individual sites and those contacted. The following persons were the GAO team: Phillip S. Hughes, William McGee, Carl Myslewicz, Donald Eggen (technical consultant).

<u>Oct. 20, 1975</u>: Risely, England (near Warrington). The overall program and organization were discussed. Those present: John Moore, C. E. Iliffee, George Kinchin, R. D. Smith.

<u>Oct. 21, 1975</u>: London Office, England. Continued discussion, more specific on financial and organizational matters. Ms. Mac Lean discussed foreign cooperative program past, present and future. Those present: P. J. Searby, Hugh Hunt, C. E. Iliffee and Barbara Mac Lean, David Clarke.

<u>Oct. 22, 1975</u>: Cadarache, France (near Aix-en-Provence). The fast reactor research and development program is centered at Cadarache. The R & D program was discussed in its relationship to Rapsodie, Phenix, and Super Phenix. There was a tour of the Rapsodie control room, hydraulic laboratory, sodium components laboratory, and associated buildings. Those present: M. M. Stosskopf, Gallion, Estavoyer, and Pontier.

<u>Oct. 23, 1975</u>: Marcoule, France (near Avignon on the Rhone river) site of the Phenix reactor. An excellent documentary movie was shown and Dr. Carle gave a history of the development of the Phenix and its status. A tour of the pla was included. Those present: M. M. Carle (CEA) and Giraud (EdF).

<u>Oct. 24, 1975</u>: CEA Headquarters, Paris, France. A very frank and useful discussion was led by Dr. Vendreyes about the French program, organization, policies, and cooperative projects. Those present: M. M. G. Vendreyes, L. Vautrey, P. Zaleski (EdF), C. Moranville, C. Clovet d'Orval, M. Salmon (U.S. Embassy).

<u>Oct. 24, 1975</u>: U. S. Embassy, Paris, France. Discussions about the observation by the Scientific Commission concerning the possibilities of cooperation with French. Those present: Ed Malloy and M. Salmon.

<u>Oct. 28, 1975</u>: U. S. Mission to the European Community. Discussion with ERDA representative concerning the various European programs, their strengths and weaknesses, organizations, politics, etc. Those present: Sol Rosen and Julius Rubin.

Oct. 29, 1975: (Morning)	Ministry for Energy, Bonn, Germany. The discussions were held at the Ministry's headquarters. The overview of organization, finance, international aspects, and program was presented. Those present: Dr. Däunert and Kempken, C. L. McClelland (U.S. Embassy)
Oct. 29, 1975: (afternoon)	Interatom, Bensberg (near Cologne) Germany. Discussions in the conference room presented the German design, development and construction program under the direction of Interatom and RWE. A tour of the sodium test facilities was included. Those present: Traube, Däunert (LMFT), A. Branstetter, Mentrap, Berke, Ringeis (RWE), R. Klüper (GFK), Guttmann, and Gilles (on assignment from HEDL), C. L. McClelland (U.S. Embassy).
Oct. 30, 1975:	GfK (research center) Karlsruhe, Germany. The mission of the research center, its organization and facilities were presented. A discussion of the study of energy needs and the role of LMFBR's was given. Safety and physics analysis and fuel development and processing are important missions. Those present: H. H. Hennies, G. Kessler, Kluper, and Guttman (IA-KNK).
Oct. 31, 1975:	GfK. The author remained an extra day to discuss the technical programs in fast reactor safety and physics with the staff scientists in the institutes. Those contacted: Drs. Kessler, Smidt, Strueve, Karmer, Heusener, Froehlich (physics).
Nov. 24, 1975:	GAO-HQ-Washington. Discussion with GAO staff about the format and content of the reports from technical consultants. Also a preview of GAO report to Congress. Those present: William McGee, Michael Moffatt, Kenneth Lightner (also contacted Myslewicz and Carlone); Eldon Alexanderson.

Appendix C

Abbreviations and Terms Found in Text

USA

ACRS	Advisory Committee on Reactor Safeguards
ANL	Argonne National Laboratories (Illinois and West)
BWR	Boiling Water Reactor
10CFR73	Code of Federal Regulations, part 10 (atomic energy) section 73 (security)
CRBR(P)	Clinch River Breeder Reactor (Project), the U.S. demo plant
EBR-II	Experimental Breeder Reactor-II located in ANL-West, Idaho
enriched	Nuclear fuel with more (U-235 or Pu) in U-238 than natural (0.7% U-235)
EPRI	Electric Power Research Institute
ERDA (RRD)	Energy Research and Development Administration (Reactor Research and Development)
FFTF	Fast Flux Test Facility located at Hanford, Washington
Fermi	An early demonstration fast reactor located in Michigan near Detroit
GAO	General Accounting Office
Hallam	A sodium graphite reactor formerly located in Nebraska
HEDL	Hanford Engineering Development Laboratory
HFEF	Hot Fuel Examination Facility located at ANL-West
hot leg	Reactor heat transport pipe between reactor tank and IHX
(I)HX	(intermediate) heat exchanger, between primary and secondary sodium heat transport systems
LCTI	Large Component Test Installation to test steam generators at LMEC
LMEC	Liquid Metal Engineering Center located at Santa Susana, CA
LMFBR	Liquid Metal Cooled Fast Breeder Reactor
loop	Piping, between the reactor, pump, IHX, and back to reactor. Piping is external to the reactor vessel (not "pool")
LWR	Light Water Reactor (a BWR or PWR)
NCBR	Near Commercial Breeder Reactor (next generation after CRBR)
NRC	Nuclear Regulatory Commission
NSSS	Nuclear Steam Supply System, the reactor and associated plant through the steam generator

PCTL	Prototype Component Test Loop, an expanded version of the pump test loop and LCTI to test large sodium components for NCBR
Pu	Plutonium a fissile nuclear fuel used in fast reactors
PWR	Pressurized Water Reactor
RDT	Reactor Development and Technology, old name of RRD, still associated with nuclear standards
SEFOR	Southwest Experimental Fast Oxide Reactor used for doppler effect verification, located near Fayetteville, Ark.
SEREF	Safety Excursion Reactor Experimental Facility
SNAP	Space Nuclear Auxiliary Power Source
TREAT	Transient Reactor Experiment and Test
U	Uranium, the fertile part of nuclear fuel used in fast reactors
ZPR	Zero Power Reactor - ANL fast critical experiments
ZPPR	Zero Power Plutonium Reactor

ENGLAND

(UK)AEA	United Kingdom Atomic Energy Authority
BNFL	British Nuclear Fuels Ltd., a government corp. to manufacture and process nuclear fuels (]00% controlled by UKAEA)
CEGB	Central Electric Generating Board, owner of power plants
CFR 1	Commercial Fast Reactor 1, next generation after PFR
DFR	Dounreay Fast Reactor - first demo reactor comparable to EBR-II, Fermi. Rapsodie
NNC	National Nuclear Corp., owner of NPC, owned by General Electric, Co., AEA, and British Nuclear Associates
NPC	Nuclear Power Company, designer of NSSS
PFR	Prototype Fast Reactor, a 300 Mwe demo plant comprable to CRBR, Phenix, BN-300
ZEBRA	Zero Energy Breeder Reactor Assembly, the British critical facility

FRANCE

CEA	Commissariat á Energie Atomique (atomic energy commission)
CABRI	Safety test facility comparable to TREAT
Cadarache	National Research Laboratory located near Aix Provence
EdF	Electricité de France - national utility which runs power plants
GAAA	Groupement pour les Activités Atomiques et Avancées, a consortium, mainly Companie Générale d'Electricité-Alsthom and Babcock
Masurca	Fast critical reactor (ZPR) located at Cadarache
MIR	Ministère de l'Industrie et de la Recherche (Ministry of Industry and Research) authorizes construction, similar to U.S.-NRC
NERSA	An international group of utilities (EdF, ENEL, and RWE) who will operate Super Phenix.
Phenix	Demo plant located near Marcoule
Rapsodie	Fast test reactor located at Cadarache - used for fuel irradiation testing.
SCARABEE	A safety test facility for loss of coolant accident studies located at Cadarache
SCSIN	Service Central de Sûreté des Installations Nucléaires (Central Service for Safety of Nuclear Installations), comparable to ACRS
TECHNICATOME	A company owned by CEA and EDF to design and construct fast reactor NSSS.

GERMANY, BELGIUM, NETHERLANDS

BMFT	Bundes Ministrie fur Forsungen and Technologie (German Ministry for Research and technology) includes department for energy R and T.
CAPRI	A master computer code for fast reactor physics and safety analysis. Comparable to SAS in U.S.

CEN Centre d'Etudes Nucléaires (center for nuclear energy), a national laboratory located in Mol, Belgium

ESK Europaeische-Schnell-Brüter-KernKraftwreks gesellschaft(European Fast Breeder Power Company), an international consortia of electric utilities similar to NERSA composed of RWE(51%), EdF(16%), and ENEL (33%) to build and operate the first commercial plant in Germany. Counterpart of NERSA for the Super Phenix.

GfK Gesellschaft für Kernforschung (center for nuclear research), a national laboratory located at Karlsruhe

INB Internationale Natrium-Brutreaktor-Baugesellschaft, mbH (Interatom, Neratoom, and Belgonucleaire) a consortium to manufacture SNR

KNK Kompackte Natriumgekühlte Kernreaktoranlage Karlsruhe (Compact Sodium Cooled Nuclear Reactor, Karlsruhe) 10 Mwt thermal reactor using U-Zr hydride fuel and moderator

RCN Research Center for Nuclear Dutch national laboratory located at Petten

RWE Rheinisch-Westfälisches Elektrizitätswerk, AG the largest utility in Germany, located in northwest area along the Rhine, owner/operator of the SNR's.

SBK Schnellbrüter-Kernkraftwerksgesellschaft (Fast Breeder power company), owner operator of SNR-300, a consortia of RWE

SNEAK Fast critical assembly at Karlsruche

SNR Schneller Natriumgekühlter Reaktor (fast sodium cooled reactor), fast breeder concept

TUV Technischer Überwachungsverein (technical overseer inspection), the counterpart of the U.S.-NRC

<u>OTHER</u>

USSR (Russia) Union of Soviet Socialist Republics

BN-350 (Russia) Breeder Reactor - 350 Mwe equivalent, the Russian demo plant located in the Caspian Sea.

APPENDIX VI

ENEL (Italy) Italian national electric utility

CNEN (Italy) Comitato Nazionale Energia Nucleara (Italian AEC)

CONSULTANT REPORT TO THE GENERAL ACCOUNTING OFFICE ON U.S. AND FOREIGN FAST BREEDER REACTOR PROGRAMS, ELDON L. ALEXANDERSON, JANUARY 21, 1976

Eldon L. Alexanderson has been employed by the Detroit Edison Company since 1946. From 1961 until the present, he has been on assignment with the Power Reactor Development Company, which was responsible for construction and operation of the Enrico Fermi fast breeder reactor. Since 1972, Mr. Alexanderson has been the General Manager of the Power Reactor Development Company with responsibility for decommissioning the Fermi plant.

CONSULTANT REPORT TO THE GENERAL ACCOUNTING OFFICE ON U.S. AND FOREIGN LMFBR PROGRAMS

Eldon L. Alexanderson

January 21, 1976

SUMMARY

The philisophy of the U.S. LMFBR development program has been to develop a sufficiently strong technological background for building LMFBR's that, once a decision is made to build, there is little risk of failure or of serious problems. The French and Russians on the other hand have emphasized learning by building plants, rather than by devoting as large a part of their resources as does the U.S. to a base technology program. So far, the higher risk French and Russian approaches have given these countries an apparent lead over the U.S. in the effort to obtain economic LMFBR's. The German, British and Japanese programs also appear to accept more risk of failure than does that of the U.S. in that they have proceeded more directly into plant construction programs. It is the opinion of many that the lack of a large operating breeder reactor in the United States is a significant weak point in our program and that it is time to accelerate building CRBRP.

One of the ways to speed up the development program is to participate in exchange programs with other countries. ERDA (and the former AEC) has done an excellent job in working out and using bilateral exchange agreements. Their efforts to expand this program should be supported, particularly in promoting more joint programs comparable with the U.S.-German effort on SEFOR and in promoting more personnel exchange programs. The latter should include more short-term foreign visits. A cooperative program with the USSR on BN-350 steam generators looks as if it could be quite rewarding to both. There are a number of problems that need to be overcome in making a success of cooperative programs, but the rewards are worth the effort needed.

Another way to speed up progess toward an economic LMFBR is to work out commercial or other agreements with the French on Phenix and/or Super-Phenix and possibly also with the Germans on SNR-300. Although it doesn't appear to be wise to depend entirely on obtaining information from foreign sources, it may prove advantageous to purchase designs and components wherever significant success has been demonstrated. The U.S. may also find it worthwhile to adopt some of the organization and management structures used in foreign efforts which have been successful in controlling costs and in minimizing completion time.

STATUS OF U.S. TECHNOLOGY

A description and timetable for the U.S. LMFBR development program is outlined in Attachment 6 of ERDA-1, January 1975. This description is brief, to the point, and easily referenced so that I will not attempt to repeat it or abstract it here. The main item of importance is the philosophy behind the program--develop a very comprehensive base technology that presumably provides a sufficiently strong background for building LMFBR's that, once a decision is made to build, there is little risk of failure or of serious problems. It is clearly a low risk, high cost and time-consuming approach in contrast to the Russian and French approaches; they plan to learn from building and operating demonstration plants what they really need to know to build more and larger units. The German, British, and Japanese approaches all seem to accept more risk than that of the United States.

The U.S. base technology program is quite strong, more so than any other country. As such I feel it is sometimes overdone to the extent that some of what has been learned in the past 20 years is ignored or not searched for in the literature for design and development studies. For example, the fact that stratification exists in horitizontal sodium to sodium heat exchangers (cold trap economizers) has been discovered twice; very extensive pump tests have been carried out on pumps very similar in size to the pumps built in 1959 and operated very successfully at Fermi from 1961 through 1972; materials compatibility tests are still going on which may be duplicating or adding little to efforts at ANL and Fermi since 1955, though probably carried out today with much better knowledge of sodium chemistry. It appears that it is time to concentrate on CRBRP and FFTF to find out what further effort in base technology is really needed and where significant rather than marginal gains can be obtained.

The U.S. has a strong base physics program with a larger, more versatile plutonium critical facility than any other in the world. EBR-II provides a most useful radiation facility run by dedicated, well qualified people. Much operating data can be obtained from it. FFTF will add significantly to the capability for advanced fuel testing. LMEC provides a wide spectrum of sodium test and necessary support facilities. Other facilities at Westinghouse, Hanford, General Electric, Atomics International, and Kerr-McGee (among others who supply needed fuel and components) form strong support in the total LMFBR program.

From what I have been able to observe, there are two weak points that have existed or still exist in the U.S. program. The first I have mentioned above--we tend to ignore information already on record for use in the total program. Part of this is due to the tremendous explosion of information being published in the atomic energy field making it difficult and time-consuming to isolate and obtain all needed information. The second weak point is believed by many to be the lack of a large LMFBR operating plant. A comparsion is made with the French having Phenix, the Russians having BN-350, the British having PFR and the U.S. having only EBR-II. FFTF is still under construction and CRBRP is underway but with an operating date which always seems to remain about 8 years ahead of whatever date is on today's calendar. This comparsion is unfavorable except that ERDA and some others believe that the U.S. base technology program is such that we can proceed faster and with more assurance of success once we decide we are ready to build a near commercial and then commercial LMFBR's. As indicated above, this was a deliberately set policy.

The weak point in not having a large LMFBR operating plant in the United States can be helped to some extent if we can exchange some of our base technology effort in strong areas, such as physics and safety, for operating and design data from PFR, Phenix, and/or BN-350. Of principal interest from an operating plant are: fuel design and performance data, behavior of core materials, component and system performance, reliability data, maintainability information, instrumentation performance, and overall core physics and control response as well as general experience gained by operating as part of a power system. Successful designs as well as problem areas are important. For example, it could be very worthwhile to purchase special instruments in Europe for hydrogen detection in sodium if they have notable success in one of the plants, and in turn sell them under-sodium scanning devices such as the one developed at Hanford (started at APDA). Detailed designs of successful components are needed if operating information on those components is to be useful.

It has been stated by private industry officials that the base technology program contains projects which (1) are delaying the U.S. effort and (2) will not be of any practical use to the U.S. effort. When a broad base technology program is carried out, there surely will be items included which prove to be of no practical use -- the data obtained may or may not be needed depending on problems which later arise.

This is one reason I favor a concentrated effort on completing FFTF and proceeding promptly with CRBRP at the expense, if necessary, of a reduction in the base technology program. We need to find out more about what information is really needed to give better direction to the base technology program and avoid at least some of those things which will prove to be of no practical value.

Whether the base technology program is delaying the U.S. effort is arguable, as is indicated above. The DRRD of ERDA believes a strong base technology program will get the U.S. to an LMFBR industrial base with more assurance than building plants. Some of U.S. industry, and I agree with their view, believes that the more direct approach of building plants will pay off sooner. This is the reason I believe FFTF should be expedited, as well as CRBRP, and strong backing given to the joint ERDA-EPRI start on the near commercial plant.

One view of utility disenchantment with the LMFBR program emphasis on base technology is expressed in an article in the August 1974 issue of Nuclear News[2] written by L.J. Koch.* He states "In August 1964, the U.S. LMFBR program was the most advanced in the world, and the nation had an operating experimental LMFBR power station to obtain experience to provide the vehicle for evolutionary improvement. Nevertheless, the United States did not proceed with the next logical step in the development of commercial LMFBR's. The Europeans did, and they did it by exploiting and extending our technology." He recommends that the U.S. take the necessary steps to shorten the indicated schedule and to redirect the course of the development program. To do this, he suggests the following guidelines with which I agree:

1. The demonstration plant program (CRBRP, etc.) should be given top priority, and the development of supporting technology should have priority over FFTF technology and general LMFBR technology.

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*Mr. Koch, now manager of nuclear projects for Illinois Power Company was associate project engineer on EBR-I and project manager for the development, design, and construction of EBR-II for ANL.

2. Components and systems, specifically for the demo plant, should be developed and tested. (The demo plant requirements should be sufficiently representative of long-range needs to satisfy general LMFBR program requirements; if they are not, the demo plant is not properly designed.)

3. The program emphasis should be shifted to power station requirements (as contrasted to test reactor requirements) with an increase in emphasis on power-generating equipment and systems.

4. Preparation of LMFBR standards should be deferred until a broader technological base has been established and a consensus is feasible. Detailed records should be prepared and maintained to describe the work performed and to ensure that this information will be available for future units. This should avoid the additional effort that would be required to standardize too early, while preserving the information for future use.

Utility disenchantment with the strong emphasis on the base technology program is supported to some extent by the Office of Technology Assessment (OTA) in its criticism of Volume 2 of ERDA-48. As reported in Science magazine,[3] OTA found an "overemphasis on complex, costly technology -- the sort of fancy gadgetry that tends to appeal to scientists and engineers, who are often bored by 'low technology' approaches to a problem." This may or may not have been directed at the LMFBR program, but I believe that it could have been. A more pragmatic approach in asking -- do we really need to have this information to get to an economic LMFBR or could we learn faster by building plants -- might rule out some of the complex, costly technology efforts.

At this point it is well to discuss the costs of CRBRP. I do not feel qualified to discuss this in detail, but do have some general comments. One is to note the deep concern of industry, particularly utilities, that the rapid escalation of cost estimates for CRBRP threaten its ability to lead the way to an economic LMFBR.[4] It has even been suggested that plans for the plant ought to be cancelled and started all over again. One way to restart would be to pick up Phenix and Super-Phenix design information and perhaps, more importantly, look hard at how the French manage and engineer a project to control costs. Even if Phenix costs are escalated at an appropriate value to compare with CRBRP costs and CRBRP costs are limited to construction costs alone (not including R&D), the escalated Phenix costs are a factor of two lower than those of CRBRP.[5] I believe cancelling CRBRP would be a step backwards, not forwards. But certainly those involved in the near commercial studies now underway should be taking a hard look at the pool type plant such as Phenix, should look at all possible French design information so that we might simplify our presently complex design, should examine the French management structure, and incorporate all of value in their final recommendations. To give the three reactor manufacturer-architect engineer design teams, which have been selected for the EPRI-ERDA NCBR studies, a target in order to keep them focused on costs, perhaps we ought be have a fourth reactor manufacturer-architect engineer work with the French to get a bid package, similar to what the other three will have in their final reports, on what it would cost in time and money to build and license a Super-Phenix in the United States!

Note that Super-Phenix (and also the U.K. PFR and Russian BN-600) are pool type reactors in contrast to the U.S. CRBRP, the German SNR-300, and the Japanese Monju. A pool type reactor, as the name implies, contains the reactor and the complete radioactive primary system in one pool of sodium. The core, blanket, neutron shielding, primary pumps, and the intermediate heat exchangers are located in a big tank filled with the primary sodium. The principal advantages of a pool type primary system generally recognized are: the pool can be used as a transport medium, and the containment of the primary system can be a single, simple, low stressed inspectable envelope.[6] The single container is difficult to support and roof over in very large sizes. In contrast, the loop system has separate containers for the reactor, the pumps, and the heat exchangers which are all interconnected by very large piping, up to 5 feet in diameter in 1200 Mwe size plants. Each vessel is far less complicated than one large container. There are many important design aspects that must be considered in each type of plant such as providing for: seismic loading, pipe support, thermal insulation, thermal expansion, thermal shock, neutron shielding, maintainability, inspectability, secondary containment, emergency cooling, plug and deck support, refuelling accessibility, fabricability, and the loss of coolant accident. Some are more easily provided for in a pool type and some in a loop type. Japan is not studying the pool type; Russia continues to study it and so far rates the two as a standoff at some point above 1500 to 4000 Mwt with balancing advantages and disadvantages.[7]

FOREIGN TECHNOLOGY AND COMPARISON WITH U.S. TECHNOLOGY

European Programs

As a part of the package of information material sent to me for use on the GAO assignment, there was included a letter dated March 25, 1975 from R. B. Richards, then of General Electric Company, to Mr. Thomas A Nemzek with an attachment[8] entitled "Comparative Status of U.S. and European LMFBR Technology" prepared by members of the G.E. fast breeder staff. It presumably has input from specialists in various areas. I am in quite general agreement with the comparison made in that attachment, including the areas of strength the U.S. has to offer in exchange agreements with European countries. I would like to emphasize two of the points covered.

Under Fuels and Materials, the point is made that "a great deal of information that the U.S. has generated has been published and is, to varying degrees, available to the European scientific community." This is not only true in the Fuels and Materials area, but is generally true throughout the LMFBR program. We tend to publish in open and available literature all that we do in the LMFBR area so that, in effect, it is available free to all foreigners. This problem is addressed in a memorandum entitled "Exporting Technology Generated under U.S. AEC Funded Contracts in the LMFBR Area" attached to a letter[9] from J. J. Taylor of Westinghouse to T. A. Nemzek, dated January 31, 1975. The easy accessibility of U.S. LMFBR data is one of the difficulties in working out equitable exchange programs -- we export most all we know for free so why should others pay for it by exchanging their knowledge in other areas? I am not aware that this has been a significant problem, however, except perhaps in dealing with the French.

It is also of interest to note that sixteen engineers from Belgium, eight engineers from France, seven engineers from Italy, and several engineers and technicians from Germany (plus others from Sweden, Pakistan, and India) received much of their early training in LMFBR's by actively working with APDA and PRDC on the Fermi Project. Some of these people now work for Euratom, some on SNR-300, and some have been on Phenix and are now on Super-Phenix. Other people in these programs received training by working at U.S. national laboratories and facilities such as ZPR-III, ZPPR, EBR-II, etc. Much of our base technology knowledge has been exported to foreign countries through the assignment of foreign nationals to these programs.

Mr. Richards also notes in evaluating the overall program: "The U.S. has expended great effort on technological development and appears to have a wealth of data. France has a plant with a good track record for at least the first year; the British have a less effective plant; and the Germans have a plant under construction. The U.S. does not have a plant. The conclusion cannot be based only on operating plants, but certainly this is significant. If less development and greater risk produce an adequate plant, then the French are more in tune with the overall program. On the other hand, if basic technology, and a well-organized development plan are viewed with respect, the position of the U.S. should not be slighted." There are many in industry and utilities in the U.S. who believe the French are more in tune with the overall program and that more of our effort ought to go in that direction.

The European and U.K. LMFBR development programs are characterized by close coordination between government laboratories, electric utilities, and reactor manufacturers with little or no attention paid to developing internally competitive industries. They tend to develop industries in specific technology areas and appear to be less concerned with monopoly and antitrust considerations. This is probably a more efficient approach than developing a broad based industry, at least until the market becomes large enough to support a competitive industry.

Japanese Program

A few years ago, the Japanese were well behind the U.S. in LMFBR development. Today they are still behind, but moving ahead strongly. Many of their poeple have been trained in the U.S., some long ago at the Argonne School and many more recently by their association with the Fermi Plant through the Central Research Institute of Electric Power Industry (CRIEPI). More than 40 Japanese engineers were assigned to APDA and PRDC for 2 to 4 years from 1967 through 1974, extending into the plant decommissioning period. Others have been assigned elsewhwere in the U.S. program. Many of these people occupy key positions in the present Japanese LMFBR and other nuclear programs. Their technology development program is patterned largely but not entirely along the same lines as that in the U.S. Their principal effort in the last few years has been to build and get ready to operate their experimental fast reactor Joyo.

Construction is complete, much preoperational testing has been done, sodium has been loaded into dump tanks and will be loaded into the reactor in January (primary system heatup is in progress), the blanket is in place, and the mixed-oxide core is fabricated and ready to load later in 1976. Initial core power will be 50 Mwt, a later core will be designed for 100 Mwt. There is no steam turbine -- heat is transferred from sodium to air via a heat exchanger as in FFTF. They have a high degree of confidence in their fuel from tests made in DFR and Rapsodie. They have had no fast radiation facility of their own and will not have until Joyo is at power. They have no plans for a facility comparable to FFTF.

Much effort is going into the design of Monju. This is to be a 300 Mwe loop type plant based on preliminary design studies carried out at APDA and expanded since by PNC. The design is complete, but it is being refined while the siting problem is resolved. Because their country is small and isolated sites are not easily obtained, and also because they have powerful pressure groups such as the fishermen who sometimes exact a steep price for site concurrence, the siting approval process is even slower and more difficult than it is in the U.S. Their schedule calls for a start on Monju construction in 1977.

To backup their Monju design, a 50 Mw steam generator test facility has been constructed at O-arai. This facility has a primary sodium circuit, secondary sodium circuit, IHX, pumps, etc., as well as the steam generator to test about 1/5 size models of Monju components. I understand they plan to scale up to Monju size components without much further testing. The first steam generator tested was operated at design conditions for 4000 hours and then removed for examination. No operational problems were found; subsequent examination has so far shown some evidence of fretting corrosion at tube supports. A second steam generator of slightly different design by a different manufacturer has been installed and will soon be under test.[10]

When asked directly what effort was going into hypothetical core disruptive accident (HCDA) studies and experiments, we were advised that there was some effort but that it was very small. They stated they felt much more effort should go to designing to prevent the accident rather than work on core catchers and hypothetical accidents. I agree with this approach. They also appear to be willing to scale up successful designs by a factor of 5 to 6 with only limited testing of some of the full scale components (flow testing only). There is no special emphasis at this time on obtaining low doubling time, though advanced fuels are being studied.

The LMFBR development program in Japan is marked by close cooperation between government and industry. Power Reactor and Nuclear Fuel Development Corporation (PNC) was organized by the government to be responsible for the development of advanced power reactors and to integrate contributions from research institutions, universities, manufacturers, and utilities. Personnel are moved rather freely from these organizations to PNC and back to their home companies with salaries continuing to be paid by the latter. Manufacturing and R & D contracts, as well as trained people, flow back to the companies. The government strongly supports all of the organizations involved, and they in turn are dedicated to making the atomic energy program a success. Profit and anti-trust considerations take a back seat to the overall program.

Russian Program

The USSR-FBR program has been underway for the past 25 years. They have given it high priority and strongly emphasize the need for a breeder with low doubling time to meet future energy requirements.[11] The Russians, like the French, have emphasized learning by building plants rather than devoting as large a part of their resources as does the U.S. to a base technology program. They have progressed through BR-5 (now BR-10), through BOR-60 to BN-350 and BN-600. BN-350 (350 Mwe equivalent, 1000 Mwt) has been operating for the past 2 to 3 years at about 30 percent of design power, limited we are told by availability of steam generators. They report no other significant problems. They have rebuilt three of their 6 steam generators as of June 1975, and one of the 3 rebuilt units had a major Na-H_2O reaction in February of 1975. Thus they are very interested in a cooperative program on steam generators as discussed separately in this report. BN-350 is a loop type plant with 5 loops plus 1 spare, 6 in all.

It has recently been reported[12] that BN-350 is operating at 52 percent of capacity on 4 loops with power gradually being increased to 65 percent of the 1000 Mwt rating. They are presently limited by some aspects of the electrical system rather than by the reactor. They have experienced water-to-sodium leaks in 5 of the 6 loops, in at least one of the 2 evaporators in each of the 5 loops. Three of these leaks have resulted in large Na-H_2O reactions. One evaporator (possibly both in that loop) with the original 34 mm tube, 2 mm wall thickness, has operated with no problems for more than 20,000 hours. None of the 12 super-heaters has leaked since being put into sodium-water service.

BN-600, presently being built at Beloyarsk, is a 600 Mwe pool type plant which is expected to be in operation in 1977 or 1978. Note that they are building one pool type unit after having built a loop type unit. They have institutes, laboratories, and test facilities at Obninsk, Dimitrovgrad, and Kurchatov to do basic design, base technology and test programs to support their building program. Their emphasis, however, is on integral experiments -- build a reactor and test it as a whole rather than perform a lot of individual tests. They should have operating data from BN-600 by 1978-79 and perhaps full power operating data from BN-350 in 1976 depending on steam generator performance. Operating data such as this would be of great interest to the U.S. and certainly we have much to offer them in exchange from our base technology program. They were very interested at Dimitrovgrad in EBR-II experimental techniques for application in BOR-60.

We might also interest them in safety results, and perhaps they could influence the U.S. toward a more conservative design philosophy which could in turn lessen our emphasis on the HCDA. They state that "we have never believed that such a process could take place."[13] They do not have steel containment buildings, but the reactor building structure and hatches at BN-600 seemed to be upgraded from the non-gastight reactor building at BN-350. There certainly is opportunity for cooperation in many areas to the benefit of both. ERDA has actively pursued cooperation with the Russians with an agreed upon protocol from which more definitive agreements are expected. Cooperation between the U.S. and USSR on a steam generator for BN-350 has been seriously discussed, and a series of five seminars and familiarization visits in 1974-1976 has been scheduled. ERDA's efforts to expand cooperation with the USSR should be supported.

One apparent weakness in Russia is in the general area of quality of manufacture and quality control. Part of this can be seen by observing the way cables are run, general neatness of construction, the way bricks and blocks are laid, etc. -- they are not up to U.S. standard practice in the areas visited. I understand that replacement tubes for BN-350 steam generators were purchased in Germany, probably to obtain the quality control desired.

FEASIBILITY, ADVANTAGES, DISADVANTAGES AND IMPEDIMENTS OF USING FOREIGN LMFBR TECHNOLOGY

ERDA-1 lists five courses of action which represent a spectrum of actions available for cooperative arrangements with foreign breeder programs as follows:

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

2. Purchase from foreign sources LMFBR components that have been developed in foreign programs for testing and/or usage in the U.S. plants.

3. Negotiate with one or more of the countries planning an intermediate size LMFBR power plant for a cooperative program to design and construct such a plant, to be located either in the U.S. or abroad.

4. Rely on obtaining information from a foreign plant instead of building an intermediate size plant in the U.S.

5. Depend totally on foreign sources for LMFBR technology and power plants.

With respect to number 1 above, this is clearly advantageous to us and I assume to others in a fair mutual exchange. ERDA has diligently pursued this course through multiple bilateral agreements. There is for example, an agreement with the Japanese through which much information has been exchanged. Correspondence and personal contacts are in progress to expand the areas of exchange particularly with respect to Joyo, Monju, FFTF, and CRBRP. We were advised that there had been a very worthwhile exchange of construction information concerning the Hot Fuels Examination Facility (HFEF) at ANL-West and their Material Monitoring Facility (MMF) at O-arai.

One of the most effective means of cooperation is through assigning people to participate directly in other countries' similar programs. One man from ANL-West (Mr. Chin) is now at O-arai in Japan. In exchange, one Japanese (Mr. Tsuchiya) is scheduled to report to ANL-West in March, each for a one-year assignment. Seminars and reports by these people can spread the information they obtain. A similar arrangement has been made for an exchange between O-arai and Brookhaven with one Japanese (Mr. Tanaka) already at Brookhaven. There is an ANL-West man (Mr. Girard Hoffman) assigned at Phenix, but the French are quite secretive about Phenix data and I do not know how much he is able to learn -- he is probably limited to specific areas.

There is an initial umbrella agreement signed with Russia which is to lead to further agreements now in negotiation. There are other similar agreements under negotiation with the U.K., France, and West Germany with much exchange, however, already taking place through informal channels. There are also formal agreements with the U.K. and with West Germany in several specific areas, the former coming under a more general intergovernment agreement. Most all countries are willing to work out new agreements or expand on old ones. Sir John Hill of the UKAEA has stated that "the Authority have already taken part in a great deal of international collaboration between research organizations and are convinced that more extensive collaboration will bring further substantial benefits."[14]

The principal impediments to exchanges of personnel (other than costs) are willingness of people to relocate and a language barrier. The latter leaves the U.S. at a disadvantage since foreigners often know English but U.S. people seldom are well versed in Russian, Japanese, German, or French. The incentive is there, however, to overcome these barriers. One difficulty in negotiating fair exchanges is that foreign countries already have rather free access to much of what we have to offer.

Power Reactor Development Company had a bilateral agreement with the U.K. We exchanged visits, held technical seminars, and also exchanged reports. The report exchange was not as productive as expected. However those reports on specific problems were very useful. The technical exchanges during visits were generally very helpful -- more people involved and thus more people educated on progress in each country. People seem willing to take time to attend a meeting or seminar but reading a report is often avoided. In their reply to the GAO questionnaire on LMFBR programs, the UKAEA listed their agreement with PRDC/APDA as being "of considerable mutual benefit" particularly in the reactor operating experience area.

With respect to number 2 option above, this is certainly a feasible and sometimes attractive choice. Steam-electric turbines have been purchased overseas for use with the U.S. reactors primarily because of a cost advantage. Purchasing abroad because of a design advantage is also justified --

all innovative ideas do not orginate in the U.S. It is of course preferable to use our own labor to produce needed components to keep dollars and jobs in this country. Obtaining all the needed data to meet the quality assurance aspects of U.S. licensing requirements is somewhat of a problem area, but this appears to have been solved for LWR components.

With respect to number 3 option above, if the French, Italians, and Germans can do it for Super-Phenix, we ought to be able to negotiate a similar arrangement, given the opportunity. Monday morning quarterbacking says that it would have been a very wise move indeed to have had a share of Phenix five years ago in return for all of their design, performance, and operating data today. Similarly with Super-Phenix -- if the French do not exact too high a price, it would be well to have a piece of the action. With the constraints we seem to have in the U.S. which slow a project down, Super-Phenix at 1200 Mwe may be operating and providing data in France before CRBRP is operating in the U.S. A stake in SNR-300 could also be worthwhile. They are well ahead of CRBRP in time scale. Obtaining an equitable agreement is the principal impediment, along with the language problems and relocation problems discussed earlier. Also the French seem to place an excessive value on their design and operating information. U.S. manufacturers should be encouraged to get involved in these programs through commercial agreements, possibly exchaning LWR design and operating information for that on LMFBR's.

Relative to option number 4 above, it is certainly feasible to rely on information from foreign plants (not from one alone) instead of building an intermediate-size plant in the U.S. I believe, however, that we need to retrain the LMFBR design, building, and all associated skills in this country for the future. To keep this technology current, we must continue an active design and construction program. Though we might find a short-term cost advantage to this option, the long-term disadvantage of not retaining a total U.S. qualification for designing, building, licensing, etc., for LMFBR's is very large. I don't believe this is an option to be seriously considered.

Option number 5 -- depending totally on foreign sources for LMFBR technology and power plants -- is not an option to be seriously considered. This is only valid for small countries which cannot afford or don't have the industrial base to become qualified in all areas and are forced to make a choice as to where they best can devote their resources.

There is one further option worth discussing which is not included in the five listed above. That option is to set up jointly sponsored programs in certain areas. If we truly want to have a cooperative effort to benefit all, rather than a competitive effort, then there are joint development programs which can be undertaken. Why cannot ANL-West with their large fast critical and large inventory of plutonium become the center for almost all fast reactor physics work, with many nations participating and contributing? Why not another country selected to do the design and testing of a very large steam generator for the 1000 to 2000 Mwe plants and all contribute money and talent to get the job done with patent rights to all countries involved and not to any individual company or country? Dr. Hans Bethe[15] has suggested a joint research program with the British or French (why not both and more?) on improved LMFBR fuel. There is much present duplication of effort, some of which is productive, but much of it merely corroborative or competitive, which could be avoided. The very large cost advantage here would outweigh the problems of language and moving people which were discussed before. Determining equitable shares, what country would do which job, and obtaining suitable patent agreements are the major other impediments. If patent agreements cannot be arranged, common test facilities would accomplish part of the goal of reducing costs.

Another impediment which applies to this added option and to option number 3 as well (discounting 4 and 5 as not acceptable) is the somewhat differing safety philosophies in different countries. One of the things that might be helpful here would be a study of fast reactors similar to the Rasmussen study on water cooled reactors. Perhaps we could learn, for example, what is the probable saving in lives and property with 1000 fast reactors in the U.S. if all are equipped with 100 percent effective core catchers. And what is the cost? At any rate, there would have to be an agreement on safety philosophy before some programs could begin. Even a cooperative physics program would have to spell out how much work would be devoted to studying meltdown configurations, core catcher physics, and the like. It would be easier to deal with the U.K. and Germany, for example, than with Russia in these matters but perhaps we need the tempering effect of the latter in questioning the gain from spending multimillions on high consequence but extremely low probability events.

A specific area of cooperation which I believe deserves support is having one of the Atomics International hockey stick steam generators installed and tested in BN-350. Testing the steam generator at full power and under the varying operating conditions experienced with a reactor (power reductions, scrams, and fast shutdowns) is more desirable than the lower power, more sterile environment of a test facility. (It appears the Russians would like two evaporators and one or two superheaters of the hockey stick design, the total sized to provide 200 Mwt for one of the 6 BN-350 loops.) I believe ERDA is actively negotiating a program with Russia and would hope that operating data and experience on BN-350 itself would be part of the return on the U.S. investment in the program. The principal problem with BN-350 has been with steam generators. If we can help them solve that, we'll get better operating data (at full reactor power) and may be able to sell them additional units.

LICENSING OF FOREIGN TECHNOLOGY

Licensing of foreign technology is an area of much uncertainty and controversy. Many times the answer is more politically than truly safety motivated. The British decided that LWR's imported from the U.S. were unsafe and they are going to build SGHWR's. Most people working in the reactor field in the U.S. believe this was done for foreign exchange and national prestige rather than for safety reasons. In the U.S., we tend to deprecate the very successful Phenix reactor as not licensable in the U.S. To counteract this, the French have asked Bechtel Corporation to study what in their best judgment would have to be done to the Super-Phenix design to make it conform to U.S. licensing requirements and codes and to estimate the effect of these changes on cost and schedule. It is a major (two year) study and an area in which I cannot give good answers with a short-term effort. However, I can comment in general on some of the differing approaches to design.

The Russians appear to be becoming more interested in major safety questions but at present do not even design reactor buildings to the standards we do. The Japanese emphasize containment, but have spent very little effort on HCDA's and core catchers. They prefer to spend more of their effort on design to prevent the HCDA. However, at PNC they stated that they felt they were very close to meeting all U.S. safety standards. The British, Germans, and French have licensing bodies comparable in many ways to the U.S. and this has led them to be more conscious of HCDA calculations, after accident cooling, and such devices as core catchers. It appears to be the German intention to design to contain the Bethe-Tait accident when the severity of it is agreed upon.[16] The SNR-300 in Germany is to have a sodium cooled core catcher,[16] and with this design, it could probably be licensed in the U.S. W. B. Wolfe of Atmoics International has labelled the German licensing requirements as the strictest in the world.[17] Super-Phenix is incorporating an in-vessel core catcher of limited capability.[18] Whether or not this is acceptable in the U.S. should be answered by the Bechtel study.

The safety area is one in which a great deal of international cooperation is possible. Sir John Hill, Chairman of the UKAEA has stated that "safety is an area particularly suited to international collaboration. The Authroity take every opportunity to increase international coopration in this area."[14] A particularly interesting project for cooperation with the U.K. would be to join with them to determine what sort of safety experiment could best be accomplished with DFR just prior to its decommissioning in October 1976.

There is an NRC-MIR (U.S.-French) agreement[18] to establish a continuing exchange of information pertaining to regulatory matters and to collaborate on standards required for the regulation of safety and environmental matters of nuclear facilities which has been in effect since June 1974. The exchange of information could lead to more direct coopration in safety work. More international cooperation in safety studies should be encouraged.

The Germans have indicated a significant interest in participating in the proposed U.S. Safety Research Experimental Facility (SAREF) program.

MISCELLANEOUS COMMENTS

1. More work is need by the LMFBR program (internationally) on steam generators. One apparently successful U.S. design is not enough. The double wall tube design at EBR-II which has been notably successful on a small scale, deserves a scale-up study. The extra cost to make a double wall tube design may be a small penalty to pay for high reliability and early potential leak detection. The very compact Fermi steam generator design deserves a re-examination -- the problems which were had with it can be solved.

2. LMFBR standards have been overdone at this stage -- standards could have come out of FFTF and CRBRP (and possibly the NCBR) rather than be an input so early in the development program.

3. "Qualifying suppliers" is generally not a legitimate present goal except for obtaining specifically needed components. D. E. Makepeace was "qualified" to build the Fermi core but never built another.

4. More U.S. effort is needed on the back end of the fuel cycle, both for core and blanket, including processing of advanced fuels. Reprocessing and waste disposal are still problem areas with LWR's even after a number of years of commerical reactor plant operation. The importance of development of reprocessing technology (including waste disposal) has not been emphasized enough with either LWR's or LMFBR's.

   In connection with development work in reprocessing and in the associated area of making mixed oxides and refabricating fuel, additional work should be initiated in development of suitable safeguards. Most of what is needed may come out of the Generic Environmental Impact Statement on the Use of Mixed Oxide Fuel (GESMO) but not necessarily since this will treat dilute mixtures of PuO_2 in UO_2. Premixing the oxides at the reprocessing plant before shipping as proposed[19] for water reactors is not nearly as meaningful for fast reactors. However, energy parks to elminate transportation outside of a guarded area, or the use of "hot strips" of irradiated cobalt or other gamma emitters in the shipment[20] can be acceptable solutions. Reference 20 also states that "the problems of materials safeguards and homemade bomb fabrication has been exaggerated and distorted by overemphasizing the possible while ignoring difficulties and means of prevention." More effort on means of prevention, including using low-decontaminated uranium in remotely refabricated fuel similar to EBR-II pyro-reprocessing, is in order.

5. The U.S. has more base technology available than the French have. To build a reactor comparable to Phenix, leadership and determination are needed to keep costs down. Too many ground rules result in over-complication. For the NCBR, the U.S. should get industry and utilities heavily involved,

with ERDA in an advisory role. The pool type should be carefully considered if it proves simpler to design from the seismic, emergency cooling, and stress standpoints as well as in providing instrumentation and in fuel handling.

6. ERDA (and the former AEC) has done an excellent job in working out and using bilateral exchange agreements. At APDA/PRDC, it seemed there was more information in the form of research reports being exchanged than could truly be absorbed -- the more pragmatic reports on design and operational data were better utilized. I suspect others have had the same problem. It would be well to organize more joint programs comparable to the German-U.S. cooperation on SEFOR.

7. The proposed SAREF porgram needs a thorough cost-benefit analysis. If current designs are made very conservative so the kind of data SAREF will provide is not needed for them, then SAREF could be used to remove the design conservatism. The value of this and the cost can be estimated. I believe that many experiments in SAREF will wind up with more questions than answers and each original experiment will fission into several more in order to obtain the desired detail resulting in a never ending program.

8. It would have been very meaningful to have had the Fermi Plant operating at this time with an oxide core at close to 150 Mwe as proposed in 1970-1972. The cost would have been small, it could probably have been licensed for short-term operation, and could have been providing operating data by now that we are saying would be so valuable from Phenix!

9. A general comment made by several people in the U.S. to visitors at their facilities was that international travel money was too limited. Valuable personal contacts between specialists are made during international meetings and during other visits. These contacts are presently rather limited because of the shortage of international travel funds. People at PNC in Japan complained that too few U.S. specialists were able to visit Japan for these personal contacts.

10. The ultimate goal of the LMFBR development program must always be kept in focus -- the commercial version must produce economic power. The commercial plant must be a product that U.S. industry can offer to utilities and overseas customers on a competitive basis with LWR's, with coal and oil fired plants, and without subsidy. If it takes commercial cross-licensing and importation of a Super-Phenix to accomplish that job, then that is the direction to go.

    One of the methods to use to help made the commercial plant meet the goal of economic power is to develop standard equipment that can be used in many plants. If each plant has to have an individual design and test program for each of its different components in the manner of FFTF and CRBRP, the cost will be prohibitive. This may mean, for example, that it is necessary to have one approved primary pump which is a product of a design and test program which gives rights to any manufacturer to build that pump in order to keep a competitive industry. Because of the large cost involved in proof testing, we may need more government-industry cooperation than we normally have, more in line with what exists in Europe and Japan. Perhaps the U.S. needs to organize a company along the lines of PNC to be the LMFBR technology center. It will be a long time before there is enough LMFBR business to keep several manufacturers and several architect-engineers competent in all needed areas. A program somewhat comparable to SNUPPS wherein several entire plants are built as identical units may be what is required to obtain economic LMFBR generated power.

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List of Abbreviations

AEC	Atomic Energy Commission
ANL-West	Argonne National Laboratory western site in Idaho
APDA	Atomic Power Development Associates, Inc.
CRBRP	Clinch River Breeder Reactor Project
CRIEPI	Central Research Institute of Electric Power Industry, Japan
DRRD	Division of Reactor Research & Development
EBR-II	Experimental Breeder Reactor No. 2
EPRI	Electric Power Research Institute
ERDA	Energy Research and Development Administration
FFTF	Fast Flux Test Facility
GAO	General Accounting Office
GESMO	Generic Environmental Statement on Mixed Oxide Fuel
HCDA	hypothetical core disruptive accident
HFEF	Hot Fuel Examination Facility
LMFBR	liquid metal fast breeder reactor
LWR	light water reactor
MMF	Material Monitoring Facility
NCBR	near commercial breeder reactor
NRC	Nuclear Regulatory Commission
OTA	Office of Technology Assessment
PFR	Prototype Fast Reactor at Dounreay, Scotland
PNC	Power Reactor & Nuclear Fuel Development Corporation of Japan

PRDC	Power Reactor Development Company
Rapsodie	fast test reactor in France
R & D	research and development
SAREF	Safety Research Experiment Facility
SEFOR	Southwest Experimental Fast Oxide Reactor
SGHWR	steam-generating heavy water reactor
SNR-300	300 Mwe sodium cooled fast reactor in Germany
SNUPPS	Standard Nuclear Unit Power Plant System
UK	United Kingdom
UKAEA	United Kingdom Atomic Energy Authority
ZPR-II	Zero Power Reactor No. 3
ZPPR	Zero Power Plutonium Reactor

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