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Status and Program of Development of the Fast Breeder Reactor System in the U. S.

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Introduction

From the early days of the development of nuclear power, the need for and feasibility of extending uranium resources through fuel breeding in nuclear reactors was recognized. Today, with our current knowledge of uranium resources, and today's energy needs and our capabilities to meet them, the breeder reactor has taken on a crucial importance. As a result, a heavy commitment to the development of the breeder reactor has been undertaken by the major industrialized nations. As in the other nations, the U.S. program has been focused for a number of years on the Liquid Metal Fast Breeder Reactor (LMFBR) concept. This paper will summarize the important elements of the U.S. LMFBR program and describe how these efforts are being scheduled and integrated for the achievement of our objectives. In addition, since this complex technical development is being conducted in a national framework with strong implications concerning public acceptance and international policy, relevant issues and policy aspects will be discussed as well.

Objectives

The objective of the LMFBR program is to develop and demonstrate the entire LMFBR system so that a safe, reliable and economical source of electric power is available to meet future United States energy needs. As an integral part of this objective, it is necessary to develop the industrial base and institutional structure necessary to integrate this concept effectively into our society. The specific goal of the U.S. program is to have the breeder system available in the mid 1990s, with the installation by utilities of a 30-60 GWe capacity by the year 2000, supplied by a competitive industry.

The development approach is based on the following elements:

- A series of reactor projects of increasing size, leading to commercial plants of around 1000 MWe
- A strong base technology program
- A fully capable fuel cycle
- Resolution of environmental and safety concerns.

These elements have been logically combined into a specific plan of action, which is documented as ERDA-67 "LMFBR Program: Overall Plan." The plan identifies the scope of the elements to be performed, the schedules, and the estimated cost of the work.

The program has an important constraint placed upon it in the form of a decision to be made in 1986 by the Administrator of ERDA with respect to proceeding to commercialization of the LMFBR. This decision will be based on the status of technology and engineering at that time, the projected economics of the breeder compared to alternatives, the available information on reactor safety, safeguards, waste management, health effects, uranium resources and the findings of the Final Environmental Impact Statement on the LMFBR.

Program Status

The development of a series of successively larger reactor plants is the key element of the LMFBR program, on which the remaining elements are focused. The plant sequence comprises the Fast Flux Test Facility (FFTF), the Clinch River Breeder Reactor (CRBR), the Prototype Large Breeder Reactor (PLBR), and the initial Commercial Breeder Reactor (CBR-1). Each of these projects will be described further.

The plants are phased so that each successive plant is initiated shortly after the design of the previous plant is completed. In this way, each plant will benefit from experience gained in the design, procurement, licensing and component fabrication and testing of the preceding plants. In addition, operating experience will be gained from earlier plants. It is planned that the design of the first commercial plant will be started in 1982 or 1983 with a commitment to construction following the commercialization decision in 1986.

FFTF

The Fast Flux Test Facility is a 400 MWt sodium cooled hard spectrum test reactor for use principally in the development of fuels and materials for fast breeders. It will have the operating environment and instrumented test capabilities which will enable fuels and materials tests to be conducted under prototypical commercial reactor conditions, and is an essential tool for our strong base technology program. In addition, the FFTF is a major building block in the size development sequence for LMFBR systems and components. The lessons learned in design, construction testing and safety review are being incorporated now into the CRBR. Through the development and testing programs, the performance of large components such as pumps, valves and intermediate heat exchangers has been carefully characterized, with the expectation of significant reductions in the design and operation problems of larger components for future plants. Improved construction techniques, such as automatic welding of large diameter piping have been developed. Although the FFTF is not a licensed plant, the Nuclear Regulatory Commission (NRC) has been kept apprised of the design and development, and has reviewed and commented on the safety aspects of the plant. In this way, the basis for the licensing of future LMFBRs has undergone considerable evolution.

Procurement of the major components of FFTF was more than 99% complete and construction was about 70% complete as of the end of 1976. Criticality is expected in 1979 and operation as a test reactor should begin in 1980.

CRBR

The CRBR is the LMFBR demonstration plant. It will have a gross output of 380 MWe and is planned for criticality in 1983. The objective of the CRBR is to demonstrate safe and reliable operation on a utility grid of a large sized LMFBR which has been designed and constructed by commercial suppliers. It will demonstrate the safety, environmental advantages and economic potential of LMFBR power plants. Its present estimated cost including five years of operation, escalation and contingency is $1.95 billion. See Table 1.

Table 1

CRBR TOTAL PROJECT AUTHORIZATION
(Millions of Dollars)

Plant Investment	729
Development Cost	364
Operating Cost (includes credit of 72 for revenue)	26
Contingency	197
Escalation (8%/yr. av.)	634
Total	1,950

The CRBR is a joint venture of the federal government, which provides project management and major financial support, and a consortium of 700 utilities (principally the Tennessee Valley Authority (TVA) and Commonwealth Edison) which contributes both financial support and technical assistance. The reactor plant will be operated by TVA and will provide power to its electrical grid.

Long lead items including the reactor vessel and other major components such as the intermediate heat exchanger have been ordered. Preparation of the site, located near Oak Ridge, Tennessee, is expected to proceed this year following the approval of a Limited Work Authorization by NRC. The licensing process, as expected, has been and continues to be complex, with attendant costs in special plant features and impacts on the overall schedule. However, the process is valuable in the experience gained by NRC, the utilities and the contractors who are performing the same roles that they would in a fully commercial reactor license application. Also, licensing issues are being faced at the developmental stage of the LMFBR which would have been faced in any event in commercial licensing.

PLBR

The PLBR is a joint project of ERDA and the Electric Power Research Institute (EPRI) to design an LMFBR which will be prototypical of early commercial breeder reactors in the sizes and ratings of its components and systems. It is the next step towards commercialization.

Competitive design efforts are underway by three teams of reactor vendors combined with architect engineers. It is planned to initiate the final design under the direction of the utility owner in late 1978, with operation of the PLBR on the utility grid in 1988.

The design of the reactor will reflect US engineering and technology experience with the FFTF and CRBR and will take into account developments in the base technology program. It will be rated at about 1000 MWe and will be a loop type reactor.

The components in the PLBR heat transport systems will be prototypical of the size planned for use in early commercial LMFBRs. This approach will ensure that the development programs for these complex components will be fully applicable to early commercial reactors. A similar philosophy was used for FFTF and CRBR which will be of comparable benefit to PLBR.

Phase 1 has been completed, which has provided three conceptual designs, and the identification of much of the necessary research and development.

Concurrent with the conduct of the PLBR design studies, financing and program management arrangements must be agreed to between interested utility organizations and ERDA. It is intended that this next breeder reactor will be owned and operated by a utility or a consortium of utilities. ERDA plans substantial support for this project in the form of research and development and in other ways yet to be determined.

CBR

The Commercial Breeder Reactor has been preliminarily defined in conceptual studies as a means for assuring that the PLBR can be readily extrapolated to this next step with a minimum of additional development. It may be identical to the PLBR or it may be higher powered, for example, by adding a fourth heat transport loop to a three loop design. It is expected that design for this reactor plant would be initiated in 1982 or 1983, and the plant would be operational in 1993.

Technology

A major strength of the U.S. LMFBR program is the broad technology base which has been and is continuing to be developed for this concept. To the extent practical, all major aspects of the LMFBR system are under technological development to assure that a detailed basic understanding of its behavior has been addressed prior to commitment to hardware. In this way, problems will be identified and corrected prior to a more costly development stage. The technology program emphasizes support of the projects, primarily those in the design stage.

The elements of the base technology program are reactor physics, materials and chemistry, fuel performance, fuel cycle, (fabrication, reprocessing, shipping) components and systems, and safety, including environmental effects. This extensive program is conducted by a large number of industrial contractors, in our national laboratories and in specialized engineering laboratories. Highly useful technical information exchanges and cooperative programs are undertaken with other countries which are also developing the LMFBR.

The objective of the Physics program is to improve the accuracy of reactor neutronic analysis so that reactor designs can be optimized for performance and economics. Development work is conducted in the acquisition of physics data such as cross-sections and dynamic reactor parameters, in analytical methods for predicting systems behavior, and in verifications of predictive capability using large scale experiments such as critical assemblies and shielding mock-ups.

Advances in reactors physics have resulted in substantial improvements in the predictability of reactor systems behavior. A significant factor has been the use of large plutonium fueled critical assemblies. The Zero Power Plutonium Reactor (ZPPR) will soon have a capacity of over 3000 kg of plutonium including space for the blanket assemblies. This loading is characteristic of commercial sized LMFBRs. More powerful calculational techniques and more precise nuclear data are also important factors. Design uncertainties such as critical mass and control rod worth have been significantly reduced from a few years ago. Current levels of knowledge permit confident design of safe and reliable reactors. Further program effort is needed and planned to provide an adequate and timely physics capability for economic optimization of LMFBR designs.

Experimental support in Physics has been given in the past to the design of the FFTF. Currently the program is addressing the needs of the CRBR and the advanced fuel program. In 1978, experiments will be initiated in support of commercial sized cores.

A major technical problem to be solved for the LMFBR is to develop a fuel system and cycle which will be economically competitive with other energy systems, and will provide a sufficently short doubling time to meet the fuel requirements of the predicted expansion of the LMFBR industry. While the required doubling time is sensitive to assumptions related to population growth, per capita use of energy, competing sources of electric power supply and demand and reactor mix, it is generally accepted that a breeder fuel doubling time between 10 and 15 years should permit an adequate rate of growth of electrical power supply. A doubling time of 15 years is believed achievable with the reference fuel design of cold worked 316 stainless steel clad mixed oxide fuel, assuming only modest improvements in current technology. Shorter doubling times down to 10 years or less will necessitate the use of mixed carbide or nitride fuels. Advanced mixed oxide, carbide and nitride fuels are currently under development in the U.S. In addition, a program to develop a low swelling alloy with good in-pile creep strength for use in cladding and flow duct applications is well under way.

An important fuel parameter which influences fuel cycle economics is burnup. The advanced fuel development program is aimed at a peak burnup capability of 150,000 MWd/t.

The fuel development program is conducted principally by irradiating test rods under conditions as similar as possible to those expected to be encountered in large power producing LMFBRs and subsequently testing and examining them to measure their performance. A principal facility in which these irradiations are performed is the Experimental Breeder Reactor II (EBR-II) located at the Idaho Nuclear Engineering Laboratory.

The development program for mixed oxide fuels in the U.S. is the subject of a paper by Dr. G. W. Cunningham[1/] at this conference, and a more detailed description of the program and its status can be found there. It is sufficient to observe here that it is confidently expected that the required fuel performance will be available when needed.

Prior to moving on to other technology areas, mention should be made of the Fuels and Materials Examination Facility (FMEF) which is being planned for construction at Richland, Washington. The FMEF will be located close to the FFTF, and will provide a capability for the examination and testing of irradiated fuels rods and material samples with the high volume throughput and rapid turnaround which is needed to match the capabilities of the FFTF and meet our programmatic needs in this important area of technology. The FMEF is in the design stages and is planned for operation in 1982.

There is a wide range of materials development effort, not related to the reactor core, which is important to the achievement of safe, economic and reliable LMFBRs. Examples are: improved techniques for steam generator tube to tube sheet welds and for transition joints from the ferritic materials of the steam generator to the austenitic steels of the sodium system piping; mechanical property data for unirradiated as well as irradiated structural materials required for advanced high temperature design methods; volumetric inspection methods for in-service inspection; and sodium chemistry impurity controls and purification techniques. Programs in materials development are closely coordinated with project efforts and are planned for completion in time to support the 1986 commercialization decision.

A basic element of the LMFBR program strategy is to develop and demonstrate main heat transport system components such as piping, pumps, heat exchangers and steam generators to assure availability of proven designs for PLBR and commercial reactors. Early experience in the U.S. with sodium cooled reactors has provided a basis for confidence that it is feasible to develop satisfactory components for operation in high temperature LMFBR systems. This confidence has been further borne out by the design and testing experience for FFTF components. However, the FFTF has no steam generators, so this component is receiving special attention in the component development program. Sodium heated steam generators are probably the most critical of the nonnuclear elements of the LMFBR, owing to the requirement for extremely high reliability of the boundary separating sodium from water. Satisfactory experience with sodium steam generators in the U.S. provides assurance that the difficult design, fabrication and operating problems can be solved, despite some unsatisfactory foreign and domestic experience.

1/Plutonium Bearing Oxide Fuels for Recycling in Thermal Reactors and Fast Breeder Reactors - G. W. Cunningham, Director, Waste Management, Production and Reprocessing Division, U.S. Energy Research and Development Administration

Also, an extensive development program related to steam generator failures is underway to provide a basis for understanding failure modes and effects, and means of predicting and accommodating the effects of large sodium water interactions.

CRBR components, with the exception of the steam generator, are scaled up versions of FFTF components. For PLBR, and beyond, larger steam generators will be required. Development programs have recently been undertaken for two principal concepts. The first is a double walled tube unit with the capability of detecting the failure of one of the duplex walls separating the sodium and the water. The second is a helical coiled unit having single walled tubing.

Pump programs are underway to establish mechanical pump designs for large plants. Both full scale primary and secondary prototype pumps will be sodium tested.

Supporting the component development program, and in response to the demanding thermal environment of the LMFBR, a program for the further refinement of high temperature structural design methods is being conducted. This is necessary to simplify current costly design techniques required to properly accommodate the inelastic behavior of reactor core and structural materials at the higher operating temperatures. Also, extensive vibration, hydraulic and mass transfer programs are being conducted to provide a basis for sufficient margins for reliable component operation.

Fuel handling systems developed for FFTF and adapted for use in CRBR will probably be replaced by the A-frame concept for PLBR for transferring the reactor fuel between the reactor vessel and storage vessel. Conceptual designs for this part of the PLBR will begin in the next two years, with testing of plant units during the early 1980s.

The commercial success of the breeder is dependent upon a low cost fuel cycle. Short turnaround time for irradiated fuel in reprocessing and refabrication into new fuel, together with low losses are keys to the desired short fuel doubling time.

In fuel fabrication, it will be necessary to process fuel material with a content of radioactive Pu 240 up to 25%, substantially higher than used heretofore, at a volume orders of magnitude greater than at present, at a substantially lower cost, with lower exposures to operating personnel and stricter protection against diversion. To meet these difficult and conflicting requirements, high speed equipment such as pressing, sintering, inspection and loading machines which can be operated remotely is being developed. A complete processing line, utilizing this equipment will be operated in the planned High Performance Fuels Laboratory (HPFL) to be built at the Hanford Engineering Development Laboratory (HEDL). This facility is in the design stages and is planned for operation in 1982. The technology demonstrated in the HPFL will be available to commercial fuel producers.

The schedule for the establishment of a commercial fuel fabrication facility, meeting the requirements previously indicated is extremely tight. Estimates of fuel fabrication capacity needs for the first commercial breeder operating in 1993 indicate that a commercial fabricator will need to make a decision to invest heavily in a fuel fabrication plant based on, at best, only a few years of operation of the HPFL. Considerable attention will be paid to this critical part of the fuel cycle so that scheduled goals can be met.

LMFBR fuel reprocessing development is in the base technology stage at this time, but plans are being firmed up for an intermediate scale demonstration called the Hot Pilot Plant (HPP). Currently, this plant is scheduled for operation in 1988, however, efforts are underway to improve the schedule by two years to be more consistent with the commercialization decision in 1986. The plant will have a throughput capacity of between 1/4 and 1/2 ton per day and will demonstrate the operation of all phases of reprocessing. Currently, these process steps as applied to LMFBR fuels are mostly in the laboratory stage of development, with cold pilot scale efforts to be undertaken in the near future. When the plant is operational, it will be able to reprocess all the fuel from the developmental LMFBRs as well as that from the first several commercial plants.

The design and operation of the HPP will provide NRC with licensing experience related to reprocessing plants, and will provide an arena for the establishment of the requisite criteria. In addition, safeguards systems against Pu diversion are being developed and will be demonstrated, including consideration of co-reprocessing, a method in which the Pu is always diluted by sufficient U to make the resultant mix unattractive from a diversion threat standpoint. If the accelerated schedule for this plant can be established and maintained, a good basis will have been provided for commercial reprocessing of LMFBR fuels in the late 1990s, when it will be needed.

Fuel shipping is also at an early stage of development. Shipping cask designs to meet FFTF and CRBR spent fuel shipping needs are being conducted. To serve the needs of shorter doubling times, questions regarding fuel cooling time, coolant material, shipping cask capacity and safety aspects are being considered.

Three decades of operating experience with fast reactor systems have shown that LMFBR reactors can be operated safely, and nuclear safety research and development are now mainly concerned with protection against low probability events. In describing the LMFBR safety research and development program, four lines of assurance are addressed.

1. Prevent accidents
2. Limit core damage
3. Contain accidents effects in the primary system
4. Attenuate radiological products.

The first line of safety assurance takes advantage of the intrinsic stable characteristics of a normally operating LMFBR, coupled with proper design, construction and operation, which provide highly reliable operation. A high degree of freedom from failures and maloperations assures a maximum of safety. An essential aspect of this approach is the use of tested components built in accordance with appropriate codes and standards and the implementation of a stringent quality assurance program.

The second line of assurance is aimed at maintaining sufficient heat removal capability for the core to assure that any local fuel damage which might inadvertently occur will not propagate. Failures of concern would be local blockages due to such causes as fuel swelling, fuel failure from internal gas pressure and local coolant channel blockage due to the introduction of foreign objects into the coolant.

The third line of assurance is related to the characterization of hypothetical core disassembly accidents (HCDA) and the designs which can reasonably be included in the reactor system to provide margin to accommodate these extremely unlikely events. Mechanisms which are postulated to lead to HCDA's are severe over power transients from large inadvertent reactivity insertions and loss of flow of primary coolant which is not accompanied by a reactor scram. These events are sufficiently improbable to be not considered design basis accidents, however, additional margins to accommodate the potential consequences are provided.

The fourth line of assurance is aimed at reducing the radiological consequences of accidents by developing and prooftesting engineered safety features such as containment air cleaning systems, and by improving our understanding of natural attentuation mechanisms, such as depletion and transport of radioactive aerosols.

The safety research and development program provides the analytical tools and agreed upon data base which will enable prediction of the related phenomena so that LMFBRs can be designed to operate reliably and safely. The work performed in the past on the first two lines of assurance have provided a great deal of confidence that LMFBRs can meet safety objectives. Tests and experiments have indicated that:

1. Single pin failures are very unlikely to propagate.

2. Realistic flow blockages do not lead to large accidents.

3. Sufficient reliability of the primary system boundary and the reactor protection system can be attained so that failures in these areas do not lead to public safety concerns.

4. There is a high degree of confidence that the work energy released in HCDAs in an LMFBR can be readily accommodated by containment provisions.

5. There is a high degree of confidence that the molten fuel pool postulated to result from an HCDA can be cooled in place in the primary system or in the reactor containment.

Large scale tests are being planned to be undertaken in Safety Research Test Facilities (SAREF) to be built in the near future. These facilities will enable the simulation of hypothetical accident conditions in a larger fraction of the reactor core than is now possible in the Sodium Loop Safety Facility (SLSF) or Transient Reactor Test (TREAT) facility at the Idaho Nuclear Engineering Laboratory. These more realistic simulations will provide a more detailed test of our ability to predict the course of events of such accidents and are intended to provide a basis for all concerned parties to agree that the safety questions for LMFBRs have been finally laid to rest.

Issues

The preceding program summary has provided a concise overview of the large and complex LMFBR development and demonstration program. While good progress is being made in the hardware and technological parts of this program, many obstacles to timely success are present. Several of these, which are related to concerns for safety and protection of the environment, have much in common with the problems of deployment of light water reactors as well, for example, plutonium toxicity, release of radioactivity to the environment, and waste management. A topic of great international concern is the potential spread of nuclear weapons production capability which could accompany the worldwide establishment of reprocessing and recycle capacity. The United States interest in limiting proliferation have been addressed by both Presidents Ford and Carter. President Ford's Nuclear Policy Statement of October 28, 1976 identified specific policies and activities by the U.S. Government to reduce the risk of nuclear weapons proliferation while providing for the continued use of nuclear power worldwide.

While these policies do not affect the U.S. program of research and development on the breeder reactor, they could impact the availability of Pu feed required for the initial startup of commercial breeders. The initial core loadings of breeders require LWR generated and reprocessed Pu, at least until reprocessed LMFBR fuel is available. It had previously been assumed that LWR reprocessing capability would be available for this purpose. However, President Ford's nuclear policy directed ERDA to suspend reprocessing and recycle commercialization efforts and to evaluate LWR reprocessing and recycle consistent with U.S. nonproliferation objectives. Alternative technologies not requiring the separation of plutonium are also being evaluated.

Although the reprocessing of LWR fuel for recycle into LWR's is being evaluated, improved technologies for LMFBR fuel handling will also be assessed. The LMFBR fuel cycle has potential nonproliferation advantages since it may be possible to fuel fast breeders with reprocessed LWR fuel still containing highly radioactive impurities which would render the fuel unsuitable for nuclear explosives or to use co-reprocessing as referred to previously. The feasibility and impact of such approaches are being evaluated by ERDA.

I believe these activities demonstrate the United States resolve to deal with the proliferation question in an imaginative and realistic way while still providing for the continued growth of nuclear power to meet vital worldwide energy demands.

Plutonium Requirements

Pu will be needed for the development and demonstration program in two areas, namely, for operating FFTF, the CRBR and the PLBR, and for developing and demonstrating reactor fuel performance and fuel cycle technology using prototypical LWR fuel with its higher Pu-240 content.

Also, a reliable source of Pu will be needed for initial market penetration and early deployment of commercial LMFBRs. To meet this requirement, commercial LWR fuel reprocessing will be needed by 1983 to support a utility decision for the first commercial breeder for operation in the mid 1990s.

Conclusion

This review has briefly described the status and interrelationships of the main features and elements of the US/LMFBR program. In such a limited space it is not possible to provide many of the important details or to acknowledge the vital contributions of the many participating organizations and of the large numbers of individuals. At best, only the broad thrust of the program and the problems that remain to be overcome can be addressed in this context.

The U.S. LMFBR program has been provided with the essential resources, the incentive to succeed is very great and clear paths for the resolution of most of the difficulties can be identified. The challenge is to put these elements all together in the requisite time frame. This is a difficult challenge, which must and can be met.