STATUS OF FAST BREEDER REACTOR DEVELOPMENT IN THE UNITED STATES OF AMERICA – April 1984

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1. INTRODUCTION

The economy of the United States is increasingly being based on the use of electricity. One-third of domestic energy consumption is now used to produce electricity; up 25 percent from just a decade ago. Additional electrical capacity will be needed to meet continued growth in demand, plus replacement of physical and economic obsolescence of existing generation capacity.

Nuclear power and coal plants will continue to play a key role in assuring that future electrical demands are met. Current nuclear capacity, in the form of light water reactors (LWR), already provides about 13 percent of our domestic electricity. However, the next generation nuclear technology--the breeder reactor--promises to expand this role because of its advantage in resource conservation, its potential for economic competitiveness, and its potential inherent safety advantages. The breeder reactor is recognized by many advanced nuclear nations as the most promising inexhaustible source of energy that could be available around the turn of the century, and all are actively pursuing its development as exemplified by presence at this meeting. In order to achieve that potential for the United States, the goal of the Department of Energy (DOE) breeder R&D program is to develop the technology for an inherently safe, reliable, and marketable breeder that is competitive with energy sources to support commercial introduction by the private sector early in the next century.

The amount of energy that can be extracted by the breeder from presently available material that would otherwise go untapped is enormous. From uranium enrichment plant byproducts that have already been mined, processed, and stockpiled near Federal fuel processing facilities, the breeder can obtain some 11,000 quads of energy, which is more than 140 times the total annual U.S. energy consumption and more than the known U.S. coal reserves. In addition, there is enough fissionable ore remaining in the ground to last for thousands of years.

Because the breeder reactor requires only a small annual quantity of uranium compared to conventional light water reactors (about 1/100), its economics are relatively insensitive to uranium price and are controlled primarily by plant capital cost. The price of power from breeder reactors will, therefore, be uncoupled from price fluctuations in fuel cost that have impacted other energy sources. In addition, unlike conventional reactors, the breeder can also make effective use of low-grade ores, thus assuring a virtually inexhaustible source of electrical energy.

The Reagan Administration fully supports nuclear power as an imperative, not an option, for assuring reliable and adequate electricity supply in the United States and the rest of the world. The goal of the Department's nuclear enery program is to provide a safe and economic source of electrical energy in the near term and to help ensure reliable sources of the energy needed for long-term economic development and national security. In the next 5 to 10 years, the Department's Nuclear Energy programs will provide the technical base to support industry's efforts to revitalize the development of nuclear power as an economic and environmentally acceptable source of baseload electric power.

The Federal role in breeder development has been restructured during the past year to focus on resolving those technology issues that are key to improved breeder economics and predictable, safe performance, and on resolving the technological and economic uncertainties which are a prerequisite for the private sector to demonstrate and deploy the breeder. The revised breeder R&D program will be fully consistent with our national energy R&D policy in that there will be no Federally funded demonstration project. The responsibility for demonstrating breeder reactor technology will now rest with the private sector, including definition of project scope, timing, funding arrangements, and management.

During the past year, both the Experimental Breeder Reactor-II (EBR-II) and the Fast Flux Test Facility (FFTF) demonstrated continued excellent performance. The EBR-II plant has operated over twenty years, achieving a plant capacity factor of 72 percent over the past five years, even with frequent planned outages required to fulfill its experimental mission. The FFTF completed a highly successful year of operation in 1983 with a 56.9 percent capacity factor and two operational cycles of over 100 days operation. The oxide fuel attained the goal burnup of 81,000 MWd/MT demonstrating capability for 1 year of reactor operation. Driver fuel performance was flawless during the three operational cycles.

During 1983 the Congress of the United States failed to appropriate funds for the Clinch River Breeder Reactor Plant (CRBRP) Project, thus causing termination of the project. It is important to recognize that even though the CRBRP will not be built, the United States probably received 30 to 40 percent of the value out of the project. Maximum program benefit will be gleaned from the experience to date in the development of the CRBRP. The experience gained in the design, component testing, licensing, and analysis from the CRBRP project will be codified, carefully documented, and used in the U.S. breeder program and as a medium for data exchange with other nations.

The Large Scale Prototype Breeder (LSPB) program has been a joint effort of the U.S. Government and private industry to develop a large scale prototypical breeder demonstration plant. Private industry was to be responsible for the construction of the plant with the Government aiding industry in the responsibility for the first of a kind plant costs. The plant was to have been the logical follow-on to the CRBRP project as a full-scale demonstration plant.

It is now clear that the responsibility for future demonstration plants will lie with the private sector. Therefore, the Government sponsored design efforts on a large scale prototype breeder plant will be phased down in an orderly manner. The LSPB design will be maintained as a frame of reference for benchmarking advanced concepts developed under the base program.

The Department of Energy will be embarking on a program to conduct competitive design studies. The Department believes that the successful conduct of such studies will stimulate commercial development of a marketable liquid metal fast breeder reactor, acceptable to the public and to the customer. Such studies will act as a bridge between the base research and development program and industry, by identifying practical research and development needs to DOE, while DOE, in turn, will conduct its proper role of developing technology in high risk areas which will support efforts by industry to commercialize the LMFBR.

A competitive approach has been chosen to encourage the needed innovation. It appears, based on work to date, that this is a very fruitful approach and will produce more rapid achievement of low cost and inherently safe designs. This, in turn, promotes efficient use of taxpayer dollars while taking the Government out of the business of controlling and selecting the design to be eventually commercialized. Rather, the winners of the contracts will be required to determine, on their own, what the needs of the marketplace are and tailor their designs to meet those needs.

Successful bidders will be evaluated on an annual basis in the areas of reduced cost, increased safety, technical performance, and marketability. Such annual assessments will result in adjustments of contracts as necessary.

The Breeder Technology program continues to produce viable information on fuel performance, nuclear systems technology, and power conversion technology. The unique testing capabilities design into the FFTF have resulted in well-validated materials and fuels irradition information that has confirmed and extended previous data bases. Current directions for the research and development program are to improve the technology for power conversion systems, components, instrumentation, and materials technology to the point where cost reduction and reliability potentials are realized.

Operation of the breeder test facility complex at the Hanford Engineering Development Laboratory (HEDL), the Energy Technology Engineering Center (ETEC), and the Argonne National Laboratory (ANL) continues to provide the experience base and test capability for the breeder R&D effort.

International cooperation will be even more important in the future than in the past for several reasons. Significant new investments still have to be made in breeder R&D to improve designs, achieve economic competitiveness and to develop practical breeder fuel cycle capabilities. Progress can be accelerated, redundancies avoided, and economies achieved if nations coordinate their programs, and where possible, divide up the work. In addition, there is clear mutual benefit in encouraging the countries involved in breeder development to harmonize standards and regulations related to safety. It is also important that the advanced nations work together closely in assuring that adequate international safeguards, export controls, and national physical security measures keep pace with breeder reactor and fuel cycle developments.

2. PLANT PROJECTS

Current USDOE Plant projects include the Experimental Breeder Reactor-II (EBR-II) and the Fast Flux Test Facility (FFTF). The EBR-II continued operating successfully in its nineteenth year of routine operation. The FFTF completed its third cycle of operation, reaching goal burnup for the initial fuel loading without a single fuel failure. Termination occurred on the Clinch River Breeder Reactor Project (CRBR) when funds were not appropriated in FY 1984. Termination activities are underway. Similarly, Government sponsored design efforts on a Large Scale Prototype Breeder are being phased down in an orderly manner as the Government withdraws from the arena of demonstration plants.

2.1 Experimental Breeder Reactor-II

The EBR-II is a 62.5 MWt (20 MWe) sodium-cooled pool-type fast reactor. EBR-II operates as a complete powerplant, generating electricity while providing information and experience concerning liquid sodium cooled plant operation, maintenance and component performance. It will continue steady-state irradiations of fuels and materials at a reduced level and supplementary to FFTF. The reactor is deployed to conduct an operational reliability test program covering sustained operation of breached fuel elements, transient overpower and undercooled testing of intact and breached fuel, and shutdown heat removal testing. During routine operation since 1965, EBR-II has generated 223,513 MWd of energy corresponding to a 55.9 percent Plant Capacity. In 1983, the EBR-II generated 13,677 MWd of energy corresponding to a 64.5 percent Plant Capacity, off somewhat from the 72 percent average over the past five years. Current metal fuels are routinely discharged at 8.5 percent burnup, although the limit exceeds 10 percent. A limited number of elements have attained 18.5 percent burnup. New elements with a minor design change are expected to reach about 14 percent burnup.

2.2 Fast Flux Test Facility

The FFTF is a 400 MWt sodium cooled reactor designed specifically for irradiation testing of nuclear reactor fuels and materials for fast breeder reactors (Figure 2.1). FFTF is a testing reactor and is not designed to breed fuel or to produce electricity. The reactor is shown in Figure 2.2. It provides vital information for plant design and base-technology programs in the areas of plant system and component design, component fabrication, and prototype testing. In addition, FFTF provides experience in the operation and maintenance of a reactor plant having coolant loops and components at temperatures and coolant velocities typical of LMFBR powerplants. This experience, combined with the operating and maintenance experience from other test facilities, provides a proven baseline for scaling of systems and components. FFTF is being used to test fuel elements up to failure under dynamic sodium flow conditions to establish ultimate capability and failure modes. Understanding of failure modes is essential to establish reactor core reliability, performance, and maximum life. It is also used in tests to develop the advanced fuels and the advanced cladding and duct materials essential to attaining long lifetime, high performance LMFBR core components.

The FFTF completed three full cycles of operation in late calendar year 1983; the reactor was operated for a nominal 100 days during each cycle. FFTF technical parameters are listed in Table 2.1.

The first cycle began April 1982 as shown in Figure 2.3. All systems operated as expected until the fuel failure monitoring system detected a small fission gas leak. The subsequent gas tag analysis identified the faulty element (an experiment) and reactor operation continued uninterrupted. During the recovery from a subsequent scram, several primary pump problems arose which took several months to resolve. After the pumps were returned to service, the plant operated at full power for 53 consecutive days, surpassing the previous U.S. record for an LMFBR. The cycle ended in November 1983. Cycle parameters are listed in Table 2.2.

Cycle 2 operation was initiated in January 1983. Full-power operation followed several planned holds at various power levels to allow restructuring of fuel. During the initial power ascent, two phenomena were observed: 1) a power fluctuation of approximately 0.7 percent and 2) a number of experimental tag gas releases from a materials experiment which were detected by the fission gas monitoring system. Both these phenomena continued throughout Cycle 2 but did not impact overall plant operation. In later diagnostic tests the power fluctuations were determined to be caused by an experimental control rod.

Cycle 3 operation, the most successful to date, began in July 1983. The plant operated at full power for 56 days when one of the dump heat exchangers had to be isolated due to a fan trip, causing a power reduction to 91 percent. Later a second module was isolated, again due to a fan problem. The power was reduced to 5 percent to recover the isolated modules and then the plant returned to full power. Shutdown was initiated in October after over 100 days of uninterrupted nuclear operation.

The FFTF is currently in Cycle 4, having returned to operation in January 1984.

The performance of the current fuel subsystem is especially noteworthy. The design goal burnup is 80,000 megawatt days per tonne of fuel and several of the driver fuel assemblies exceeded this design goal by the end of the third cycle. This performance without a single fuel pin failure demonstrates fuel capability and shows that the design margins were in fact conservative.

Operation of the plant during the first three cycles has confirmed that the nuclear characteristics are well within design predictions with all parameters remaining inside the operating envelope defined by the technical specifications. Temperature and power coefficients have remained substantially negative as the core burnup reaches an equilibrium value. Stability margins are large and reproducible. Figures 2.4 and 2.5 provide reactor performance and fuel burnup achievements of FFTF compared with its counterparts throughout the world.

Physics parameters measured during the startup and initial operations have always been close to predicted values. For example, during the Cycle 4 startup, the secondary rod bank height at criticality was 13.1 inches vs. a predicted 12.8 inches (maximum heigh - 36 inches). These data generally indicate sufficient reactivity to complete an operating cycle of 110-112 EFPD.

Operation through the first three cycles has demonstrated a very constant intermediate heat exchanger thermal performance of approximately 7530 W/m^2 - °C (1325 $BTU/HR\text{-}Ft^2$ - °F) with little variation between the three units (approximately 3 percent). Dump heat exchanger thermal performance has also been constant with little variation between units.

Pump hydraulic performance is checked quarterly by comparing measured operating characteristics (pump speed, flow and head) to the original pump curve. No significant changes or variations between pumps have been noted. Pump coast-down times are also measured periodically and no significant changes have been noted.

No difficulties have been encountered in the operation of the sodium purification systems. Tests of impurity source rates, by isolation of the cold traps during power operation, have demonstrated that sources are much lower than expected in the secondaries and are comparable to design in the primary. The measured sodium impurity sources are 30 g/day in the primary and 0.9 g/day in each secondary, versus an expected 20 g/day and 10 g/day respectively.

Three in-vessel handling machines are used to transfer core components from core positions to in-vessel storage positions or to one of the three fuel transfer ports. Considerable effort was expended during the installation and initial operation of these units to achieve dependable operation. Since start of fuel loading in 1979, the three machines have performed all required tasks without significant maintenance.

The nine control rod drive mechanisms have given five years of service with only limited maintenance. There has been no detectable change in performance with service time. Early in life two of the units experienced bellows leakage--most likely faulty at time of installation. These leaks caused the position indication rods to bind from sodium oxide formation. These units were replaced and there have been no further problems of consequence.

The instrument trees provide temperatures and sodium flow rates from the discharge of each individual core component. They must be rotated away from the core during refueling. Two of the units have been trouble-free. The third unit, however, has experienced high rotating torque possibly due to sodium frost formation in the superstructure. The torque to rotate seems to have stabilized for the past two years and no further impact on operation is expected.

Operation of the FFTF to date has resulted in significant insights into plant operating techniques. The capacity factor has increased steadily since initial criticality, due in large measure to lessons learned in how to manage scheduled outages. The plant has proved to be easily maintained; the time required for routine maintenance operations has been steadily reduced; refueling operations and the loading of experiments have become efficient; in-service inspections have been done more efficiently and in less time; and the total planning and scheduling process has been refined.

2.3 Clinch River Breeder Reactor Project

There were no funds appropriated to continue the CRBRP in FY 1984. Therefore, in November 1983, the parties involved in the project--the DOE, Tennessee Valley Authority (TVA), Commonwealth Edison, Project Management Corporation (PMC), and Breeder Reactor Corporation (BRC)--agreed to terminate the CRBRP project. The agreement was formalized when the last signature to the four party termination agreement was obtained in December 1983. The DOE has lead responsibility for managing the termination of the CRBRP project.

Prior to termination the project had accomplished the following:

- o Completed 91 percent of the plant design.
- o Completed about 8,983 architect-engineering drawings of the total required number of about 9,633 drawings.
- o Placed procurement contracts for approximately $770,000,000 of hardware, of which $418,000,000 had been manufactured.

- Contributed to the advancement of the worldwide state-of-the-art in LMFBR plants with developments such as the heterogeneous core.
- Continuously evaluated and updated the plant design to remain current with changing regulatory requirements.
- Completed more than 90 percent of the site preparation.
- The Nuclear Regulatory Commission (NRC) had issued the Final Environmental Statement Supplement and Site Suitability Report, which concluded that the site was suitable and that the action called for under the National Environmental Policy Act was the issuance of a construction permit.
- The NRC had issued a limited work authorization.
- The NRC had issued the Safety Evaluation Report and Supplements, which concluded that the CRBRP can be constructed safely and reliably and that the design and site satisfied applicable NRC regulations.
- The Advisory Committee on Reactor Safeguards completed its review of the CRBRP and recommended that a construction permit be issued.
- The NRC Atomic Safety and Licensing Board completed evidentiary hearings concerning the safety and environmental acceptability of the CRBRP.

In FY 1984 termination activities will be conducted. These include the termination and relocation of project personnel; termination of contracts and subcontracts; site redress work; settlement of terminated subcontracts; settlement of the Technology for Energy Corporation prime contract (Probabilistic Risk Assessment); documentation of certain completed work; completion of selected computer verification efforts that were approaching completion when the project was terminated; arranging for retention and appropriate availability of scientific and technical information generated under the project; storage, maintenance, relocation of CRBRP components, equipment, materials, etc., for use within the LMFBR program and other Government programs, as appropriate; and disposition of inventories not of interest to the LMFBR program.

2.4 Large Scale Prototype Breeder

The LSPB conceptual design effort advanced U.S. LMFBR concepts from the intermediate-scale CRBRP; incorporated new and innovative LMFBR concepts; provided a focus for the base technology program; and resulted in a joint Government/utility effort to develop LMFBR concepts.

LSPB design optimization and cost reduction activities significantly reduced the estimated capital costs of a large LMFBR from $2,320/KWe in March 1981 (for a first replicate plant, 931 MWe net) to an FY 1984 estimate of $1,401/KWE (for a first replicate plant, 1319 MWe net). The LSPB incorporates innovative LMFBR design and safety features such as low pressure rectangular containment building, improved and simplified decay heat removal system using natural circulation, heterogeneous core, siphon breakers, compact piping layout, multiplexing, and advanced construction techniques.

Further work on the LSPB will be deferred after FY 1984 in favor of competitive development of LMFBR concepts that offer improved safety and cost advantages. The potential of developing LMFBR's in smaller sizes will be explored. The

LSPB design will serve as a cost and technical baseline for the competitive studies; a vehicle for international LMFBR information exchange; a basis for near-term licensing interaction with the NRC, and a future commercial breeder design, if appropriate.

3. BREEDER TECHNOLOGY

This program provides the technology base for the private sector to be able to construct and operate safe, reliable liquid metal fast breeder reactor plants for supplying electricity to the grid. This includes the conduct of studies of the technical features applicable to future private sector initiatives. The program has been reoriented to place primary emphasis on achieving inherent safety and economic competitiveness in future advanced concepts.

3.1 Power Conversion Technology

The primary objective of the power conversion technology program is to achieve the state-of-knowledge in power conversion systems, components, instrumentation, and materials technology to the point where the technical and economic advantages of these elements in a future liquid metal reactor power system are captured and can be undertaken by the private sector. The power conversion technology activities cover a range of power system sizes.

The primary goal is to assure that accident situations (including equipment failures) will not threaten plant safety or impose economic losses beyond normally incurred maintenance and replacement and that this safety margin is accompanied by significant reductions in component costs. These cost reductions are to be achieved through plant standardization, simplification, elimination of excessive requirements, and application of new technology and concept changes. Reductions center on steam generators, pumps, instrumentation development, materials assessment, and systems studies. A major product of systems studies is the identification of more cost-effective means to achieving the legitimate objectives of codes, standards, quality assurance, and engineering practices.

The strategy has been to perform the necessary system studies, R&D, and experiments that will (1) permit reliable and economic mechanical and direct conversion element design, fabrication, and operation, (2) identify approaches to minimize the effects of balance of plant problems on the nuclear portion of the plant, and (3) verify the adequacy of the technology by testing critical features, small models, and egineered development units.

To enhance the technological and economic attributes of power conversion elements associated with high plant availability to a level from which the private sector could continue development, significant advances must be made in performance predictability and reliability of power conversion components. Experience with liquid metal reactor powerplants in this country and abroad (Fermi, PFR, Phenix, BN-350, and BN-600) has shown that failure of plant components, most notably steam generators, is a major cause of plant unavailability and economic losses to the consumer. Plant operational capability has been seriously affected by component difficulties. These reliability problems cause major economic consequences. The power conversion technology development activities, including steam generator component and leak protection system development, support this requirement for improved performance predictability and reliability.

The base program does not develop specific prototype elements for a plant project; this is a task for the private sector. The base program does perform R&D and system studies on new concepts that will form the technology base from which an industrial decision can be made. The program supports the development of innovative new concepts, such as an advanced inducer pump design, through the identification and resolution of critical technical problems with emphasis on cost-effective design changes, computer code prediction of the behavior of the chosen materials in new configurations, environments, and evaluation of the testing of integrated concepts as models or as test units to verify successful performance prediction and problem resolution.

The R&D underway to support power conversion technology development includes high temperature structural design methods, flow induced vibration analysis, flow distribution testing and analysis, mixing and stratification testing and analysis, subcomponent development and testing, fabrication process development, inspection development, and procedure development. Efforts are required to develop data on materials properties, including fabrication and environmental effects, and the documentation of these data in a handbook form that will serve as an authoritative source for use in the design and licensing processes. The program also includes the development of a modified 9 Cr-1 Mo steel which offers significant economic and engineering advantages over current reference structural alloys. Design, fabrication, and testing of a model steam generator made of this alloy is being considered. Specific attention is being given to the application aspects of the program output in terms of cost-effective means of achieving the fundamental objectives of the applicable codes, standards, quality assurance, and engineering practices.

A major accomplishment has been the successful completion of sodium testing of the hockey stick steam generator in both the recirculation and once-through modes. This was conducted at the ETEC Sodium Components Test Installation. Additionally, preparations continue for sodium testing the 70 MWt helical coil model steam generator which was delivered to ETEC in August 1983. Fabrication of the 70 MWt double wall tube model steam generator is proceeding smoothly with delivery to ETEC scheduled for late 1985.

Sodium testing of the CRBRP 35,000 GPM pump was completed successfully. Water testing of the 85,000 GPM two stage primary pump was successfully completed in December 1983 and all pump system parts are being shipped to ETEC for future use. The water testing exhibited excellent pump mechanical, hydraulic, and dynamic performance and demonstrated successful operation of the solid state motor speed controller, the largest of its kind for this application. Sodium testing of the 85,000 GPM two stage primary pump and further development of the 85,000 GPM intermediate pump will be deferred pending development of advanced concept requirements.

3.2 Fuel Performance and Supply

The goals and objectives of the Fuel Performance and Supply program are based on developing a competitive reliable breeder system. Their purpose is to prove the performance of fuel, blanket, and absorber core components under prototypic operating conditions; demonstrate safe, reliable, and licensable core systems; extend the lifetime of core components that are economically competitive to a minimum of 3 years; develop, establish, and demonstrate an integrated fuel supply system; automate fuel fabrication to achieve competitive fabrication costs, improve safeguards and reduce personnel exposure; and to transfer developed technology to industry. All program activities focus on safe, reliable, economically competitive performance, and reduced costs, and are directed at reducing technological uncertainties important to further commercialization/industrialization of competitive LMFBR's by the private sector.

In the core components area, operation of the intial FFTF oxide fuel and absorber systems continues to provide oxide performance data for assuring long lifetime reliable fuel and core performance. Post irradiation examination of selected driver fuel assemblies irradiated to one-third and two-thirds of goal exposure has been completed, demonstrating excellent fuel capability at those burnup levels. Results of these examinations are being combined with assembly withdrawal load measurements to prove performance capability and margins of the FFTF oxide fuel system. This fuel system, designed for 80,000 MWd/MT (peak) passed the 100,000 MWd/MT level on March 31, 1984. Long term irradiation of fuel, blankets and absorbers in FFTF utilizing improved low swelling alloys (D9 and HT9) are continuing in order to extend the lifetime of the reference fuel system and to qualify core components for long lifetime future breeder plants. Irradiation of an FFTF test assembly with fuel fabricated to relaxed specifications to achieve reduced costs for FFTF cores is underway. Oxide blanket assembly test irradiations in FFTF utilizing prototypically designed assemblies are also underway. Forty-nine assemblies are currently undergoing irradiation in FFTF Cycle 4 as listed in Table 3.1.

A uniquely instrumented test device, the Materials Open Test Assembly or MOTA, shown in Figure 3.1, is being used to irradiate test materials while maintaining automatically controlled temperatures. Thirty in-core canisters each contain 30 to 100 small metal specimens, including pressurized tubes used for creep and creep-rupture tests. A tag gas system provides accurate identification of in-reactor rupture of these specimens.

Additional instrumented assemblies in FFTF include a Fuel Open Test Assembly (one was removed after three cycles of operation) and a Absorber Open Test Assembly measuring gas pressure buildup and temperatures for the boron-carbide absorber material. A Vibration Open Test Assembly was used to measure vibrational and nuclear startup characteristics within the core and has been removed after clearly demonstrating the lack of abnormal vibrations in the core.

The development of carbide and metal fuels is proceeding, at a low level of effort, because of the potential advantages for use in innovative core designs which can exploit the special nuclear and physical characteristics of these fuel types.

In the Fuel Supply area, activities will continue toward completing the Secure Automated Fabrication (SAF) line. Procurement of equipment and its installation in the Fuels and Materials Engineering Facility (FMEF) will continue. Upon its completion and operation in the late 1980's, the SAF line will demonstrate breeder fuel fabrication technology that can be deployed commercially by industry.

3.3 Nuclear Systems Technology

The Nuclear Systems Technology program objective is to develop the technology base, beyond the private sector capability, required for demonstrating advanced reactor concepts which are economic, reliable, and inherently safe. The disciplines of safety, physics, structures, thermal hydraulics, and reactor core design are integrated into a single cohesive unit directed toward the accomplishment of the program objective. The program will focus on demonstrating experimentally the feasibility of advanced reactor concepts of varied design, size, and fuel type that exhibit self-terminating capability under failure conditions. All functions needed to assure nuclear safety under any upset conditions are integrated into the nuclear systems. Demonstration of inherently safe nuclear systems operations will relieve the balance of plant requirements for safety grade structures and systems and enable the development of a relible advanced technology that is competitve and compatible with user needs and capability.

A new emphasis is focusing on accident prevention such as development of concepts and technology that prevent core disruption rather than studying in great detail what happens after a core meltdown. Studies on how best to use the positive attributes of sodium coolant to remove decay heat are being undertaken. Varied fuel types (metal, oxide, carbide) and fuel pin sizes will be evaluated, as well as the effects of varied core designs on voiding, temperature, and reactivity coefficients. Attributes supporting inherently safe operation including axial fuel expansion, control rod expansion, grid support plate expansion, and reactivity matching voiding incoherence will be developed. To summarize, the integrated R&D activities will be focused on providing the necessary test data, methods, and evaluations needed to establish the performance and licensability of advanced designs which emphasize cost reduction, inherent, self-terminating capability for failure sequences, and the ability to compete with alternative energy sources.

The Nuclear Systems Technology program integrates those activities which beneficially influence advanced concept designs by identifying and exploiting plant characteristics that enhance inherently safe operation, reduce complexity, and thereby reduce cost. Enhancement of LMFBR operational safety is a major objective of the Nuclear Systems Technology program. The operational safety of a reactor system (hardware, software, humans) must be beyond question if private investment is to be realized. This can be achieved if the reactor core and its associated structures and systems are designed to have a high degree of reliability and inherent safety so that significant deviations from normal operating conditions can be borne without physical damage, and so that safe recovery from abnormal conditions is assured in all cases. The reactor system that meets these criteria will be virtually invulnerable to core damage, and its operational safety will be self-evident. Also, the absence of credible core damage scenarios will assure protection of public health and safety, an essential consideration in reactor licensing.

A major accomplishment was the completion of safety transient tests in TREAT to demonstrate the inherent dispersal of molten fuel away from the core mid-plane, thereby safely terminating the transients. Work will continue in support of upgrading the TREAT reactor to provide the principal in-reactor safety phenomena testing capabilities. Also, a viable program of integrated system operational safety experiments will be conducted at the EBR-II reactor facility.

The Nuclear Systems Technology program will develop seismic design data, methods, and criteria to provide users with means of optimizing safety and economics of reactor systems. The overall strategy includes: (1) conducting specific R&D required for respective advanced design concepts, (2) establishing and documenting the generic technology base for advanced plant design, and (3) maximizing the use of information derived from foreign exchange agreements.

Major functions include the conduct of critical measurements on core configurations of interest, the improvement and validation of the nuclear data and design methods, and the application of available analysis methods to advanced LMFBR concepts. Critical experiments are carried out at the ZPPR facility in Idaho. The current program, ZPPR-13, consists of studies on heterogeneous LMFBR cores assumed to be about 700 MWe with mixed U/Pu oxide fuel. Emphasis has been on control rod worths and power distributions with a variety of internal blanket configurations. Size, sodium voiding, and spatial kinetics effects are also being addressed. Reactor physics code and method development included validation of transport theory and three-dimensional diffusion theory design methods for analyses of critical experiments, reactor operating data, and advanced LMFBR's. Developmental work also continued on nodal diffusion-theory and Monte Carlo codes. Reaction rate and burnup data collected during the initial characterization program and Cycle 1 at the FFTF are being used as a benchmark test of LMFBR analytical methods. Small power fluctuations observed at the FFTF were investigated and proven to be due to an advanced control rod being tested in FFTF prior to procurement for the recently cancelled CRBRP.

3.4 Nuclear Fuel Cycle

The Nuclear Fuel Cycle Program activities focus on development of the LMFBR fuel cycle technology with primary emphasis on breeder reprocessing. Also associated with these efforts are those activities necessary to assure adequate means exist to handle and ship irradiated breeder fuel.

This activity provides for development of remotely operable and maintainable reprocessing equipment and systems, and technology related to breeder spent fuel shipments. The more stringent requirements associated with reprocessing and shipments of breeder fuels as compared to LWR fuels, including the higher thermal and radiation burdens, higher fissile content, sodium contamination, and more complex fuel assembly configuration, result in much more difficlt, longer term, and higher risk research and development. The program focuses on development of technology that will provide for reduced radiation exposure to workers, increased environmental protection, increased reliability, enhanced safeguards, and reduced costs. These efforts will maintain a level of expertise in fuel cycle development and facilitate future closure of the breeder fuel cycle as the need is identified.

Design, fabrication, and testing of advanced smaller size, higher throughput equipment in the Integrated Equipment Test (IET) facility at Oak Ridge will continue to evaluate performance and remote maintenance concepts. Specific items to be tested include fuel disassembly and shear systems, a continuous rotary dissolver, centrifugal contactors for solvent extraction, and an advanced servomanipulator needed for remote operations and maintenance. At some later date, the equipment, components, and remote manipulators will be tested in a small-scale reprocessing line in a representative radioactive environment using fully irradiated FFTF spent fuel.

4. TEST FACILITIES

4.1 Hot Fuel Examination Facility (HFEF)

The HFEF is integral to the ANL-West EBR-II site and is comprised of two adjacent hot cell complexes--HFEF north and HFEF south. The HFEF provides the operational support to EBR-II for examining and reconstituting experimental subassemblies irradiated in EBR-II for breeder reactor programs on fuels and materials. HFEF is also being used for FFTF postirradiation examinations. In addition, HFEF will continue to be used to assemble, disassemble, and examine tests from TREAT.

4.2 Transient Reactor Test Facility (TREAT)

TREAT is an air-cooled, thermal, heterogeneous reactor at ANL-West which is used to simulate postulated reactor transients and transient undercooling events. Its was operated to evaluate the performance of multi-pin fuel bundles under specific transient during 1983. The facility was then shut down for TREAT upgrade construction activities to extend its capability to irradiate larger multi-pin reactor fuel bundles and structural materials under conditions more closely simulating various types of nuclear excursions and transient overpower and undercooling situations.

4.3 Zero Power Plutonium Reactor (ZPPR)

ZPPR is the world's largest and most flexible critical facility. It was used extensively in studies of the CRBR heterogeneous core configuration. Benchmark and mockup experiments will be carried out at ZPPR during the 1980's to guide and confirm the designs of cores which may incorporate such additional features as heterogeneous configuration, advanced fuels, and high burnup capabilities.

4.4 Energy Technology Engineering Center (ETEC)

The Energy Technology Engineering Center, located northwest of Los Angeles, is the Breeder programs nonnuclear component testing center. Principal ETEC facilities include: 1) the Sodium Components Test Installation (SCTI), a 70 MWt steam generator test facility; 2) the Sodium Pump Test Facility (SPTF), used for prototype sodium pump testing; and 3) the Small Components Test Loop (SCTL), used for sodium valve testing. Testing of the double suction prototype pump in the SPTF is complete.

Testing in the SPTF of the two stage primary pump sodium test unit is being deferred pending concepts and requirements needs. The prototype hockey stick steam generator test program was completed in the SCTI in 1983. Preparations for testing a 70 MWt helical coil steam generator test unit, which is to follow the 117 MWt prototype hockey stick test unit, will be completed in 1985. This 70 MWt unit has been delivered to ETEC. Efforts will continue toward realizing innovative methods for economical long term steam generator testing.

4.5 Fuel Storage Facility (FSF) and Maintenance and Storage Facility (MASF)

The Fuel Storage Facility, located adjacent to the FFTF at HEDL, is used to store and remove decay heat from irradiated FFTF fuel and reactor experiments. The Maintenance and Storage Facility, also located adjacent to the FFTF, provides for sodium removal, decontamination, repair, storage, and staging of large components for the FFTF and related breeder reactor program facilities.

4.6 Fuels and Materials Examination Facility (FMEF)

Construction of the FMEF, located at HEDL, will be completed in the summer of 1984. FMEF is designed to accomodate the SAF line which will demonstrate an advanced manufacturing technology for plutonium oxide breeder reactor fuel pins. This line will be the source of fuel for the FFTF. The SAF line will utilize technology that focuses on improved safety features for plant operating personnel, the public, and the environment. Equipment and process improvements incorporated by the SAF line will yield significant gains in nuclear materials safeguards, product quality, productivity, and cost. The SAF line provides the key link between development and full-scale demonstration of technology that will enable commercialization of LMFBR fuel fabrication on an economically competitive basis in the future. Preconceptual designs have been completed for a small-scale reprocessing line in FMEF. This line, the Breeder Reprocessing Engineering Test (BRET) could be used to test the breeder fuel reprocessing concepts developed at the Oak Ridge National Laboratory, using FFTf fuels.

5. INTERNATIONAL COOPERATION

International cooperation has been in an upward swing over the past several years with a continued emphasis on expanded bilateral agreements. Our Federal Government continues to aggresively pursue new avenues of cooperation in order to produce economic benefit, maintain program momentum, and avoid expensive duplication of work. These joint efforts will also encourage uniform or compatible activities across the spectrum of analysis, design, construction, operation, and safety.

5.1 US/Japan Bilateral Activities

The United States and Japan (as represented by the Power Reactor and Nuclear Fuel Development Corporation (PNC)) signed an agreement for cooperation in the area of LMFBRs in 1969. This "umbrella" agreement was renewed in 1979, and it calls for cooperation in all technology areas of the LMFBR and its fuel cycle. During the past 12 months three new specific agreements were executed under the aegis of the umbrella agreement. Specifically, these new agreements were for:

(1) Nuclear Fuel Criticality Data Development
(2) A Common Approach to LMFBR Safety Criteria
(3) CRBRP/MONJU Cooperation

The total number of such specific agreements we now have active with PNC is eight.

In view of the interests of the membership of the IWGFR it is perhaps worthwhile to dwell a moment on the CRBRP/MONJU agreement. This long-term agreement to cooperate on the design, construction, fabrication, and operation of the CRBRP and MONJU reactor projects was signed in September 1983. The significant U.S. experience in terms of CRBRP system and equipment design, fabrication, and testing is now available to PNC for the MONJU project. Japanese experience and activities as the MONJU project moves forward will be shared with the United States.

The agreement is mutually supportive and comprehensive. Both parties have already exchanged engineers at each other's project office to enable a more effective interchange of information. There have also been a number of specialists meetings held at which information has been reviewed on such topics as in-service inspection and sodium leak detection. These personnel assignments and specialists meetings are important elements of the exchange and are expected to continue on into the construction and operation of the MONJU reactor.

5.2 US/United Kingdom Bilateral Activities

The U.S.DOE and the United Kingdom Atomic Energy Authority (UKAEA) signed an "umbrella" agreement for cooperation in the area of LMFBRs and the associated fuel cycle in 1965. Similar to the USDOE-PNC arrangement, there have been numerous specific agreements drawn under the umbrella agreement. Over the preceding 12 months two new specific agreements were executed: one for cooperation in studies on the dissolution of fuel and one for measurement of residual fuel in LMFBR head-end wastes. This brings the number of active specific agreements to eight between the USDOE and the UKAEA.

5.3 US/CEA/DEBENE Trilateral Activities

The USDOE has signed agreements for cooperation with the French Commissariat A L'Energie Atomique (CEA) and the Federal Minister for Research and Technology of the Federal Republic of Germany (BMFT) in 1977 and 1976, respectively. The scope of each of these agreements differed somewhat from each other, however, in 1978 the USDOE, CEA, and BMFT decided to initiate tripartite implementation of these bilateral agreements, consistent with the then-recent harmonization of the German and French breeder programs. The scope of the resulting tripartite arrangement included safety, reactor core, systems and components, and fuels and materials.

6. SUMMARY

The Federal role in breeder technology was, of necessity, restructured during the past year. Program emphasis has switched from plant projects and a supporting base technology program to a supporting base technology program having a newly proposed effort to develop new concepts for industry review.

The FFTF has quickly established itself as the world's finest test bed for irradiating full-size LMFBR core components as well as providing the most accurate irradiation conditions for materials evaluation. The Breeder Technology program has been realigned to enhance interdependent relationships within the Federal Program, with industry, and with international partners.

The USDOE expects to place more emphasis on international cooperative efforts directed at breeder industrialization. Such efforts should result in economizing the total funds expended by the breeder developing nations and help assure that the breeder option is available when needed.

FFTF CUTAWAY

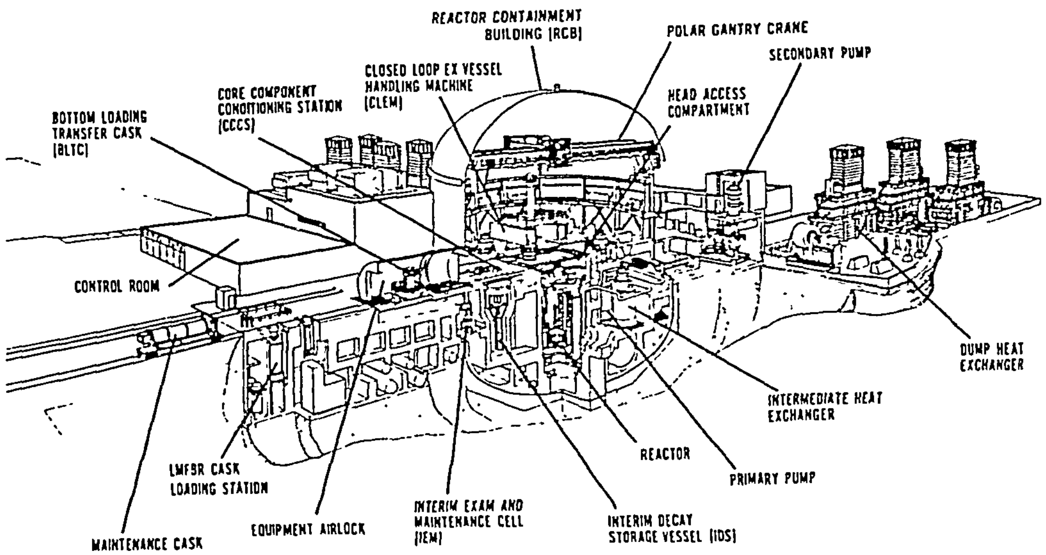

FIGURE 2.1

FFTF REACTOR CUTAWAY

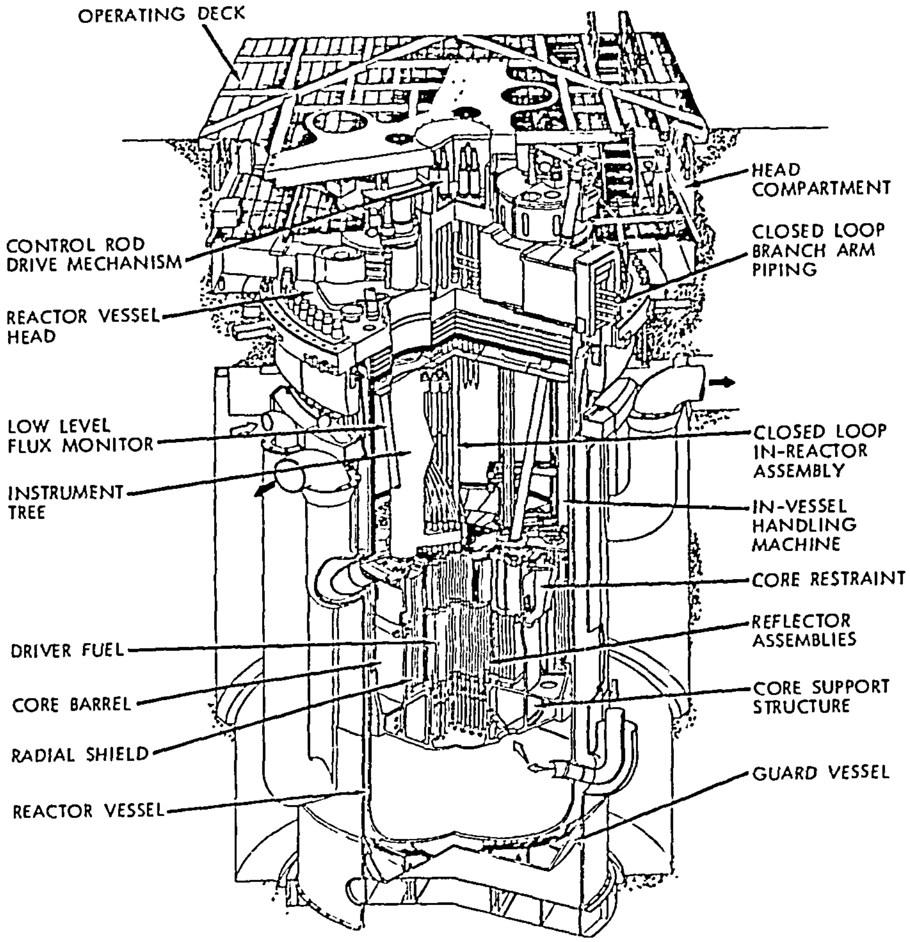

FIGURE 2.2

TABLE 2.1

FFTF TECHNICAL PARAMETERS

o THERMAL POWER		400 MW
o MAXIMUM CORE OUTLET TEMPERATURE	1100°F	593°C
o REACTOR VESSEL INLET OPERATING TEMPERATURE	680°F	360°C
o REACTOR VESSEL OUTLET OPERATING TEMPERATURE	938°F	503°C
o NOMINAL CORE ΔT	300°F	167°C
o PRIMARY SODIUM FLOW CAPABILITY	43,500 GPM	2745 ltr/sec
o PRIMARY SODIUM DYNAMIC HEAD	500 ft	152.4 m
o CORE DIAMETER	4 ft	121.92 cm
o CORE HEIGHT	3 ft	91.44 cm
o PEAK FAST FLUX	7×10^{15} n/cm^2-sec	
o BACKUP HEAT REMOVAL	NATURAL CIRCULATION	

FFTF OPERATING HISTOGRAM - CYCLES1 THRU 4

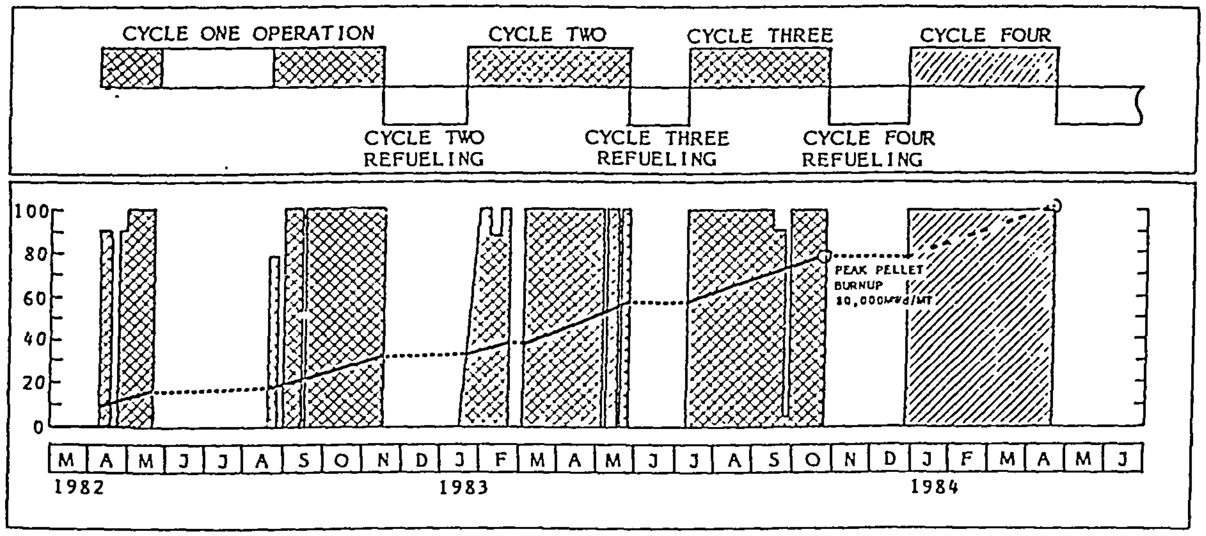

FIGURE 2.3

TABLE 2.2

FFTF OPERATIONAL PARAMETERS

	CYCLE 1	CYCLE 2	CYCLE 3	CYCLE 4
START DATE: END DATE:	APR 16, 1983 NOV 11, 1983	JAN 18, 1983 MAY 22, 1983	JUL 4, 1983 OCT 23, 1983	JAN 1, 1984
EFPD FOR CYCLE:	101.5	100.5	101.5	(112-115)+
CYCLE CAPACITY FACTOR (%):	50.2	83.1	93.5	
AVAILABILITY FACTOR (%):	53.0	90.6	99.0	
TOTAL PLANT EFPD AT END OF CYCLE:	134.3	234.8	336.3	
MAXIMUM FUEL BURNUP AT END OF CYCLE:	35	60	81	(106)+

+ NOTE: TARGET VALUES

ANNUAL OPERATIONAL PERFORMANCE

	1982*	1983
CAPACITY FACTOR (%)	40.5	56.9
AVAILABILITY FACTOR (%)	42.8	61.1

*NOTE: REPORTING BEGAN AT START OF CYCLE 1, APRIL 16, 1983

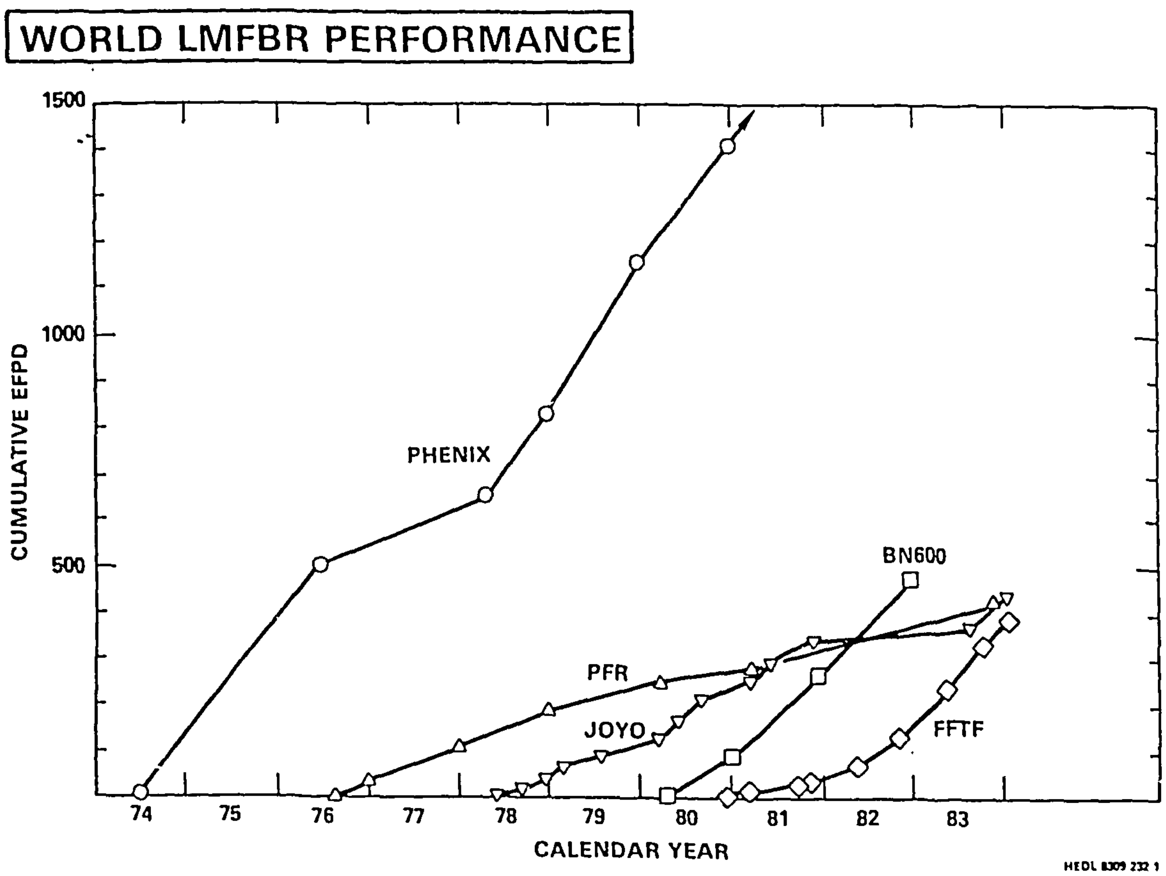

FIGURE 2.4

BURNUP ACHIEVEMENTS WITH REFERENCE FUEL

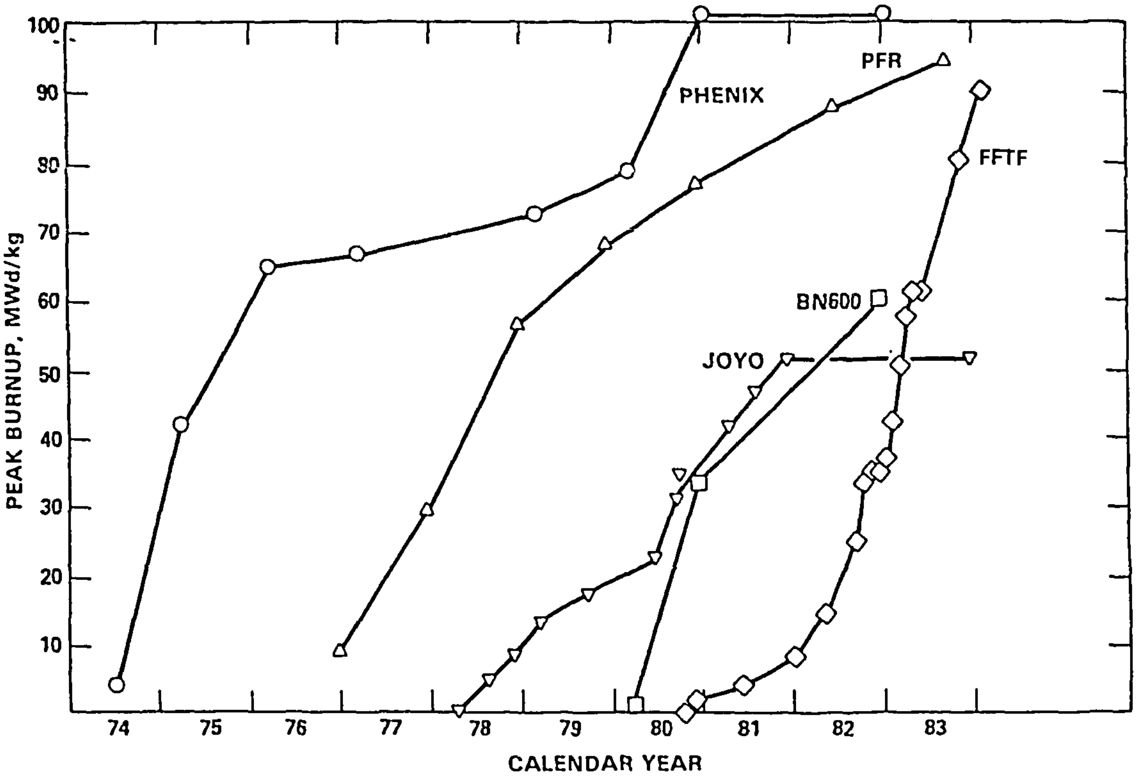

FIGURE 2.5

TABLE 3.1

FFTF CYCLE 4 EXPERIMENT LOADING

TYPE	NUMBER IN CORE	OBJECTIVE
FUEL VERIFICATION	20	ESTABLISH REFERENCE FUEL DESIGN LIFE AND INCREASE IF POSSIBLE.
FUEL DEVELOPMENT	15	EXTENDED LIFETIME WITH NONSWELLING ALLOYS AND REDUCED FABRICATION COSTS.
BLANKET DEVELOPMENT	2	BLANKET DESIGN FOR FUTURE REACTOR.
CONTROL ROD	5	INCREASED LIFETIME, VENTED PINS, LARGER DIAMETER PINS.
SAFETY TESTS	2	PROVIDE PRE-IRRADIATED PINS FOR TRANSIENT TESTING.
STRUCTURAL MATERIALS	5	LONG-TERM IRRADIATION EFFECTS ON STRUCTURAL MATERIALS. ADVANCED ALLOY DEVELOPMENT.

STRUCTURAL MATERIAL EXPERIMENT

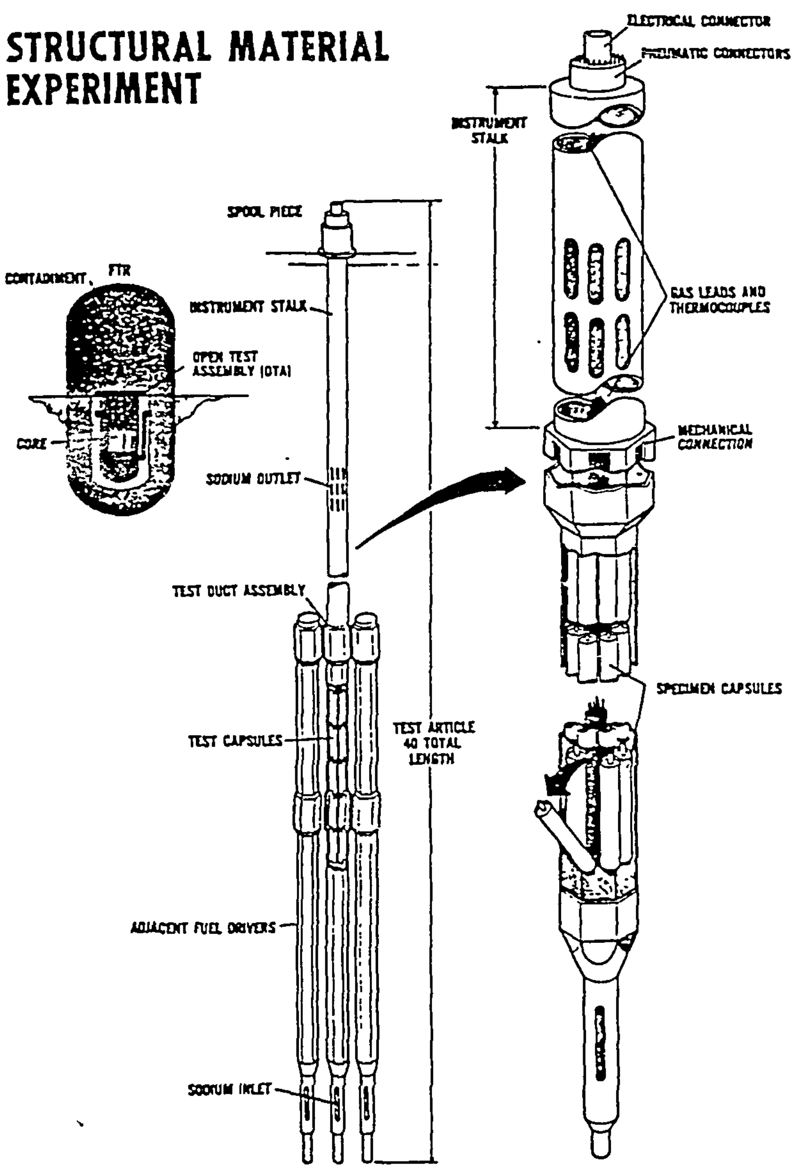

FIGURE 3.1

REVIEW OF FAST REACTOR ACTIVITIES IN INDIA (1983–84)

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1.0 General Background

The last year was very significant for Indian Nuclear Energy Programme as the first indigeneously built heavy water moderated natural uranium reactor called Madras Atomic Power Plant Unit-I was made operational and connected to the grid. The power level has been gradually increased and the reactor has been operating at a power level of 200MWe (temporarily limited by Plutonium build up during approach to equilibrium core loading). The 'plutonium peak' will be crossed shortly clearing the way for raising the reactor to the full power of 235MWe gross. The second unit of MAPP, is well advanced and barring unforeseen difficulties, is expected to become operational during this financial year. This has been a big morale booster for the programme in general and the Fast Reactor Programme in particular as plutonium produced in these reactors is expected to be the inventory for Prototype Fast Breeder Reactor. It may be recalled that in the last report to this group, a reference was made to initiation of some preliminary design studies for such a reactor.

Demand for all commercial forms of energy has continued to rise even during the last year as against decrease in the demand for electricity observed in many of the industrialised countries of the Western world. Both industrial production and Gross National Product have registered a significant growth (over five percent). Hence in spite of continued increase in the generation capacity, most of the regional grids in India had to impose restrictions on the consumption of electricity. It is also being recognised that reserves of fossil fuels which to-day appear large are really not large. Consequently, there is increasing realisation of the need to