PHENIX, PHENIX 450, SUPERPHENIX
POWER PLANTS CHARACTERISTICS

Figure 3

	PHENIX 250	PHENIX 450	SUPER PHENIX
Gross electrical rating	250	450	1.200
Thermal rating	563	1050	2.990
Core volum	1227 l	2135 l	10.000 l
Lenght assembly	4,3 m	4,3 m	5,5 m
Fuel pins per assembly	217	217	271
Pin outside diameter	6,6 mm	6,6 mm	8,65 mm
Maximum linear power	430 W/cm	430 W/cm	450 W/cm
Burn-up	50.000 MWJ/T	70.000 MWJ/T	70.000 MWJ/T
Maximum total neutron flux	$7,2.10^{15} n/cm^2s$	$7,3\ 10^{15} n/cm^2s$	$6,2\ 10^{15} n/cm^2s$
Breeding ratio	1,12	1,15	1,24
Control rods with mixed functions	6	9	21
Complementary shut down system	0	3	3
Nominal cladding temperature	650/700° C	630/700° C	620/700° C
Sodium temperature inlet / outlet core	400/560° C	390/540° C	380/530° C
Intermediate exchanger inlet / outlet secondary	350/550° C	350/530° C	330/510° C
Primary pumps	3	4	4
Intermediate exchangers	6	8	8
Secondary loops	3	4	4
Primary Na flow	2760 Kg/s	6300 Kg/s	15700 Kg/s
Secondary Na flow	2210 Kg/s	4600 Kg/s	12000 Kg/s
Steam temperature	510° C	495° C	490° C
Inlet H2O temperature	246° C	246° C	235° C
Steam pressure (bars)	168	180	184

5. Status of the USA Liquid Metal Fast Breeder Program, April 1975; by G. W. Wensch, the USA.

LIQUID METAL FAST BREEDER REACTOR PROGRAM

Introduction

This report was prepared for the Eigth Annual Meeting of the International Working Group on Fast Reactors of the International Atomic Energy Agency. It is a summary of the major projects and activities of the U.S. high priority LMFBR program and should permit the reader to obtain some insight into this large, complex, government-industrial undertaking. It is an undertaking that is gaining momentum in scope and drive as the industrial capability of the U.S. becomes more deeply involved in the program, both as potential customers and manufacturers. The human factor, too, cannot be ignored as more skilled resources have become experienced in sodium reactors technology and are contributing by helping to provide the requisite trained manpower.

As the program continues in furthering the required technology, new problems have become identified and defined and means of their resolution planned. Some of the problems as well as achievements are described in this report.

The unstable financial situation has contributed to problems in the development of the LMFBR. Cost over-runs on the FFTF and CRBR (Demonstration Plant) and in the entire program have impressed upon us the need for improved management. We are strengthening the management of the program to avoid future over-runs and delays which have plagued the program.

STATUS OF NUCLEAR POWER

As of January 1, 1975 there were 55 central station nuclear power generating units authorized to operate, although a few of the most recent additions have not yet been brought to full commercial operation. In the aggregate, these 55 nuclear units represent an installed capacity of about 36,800 megawatts electric (MWe), or almost 8% of the total installed electric capacity in the U.S.

Figure 1 shows the number and general locations of nuclear plants in operation, under construction, or under contract. There are 30 more marks on the figure than last year, representing the 30 units, totalling over 35,600 MWe in capacity, that were sold to U.S. utilities in 1974.

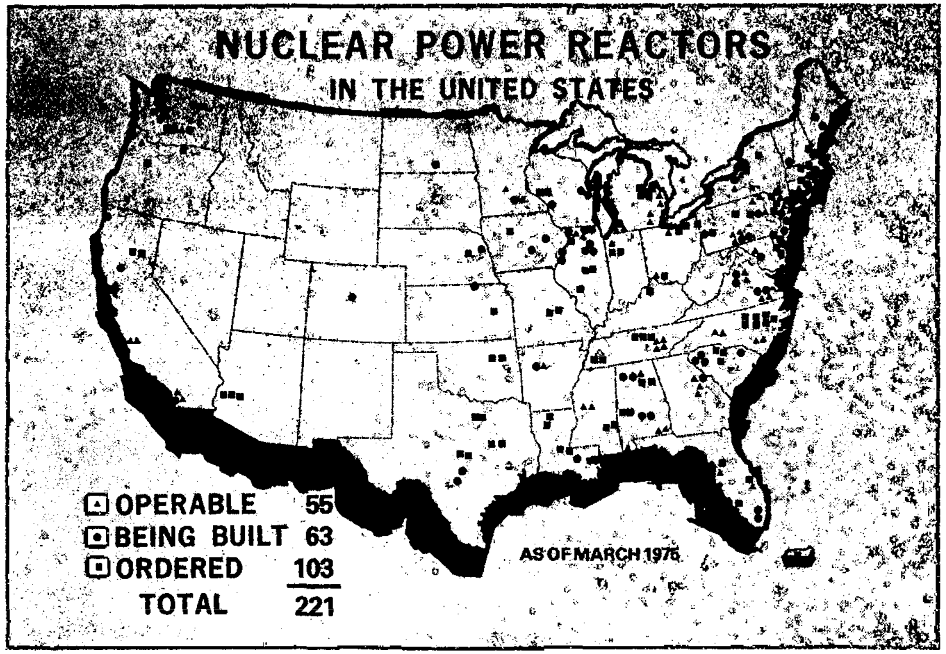

Figure 1

As of January 1, 1975 there were 221 nuclear power plant units authorized to operate, under construction or ordered in the U.S., comprising a total generating capacity of 215,780 MWe. Another 14 units, totalling about 17,000 MWe, were announced as planned by the electric utilities, but nuclear steam supply systems had not yet been ordered for these units.

During 1974 utilities also ordered fossil fueled generating plants totalling 44,400 MWe. After exceeding fossil plant orders in the preceding two years, nuclear orders dropped to 44.5% of total ordered capacity in 1974.

STUDIES AND ASSESSMENTS

Status of the Environmental Statement for the LMFBR Program

In the last year considerable effort was applied to the NEPA review for the LMFBR Program. On January 17, 1975 the Commission issued for public comment a Proposed Final Environmental Statement for the LMFBR Program (WASH 1535). It was issued in its "proposed" final form to afford the Administrator of ERDA the opportunity to review the document and receive additional public comment before concluding the NEPA review process. A chronology of the development of the Environmental Statement is shown in Figure 2.

ENVIRONMENTAL STATEMENT FOR THE LMFBR PROGRAM
CHRONOLOGY

JUNE 12, 1973	COURTS REQUIRE PREPARATION OF A PROGRAM STATEMENT
MARCH 15, 1974	DRAFT ENVIRONMENTAL STATEMENT ISSUED
APRIL 25-26, 1974	PUBLIC HEARING
AUGUST 13, 1974	PUBLIC MEETING WITH EPA
JANUARY 17, 1975	PROPOSED FINAL ENVIRONMENTAL STATEMENT ISSUED
APRIL 9, 1975	END OF COMMENT PERIOD
APRIL-MAY, 1975	POSSIBLE INFORMAL HEARING

Figure 2

The Proposed Final Statement extends the discussion of the subjects covered in the Draft Statement (issued on March 14, 1974) and considers comprehensively the numerous comments received from the public and interested organizations. The principal conclusions of the Statement are that:

(1) The LMFBR can be developed as a safe, clean, reliable and economic electric power generation system and the advantages of developing the LMFBR as an alternative energy option for the Nation's use far outweigh the attendant disadvantages.

(2) Utilization of the LMFBR would involve recognized, but solvable, environmental problems, which would differ in degree but not in kind from those of other nuclear fuel cycles:

(a) The amount of plutonium that must be processed and transported would be greater for the LMFBR industry than for the LWR industry.

(b) Plutonium is a highly toxic substance which must be carefully handled and controlled. The Statement shows that, with the use of prescribed procedures, plutonium would present little risk to the public either from normal operations or from postulated accident situations.

(c) Safeguarding of nuclear materials and facilities against theft or sabotage will become increasingly important as the industrial use of plutonium increases. A program has been instituted to strengthen and improve safeguards to meet the expanded industry activities that are projected.

(d) Management of radioactive wastes is an unavoidable consequence of the LMFBR and all other nuclear power concepts. Alternatives ranging from interim storage in retrievable storage facilities to permanent disposal in geologic formations or transmutation to less noxious forms are under study. It is reasonably certain that radioactive waste management can be adequately dealt with in the future.

(3) The LMFBR option offers a well-advanced technology which has reached the demonstration plant stage. Commercial utilization of the LMFBR would:

(a) extend the utilization of low-cost uranium resources from decades to centuries;

(b) reduce the environmental impact from waste heat discharges, from air pollution, and from mining, milling, and enrichment of uranium, and reduce occupational injuries and fatalities;

(c) provide substantial economic benefits in reductions of fuel cycle costs and in the avoidance of large capital cost investments in the mining and enrichment of uranium. These considerations in conjunction with superior fuel resource utilization would provide an essentially unlimited supply of low cost energy.

(4) The electrical energy needs of the Nation are so large and are likely to grow to such an extent, that existing methods of energy production will be insufficient to meet the requirements. Additional options will be needed if the Nation is to be assured a secure electrical energy supply.

It is worth noting that the public has been afforded multiple opportunities to be involved at all major stages of Statement preparation. For example, shortly after the U.S. Court of Appeals for the District of Columbia decided on June 12, 1973 that the AEC should prepare an environmental statement for the LMFBR Program, a notice was entered into the Federal Register soliciting suggestions from the public and other interested organizations regarding the scope and content of the Statement. Having considered such suggestions, the AEC then issued a Draft Environmental Statement in March 1974 for review and comment by Federal, state and local agencies; interested environmental, industrial and other organizations and the public. At the end of this comment period on April 25-26, 1974, the Commission held a public hearing at which time those issues involved in the LMFBR Program in general and on the draft Statement in particular were fully aired. In addition, an open meeting was held in August 1974 to discuss publically the issues which EPA raised as a consequence of its review of the Statement. Another more recent example of involving the public is the issuance of the Proposed Final Statement for public comment. It should be noted that of all the actions taken only the issuance of the Draft Statement for public comment is required under the guidelines for preparation of environmental statements as set forth by the Council on Environmental Quality.

Having made extensive use of laboratory staffs, employed consultants on several special topics, conducted an independent internal review and utilized the broad technical capability in the various ERDA Divisions, it is believed that the Statement represents a reasonable and comprehensive assessment of the cumulative environmental impact of a fully developed LMFBR industry.

LMFBR Commercialization Study

Within the past year several major reviews of the LMFBR program approach have been made. The first of these occurred last summer as part of a continuing internal assessment of the program. RRD requested and received input from the program laboratories, the reactor manufacturers, and the utility community. All of the reviewers indicated strong support for continuing the LMFBR program and stressed the urgency of reaching commercialization at an early date with a competitive, multi-vendor industry. Specific recommendations of the reviewers were that the program requires:

- an early start on the design, development and construction of a 1000-1500 MWe plant;
- a vigorous large component development (design, fabrication and verification) program;
- development of advanced fuels and improved core and structural materials;
- an early start on demonstration of a complete fuel cycle with short doubling time; and
- continuing a strong safety R & D program.

Analysis of these recommendations resulted in the conclusion that the LMFBR program was not equally balanced among the various program elements. It was concluded that the basic technology areas are being adequately covered but that not enough attention has been given to development and engineering of large sodium components. Heretofore, the program has depended on the stepwise developmental progression of fabricating these large components for the FFTF, CRBR, follow-on demonstration plants, and early commercial plants, using these plants as test beds for components such as pumps, heat exchangers, valves, and steam generators.

The program is being reoriented to focus more heavily on component development through non-nuclear testing prior to use in a reactor. This should allow the industry to provide large commercial plants with full size components sooner than previously contemplated and to do so without the necessity of a sequence of government sponsored demonstration plants.

Plans for a multi-plant demonstration have been discontinued and it is planned to proceed directly from the CRBR to a plant of commercial size. Sufficient early plant operational experience will be gained through operation of the FFTF and CRBR and from the experience gained by foreign countries in the operation of LMFBR's. Differences between the previously and currently planned LMFBR program are discussed in the LMFBR section of this document.

LMFBR Program Review Group

On October 2, 1974, the Chairman of the Atomic Energy Commission appointed a group to review the LMFBR program and the Clinch River Breeder Reactor (CRBR) project. The purpose of the review was "to reassess the need for and timing of the LMFBR in light of the latest information available and to determine if the purpose and schedule of the CRBR are compatible with that need and the state of LMFBR technology." As information for the review was being developed and during the discussions of the group, the related questions which have been raised by critics of the LMFBR program and the CRBR were also considered.

The topics addressed by the Review Group and conclusions reached under each topic follow:

Topic I - Need for the breeder program and timing in relation to uranium supply. Conclusions:

- Even if estimates of low electrical demand growth rate are realized, a significantly expanded program of uranium exploration is needed.
- If enough uranium can be found to double present resource (not reserve) estimates (at up to \$30/lb. U_3O_8), construction of converter reactors might be extended to the year 2020.
- Careful planning is needed to avoid a pinch in uranium production capability.
- There does not appear to be any breakthrough available in converter reactor technology which could ease the demand/supply situation significantly.
- Uranium prices will fluxuate with demand/supply but the overall trend is upward as higher grade ores are consumed.
- Commercial breeders should be available in the early 1990's because of a lack of assurance of adequate supplies of uranium at acceptable prices.
- If electrical demand growth rate returns to historical levels, the breeder introduction date may already be late.

Topic II - Essential elements for success and reasonable balance in the LMFBR program. Conclusions:

- There is an appropriate balance among the essential elements of the program: plant experience, component development, fuel technology, safety.
- Cooperation with industry appears good.

Topic III - Relationship between U.S. and foreign LMFBR activities.

Conclusions:

- Maximum benefit should be made of scientific and technological information from abroad including purchasing selected information such as some component technology.

Topic IV - Contribution of CRBR to commercialization goal.

Conclusions:

- The CRBR provides a logical step in the scale-up of LMFBR technology, the licensing experience necessary for early resolution of issues, and the early involvement of utilities in the program.
- The design decisions and judgments made are reasonable at this stage.
- It would be imprudent to scale up to any size significantly larger than that proposed.
- Feedback from an operating plant is needed as soon as possible, and proceeding on the current CRBR schedule is a reasonable risk.
- While the capital cost estimated for CRBR is high, factors such as scale, multiple unit production, and technology advancements should reduce costs of future plants.

Topic V - Schedule of CRBR in light of licensing process, safety issues and potential technology problems.

Conclusions:

- It is possible that not all data will be available when necessary to support the construction permit application.
- The component development and testing program involves a risk of delay.

Topic VI - Organizational relationship among the CRBR partners.

Conclusion:

- There is a potential for cost and schedular impact unless the present complex and cumbersome organizational arrangement is streamlined.

Topic VII - Reasonableness of overall CRBR cost and schedule.

Conclusion:

- Although the presently estimated cost and schedule are reasonable in light of the current state of knowledge, they could be adversely affected by delays in resolution of licensing issues, design changes due to licensing requirements, unanticipated problems in component development and the diffuse project management.

Topic VIII - Alternatives.

Conclusion:

- The current approach is a reasonable approach.

In summary the Review Group concluded that:

- LMFBR development should proceed expeditiously.
- Known economically recoverable domestic uranium reserves (approximately 700,000 tons) will be committed to converter reactors within a few years.
- The planned LMFBR program contains the essential elements for success and is balanced.
- Foreign LMFBR programs can contribute to but not subititute for the U.S. program.
- Proper balance and effective progress in the LMFBR program require the design, development, construction and operation of the CRBR at this point.
- CRBR schedule for criticality in 1982 is a reasonable balance between schedular risk and efficient use of manpower and manufacturing resources.
- The present CRBR organizational relationship is not the most efficient.
- There are no other special factors foreseen which could adversely affect CRBR cost and schedule.

Based on the conclusions listed above, the review group submitted the following recommendations noted in Figure 3.

LMFBR PROGRAM REVIEW GROUP

(ERDA-1, DECEMBER 1974)

RECOMMENDATIONS

- Proceed expeditiously to early 1990's commercialization.
- Do not relax CRBR schedule at this time.
- Undertake aggressive uranium exploration effort.
- Determine stretch capability of CRBR design.
- Streamline CRBR management organization.
- Obtain and use foreign data and experience.

FIGURE 3

RRD BUDGET

The total funding for the Fission Power Reactor Development program is $568.6 million for FY 1976. As shown in Figure 4, $411.8 million is for the Reactor Research and Development (RRD) operating budget for FY 1976. The FY 1976 budget is an increase of $58.0 million over the current FY 1975 estimate. In addition to the operating funds, $108.1 million in construction obligations and $48.7 million for capital equipment -- an increase of $19.8 million over the FY 1975 estimate -- are included.

Figure 4

FISSION POWER REACTOR DEVELOPMENT PROGRAM OPERATING COSTS BY RRD SUBPROGRAM (In Millions)

	Actual FY 1974	Estimate FY 1975	Estimate FY 1976	Estimate Transition
Liquid Metal Fast Breeder Reactor	$193.0	$250.0	$261.3	$ 71.0
Cooperative Power Reactor Demonstration	14.1	14.0	35.4	20.0
Gas Cooled Thermal Reactors	12.6	21.9	31.4	8.2
Gas Cooled Fast Breeder Reactors	1.8	4.2	6.0	1.5
Molten Salt Breeder Reactors	1.6	4.0	3.5	0.9
Reactor Safety	30.0	39.6	45.8	12.1
Supporting Activities	7.4	20.1	28.4	8.0
Total	$260.5	$353.8	$411.8	$121.7

OVERVIEW OF LMFBR PROGRAM

The basic objective of the LMFBR program is to develop a broad technological and engineering base, with extensive utility and industrial involvement, which will establish a timely capability for a competitive and commercial breeder industry. This program is based on technology developed over twenty-five years with intensive effort focused over the last nine years. The major participants in the LMFBR program are the multi-purpose laboratories -- Argonne National Laboratory (ANL), Los Alamos Scientific Laboratory (LASL), Holifield National Laboratory (HNL), the engineering laboratories -- Hanford Engineering Development Laboratory (HEDL), the Liquid Metal Engineering Center (LMEC), and the industrial organizations of Atomics International, General Electric and Westinghouse.

Some of the major accomplishments in the LMFBR program to date include:

- over ten years of successful operation of EBR-II,
- the establishment of a broad spectrum of operating support facilities especially at HEDL and LMEC,
- the development of a reliable mixed oxide fuel system,
- the establishment of the world's largest plutonium critical facility (ZPPR),
- the confirmation of the inherent safety of mixed oxide fuels through the operation of the Southwest Experimental Fast Oxide Reactor (SEFOR),
- development of sufficient LMFBR base technology to construct the highest performance test reactor in the world, the FFTF,
- the establishment of an industry/utility team to design, construct and operate the Clinch River Breeder Reactor.

LMFBR Program Cost Estimate

A number of questions have recently been raised publicly regarding the increase in the overall LMFBR program cost estimate and allegations have been made that the program has experienced unprecedented "overruns."

First, these estimates focus on a period from 1950 to the year 2020 --- 70 years. It is not often that one attempts to make an estimate over such a long period, particularly of a very complex undertaking. Nevertheless, past questions relating to "cost benefits" have led RRD to attempt such a long term estimate.

Five updates of the LMFBR overall cost projection have been published over the past five years. The original estimate (WASH-1126) was issued in April 1969, and an updated version of the estimate was published in January 1972. As part of the Environmental Statement for the U.S. Breeder Program, a revised estimate was issued with the draft statement in March 1974, and a further revised version was issued with the proposed final Environmental Statement in December 1974. The most recent estimate is in the report of the LMFBR Program Review Group (ERDA-1), published in December. This estimate, however, is merely an escalated version of the estimate appearing in the proposed final Environmental Statement, i.e., the latter displays the estimate in 1975 dollars and ERDA-1 displays the same estimate in 1976 dollars. Each year the total estimate to complete the program will be updated to reflect current budget year dollars. Figure 5 summarizes these various long range projections made since 1968. Note the differing assumptions or conditions used for each projection. Of most significance is the value of the dollar used and the period of years covered.

Figure 5 Comparisons of LMFBR Program Cost Projections (Billions of Dollars)

	WASH-1126	WASH-1184	WASH-1535 Draft	WASH-1535 Final	ERDA-1
LMFBR Base Program	2.0	2.4	4.0	5.1	5.5
Supporting Technology	1.3	1.3	2.6	3.0	3.3
Total	3.3	3.7	6.6	8.1	8.8
ASSUMPTIONS					
Year dollars used	1968	1970	1975		1976
Period covered	1970-2020	1972-2020	1975-2020		1975-2020
First Commercial Plant Operations	1984	1986	1987		1987

Escalation experienced since 1968 has had a significant impact on these projections. For example, as shown in Figure 6, a comparison of the current estimate in 1968 vs. 1976 dollars shows that $3.6 billion had to be added to the projections to account for escalation since 1968.

Figure 6 LMFBR PROGRAM COST PROJECTION DOLLAR VALUE COMPARISON (Billions of Dollars)

	1950-1969	1970-1974	1975	1976-2020	70 Year Estimate
Current Estimate ERDA-1	(Actual)	(Actual)	(Actual)	(1976$)	
(1976 dollars)	.5	1.3	.5	8.3	10.6
Current Estimate ERDA-1	(Actual)	(1968$)	(1968$)	(1968$)	
(1968 dollars)	.5	1.0	.3	5.2	7.0
				Escalation 1968 thru 1976	$ 3.6 B

Other changes between the original and current estimates representing scoping differences are shown in Figures 7 and 8.

Figure 7 LMFBR PROGRAM COST PROJECTIONS ORIGINAL VS CURRENT ESTIMATE SCOPE DIFFERENCES (Billions of 1968 Dollars)

	1950-1969	1970-1974	1975	1976-2020	70 Year Total
Current Estimate ERDA-1	.5	1.0	.3	5.2	7.0
Original Estimate WASH-1126	.5	1.2	.3	1.9	3.9
					$ 3.1 B

Figure 8 LMFBR PROGRAM DIFFERENCES ORIGINAL VS. CURRENT LONG RANGE ESTIMATE (IN BILLIONS OF DOLLARS)

Original Estimate (WASH-1126)	3.4
Current Estimate (ERDA-1) - Less Original Estimate	3.1
Fast Flux Test Facility	.6
Clinch River Breeder Reactor	.6
Advance Fuel and Reprocessing	.4
Large Component Development	1.2
Safety	.1
Equipment and Misc. Capital Projects	.2
Escalation (1968 to 1976)	3.6
Costs Thru 1969	.5
TOTAL Current Overall Estimate (1948 thru 2020)	10.6

Cost increases in the FFTF program are due to underestimating the complexity of the project which has experienced a four to five year slippage from the original schedule. This facility, when completed, will be the highest performance test reactor in the world, and it is necessary to assure that LMFBR's built in the future will have an optimum breeding capability.

Similar to the FFTF, the complexity of the first demonstration plant, Clinch River Breeder Reactor, was underestimated. The estimate has gone from $700 million to over $1.7 billion which includes a significant amount of escalation and contingency. Without escalation and in terms of 1968 dollars, government support must be increased to over $600 million . This demonstration plant is an essential step toward the commercialization of the breeder in this country. Details of the CRBR cost estimate are contained later in this document.

Many of the difficulties encountered in the FFTF and CRBR are due to a lack of sufficient large sodium component engineering technology. Hence, it has been necessary to significantly strengthen the overall LMFBR program in this area thus requiring a much expanded research and development effort as well as additional facilities for testing large commercial size components.

The majority of the increase noted under the fuel category is related to the need to fully develop the fuel refabrication and reprocessing capability in this country. The original plan allowed industry to accomplish this task. Recent setbacks in this technology area have caused these plans to be readjusted. Other increases, particularly in the advanced fuel area, are essential to meeting the breeding performance of this system.

Since the original plan, the need for additional safety technology has been identified, and plans have been adjusted to include the construction and operation of a large safety test facility which can be used in support of a large commercial breeder which will be built in large numbers beginning in the mid-1990's.

Experience has shown that there is an approximate linear relationship between the base R&D program and the need for capital equipment and small capital projects to support the base program. In view of the increased costs shown above, the estimate for this category has been increased as well.

The FY 1976 budget R & D request for FFTF of $50.0 million is a $14.6 million decrease over that for FY 1975. The total estimated cost of this project is $530 million, including $110 million for expense funded equipment.

Total operating costs decrease as the design engineering nears completion, expense funded equipment is delivered, and development and procurement of prototype equipment is completed. The increase shown under operation is associated with required system and plant component tests, operator training, and preparation of detailed operating and acceptance test procedures.

The fundamental purpose of the FFTF project is to provide a reactor complex specifically designed for testing fuels and materials in a fast flux environment, prototypic of the commercial fast breeder reactor plants. When completed, FFTF will enable the fast flux testing needs of the LMFBR program to be met and will be available as a fast flux testing facility for other ERDA programs. Principal characteristics of FFTF are shown in Figure 9.

Figure 9

FFTF DESIGN AND OPERATING CHARACTERISTICS

ITEM	RATED CONDITION
Reactor Power	400MWT
Coolant Outlet Temp.	1050°F
Coolant Inlet Temp.	792°F
Fuel Assembly Ave. Outlet Temp.	1100°F
Total Coolant Flow	42,730 GPM
Primary Heat Transport Loops	3
Heat Rejection	Air
Plant Design Life	20 Years
Core	
— Closed Loops	6 at 4.2 MW Each
— Open Test Positions — Instrumented	8
— Fuel Assembly Length	120 Inches (Fuel 36 in.)
— Fuel Pin Length	94 Inches
— Fuel Composition	25 WT % PUO_2 in UO_2
— Fuel Target Burnup	4500 MWD/MT
— Peak Flux	0.7-1 x 10^6 NV

Status

Through the end of calendar year 1974, overall engineering was 90% complete and contracts for all major plant components were let with 42% delivery already achieved. These deliveries were highlighted by delivery of the 200 ton capacity polar gantry crane, the Dump heat exchanger components, the Auxiliary system tanks, and the arrival at the site of items such as pipe spools, hangers, and valves in sufficient quantities to allow start of piping installation. The equipment delivery will continue to accelerate throughout CY 1975.

Construction was 36% complete through December with essentially all concrete pours and building superstructure erection completed. The installation of the Reactor Guard Vessel, the Main Support Structure, and the Reactor Vessel marked the achievement of major milestones in the FFTF Project. The polar crane support structure within the containment building, was erected and the large 200 ton capacity polar crane was set on its structure during January. Significant progress in the reactor heat transport system was achieved with the installation of some components, the start of large sodium pipe installation, and the erection of dump heat exchanger structures. Miscellaneous piping systems installation was started throughout the plant. Electrical cable tray installation outside of the containment building is 37% completed. Power cable was pulled and connected to the main plant switchgear thereby providing useable power to the plant during January 1975.
Continuing efforts in FY 1975 will include the installation and acceptance testing of the FFTF equipment leading to start of sodium fill procedures. After numerous meetings with ACRS and NRC, the Final Safety Analysis Report is well along in preparation and should be submitted to NRC early in FY 1976.

Procurement of FFTF mixed oxide fuel under contracts administered by HEDL with Kerr-McGee Corporation and NUMEC proceeded during the year. Of the approximately 18,000 fuel pins to be supplied by each vendor, over 12,000 and 11,000 have been delivered by Kerr-McGee and NUMEC respectively. It is expected that deliveries from both vendors will be complete around the end of the fiscal year.

Cost and Schedule

A change is not being proposed in the official ERDA estimate of FFTF project cost -- $530.0 million, and scheduled completion date -- November 1977, at this time. However, the project is experiencing substantial inflationary growth in costs of material and labor, in addition to adverse market conditions in availability of materials. Area wide labor disputes over contract settlements have directly impacted the project schedule. On the basis of these current trends, the project is forecasting a project cost of $622 million, compared to $530 million and a schedule completion date of August 1978 instead of November 1977. It should be emphasized that this is a forecast based on present visibility on estimates of costs, escalation and contingency.

The $92 million increase which is being forecasted includes $78 million of cost growth already experienced or allocated. Of the $78 million growth, $12 million is attributable to design evaluation since 1973, $24 million is due to low estimating caused by the first-of-a-kind nature of certain aspects of the project, and $42 million was caused by escalation and unusual market conditions. As an example of the escalation experienced, labor negotiations in 1974 have resulted in settlements ranging from 38 to 48% hourly wage rate increases for essential crafts over the next two years. Comparable increases are anticipated on contracts to be negotiated in the coming year. This is substantially higher than the 5.5% per year forecast in 1973. It should be noted that the forecast includes $88 million of escalation and contingency for presently unidentified growth.

Major attention by all FFTF contractors continues to be focused on ways to recover the forecasted cost growth and schedule slippages. For example, an intensive critical path analysis is being performed to identify and allow massive expediting of components that have a time-forcing effect on the end date. Similarly, where the schedule is purely construction-restrained, the project is examining, on a cell-by-cell basis, the ways to reduce interferences and increase productivity for bulk installation. Improved management systems are providing management with the visibility requisite to managing those areas that are controllable to avoid further increases and offset increases due to market conditions and inflationary trends. A formal cost reduction-cost avoidance program has been initiated. Change Control Boards have been established both in the contractor organizations and RRD. These boards, staffed with senior management personnel, are intended to control the Project contingency and minimize controllable cost increases.

CLINCH RIVER BREEDER REACTOR

The budget request for the CRBR in FY 1976 includes $49.6 million of R & D support from our base program and $35.4 million of direct assistance funds under the Cooperative Power Reactor Demonstration program for a total request of $85 million.

The CRBR is a principal step in the LMFBR program that assumes added significance in light of the decision to drop plans for added demonstration plants prior to construction of a full-size commercial plant. Figure 10 compares significant features of FFTF, CRBR, and a typical commercial or near-commercial LMFBR.

The principal objectives of CRBR are:

1. to demonstrate safe, clean and reliable operation with high availability in a utility environment,
2. to focus the development of systems and components, and
3. to develop industrial and utility capabilities to design, construct operate and maintain an LMFBR, and
4. to demonstrate the commercial licensability of LMFBR's.

The development to maturity of a reactor system requires two or more decades of persistent effort. Even the LWR system, despite the substantial commitment of money and manpower by the AEC and industry has not yet fully matured. Major problem areas still confront the industry in several areas: safety, quality assurance and standards, fuel cycle, shortages of trained manpower, and reliability and maintainability of plants already built.

The design effort necessary to permit procurement of a significant portion of CRBR major long lead hardware is scheduled for completion in FY 1975 and 1976. This design effort and equipment procurement, plus the planned commencement of the construction phase during 1976 will result in a substantial increase in expenditure rate over previous years as project momentum increases. The ordering of critical material for long-lead components has been accomplished and delivery of these materials is expected to be consistent with project need dates.

During the past year a thorough design review was completed and a firm design base was established. A major reestimate of cost and schedule also was completed. The list below summarizes significant overall and technical accomplishments during 1974:

COMPARISON OF DESIGN PARAMETERS

Design Parameter	FFTF	CRBR	Commercial and Commercial Prototype
Overall Plant			
Thermal Power, MWt	400	975	3,800
Net Electric Power, MWe	NA	350	1,500
Net Plant Heat Rate, Btu/kwhr	NA	9,507	8,650
Number of Primary Loops	3	3	3
Containment Diameter	135	186	168
Reactor			
Fuel Material	Oxide	Oxide	Oxide
Cladding Material	SS 316	SS 316	SS 316
Fuel Rod Diameter, in.	.23	.23	.27
Number Fuel Rods	16,492	42,966	86,178
Core Height/Diameter, Ft.	3.0/4.0	3.0/6.2	4.0/10.2
Peak Fuel Burnup, MWD/T	80,000	150,000	150,000
Breeding Ratio	NA	1.2	1.25
Doubling Time, yrs.	NA	23	12/15
Vessel Diameter/length, ft.	20.7/43.8	20.7/53.8	23.5/59.5
Primary Heat Transport System			
Reactor Outlet Temperature, ^{o}F	1,050	995	1,000
System Flow Rate, Total 10^6 lb/hr.	18.3	41.5	136.8
Pump Flow Rate at Pump Temperature, gpm	14,500	33,700	122,400
Intermediate Heat Transport System			
Hot Leg Temperature, ^{o}F	950	936	935
Cold Leg Temperature, ^{o}F	600	651	650
Pump Flow Rate at Pump Temperature	14,500	29,500	101,100
Steam Generation/Turbine System			
Turbine Cycle	NA	Straight Expansion	Steam Reheat
Superheater Outlet Temperature, ^{o}F	NA	905	905
Superheater Outlet Pressure, psi	NA	1,525	2,520
Steam Flow Rate, Total, 10^6 lb/hr	NA	3.34	12.6

Figure 10

CRBR Major Accomplishments - 1974

A. Overall

1. Reference design, cost estimate and schedule established.
2. Integrated cost-schedule control system developed.
3. Specific scopes of responsibility defined among contractors.
4. Management procedures and requirements prepared.
5. Project quality assurance programs established and submitted for NRC review.

B. Technical

1. Majority of NSSS system designs approved - including all major systems.
2. All building general arrangement drawings completed.
3. Project Environmental Report submitted to NRC and requests for additional information are being satisfied.
4. PSAR under preparation, with submission planned for Spring 1975.
5. Component concepts selected and designs initiated for the IHX, steam generator, reactor vessel and closure head, large sodium valves, dreactor internals, reactor refueling equipment and radioactive equipment handling machines.
6. Plant control and protective system designs, along with major instrumentation system designs established.
7. Instrumentation, reactor thermal-hydraulics, safety and steam generator development programs well underway.
8. Site geology surveys completed.

CRBR Cost Estimate

A revised cost estimate has been prepared for the CRBR Project. This new cost estimate is based on careful evaluation of the reference design and schedule and utilizes detailed estimates of the reactor manufacturers and the architect-engineer. The estimate totals $1,736 million divided as follows: $1,202 million for the plant, $434 million for development, and $100 million for five years of operation. This is shown in detail in Figure 11. A large amount of engineering effort has gone into the preparation of this cost estimate and the design upon which the estimate is based is mature for this stage of the project. Extensive reviews were conducted by ERDA and PMC and by two separate independent review groups. The conclusion of those reviews is that the cost estimate appears reasonable.

There have been several factors which account for the financial increase, with escalation being the most obvious. In addition, the 1972 estimate was based on conceptual design ideas as opposed to the firm reference design upon which the revised estimate is based.

Further, there also have been changes that have improved plant availability and maintainability from the utility point of view. Additional safety systems, unique to the CRBRP, have resulted in additional cost. These include diverse shutdown systems, parallel designs associated with ex-vessel post-accident heat removal and other fallback designs. All were added after the original estimate was developed. The need for additional R & D to be applied directly to the project also increased significantly.

The contingency funding increased from the application of standard contingency factors to a larger sum of money as well as reevaluation by RRD that the increased contingency was appropriate at the present stage of design.

Items affecting the cost estimate are shown in Figure 12. This cost estimate includes a number of important assumptions. Probably the most important is the placement of orders for major components, that are near the critical path of the project schedule, by mid FY 1975. The schedule also assumes standard licensing approval times are achieved. It has also been assumed that there will be no major changes in the safety approach, that the research and development efforts will continue to be successful and construction craft and materials will be available. The scheduled criticality date has been changed from 1980 to 1982.

Long-Lead Procurements

There are numerous materials and components of the CRBR which have procurement lead times of one year or more. Purchase orders for some of these items have been placed or are very near being placed.

In the case of long-lead time materials, over $7 million has been obligated for the purchase of materials. This includes shell plate, tubesheets, and forgings for the reactor vessel, IHX, steam generator and lower core support. It is expected that the purchase orders for a significant fraction of the long-lead time materials will be placed this Spring and that the delivery of the material will be consistent with the expected need date.

For long-lead time components, some of the planned purchase order placement dates have slipped. In most of the cases where the dates have slipped, there is still sufficient slack time in the schedule to accommodate the current expected purchase order placement date. In the case of the reactor vessel and turbine generator purchase order placements, however, it is beginning to impact the criticality date. In particular, the reactor vessel purchase order placement is on the critical path. ERDA is experiencing difficulties in negotiating with the vendor who cannot accommodate the fabrication schedule without affecting reactor vessel production for light water reactors. ERDA is continuing to negotiate with them and at the same time has identified an alternate vendor. It is expected that a purchase order will be placed in a few weeks. *Prepared place identical FFTF*

The turbine generator purchase order placement is also being delayed due to vendor negotiation problems and would be a critical path item if order placement is not effected by May 1975. It is expected that a purchase for the turbine generator will be placed by the end of March.

Figure 11 CRBRP PROJECT COST ESTIMATE* (Millions of dollars)

	1972	1974
PLANT INVESTMENT		
Equipment & Construction	240	$ 506
Engineering	38	110
Contingency	36	186
Escalation	94	324
Plant Cost	408	1126
Fuel Fabrication (Initial Core)	22	37
Contingency	0	5
Escalation	7	24
Fuel-Special Nuclear Material	10	10
Total Plant Investment	447	1202
DEVELOPMENT COST		
Development, Systems Engineering Prototypes and Testing	100	272
Contingency	20	29
PMC Staff and Insurance	30	27
Escalation	45	106
Total Development	195	434
OPERATING COST (5 YEARS)		
PMC Staff and Insurance	37	10
Operating & Maintenance	15	49
Fuel Fabrication (Reload Core)	23	39
Contingency (Fuel)	-	5
Revenue	(31)	(47)
Escalation	13	44
Total Operating Cost	57	100
TOTAL PROJECT COST	$ 699	$1736

*1972 Estimate in 1972 Dollars; 1974 Estimate in 1974 Dollars

Figure 12 Items Affecting CRBR Estimate Since 1972

Total Project Cost Estimate in 1972 (Unescalated) (Including $56M in contingency)		$ 540M
Factors Affecting the Estimate Since 1972 (Including Estimated Impact)		
. Improved Plant Availability and Added Safety Provisions	$ 85M	
. Revised Requirements, Codes, and Standards	$135M	
. Impact of Marketplace	$ 35M	
. Additional AEC Technology Efforts	$ 75M	
. Scope, Schedule	$ 50M	
. Additional Contingency	$173M	
Total Impact		$ 553M
Total Escalation (Including 1972-1974)		
. Escalation from 1972-1974 on the Factors Affecting the Estimate (Excluding Additional Contingency)	$145M	
. Escalation from 1974-1987 (1979-1982)	$498M	
Total Escalation		$ 643M
Revised Total Project Cost		$1736M

Summary	1972	1974
Project Cost	484	1013
Contingency	56	225
Escalation	159	498
Total	699	1736

SUPPORT FACILITIES

The FY 1976 request is tabulated in Figure 13 and totals $50.8 million, an increase of $7.8 million over FY 1975. This category includes the operational support required for key LMFBR facilities: Experimental Breeder Reactor II (EBR-II), Hot Fuel Examination Facility (HFEF), Zero Power Reactors (ZPRs), the Liquid Metal Engineering Center (LMEC), and the Hanford Test Facilities and provides conceptual design support for new facilities. LMFBR support facilities are built and operated to support the development of fuels, materials, and physics and to proof-test major reactor and plant hardware such as refueling machines, pumps, valves, piping, steam generators, heat exchangers, and instrumentation.

LMFBR SUPPORT FACILITIES OPERATING COSTS (In Millions)

	Actual FY 1974	Estimate FY 1975	Estimate FY 1976
Experimental Breeder Reactor II	$ 9.8	$13.7	$16.0
Hot Fuel Examination Facility	3.3	4.0	4.9
Zero Power Reactors	2.8	2.4	2.8
Liquid Metal Engineering Center	13.1	17.8	20.0
Hanford Test Facilities	3.9	4.3	6.0
Other Test Facility Support	-	0.8	1.1
Total	$32.9	$43.0	$50.8

Figure 13

Experimental Breeder Reactor II (EBR-II)

The EBR-II emphasis continues to be placed on irradiation testing and examination of breeder fuels and materials.

During the past year, EBR-II achieved a plant capacity factor of 58.7%. The following are other EBR-II accomplishments over the past year:

1. Initiated longer reactor runs; i.e. increased from 1550 to 2700 megawatt-days.
2. Initial delivery from Atomics International of 150 preproduction, commercial-vendor, EBR-II driver fuel elements was made in November 1974.
3. Installed the third instrumented test position.
5. Installed 48 new or reconstituted experimental subassemblies.
6. Completed two training classes for FFTF operators.
7. Completed engineering, procurement, and fabrication for sodium leak detectors for the steam generator.
8. Completed fabrication, assembly, and installation of XX07, an instrumented subassembly for characterizing the reactor environment.

Hot Fuel Examination Facility (HFEF)

The HFEF comprises a complex of two major hot cell (shielded-remote handling) installations: HFEF-North and HFEF-South located at the Idaho National Engineering Laboratory (INEL) adjacent to the Experimental Breeder Reactor No. 2 (EBR-II). The HFEF complex plays a vital role in the development of LMFBR fuels. The EBR-II Driver Fuel, as well as Irradiation Program Experiments, require the remotely controlled equipment at HFEF to obtain precise data of fuel rod diameter, length, bow and twist. Radiography and metallography are also performed. Many of the remote operations must be accomplished in a controlled inert atmosphere to preserve the latent data. HFEF also provides similar support for experiments conducted in Transient Reactor Test Facility (TREAT) as well as for new programs planned for the Engineering Test Reactor (ETR).

Accomplishments during 1974 included:

1. Receipt and dismantling of 38 EBR-II experimental subassemblies.
2. Receipt and dismantling of 12 EBR-II driver subassemblies for surveillance or other post-irradiation examination.
3. Reconstitution and shipment of 25 experimental irradiation subassemblies to EBR-II following completion of interim examination.
4. Examined nondestructively 4812 fuel elements.
5. Dismantled the 1000th irradiated EBR-II subassembly using the veritical assemblier/dismantler.

All of the above activities contribute data on fuel element swelling, maximum capabilities, and mechanisms of cladding breach that are vital to the development of LMFBR fuels. The photograph on the following page shows EBR-II, HFEF, and ZPPR which is discussed next.

Zero Power Reactors

This includes the operation of the Zero Power Plutonium Reactor (ZPPR) facility at Argonne-West and ZPR-6 and ZPR-9 at Argonne-East.

The Zero Power Reactor Program includes the operation of two related facilities at Argonne East and West, containing a total of three split table critical assembly machines. These facilities are designed to accommodate the study and simulation of the neutronic characteristics of a great variety of proposed reactors. Both general studies, appropriate to development and validation of nuclear design approaches, and design confirmation studies can be done.

The Zero Power Plutonium Reactor Facility (ZPPR) at Argonne-West is being equipped to accommodate commercial plant sized core and blanket assemblies. ZPPR is now providing neutronic data related to typical CRBR sized breeder reactor cores. Operations were completed on schedule to conclude CRBR-Assembly 4 critical experiments characterizing effects of plutonium buildup and CRBR blanket (fertile material) performance.

The Zero Power Reactor facilities (ZPR-6 and ZPR-9) at Argonne-East are somewhat more limited in size, but they have equipment for more specialized measurements. ZPR-9 has been used for the past four years for neutronic confirmation studies related to the type of problems encountered in FFTF core design. ZPR-9 operations were completed on schedule to conclude the FFTF Critical Experiments Program in this facility.

Liquid Metal Engineering Center (LMEC)

The LMEC is of fundamental importance in developing sound foundation of component technology and thorough testing of components up on which the LMFBR program is structured. As discussed earlier, the need to strengthen the program of component development and testing is recognized. LMEC supports the LMFBR program by providing testing of sodium plant components including steam generators, pumps, valves, instrumentation, and heat exchangers.

The principal test facilities available, under construction, or planned are shown in Figure 14.

Figure 14

LMEC FACILITIES

Status as of February 1975

Facility	Status
Sodium Components Test Installation (SCTI)	Under Modification
Sodium Pump Test Facility (SPTF)	Operational in FY 1975
Small Components Test Loop (SCTL)	Operational
Component Handling & Cleaning Facility (CHCF)	-Handling Operational, -Cleaning Operational in FY 1975
Large Leak Test Rig (LLTR)	Operational in FY 1975 or early FY 1976
Thermal Transient Test Facility (TTF)	Design and Procurement Underway
SCTI Expansion	Under Design
Plant Component Test Facility (PCTF)	Conceptual Design

Construction of SCTL and modifications to SCTI for the FFTF Dump Heat-exchanger were completed this year. Also the success of an alcohol cleaning process with complex sodium wetted components was demonstrated through the cleaning of the Atomics International (AI) Modular Steam Generator following test in SCTI. The AI steam generator design is being used in the CRBR.

Currently underway is the conceptual design effort and development of a cost estimate for the Plant Component Test Facility. This effort will be expanded in order to be properly prepared to submit a line item request in FY 1977. In addition, testing of the FFTF sodium pump in SPTF is expected to begin this summer.

Hanford Test Facilities

The principal LMFBR Test Facilities at HEDL are located in 9 major buildings and encompass approximately 30 significant test systems and laboratories which are being operated, modified, and expanded to provide the testing needed for developing and verifying the quality reactor components required for safe and reliable reactor plant operation and for examining irradiated fuels and materials.

The majority of these facilities are being actively used around the clock to provide engineering and operational data for the high priority LMFBR projects.

Key test facilities at HEDL are listed in Figure 15.

Figure 15 HANFORD ENGINEERING DEVELOPMENT LABORATORY

TEST FACILITIES

- HYDRAULIC CORE MOCKUP
- HEAT TRANSFER LOOP
- SOURCE TERM CONTROL LOOP
- HIGH TEMPERATURE SODIUM FACILITY
- FUEL ELEMENT FABRICATION DEMONSTRATION FACILITY
- SPECIAL ENVIRONMENT RADIOMETALLURGY FACILITY
- COMPOSITE REACTOR COMPONENTS TEST ACTIVITY
- CORE MECHANICAL MOCKUP
- PROTOTYPE APPLICATIONS LOOP
- LMFBR HOT CELL TRAINING FACILITY
- SMALL COMPONENTS EVALUATION LOOP
- ALKALI METAL CLEANING FACILITY
- LARGE SODIUM FIRE FACILITY
- TRANSIENT TEST LOOP
- SODIUM REMOVAL DEVELOPMENT APPARATUS
- INTEGRAL REACTOR FLOW MODEL

The High Temperature Sodium Facility (HTSF), which is this country's only facility for testing large LMFBR reactor components at prototypic sodium temperatures (up to 1100°F), was made operational at HEDL this year. HTSF contains the Composite Reactor Components Test Activity (CRCTA), for testing FFTF reactor components in a prototypic sodium thermal environment; and the Core Mechanical Mockup (CMM), for testing FFTF reactor components in a temperature and humidity controlled environment.

The FFTF reactor Instrument Tree was tested in the CRCTA at sodium temperatures up to 1100°F and the FFTF in Vessel Fuel Handling Machine was tested in the CMM. Other large sodium reactor components which will be tested in CRCTA include the Closed Loop Exvessel Machine (CLEM) and the core restraint mechanism. Such prototypic testing of large reactor components will reduce the probability of problems being encountered in these components after they are installed in the reactor system. This facility could also be used for testing CRBR reactor components. Other test facility activities during 1974 included the design, construction and operation of a sodium loop for testing small valves (up to 4") at prototypic temperatures (up to 1200°F) and transient conditions. The photographs on the following pages show some of these components in, or awaiting, test as well as the Hanford Test Facilities.

ENGINEERING AND TECHNOLOGY

As shown in Figure 16 the budget request for engineering and technology is $110.9 million in FY 1976, an increase of $10.7 million over FY 1975. This includes $56.1 million for research into the basic technology areas of physics, fuels, materials, fuel recycle, and chemistry and $54.8 million for engineering development of components and systems for LMFBR plants. This program provides the necessary data for a strong technology base which is the backbone of the LMFBR program.

Physics

The design of a reactor is based on predictions of various reactor physics parameters such as critical size, detailed power distributions, control rod worths, breeding ratio, neutron flux distributions, temperature, power, void coefficients, and dynamic neutronic characteristics. These parameters affect design considerations such as fuel enrichment, size and number of fuel pins, cladding thickness, number and dimensions of control rods, shielding design, and instrumentation and control requirements. The basic objective of the physics program is to improve the accuracy of reactor neutronic analyses so that reactor designs can be optimized for performance and economics.

Figure 16

LMFBR ENGINEERING AND TECHNOLOGY OPERATING COSTS (In Millions)

	Actual FY 1974	Estimate FY 1975	Estimate FY 1976
Technology			
Physics	$ 9.5	$ 9.4	$ 9.5
Fuels	16.3	20.0	21.8
Materials	10.9	14.1	13.9
Fuel Recycle	2.8	4.7	7.7
Chemistry	5.5	3.4	3.2
Subtotal-Technology	45.0	51.6	56.1
Engineering			
System Development	9.3	11.2	20.2
Component Development	44.9	37.4	34.6
Subtotal-Engineering	54.2	48.6	54.8
Total	$99.2	$100.2	$110.9

The following are major accomplishments in the Physics program during the past year:

1. Completed Fast Test Reactor (FTR) Engineering Mockup Critical programs to confirm FTR design and the performance when fueled with plutonium produced in light water reactors.
2. Completed Phase I planning and initiated ZPPR-CRBR engineering mockup critical studies to confirm safety related parameters such as sodium void reactivity and Doppler coefficients as well as fuel worths.
3. Completed general planning of experiments to support Gas-Cooled Fast Reactor concept. Experiments include critical mass, spectra, reaction rate distributions, streaming effects and steam entry effects.
4. Completed experiments at Tower Shield Facility (TSF) at Holifield National Laboratory (HNL) to determine the effects of stored fuel on ex-vessel subcriticality monitoring.

Fuels

This program focuses on developing fuel, cladding and duct materials and reactor control elements through fundamental research, developing analytical models to provide a predictive capability, and verifying results through in-pile testing. Continued emphasis is placed on developing fuel capable of sustaining operation to target burnups of at least 100,000 megawatt days per ton (MWD/T) average and 150,000 MWD/T peak and on developing a qualified industry to manufacture LMFBR fuel and related components.

The fuel development program which encompasses a total of 1800 mixed oxide fuel-pin tests in EBR-II has demonstrated that LMFBR mixed uranium-plutonium oxide fuel pins can be run to peak burnup levels greater than 150,000 MWD/MT, the target burnup for commercial plants. Approximately 111 prototypic fuel pins have been irradiated to at least 110,000 MWD/MT burnup before two failures occurred. However these two failures were not fuel pin associated but were due to a non-prototypical test assembly condition in EBR-II. An additional 264 prototypic fuel pins have attained burnups in excess of the FFTF average burnup of 45,000 MWD/MT without failure, for a success rate of 100%.

Major accomplishments during the past year include:

1. Implementation of a coordinated national program to study fuel-fission product-clad chemical interaction. Goals include characterizing observations, determining the controlling mechanisms, and investigating methods to alleviate or stop the interaction.

2. Completion of a major fraction of the inital transient overpower test series to investigate the margin that exists between design base transients and clad failure. Test results indicate that a significant margin exists.

3. Successful completion of the proof testing phase of the Mark II-C loop for TREAT reactor multi-pin testing of overpower and under-cooling transients in flowing sodium. The TREAT testing phase can now proceed.

4. Irradiation of approximately 1,400 unencapsulated mixed oxide fuel pins to various burnup levels in EBR-II. One pin has attained a burnup level in excess of 200 percent of the peak burnup level expected in FFTF. Thirty-eight pins have achieved burnup levels between 150 and 180 percent that of the FFTF peak burnup while 206 pins attained burnups between 100 and 150 percent of the FFTF peak burnup.

   A peak burnup in excess of 100,000 MWD/MT was achieved in EBR-II irradiation of grid type mixed oxide fuel assemblies. This exceeds the maximum burnup expected for FFTF. These irradiations are continuing to higher burnups to determine the maximum capabilities of this fuel, to study fuel pin-grid support system interaction and to study mechanisms leading to clad breach.

   Two EBR-II high temperature oxide fuel pin tests have successfully achieved 50,000 MWD/T exposure at rated FFTF core condition (800°F inlet sodium and 1325°F peak clad temperature). This increases the confidence that fuel pins of this type will perform as expected in FFTF. A third high temperature test has been loaded into EBR-II.

5. The run-to-failure program to establish mode of clad breach and probability of end-of-life clad breach as a function of reactor operating burnup limit is showing the mode of failure to be benign. Clad breach occurs predominately as hairline cracks or very small pin holes with attendant fission gas release and without solid fission product release. The reference fuel pin design should attain the FFTF reactor design lifetime of 80,000 MWD/MT burnup with a very low probability of clad breach of any of the fuel pins in FFTF at initial core, 600°F inlet sodium, operating conditions.

6. Insertion in EBR-II of a test assembly to study the effect of pin bundle porosity on fretting and wear of the fuel pins. These tests are required to investigate these mechanisms that can contribute to premature breach of the cladding. This test has achieved a burnup of 10,000 MWd/T to date.

7. Completion of GETR irradiations of fuel pins fabricated by vendors qualified to supply FFTF mixed oxide fuel. Post irradiation examinations completed on 2 pins irradiated to 12,000 MWD/T indicate no difference in lifetime or in thermal performance between the NUMEC fuel and the HEDL fuel.

8. The HEDL P-15 test containing FFTF vendor fuel is under irradiation in EBR-II, as part of the vendor fuel overcheck program, to obtain additional data on the resistance of this type of fuel to low temperature densification. This test is undergoing its first interim examination.

9. Results of void swelling measurements of several lots of cold worked type 316 stainless steel to a fast neutron fluence of 8 to 10 x 10^{22} n/cm^2 indicate that swelling is less than had been predicted and that FFTF operational goals will not be compromised by void swelling. Lot to lot variations indicate that neutron induced swelling can be correlated to composition and microstructure. Complementary data obtained by charged particle irradiations indicate that void swelling in stainless steel may be controllable through control of composition and microstructure and allow nearer term LMFBR goals to be attained.

10. Post irradiation creep and tensile test results show that the ductility loss caused by neutron irradiation can probably be significantly reduced by composition and microstructure control.

11. Successful completion of 22 months of exposure in the EBR-II of a sophisticated instrumented test containing the candidate neutron absorbers boron carbide and europia. This test provided continuous measurement of reactor temperature and B_4C gas (He) release. The data from this test enable experimenters to derive accurate irradiation performance correlations for the two absorber materials.

Materials

Efforts are directed at characterizing advanced engineering structural materials and developing fabrication techniques to provide a basis for large reliable plant components and structures. In addition, high temperature engineering design and stress analysis methods are being developed which will permit safe and reliable plants to be built. Continued emphasis is planned on welding development, structural materials development with emphasis on steam generators, development of high temperature design methods, and evaluations of alternate core materials for improved performance.

Major accomplishments during the past year include:

1. Completion of approximately 80% of the 2 1/4 Cr - 1 Mo steel mechanical property correlations to develop data required for CRBR steam generator design. Boiling water corrosion tests and decarburization tests in sodium support the selection of the Cr-Mo steel for the CRBR.

2. Completion of tests demonstrating that the reference FFTF fuel duct load pad hardsurfacing material will perform as designed.

3. Establishment of the potenital for extending the 10-year lifetime of the FFTF core basket by irradiation experiments on base metal and welds.

4. Confirmation of mechanical properties used in the design of FFTF core components (reflectors, core supports and others) to design neutron fluences.

5. Determination by nondestructive examination that the EBR-II steam generator evaporator tubes are satisfactory for continued operation.

6. Significant progress has been made towards developing an ultrasonic inspection method for thick-walled, austenitic stainless steel weldments such as reactor vessel downcomers and nozzles. Such an examination technique is needed to complement existing methods used to ensure the mechanical integrity of reactor components.

Fuel Recycle

The LMFBR requires that fuel which has been used in the reactor be processed to recover the newly bred fissile material as well as the remains of the original fissile and fertile material. This requires shipping the used fuel, reprocessing it and refabricating it into new LMFBR fuel elements. The efficiency with which these processes are accomplished has a strong effect on the fuel doubling time and hence on both the economics and capability to meet expanding energy requirements.

Significant accomplishments during the past year include:

1. Completion of a cask design which is undergoing licensing review for transport of FFTF and CRBR fuel.

2. Completion of four engineering and procedural standards for fuel packaging and transportation.

3. A significant expansion of large scale engineering development of LMFBR fuel reprocessing technology at Oak Ridge.

4. Signing of several design study and development subcontracts with industrial equipment suppliers in an effort to develop commercial sources of supply for major pieces of equipment to be used in LMFBR reprocessing.

Chemistry

Major effort in this area is centered around development of instrumentation for control of transport of radioactive materials and development of processes for cleaning components of sodium and radoactivity prior to maintenance.

Included among the accomplishments of the past year was the establishment of a firm technical basis and cleaning procedures for safely removino sodium from components, proof testing of a laboratory scale nickel mesh nuclide trap, and the measurement of the effect that oxygen concentration has on controlling radioactive transport in a sodium system.

System Development

This supports design and development leading to the proper integration and compatibility of all reactor components and subsystems into workable reactor designs. Continued progress was made in development of LMFBR gas system purification and cleanup technology and special instrumentation development and testing, together with the supporting engineering analysis in these and related systems activities. Continued support of this area is important to provide the underlying technology for the program. Other areas investigated include design simplification, cost reduction, reliability improvement and the large commercial plant design studies which are beginning in FY 1975. These designs, conducted by two, or more, reactor manufacturers will form the engineering base for the planning and execution of the large component development program and associated Plant Component Test Facility (PCTF) and for the design of the first full-size commercial plant. These studies are being undertaken in cooperation with EPRI. Through EPRI the utility companies of this country will be kept informed on these full size commercial LMFBR plants designs. Other increases in system development will be applied to improve secondary heat transfer systems and on shutdown heat removal system reliability.

Component Development

The following plant and reactor system components are developed under this category:

Plant System	Reactor System
Steam Generator	Instrumentation & Control
Heat Exchanger	Fuel Handling
Pump	Reactor Vessel & Internals
Piping & Valves	Fuel Assembly Reactor Control Mechanisms

The principal effort in component development is to support an extensive steam generator development and test program to resolve the design uncertainties of this component, to develop a means of reducing the probability of sodium-water interactions within this component, and to develop improved means of detecting leakage.

During the past year developmental activities associated with heat exchangers, pumps, valves, fuel assemblies and reactor mechanisms has shifted from near-term support efforts to new programs being initiated on large, commercial-sized components.

Significant accomplishments during the past year include:

1. Steam generators

   Requests for proposals have been released for the design and fabrication of the Large Leak Test Vessel (LLTV). This vessel will be installed in a rig at the LMEC to experimentally determine energy release and damage which results from a large water to sodium leak. A conceptual design was completed and a work plan has been prepared for the design and fabrication of the Large Leak Test Internals (LLTI). These internals, which simulate a full scale steam generator tube bundle, are inserted into the LLTV.

2. Pumps

   The annular linear induction pump (ALIP) was selected from among several design concepts for electromagnetic pumps. Development and design leading to the fabrication and test of a 14,500 gpm prototype was initiated. In order to confirm the feasibility of building the pump as configured in the preliminary design, fabrication and assembly of the stator and center iron core models for the first EM pump prototype were completed with satisfactory results. Thermal testing of the center iron core model was initiated to confirm design calculations of pump behavior at design temperatures.

   Progress in large pump development during the year included full scale water loop testing of the pump type to be used in FFTF. Testing showed some dynamic performance anomalies which are being resolved to assure long term reliable operation under the full range of pump operating conditions. Plans call for final proof testing of the pump in the SPTF (Sodium Pump Test Facility) at LMEC and the pump components are already being delivered to LMEC for testing.

3. Piping and Valves

Fabrication and testing of a 12 inch offset rotating ball valve prototype were completed, and hydraulic, operating torque, seat leakage, and proof pressure test data were obtained. These data are being used to confirm predicted hydraulic and operating characteristics and to provide a basis for proceeding to larger sizes.

Tests have shown that small cracks in pipes containing sodium tend to plug after leaking sodium for a few hundred hours into a gaseous atmosphere such as presently exists in the primary system of LMFBRs. This information is a part of the data needed to define small leak behavior and sodium-to-gas leak detection requirements for LMFBRs.

Manufacturing processes, qualification, and proof testing of small sodium valves continued with emphasis on qualification of valve assemblies under simulated operating temperatures and thermal transients. Development of valve operators capable of reliable performance under the radiation conditions in an LMFBR plant environment was accomplished during the year.

4. Instrumentation and Control

Holifield National Laboratory (HNL) successfully developed and operated, in a reactor at 2250°F for 3000 hours, a small size resistance-noise type temperature sensor for use in high temperature reactor fuel experiments. This device extends the range over which direct temperature measurement can be made and makes it possible to place sensors within the very limited confines of the fuel pin.

HEDL demonstrated the operation of a 1100°F microwave resonant cavity type pressure sensor for measuring fission gas pressure in fuel pins during long term irradiation tests. Under this same task, HEDL also successfully operated an 1100°F microwave resonant cavity type biaxial extensometer for measurement of dimensional changes in fuel pins and other specimens during irradiation tests.

To permit the location and identification of reactor components or foreign objects submerged in opaque liquid sodium, an ultrasonic pulse-echo system was developed at HEDL that presents a three-dimensional projected image on a TV type of tube. The images can also be stored on tape for future playback and reference.

High temperature, sodium immersible, acoustic transducers developed at ANL have been placed in the EBR-II to check their performance in an actual reactor environment.

Fuel Assemblies

5. Fuel Assemblies

The construction of two 1/15 scale model upper reactor plenums for testing in sodium and in water was completed and test results to date show:

> Large local temperature fluctuations at the interface between the hot and the cold fluid in the plenum, that were identified during the tests, can impose severe thermal stresses on components in the reactor vessel.

Grid Spaced Fuel Assemblies have potential for reduced overall pressure drop and are being developed as an alternate to the wire wrap fuel assembly design. Grid spaced driver assembly (GSDA) designs for testing in FFTF were finalized. Fully instrumented 217-pin flow and vibration test assemblies were fabricated, and flow induced vibration tests were successfully completed on the Westinghouse unit. An interim examination of a test GSDA of preliminary design being irradiated in EBR-II was completed with satisfactory results, and the assembly was reinserted for continued high level irradiation to determine actual performance capabilities.

Evaluation of various wire wrap configurations having potentially improved characteristics was completed. A promising new configuration labeled the "locked wrap" design was identified. This configuration has potential for increased clad swelling accommodation at high burnup while maintaining necessary tightness at beginning of life. Test equipment for checkout of the locked wrap and other promising designs was completed.

LMFBR SAFETY PROGRAM

The funding request for the LMFBR safety program for FY 1976 is $40.4 million, an increase of $4.5 million over the 1975 estimate. The objective of this program is to develop a base of data and analytical tools that will provide input to the LMFBR design process to contribute to the evolution of designs that are safe in all phases of operation, with maximum tolerance for errors and abnormalities, and that will provide the basis for an accurate determination of the safety of LMFBR's.

To fulfill the LMFBR-safety objectives and to resolve the technical issues: (a) models and methods are being developed and experiments are being performed to generate an adequate technological base for understanding the potential causes, courses, and consequences of accidents, (b) methodology is being developed to combine with the understanding of potential consequences to allow making informed risk assessments, (c) design options to enhance LMFBR safety are being provided, and (d) the facilities needed to establish the technological base are being defined and acquired.

Major reactor safety tests are conducted in large facilities to provide integral confirmation of analytical tools for accident analysis and to supplement the data base for understanding the fundamental phenomena involved in model development. The major facilities used include the Transient Reactor Test Facility (TREAT), the Fuel Failure Mockup (FFM), the Sodium Loop Safety Facility (SLSF) in the Engineering Test Reactor (ETR), and potentially the Power Burst Facility (PBF).

FY 1975 Accomplishments

During FY 1975, the ACRS completed a review of safety research for liquid metal cooled fast breeder reactors which was reported in a January 14, 1975 letter to the Chairman of the AEC. In that letter, the ACRS stated:

> "The Committee believes that substantial advances in our knowledge of fast reactor safety have resulted from the Commission's research program."
>
> "The purposes and needs for new LMFBR safety research in pile test facilities were also discussed at the July 1974 ACRS Subcommittee meeting. This matter is quite properly under active investigation by both RRD and RSR. The categories of possible new facilities, their complexity, and their potential varied widely, and no definite recommendations were presented. It is likely that any new in pile safety research facility will be expensive and take a considerable time to obtain. The Committee believes it important to initiate steps to provide such facilities and to expedite decisions regarding their specific nature and capability."
>
> "In conclusion, the Committee again states its general approval of the current program in LMFBR safety research and emphasizes the need for expediting decisions on new programs and facilities to meet the safety research requirements of commercial LMFBRs."

Modeling of fuel, cladding, and coolant heat transfer and dynamics. Analytical techniques are being developed to describe, provide and improve understanding of the progression and consequences of postulated severe accidents. In FY 1975, specific analytical models were developed to improve descriptions of heat transfer among fuel, cladding and coolant; fuel motion, cladding failure, fission-gas release, and coolant expulsion or boiling.

Several of the analytical models developed were validated experimentally by:

1. Overpower test in TREAT of 7 pins with medium power structure.
2. Single- and 7-pin fuel-sweepout tests in a small out-of-pile loop.
3. Fuel dispersion tests in TREAT based on fission-gas released and fuel vapor pressure.
4. Out-of-pile experiment on fuel-coolant interaction in pin bundle geometry. Test results confirm benign nature of event.
5. Out-of-pile characterization of loss-of-pipe-integrity flow transient in FFM (19-pin geometry).
6. Inlet flow blockage tests in FFM demonstrated ability to accommodate up to 80% axial blockage (19-pin geometry).

The remaining major key problem areas include: The extension of the fuel, cladding and coolant heat transfer and dynamics models to two and three dimensions; the introduction of further refinements into the models; and continuing experimental validation of models developed and being developed.

Fuel-element failure propagation (FEFP). An area long postulated as a potential problem is the propagation of a single defect or failure of a fuel pin so as to involve a number of pins or assemblies. To assure that slightly off-normal failures, such as fuel-pin failure, do not progress to a situation of serious consequence to the plant or public, the effects of flow blockages, fission-gas release and intersubassembly effects are being studied. In FY 1975 substantial progress was made in completing the definition of test requirements for FEFP.

1. As a result of out-of-pile test programs, it was concluded that local faults will not result in rapid pin-to-pin failure propagation. Consequently, the need for an extensive in-pile program was reduced to that of confirming that new effects do not occur in-pile.

2. Test programs in the Fuel Element Failure Propagation Loop (FEFPL) were reoriented to investigate the key remaining problems of flow transients (loss of flow and loss of pipe integrity) and questions of slow pin-to-pin propagation and subassembly-to-subassembly propagation. The test loop was renamed the Sodium Loop Safety Facility (SLSF) to reflect the broader role in the safety program.

Postaccident containment and heat removal. Programs are underway to increase our understanding of the behavior of reactor core materials after an assumed gross loss of initial geometry. The main areas of interest are in determining material properties and behavior that affect the capability to effectively cool the debris. The potential for the resulting debris to form a recritical configuration is also being studied. Key problem areas are developing understanding of: (a) molten-pool heat-transfer behavior and (b) interactions of sodium and molten fuel with sacrifical materials. In FY 1975 significant progress was accomplished in defining the conditions under which cooling of particle debris beds in sodium can take place and substantial support was provided to the preparation of the FFTF Safety Analysis Report. Out-of-pile heat transfer experiments were completed on particle-bed cooling using debris sizes that extended below 100 microns. Additional tests were completed that used mixed beds of fuel and steel and a combination of layers of fuel and steel. The overall result is that several inches of particulate debris can be cooled by overlying sodium. Additional accomplishments follow:

1. A small-scale apparatus was developed for direct-electrical-resistance heating apparatus for UO_2. A scaled-up version will be used for direct measurements on heat-transfer rates from molten pools.

2. Mockup tests were completed on the delay to meltthrough that occurs when molten debris attempts to penetrate fuel assembly inlet structures. Holdup time on the order of hours is likely, which will lower decay-heat levels in the debris.

3. In-vessel and ex-vessel post-accident heat removal reports in support of FFTF were completed. These reports contain data needed for continuing design efforts.

4. Screening tests of sodium and sacrificial barrier materials were completed, and some criteria for choosing such materials were defined. This information is needed to support decisions on the design of any ex-vessel core catcher.

Assessment modeling of radiological consequences. This program is concerned with modeling fuel and fission-product release from an LMFBR core under postulated accident conditions, attenuation of the material as it passes through the surrounding sodium, its release from the reactor vessel, behavior in the reactor containment building, release to the environment, transport to site boundary, and potential radiological consequences. In FY 1975 preliminary experiments were completed and initial analytical models were developed for analyzing the release and transport of fuel, fission products, and sodium under postulated accident conditions, and tests of emergency air-cleaning systems were conducted.

1. The development of a model to assess the radiological consequences of Hypothetical Core Disruptive Accidents (HCDA's) was initiated and experiments were conducted to support the modeling of the transport of fuel and fission products from the core to the environment.

2. A program to develop an emergency air-cleaning system for LMFBR containments was initiated; several concepts were evaluated and initial tests were conducted.

3. The initial version of a code to analyze the consequences of sodium spray fires was developed and several small-scale supporting experiments were completed.

The key problems are the assessment of: (a) leakage paths in the primary system and (b) the fuel and fission-product attenuation within the primary system.

Inherently safe core design. GE, ARD, AI, and ANL were selected to review core design(s) so as to identify approaches that would prevent or substantially mitigate accidents through inherent properties and/or characteristics of the design.

1. Design areas that can be emphasized to increase inherent safety were defined initially.

2. Criteria were defined for selecting a design to be continued; screening was initiated.

Additional accomplishments include:

1. Technology reports were prepared to support FFTF FSAR development on fuel-dynamics transient-overpower and loss-of-flow experiments.

2. A compendium of computer codes for safety analyses of LMFBR's was compiled and distributed to industry, government agencies, and national laboratories.

3. Experiments were performed to validate the reactor-system structural response to rapid transient loadings analysis code series (REXCO); agreement between models and experiments was generally good.

4. The state-of-the-art understanding of the response of fuel rods during reactor accident transients was reviewed; a report was prepared for use by designers and licensing organizations.

5. Programs were conducted at Combustion Engineering and ANL to identify safety implications resulting from unique characteristics of advanced fuels.

Facility design and development

Current development work on the systems and areas described above is being conducted in existing facilities. Their limitations make necessary the greater size, harder neutron spectrum, and longer experiment duration of the Safety Research Experiment Facility (SAREF) in the early to mid-1980's to complete the understanding of the problems and to find acceptable solutions. In addition, a Super TREAT probably will be needed in the early 1980's to provide a more suitable transient environment than is obtainable in existing facilities or in SAREF. These two new test reactors are required for prototypic tests of failure threshold and design prooftests. Their needed features are being determined.

Figure 17 lists the major safety facilities.

SAREF, as envisioned, would provide a fast-flux zone for testing up to seven full-scale LMFBR fuel assemblies to and through loss of fuel-element integrity caused by overpower, transient, flow-coastdown, and flow-blockage accident conditions. As indicated by Figure 49, SAREF will provide the capability for testing large-scale phenomena of large fast-reactor zones beyond fuel failure. Data from SAREF are expected to enable us to understand key safety phenomena, such as channel voiding, transient fuel-element failure, core slumping, fuel disassembly, and fuel motion.

The need for SAREF was established from inputs from the nuclear community, regulatory organizations, and other concerned organizations. Licensability and safe operation are important considerations in the commercialization of the LMFBR; SAREF will be the major facility needed to resolve these issues. It should be built and operating by the early 1980's to meet program requirements. Facility cost is estimated to be about $200-$300 million.

During FY 1975, ANL and GE initiated conceptual design studies of SAREF; in FY 1976, these are expected to be completed and the concept and contractor will be selected.

Super TREAT as presently envisioned will provide unique capabilities for prototypic transient power, temperature, and flow tests under conditions of hypothesized LMFBR accidents.

Advanced Fuel Technology

The budget request for FY 1976 is $13.5 million, an increase of $2.0 million over FY 1975. This is a development program to assess the potential of advanced fuels and materials which may be capable of a fuel doubling time of ten years or less. Fuels being investigated include mixed carbides and nitrides. In addition, improved oxide fuels are being investigated. Extensive in-pile testing of these fuels in EBR-II will continue. Development of advanced alloys for cladding and core structural materials is being emphasized. Actions are directed toward ascertaining, at the earliest possible date, which fuel system should receive priority commitment.

Major accomplishments during the past year include:

1. Plutonium fuel element fabrication facilities of three contractors were recommissioned in preparation for fabricating fuel in 1975.

2. A 19-pin advanced carbide fuel subassembly achieved a burnup of 75,000 megawatt-days per ton (MWD/T) without failure in EBR-II. This is 50% of the burnup expected in a commercial LMFBR.

FIGURE 17

LMFBR PROGRAM
MAJOR FACILITIES–SAFETY

FACILITY	LOCATION	USE
TREAT	ANL-WEST	TESTS BEHAVIOR OF FUEL IN SODIUM WITH FLOW, TEMPERATURE AND POWER TRANSIENTS
FUEL FAILURE MOCKUP (FFM)	ORNL	TESTS THERMAL HYDRAULICS OF FUEL FAILURE AND PROPAGATION IN SUBASSEMBLIES OUT OF PILE
POWER BURST FACILITY (PBF)	INEL	FUEL TESTS IN-CORE UNDER STEADY-STATE AND TRANSIENT CONDITIONS
SODIUM LOOP SAFETY FACILITY (SLSF IN ETR)[c]	INEL	FLOW TRANSIENT AND FUEL FAILURE PROPAGATION TESTS
SUPER-TREAT[p]	UNDETERMINED	TESTS OF SUBASSEMBLIES UNDER ABNORMAL CONDITIONS
SAFETY RESEARCH EXPERIMENT FACILITY (SAREF)[p]	UNDETERMINED	TESTS OF PARTIAL CORE CONFIGURATIONS UNDER ABNORMAL CONDITIONS

c = UNDER CONSTRUCTION
p = PLANNED

3. A contract was negotiated and fabrication initiated for an irradiation experiment on candidate advanced cladding and duct materials to be conducted in the British Prototype Fast Reactor (PFR). This experiment will accumulate neutron doseage at approximately twice the rate of a comparable experiment being performed in EBR-II.

4. Initial studies of the advanced oxide fuel system indicate that operation at a very conservative average power can result in a 12 to 16 year simple doubling time with an estimated fuel pin burnup capability of at least 80,000 MWD/MT maximum.

6. Commission of the European Communities - Presentation at the 8th Annual Meeting of the International Working Group on Fast Reactors; by H. J. Allgeier.

The contribution of the European Communities to FBR development, modest compared to national programmes, is designed to complement national programmes and to promote cooperation and coordination particularly within the Community. The last year has brought about a general confirmation of this policy and has led to a modest increase of our activities.

Thus the Fast Reactor Coordinating Committee (FRCC) has approved the setting up of a Working Group "Codes and Standards" which has held two meetings to date and has in particular charged two specialist teams to compile existing and applicable codes and standards, and to identify areas where new ones are needed, respectively. The Safety Working Group (SWG) of the FRCC has pursued its work actively and is now completing a first round of discussions and deliberations. Its work has contributed considerably to establishing a valid dialogue on the overall safety of the LMFBR-system in the Community between technical experts of all parties concerned. The Group has improved mutual information about programmes, identified areas of collaboration, and should now define areas and priorities for its future work. The SWG has also contributed indirectly to improving bi-and multi-national collaboration in the area of LMFBR-safety within the Community. Its sub-group on Whole Core Accident Codes has made considerable progress. It has performed comparative calculations of typical accidents on a notional reactor using the different