STATUS OF LMFBR DEVELOPMENT PROJECT IN JAPAN

GORO NAGANE, Vice President

Power Reactor and Nuclear Fuel Development Corporation
1-9-13, Akasaka, Minato-ku, Tokyo 107, Japan
Tel. (03) 586-3311
Telex J26462
Cable PNDCNIPPON

MICHIO AKEBI, Director; Y. MATSUNO, Director

Power Reactor and Nuclear Fuel Development Corporation
1-9-13, Akasaka, Minato-ku, Tokyo 107, Japan
Tel. (03) 586-3311
Telex J26462
Cable PNDCNIPPON

ABSTRACT

Initiation of the LMFBR development project in Japan was decided by the Atomic Energy Commission of Japan in 1966. In 1967, the Power Reactor and Nuclear Fuel Development Corporation (PNC) was established to realize the project as a part of its tasks of a wide scope covering all the research and development activities concerning fuel cycle. In the present paper the status of experimental fast reactor (Joyo), which is the first milestone of the LMFBR project, prototype fast reactor (Monju) and R & D activities supporting the project including that for larger LMFBRs in the future is described.

INTRODUCTION

The Power Reactor and Nuclear Fuel Development Corporation (PNC) was established in 1967 with the charter that "independent development of advanced reactors for stable supply and effective utilization of nuclear fuel to maximally prove the advantage of nuclear power generation in energy policy and also to strengthen the industrial infrastructure with enhancement of related scientific and technical branches." Accordingly, PNC has been promoting two types of advanced reactors, namely ATR and FBR as national projects.

With respect to ATRs, full power operation of the prototype reactor Fugen started in March, 1979, and it is continuing stable operation. As to LMFBRs, the experimental fast reactor Joyo completed its role with the breeder core (MK-I), and started rated power operation as the irradiation core (MK-II) in August, 1983. For the prototype reactor Monju a pre-construction permit (safety examination by the Nuclear Safety Commission) was granted in May, 1983. Then the construction was permitted in September, 1985 and the construction was started in October of the same year. Monju is the first power-generating fast breeder reactor in Japan and maximum effort is being directed for its successful completion to prove safety, reliability, operability and maintainability of an LMFBR, based on techniques and experiences accumulated at the experimental fast reactor.

In the LMFBR area, how to promote development of the demonstration reactor is being discussed since May 1983, in the "Advisory Group for Development of LMFBR" established within the Commission. The basic attitude of the Commission on a project which has entered into a new stage of near-commercialization is to implement future activities around the private sector under governmental support.

Based on the above thinking, PNC is conducting basic R & D activities in the Oarai Engineering Center and at the same time working in the selection of the basic specifications for the demonstration reactor, supporting utilities with its technical expertise accumulated for Joyo and Monju. During this period the conceptual design, evaluation studied and R & D necessary for selection of basic specifications will be carried out, and close cooperation and coordination will become increasingly important among the utilities, industry, academia and governmental agencies.

Regarding the overall development of LMFBRs, the operation of Joyo and the steady progress of Monju construction will be quite important in planning smooth transition to commercialization. For this purpose, effective utilization of developmental experience and of the facilities available is mandatory in pursuing safety, operational reliability, operation and maintenance and economy. These four factors constitute four "pillars" of the research and development, the results of which must be fed to the demonstration reactor. Hereunder, the present status and the future program on LMFBRs are reported.

EXPERIMENTAL FAST REACTOR JOYO

A view of Joyo is shown in Fig. 1. Joyo attained initial criticality in 1977 as the experimental reactor for liquid metal cooled fast reactors, and it commenced operation in 1978 with thermal output of 50 MW. Thereafter the rated thermal power was increased to 75 MW and operation was continued smoothly. All the breeder core testing was successfully completed in December, 1981. This operation accomplished the first objective of accumulating technical experience for LMFBRs through its design, construction and operation.

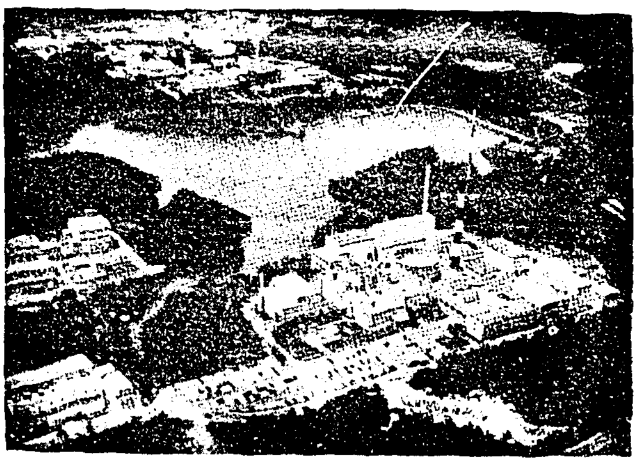

Fig.1. A view of the Experimental Fast Reactor Joyo

Since the initial criticality, the reactor has been operated without any serious troubles or accidents, producing a lot of technical informations which must be reflected to Monju and future LMFBR design. The records of the operation by December 1986 are as follows:

.Acc. reactor operation time 28,442h
.Acc. heat generation 2,031,359MWh
.Max. fuel burnup 50,000MWd/t

Tab.1. Main Core Parameters of Joyo

		MK-I		MK-II
		First	Second	
Reactor Output	MWt	50	75	100
Primary Coolant Flow Rate	t/h	2,200	2,200	2,200
Reactor Inlet Temperature	°C	370	370	370
Reactor Outlet Temperature	°C	435	470	500
Core Stack Length	cm	60	60	55
Core Volume (max.)	ℓ	294	304	250
Linear Heat Rate (max.)	W/cm	210	320	400
Fuel Pin Diameter	mm	6.3	6.3	5.5
$PuO_2/(PuO_2 + UO_2)$	W/O	18	18	30
U^{235} Enrichment	W/O	23	23	12
Neutron Flux (max.)	n/cm²sec	2.1×10^{15}	3.0×10^{15}	5.1×10^{15}
Neutron Flux (Core av.)	n/cm²sec	1.2×10^{15}	1.9×10^{15}	2.6×10^{15}
Max. Excess Reactivity	% ΔK/K	~4.5	~4.5	~5.5
Control Rod Worth	% ΔK/K	Safety Rod ~5.6 Regulating Rod ~2.8	Safety Rod ~5.6 Regulating Rod ~2.8	~9
Max. Burn Up (pin av.)	MWd/t	25,000	42,000	50,000
Operation Cycle		45 days Operation 15 days Outage		

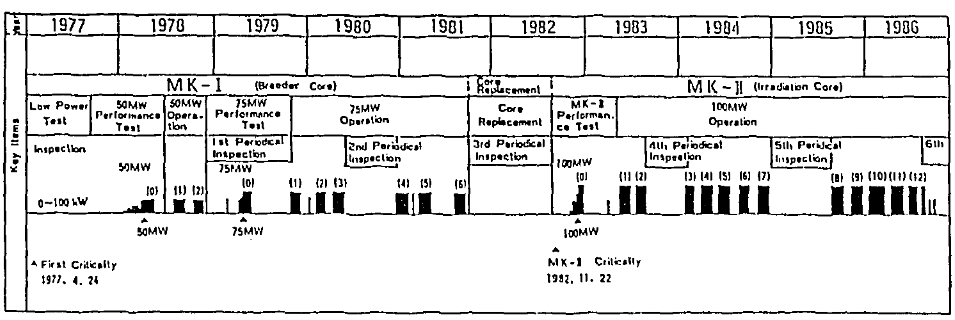

Fig.2. Operating History of Joyo

In 1982, modification of the core for the second objective was carried out, namely to use it as the irradiation facility for fuel and materials. Rated cycle operation at thermal output of 100 MW was started from March 1983, and the operation is continuing smoothly, while carrying out irradiation tests for the fuel materials of Monju, as well as the plant characteristic tests by using the actual plant. Operating history is shown in Fig. 2. Main core parameters of Joyo are shown in Tab. 1.

.Number of start-ups 396 (including critical test)
.Number of core sub-assemblies handled 1,428
.Number of annual inspections 6

Main technical results confirmed through operation and testing are:

.Core physics Agreed with design within 10%

- .Core thermal-hydraulics — Agreed with design within 5%
- .Reactor shielding — Adequate with design margin
- .Plant parameters — Agreed with design within 5%
- .Plant dynamics — Stable with sufficient negative feedback
- .Design features — Satisfactory
- .Operability — Simple and reliable
- .Maintainability — Satisfactory
- .Sodium/cover gas purity control — Satisfactory
- .CP accumulation — Acceptable (15-20 mrem/h on entire PHTS)
- .Occupational radiation exposure — 209 man rem (3.1 man rem/GWd)
- .Earthquake experience — 33 gal (MIYAGI-OKI earthquake)
- .Unscheduled outage — 294 h (1.1%)

Some results of typical tests conducted at Joyo are shown below,

(1) Natural circulation tests

In order to confirm the inherent safety of the LMFBRs, tests for decay heat removal by natural convection were carried out at the full power operation both on MK-I core and MK-II core, i.e. at 75 MW_t and 100 MW_t, respectively. The tests were carried out stepwise in the power from the view point of safety. Test results are shown in Figs. 3 and 4, and comparison between measured and calculated values is shown in Figs. 5 and 6. As shown in the figures the calculation reproduces the measured value satisfactorily. Because the hydrodynamic parameters of MK-I and MK-II cores are different and therefore the flow distribution at the core region of MK-I core differs from that of MK-II's, the fact that the agreement between calculation and measurement was satisfactory on both cores, indicates high reliability of analysis method and computational technique. Computational codes thus verified are to be applied to predict the capability of the natural convection at Monju as well as larger LMFBRs.

Test		Test Conditions			Test Results		
		Power	Main Pumps Pri.	Main Pumps Sec.	Central Subass. Outlet Temp.	Loop Flows Pri.	Loop Flows Sec.
Steady State Test	TEST-A	0.5MW	10% Flow ↓ Stop	40% Flow	305°C	~1 %	—
	TEST-B	1MW			310°C	~1.2%	—
	TEST-C			40% Flow ↓ Stop	315°C	~1.2%	~1 %
Transient Test	TEST-D	30MW ↓ Scram	100% Flow ↓ Stop	100% Flow ↓ Stop	450°C	~2 %	~4 %
	TEST-E	75MW ↓ Scram			490°C	~3 %	~4.5%

Fig.3. Joyo Natural Circulation Tests (MK-I core)

Test		Test Conditions			Test Results		
		Power	Main Pumps Pri.	Main Pumps Sec.	Central Subass. Outlet Temp.	Loop Flows Pri.	Loop Flows Sec.
Steady State Test	TEST-IIA (84.10.22)	1 MW	15% Flow ↓ Stop	40% Flow ↓ Stop	347°C	~1 %	1~3%
Transient Test	TEST-IIB (85.4.27)	30MW ↓ Scram	100% Flow ↓ Stop	100% Flow ↓ Stop	448°C	~1.5%	~ 3 %
Steady State Test	TEST-IIC	2 MW	15% Flow ↓ Stop	40% Flow ↓ Stop	—	—	—
Transient Test	TEST-IID (86.3.31)	75MW ↓ Scram	100% Flow ↓ Stop	100% Flow ↓ Stop	498°C	~2.3%	~4.3%
	TEST-IIE (86.10.29)	100MW ↓ Scram			519°C	~2.6%	~ 6 %

Fig.4. Joyo Natural Circulation Tests (MK-II core)

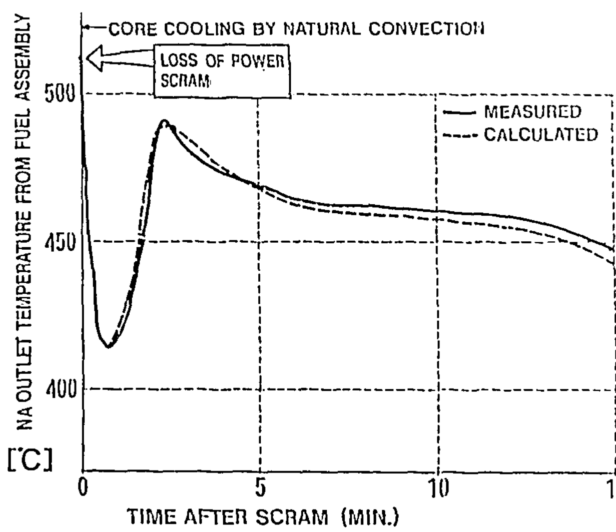

Fig.5. Coolant Outlet Temp. of Centre Fuel Assembly of MK-I core (Test-E, 75MW Transient Test)

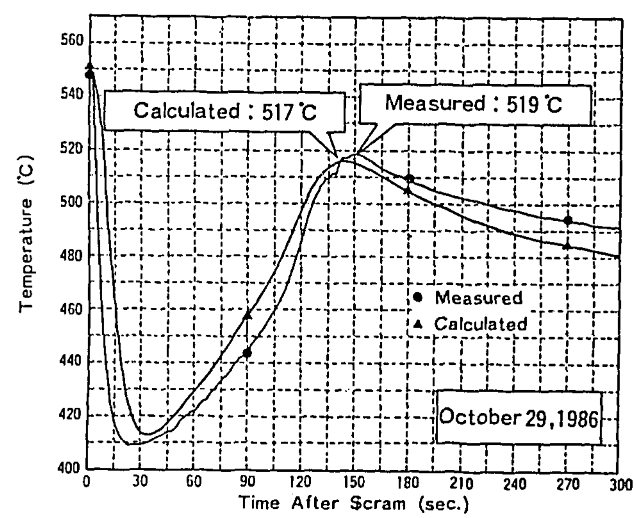

Fig.6. Coolant Outlet Temp. of Centre Fuel Assembly of MK-II core (Test-II-E, 100MW Transient Test)

(2) Simulated fuel failure test

A demonstration test for the gas tagging method simulating fuel failure was carried out at Joyo in April 1985. In this test, a dummy fuel pin with a slit which contained a tag gas capsule was loaded in the core and a fraction of the tag gas was released to the reactor cover gas at the reactor power of 3MWt.

The tag gas was collected and enriched by the cryogenic adsorption bed with activated charcoal.

In this method, after release of the tag gas from the pin, a large charcoal trap is opened to the cover gas system, and adsorbs the tag gas contained in the cover gas at -180°C. The gas is desorbed by warming the trap, and readsorbed with another small trap. Then, the gas is purified and desorbed by helium gas flushing at -80°C, and collected into a measurement vial.

By means of mass spectrometric analysis, it was confirmed that the measured contents of the collected tag gas agreed with those of as built within the required precision. As the result, the method of cryogenic adsorption developed by PNC was proved to be valid for practical use, and some experimental data were obtained on behaviors of tag gas in the reactor vessel.

(3) FFDL test

An FFDL (Failed Fuel Detection and Location System) employing in-core wet sipping method has been developed in Joyo. The sipping and sniffing mechanism of the FFDL is illustrated in Fig. 7.

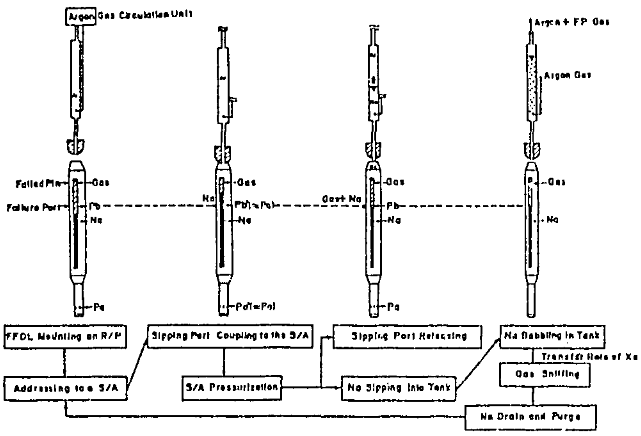

Fig.7. Sipping and Sniffing Mechanism of FFDL

In order to verify the performance of the FFDL, an inpile simulation test was carried out using two identically slitted fuel pins. The slit is 1.0mm in length and 0.1mm in width, and perforated on the fuel claddings at the gas plenum position.

The major results of the test and the analyses are as follows:

(a) In the FFDL operation, a signal level of the test assembly was several hundreds times of the background which was measured for other core subassemblies. Thus, it was confirmed for the FFDL to have a capability to identify the failed fuel with defect at gas plenum.

(b) Measured amount of ^{113}Xe released from the test pins to the cover gas by the FFDL operation was 50% of the predicted with an assumption of the FP release-to-birth ratio to be 0.05. Consequently,.the sipping mechanism of the FFDL from the defect at gas plenum was proved.

(c) Measured amount of ^{113}Xe introduced into the gas circulation unit of the predicted. This low sampling efficiency may be due to the dead time of 7 seconds between release of the sipping port from the assembly and sodium introduction (see Fig. 7). Most of the FP gas in the test pins might be released during this dead time. Further tests of the FFDL for pins with slit at fuel column are planned to be carried out in the near future.

(4) Fuel and materials irradiation tests

In the R & D activity for LMFBR one of the most important items in the development of fuel and materials which are subjected in a severe conditions of high level of neutron field and high temperature sodium circumstances. To develop materials with higher performance many kinds of irradiation tests have been planned and conducted using Joyo core. Fig. 8 shows the irradiation test program for purposes described in the column of test objectives in the figure.

(5) Observation of the on-power fuel behaviour

To obtain informations on fuel behaviour during the operation a test fuel assembly was instrumented by sensors for measuring neutron flux density, temperature of fuel pellet and cladding, fission gas pressure and in-cell coolant flow and irradiated in the core of Joyo. Some results are illustrated in the Fig. 9 and 10. By these results the availability of the code (CEDAR) based on a theoretical model was verified.

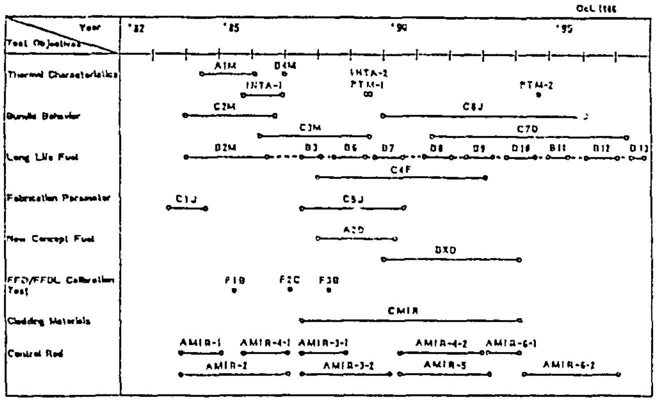

Fig.8. Irradiation Test Program for FBR Fuel at Joyo

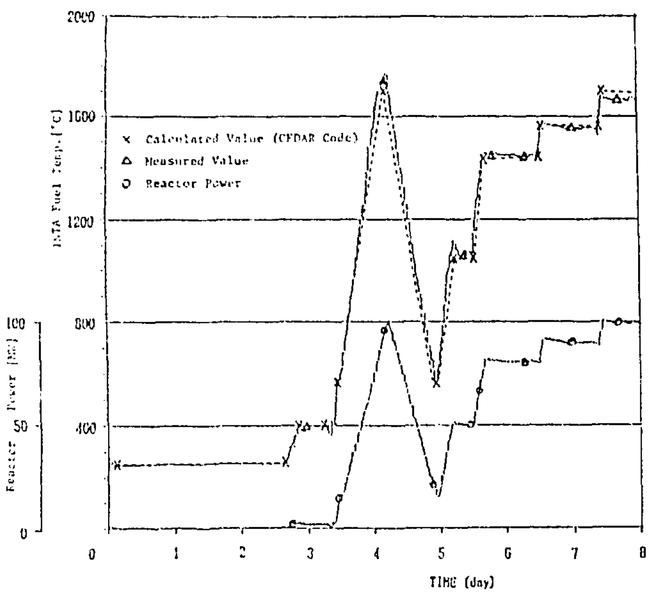

Fig.9. Fuel Centre Temperature On-Power Measurement (INTA)

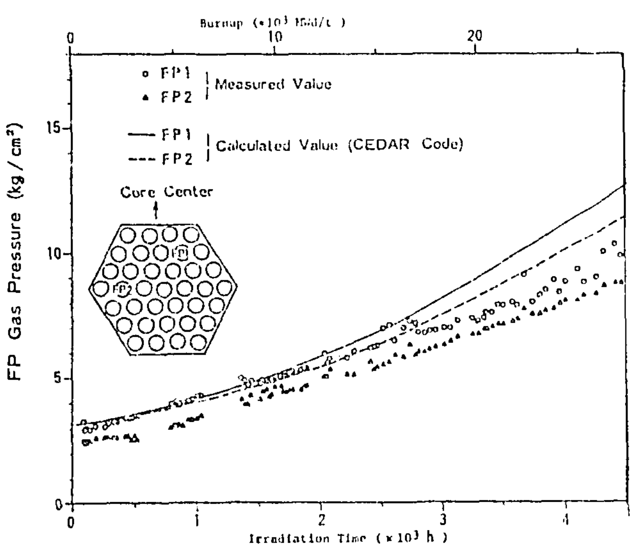

Fig.10. FP Gas Pressure On-Power Measurement (INTA)

PROTOTYPE FAST BREEDER REACTOR MONJU

Summary

Fast breeder reactor Monju plant is a nuclear power plant of medium size, which is being built at Shiraki in Tsuruga City, Fukui Prefecture, approximately 400km west of Tokyo. Monju is a prototype reactor, which stands between the experimental reactor and the demonstration reactor in the development program of the fast breeder reactor, and aims to attain technological advancement and economic prospect towards the establishment of commercial viability of future nuclear power plants.

Power Reactor and Nuclear Fuel Development Corporation (PNC) undertook the design of Monju and the selection of its site in 1968, and in 1970 Shiraki area was chosen as a prospective site. Since then PNC conducted an environmental assessment and safety evaluation. The environmental assessment was completed by the local authorities of Fukui Prefecture in June, 1982, and by the government in July of the year. The first stage of the safety examination was made by the reactor regulatory section of the Science and Technology Agency (STA) and the second by the Nuclear Safety Commission, after which approval was granted for the reactor establishment in May, 1983. Preparatory construction work began early in 1983 such as preparation of the building site and the roads around the site.

In January, 1984 PNC contracted with four of the main component manufacturers (Toshiba, Hitachi, Fuji Electric and Mitsubishi Heavy Industry) for design, fabrication, and installation of a containment vessel, design and fabrication of a reactor vessel, and design of the primary and secondary heat transport system, steam generator, electrical system, fuel handling system, etc., as the first stage. At present PNC is making applications for the licensing approval of the designs and construction methods step by step. Reviews on the design and methods of construction by STA and on the construction plan by Ministry of International Trade and Industry (MITI) were initiated at almost the same time in December 1984. In last November STA licensed the 4th step of application, and MITI issued approval of licensing for the 5th application in February.

Concrete placing for the reactor building and the auxiliary building is completed. The containment vessel is completed to the level of the polar crane. The polar crane was installed in December 1986. Overall plant construction progress is approximately 24.1% at the end of December 1986.

Overall Design

In the design of this plant particular attention has been given to safety and to achieving reliable operation. Monju is an about 280 MWe, loop type power reactor, fueled with mixed oxides of plutonium and uranium. The reactor inlet and outlet coolant temperatures are approximately 397°C, and 529°C, respectively. The expected average fuel burn-up and the breeding ratio are 80,000 MWd/t and 1.2, respectively.

Components in the primary coolant system are enclosed with guard vessels and connected with elevated pipes to prevent lowering the level of sodium in the system below the minimum required safe level.

Decay heat removal is normally accomplished by means of three parallel auxiliary cooling systems (ACS), which have air coolers. Small pony motors on the main circulating pumps can provide continued coolant circulation using emergency power in the event of loss of the main power supply. A key feature, is the natural circulation capability to remove decay heat without any reliance on emergency power.

The reactor uses a simple, top-supported reactor vessel, about 7 meters in diameter and 17.3 meters in height. The reactor vessel is a cylindrical shell with a hemispherical bottom head. The vessel is surrounded by a guard vessel and these are housed in reactor cavity which is inside the concrete biological shield structure.

The reactor vessel internals are supported at the lower part of the vessel and the core is concentric with the vessel. Each fuel subassembly in the core has 169 fuel pins being hexagonally bundled and 61 fuel pins in the radial blanket fuel subassembly. The flow distribution in the core is controlled by fixed orifices at the bottom of the fuel assembly. The fuel assemblies are hydraulically held down to the support plate. Cladding material of fuel pins is SUS316. The length of the subassembly is 4,200 mm including shielding portions. The refueling interval is fixed at about six months and the core will be fueled by five-batch scatter loading scheme.

The reactor is equipped with 19 control rods (13 regulating and safety rods and 6 backup safety rods) and B_4C is used as the absorbing material. Provision is made for instrumentation on the complete core and a portion of the radial blanket. The design provides two thermocouples for each core sub-assembly and two thermocouples for each selected innermost radial blanket sub-assembly. Flow meters are provided to some of the sub-assemblies.

Reactor fuel handling accomplished by use of the single rotating plug and one in-vessel fuel handling machine which consists of a fixed arm and a pantograph type handling machine.

Construction schedule is illustrated in Fig. 11 and the present status is shown in Fig. 12.

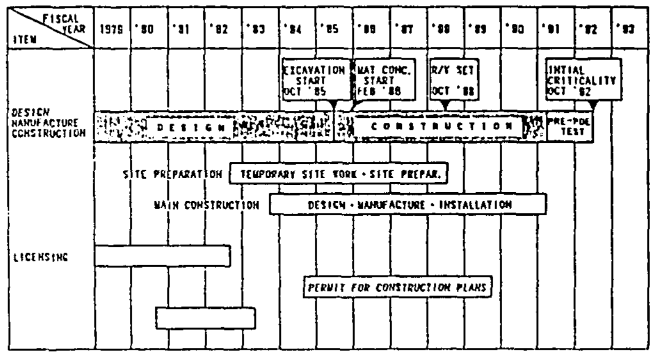

Fig.11. Construction Schedule of Monju

Fig.12. Status of Monju Construction

FUTURE PROGRAM

Overview

From the stage of demonstration plant a collaborative work of various organizations which have been engaged in the development of fast breeder reactor was recognized to be important. In order to realize closer collaboration of the organizations a steering committee for LMFBR R& D was established in summer 1986 and initiated its activity.

Utilities have been carrying out design rationalization study both on loop and tank type plants. This design study has been conducted under the initiative of FBR Project Office of the Federation of Electric Power companies, the role of which was recently succeeded to the Japan Atomic Power Company (JAPC).

PNC is playing a role of consultation and giving suggestions to JAPC's design studies and relevant R & D works in such fields of technology as safety design, core design, shielding and structural materials.

Design Study of DFBR

The utilities had carried out the conceptual design studies under cooperation of ten private electric power companies until 1983. The study consisted of three phases. Regarding the study of the loop-type reactor, key concepts of the design were selected in the phase I and the design was reviewed mainly from the standpoint of operation and maintenance in the phase II. Design specifications were established on the basis of the further design of the total system and components in the phase III from FY 1981 through 1983. Regarding the study of the pool-type reactor, a preliminary concept definition was carried out studying the design of preceding plants in phase I and it was reviewed mainly from standpoint of seismic characteristics in phase II. The key subsystems of the pool-type reactor were designed in phase III in parallel with model tests studied by the Central Research Institute of Electric Power Industries (CRIEPI).

Presently, utilities are carrying out design rationalization study in order to survey feasibility of construction cost reduction and to prepare data for determination of reactor specification.

PNC is carrying out the parametric survey of the principal design items of the large scale FBR based on the design, construction and operation experience of Joyo and Monju to assist JAPC's DFBR design study.

Demo plant development scenario is briefly shown in Fig. 13.

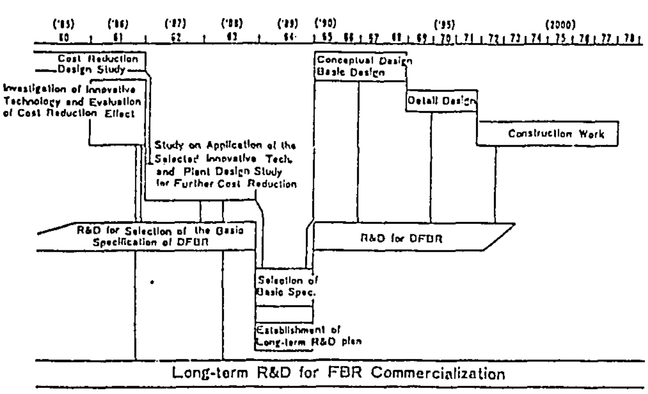

Fig.13. Scenario of DFBR Development

SUMMARY

As described in preceding chapters we obtained large amount of technical knowledge in the level of the experimental LMFBR and design experience in the level of prototype LMFBR which will generate electric power. Construction experience will also be accumulated during the construction period of Monju.

Further effort in the LMFBR development must be concentrated in technology development in order to decrease the construction cost which is now essentially higher than that of LWRs, keeping the safety in the same level as that of LWRs. For this purpose further R & D activities are required extensively in areas such as safety, core and fuels, structural materials, plant component and equipment, thermohydraulics as well as seismic studies, including innovative technologies, based on the technical knowledge obtained up to now.

This tendency seems to be common for all the countries which are interested in the LMFBR development. It is, therefore, obvious that the international cooperation in the area of technical information exchange as well as in collaborative implementation of R & D items will be getting more and more important in order to establish the fast breeder fuel cycle at a reasonable cost.

REFERENCES

1. H. Sakata, "Construction and function tes of experimental fast reactor Joyo," Energy Development in Japan, 1978, 105.

2. S. Nomoto, H. Yamamoto, and Y. Sekiguchi, "Physics measurement at the start up to Joyo," Proc. International Symposium on Fast Reactor Physics, International Atomic Energy Agency OECD Nuclear Energy Agency, Aix-en-Provence, IAEA-SM-244/8.(1979)

3. H. Taniyama, et al., "Joyo Progress Report," Vol. 7, 1983, PNC N 930-81-03.

4. J. Endo, et al., "Experimental Fast Reactor Joyo,The Third Anuual Inspection Report," 1983, PNC SN941 83-150, PNC report.

5. I. Sato, et al., "MK-II Core Conversion Activities Result in the Experimental Fast Reactor Joyo." 1983, PNC N941 83-27, PNC report.

6. Y. Matsuno, et al., "Joyo Progress Report," Vol. 9, 1983, PNC N 930-83-02.

7. K. Tomabechi, "Experimental Fast Reactor Joyo," Proc. of 2nd International Conference on Liquid Metal Technology in Energy Production, April 20-24, 1980 Richland, WA, U.S.A.

8. S. Nomoto, et al., "Operational Experience from the Joyo Fast Breeder Reactor," Proc. of ANS Meeting in Miami, U.S.A., June 8-12, 1981.

9. Y. Yamashita, et al., "Power Coefficient Anomaly in Joyo," IAEA IWGFR Meeting in Rome, Italy, June 2-5, 1981.

10. H. Yamamoto, et al., "Reactor Physics Characteristics from Operational Testing of the Joyo Experimental Fast Reactor," Proc. of ANS Topical Meeting, 1980 Advances in Reactor Physics and Shielding, September 15-17, 1980 Sun Valley, U.S.A.

11. Y. Matsuno, et al., "Some Topics from Operating and Testing Experience on the Experimental Fast Reactor Joyo," Proc. of International Topical Meeting on LMFBR safety and Related Design and Operational Aspects, July 19-23, 1982, Lyon-Ecully, France.

12. Y. Matsuno and H. Yoshimi, "Development of Fast Breeder Reactor in Japan," Ōyō Buturi, Vol. 48, No. 8 (1979)(in Japanese).

13. Y. Matsuno, et al., "Recent Operational Results and Future Aspect of Joyo, Donen Giho, No. 54-6 (1985)(in Japanese).

14. M. Koyama, et al., "Irradiation Tests Using the Experimental Fast Reactor Joyo," Journal of the Japan Institute of Metals, Vol. 24, No. 8 (1985)(in Japanese).

15. A. Endo and Y. Matsuno, "Instrumentation of the Experimental Fast Reactor Joyo," Journal of the Society of Instrument and Control Engineers, Vol. 20, No. 11 (1981) (in Japanese).

16. Y. Matsuno, et al., "Plant Characteristics Evaluation of Experimental Fast Reactor Joyo," Journal of Atomic Energy Society Japan, Vol. 24, No. 11, pp833-864 (1982)(in Japanese).

17. G. Nagane, et al., "The Role of Joyo and Monju for FBR Development in Japan," Proc. of a Symposium Lyon, Fast Breeder Reactors: Experience and Trends, IAEA-SM-284/5 (1985).

18. Y. Nara, et al., "FBR Technology Development at the Experimental Fast Reactor Joyo," Nuclear Engineering, Vol. 32, No. 2 (1986).

19. Member of the Power Reactor Construction and Operation Division, "An Aspect of the FBR Monju," Nuclear Engineering, Vol. 32, No. 5 (1986)(in Japanese).