INTERNATIONAL CONFERENCE ON NUCLEAR POWER AND ITS FUEL CYCLE

SALZBURG, AUSTRIA • 2–13 MAY 1977

INTERNATIONAL ATOMIC ENERGY AGENCY

IAEA-CN-36/164

PROGRAMME AND CURRENT STATUS OF FAST BREEDER REACTOR DEVELOPMENT IN JAPAN

TOKUO SUITA
Atomic Energy Commission
Tokyo, Japan

AKIRA OYAMA
Power Reactor and Nuclear Fuel
Development Corporation
Tokyo, Japan

1. Introduction [1],[2]

Stable supply of energy is the fundamental requirement for Japanese social life and economy. Nuclear energy is thought to be the only alternative to fossile fuels and the development of the breeder reactor has been regarded as the most important alternative in the near future by the Atomic Energy Commission of Japan (AECJ).

Based on the two-year study to establish the basic strategy for developing advanced power reactors including the fast breeder reactor (FBR), AECJ issued in 1966 a revised long-term programme for atomic energy development.

Thus the Power Reactor and Nuclear Fuel Development Corporation (PNC) was established in 1967 as a nucleus of the project for developing advanced power reactors. In 1968, the Prime Minister of the Japanese Government set up the basic principle and the first phase programme for PNC's FBR Project. Here it stipulates that, two liquid metal cooled fast breeder reactors be constructed: one, the experimental fast reactor of about 100 MW thermal; and the other, the prototype fast breeder reactor plant of about 300 MW electricity. In 1975, after the oil crisis, an experts' committee on advanced power reactors was organized by AECJ to revaluate the energy policy, in particular, the evaluation of nuclear fuel cycle and the policy on advanced power reactor development. In September 1976, AECJ released a report submitted to it by the experts' committee. It states that the transition from the light water reactor (LWR) to FBR be the essential route in view of the nuclear energy strategy in Japan; that the construction of the prototype FBR "MONJU" be initiated as scheduled; and that the demonstration fast breeder reactor start its construction following "MONJU" operation.

In order to reach these conclusions, the following assessments were made:

i) The capacity of nuclear power stations in Japan is assumed to be more than 100 GWe in the year 2000, covering 30 to 40 % of the total electric generating capacity. In Figure 1, the solid lines represent the extrapolation of the current forecast up to 1985, and the dotted lines, the one with more conservative assumptions.

Based on these assumptions, more than 500,000 cumulative metric tons of uranium would be consumed up to the year 2000 even with the introduction of FBRs in 1990. Because of decreasing uranium reserves and their increasing cost, saving of uranium is strongly needed.

ii) By breeding, FBR has the potential of extracting almost all the energy from uranium, yielding a far greater amount of energy than fossil fuels. It is also favourable in not relying much upon enriched uranium and being able to make use of the depleted uranium disposed from the enrichment process.

iii) FBR can close the uranium-plutonium fuel cycle most effectively, by utilising the plutonium which would be produced in a great amount in the near future in LWRs and in later stages in FBRs themselves, thus establishing an independent and more flexible fuel cycle. Figure 2 shows the projected accumulation of fissionable plutonium in Japan.

iv) The construction cost would be more or less higher for FBRs than that for LWRs, but we can anticipate its decrease through improvement of technology, scaling-up and multi-units production. In view of the lower fuel cost of FBR and the increasing trend of uranium price, the electricity production cost of FBR plants would become competitive to that of LWR plants before 2000.

vi) Normal operation and anticipated operational occurrences of FBR plants are not practically different from those of LWR. FBR can keep the integrity of the primary coolant boundary rather easily. The reaction between sodium and water or air can be accommodated well enough by design and fabrication so as to avoid any damage to the reactor core. Thermal pollution is about 30 % less than that of LWR of the same electric capacity.

Radioactive effluents would be same or less than those of LWR. Our experience for many years on plutonium handling, fuel fabrication, and post-irradiation examination as well as the technical progress and effort indicates that the release of radioactive materials to the environment from nuclear power and reprocessing plants and during transportation could properly be prevented.

Concludingly, the fast breeder reactor has an important role in securing the energy supply and it would be the most promising reactor in safety, environmental impact and economy.

The following summarises the current status and future plans in each area of FBR development.

2. Experimental Fast Reactor "JOYO"[3],[4],[5]

2.1 Introduction

"JOYO" is an experimental sodium-cooled fast reactor of the loop type whose core is loaded with mixed oxide fuel of plutonium and enriched uranium and surrounded by blanket fuel of depleted uranium oxide. The rated output of "JOYO" is 50 MW thermal at the first stage (MK-I) and will later be raised up to 100 MW thermal for use as an irradiation facility (MK-II). Figure 3 shows the "JOYO" plant. The reactor cooling system consists of two identical primary and secondary loops and the generated heat is dissipated to air through the terminal heat exchangers. The construction of "JOYO" began at the beginning of 1970 at the O-arai Engineering Center (OEC) of PNC.

2.2 Commissioning tests

The commissioning tests started in April 1975, and are divided into two steps: the first is functional tests and the second, the nuclear tests.

The former has three phases in series, i.e., cold, hot and in-sodium. The cold tests are principally for preliminary testing of fuel handling and transfer systems in air atmosphere at room temperature.

In the hot tests, the reactor components and pipings were heated up to 200 $^{\circ}$C in argon gas atmosphere and their functional behaviour and thermal deformation, if any, were tested.

The in-sodium tests began in early 1976. Functioning and performance of the fuel handling system, entire cooling system and reactor shut down systems were tested in sodium but under non-nuclear conditions.

Nuclear tests will begin with initial fuel loading in the spring of 1977. Then low power tests and power-up tests will follow, step-by-step at several power levels up to the nominal power.

2.3 Future Programme

"JOYO" has plans of increasing power to 75 MW thermal (MK-I phase II) first and then to the target power of 100 MW thermal (MK-II).

a) MK-I, Phase II

For increasing power to 75 MW, no modifications are needed for the hardware of the plant. The data of fuel irradiation has demonstrated the capability of operation at a power level of 75 MW.

b) MK-II

Studies have been made for a high neutron flux core suitable for irradiation purposes. Necessary modifications will be made only to the core component structures, such as core subassemblies, control rods, and reflector subassemblies which replace the blanket subassemblies of the MK-I core. Main design parameters are tabulated in TABLE I together with those of the MK-I cores. Conversion work to the MK-II core is expected in 1979 and then the rated 100 MW operation will begin in 1980.

3. Prototype Fast Breeder Reactor "MONJU" [6],[7],[8],[9],[10]

The prototype fast breeder reactor "MONJU" aims at demonstrating the feasibility of safe, reliable and economic FBRs on the commercial scale. Its design concept was chosen based upon the extrapolation of proven technology, with emphasis on good maintainability and repairability, rather than upon the retro-polation from a target of a future commercial reactor.

Several conceptual designs have already been completed and the final design is now in selection. Figure 4 shows a cut-view of the "MONJU" reactor system.

Meteorological and geological surveys have started at the proposed site. Construction of the reactor will start in 1978 with criticality aimed in 1984. TABLE II indicates the principal design and performance data. "MONJU" is a 714 MW thermal, 300 MW electricity, loop-type FBR plant, fuelled with mixed oxide of plutonium and uranium. The core consists of two different Pu enrichment zones and is composed of hexagon-shaped fuel subassemblies. The reactor inlet and outlet coolant temperatures are 397 °C and 529 °C, respectively. The expected average fuel burn-up and the breeding ratio in the first stage of operation are 55,000 MWd/tonne and 1.2, respectively. The plant systems, however, are designed to accommodate an average fuel burn-up of 80,000 MWd/tonne.

Heat is removed from the reactor by the primary sodium coolant, transferred to the secondary sodium coolant by the three parallel intermediate heat exchangers, and finally to the three once-through type steam generators composed of helical coil tubes. The generated superheated steam at 478 °C at 132 kg/cm^2(g), is sent to the turbine generator.

The main pumps are located on the cold legs for both the primary and secondary systems, and these pumps are of the free-surface centrifugal type. The intermediate heat exchangers are of the vertical shell-and-tube type. Each steam generator consists of an evaporator, a superheater and a reheater.

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

Decay heat removal is normally accomplished by means of the three parallel auxiliary core cooling systems (ACCS). The main primary coolant system and the main intermediate heat exchangers form the primary side of the ACCS and the main intermediate heat exchangers are equipped with auxiliary helical coil tubes as the secondary side of the ACCS.

The plant uses a simple, top-supported reactor vessel, 7.1 meters in diameter and 17.8 meters in height, which is closed at the top by a two-piece shield plug. One piece is fixed while the other is rotary. The reactor vessel is a cylindrical shell with a hemispherical bottom head where three 24-inch main coolant inlet nozzles are located, and three 32-inch main coolant outlet nozzles are located about 1 m above the top of the core. The vessel and its surrounding guard vessel are housed in a reactor cavity which is inside the concrete biological shield structure.

The reactor vessel internals are supported at the lower part of the vessel. Each fuel subassembly in the core has 169 fuel pins in a hexagonal bundle and the radial blanket fuel subassembly consists of 61 fuel pins. The flow distribution in the core is controlled by fixed orifices at the bottom of the fuel subassembly. The fuel subassemblies are hydraulically held-down to the support plate. Cladding material for fuel pins is SUS-316 equivalent to AISI-316 stainless steel. The length of the subassembly is 4,200 mm including shielding portions. The refuelling interval is fixed at around six months and the core will be fuelled by a four-batch scatter loading scheme.

The reactor is equipped with 19 control rods (12 regulating rods, 4 safety rods and 3 back-up safety rods) and B_4C is used as the poison material. A provision is made for instrumentation over the complete core and a portion of the radial blanket. The design provides two thermocouples and a flow meter probe for each core subassembly and two thermocouples for each selected innermost radial blanket subassembly.

Reactor fuel handling is accomplished by use of the single rotating plug and an in-reactor fuel handling machine of a fixed arm length and pantograph-type. The spent fuel is transferred from the core to the storage position within the vessel for decay.

Following decay, fuel is placed into sodium filled pots and pulled up into a charging-discharging machine. The spent fuel will be transported by the machine to the decay storage facility located outside the containment vessel. The decayed spent fuel is then transferred to a steam cleaning facility by an underground transfer car and a rotating transfer machine. Fresh fuel subassemblies will be loaded to the reactor in the reverse process.

4. Research and Development

PNC established the above stated OEC in 1970, where "JOYO" and sodium technology and components test facilities including 50 MW steam generator, and the post-irradiation examination facilities are located.

Since PNC was established in 1967, about 500 million dollars have been invested up to the 1976 fiscal year for the FBR development project and the current number of personnel engaged in the project is around 800 at PNC plus other national institutions but excluding manufacturers and utilities. International cooperation is also being implemented actively with foreign organisations carrying out FBR development.

The following are the current status of each R and D area:

In the reactor physics area,[11] the critical and engineering mock-up experiment of the "JOYO" core had been carried out at the Fast Critical Assembly of Japan Atomic Energy Research Institute (JAERI). For "MONJU", full scale mock-up experiments, called the MOZART programme have been carried out at ZEBRA in collaboration with UKAEA and was completed in early 1973.

In order to assure the reliable performance of the components, full-size prototype components or otherwise scaled-down models were tested in sodium.[12],[13] Prototypes of many key components of "JOYO" were tested at the Large-Component Test Facility at OEC, as well as at industry-owned test facilities.

1 MW and 50 MW steam generator test facilities were constructed at OEC. The first unit of 50 MW steam generator started operation in June 1974 and completed successfully all the tests in mid-1975 without any leakage. A second unit made by a different manufacture was installed in the facility and has been operating and tested without trouble.

Sodium technology development[14] includes tests on compatibility with other materials, thermohydraulics and impurities analyses and their control. In the instrumentation and control area[15], in-core and out-of-core neutron monitors, failed fuel detection and location system, early warning devices for core anomalies and process instrumentation including an under-sodium viewer are being developed.

In fuels and materials,[16],[17],[18] many pilot fuels, materials and fuel subassemblies were and are being irradiated in Rapsodie, DFR, GETR and JMTR and will be also in Phenix. OEC has three post-irradiation examination facilities: Fuel Monitoring Facility, Material Monitoring Facility and Alpha-Gamma Facility. So far post-irradiation examinations have proved that the "JOYO" fuel can withstand 50,000 MWD/tonne of irradiation, and some of test pins reached 120,000 MWD/tonne. For structural design and materials, high temperature structural design analysis method including inelastic and thermal stress analyses are being developed.

In the safety are,[19]PNC is conducting under-cooling experiments in GETR in the U.S. as a joint project with GE, and transient overpower experiments in CABRI in France as a junior partner to the CEA-GfK CABRI Project. Out-of-pile experiments on sodium boiling and fuel failure propagation are being conducted at OEC and those of fuel coolant interaction which have been conducted at PNC's Tokai Works will be intensified at

OEC. Other out-of-pile tests being conducted comprise scaled-down model tests of "MONJU" reactor vessel against internal shock waves; performance tests of aseismic mechanical snubbers operable under high-radiation environments and capable of withstanding thermal expansion; study on piping systems against severance and fracture induced by creep; and development of alternate reactor shut-down systems. Sodium water reaction is studied in three areas: the first, large leak experiment, the second, small leak experiment and the third, integral steam generator safety experiment. The facility of the third experiment was completed in early 1975 and three tests were conducted successfully by the end of 1976. A sodium in-pile loop at JAERI was operated to observe behaviour of the fission product released from bare fuels into flowing sodium.

Beside those R and D activities relevant to the development of "JOYO" and "MONJU", there are other basic activities in Japan in relation to the development of LMFBR's. Examples are those of JAERI where basic studies of fast reactor physics analysis, tests of advanced carbide fuels are being conducted. Also universities and reactor manufacturers have their own sodium and other test loops to conduct experiments and tests. Electric utilities have joint studies with reactor manufacturers on designs of demonstration and commercial FBR plants.[20]

5. Key issues relevant to commercialisation of fast breeder reactors in Japan.[2]

Commercialisation of fast breeder reactors in Japan is now anticipated in mid-1990's. To meet this goal, the following key issues must be assessed.

i) Fast reactor fuel cycle.

Fast breeder plant capacity around 2000 is expected to exceed 10 GW electricity in Japan. Development of remote handling technology, automation in fabrication processes to handle heavy isotopes and larger-cask transportation technology will be needed. In fast reactor fuel reprocessing, developmental work should start in such areas as pre-treatment, voloxidation, solution and solvent extraction technology, and waste treatment. A trial-reprocessing of spent fuels from "JOYO" is being planned. Environmental impact of a large scale FBR fuel cycle should be studied and demonstrated to be insignificant.

ii) Economy of fast breeder reactors.

FBR plants will be competitive with LWR plants by 2000, assuming possible reductions of the FBR construction cost by serial introduction of commercial fast reactor plants, employment of proper and economical designs in addition to the safety design, and studies on scaling-up and improvement of performance and reliability. Here codification and standardisation of FBR design, fabrication and inspection would be a key issue.

iii) Future R and D Programmes.

Following the operation of the prototype reactor, but prior to the commercialisation it appears necessary to construct a demonstration reactor plant which has almost the same capacity with the commercial one and which can demonstrate the economy and performance of commercial plants. The demonstration plant planned in Japan would be of a 3-to-4 loop-design with 1000 ~ 1500 MW electricity in capacity and its construction should start 1 to 2 years after the operation of the prototype reactor.

R and D work for the plant would comprise scaling-up of components, improvement of safety, reliability, operating condition including a higher flow rate in the circulation system, and provision of fundamental data of nuclear constants and material property data, etc.

iv) Organisation for the Development.

In Japan the development has so far proceeded with PNC as a nucleus to implement the work. It would, however, be necessary in the future for the electric utilities to play more important role in the development and demonstration of the FBR plant and for reactor manufacturers in developing system engineering technology so as to obtain the capability to construct commercial FBR plants. Currently PNC has the major role to develope "MONJU", and its efforts will, in the long run, be intensified in areas such as the design of the demonstration plant, safety and fuel cycle research and development.

6. Conclusions

Above stated are the programme and current status of fast breeder reactor development in Japan.

In summary:

1) Fast breeder reactor development in Japan has been carried out as a national project.

2) The experimental fast reactor, "JOYO" has 50 MW thermal as the initial output and would be critical in 1977, eventually its output will be increased to 100 MW.

3) The prototype fast breeder reactor, "MONJU" of 300 MW el icity has almost been completed in its conceptual design and the mc..itoring and survey have started at the proposed site.

4) The Atomic Energy Commission of Japan has recently reconfirmed the highest priority for fast breeder ractor development.

Thus the fast breeder reactor would play a major role solving the energy problem in Japan.

REFERENCES

[1] Oyama, A., et al., "The Program and the present status of fast breeder reactor development in Japan," Peaceful Uses of Atomic Energy (Proc. 4th Int. Conf. Geneva, 1971) 5, UN, New York, and IAEA, Vienna (1972) 101

[2] FBR Subcommittee, Experts' Committee on Advanced Power Reactor, A Report to the Atomic Energy Commission, AEC, Tokyo, (1976)

[3] Hara, T., Kosugi, H., Abe, S., "JOYO" Construction and Preoperational Test Experience, (Joint ASME/ANS Int. Conf. on Advanced Nucl. Energy Systems, Pittsburgh, 1976)

[4] Matsuno, Y., et al., Safety related Design Philosophy and Experience of the Experimental Fast Reactor "JOYO", (ANS/ENS Int. Conf. on Fast Reactor Safety and Related Physics, Chicago 1976)

[5] Inoue, T., et al., R and D on JOYO Core Performance, Journal of Atomic Energy Soc. of Japan, 18 9 (1976) 554 (in Japanese)

[6] "Monju" Group, "MONJU Design Modification (II)", Dohryokuro Giho No. 17, Power Reactor & Nucl. Fuel Development Corp., Tokyo (1976) 52. (in Japanese)

[7] Miki, R., et al., "Brief Description of planned prototype FBR MONJU of Japan", (Proc. Int. Conf. BNES, London, 1974) BNES, London (1974) 85

[8] Suzuki, Y., et al., "Nuclear Performance of MONJU", (Proc. Int. Conf. BNES, London, 1974) BNES, London (1974) 263

[9] Kawashima, K., Suzuki, Y., Safety Related Design of MONJU (ANS Int. Conf. on Fast Reactor Safety and Related Physics, Chicago 1976)

[10] Nakai, Y., et al., "Steam Generators for the MONJU plant", (Proc. Int. Conf. BNES, London, L(&S), BNES, London (1974) 151

[11] Inoue, T., Review of Fast Reactor Physics Activities relevant to LMFBR Programme in PNC, Japan, June 1975 ~ May 1976, PNC Rep. N241 76-07, (the 19th Meeting of NEACRP Chalk River 1976)

[12] Nakai, Y., et al., Reactor System Components of Japan's Fast Breeder Reactors, (Joint ASME/ANS Int. Conf. on Advanced Nucl. Energy Systems, Pittsburgh 1976)

[13] Nakai, Y., et al., LMFBR Coolant System Components, (Joint ASME/ANS Int. Conf. on Advanced Nucl. Energy Systems, Pittsburgh 1976)

[14] Yuhara, S., et al., Sodium Compatibility and Corrosion Tests for Component Materials, (ANS Int. Conf. on Liquid Metal Technology in Energy Production, Champion, Pa., 1976)

[15] Nishikawa, Y., et al., "Fuel Failure and Instrumentation on LMFBR's Safety", (Proc. Int. Conf., BNES, London, 1974) BNES (1974) 497

[16] Uematsu, K., et al., "Operating Experience of the Alpha-Gamma Facility (AGF)", (Proc. of 22nd Conf. on Remote System Tech. 1974) ANS, Chicago (1974) 3.

[17] Uematsu, K., et al., "Materials Monitoring Facility (MMF) for Fast Reactor Material Testing", (Proc. of 22nd Conf. on Remote System Tech., 1974) ANS, Chicago (1974) 11.

[18] Uematsu, K., et al., "Fuel Monitoring Facility (FMF) for Fast Reactor Fuel Subassembly Examinations", (Proc. of 22nd Conf. on Remote Systems Tech., 1974) ANS Chicago, (1974) 20.

[19] Kawaguchi, O., "LMFBR Safety Research and Development at PNC" (Proc. Fast Reactor Safety Meeting, Beverly Hills, 1974) ANS, Hinsdale and USAEC, Washington (1974) 385

[20] Tanaka, N., Kojima, T., A Study of Commercial Fast Breeder Reactor in Japan (ASME/ANS Int. Conf. on Advanced Nucl. Energy Systems, Pittsburgh, 1976)

TABLE I Design Data for JOYO Core

		MK – I Core		MK – II Core
Power	(MW)	50	75	100
Max. Neutron Flux	($n/cm^2 sec$)	2.1×10^{15}	3.2×10^{15}	5.0×10^{15}
No. of Core Fuel Assemblies		67	68	68 (incl. 6 ass'ys for irrad.)
No. of Blanket Fuel Assemblies		191	190	–
Core Fuel				
Pu Content $PuO_2/(PuO_2+UO_2)$	(W/o)	17.7	17.7	30
U Enrichment U^{235}/U	(W/o)	23	23	12.
Clad Diameter Outer/Inner	(mm)	6.3 / 5.6	6.3 / 5.6	5.5 / 4.8
Max. Linear Heat Rate	(W/cm)	231	347	390
Max. Burn up	(MWD/T)	30,000	50,000	60,000
Control Rod				
No of Control Rods		6	6	6
Type		Seal	Seal	Vent
Flow Rate	(ton/hr)	2,200	2,200	2,200
Reactor Out/In Temp.	(°C)	435 / 370	468 / 370	500 / 370

TABLE II Principal Design and performance data

Reactor Type	Sodium cooling loop type
Thermal Power	714 MW
Electrical Power	300 MW
Fuel Material	PuO_2 - UO_2
Core Fuel	
Equivalent diameter	1,790 mm
Height	930 mm
Volume	2,340 lit
Pu Enrichment (Pufiss %)	Inner core/outer core
Initial core	15.0/21.2
Equilibrium core	15.5/21.2
Fuel Inventory	
Core (U + Pumetal)	5.9×10^3 kg
Blanket (Umetal)	1.75×10^4 kg
Average Burn up of	55,000 MWD/T (initial)
Discharged Fuel	80,000 MWD/T (target)
Cladding Material	SUS 316
Cladding Outside Diameter/Thickness	6.5/0.47 mm
Permissive Cladding Temperature	
(Middle of Thickness)	675°C
Power Density	273 KW/lit.
Blanket Thickness (axial/radial)	Upper 300 mm Lower 350 mm/306 mm
Breeding Ratio (initial/equilibrium)	1.22/1.20
Reactor in/out Sodium Temperature	397/529°C

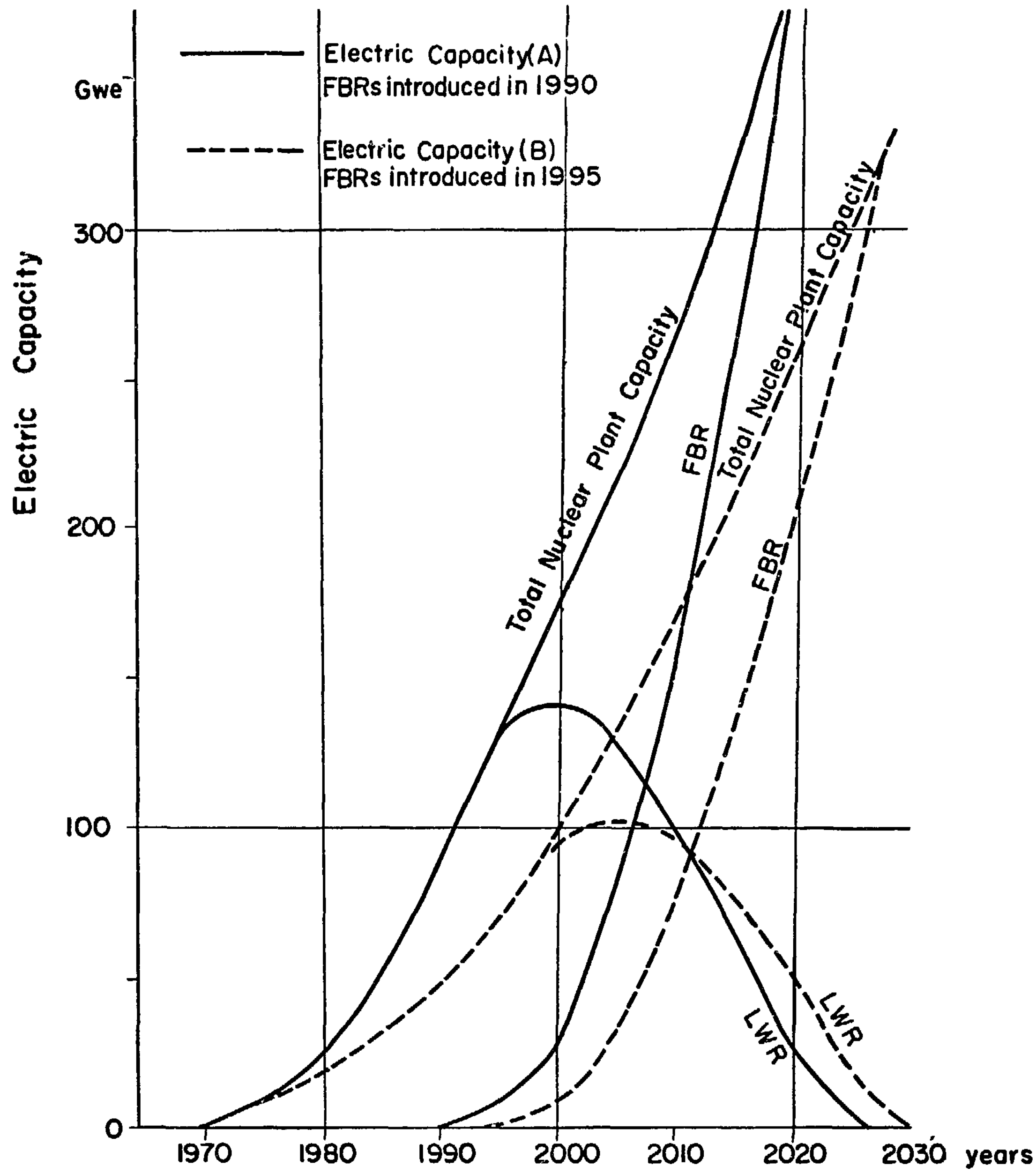

Fig.1 Nuclear Power Plant Capacity and Reactor Types

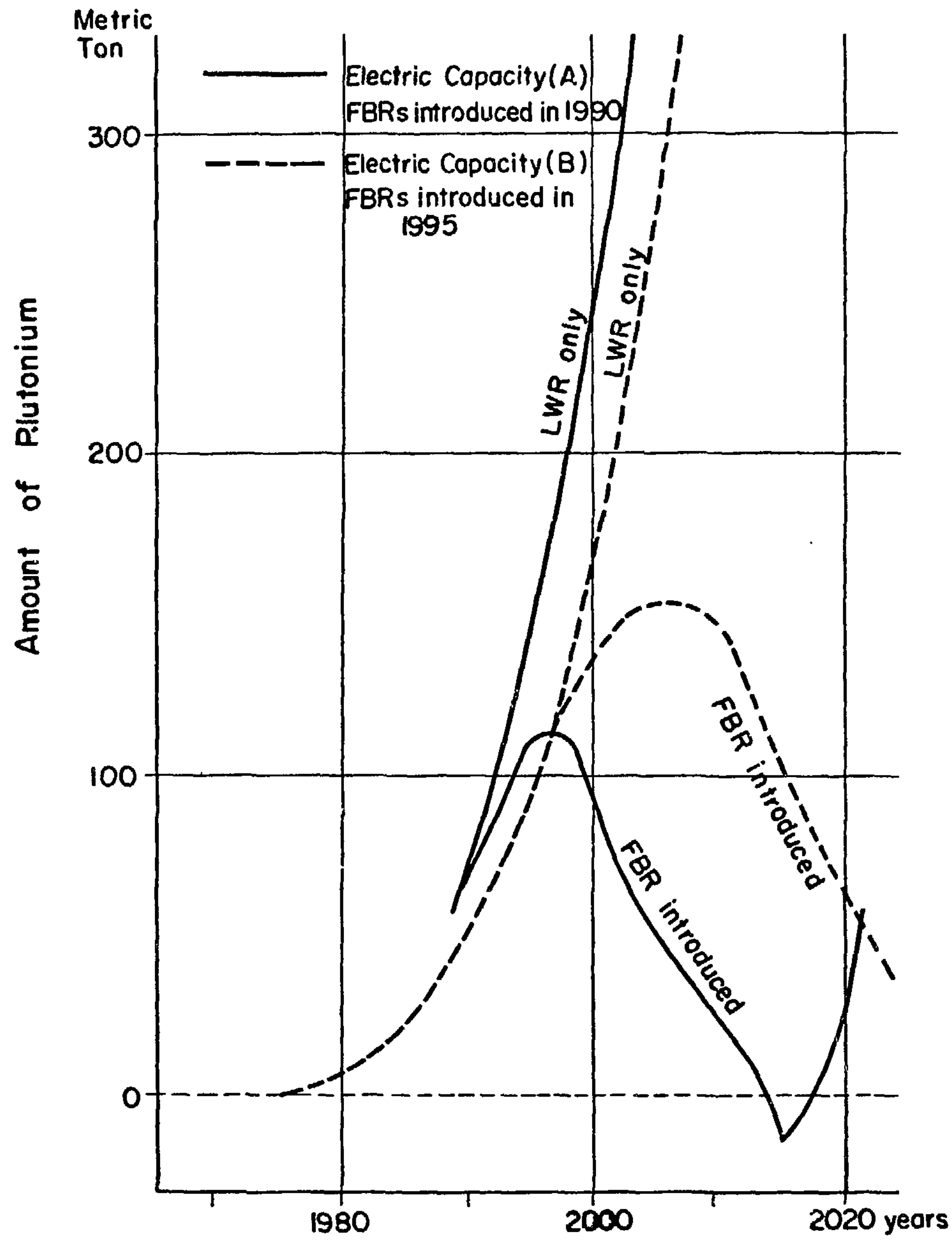

Fig.2 Cummulative Amount of Fissionable Plutonium

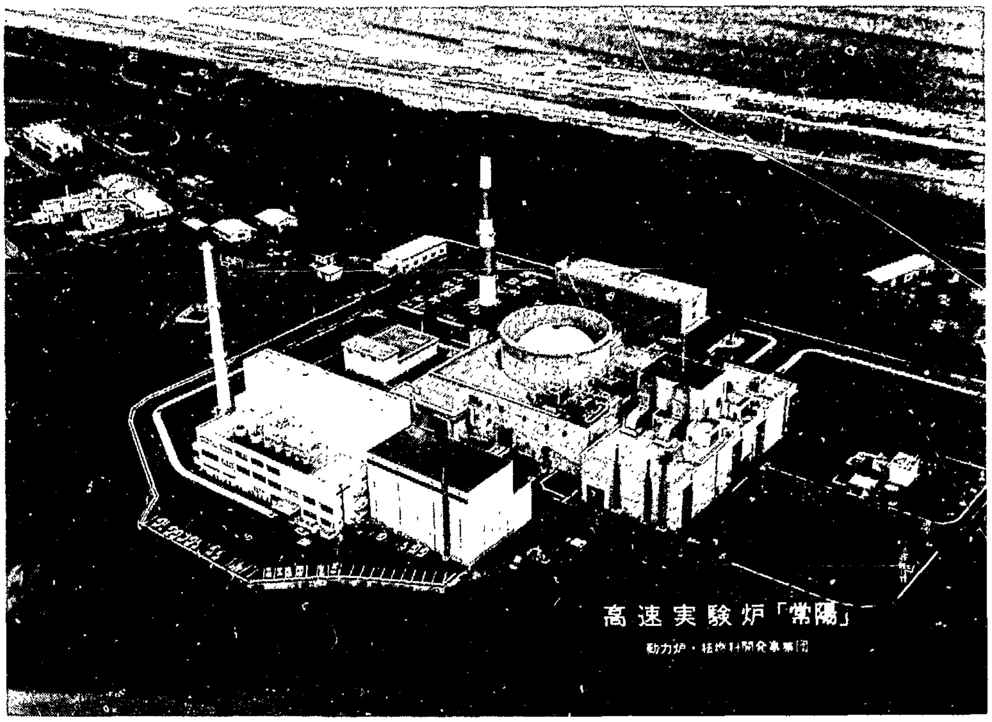

Fig.3 The "JOYO" Plant

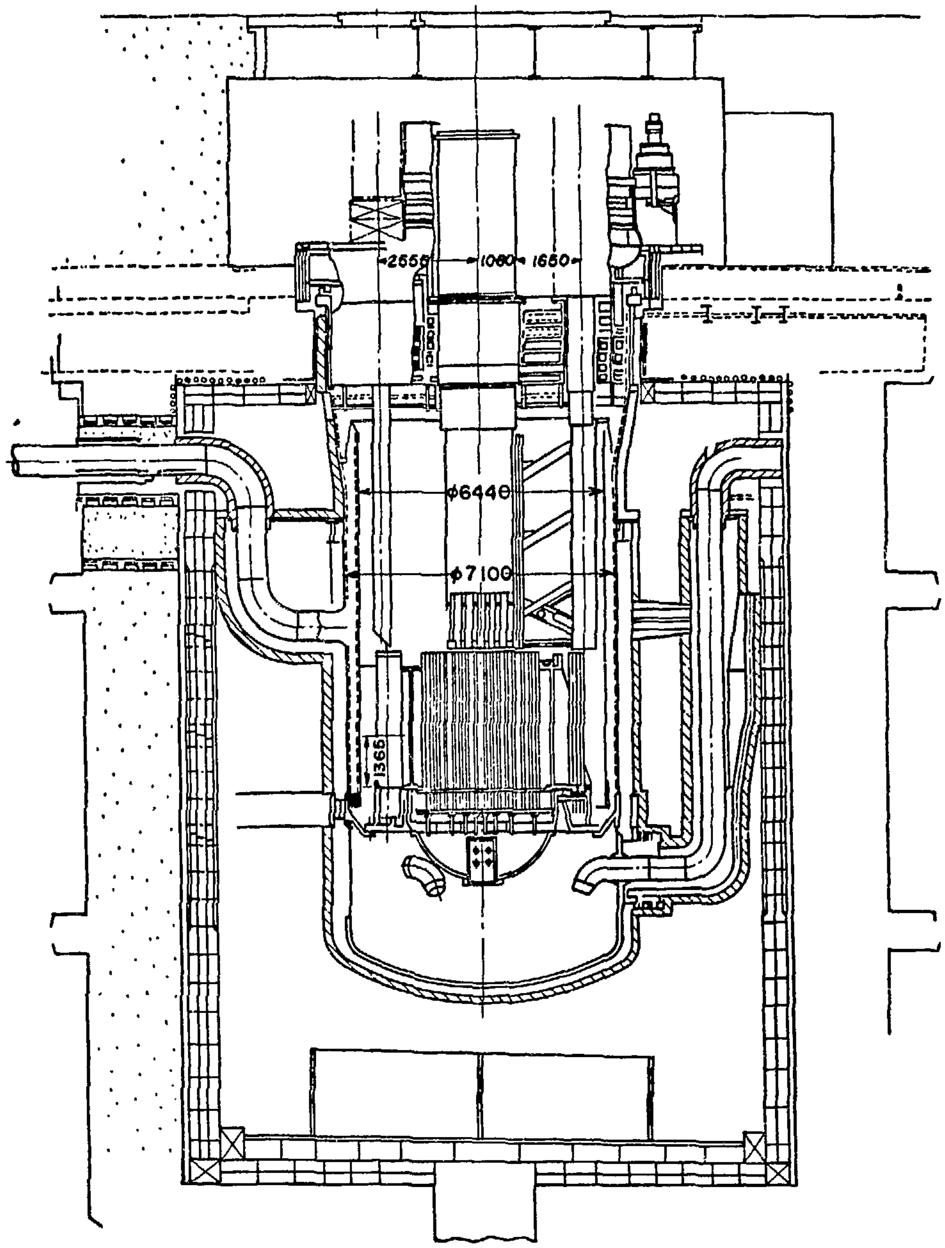

FIG. 4 MONJU REACTOR SYSTEM