CURRENT STATUS OF SODIUM-COOLED FAST BREEDER REACTOR DEVELOPMENT IN JAPAN

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I. INTRODUCTION

Development of fast breeder reactor in Japan is one of the national projects which is given the top priority to execute in order to play an important role in solving the energy problem in this country. This paper describes historical background to establish the national policy and the current status of fast reactors' design and construction and relevant R and D efforts.

II. ESTABLISHMENT OF BASIC PRINCIPLES FOR DEVELOPING FAST BREEDER REACTORS IN JAPAN

In the mid 1960's, the significant rise in demand for electrical power has emphatically brought up the need for nuclear power generation in Japan and our government has considered as a policy that the most essential and urgent task was to develop advanced power reactors and not to rely simply on conventional reactors such as light water reactor, so as to assure the supply of nuclear fuels, and to make full use of them.

A study made by a committee organized by the Japanese Atomic Energy Commission lead to a decision by our government to set up the national policy for developing fast breeder reactors.

The policy states that a) technology for the fast breeder reactor in Japan be established before the latter half of the 1980's when its commercialization would come into sight, b) the type of reactor to be developed would be sodium cooled, fuelled with mixed oxide of plutonium and uranium (LMFBR), c) one experimental fast reactor of 100 MWt and one prototype fast breeder reactor of 200 ~ 300 MWe would be built, d) to ensure the nation-wide collaboration to the LMFBR project, a new organization with an unified system be established, while those tasks considered appropriate be assigned to selected institutions so as to get all the capacity available across the nation.

In order to implement the policy, an organization called the Power Reactor and Nuclear Fuel Development Corporation (PNC), was established in October 1967. Since then development of the two reactors has been carried out under the responsibility of PNC, with co-operation of the Japan Atomic Energy Research Institute (JAERI), universities, industries, electrical utility companies and some national research institutes.

In recent years, after the oil crisis in particular, the forecast of energy demand is getting much less than it has been expected before. One can say that the nuclear energy demand might be in the same trend. Besides, we are facing a delay of construction of some stations as well as "reported" incidents at several nuclear power stations. Nevertheless, it is believed that the basic motive force to the need of nuclear energy in Japan can not afford to be altered and the development of fast breeder reactor should be the key effort for us to make. It is because we have shortage of natural resources in our country whereas LMFBR has potentials to close uranium fission fuel cycle most efficiently and to attain the near-term commercialization in engineering wise.

We are now in the first phase of development of LMFBR. The target of the first phase is to reach to the following milestones around the beginning of 1980's.

1) Accumulation of operational experiences of several years with an experimental fast reactor, "JOYO", as an irradiation facility for developing advanced fuels and materials.
2) Successful completion of a prototype fast breeder reactor, "MONJU".
3) Sufficient confidence of LMFBR component technology based on operational experience of several years with large component test facilities, such as steam generator test facility and sodium components test facility.
4) Sufficient confidence of relevant basic technology, such as those of fuels and materials, reactor physics and safety.

After reaching to these milestones, it will be possible to enter into the second phase in which construction of a large LMFBR plant will be involved. It is expected that the details of the program of the second phase will be defined in the near future.

III. THE EXPERIMENTAL FAST REACTOR, "JOYO"

Purpose of constructing "JOYO" is to acquire experience of design, construction and operation of sodium-cooled fast reactor, the first of its kind in Japan. After completion, the reactor will be used as an irradiation facility for developing advanced fuels and materials.

The concept of "JOYO" whose name came after a literary name of the area where the reactor is located, was originated from a preliminary design done by JAERI in 1964 and 1965.

Having handed over design data of this reactor to PNC in 1968, the new Corporation initiated the conceptual design of the reactor, making use of the experience of domestic manufacturers for designing and manufacturing many reactors in Japan. At this stage, thermal output was set at about 100 MWth.

However an output of 50 MW was adopted as the first step in the application for the construction permit which was approved by the regulatory body in 1970.

Its construction and installation of components have already been completed at the O-arai Engineering Center of PNC. It is now under precommissioning test and expected to be critical toward the end of this year.

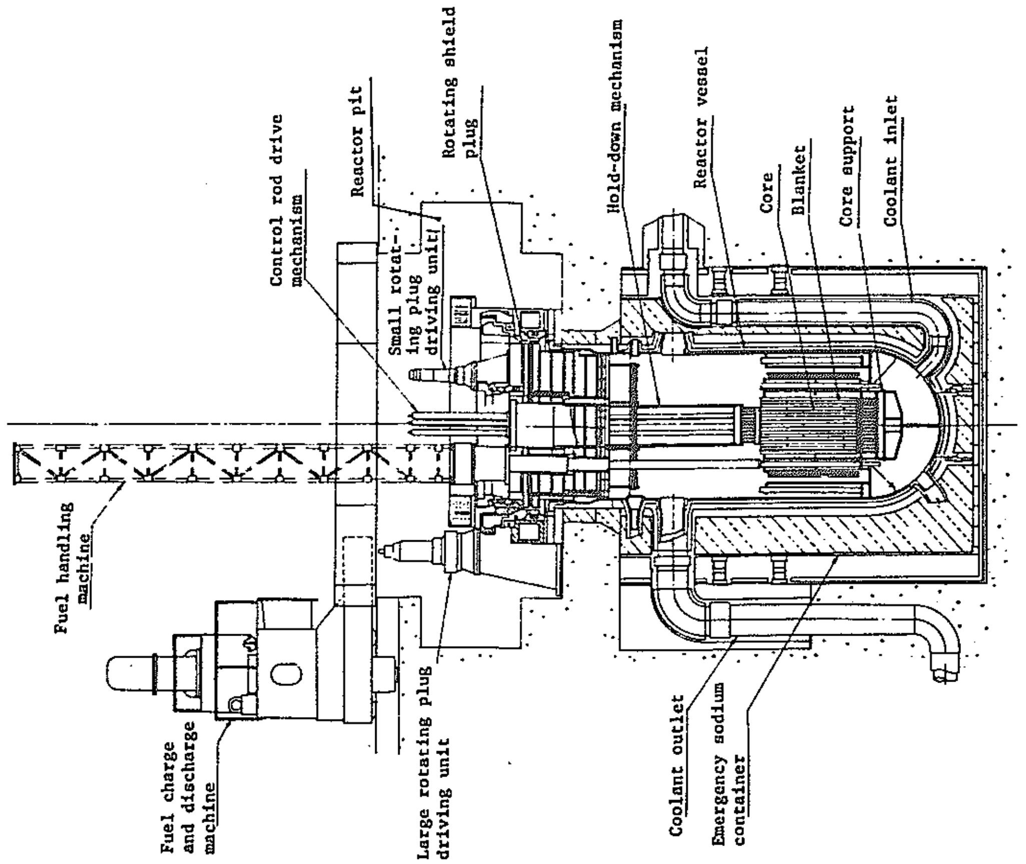
Table 1 shows the main design specification of "JOYO" at 50 MWth operation and Figure 1 shows its sections. The core of "JOYO" is fuelled with mixed oxides of uranium and plutonium, surrounded by a blanket of depleted uranium oxide. "JOYO" as well as "MONJU", (the prototype fast reactor explained later) are so-called loop-type reactor. A debate with regard to design concepts of loop versus pool (tank) is well known in the current fast reactor community of the world. We considered that both types may be used together when ~~with~~ the large fast reactor comes into practical use, however, the maintenance or repair work on major components in the primary cooling system may be inevitable, at least, on early plants to be built and for such work, loop concept has certain advantages because of easy access to the components. Thus we have chosen loop type for our reactors.

"JOYO" has two identical sodium loops; each having heat removal capacity of 50 MWt. Each loop consists of a primary cooling system, an intermediate heat exchanger and a secondary cooling system. Thus, heat generated in the core is finally dissipated into the air. The reactor has two control rods and four safety rods.

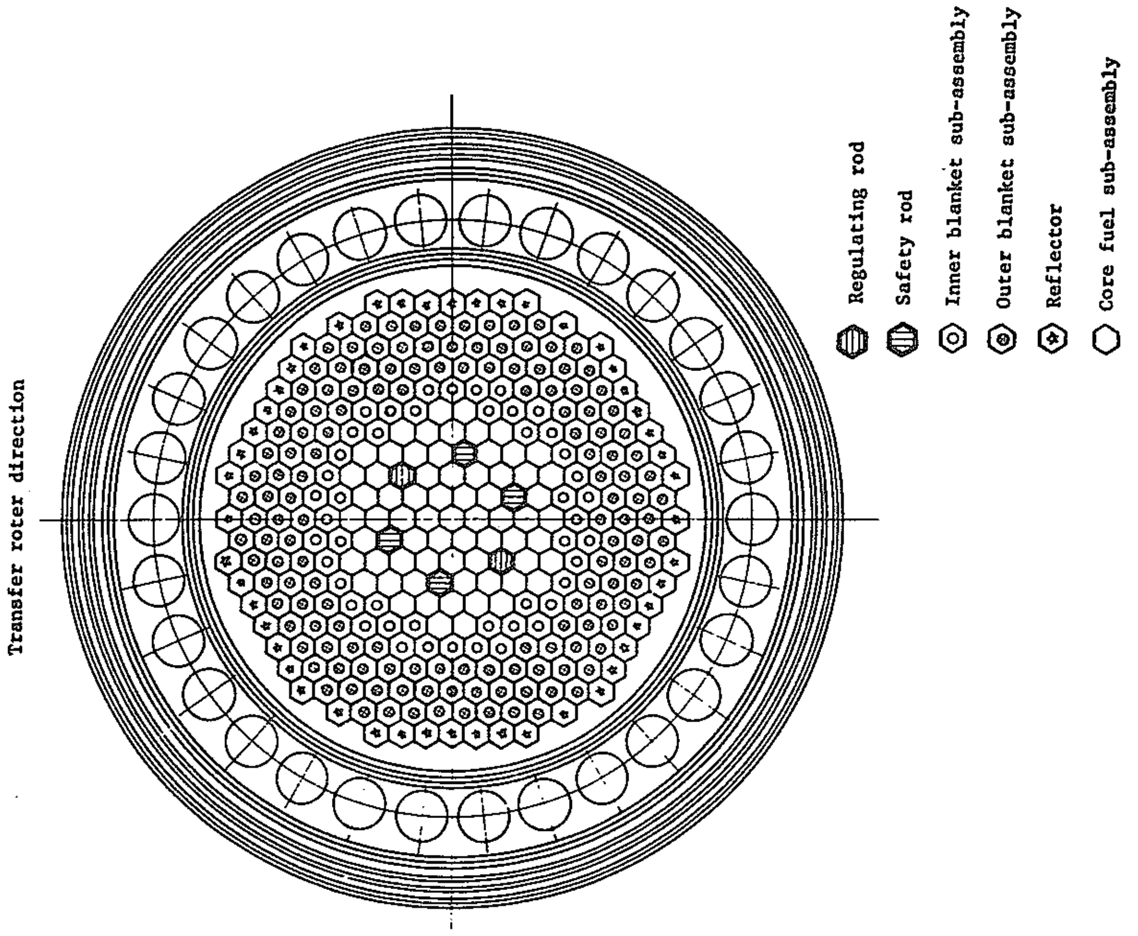
The reactor vessel is a double-walled cylinder of stainless steel, the space between the walls being filled with nitrogen gas not only for preheating and maintaining temperature, but also for preventing sodium from leaking into the atmosphere. The top of the reactor vessel is covered with a main rotating plug composed of graphite and concrete and

Table 1. Design Data for "JOYO" Core

		MK - I Core		MK - II Core
Power	(MW)	50	75	100
Max. Neutron Flux	($n/cm^2 \cdot sec$)	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	11.8
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



a) Vertical Cross Section of JOYO Reactor



b) Core Diagram and its Surroundings of JOYO

Fig. 1 Sections of "JOYO"

is equipped eccentrically with a small rotating plug set in the large one.

Around the reactor vessel is graphite shielding and outside this is the biological shielding of concrete. Heat generated in the reactor is transferred by the coolant to the intermediate heat exchanger where the heat is transferred to sodium in the secondary circuit. This secondary sodium is circulated and cooled by an air cooler.

"JOYO" has an air-~~githt~~tight steel containment vessel in which the whole primary cooling system as well as reactor are enclosed.

It is planned to increase the present power of 50 MWt to the final power of 100 MWt, after successful commissioning of the reactor. The present program includes to increase the reactor power to 75 MWt first, without any modification, and then to 100 MWt by slightly modifying fuel design. With the modified fuels (called Mark II core) a neutron flux of 5×10^{15} n/cm^2 sec will be attainable.

Table 1 figures the design data of Mark II core also.

IV. PROTOTYPE FAST BREEDER REACTOR, "MONJU"

"MONJU" whose name came from one of the Buddha's principal disciples commenced its design in 1968. This reactor aims at demonstrating reliability, safety, operability and ease of maintenance of fast breeder power reactor station. Several phases of conceptual design have already been completed.

It is now under "Check and Review" by the Japanese Atomic Energy Commission since last August. The "Check and Review" is a process in Japan prior to submitting an application of construction permit to the government for evaluating "MONJU" in the standpoint of the future energy policy in Japan as well as its design, and relevant

R and D and their results obtained.

It is hoped the plant will be put in its construction in 1977.

"MONJU" is an 714 MWt, 300 MWe, loop type fast breeder reactor plant, fuelled with mixed oxides of plutonium and uranium. The heat generated in the reactor is transported by three primary and secondary sodium loops to three sets of once-through steam generators that produce 132 Kg/cm^2 steam at ~~487~~ 483 °C. The fuel handling system consists of a single rotating plug and one under-the-plug fixed arm fuel handling machine in the reactor vessel.

The core is zoned for two different Pu enrichment and composed of hexagon-shaped fuel subassemblies. The expected mean fuel burn-up and breeding ratio are 80,000 MWd/t and 1.2, respectively. The reactor inlet and outlet temperatures are 397 °C and 529 °C, respectively. The plant uses a simple, top-supported reactor vessel, 7.1 meter in diameter and about 18 meter in height.

All primary system components are located below the main operating and shield floor in an inert atmospehre in the leak tight double containment structure of approximately ~~51~~ 49 m in diameter and 80 m in height.

The principal design parameters of the plant are listed up in Table 2 and Figs. 2 and 3 show the main heat transport system diagram and reactor vertical section, respectively.

The core has two radial zones of different enrichments. It is surrounded by axial and radial blankets of the depleted uranium oxide, whose thicknesses are about 30 cm and 35 cm respectively. The fission gas plenum is located at the top of the fuel rod.

Each fuel assembly in the core has 169 fuel rods, being hexagonally bundled and 61 fuel rods in the radial blanket fuel assembly.

Table 2. Design parameters of "MONJU"

Power	714MWt 300MWe
Coolant	Na
Reactor in/out temp.	397/529 °C
No. of 1ry/2ry loops	3/3
1ry coolant flow rate	4,000 t/h
Steam condition	483 °C/127 atg/32 atg
Core height	93 cm
Equivalent diameter	177.5 cm
Axial blanket height	30 cm (top) 35 cm (bottom)
Radial blanket height	160 cm
No. of core subassemblies	198
No. of blanket subassemblies	174
No. of control rod	19
Core Fuel	
Pufiss/(Pu + U) (inner/outer)	15.5/21.2 %
U^{235}/U	0.2 %
Pellet diameter	5.4 mm
Clad outer diameter	6.5 mm
No. of pins/subassembly	169
Inventory (PuO_2 + UO_2)	5,900 Kg
Bleeding ratio	~ 1.2
Average neutron flux	4×10^{15} n/cm^2·sec.
Average fuel burn-up (target)	80,000MWD/t
Max. linear heat rate	417 w/cm
Reactor vessel diameter/height	7/18.0 m
Reactor container	
Inner diameter	49 m
Height above ground	45 m
Fuel Handling	Single rotating plug with fixed arm
Steam Generator	
No. of EV/SH/RH	3/3/3
Type	Helical coil tube

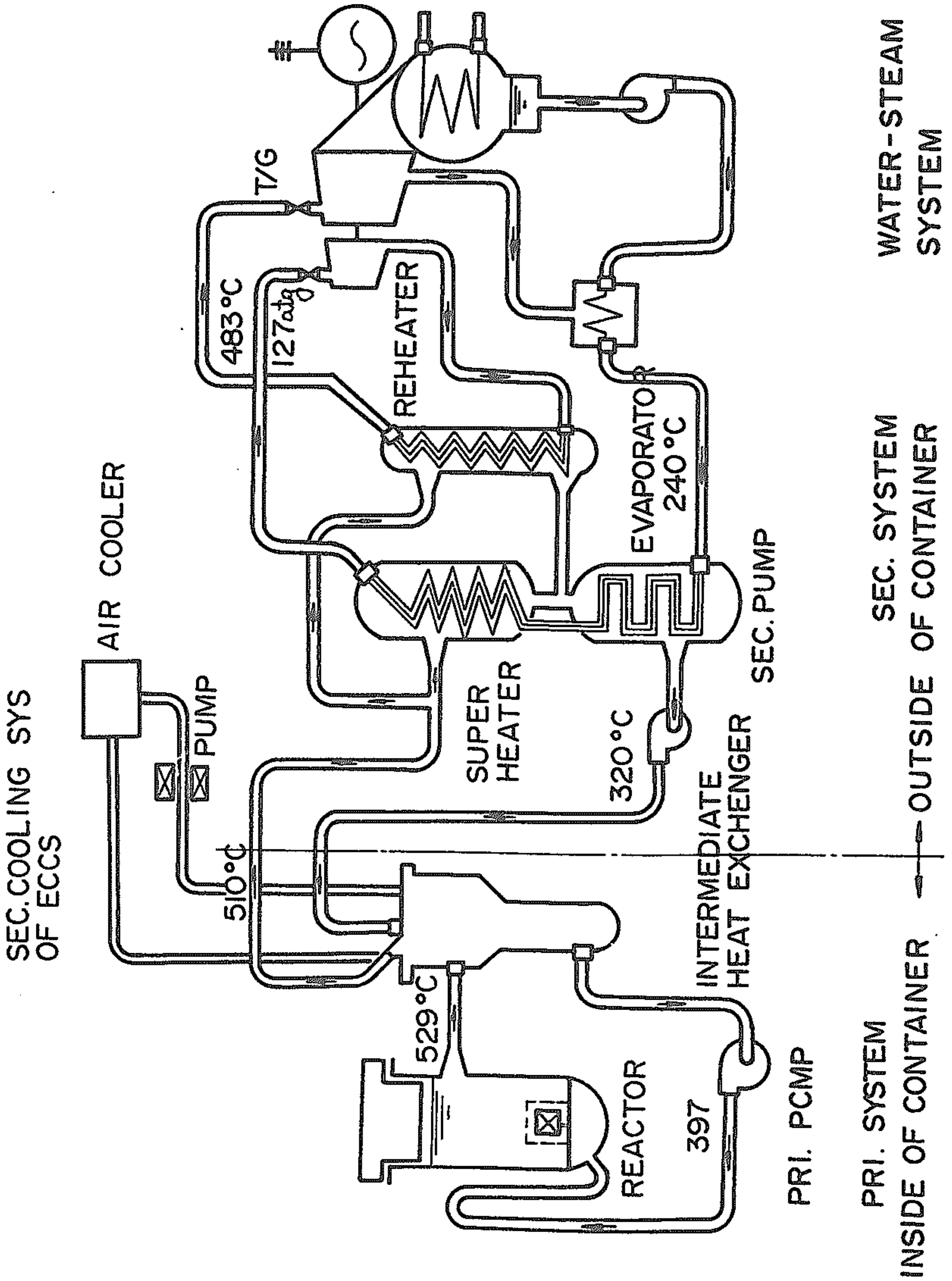


Fig. 2 MAIN SYSTEM OF MONJU

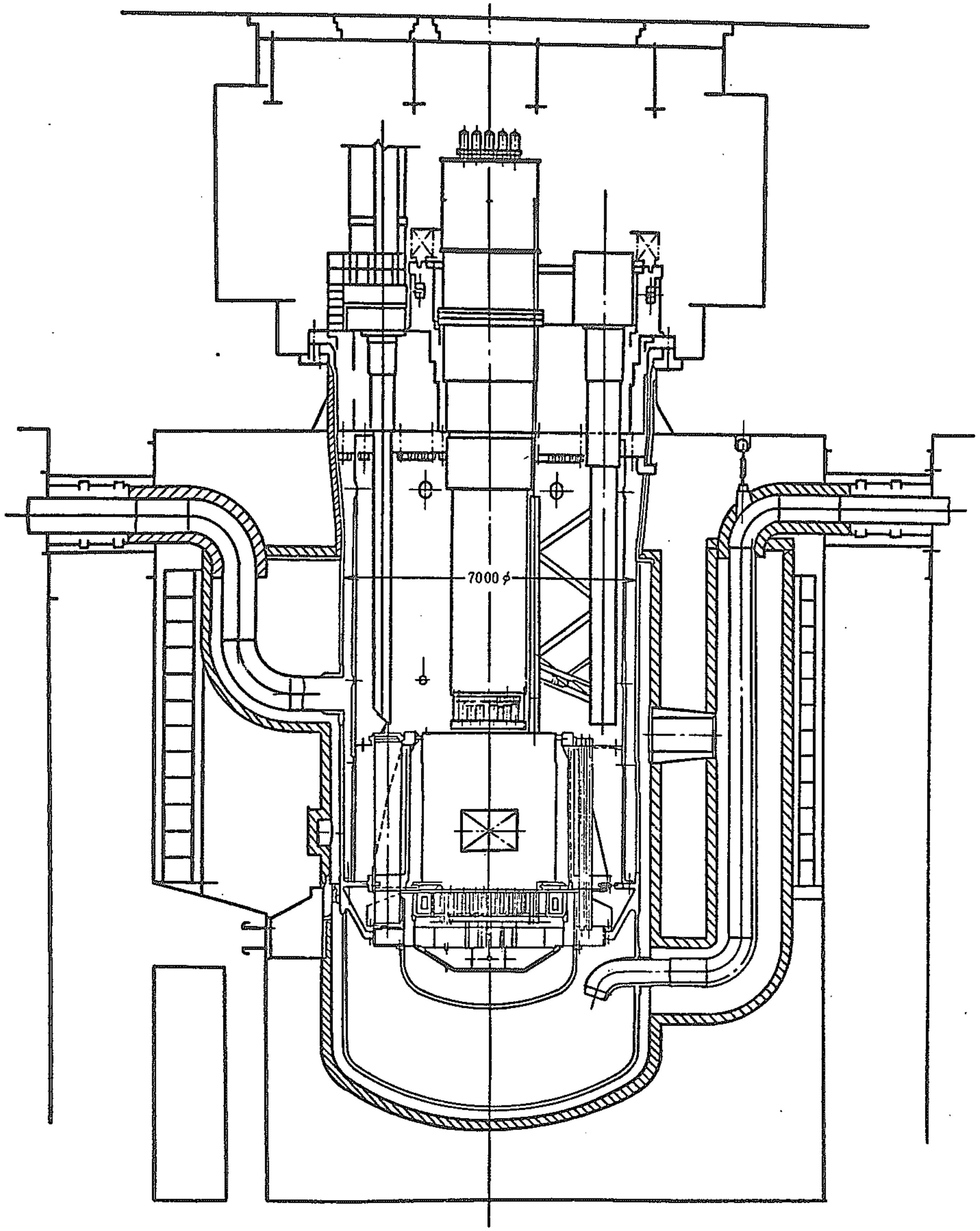


Fig. 3 REACTOR PROPER OF MONJU

The flow distribution in the core is controlle dby fixed orifices at the bottom of the fuel assembly. The fuel assemblies are fixed hydraulically at the bottoms to the support plate. The average removal burn up for the equilibrium core is chosen to be 80,000 MWd/t. The refueling interval is fixed at around six months and the core will be fueled by about five-batch 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.

The reactor vessel is a cylindrical shell where three 24 inch main coolant inlet nozzles are located with a hemispherical bottom head and three 32 inch main coolant outlet nozzles are located about 1 m above the top of the core element. The reactor vessel is supported free radially at the lower part for earthquake. Core clamping mechanism is equipped around the core preventing the bowing and vibration of the core elements during the reactor operation and being reliable for the refueling. The reactor vessel is surrounded by the guard vessel which is inside the concrete biological shield structure.

The shield plug consists of the small rotating plug with the hold down mechanism and mounting the refueling machine and the large fixed plug.

The basic concept of the refueling of "MONJU" is the under-the-plug system in the reactor vessel. It has a single rotating plug at the top of the reactor vessel with a rotating arm fuel handling machine. With this system, the spent fuel is transferred from core to the in-vessel storage rack and the new fuel subassembly is transferred from the transfer rack to the core and blanket region.

Ex-vessel fuel handling system includes the fuel transfer

machine, cask car, spent fuel storage tank, cleaning facility and water pool.

The flow diagram for the main coolant system is shown in Fig. 2. Each of the primary coolant loops consists of an intermediate heat exchanger, a main coolant pump, a check valve and piping, while each of the secondary loops has flow control valves, stop valves, a steam generator set, a main coolant pump and piping.

The emergency cooling system is provided with the air cooler as the heat sink. The primary argon cover gas system is a closed cycle system. It gives a pressure common to the cover gas ~~is~~ in the reactor vessel, the main coolant pump and pump overflow tanks.

The main pumps are located in the cold legs for both the primary and secondary systems, and these pumps are free surface centrifugal type. The intermediate heat exchangers are vertical shell and tube type with the primary coolant flow in the shell and the secondary coolant flow in the tube.

Each steam generator comprises an evaporator, a super-heater and a reheater.

The steam generators are the once-through type with the helical coil tubes. The choice of the helical coil type of heat transfer tubes is based on the compact, economic, reliable for manufacturing and operation.

The reactor containment is the double wall type and the inner containment consisting of the reactor pit and cooling system cavity is filled with nitrogen gas during reactor operation and the outer containment made of the steel cylindrical containment surrounded by concrete wall is filled with air. This reactor containment is located in the center of the reactor building which has the rectangular shape about

98m x 112 m, being very rigid against earthquake.

V. RESEARCH AND DEVELOPMENT OF FAST REACTOR

Research and development efforts of LMFBR in Japan had commenced before PNC was established though not a large scale. Preliminary study on sodium technology had started in the mid 1960's at an industrial company under the auspices of the government, JAERI activities being followed. The plutonium laboratory was set up in 1964 at the Atomic Fuel Corporation (AFC), now united with PNC and the Fast Critical Assembly of JAERI was in operation in 1966. The Central Research Institute of Electrical Power Industries (CRIEPI) has participated in the activities of the Atomic Power Development Association, Inc., USA since 1966. This participation could contribute to foster many Japanese nuclear engineers to obtain experience on fast reactor operation and maintenance.

With all these efforts in hand, Japan could move ahead on the development of LMFBR, putting PNC as the core of the project and assigning individual R and D tasks to the appropriate research organizations, in and out of the country. Such tasks as the engineering of large-scale components and the post-irradiation examination of fuels and materials, which we believed to be crucial for realizing the reliable operation of LMFBR's but which could not be assigned to any other organizations, had to be undertaken by PNC itself.

Thus PNC established the O-arai Engineering Center (OEC) which was officially inaugurated early in 1970. On the other hand, a variety of other R and D works relevant to "JOYO" and "MONJU" are assigned to many research institutions.

Following are the current status of each of R and D areas.

Reactor Physics: The critical and engineering mock-up experiment of "JOYO" core had been carried out at Fast Critical Assembly of JAERI including control rod worth test, while neutron shielding and source tests were made at "JAYOI" reactor of Tokyo University. For "MONJU", full scale mock-up experiments, called the MOZART programme has been carried out at ZEBRA in collaboration with UKAEA and completed in early 1973. A great variety of information necessary for predicting physics parameters of the "MONJU" core was obtained. On the contrary, a partial mock-up experiment was started in 1972 at FCA, JAERI, under the contract between PNC and JAERI to obtain many data necessary to design, such as Doppler coefficient, sodium void effect, etc. Modification of FCA to accommodate a larger core than the present one was completed last June. A variety of cores of approximately 300 Kg of plutonium and 550 Kg of uranium can be accommodated. Development of analytical method is another area, in which improvement of JAERI-FAST cross-section set and development of analysis code of "JOYO" operational performance are major tasks.

Components Development: Since "JOYO" is the first reactor of its kind in Japan, we have applied conservatism to its design and development of components. In order to assure and demonstrate the reliable performance of the components and/or systems, it would be essential to test full-size prototype components or otherwise scale down models at the environment as similar as possible to the actual reactor's one before it will be actually manufactured.

Therefore prototypes of many key components of "JOYO" were tested at the Large-Component Test Facility at OEC, ~~PEN~~ PNC including full size prototype of reactor vessel, rotating shield plug, fuel handling machines and pumps. Not a few valuable experience were obtained during the test operation of these components and they could be fed into either design or manufacture of the actual reactor components. Some of other key components or their parts have been tested at sodium and water test facilities owned and operated by domestic manufacturers.

One of the most crucial and important components for "MONJU" is steam generator. Thus 1 MW and 50 MW steam generator test facilities were constructed at OEC. The 1st unit of 50 MW steam generator has started its operation in June 1974 and completed all the tests in the middle of 1975 most successfully without any leakages. Now the facility is about to restart with the 2nd unit. Other tests, for instance, for sodium thermal shock to the components and performance of control drive mechanism are also under way at the OEC.

Sodium Technology: Sodium has less affinity to human being than ordinary water, though the former has many advantages as the reactor coolant over the latter.

The tests in this area aim at demonstrating the materials and/or components selected to be used in sodium of "JOYO" and "MONJU" can withstand the specified design conditions or finding out the data needed for designing various components.

Major tasks are handling of nonradioactive and radioactive sodium, its compatibility with other material, effect to mechanical properties and strength of materials and their welded parts, thermohydrodynamics and impurity analyses and its control. For these studies works are being performed at many sodium loops at the OEC.

Instrumentation and Control: In-core and out-of-core neutron monitors, failed fuel detection and location system, early warning devices for core anomalies and many kinds of process instrumentation are being developed while steam generator and plant dynamics are being analysed using both digital and hybrid computers.

Fuels and Materials: "JOYO" core fuel assemblies completed their fabrication at the Tokai Works of PNC last Many while all the blanket assemblies were made by domestic industrial companies and have already been installed into the "JOYO" reactor.

Many pilot fuels, materials and fuel assemblies were and are being irradiated at Rapsodie, DFR as well as GETR and JMTR. At the OEC of PNC we have three post-irradiation examination facilities, i.e., Fuel Monitoring Facility, Material Monitoring Facility and Alpha-Gamma Facility. So far PIE has shown the "JOYO" fuel could withstand 50,000 MWD/T of irradiation.

Endurance-in-sodium-test were performed for full size dummy fuel assemblies of "JOYO" and "MONJU" at the design sodium flow condition. Gradual increase of flow impedance through the fuel channel was obtained.

Though knowing the importance, studies related to fuel cycle are not actively carried out yet.

Safety: In connection with accident analysis, two major experiments will soon be commenced at GETR and CABRI. The former is to confirm the integrity of the "MONJU" fuel pins under the primary coolant pipe being damaged and blockage accident in local flow. The latter, although PNC is a junior partner to the joint CABRI project, is to observe transient behaviour of fuel pin during reactivity excursion. In connection with these experiments development of codes analyzing whole core accidents has been started actively. At OEC, experiments of sodium boiling and fuel failure propagation are being conducted while those of fuel coolant interaction are emerging at the Tokai Works.

As for the structural safety studies, scale-down model of "MONJU" reactor vessel were tested against the internal shock wave generated by a slow explosive simulating the hypothetical core disruptive accident. A mechanical snubber operable under high-radiation circumstances as well as capable of withstanding both thermal expansion and earthquake has been developed.

Study on piping system against severance and fracture mode induced by creep and alternate reactor shut-down systems are being performed.

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 early in 1975 and the first experiment was conducted successfully.

In relation to hazard analysis, a sodium in-pile loop (SIL) was installed at an experimental hole of a research reactor JAERI to observe behaviour of fission product released from bare fuel into flowing sodium. A couple of years operation and experiment were discontinued from 1974 to 1975 due to repair of the reactor. Other activities include removal of noble gas from cover gas, thermophoretic adherence of nuclear aerosol on the containment wall, and development of a new type air filter with high sodium loading.

Above ~~area~~ are R and D activities relevant to development of "JOYO" and "MONJU". Here I have to mention that beside these activities, there are many other activities in Japan in relation to development of LMFBR's. Examples are those of JAERI where basic studies of fast reactor physics analysis, tests of advanced carbide and nitride fuels

and universities and industries have their own sodium loops to conduct experiments and tests. Electrical utility companies have joint study with industries on design of large fast breeder reactor plant.

Thus it can be noticed that very broader R and D efforts are being made in Japan for realization of "JOYO", "MONJU" and large fast breeder reactors.

VI. CONCLUSION

Above described are establishment of development policy of LMFBR in Japan, design and construction of "JOYO" and "MONJU" and relevant R and D efforts. We are now in the first stage and there are still many areas to be developed for commercialization.

However, we are sure that LMFBR can and must play the major important role as a key energy resource in the near future so long as fission energy from uranium would have to be used.

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