Upgrading Program of the Experimental Fast Reactor Joyo

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Abstract

The experimental fast reactor Joyo finished its operation as an irradiation core in June, 2000. Throughout the operation of MK-I (breeder core) and MK-II (irradiation core), the net operation time has exceeded 60,000 hours. During these operations there were no fuel failures or serious plant problems. The MK-III modification program will improve irradiation capability to demonstrate advanced technologies for commercial Fast Breeder Reactor (FBR). When the MK-III core is started, it will support irradiation tests in feasibility studies for fast reactor and related fuel cycle research and development in Japan.

Introduction

The experimental fast reactor Joyo attained its initial criticality in April, 1977 with the MK-I breeder core. Initially, the reactor operated at 50MWt and was later increased to 75MWt. In 1982, the MK-II irradiation core increased the rated thermal output to 100MWt to utilize Joyo as an irradiation test bed for FBR fuels and materials. Thirty-five duty cycle operations and several special tests with the MK-II core were completed by June 2000. Today, the Joyo net operation time exceeds 60,000 hours and the maximum burn-up of the irradiation test fuel has reached 144,000MWd/t. The operation history of Joyo is shown in Figure 1.

A large number of tests were conducted with the MK-II core. Irradiation tests using four online irradiation rigs (two for fuel irradiation and two for material) and sixty-four offline irradiation rigs (seventeen for fuel and forty-seven for material) were conducted. Other tests include two Power To Melt tests (PTM) and three performance tests of Failed Fuel Detection system (FFD) and Failed Fuel Detection and Location system (FFDL).

Special diagnostic equipment developed during these tests includes the INstrumented Test Assembly (INTA) which was developed to measure the temperature at the center of fuel pellets. The MAterial testing RIg with temperature COntrol (MARICO) was also developed for in-pile creep rupture test of cladding materials under the fast neutron irradiation [1]. The MARICO has irradiation capsules and the temperature inside of the capsule can be controlled by the mixture ratio of argon gas and helium gas, which is enclosed in the capsule's double wall thermal insulated gas gap.

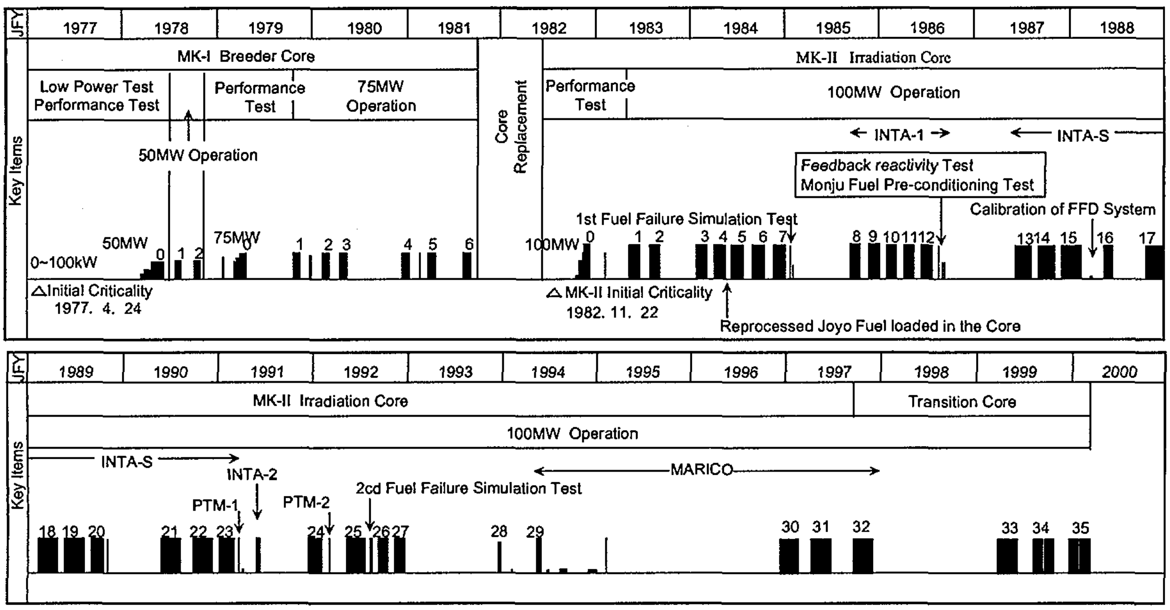

Figure 1 Joyo Operational History

Outline of MK-III program

Joyo is expected to play a greater role by providing a test bed for irradiation tests of various kinds of fuels and materials. To support the increasing requirements for these tests, the MK-III program [2,3 and 4] improve Joyo irradiation capability. With the MK-III upgrade, Joyo can better support irradiation tests for the development of future fast reactors, the transmutation of Minor

Actinides (MA), and other studies. In addition, Joyo will be more readily available to institute and universities throughout Japan and the world.

Basic design studies and experiments required for the modification started in 1987. The government safety review of the MK-III reactor started in January 1994 and completed in September 1995.

The nuclear design method for the MK-III core use two-dimensional diffusion calculations with the JFS-3-J2 set of 70 groups structure, that is based on the JENDL2. The bias factors for the criticality and reaction rate distribution were evaluated based on the analysis of the MK-II core performance tests.

The MK-III upgrade increases the maximum number of fuel subassemblies from 67 to 85. The upgrade relocates two control rods to the edge of the core to enlarge the high neutron flux irradiation field. The MK-III core is divided into two regions with different plutonium contents. The core will contain 25 fuel subassemblies in the inner core and 60 in the outer core. To obtain higher neutron flux, the upgrade decreases the active core height from 55cm to 50cm. As the result of a whole plant design optimization, reactor thermal rating increases from 100MWt to 140MWt. The maximum allowable linear heat rate was re-evaluated for the increase of the reactor thermal rating but the driver fuel specifications remain principally the same as current MK-II fuel.

The MK-III core fast neutron flux increases more than 30% and the maximum allowable number of fuel irradiation test rigs increases from nine to twenty-one. Two layers of stainless steel reflector are replaced by shielding subassemblies, which contain boron carbide pellets, to reduce the neutron fluence in the radial direction. The comparison of MK-II and MK-III main core parameters is shown in Table 1 and the core configuration comparison is illustrated in Figure 2.

Table 1 Main core parameters of MK-II and MK-III

Items			MK-III	MK-II
Rector Thermal Output		(MWt)	140	100
Max. No. of Driver Fuel S/A			85	67
Max. No. of Test Fuel S/A			21	9
Core Diameter		(cm)	80	73
Core Height		(cm)	50	55
^{235}U Enrichment		(wt%)	18	18
Pu Content		(wt%)	... 30	... 30
Pu fissile Content	(Inner / Outer Core)	(wt%)	` 16/21	` 20
Neutron Flux	Total	(n/†C¥s)	5.7~ 10^{15}	4.9~ 10^{15}
	Fasti„ 0.1MeVj	(n/†C¥s)	4.0~ 10^{15}	3.6~ 10^{15}
Primary Coolant	Flow Rate	(t/h)	2700	2200
	Temp.(Inlet / Outlet)	(Ž)	350 / 500	370 / 500
Max. Burn up(Pin Ave.)		(GWd/t)	90	75
Reflector / Shielding			SUS / B_4C	SUS / SUS

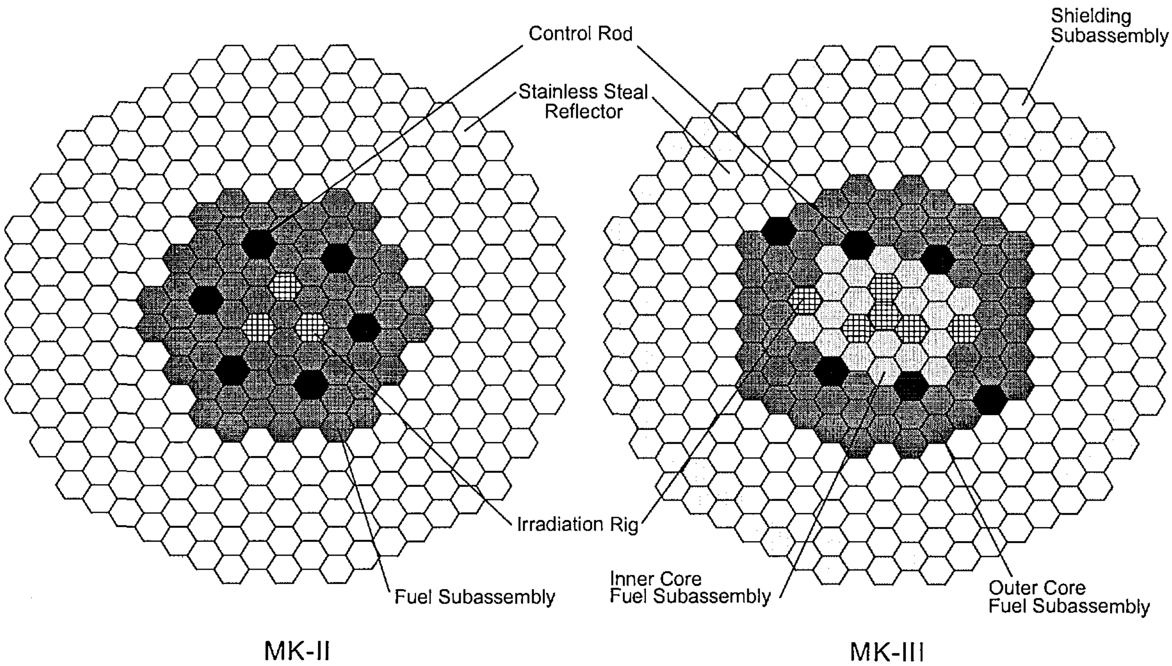

Figure 2 Configurations of MK-II and MK-III Cores

The modified reactor cooling system is shown in Figure 3. To increase cooling system heat removal capacity, the sodium coolant flow rate in the primary system increases by 20% and all Intermediate Heat Exchangers (IHX) and Dump Heat Exchangers (DHX) will be replaced. IHXs use a new stainless steel, 316FR, with superior elevated temperature properties. This steel was developed for future large-scale FBR applications.

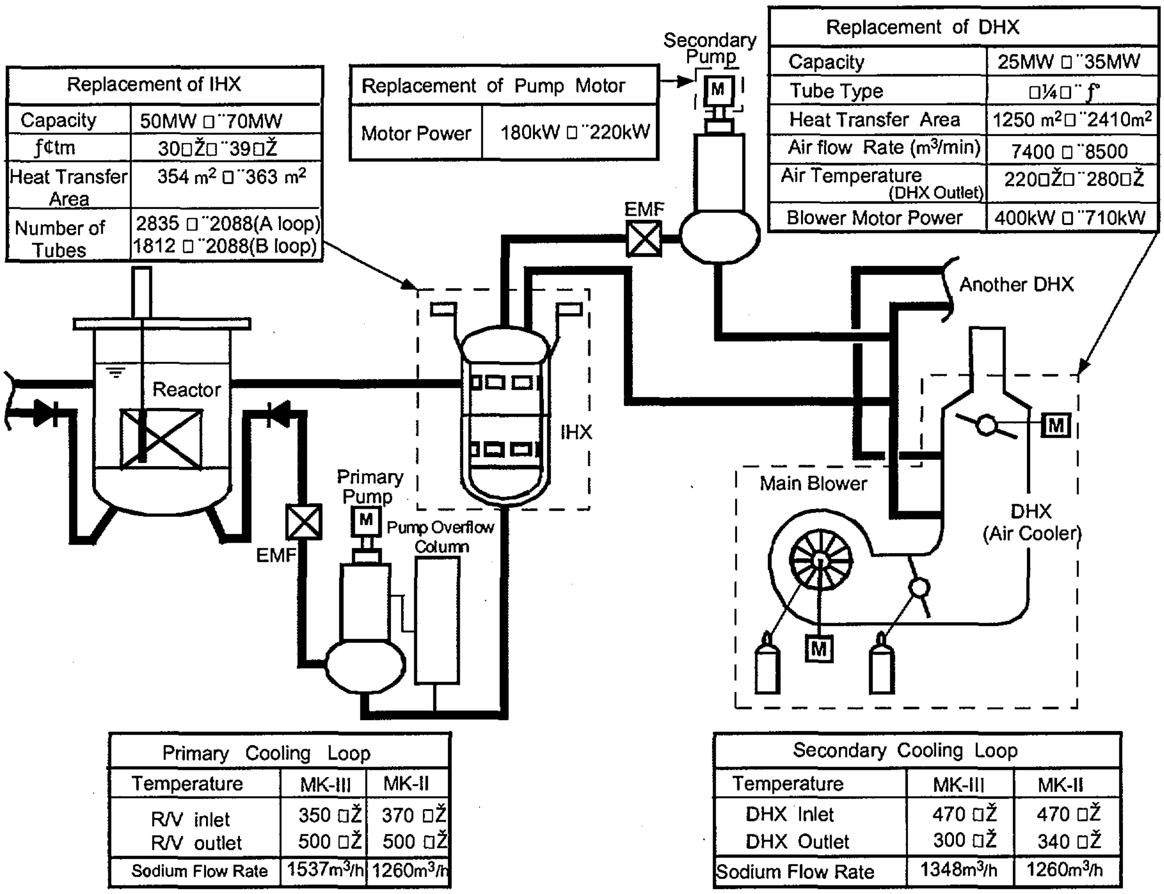

Figure 3 Reactor Cooling Systems and Heat Balance in MK-II and MK-III Plants

The schedule for the core and the cooling system modifications is shown in Figure 4. The design approvals for the driver fuel, shielding subassembly and the cooling system components were submitted after the license for the MK-III modification was issued in 1995. Design permits have been obtained and the fabrication and inspection of subassemblies and cooling system components has started. Bodies for twenty MK-III outer core fuel subassemblies have been loaded into the core and the manufacturing of large components such as IHXs and DHXs is complete. The preparation work for the cooling system replacement started in October 2000. The replacement of IHXs and DHXs will be finished in August 2001.

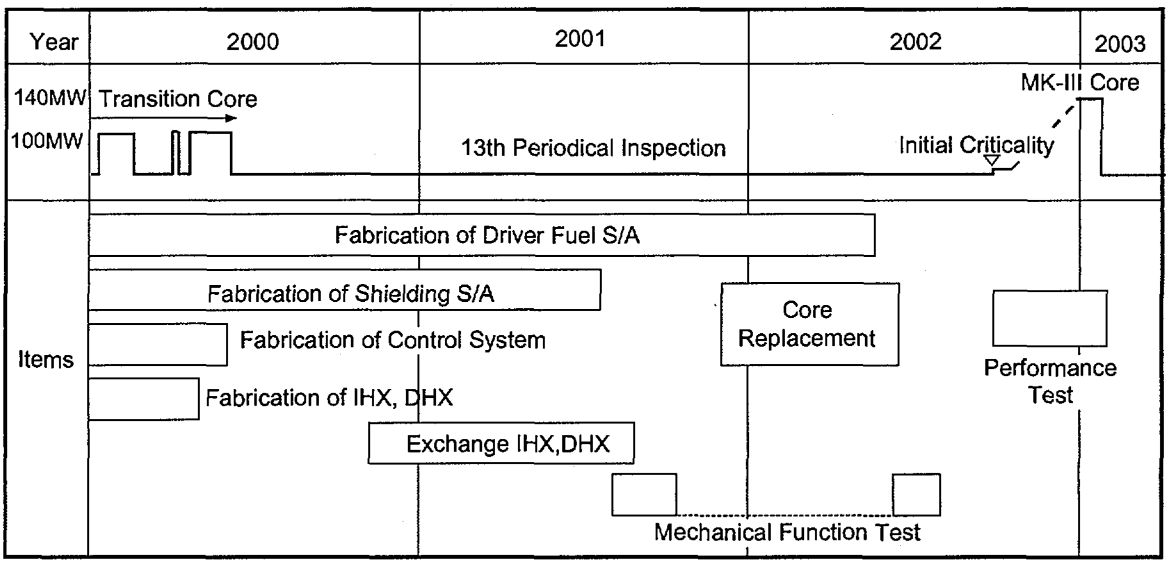

Figure 4 Core and Plant Modification Schedule

The core replacement will start at the end of 2001 with the installation of MK-III core fuel subassemblies and shielding subassemblies. When the initial MK-III core configuration is complete, the reactor power will be increased in steps as performance tests that reactivity and plant characteristics are measured. The MK-III rated power operation will be started in 2003.

Irradiation Program

Joyo will start 140MWt rated power operation in 2003 along with several irradiation tests as follows. The irradiation test program in Joyo is shown in Figure 5.

(1) Fuel irradiation tests

MOX fuel irradiation tests were conducted for the demonstration for Monju, Demonstration FBR or further large scale FBR during the MK-II operation. Irradiation tests for large scale FBR fuel will be continued in the MK-III core. The MK-III core will support irradiation testing on advanced fuels like MA doped fuel, high plutonium content MOX fuel and vibration packed fuel.

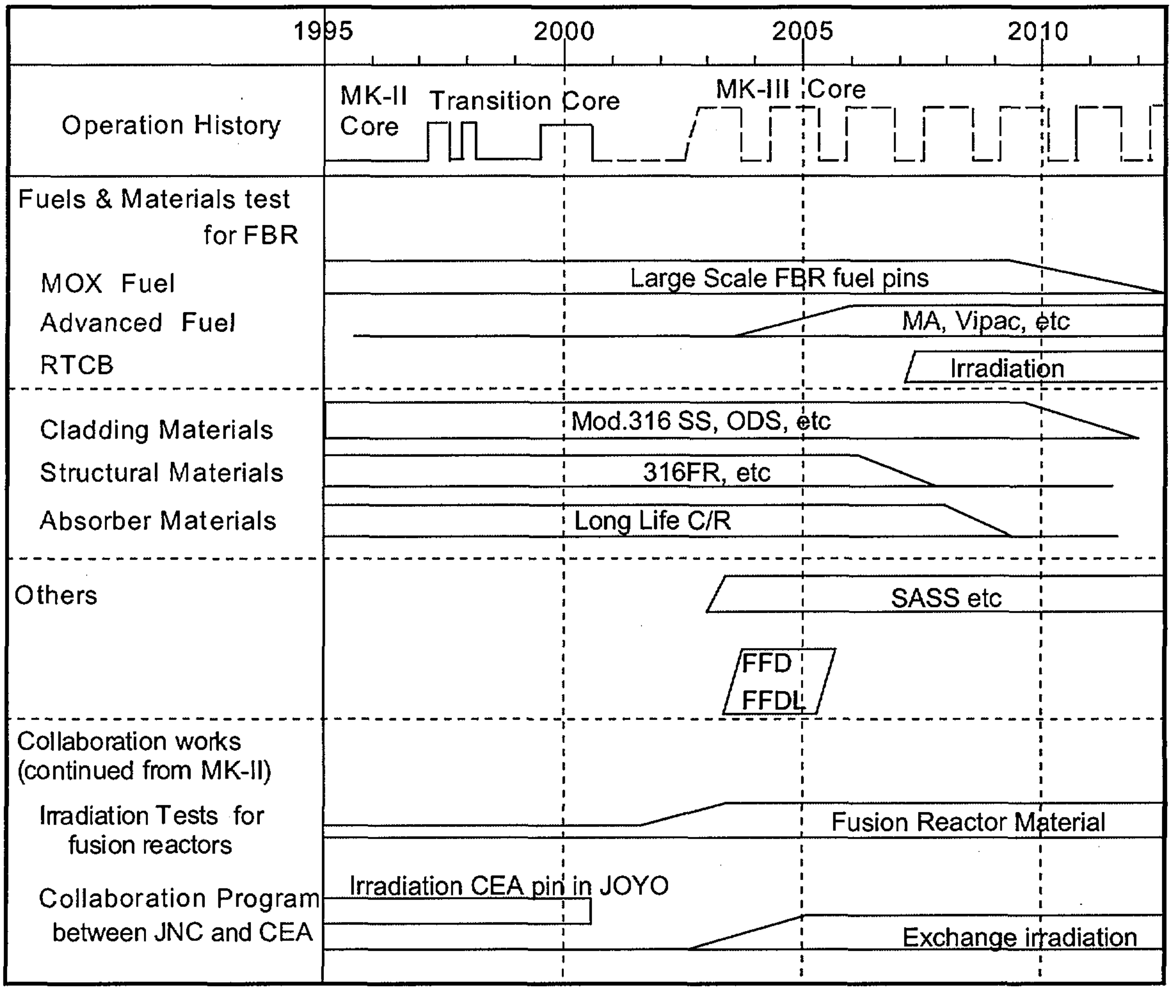

Figure 5 Joyo Irradiation Test Program

A remotely operated fuel fabrication system for the MA fuel irradiation program was installed in a hot cell in the Alfa-Gamma Facility (AGF) at the O-arai engineering Center. This fabrication system will produce americium doped fuel pellets. Successful test operations with UO2 pellets have been conducted and the americium doped fuel pellet fabrication for irradiation will start in 2002.

The license for conducting a Run To Cladding Breech (RTCB) has already permitted and preliminary irradiation tests are also planned with MK-III core. For the RTCB tests, design for the irradiation rigs with test tube is ongoing. A test fuel pin is loaded in the test tube that is surrounded by fuel pins inside of a rig. The test tube has coolant flow regulating structure to maintain the cladding temperature at a needed level and a strainer at the coolant outlet to capture fractions that comes from a breech.

(2) Material irradiation

JNC's medium and long-term program include the Feasibility Study (FS) for fast reactor and related fuel cycle [5]. Joyo's irradiation test program demonstrates the technologies that were identified by the FS.

The Oxide Dispersion Strengthened ferritic steel material (ODS) irradiation test planned in the test program. Long life core materials in a large scale FBR can use ODS because of its superior swelling resistance and high creep strength. The irradiation tests will be conducted with offline test rigs including ODS-cladded fuel pins and with an online test rig in order to conduct a creep-rupture test under temperature control. For the online irradiation test, the design for MARICO-2 is ongoing. The design contains several upgrades including the utilization of an electric heater and increasing irradiation space.

Design of a sodium bonded type pin to increase the control rod lifetime has been conducted in JNC and the submission for license was permitted in February 2000. The fabrication of sodium-bonded type has started and demonstration tests will be conducted when the MK-III operation starts.

(3) Other tests

a. SASS characteristics test

Future plans include utilizing Joyo as an experimental facility for the development and demonstration of new FBR technologies. Self-Actuated Shutdown System (SASS) has been developed to increase the reliability of the FBR shutdown system. The SASS with curie point electromagnet [6] was decided to adopt for the Japanese demonstration FBR. Two component characteristic tests for SASS with curie point electromagnet are planned in collaboration with a Japan atomic power company. The experimental equipment utilized for the tests mentioned above is shown in Figure 6.

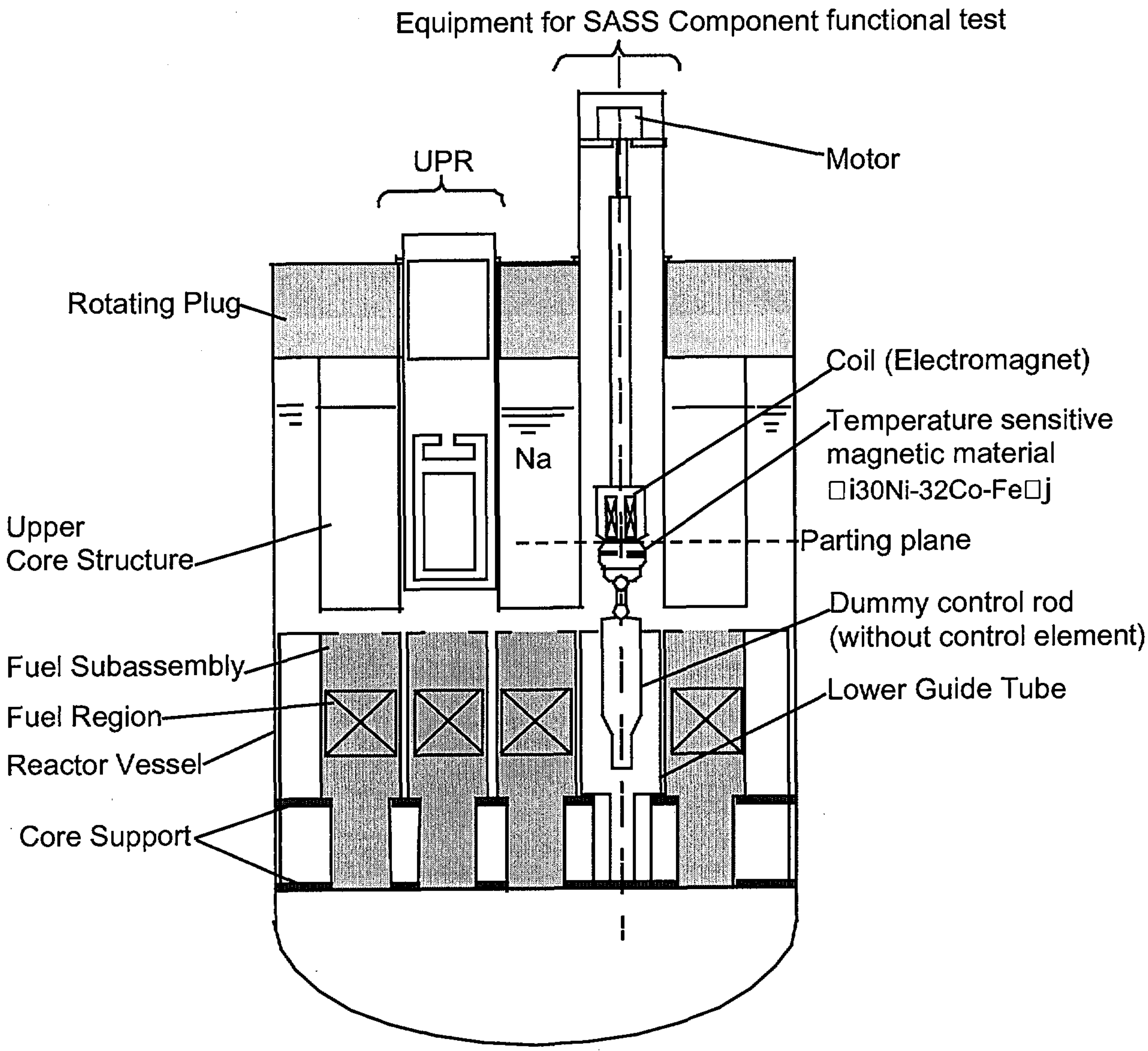

Figure 6 SASS Demonstration Experimental Configuration

• SASS element irradiation test

The SASS element irradiation test provides magnetic characteristic data for the SASS electromagnet components when they are irradiated. This test will be conducted using a Upper core structure irradiation Plug Rig (UPR) that is located in Joyo's upper core structure. In the UPR irradiation test, the neutron flux at the specimen is lower than that obtained with in-core irradiation rigs but it is possible to maintain a constant specimen temperature during irradiation with an electric heater inside the UPR.

• SASS component functional test

The purpose of the SASS component functional test is to demonstrate the reliability of the control rod holding ability. This test will be carried out using experimental equipment consisting of a dummy control rod and control rod driving system. The control rod holding mechanism is strictly modeled on SASS.

b. FFD and FFDL performance test

A performance test for the FFD and FFDL systems based on the shipping method is planned with MK-III core. By irradiating test fuel pins with a cladding hole, the test will simulate a fuel failure.

Conclusion

The Joyo MK-III core upgrade is proceeding steadily. Joyo is expected to support irradiation tests of fuels and materials and functional tests to demonstrate FBR components.

The MK-III operation will be started in 2003 and it will play an important role in the research and development of future FBRs.

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