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Development of material irradiation rig with precision temperature control in experimental fast reactor JOYO

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Abstract

In the experimental fast reactor JOYO, an on-line instrumented material irradiation rig has been developed to acquire various irradiation data. *Ma*terial Testing *Ri*g with Temperature *Co*ntrol (MARICO) is capable of collecting creep rupture strength data for fast reactor fuel cladding materials. The specimen temperature in the MARICO-1 rig is controlled with an accuracy of ±4°C by the use of a gas gap method similar to that of FFTF/MOTA. Presently, irradiation testing using MARICO-1 has been so successful that the development of MARICO-2 is under way for completion by the early part of the next century. MARICO-2 will contain an electrical heater for temperature control, a larger irradiation space and other data collecting improvements.

1. Introduction

The experimental fast reactor JOYO has been utilized for various research and development projects [1] studying the fuels and materials of fast reactors from 1983 to the present using the "JOYO MK-II Core". *Mat*erial Testing *Ri*g with Temperature *Co*ntrol (MARICO) [2,3] is an on-line instrumented material irradiation rig used at JOYO. MARICO is capable of irradiation temperature control. The physical dimensions of the device are approximately 11 m in length and 150 mm in diameter. The temperature of the instrumented capsule in MARICO can be controlled so that the temperature of the specimens may become fixed within ±4°C under irradiation testing.

Temperature control is the most desirable method to conduct on-line instrumented irradiation test of fuels and materials so that the change of the irradiation condition can be observed and controlled with high accuracy. However, technical problems due to a high temperature sodium environment and inadequate reactor design for instrumented irradiation, need to be solved in order to develop on-line irradiation rigs. In JOYO, those barriers have been overcome by the use of irradiation testing using MARICO-1, which began in 1994. MARICO-2, an upgrade is currently under design for use in the early part of next century. The design will contain several upgrades including the utilization of an electric heater and increased irradiation space.

2. Description and irradiation experience of MARICO-1

The main purpose of MARICO is to test the creep rupture strength of fuel cladding materials under the fast neutron irradiation environment. The creep rupture strength is an important factor that determines fuel life, and it is very dependent on temperature. Therefore, MARICO was developed to carry out in-pile creep irradiation test with high temperature accuracy. The capsules installed in MARICO which contain the specimens have a double wall thermal insulated structure and are filled with sodium in order to maintain isothermal test conditions. The temperature inside the capsule is measured with a thermocouple. During the

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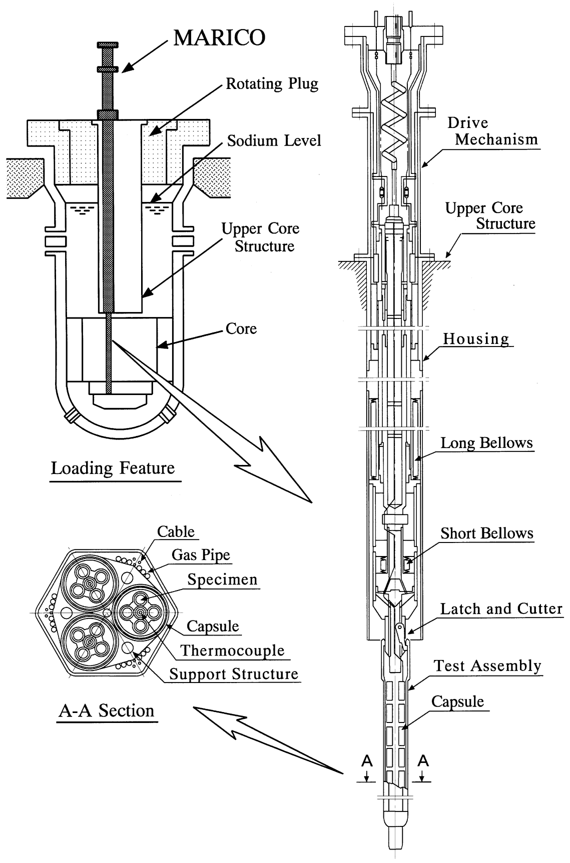

Fig. 1. Material Testing Rig with Temperature Control (MARICO).

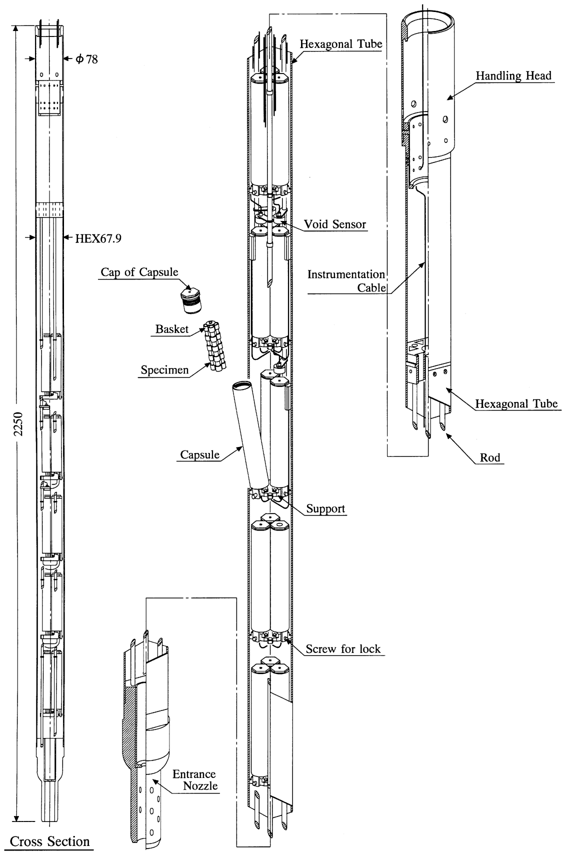

Fig. 2. MARICO-2 test assembly.

irradiation period, when the specimen rupture, gas is released from it, and then detected by a gas void sensor attached to each capsule and on-line cover gas gamma monitor of JOYO.

The features of MARICO are shown in Fig. 1 and the details of the test assembly are illustrated in Fig. 2. The structure of the irradiation capsule (a temperature control-type capsule) is illustrated in Fig. 3. The physical dimensions of MARICO are 150 mm in diameter and 11 m long. The test assembly containing the capsule cluster is attached at the bottom of MARICO. In the test assembly, there are fifteen irradiation capsules that consist of three types: temperature control, temperature instrument, and non-instrument. The irradiation capsules have been arranged in 3 rows and 5 stages in the test assembly.

In the temperature control capsule, the temperature inside the capsule is measured and controlled by using the thermocouple and gas gap method that is described below. The temperature inside the irradiation capsule is controlled by the mixture ratio of argon gas and helium gas, which is enclosed in the capsule's double wall thermal insulated gas gap. The specimens can be kept at a fixed temperature by controlling the heat flow across the gap. This method is similar to FFTF/MOTA. In the temperature instrument capsule, only to measure a temperature using the thermocouple is made. By extracting out *T*hermal *E*xpansion *D*ifference Off-line Monitor (TED) in the non-instrument capsule after the irradiation test, the peak temperature experienced during the period can be known.

MARICO-1 was first used in the in-pile creep irradiation test for 29th cycle at JOYO beginning in August of 1994. By September of 1997 test results showed 150 EFPD (Effective Full Power Days). During this irradiation test period, the temperature inside the capsule was controlled to a precision of ±4°C. The temperature control profile of MARICO-1 capsule is shown in Fig. 4.

Thirteen creep ruptures specimens have been detected to date. An on-line gamma ray monitor and a gaschromatograph for the cover gas of the reactor

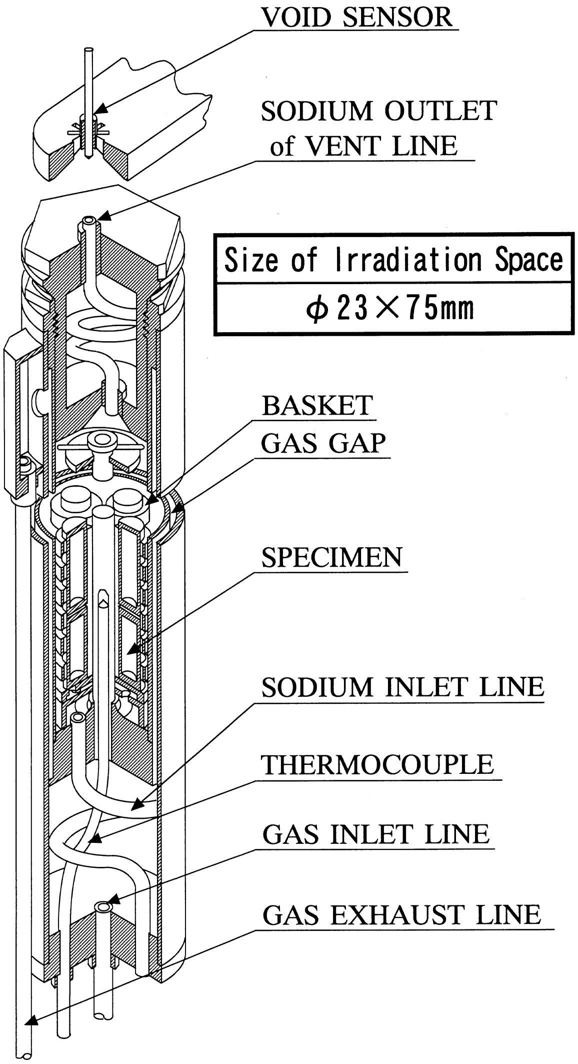

Fig. 3. Irradiation capsule (temperature controlled).

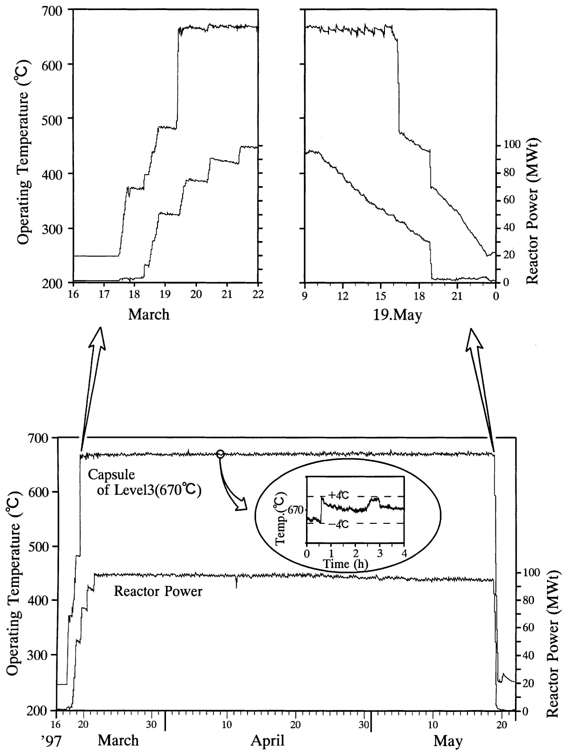

Fig. 4. Temperature control profile (30th cycle).

vessel detected the creep ruptures clearly. The gas void sensor of each capsule has failed to detect the ruptures with the exception of the two early highest pressure specimens.

3. Upgrading to MARICO-2

The success of MARICO-1 testing has raised efforts to upgrade to a second MARICO labeled MARICO-2. Table 1 shows future plans of irradiation testing using MARICO-2. Fig. 5 illustrates the development process of MARICO-2. The irradiation position and neutron flux distribution in the core of MARICO-2 are shown in Fig. 6. MARICO-2 will be irradiated in "JOYO MK-III Core" in which the maximum neutron flux level is almost equal to that of FFTF.

(1) *Development of the electric heater capsule.* The irradiation tests taken from the reactor serve another purpose: Fusion research groups in domestic universities examine the irradiation damage of general and fusion materials using JOYO. These test have been conducted, based on a contract between PNC and universities. The researchers seek test results from irradiation testing under strict temperature control prior to reactor startup, through post reactor shut down. In order to achieve these results, the use of an electric heater inside the capsule will be designed into MARICO-2. Development of the heater capsule will be difficult due to the following two reasons:

(a) The capsule space is small compared to the diameter of the sheath of the micro-electric heater.

(b) There is a lack of experience concerning the reliability of a heater in a high temperature sodium and irradiation environment.

Therefore, the out-of-pile test of the capsule would be the minimum testing that would be required. A prototype of the heater capsule has been fabricated and a life test was conducted while the unit was thermally cycled

Table 1
MARICO-2 test design and parameters

Core position	Row 3 Section E Position 3	
Capsule stack	15 Capsules (5 levels, 3 per level)	
	Temperature control	(6)
	Temperature measurement	(4)
	Non-measurement	(5)
Specimens	Fast reactor core material	
	Creep rupture specimens	(35)
	Creep distortion specimens	(47)
	Swelling specimens	(20)
	Impact specimens	(10)
	Specimens from universities	(2)
Size of irradiation space	ϕ 23 × 75 mm/capsule	
Fast flux [$E \geqslant 0.1$ MeV] (n/cm^2 s)	Level 1: 7.28×10^{14}, Level 2: 2.47×10^{15}, Level 3: 3.55×10^{15}, Level 4: 2.06×10^{15}, Level 5: 4.15×10^{14}	
Temperature range	400°C ~ 750°C	
Temperature control Method	• Variable thermal conductance of gas gap • Electrical heater	
Control range	±4°C	
On-line measurement Thermocouples	11	
Gas void sensors	4	
Off-line measurement	TED temperature monitors, dosimeters	

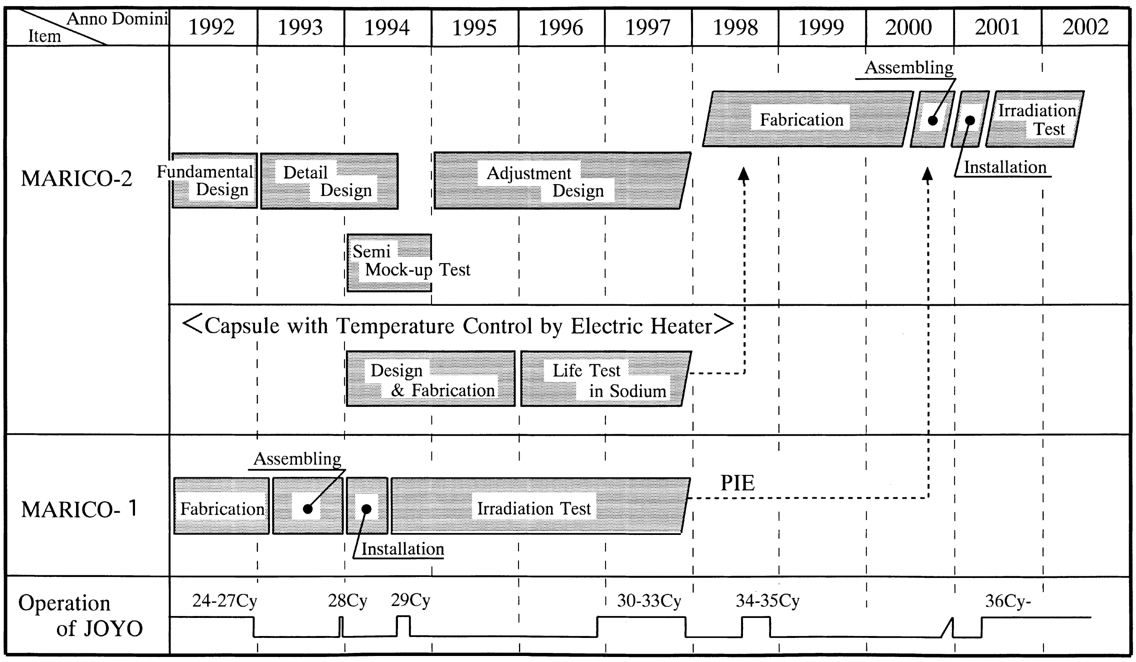

Fig. 5. Development process of MARICO.

and placed in sodium. The heater capsule within the Irradiation Capsule is shown in Fig. 7.

(2) *Enlargement of irradiation space.* The diameter of the fuel cladding specimens in MARICO-1 is approximately 5 mm. The proposed diameter in MARICO-2 will have a larger diameter of 6.5 mm. This improvement will require testing prior to storing a large number of specimens by trial fabrication.

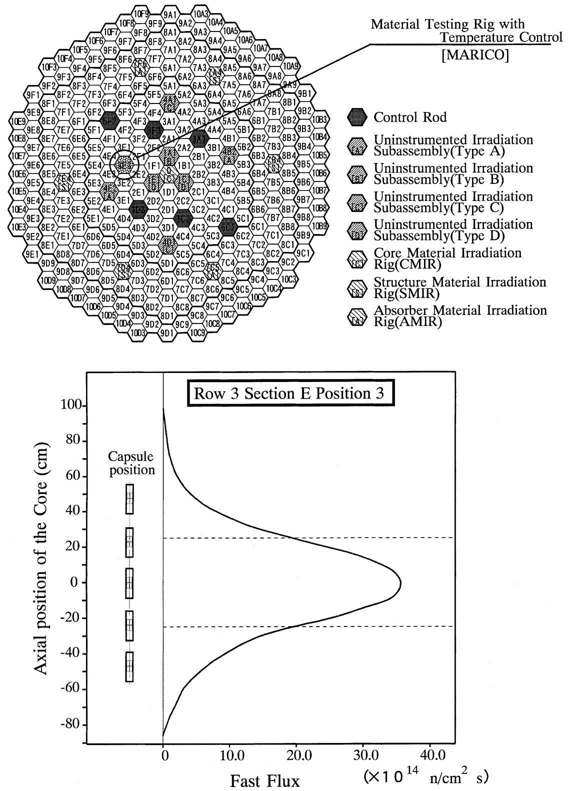

Fig. 6. Configuration and neutron flux of MK-III reactor core.

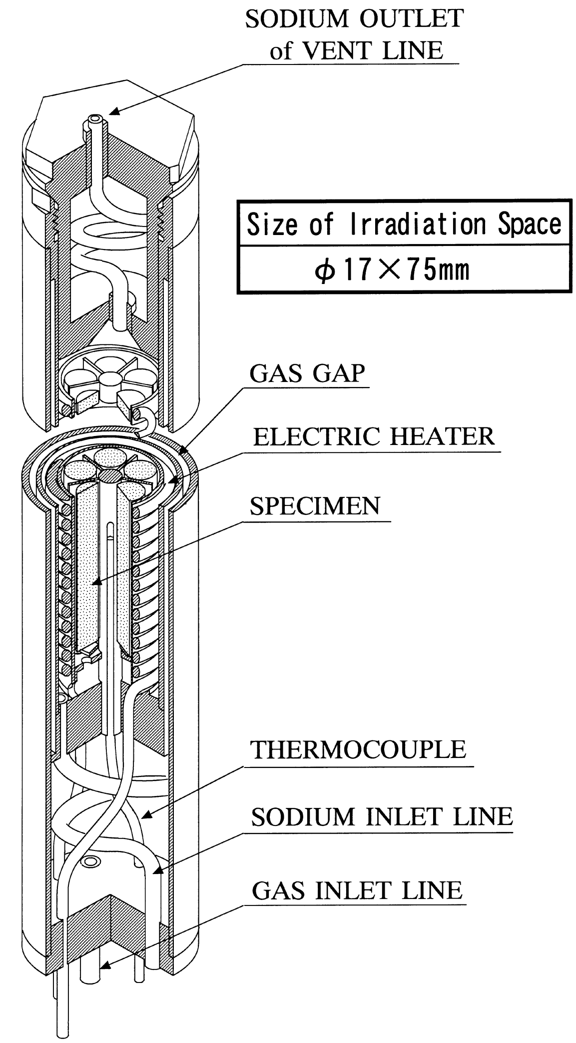

Fig. 7. Irradiation capsule (electric heater assembly).

(3) *Increased irradiation temperature range.* Currently the lower temperature limit of irradiation in MARICO-1 is 495°C with an upper limit of 670°C. MARICO-2 will have an expanded temperature range, with a lower limit of 405°C and an upper limit of 750°C.

(4) *Modification of specimen reload functions design.* In order to acquire long-term irradiation creep data, MARICO-2 will continue the process of irradiating radioactive specimens. Improvement of the structure of the test assembly and irradiation capsule to allow for the assembly of specimens in the hot cell by remote manipulation is being done. A prototype of the test assembly and a simulation in the hot cell were successfully conducted in 1994.

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