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Development of rig for systematic irradiation tests of fusion reactor materials in a fission reactor

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Abstract

Acquisition of systematic irradiation data are essential for understanding fundamental processes of irradiation effects and for establishment of a reliable database for irradiation effects in fusion reactor materials. It will take several years with expensive several different irradiation rigs in a fission reactor irradiation. There, it will take a long time to carry out the needed iterations between irradiation tests and evaluation and materials development. An irradiation rig was developed to carry out irradiation under multiple temperatures and irradiation fluences. Irradiation tests of fusion reactor materials were successfully carried out using the rig in Japan Materials Testing Reactor. © 1998 Elsevier Science B.V. All rights reserved.

1. Introduction

An appropriate control of irradiation conditions in a fission reactor [1] is needed to obtain reliable data which can be analyzed in comparison with irradiation data are obtained in different irradiation sources such as charged particles [2]. However, controlled irradiation is expensive and time-consuming in a fission reactor and it will take more than several years to obtain data in irradiation conditions covering the needed range of parameters. Also, realization of similar irradiation in different irradiation rigs in different irradiation cycles is difficult in a fission reactor, where existence of other irradiation rigs will change local neutron fluxes and gamma heating rates. An irradiation rig which could realize multi irradiation parameters was developed and controlled irradiation of fusion reactor materials was successfully carried out in Japan Materials Testing Reactor (JMTR) in the Oarai Research Establishment of Japan Atomic Energy Research Institute.

Ten irradiation conditions were realized in one pseudo-shroud-type irradiation rig in JMTR. The present paper describes the detailed structure of the developed rig and a history of successful irradiation. Examples of analyses results of irradiated fusion reactor materials will be found elsewhere in this conference [3].

2. Development of irradiation rig

Fig. 1 shows general structures for the present irradiation system. There are five transfer tubes in a temperature controlled irradiation rig and two subcapsules are loaded in each transfer tube [2], which has two independently regulated temperature zones. A pseudo-shroud system mainly consists of an irradiation rig, a protecting tube, a junction box, and a lifting devices. Small subcapsules could be lifted up from and inserted down into the temperature controlled rig in the JMTR core during reactor operation. Irradiation temperatures were controlled primarily by electric heaters encased in the rig as shown in Fig. 1. Two different temperature zones were set up above and below of the midplane of reactor core, which could be independently controlled irrespective of the reactor

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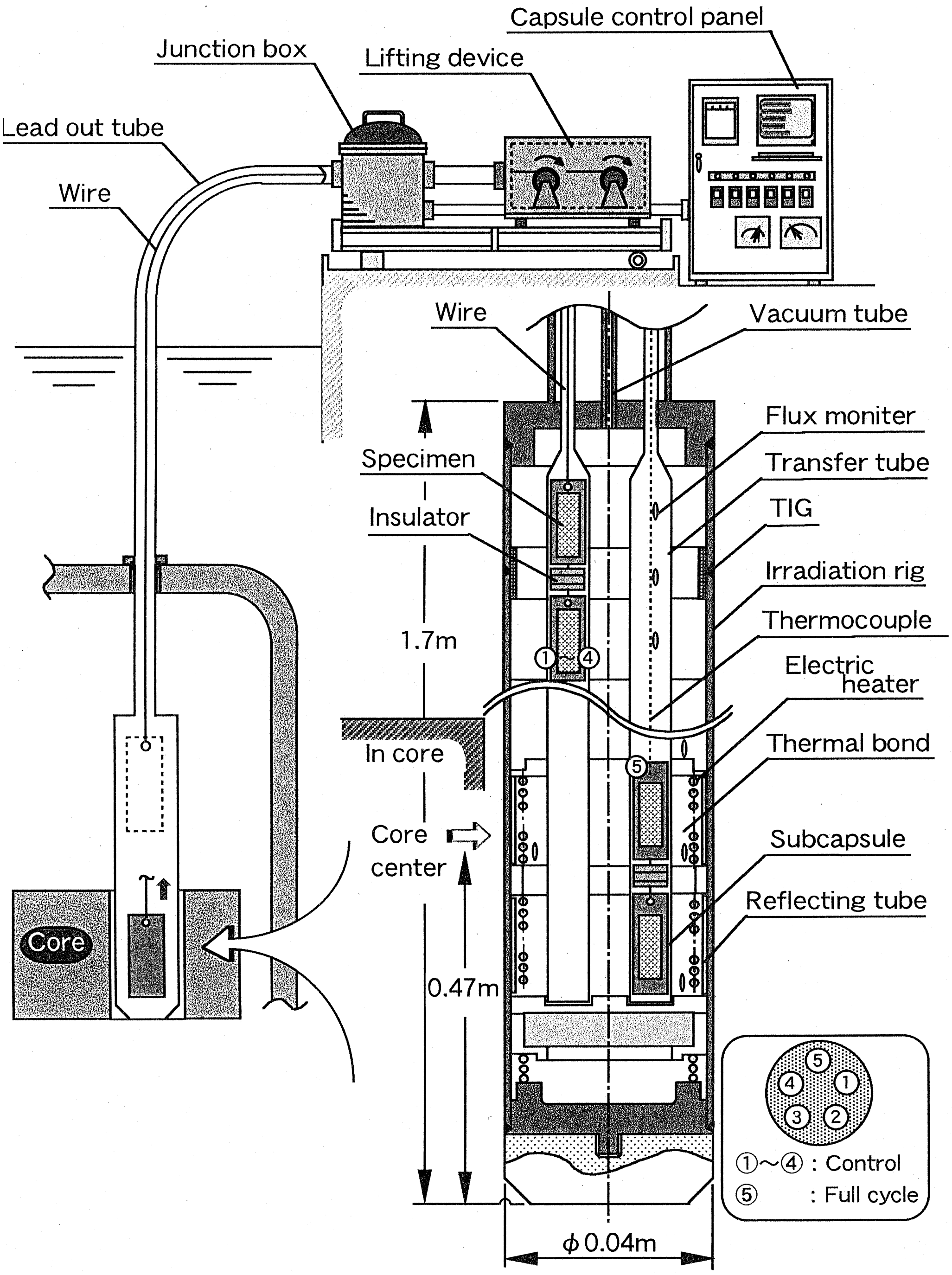

Fig. 1. Schematic view of a pseudo-shroud irradiation rig developed for controlled fission reactor irradiation.

power. Fig. 2 shows a cross sectional view of the rig accommodating subcapsules. Five transfer tubes were installed in the rig, being thermally bonded by an aluminum block. The electric heaters were coiled on the outer surface of the aluminum block, which ensures temperature homogeneity. A reflecting tube and a gap between the reflecting tube and a wall of rig (described as outer tube in Fig. 2) provides an appropriate heat-removal rate for temperature control. The gap is filled with helium gas.

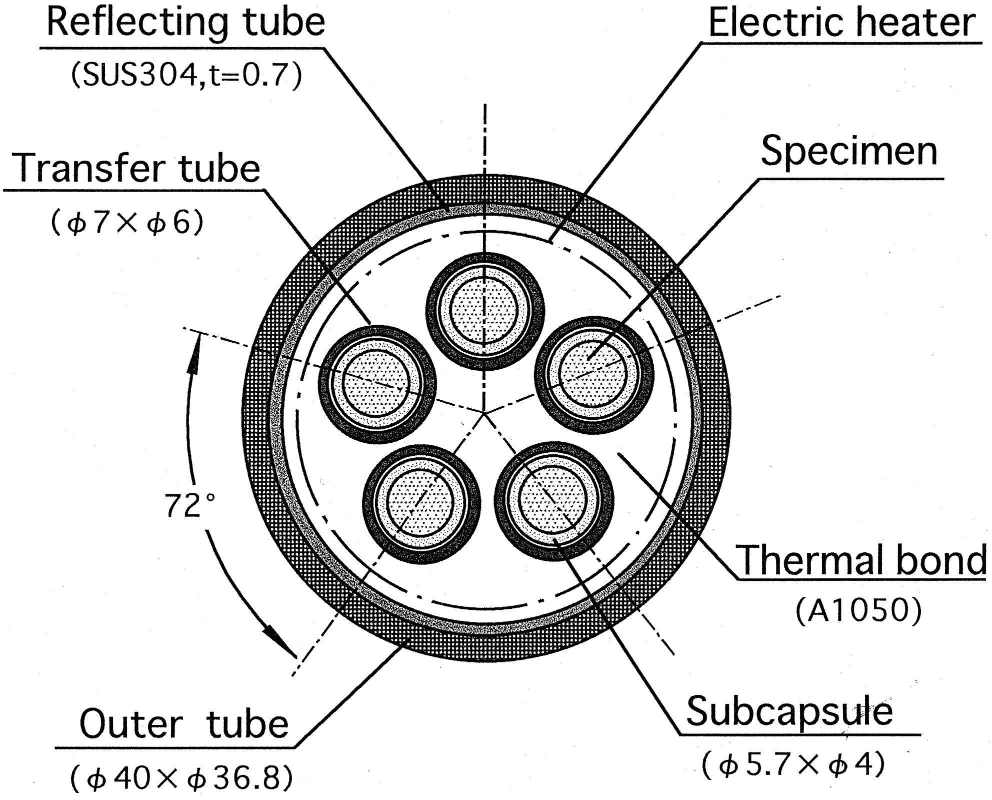

Fig. 2. Cross section of an irradiation rig accommodating five trains of subcapsules.

A schematic view of a train of two subcapsules is shown in Fig. 3. Two subcapsules were connected through an alumina thermal insulator and they could be inserted into or removed from the irradiation rig during the reactor operation. The temperature of each subcapsule was monitored by a thermocouple inserted into the aluminum top cap of the subcapsule shown in Fig. 4. Each subcapsules could be irradiated at different temperatures while maintaining in nearly the same irradiation conditions.

3. History of irradiation tests

The temperature of the irradiation rig can be controlled also by changing the helium gas pressure in the gap between the reflecting tube and the outer tube shown in Fig. 2, independent of reactor power, namely, gas-pressure–temperature control (GPTC). Fig. 5 shows one example of temperature control by this GPTC method, without using electric heaters at the reactor shutdown. The gamma heating rate decreased from about 7 W/g to less than 1 W/g, but the temperature of a subcapsule could be kept constant at about 300°C. However, when the reactor power changed rapidly by abrupt insertion of the stopping control rods during reactor shutdown, the temperature could not be controlled well by the GPTC method. In general, GPTC has advantages over the electric-heater-temperature-control (EHTC). The structure of the rig could be simpler and more specimens can be irradiated. The most important disadvantage for the EHTC method is that an electric heater always has a possibility of failure. Although electrical heaters could occasionally survive more than one year irradiation in JMTR (five cycles in a year in average), up to more than 10^{25} n/m^2 fast ($E > 1$ MeV) neutron fluence, their reliable life-time will be a-few-cycles JMTR irradiation. Development of fusion reactor materials require irradiation exceeding 10^{26} n/m^2 of fast neutron fluence. Rigs using GPTC will not have a life limitation as far as a geometry of the gas gap is not changed drastically by swelling. However, GPTC cannot control the rig temperature during an abrupt change of reactor power in the present system because it takes several minutes to attain equilibrium gas pressure in the gas gap. The base temperature control was carried out by GPTC and EHTC was used for compensating abrupt but small change of temperature especially at the reactor

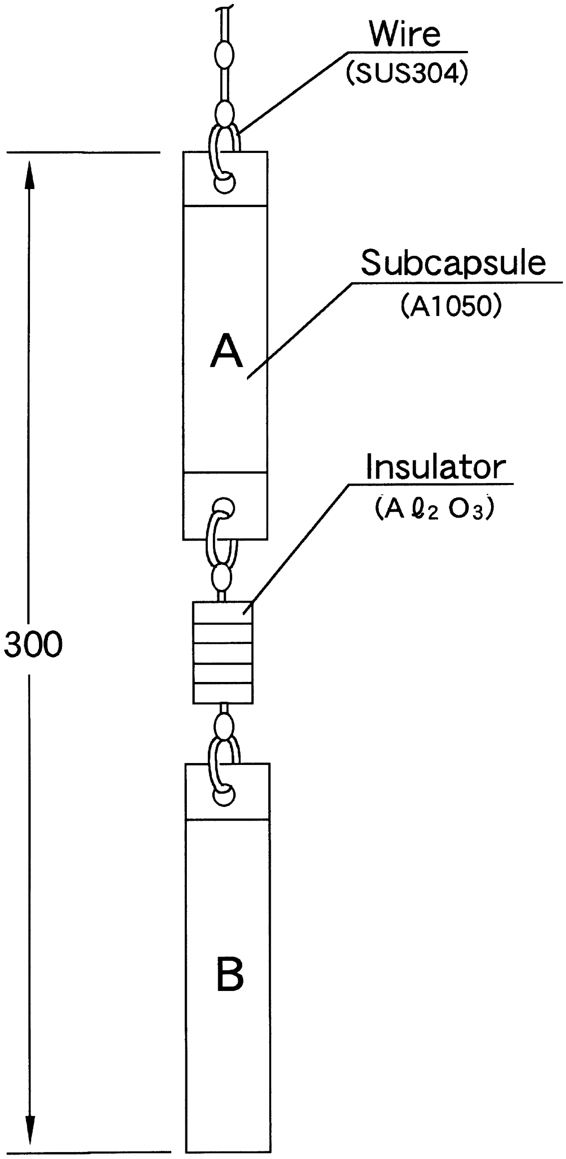

Fig. 3. Configuration of a train of two subcapsules for two different temperatures.

start and shutdown. Fig. 6 shows the temperature history of irradiation using the developed irradiation rig in 1996.

Subcapsules were inserted into the irradiation rig after the reactor power and the temperatures of the rig were stabilized as shown in Fig. 6. Then, subcapsules were sequentially removed from the rig during reactor operation. Irradiation with five different levels of neutron fluence from 9 × 10^{22} n/m^2 to 1.4 × 10^{24} n/m^2 at two different temperatures of 300°C and 400°C were realized in one irradiation period. Previous preliminary results, however, suggested that specimens were exposed to a low flux of fast neutron irradiation even when they were not inserted in the reactor core. Fig. 7 shows the induced radioactivities of iron dosimetry foils as a function of distance from the reactor core center. The induced radioactivity is roughly proportional to the fluence of fast neutrons. It can be seen that substantial neutron flux exists even in the out-of- core-region. The length of the rig was enlarged as long as possible and subcapsules were placed at about 300 mm above the edge of the reactor core to avoid exposure to the low flux neutrons, where the fast neutron flux is about 10^{-4} of that at the core center.

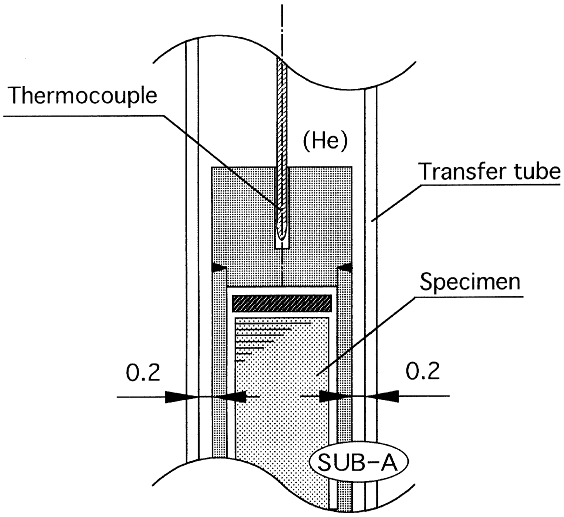

Fig. 4. Cross sectional view of a subcapsule in a transfer tube. Irradiation temperature is monitored by a thermocouple on the top cap.

More than a few thousand transmission electron microscope (TEM) specimens of different fusion candidate alloys were irradiated. Microstructural modifications due to fission reactor irradiation were examined in comparison with those under other irradiation sources such as high energy electrons in high voltage electron microscope (HVEMs) [3], where extensive data were accumulated and fundamental processes of irradiation induced microstructural evolution was analyzed as a function of a variety of a irradiation conditions.

4. Summary

A rig was developed for controlled irradiation in the JMTR fission reactor. Irradiation for five different fast neutron fluence at two different temperatures were successfully carried out using the developed rig. Good temperature and neutron fluence control was confirmed during irradiation tests.

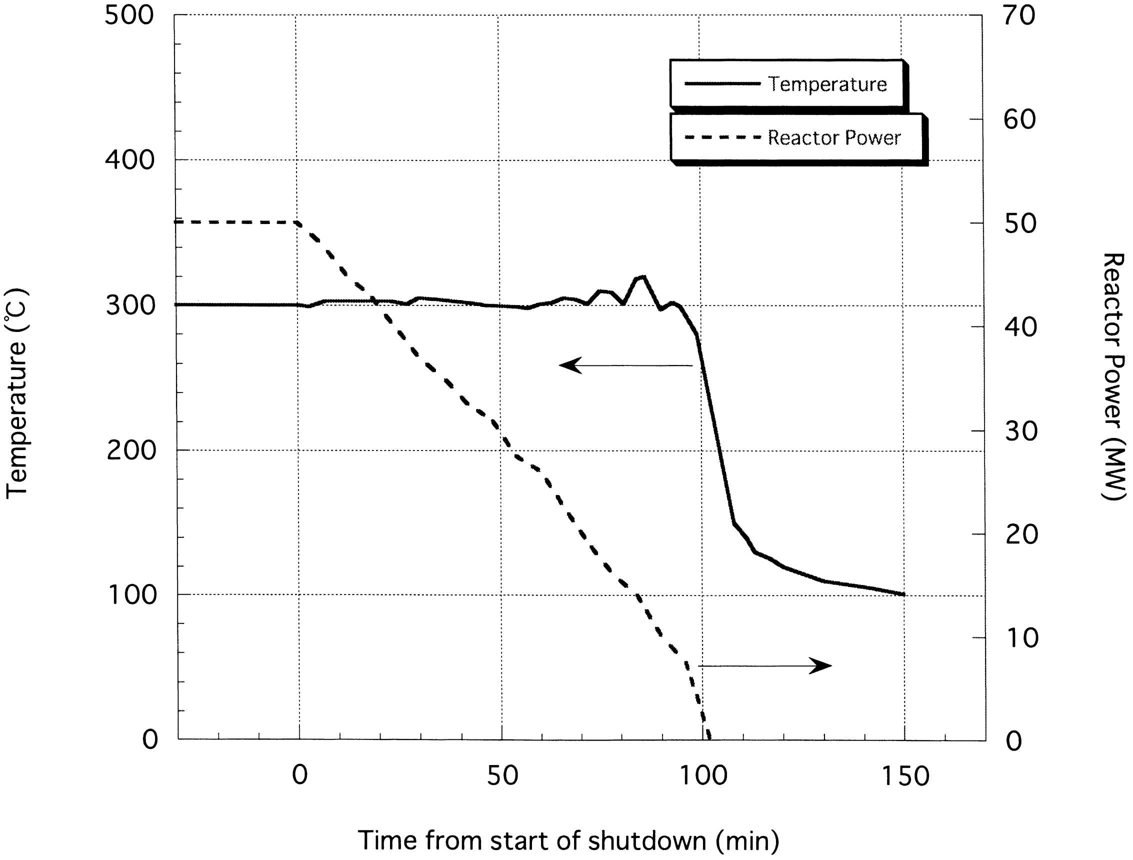

Fig. 5. Example of temperature controlled by GPTC at reactor shutdown.

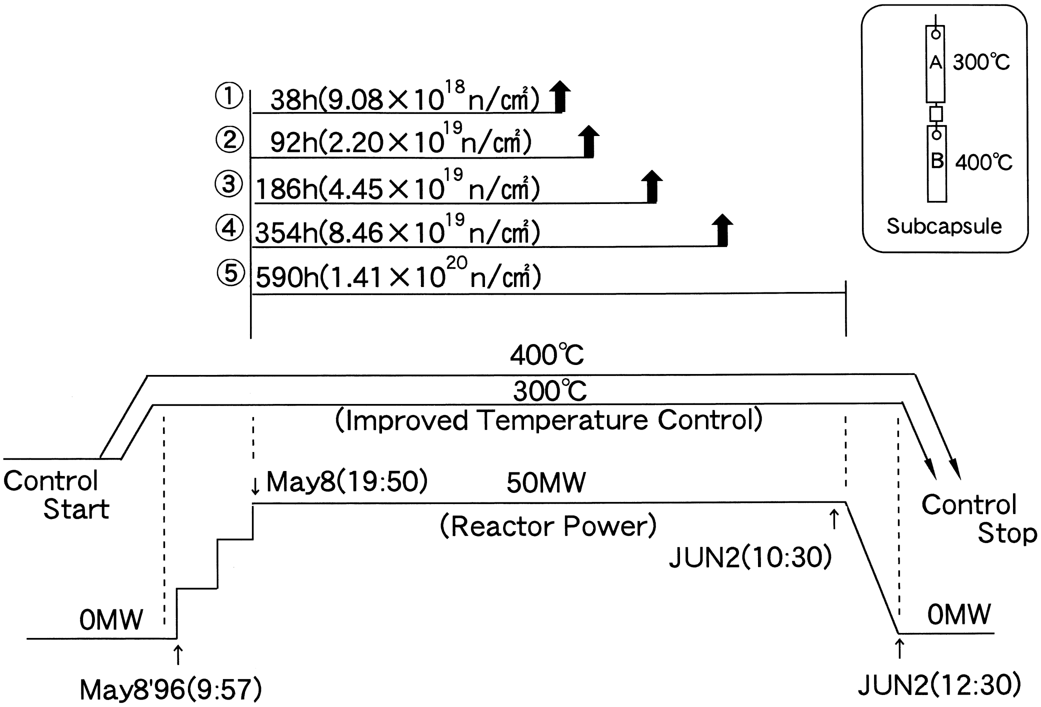

Fig. 6. Irradiation history using the developed rig. Subcapsules were inserted into and removed from the rig during reactor operation.

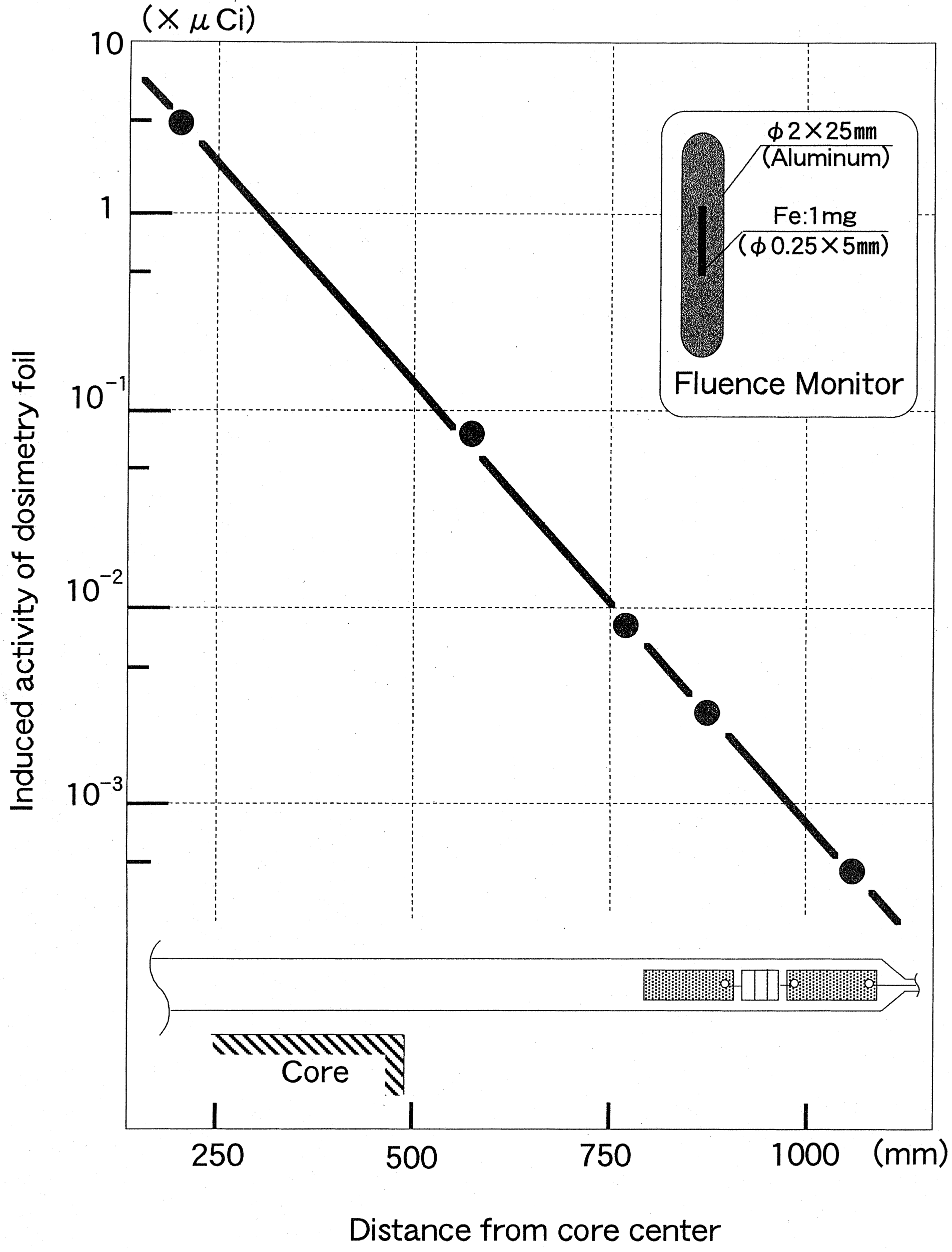

Fig. 7. Dosimetry of fast neutron fluence as a function of distance from midplane of the reactor core.

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