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Irradiation techniques under high pressurized water using hybrid type saturated temperature capsule in the JMTR

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Abstract

The IASCC is one of the major concerns on the integrity of in-core materials not only for the LWRs but also for the materials to be cooled by water in fusion reactor. It is desired to irradiate test materials in a high temperature water environment in order to investigate simultaneous effects of irradiation and corrosive environments, which are essential for the study of IASCC. In the JMTR, an irradiation rig named the SATCAP was developed and applied for the IASCC study. Inside of this capsule, cooling water is boiling during irradiation due to heat generated by gamma heating, thus the temperature of the specimens is kept nearly at saturation temperature of water. Recently a new hybrid type SATCAP with electric heaters and vacuum control systems was developed to improve temperature control capability of the original SATCAP. A design and results of performance test of the new hybrid type SATCAP are reported.

1. Introduction

The irradiation assisted stress corrosion cracking (IASCC) of in-core structural materials caused by the simultaneous effects of neutron irradiation and high temperature water environments has been pointed out as one of the major concerns not only for the light water reactors (LWRs) but also for the water-cooled fusion reactor, i.e., ITER. The IASCC of the austenitic stainless steels or nickel base alloys has been studied for more than ten years under international efforts in the various projects for the plant life assessment and extension of LWRs. However, its mechanism has not been clarified yet in spite of the extensive post-irradiation examinations. Under this situation, it is desired to perform irradiation tests under specially controlled conditions so that the effects of irradiation and high temperature water can be separately evaluated. For example, irradiation tests under different neutron doses with same temperature, or vice versa, will be valuable. In the Japan Materials Testing Reactor (JMTR), an irradiation technique using the saturation temperature capsule (SATCAP) was developed for irradiation of the materials in the water with high, but constant, temperature water and applied to study the IASCC [1,2]. This irradiation technique is based on controlling the saturation temperature of cooling water by controlling its pressure [1,2]. This technique has enabled the irradiation of the materials for the study of IASCC.

The irradiation technique using the SATCAP can be also utilized for the study of IASCC for the fusion reactor materials. In the case of fusion reactor materials, a ratio of helium generation to displacement damage (He/dpa) is expected to be smaller than that of the LWR materials. Though the irradiation in the fuel region of the JMTR is desirable for fusion materials research to simulate such damage characteristics because of higher ratio of fast neutron flux, it is difficult to keep specimen temperatures in the relatively low temperature range assumed in the ITER design, e.g., 420–570 K, in an inert gas environment due to a strong gamma heating. The SATCAP technique makes it possible to irradiate specimens for fusion research in the fuel region by cooling the specimens in water.

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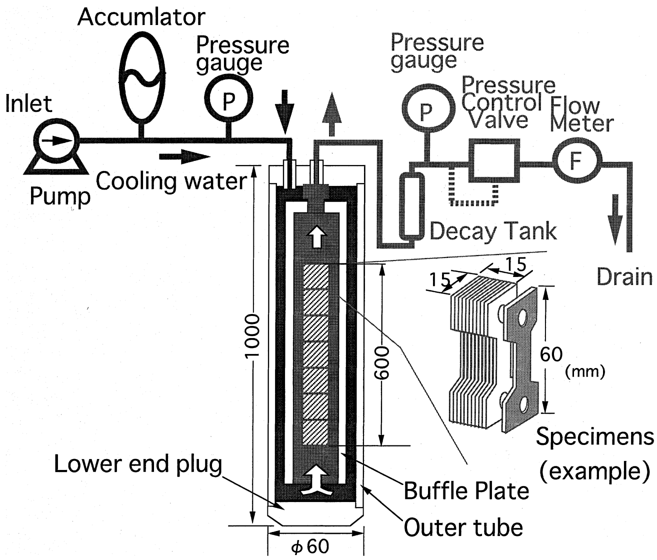

Fig. 1. Schematics of SATCAP.

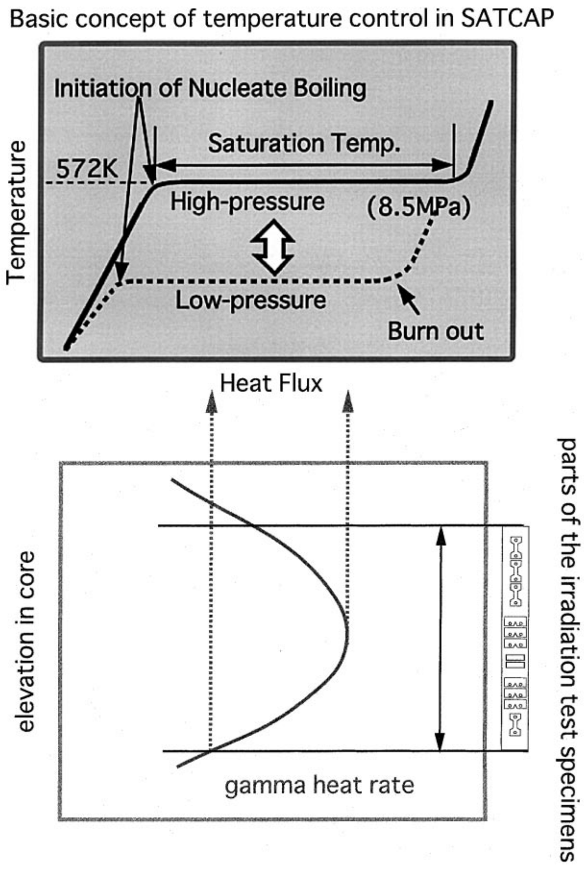

Fig. 2. Basic concept in SATCAP.

Recently, we improved the capability of the SATCAP to irradiate materials in a wide range of temperature at various channels in the JMTR core by enhancing the temperature control mechanism. The performance tests of the improved type SATCAP performed in the JMTR have proven its capabilities. The design and test results of the hybrid type SATCAP are described in the following sections.

2. Experimental procedures

A flow diagram of the original SATCAP, shown in Fig. 1, consists of the irradiation capsule installed in the JMTR core, and a water supply and drain system. Water pressurized to about 10 MPa at maximum is supplied to the capsule. It flows downwards through a gap between outer and inner walls, and changes flow direction at the bottom of capsule, then flows upwards in the inner tube. Temperature of the water increases as it flows due to the heat generated inside the materials of the capsule and the water itself by gamma heating and it reaches to a saturation temperature determined by the pressure. The pressure is controlled by the pressure control valve in the drain line. The basic concept employed in SATCAP technique is schematically shown in Fig. 2. When thermal load at the material surface is increasing, water flowing along the surface initiates nucleate boiling at some value of heat flux. As nucleate boiling continues, the temperature of the material surface is kept near the saturation temperature of water for some range of heat flux and its distribution is uniform, due to large heat transfer of nucleate boiling. For example, if the pressure of water is kept at 8.5 MPa, the specimen's surface temperature will be about 573 K.

The excellent capability of SATCAP to control the irradiation temperature was already reported [1,2]. However, SATCAP must be installed into a high gamma flux region of JMTR such as the fuel region to realize the saturation temperature, because the gamma heating of capsule materials is only source of heating. To avoid this limitation, a hybrid type SATCAP was designed. Fig. 3 show the comparison between the designs of original SATCAP and hybrid type SATCAP. As shown in this figure, the hybrid type SATCAP has a double wall with a vacuum gap and an electric heater around the specimens inside the inner tube. These improve temperature control significantly. The vacuum level in the gap is controlled by a vacuum pump and inert gas supply system which are equipped outside the reactor. This gap prevents conduction heat transfer from the capsule to coolant water of JMTR and keeps the inside temperature of the capsule elevated. The electric heater compensates for insufficient gamma heating when the capsule is placed outside the fuel region. This new hybrid type SATCAP was commissioned in JMTR in 1996 and irradiated for three reactor cycles as initial test using tensile test specimens, compact tension specimens and corrosion test specimens. One cycle of JMTR is 25 days at 50 MW of thermal output. The target irradiation temperature was 573 K. The capsule was installed in the reflector region where fast neutron flux was 1.0×10^{17} m^{-2} ($E > 1$ MeV) and maximum gamma heating rate was 2.3 w/g. Twelve thermocouples were equipped in the capsule to monitor the irradiation temperatures.

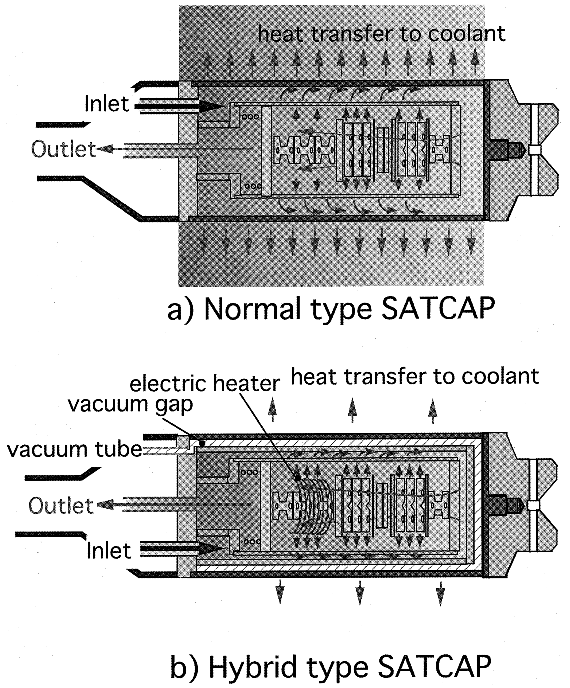

Fig. 3. The comparison of hybrid type SATCAP and normal type SATCAP.

3. Results and discussions

The performance tests were carried out for 2 days in the first irradiation cycle in order to demonstrate the control capabilities of hybrid type SATCAP. The temperature of the specimen measured by the #8 thermocouple and other controlled parameters during the test are shown in Fig. 4. In the first stage, temperature was changed by the "dump and vacuum" control mode, during each operation period with reactor power of 30, 40 and 50 MW, respectively. The vacuum pressure, which is adjusted by the He gas flow rate, was about 100 torr in the capsule. Flow rate and pressure of the cooling water were 550 cc/min and 8.63 MPa, respectively. Surface temperature of the specimen rose from 420 to 460 K, from 450 to 500 K and from 470 to 540 K at each

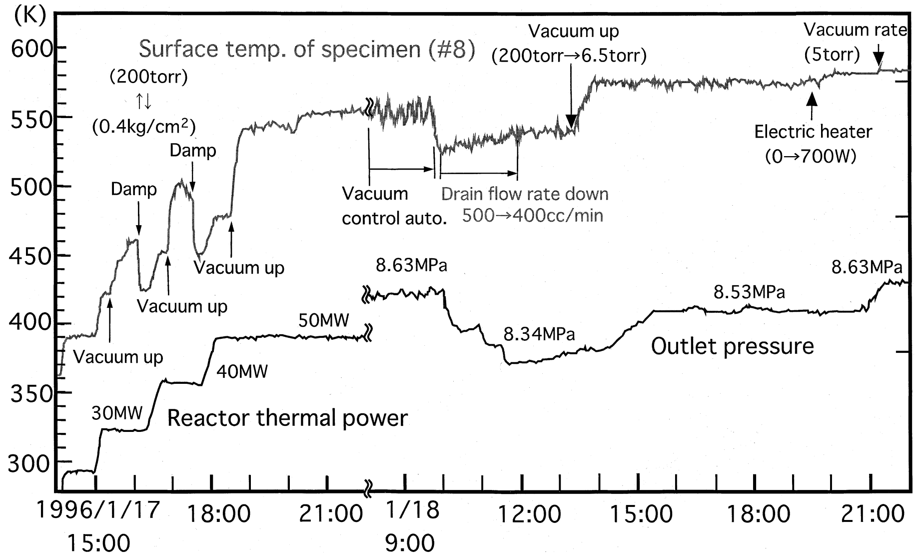

Fig. 4. The transitions of temperature and control parameters during the performance tests.

reactor power level by changing the pressure of capsule gap gas. These changes of the temperature agreed well with the values estimated by calculation. Afterwards, the temperature control mode test was begun. In the first half of the test, temperature control by the automatic vacuum control mode was tried, but it did not succeed in stabilizing conditions in the capsule. This is recognized from the cyclic fluctuation of the temperature in Fig. 4. Therefore, temperature control was carried out using manual vacuum control mode in the latter half of the test. By lowering the cooling water flow rate, decreasing vacuum and increasing power supply to the electric heater, the surface temperature of the specimen reached a saturation temperature and stabilized. At the same time, temperatures of other thermocouples also reached about 573 K which was the target temperature. At the stabilized condition, the cooling water flow rate was 400 cc/min, the vacuum pressure was 6.5 torr, and the heater

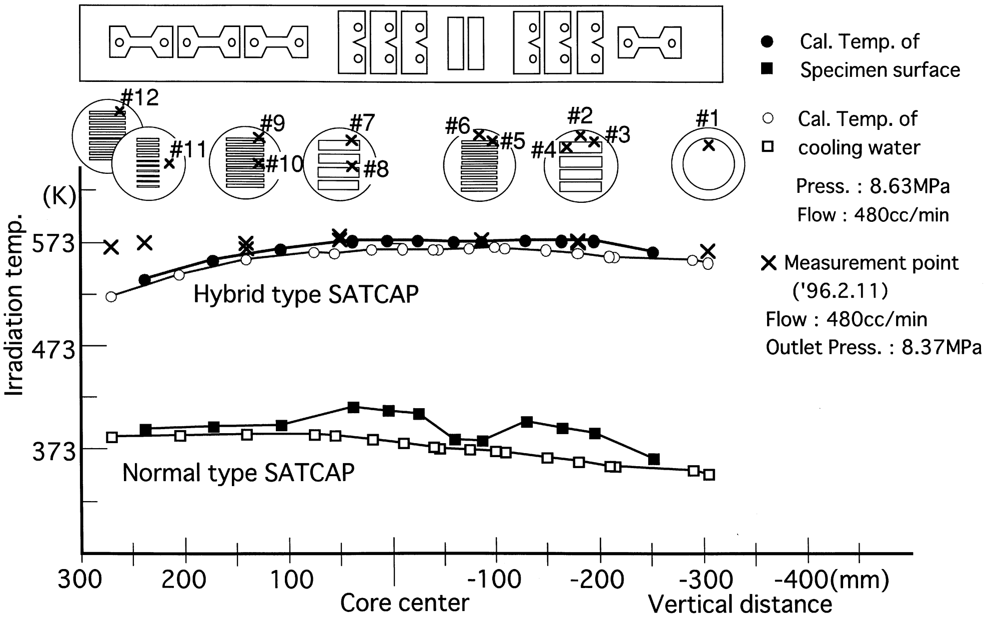

Fig. 5. Temperature distribution in hybrid type SATCAP.

Table 1
The irradiation temperature during the third cycle

Measurement point	95% distribution term (K)	Min. (K)	Max. (K)
#1 (Water temp.)	558 ± 13	543	575
#2 (Water temp.)	565 ± 10	552	576
#3 (Spe. surface)	565 ± 10	552	576
#4 (Spe. inside)	568 ± 8	556	575
#5 (Spe. surface)	570 ± 5	561	575
#6 (Water temp.)	570 ± 5	561	575
#7 (Spe. surface)	572 ± 3	566	575
#8 (Spe. surface)	575 ± 1	572	577
#9 (Spe. surface)	565 ± 7	553	574
#10 (Spe. surface)	568 ± 5	557	574
#11 (Water temp.)	567 ± 5	557	572
#12 (Spe. surface)	566 ± 5	556	573
Outlet pressure	7.95 ± 0.06 MPa	7.84	8.09
Drain flow	640 ± 20 cc/min	570	680

Data: From 1996.5.8 – 21:00 to 1996.6.2 – 9:00 (1177 points).

power was 700 W. Hereafter, stable irradiation was carried out with minor adjustment.

The temperature distribution of the specimens and cooling water inside the hybrid type SATCAP is shown in Fig. 5. Calculated temperatures of the specimens contained in the hybrid type SATCAP are also plotted, as well as the temperatures expected when the specimens were irradiated using normal type SATCAP. The measured temperatures agrees closely with calculated values and very close to the target temperature of 573 K. This shows that the hybrid type SATCAP are effective for the irradiation even in the lower gamma ray region, because the temperature inside the hybrid type SATCAP is about 200 K higher than that of normal type SATCAP, and reaches saturation condition.

During the second and the third cycle, stable irradiation were also achieved. In these irradiations, coolant pressure in the SATCAP was regulated at 7.95 MPa with saturation temperature of 570 K. In the stable operation period, cooling water flow rate and the gas pressure were controlled as 640 cc/min and 0.01 torr, respectively, while the heater was not used. The results of the temperature measured in the third cycle is shown in Table 1.

4. Conclusions

The hybrid type SATCAP was recently developed and its performance was proved by the irradiation tests performed through three operation cycles of the JMTR. Principal results obtained are as follows,

1. The hybrid type SATCAP has the capability to irradiate materials under stable and uniformly distributed temperature condition, similar to the normal type SATCAP.
2. Even in the peripheral region of the JMTR where the gamma heating rate is rather low, materials can be irradiated in a high temperature water environment using the hybrid type SATCAP.
3. By addition of the vacuum and electric heater control systems, flexibility of the condition control of the SATCAP was increased.

According to these characteristics, SATCAP provides a well controlled irradiation environment suitable especially for IASCC studies, as well as for other purposes. As a next stage, an unconfined constant load (UCL) test is planned using the SATCAP.

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