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Experimental validation of effectiveness of rod-type burnable poisons on reactivity control in HTTR

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ABSTRACT

In block-type high temperature gas-cooled reactors (HTGRs), insertion depth of control rods (CRs) into a core should be retained shallow to keep fuel temperature below 1495 °C through a burnup period, and hence excess reactivity should be reduced through a different method. Loading burnable poisons (BPs) into the core is considered as a method to resolve this problem as in case of light water reactors (LWRs). Effectiveness of BPs on reactivity control in LWRs has been validated by experimental data, however, this has not been done yet for HTGRs, because there was not enough burnup characteristics data for HTGRs required for the validation. The High Temperature Engineering Test Reactor (HTTR) is a block-type HTGRs and it adopts rod-type BPs to control reactivity. The HTTR has been operated up to middle burnup, and thereby the experimental data was expected to show effect of the BPs on the reactivity control. Hence, in order to validate effectiveness of rod-type BPs on reactivity control in the HTTR, we investigated on the HTTR results whether the BPs have functioned as designed. As a result, the CRs insertion depth has been retained shallow within allowable range, and then effectiveness of rod-type BPs on reactivity control in the HTTR was validated.

1. Introduction

Recently, high temperature gas-cooled reactors (HTGRs) have been receiving particular attention as one of the nuclear reactor type for the next generation in the world, because of their high energy efficiency and applicability of nuclear power as a heat source for hydrogen productions without release of carbon dioxide (Terada et al., 2007). Many countries have been performing design studies on HTGRs (Idaho National Laboratory, 2005; Ehster et al., 2005). Meanwhile, in Japan, Japan Atomic Energy Agency (JAEA) has been conducting a design study on the Gas Turbine High Temperature Reactor 300-Cogeneration (GTHTR300C) (Kunitomi et al., 2007; Nishihara et al., 2006), which is proposed as a future Japanese commercial HTGR. Additionally, JAEA has been operating the High Temperature Engineering Test Reactor (HTTR) (Saito et al., 1994), which is a block-type HTGR, and it has yielded useful data for conducting design studies on future commercial block-type HTGRs (Kunitomi et al., 2007; Nishihara et al., 2006; Sakaba et al., 2008).

There are two types of HTGRs: the one is block-type and the other is pebble-bed-type, and both the GTHTR300C and the HTTR are block-type HTGRs. In pebble-bed-type HTGRs, reactivity can be adjusted during operation by number of pebble, however, this method cannot be applied to the block-type one because fuel cannot be added and removed during operation. In block-type HTGRs, reactivity is controlled by control rods (CRs) and burnable poisons (BPs). No other reactivity control systems are installed like chemical shim or recirculation flow control in LWRs which can be adjusted during operation. Additionally, during rated power operation, the CRs insertion depth into the core should be retained shallow to keep fuel temperature below limit, because the large insertion depth lead to significant disturbance of the power distribution in the core, and consequently fuel temperature rise above limit. In block-type HTGRs, thus, controllable reactivity by CRs is relatively small, and then using BPs is considered as the main method of reactivity control through a burnup period.

The HTTR adopts rod-type BPs to control reactivity. This paper describes validation of effectiveness of rod-type BPs on the HTTR using the experimental data.

2. Validation method using HTTR

2.1. HTTR

2.1.1. Outline

Table 1 shows major specifications of the HTTR. The HTTR is a graphite-moderated and helium gas-cooled block-type HTGR, situ-

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Table 1
Major specification of HTTR.

Thermal power	30 MW
Outlet coolant temperature	850 °C/950 °C[a]
Inlet coolant temperature	395 °C
Core structure	Graphite
Equivalent diameter	2.3 m
Effective height	2.9 m
Fuel	UO_2
Uranium enrichment	3–10 wt.% (average 6 wt.%)
Burnup period	660 days
Reactivity control systems	
Control rod (CR)	16 pairs of 32 B_4C/C rods
Burnable poison	Incorporate two B_4C/C rods for each fuel blocks

[a] Rated operation/high temperature test operation.

ated at JAEA-Oarai Research and Development Center. It has 30 MW thermal power and its outlet coolant temperature, which can be used for nuclear heat utilization, is 850 °C in rated power operation. Additionally, the HTTR can also be operated in high temperature test operation mode, with which its outlet coolant temperature is 950 °C. The HTTR has been operated up to middle burnup, which is about 300 effective full power days (EFPD), and thereby one could obtain experimental data which show effects of the BPs on reactivity control.

Fig. 1 shows radial and axial views of the HTTR core. The core is constructed by stacking four kinds of hexagonal blocks, which are fuel blocks, control rod guide blocks, replaceable reflector blocks and irradiation blocks (for irradiation test), and is surrounded by permanent reflectors made of graphite. All these hexagonal blocks are made of high-purity graphite, and are same in 36 cm in across flats and 58 cm in height. Fuel region in the core is composed of 30 fuel columns, in which five fuel blocks are stacked in each column.

2.1.2. Fuels

Coated fuel particles (Saito et al., 1994), which have a function of preventing release fission products (FPs) from fuels to coolant, are used in the HTTR. Their maximum use temperature in normal operation condition is limited up to about 1495 °C to retain the function under considered abnormal condition. A power distribution in the core is optimized to make fuel temperature below the limit. Specifically, the power distribution is made uniform in radial direction, and relatively higher at coolant inlet side (upper side of the core) in axial direction. This optimized distribution is achieved by changing uranium enrichment (3–10 wt.%U).

2.1.3. Reactivity control systems

In the HTTR, reactivity control during normal operation is conducted by CRs and BPs. No other reactivity control systems are installed like chemical shim or recirculation flow control in LWRs.

2.1.3.1. Control rods. The HTTR has 16 pairs of 32 CRs consisting of one pair of the central CR (C-CR), six pairs of the first ring CR (R1-CR), six pairs of the second ring CR (R2-CR) and three pairs of the third ring CR (R3-CR). All of the CRs are same in material and geometry. The location in the core on the radial direction is illustrated in Fig. 2. The CRs are inserted into the core from the upper region of the core to the bottom of the fuel region through vertical holes which is placed in the CRs guide blocks. As shown in Fig. 1, each CRs guide blocks has three vertical holes, two of which are for the CRs insertion, and the other is for reserved shut down system (RSS).

During normal operation, C-CR, R1-CRs and R2-CRs are used to control reactivity, meanwhile, R3-CRs, which are only used at scram, are withdrawn from the core and not used. In order not to disturb the optimized power distribution form in radial direction, all the CRs except R3-CRs are operated so that their insertion depths into the core are the same.

2.1.3.2. Burnable poisons. Boron carbide is used as BP in the HTTR, because of its excellence in heat residence and economy. The BPs are rod-type and are incorporated into every fuel blocks (150 fuel blocks). The rod-type BPs are inserted into the vertical holes in the fuel blocks which is placed under the dowel pins (Fig. 3). Characteristics of rod-type BPs, which are effective span and magnitude as poison, are determined by its poison atom density and radius. In the HTTR, the BPs characteristics were optimized by adjustment of

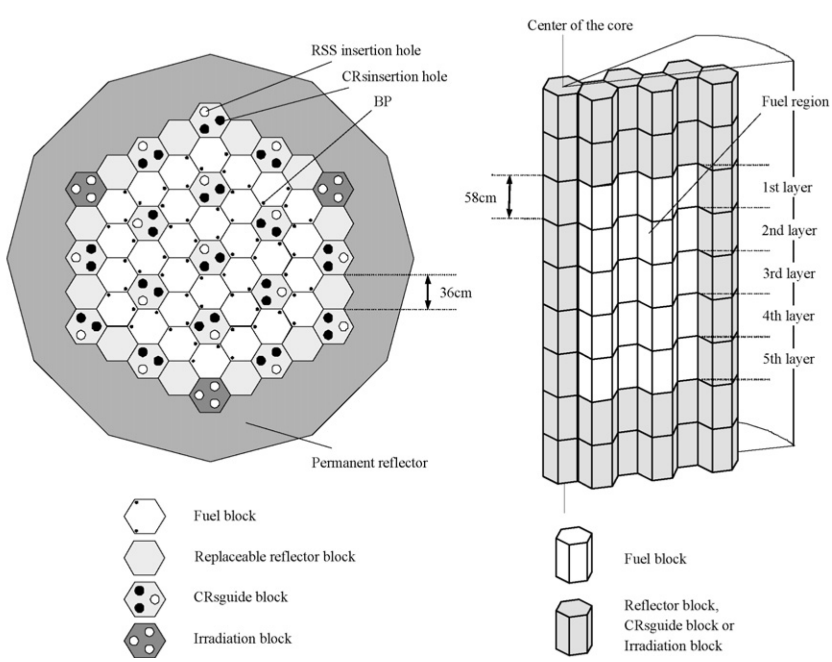

Fig. 1. Schematic diagram of HTTR core.