A Preliminary Study on the Updated Reactivity Control System of MiHTR

Jong-Hyuck Won, Jiwon Choe, Seungsu Yuk and Chan Soo Kim
Korea Atomic Energy Research Institute
111 Daedeok-daero 989 beon-gil, Yuseong-gu, Daejeon 34057, KOREA
jhwon@kaeri.re.kr

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing Micro modular High Temperature gas-cooled Reactor (MiHTR) in 2017-2019. [1, 2] The main purpose of the MiHTR is to deploy a remote site without electricity connection to supply the electricity and heat. In order to achieve it, MiHTR was designed to have long life cycle (20 years) without refueling.

In MiHTR, there are seven control blocks in the core to control the reactivity. However, the mechanisms of reactivity control are identical as control rod insertion to the system so it is required to introduce other type of reactivity control system to achieve diversity. In Ref [3, 4] the system named Reserve Shutdown Control (RSC) was used as a secondary reactivity control system for high temperature gas-cooled reactor.

In this paper, original control block of the MiHTR was modified to have RSC system and estimations of the shutdown margin for the control rod and RSC for the modified MiHTR core were conducted.

2. Overview of the MiHTR

The thermal and electric power of the MiHTR is 10MWth and 4MWe respectively. The cycle length is 20 years without refueling. The Fig. 1 shows radial core layout of the MiHTR core.

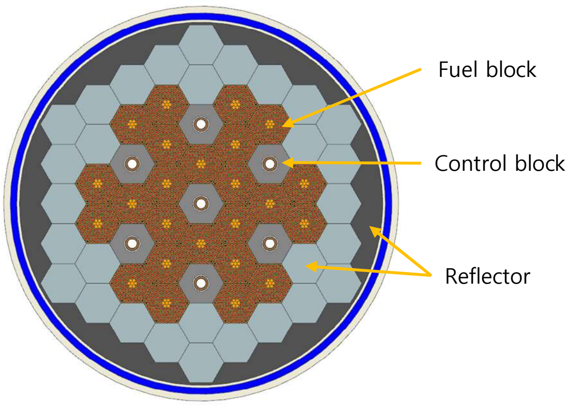

Figure 1: Radial core layout of the MiHTR

Fig.2 shows detailed geometric information of the fuel/control blocks. For the optimized MiHTR core in 2019, nuclear fuel with an enrichment of 14% to 16% was utilized. And the control block contains a central hole for control rod insertion, which has a radius of 6.35 cm.

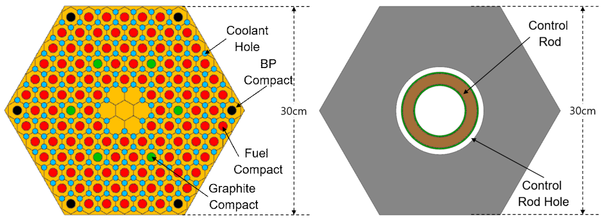

Figure 2: Radial block layout (left: fuel block, right: control block)

3. Updates of Reactivity Control System

In High-Temperature Gas-Cooled Reactors (HTGRs), a handling hole is typically located at the center of a fuel or control block to facilitate its replacement. Therefore, it is not possible to place a hole for control rod insertion in the central position, as is done in the current MiHTR control block design. Accordingly, as shown in the figure below, three holes are arranged in the block in a 120-degree symmetric configuration for modification. Two of these holes are designated for control rod insertion, while the remaining one is intended for the RSC.

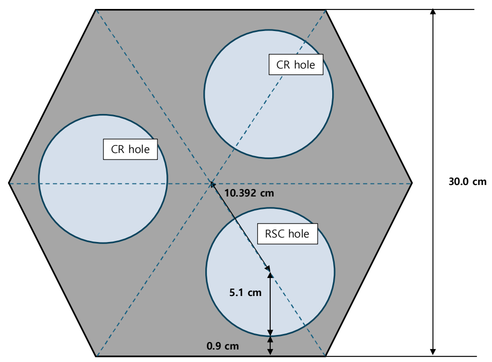

Figure 3: Modified control block geometry

While the individual hole size was decreased to a radius of 5.1 cm, the use of two control rods results in a net increase of 8.8% in the absorber volume fraction relative to the original design. The control block at the center of the core was replaced with a reflector. The figure below shows the 1/6 radial core configuration with the modified control blocks applied.

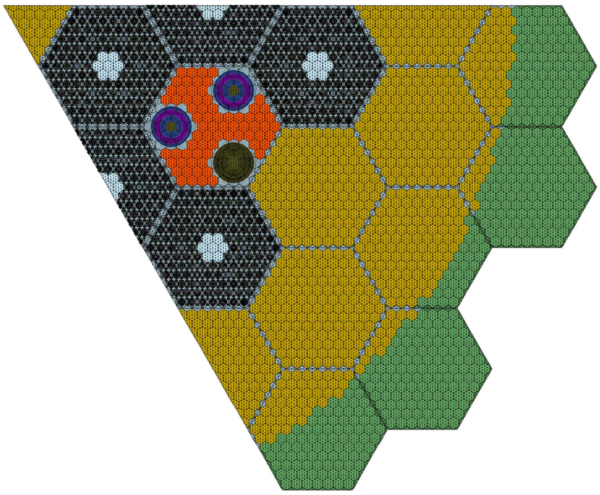

Figure 4: 1/6 radial core configuration of MiHTR with updated control blocks

Based on Ref. [4], the specifications for the RSC absorber particles were set as shown in the table below.

Table 1: Specification of the reserve shutdown control material

Material type	B4C sintered graphite
B4C fraction	40 % volume fraction
B-10 enrichment	19.9 a/o natural boron
Geometry type	13 mm sphere

4. Shutdown margin estimation

To estimate the shutdown margin of updated reactivity control system, DeCART-HTR code [5] and CAPP code [6] were utilized. The shutdown margins for each control system were evaluated with consideration of following reactivity components:

Temperature defect: In case of a reactor shutdown, the power rate decreases and the core temperature drops. As a result, positive reactivity is inserted into the system. In MiHTR, control rods should compensate for temperature defects from the hot full power condition (HFP) to the refueling condition (RC), while RSC should compensate for temperature defects from hot full power condition to the hot zero power condition (HZP)

Overpower: To ensure a conservative reactor core design, 15% overpower operation is assumed before shutdown. The additional temperature defect is evaluated to be 15% of the temperature defect from HFP to HZP.

Excess reactivity: The control rods are not only used for reactor shutdown but also for excess reactivity control for the MiHTR.

Reactivity fault: It is assumed that control rods at the one control block are withdrawn from the core. Usually only one control rod is considered to withdrawn, but for conservative approach, control block failure is assumed.

Xe elimination effect: After reactor shutdown, inventory of Xe in the reactor core will be zero eventually. Reactivity control system should compensate for this positive reactivity insertion of Xe elimination.

In Ref. [2], the shutdown margin tends to have minimum value at BOC. In this paper, shutdown margins of the updated reactivity control system were evaluated at the BOC state. Tables 2 and 3 show the estimation of shutdown margin for the control rod and RSC. In this estimation, 20% of calculation uncertainty for the reactivity and additional 20% safety margin for shutdown margin value were assumed.

Table 2: Control rod shutdown margin estimation of the MiHTR

(Unit: pcm)	Reactivity worth
Excess reactivity	371
Reactivity fault	70
Temperature defect (HFP → RC)	4258
Overpower	307
Xe elimination effect	352
Required worth for reactor shutdown (+20%)	6429
N-4 control rod worth (-20%)	13233
Shutdown margin (-20%)	5443

Table 3: RSC shutdown margin estimation of the MiHTR

(Unit: pcm)	Reactivity worth
Reactivity fault	70
Temperature defect (HFP → HZP)	2049
Overpower	307
Xe elimination effect	352
Required worth for reactor shutdown (+20%)	3333
N-1 RSC worth (-20%)	9664
Shutdown margin (-20%)	5065

In table 2, N-4 control rod insertion is considered to achieve reactor shutdown. During refueling stage, two control block positions will be utilized to equip fuel handling machine and fuel transfer cask. Therefore, four control rods are unavailable for safe shutdown for refueling. For RSC, only one RSC is assumed to be failure for the shutdown.

As shown in table 2 and 3, two reactivity control system has more than 5% $\Delta k/k$. Although the central control block was eliminated, a sufficient shutdown margin is ensured by positioning the control rods of the 3-hole control blocks closer to the core center compared to original core layout and by increasing the absorber volume fraction by 8.8%.

The excess reactivity shown in table 2 above is relatively low. It is confirmed that this is caused by the reduced graphite inventory in the core by using the 3-hole control blocks. The reactivity loss is approximately 900 pcm compared to the previous design. However, this reactivity loss is considered manageable, given the large shutdown margin of approximately 5000 pcm even though other design change will be done to restore excess reactivity.

5. Conclusion

The reactivity control system for the MiHTR has been updated to include the RSC as a secondary reactivity control system to achieve design diversity. As a preliminary evaluation, the shutdown margins for the control rods and the RSC were estimated at the BOC. The results show that a sufficient shutdown margin exists for both systems, even after accounting for calculation uncertainty and safety margins. However, a loss of excess reactivity is observed, resulting from the reduced graphite inventory in the core due to the adoption of the 3-hole control block design. This loss in excess reactivity will shorten the cycle length. Therefore, other design updates should be considered to optimize the MiHTR core in future studies.

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