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A Study on the Core Design for Decreasing the Power Peaking Factor in a VHTR Core

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1. Introduction

Korea Atomic Energy Research Institute (KAERI) has been developing a very high temperature reactor (VHTR) for hydrogen production application. In order to keep the fuel soundness under the condition of 950℃ outlet temperature, the reactor must satisfy the requirements of the power peaking factor and have sufficient excess reactivity for the cycle length.

In this paper, various 3-ring and 2-ring VHTR core were designed and compared for efficiently achieving the requirement of the power peaking factor and the excess reactivity. First, a 3-ring core based on MHTGR-350 benchmark problem [1] was designed considering the condition of the 950℃ outlet temperature and the power peaking factor and the control rod worth for the excess reactivity were evaluated. Then, a 2-ring core without the middle fuel block ring was designed for decreasing the peaking factor and the core characteristics was investigated by DeCART [2] code.

2. Methods and Results

The VHTR core designed by KAERI for the hydrogen production must have the power peaking factor under 1.4 and the excess reactivity of about 19000 pcm according to the cycle length of about 500 day. However, the demonstration reactor, PMR200 [3], by KAERI, has about 2.5 power peaking factor and MHTGR-350 has also over 2.0 due to low outlet temperature. Thus, a case study was carried out for decreasing the peaking factor using the 3-ring core based on MHTGR-350.

2.1 3-Ring Model

Fig.1 shows the typical 3-ring core of HTGR based on MHTGR-350. There are control rod holes in inner and outer reflectors.

After carrying out core analyses on a lot of loading patterns, the optimized design of 3-ring core as shown as Fig.2 was obtained. This model has four fuel block types with different packing fraction, 33, 30, 26, and 21% to satisfy the required cycle length. In the status of control rod out, the power peaking factor is about 1.60 which is occurred around the inner reflector. Also, it shows that the peaking factor with the control rod inserted is similar to the status without the control rods. The control rod worth is about 19400 pcm which can deal with the excess reactivity.

Fig.3 presents the power distribution inside the fuel block. It is shown that the pin power range from 0.73 to 1.60 and the difference is relatively large.

It is noted that the peaking factor in this model cannot meet the design requirement of less than 1.4. Thus, 2-ring core that the middle fuel blocks are replaced with the graphite block was designed for reducing the power peaking factor.

2.2 2-Ring Model with Original Block Size

Fig. 4 shows the 2-ring core designed using the same fuel block with 3-ring. In order to load the same fuel mass with 3-ring model considering the cycle length, the fuel blocks are laid in the fourth and sixth ring of the core. But, the number of the block ring increases by 10 and the core radius must be extended by the size of the one fuel block.

Fig.5 shows the relative power distribution of the 2-ring core and the peaking factor. This model has three fuel block types with different packing fraction, 33, 25, and 20% considering the fuel mass. In the status of control rod out, the power peaking factor is about 1.37 which is occurred in the middle reflector. Also, the peaking factor with the control rod inserted is about 1.40 which meet the requirement of the core design for 950℃ outlet temperature and the excess reactivity is calculated by over 19000 pcm.

Fig.6 shows the power distribution inside the fuel block. It is shown that the power range from 0.90 to 1.37 and the difference is smaller than that of the previous design.

2.3 2-Ring Model with Reduced Block Size

For overcoming the disadvantage of the extended core size in the 2-ring core, 2-ring model with reduced block size were designed by removing the outermost pin ring in the original fuel block. Thus, the radial core size is same with 3-ring core in the section 2.1. In order to conserve the fuel mass, this core must have axially 12 fuel blocks contrary to originally 9 blocks. However, it does not deeply affect the core characteristics, because the core has axial shuffling scheme.

Fig.7 presents the power distribution and the peaking factor of the reduced 2-ring core. The power peaking factors are about 1.37 in the all rod out and 1.39 in the control rod inserted, respectively. It is noted that the values are very similar to those of the previous model.

2.4 3-Ring Model with Enrichment Zoning

In this section, the 3-ring core with enrichment zoning was designed and investigated. The outermost pins in the fuel block are replaced with lower enrichment fuel pins. The original fuel block has the enrichment of 12 w/o and the modified fuel block, however, has the fuel pin with 7.5 w/o in the outermost ring and 10 w/o in the second and third ring from the boundary.

Fig. 8 shows the power distribution of the 3-ring core with the enrichment zoning. The simple modification with the zoning in the 3-ring core of section 2.1 decreases the peaking factor from 1.60 to 1.43. If more elaborate loading pattern search are carried out, it seems that the model might have a peaking factor under 1.4. Fig. 9 shows the pin power distribution inside the modified fuel block. The peak is shown in the fourth ring from the boundary as expected.

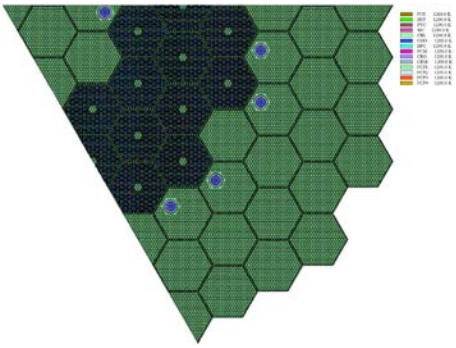

Fig. 1. Radial Configuration of 3-Ring Core

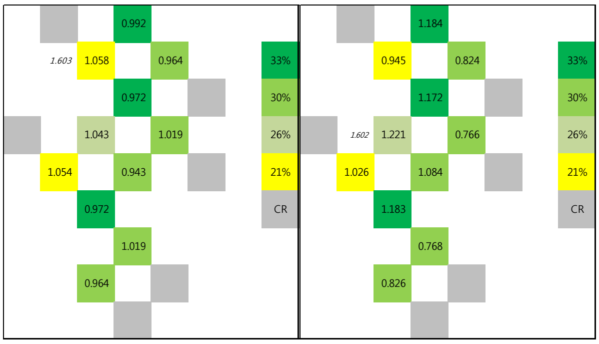

Fig. 2. Power Distribution of 3-Ring Core

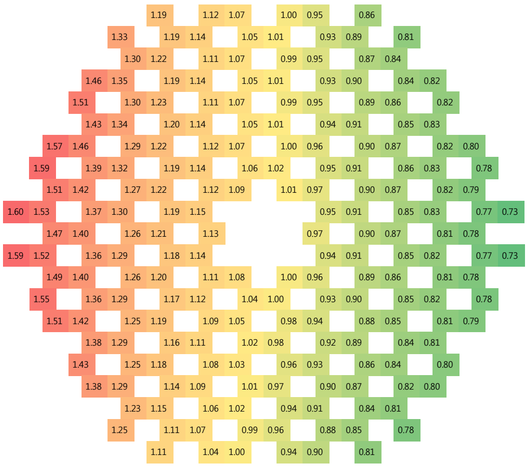

Fig. 3. Pin Power Distribution inside 3-Ring Fuel Block

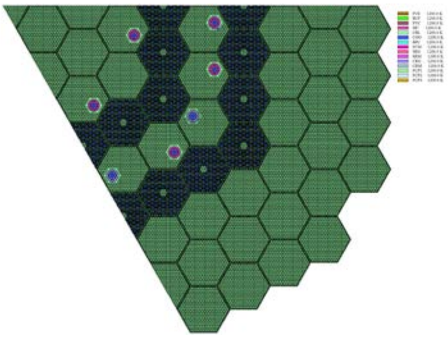

Fig. 4. Radial Configuration of 2-Ring Core

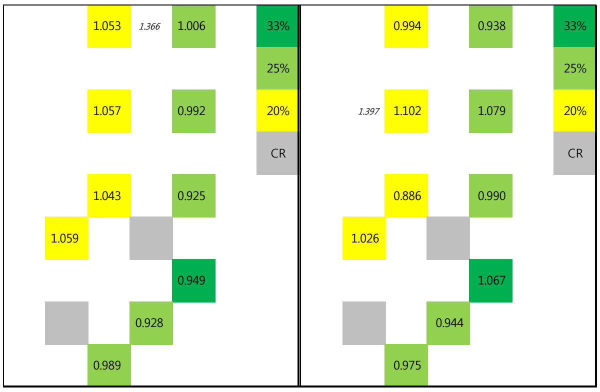

Fig. 5. Power Distribution of 2-Ring Core

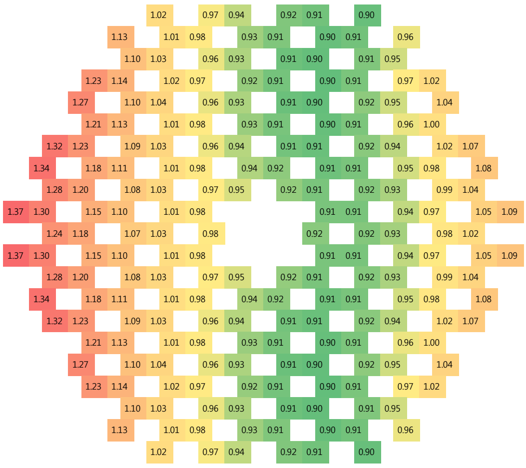

Fig. 6. Pin Power Distribution inside 2-Ring Fuel Block

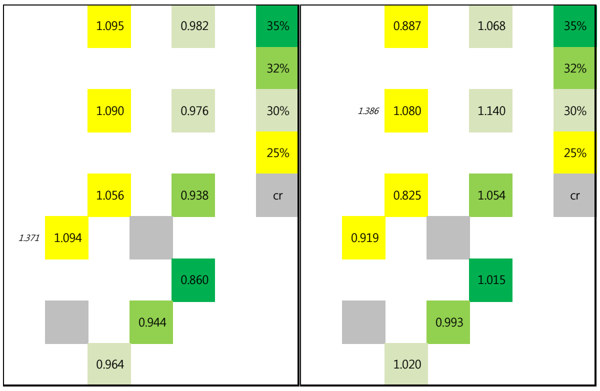

Fig. 7. Power Distribution of Reduced 2-Ring Core

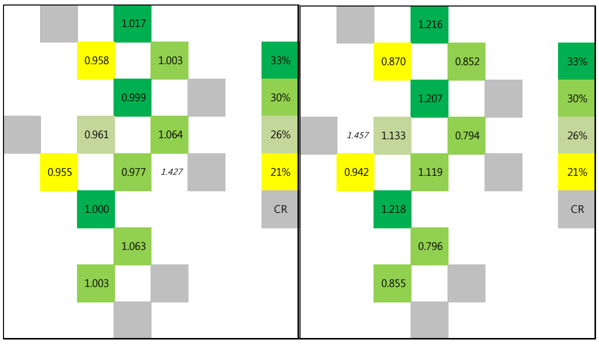

Fig. 8. Power Distribution of 3-Ring Core with Zoning

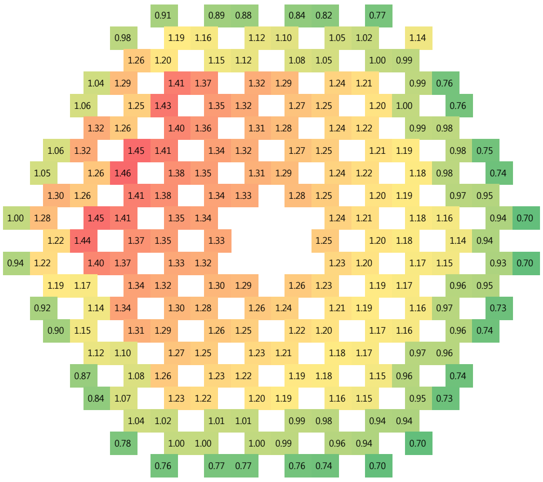

Fig. 9. Pin Power Distribution of 3-Ring Fuel Block

3. Conclusions

In this paper, the comparisons of various VHTR core designs for efficiently achieving the goal of the power peaking factor under the condition of 950℃ outlet temperature were carried out using DeCART.

First, the 3-ring core based on MHTGR-350 benchmark problem was designed and investigated. Then, the 2-ring core without the middle fuel block ring and the 2-ring core with the reduced block size were designed for decreasing the peaking factor. Lastly, the 3-ring core with the enrichment zoning was examined. Except the original 3-ring core, the other models could achieve the peaking factor around 1.4.

Therefore, it is expected that these models will be used in a VHTR core design for hydrogen production with 950℃ outlet temperature.

Acknowledgement

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