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Irradiation Swelling Analysis of Beryllium Reflectors in KJRR

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1. Introduction

It is reported that Beryllium swells under fast neutron irradiation [1], which is used as major reflectors in KiJang Research Reactor (KJRR). Dimensional changes of Beryllium reflectors due to swelling could make a problem geometrically in the core configuration, such as mechanical interference with themselves or neighboring components. It would affect a flow path in the core and make difficult to dismantle the core components. So, it is important to estimate the amount of swelling of the Beryllium reflectors and to prepare a maintenance scheme to prevent the severe condition based on the estimation. In this study, it is simulated using finite element method (FEM) how much the Beryllium reflectors swells in the irradiated environment of KJRR.

2. Analysis Methods and Parameters

Behavior model under irradiation, irradiation related material coefficients, neutron doses and analysis model are delineated in this section.

2.1 Swelling Model

The volumetric swelling model of ABAQUS [7], the commercial FEM software, is applied to simulate the behavior of the Beryllium reflectors under irradiation. This model express the swelling as a strain rate function of neutron fluence and swelling coefficient as follow.

$$\dot{\varepsilon}^{SW}=f(\Theta, \phi, f_1, f_2, \ldots)$$

Strain rate function can be defined by various variables, such as temperature, neutron fluence and other field variables. Also, as defining it at several intervals of certain variable, nonlinear dependency of the swelling on the variable can be included. However, since it is assumed that the Beryllium swells linearly according to the amount of the neutron fluence, the only one swelling coefficient is applied in this study, which is the expansion ratio to a neutron in square centimeters ($\%\cdot cm^2/n$).

2.2 Swelling Coefficients

The swelling coefficients were provided in several preceding studies [1],[2],[3] for the material behavior of Beryllium under irradiation. According to them, the swelling of Beryllium is dependent on the irradiated environment and type of the product, and coefficients are in wide range. Because the swelling of Beryllium is mainly caused by fast neutrons, coefficients that were investigated for fast neutrons over 0.8MeV are applied. Among those data, the maximum and minimum coefficients are selected as follow, and then the results are compared in two cases.

Minimum coefficient: $2.0\times10^{-23}\%\cdot cm^2/n$ [2]

Maximum coefficient: $8.2\times10^{-23}\%\cdot cm^2/n$ [3]

2.3 Neutron Flux Distribution

Neutron flux distribution ($n/cm^2\cdot sec.$) in the core including every core component was calculated by nuclear physics and provided as below in Figure 1. The flux intensity is strong in the center of the core, and become weaker as it goes to the boundaries. Due to this non-uniformity of the flux, the swellings in each part of one reflector will be different. As a consequence, it can be predicted that the reflector will swell as bended.

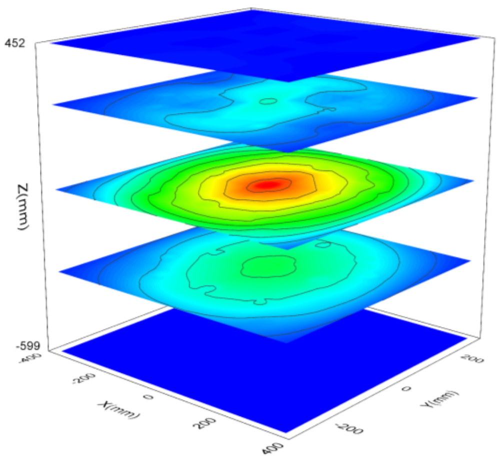
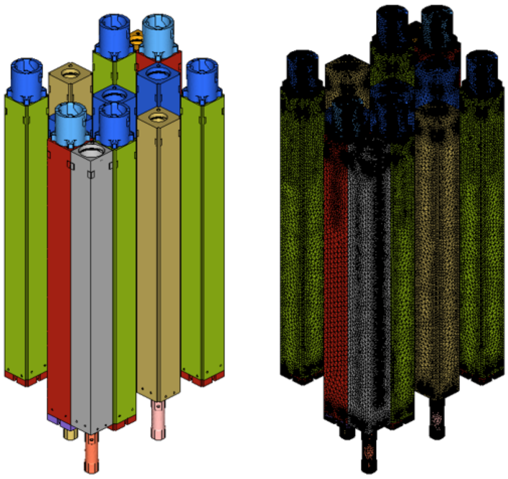


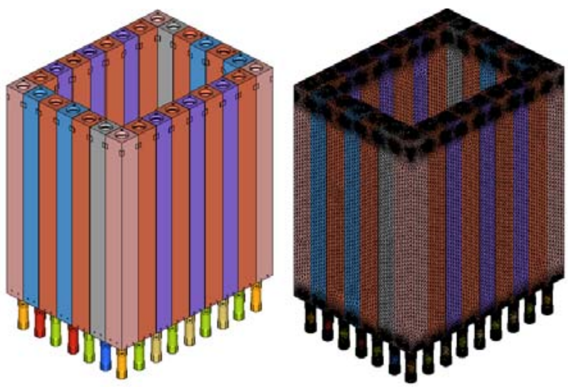
Figure 1 Neutron Flux Distribution in the Core

2.4 Finite Element Models

The Beryllium reflectors are separated in two zones of IR and OR like Figure 2. They are modeled using first order tetrahedral elements and constrained on the bottom of end fitting. Neutron fluence during one year (300 operation days) is calculated from neutron flux data and applied as a field variable in the model like Figure 3. Since grid data are not coincident between the neutron flux and the finite element model, three-dimensional interpolation scheme is necessary in the neutron fluence application. The Shepard's method which is a kind of inverse distance weighting is adopted as the interpolation scheme.



(a) IR Reflectors



(b) OR Reflectors

Figure 2 Finite Element Model of Reflectors

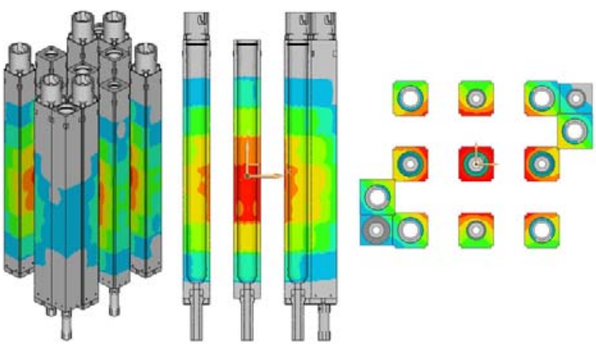


Figure 3 Neutron Fluence in the Finite Element Model

3. Results

The simulation results are analyzed in various aspects of deflection, pure dimensional changes, straightness, and gap changes among reflectors.

While the pure dimensional changes in each reflector are reasonable, the deflection due to bending is estimated higher than the expected in the design stage. However, gap among reflectors slightly change in spite of the deflection, since neighboring reflectors tend to bend into same direction. It is found that the straightness of inside hole is maintained within the tolerance which is needed to insert and withdraw the irradiation rig.

4. Conclusions

The behavior of the Beryllium reflectors in KJRR under irradiation is successfully simulated by the swelling model and FEM. Based on the simulation results, it is assessed whether the amount of swelling could geometrically affect the core configuration. It is concluded that periodic maintenance such as shuffling, rotation or replacement is necessary. Also, it is required that the maintenance period shall be determined with specific swelling coefficient in the future study.

Acknowledgements

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