# Analysis of Swelling Effect of Beryllium Reflectors in JRTR

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## 1. Introduction

Beryllium and heavy water are used as reflectors of the JRTR (Jordan Research and Training Reactor). The beryllium reflectors are located in the core region as the primary reflector material. There are a few types of beryllium reflectors in the core with different cross sections and different positions. The function of beryllium reflectors are as follows;

(1) Act as an excellent neutron reflector with sufficiently low neutron absorption cross section.
(2) Provide sites for irradiation devices and the SSRs.
(3) Allow loading and unloading of the fuel assemblies without interference with other beryllium reflector assemblies and/or the fuel assemblies.
(4) Provide the primary coolant flow path between the BRAs and the fuel assemblies for cooling of the core components.

Beryllium, as it is widely known, experiences swelling under a neutron radiation environment. This leads to deflection and internal stress of the beryllium reflectors. In one beryllium reflector, the neutron flux of the surface close to core and the opposite surface are different. Different neutron flux causes different swelling rate, which leads to the deflection of the beryllium reflectors. Beryllium reflectors are installed with its lower end inserted in holes of the grid plate within an installation clearance. The upper end is basically free. Therefore beryllium reflectors deflect with bow-like shape. Such deflection may disturb the loading/unloading of the fuels and other beryllium reflectors. Excessive deflection may disturb the operability of the reactivity control units.

However deflections caused by different neutron flux can be controlled by rotating the beryllium reflectors. The purpose of this study is to determine the maintenance (rotating) intervals for the beryllium reflectors.

## 2. Beryllium Material

The beryllium reflectors of the JRTR are made of a standard grade of beryllium designated as S-200-F of Materion Corporation. S-200-F grade beryllium is to be produced through the consolidation of beryllium powder by vacuum hot pressing. This grade consists of a minimum of 98.5% beryllium.

The swelling strain rate depending on neutron flux is a key parameter for the analysis of the deflection of beryllium. However there is few data about swelling of the berylliums made by Materion Corporation. This makes it difficult to estimate the deflections of the beryllium reflectors of the JRTR. Therefore KAERI decided to make experiments to know the irradiation behavior of the beryllium materials. The experiments were started in HANARO at September 2012 [1]. Two types of beryllium are under irradiation, S-200-F (Materion, USA) and EHP-56 (ULBA, Kazakhstan). So far, the test data is not available yet.

However the irradiation behavior of beryllium produced in Russia can be found in literatures. Therefore swelling data under irradiation of Russian beryllium is used in this analysis. The swelling behaviors of berylliums show different results depending on their product grade. Swelling of beryllium made in USA may be different from beryllium made in Russia. Therefore a conservative estimation of the swelling strain rate was made because the objective of this analysis is to establish the maintenance procedure.

Figure 1 shows swelling of four beryllium grades as a function of neutron dose, measured by change in dimensions and density of the Russian berylliums [2].

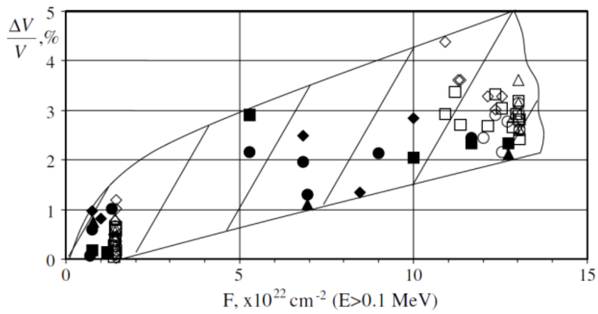



Fig. 1. Beryllium swelling rate : ○ TE-56 geometrical dimensions; ● TE-56 density; □ TE30 geometrical dimensions; ■ TE30 density; △ TIP geometrical dimensions; ▲ TIP density; ◇ DIP geometrical dimensions; ◆ DIP density

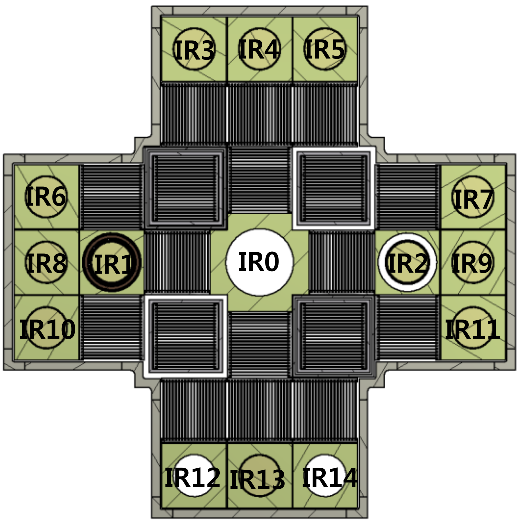
As shown in Figure 1, data are scattered in wide ranges. The upper bound of this graph was chosen as input data for the analysis of the beryllium reflectors of the JRTR. This can be regarded as sufficiently conservative assumption. The swelling behavior data used in the analysis is depicted in Table I.

Table I: Swelling Rate

| Fluence ($10^{22}cm^{-2}$) | △V/V (%) |
|---|---|
| 0.116 | 0.036 |
| 0.322 | 0.426 |
| 0.555 | 0.788 |
| 0.825 | 1.105 |
| 1.289 | 1.504 |
| 1.856 | 1.857 |
| 2.255 | 2.047 |
| 2.885 | 2.301 |
| 3.644 | 2.554 |

### 3. Beryllium Reflectors

Figure 2 shows beryllium reflectors in the core of the JRTR. Beryllium reflectors are located at the center and the outermost region of the core. There are four types of beryllium reflectors in the core with different cross sections. The beryllium reflector are installed with the bottom end inserted in holes of the core support plate so that they can stand by themselves. The upper end with wear pads is basically free with a proper clearance between neighboring beryllium or fuel assemblies for installation and thermal expansion. Gaps between core components are smallest at the wear pad region. Thus the deflections of the beryllium reflectors are limited upto 0.2mm at the wear pad region.




(a) Core cross section

(b) Typical shape of beryllium reflector

Fig. 2. Core cross section and typical shape of beryllium reflector

The neutron flux of the beryllium reflectors are varied over their positions. The maximum fluence of the beryllium reflectors are depicted in Table II.

Table II Maximum Fluence

| Position | Fluence per year ($n/cm^2$) | |
|---|---|---|
| | Maximum | Opposite side of max. fluence |
| IR 3,5,12,14 | 12.7e20 | 2.0e20 |
| IR 4,13 | 13.3e20 | 2.8e20 |
| IR 1,2 | 13.4e20 | 6.0e20 |
| IR 6,7,10,11 | 8.7e20 | 1.4e20 |
| IR 8,9 | 7.6e20 | 1.7e20 |

### 4. Results

The analysis was conducted by using ABAQUS. Volumetric swelling behavior option of ABAQUS was used to simulate the irradiation swelling. The volumetric strain rate is assumed as a function of neutron fluence only. Anisotropic swelling behavior have to be defined because S-200-F is not an isotropic material. However isotropic swelling option with maximum swelling strain rate was used for conservative analysis.

IR0 beryllium is located at the highest neutron flux region of the core. Therefore the amount of swelling is largest in IR0 beryllium. However there is no bowing effect in the IR0 reflector because the core shape is symmetric and the IR0 beryllium is located at the center of the core. Thus there is no need for rotating or shuffling of this reflector.

Table III shows the deflections of the beryllium reflectors at the wear pad region.

Table II Deflection at wear pad region

| Position | Deflection | |
|---|---|---|
| | 1year | 2 year |
| IR 3,5,12,14 | 0.12mm | |
| IR 4,13 | 0.14mm | |
| IR 1,2 | 0.08mm | 0.16mm |
| IR 6,7,10,11 | 0.08mm | 0.17mm |
| IR 8,9 | 0.07mm | 0.13mm |

The results show that IR 3,5,12,14 and IR 4, 13 beryllium reflectors shall be rotated after one year at the first operation. Then these reflectors shall be rotated every two years. The other reflectors shall be rotated after two years at the first and then shall be rotated every four years.

These results are because of the conservative assumption of swelling ratio and the actual reflectors will not be deformed as much. The rotation of beryllium reflector shall be minimized because it is very complicated and cumbersome work. Therefore deflection of the beryllium reflectors shall be periodically measured to determine the rotating cycle. For this purpose, IR 4 and 13, which show maximum deflection, will be measured during the inspection period and the rotating cycle will be determined based on these results.

## REFERENCES

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