Design of Neutron Screen for 6″ NTD Irradiation in HANARO

Hak-Sung KIM, Soo-Youl OH, Chul-Gyo SEO, Byung-Jin JUN
Korea Atomic Energy Research Institute, HANARO Management Division
150 Deokjin-dong, Yuseong-gu, Daejeon 305-353, KOREA

1. Introduction

The silicon Neutron Transmutation Doping (NTD) facility is one of the most important facilities of the HANARO. Two vertical irradiation holes, NTD1 and NTD2, are provided in the reflector region. We have been providing the commercial NTD service for 5″ silicon ingot in the NTD2 hole since the middle of 2003, and we are developing an irradiation device for 6″ ingot in the NTD2 as well as a facility for 6″ and 8″ ingots in the NTD1. This paper presents the design of the neutron irradiation device for the 6″ silicon ingot in the NTD2 hole from the viewpoint of the nuclear design.

2. Methods and Results

A Si ingot is in the shape of right cylinder of which length is normally 20 to 30cm and the diameters of ingots available in the market are 5″, 6″ or 8″. A high quality NTD-Si shall meet a requirement such that the axial and radial uniformities of the resistivity should be less than 5% and 2%, respectively. The uniformity is defined here as the relative difference between the maximum and minimum resistivity in the axial or radial distribution. The primary role of the neutron screen, the wall part of the ingot container, is to make the axial neutron flux distribution as flat as possible in the Si ingot inside. Note that the resistivity is inverse-proportional to the total number of $Si^{30}(n,\gamma)Si^{31}$ reactions occurred, and the number of reactions is proportional to the thermal neutron fluence within an uncertainty of 0.5%. Thus we are using either the thermal neutron flux or reaction rate to represent the resistivity.

2.1 Neutron Screen Design

In this work, we used the MCNP code to simulate details of the neutron screen. As the diameter of the Si ingot to be irradiated increases from 5″ to 6″, the gap available between the inner surface of the NTD2 hole (diameter of 18 cm) and the outer surface of the ingot is reduced significantly. Thus the aluminum, which is the screen material for the current 5″ service, is not suitable any more due to its small neutron capture cross section.

From preliminary analyses based on the thermal diffusion length of several kinds of structural materials, we chose the stainless steel as the material for the screen. Then we optimized the neutron screen design for the uniform irradiation in the silicon ingot in NTD2. Fig. 1 shows the shape and dimensions of the neutron screen, while Fig. 2 shows the MCNP model of the container containing two Si ingots, stacked vertically, inside the NTD2 hole.

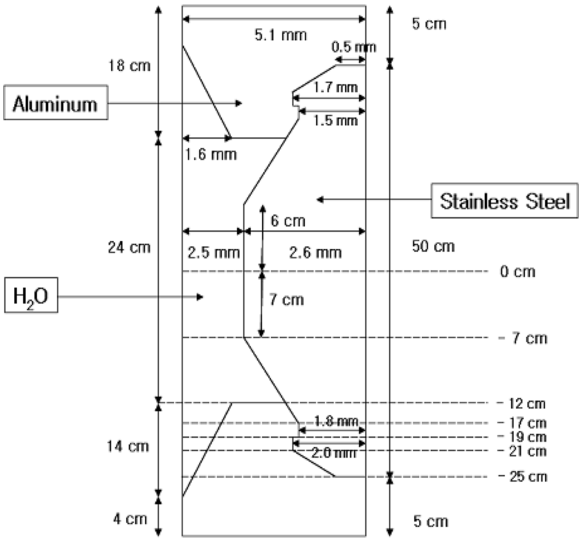

Fig. 1 Neutron Screen for 6″ Ingot Irradiation in NTD2

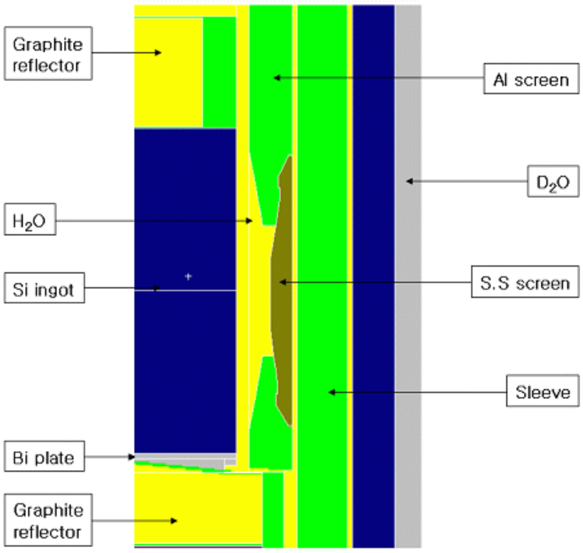

Fig. 2 MCNP model of Si ingots and neutron screen inside the NTD2 hole

In profiling the axial reaction rate distribution, 60 cm long Si ingot was axially divided into 30 plates, 2 cm-thick each. An MCNP run made use of total 30 million histories, with which the fractional standard deviation (fsd) of the thermal neutron flux was less than 0.3%.

2.2 Calculation Results

Fig. 3 shows the relative $Si^{30}(n,\gamma)Si^{31}$ reaction rate distribution. We achieved the axial uniformity of less than 2.0%, much lower than a usual requirement.

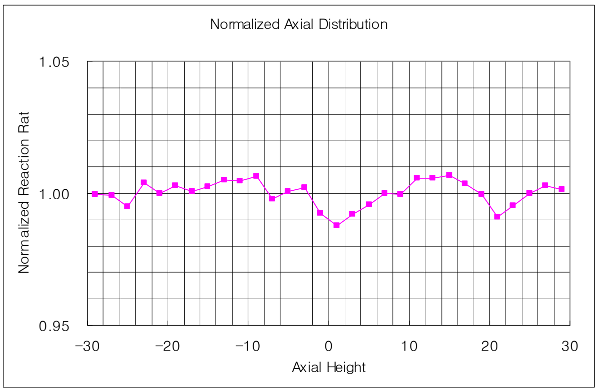

Fig. 3 Axial $Si^{30}(n,\gamma)Si^{31}$ reaction rate distribution

Fig. 4 shows the optimum insertion depth of Si ingot that strongly depends on the control rod (named CAR in HANARO) insertion. From the curve, we can decide the ingot insertion at a particular point of time of reactor operation. Note that the CARs compensate the fuel burnup in the HANARO.

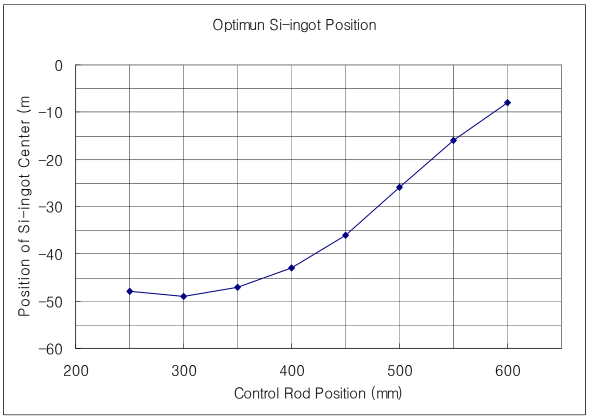

Fig. 4 Optimum insertion of Si ingot varying with control rod position (The mid-plane of the effective core is set to zero.)

Fig. 5 shows the axial profiles of the $Si^{30}(n,\gamma)Si^{31}$ reaction rate corresponding to every different control rod positions. The curve in Fig. 3 is appeared here as the case of CAR=500 mm. It is expected that the axial uniformity does not exceed 2.5% throughout the whole cycle.

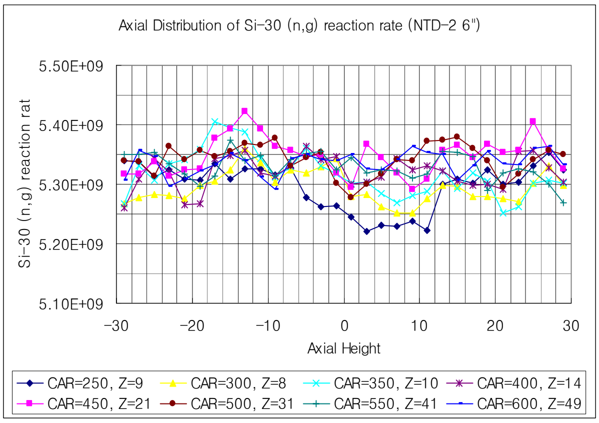

Fig. 5 Axial distributions of $Si^{30}(n,\gamma)Si^{31}$ reaction rate varying with control rod position

3. Conclusion

We designed the neutron screen for 6″ Si ingot irradiation in the NTD2 hole, which is near optimum in achieving a flat axial distribution of resistivity in the irradiated Si ingot. The fluctuations in the axial distribution were estimated to be within ±1.3% around the average. Using this design, we expect a commercial 6″ NTD service very plausible while satisfying a usual customer's requirement on the irradiation uniformity.

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