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Preliminary Neutronics Design for Fast Neutron Irradiation Facility in the KIJANG Research Reactor

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1. Introduction

The HANARO research reactor has been successfully operated in Korea. Following the experience with HANARO, KIJANG research reactor (KJRR) is now being designed by Korea Atomic Energy Research Institute (KAERI), dedicated to increasing the national radio-isotopes supply capacity including the self-sufficiency of Mo-99. And the KJRR is also expected to have the capability to provide the neutron irradiation service for power semiconductor production in a large scale. This service includes not only neutron transmutation doping (NTD) facility for ingot irradiation, but also fast neutron irradiation (FNI) facility for wafer irradiation. Fast neutron irradiation for wafer is a promising technology for efficiency gain and life extension of the power semiconductor. In this work, a FNI facility has been preliminarily designed to satisfy its requirements, and the necessary calculations are carried out through Monte Carlo simulations using MCNP5 code [1].

2. Brief Description for KJRR

The KJRR core adopts U-7Mo fuel of MTR (Materials Testing Reactor) type. Maximum thermal neutron flux requires more than 3.0E14 n/cm^2·s and 1.5E14 n/cm^2·s in core center and reflector, respectively. Figure 1 shows a core configuration of the KJRR.

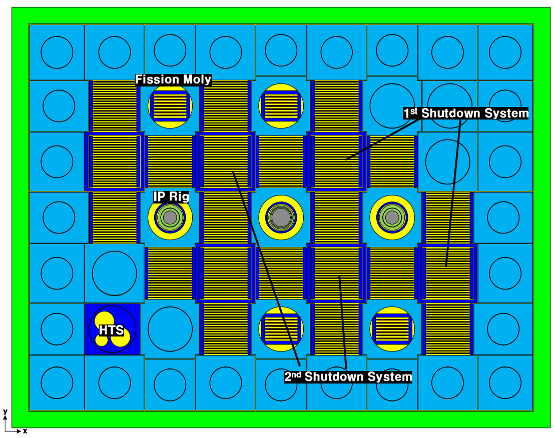

Fig. 1. Core Configuration of the KJRR

The core consists of 22 fuel assemblies with edge trimmed irradiation holes [2] which provide large irradiation volume. 6 follower fuel assemblies, which a Hf absorber is attached to the upper end of the fuel, used to control and shutdown the reactor. The core is located within a core box, and the outside of the core box is surrounded with Be, Graphite and Al. There are Pneumatic Transfer System (PTS) and 6 large holes in the outside of the core. One among 6 holes is used for FNI which can be also used for NTD. The others are only prepared for NTD. Neutronics requirements of the FNI facility are as follows:

- Fast (>1.0 MeV) neutron flux: > 1.4E11 n/cm^2·s
- Ratio of fast and thermal (< 0.625 eV) neutron flux: > 300
- Low gamma-ray field

The various FNI designs have been studied to satisfy above requirements, and we succeed to get a current model for FNI facility

3. Current Design of FNI Facility

At the conceptual design stage of the KJRR, a FNI facility was located in outside of the NTD holes to maximize the number of NTD holes. Fast neutron flux is low as a consequence of a faraway position from the core, but fast neutron flux can be boosted using spent fuel assemblies. This method has a disadvantage to use additional structures. It was recently found that one of the NTD holes can be replaced by the FNI facility, and fast neutron flux in the location is sufficient for its requirements without any supplements. Thus, FNI design target is focused on the optimization of thermal neutron flux and gamma flux in the position specified. Brief configurations for the current FNI design are shown in Figure 2 and 3.

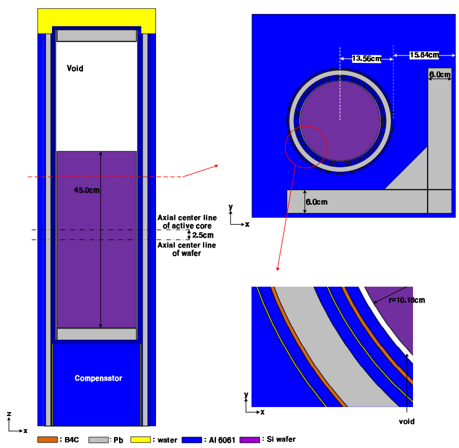

Fig. 2. Current Design of FNI Facility 1

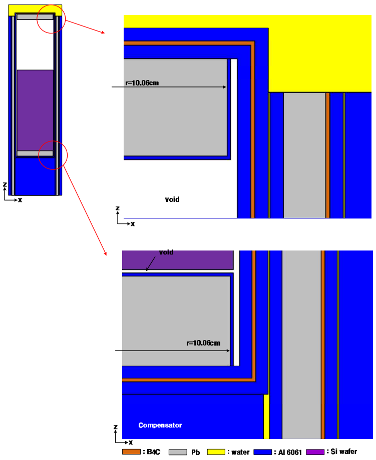

Fig. 3. Current Design of FNI Facility 2

FNI facility is composed of 3 primary components as follows:

(1) Al block with Pb blocks for shielding of gamma radiation
(2) Annular B4C and Pb canned by Al for shielding of thermal neutron and gamma, respectively, which is inserted into the hole of which radius is 13.56 cm
(3) Al can with B4C – 8 inch Si wafer and Pb blocks are put into this Al can.

4. Performance Evaluations for FNI Facility

The Monte Carlo-based MCNP5 code was chosen as a computational tool to evaluate neutronics performance of the FNI facility. The irradiation target was divided into 15 axial segments, and the fast neutron flux and gamma flux (prompt gamma is only considered) for the each segment are calculated. The results are tabulated in Table I.

Table I: Fast Neutron Flux and Gamma Flux in Si Wafer

Axial Position* [cm]	Fast Flux [n/cm^2-s]	fsd**	Gamma Flux [$photons/cm^2$-s]	fsd**
-25 ~ -22	1.08E+11	0.0075	3.37E+11	0.0046
-22 ~ -19	1.18E+11	0.0072	4.23E+11	0.0042
-19 ~ -16	1.27E+11	0.0069	4.67E+11	0.004
-16 ~ -13	1.33E+11	0.0068	4.98E+11	0.0038
-13 ~ -10	1.37E+11	0.0067	5.17E+11	0.0038
-10 ~ -7	1.40E+11	0.0066	5.28E+11	0.0038
-7 ~ -4	1.44E+11	0.0066	5.33E+11	0.0037
-4 ~ -1	1.43E+11	0.0066	5.32E+11	0.0038
-1 ~ 2	1.40E+11	0.0066	5.32E+11	0.0038
2 ~ 5	1.37E+11	0.0068	5.20E+11	0.0038
5 ~ 8	1.31E+11	0.0068	5.04E+11	0.0038
8 ~ 11	1.24E+11	0.007	4.89E+11	0.0039
11 ~ 14	1.15E+11	0.0073	4.70E+11	0.0039
14 ~ 17	1.05E+11	0.0076	4.50E+11	0.004
17 ~ 20	9.42E+10	0.0078	4.25E+11	0.004

* distance from active core center
** fsd: Fractional Standard Deviation

The maximum fast neutron flux and gamma flux are 1.44E+11 n/cm^2-s and 5.33E+11 $photons/cm^2$-sec between -7 cm and -4 cm region of wafer target, respectively. The axial uniformity of the fast neutron in the wafer region can be easily achieved by reducing the target region axially. The ratio of the fast neutron flux to thermal neutron flux significantly exceeds requirement. In addition, it was confirmed that a withdrawal of wafer transportation equipment does not perturb neutron fluxes at the NTD holes and the neutron detectors.

5. Conclusions

Current design of FNI facility in the KJRR was introduced in this paper. The performance evaluations for the FNI facility were carried out and the results meet the requirements. There is not a constraint how far gamma flux should be lowered, and the further study on this subject should be researched.

REFERENCES

[1] X-5 Monte Carlo Team, "MCNP-A General Monte Carlo N-Particle Transport Code, Version 5", LA-CP-03-0245, 2003/04/24.
[2] Chul Gyo Seo and Nam Zin Cho, "A Core Design Concept for Multi-purpose Research Reactors," Nuclear Engineering and Design **252** (2012) 34-41, 2012.