Transactions of the Korean Nuclear Society Autumn Meeting
Yeosu, Korea, October 25-26, 2018

Development of Neutron Flux Map for KSTAR Using MCNP Simulation

In-Chang Choi, Jaeyong Lee, San Chae, Yong-Soo Kim*
Department of Nuclear Engineering, Hanyang University, 222 Wangsimni-ro, Seondong-gu, Seoul, Republic of Korea
** Corresponding author: yongskim@hanyang.ac.kr*

1. Introduction

Korea Superconducting Tokamak Advanced Research (KSTAR) is a fusion reactor for developing a steady-state-capable tokamak to establish technological and scientific basis [1]. In KSTAR, 2.45MeV neutrons are produced by $d(d,n)^3He$ reactions, and due to fusion tritons from d(d,p)t reactions, 14.1MeV neutrons also produced by $d(t,n)^4He$ reactions in a deuterium plasma [2]. Components of KSTAR are irradiated by these neutrons and this results in activation of materials which is related to integrity and contamination of fusion devices. Neutron fluence map for KSTAR is necessary to be developed to ensure safety of the components and evaluate contamination for decommissioning in the future. Therefore, this study aims to develop the neutron flux map for KSTAR by Monte Carlo neutron photon transfer code (MCNP) [3] simulation.

2. Methods and Results

In this section, the method for modeling KSTAR with MCNP and simulation results are described.

2.1. MCNP

Monte Carlo neutron photon transport code (MCNP) has been well known and in wide use for a long time based on the probabilistic method [4]. For MCNP modeling and simulation, information about materials and composition of structures, source and geometry must be defined.

2.1.1 Material

The materials being use in major component are shown in Table 1. Each element of materials is assumed to follow natural abundance and evenly distributed in structures. The component ratio of bolted graphite and SA 316 (chromium-nickel-molybdenum austenitic stainless steel) in limiter is assumed to be 1:1.

Table I: Material list of the major structures

Component	Material
CS coil	Nb3Sn
TF coil	NbTi
Limiter	Bolted Graphite & SA 316L
Vacuum vessel	SA 316 L
Cryostat	SA 316 L

2.1.2 Source

It is assumed that neutrons are generated homogeneously and radiated in a random direction at the core of plasma which is assumed to be ring-shaped and placed between limiters. The minimum and maximum radius of the plasma core are set to 1.3m and 2.0m respectively from the z-axis of KSTAR. Small number of 14.1 MeV neutrons are also considered to this study since it was observed that 14.1 MeV neutrons are generated by d-t fusion reaction [5].

2.1.3 Modeling

Based on the material and source information, KSTAR model was constructed for MCNP simulation as shown in figure 1. The model is designed as a 360° degree symmetrical model without TF coils and ports. In this study, the number of coils and ports are simplified and placed at every 30° degree, 90 ° degree respectively around vacuum vessel. PF coils and minor components are not considered in the modeling in order to rapid simulation. The major and minor radius of KSTAR are set to 1.8m and 0.5m respectively, and water coolant is placed between inner and outer vacuum vessel. Cryostat is assumed to be an ellipse and concrete walls are also designed as a hexahedron of 50m in length and width and 35m in height to predict contamination for future decommissioning work. Measuring points of neutron flux are designed as 5 spheres with a radius of 2cm, and set behind limiter, cryostat, inside a port, and surface of concrete wall. Finally, total neutron flux map is developed by MCNP mesh simulation.

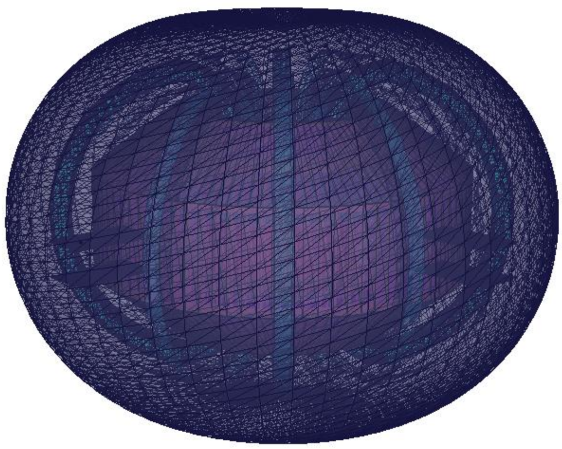

Figure 1. 3D model of KSTAR using MCNP simulation

2.2 Simulation Results

Based on the modeling of KSTAR, simulation results of the five measuring points are shown in Table II. Neutron flux at the limiter is about thirty times higher than at the cryostat and three hundred times than at the concrete walls. Since there are few components between plasma and port in this model, the flux result at the port is higher than that of cryostat. Energy bins are also set up with 1 keV intervals from 0 MeV to 14.2 MeV to observe energy distribution of neutrons at the major components. At the limiter, thermal and 2.45 MeV neutrons are dominant, whereas only thermal neutrons are dominant beyond the cryostat including concrete walls. 14.1 MeV neutrons were rarely measured compared to 2.45 MeV.

Table II: Neutron flux simulation results

Component	Neutron flux (neutrons / total neutrons·cm^2)
Limiter	$5.36 \cdot 10^{-6}$
Port	$1.16 \cdot 10^{-6}$
Cryostat	$1.65 \cdot 10^{-7}$
Concrete wall (perpendicular)	$1.95 \cdot 10^{-8}$
Concrete wall (edge)	$1.43 \cdot 10^{-8}$

In the earlier experiments, polished Ni specimens were installed at F ports for neutron activation analysis to measure neutron flux [6]. The result showed that neutron flux near the end of the F port was measured as $1.89 \cdot 10^{14}$ neutrons / cm^2·sec. Based on this result multiplied with the neutron flux fraction shown in Table II, expected neutron flux at each component is obtained as shown in Table III.

Table III: Expected neutron flux at each component

Component	Neutron flux (neutrons / cm^2·sec)
Limiter	$8.73 \cdot 10^{14}$
F Port	$1.89 \cdot 10^{14}$
Cryostat	$2.69 \cdot 10^{13}$
Concrete wall (perpendicular)	$3.17 \cdot 10^{12}$
Concrete wall (edge)	$2.33 \cdot 10^{12}$

MCNP mesh simulation is also performed to obtain neutron flux map as shown in figure 2. The whole area without concrete walls is divided into uniform meshes, cubes of 1cm in length, on the XY and XZ plane. As a result, neutrons are attenuated primarily at the limiter and coolant between vacuum vessel walls, and this indicates that limiter and vacuum vessel walls are major components subject to neutron irradiation. Furthermore, average neutron flux at the CS coils is higher than TF coils, and inner sides of the TF coils are exposed to higher neutron irradiation than outer sides of the TF coils. However, since the minor components and PF coils are not considered in this study, the actual decrease of neutron flux from PFC to cryostat is expected to be larger than the simulation results.

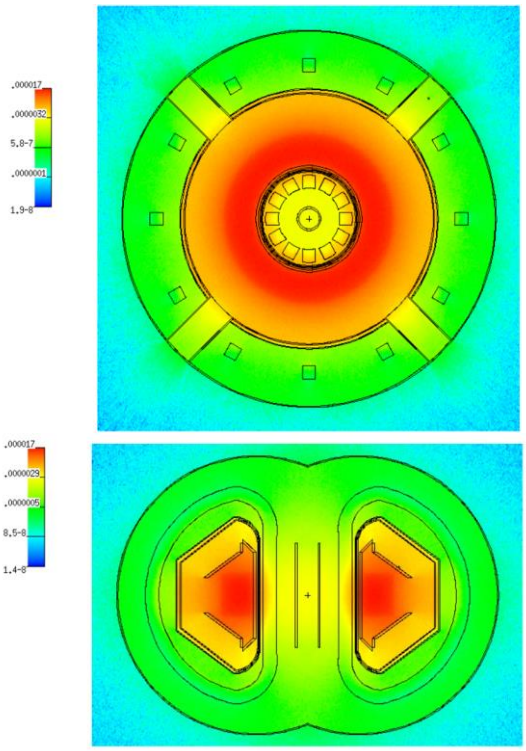

Figure 2. Neutron flux map of KSTAR on the XZ plane (upper) and XY plane (lower)

3. Conclusion

In this study, the analysis of neutron flux at the major component of KSTAR was conducted with MCNP simulation, and neutron flux map for KSTAR was drawn using MCNP mesh simulation. KSTAR model was constructed based on the material, geometrical, and source information. The number of TF coils and ports were simplified, and PF coils and minor components were not considered in this model for rapid simulation. Results showed that the neutron flux was higher in order of distance from the plasma, and the energy distribution of the neutrons was different in high energy region at the components. The neutrons primarily decreased at the limiter and vacuum vessel based on the result. Therefore, it is expected that this study can be used to predict contamination distribution of each component of KSTAR based on the neutron flux map.

ACKNOWLEDGMENTS

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korean government(MSIP:Ministry of Science, ICT and Future Planning) (No. NRF-2017M2B2B1072888)

REFERENCES

[1] G.S. Lee et al, The design of KSTAR tokamak, Fusion Eng. Des. 46, 405-411, 1999.

[2] M.S. Cheon, Y. S. Lee, A.C. England, H.S Kim, S.Pak, C.R. Seon and H.G. Lee, Diagnostic neutron activation system for KSTAR, journal of Instrumentation, 7, 2012

[3] D. Pelowitz, MCNP6 User's manual Version 1.0, LA-CP-13-00634, Rev.0, 2013.

[4] J.S. Park, S.J. K, K.H. Im, Comparison study on neutronic analysis of the K-DEMO water cooled ceramic breeder blanket using MCNP and ATTILA, Fusing Eng. Des. 109-111, 801-808, 2016

[5] J.M. Jo, M.S. Cheon, J.Y. Kim, T. Rhee, J.H. Kim, Y.J. Shi, M. Isobe, K. Ogawa, K.J. Chung, and Y.S. Hwang, Triton burnup measurement in KSTAR using a neutron activation system, Review of Scientific Instrument 87, 11D828, 2016

[6] D.S Son, J.Y. Lee, M.Y. Lee, and Y.S Kim, Contamination analysis on the outer vessel of the KSTAR using MCNP simulation measuring the neutron flux with Ni specimen, Proceedings of the KNS 2016 Spring Meeting (pp. 1CD-ROM), 2016