Evaluation of Neutron Flux Accounting for Shadowing Effect among Dry Storage Casks

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ABSTRACT: *According to the master plan for spent nuclear fuel management in Korea, dry storage facility will be constructed by 2035 and operated. It is required to assure the safety of dry storage facility before construction. NUREG-1536 recommends that the theoretical cask array, typically in the 2x10 array, should account for shadowing effect among casks to ensure safety. The objective of this study was to evaluate neutron flux accounting for shadowing effect among dry storage casks. Shadowing effect was evaluated using probabilistic program, MCNP. The KORAD-21 cask developed by Korea Radioactive Waste Agency (KORAD) was selected as dry storage casks for the evaluation. Evaluation points of shadowing effect were selected for 3 point each KORAD-21 cask surface. Shadowing effect of other dry storage casks was the highest at the center of the dry storage facility of the 2x10 array compared with the outside of the cask. The shadowing effect among the metal casks and the concrete casks were about 43% and 51%, respectively. For the concrete cask, however, it was not significantly different at each point. This result indicates that shadowing effect is more significant for metal cask compared with concrete cask. Therefore, shadowing effect should be considered to design metal cask. The results of this study will be used for comparative analysis of neutron measurement data from PWR spent fuels in dry storage cask. Additionally, this study can be applied to evaluate characteristics of PWR spent nuclear fuels and the neutron flux on the surface of the dry storage cask.*

KEYWORDS: *Shadowing Effect, Spent Nuclear Fuel, Dry Storage Cask, Neutron Flux, Cask Array*

I. INTRODUCTION

Pressurized-water reactor (PWR) spent nuclear fuels have been stored in the temporary storage facilities in the nuclear power plants in Korea. About 800 metric tons uranium (MTU) of spent nuclear fuels are added to this inventory each year. Therefore, it is expected that the temporary storage facilities for the spent nuclear fuels will be saturated from 2024. In order to solve the saturation problem of the temporary storage facilities, it was planned to construct interim storage facility. The master plan for spent nuclear fuel management in Korea was established and proclaimed by ministry of trade, industry and energy in 2016 (Ref. 1). According to the master plan, interim storage facility will be constructed by 2035 and operated. The several methods have been studied for assuring the safety of PWR spent fuels in dry storage casks in Korea (Ref. 2). NUREG-1536 recommends that the theoretical cask array, typically in a 2x10 array, should account for shadowing effect among casks to ensure safety (Ref. 3). However, there is lack of study about shadowing effect among dry storage casks in Korea. The objective of this study was to evaluate neutron flux accounting for shadowing effect among dry storage casks.

II. MATERIALS AND METHODS

Nuclear Regulatory Commission (NRC) recommends that the shielding evaluation of the dry storage casks be performed by computational analysis, such as the source term generation and the radiation shielding (Refs. 2, 7). ORNL isotope generation and depletion-Automatic Rapid Processing (ORIGEN-ARP) and Monte Carlo N-Particle (MCNP) codes were employed for this computational analysis. ORIGEN-ARP code is a calculation code for analyzing spent fuel characterization and source term generation (Ref. 4). MCNP code is a general Monte Carlo N-Particle code that can be used for neutron, photon, electron, or coupled particles transport (Ref. 5). Therefore, MCNP code is widely used for evaluation of radiation shielding and flux.

To evaluate neutron flux of dry storage cask, the axial burnup distribution and the neutron release rate of spent nuclear fuel should be considered. Fig. 1 shows axial burnup distribution of neutron and gamma-ray. Axial burnup distribution will be flatted over time due to the fuel depletion and fission product buildup that occurs near the center of fuel because it will deplete fuel near the axial center at a greater burnup rate than at the edge (Ref. 6). The gamma-ray release rate is generally directly proportional to the axial burnup distribution. The neutron axial burnup distribution is proportional to the 4.0-4.2 square of the gamma-ray axial burnup distribution (Ref. 7).

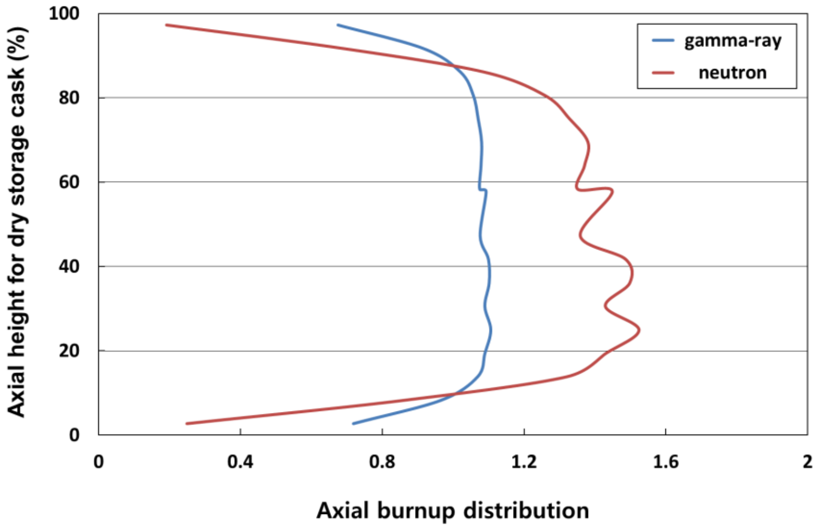

Fig. 1. Axial burnup distribution of neutron and gamma-ray

The neutron release rate varied depending on radiological characteristics of spent nuclear fuel. Radiological characteristics consist of enrichment, burnup rate, and cooling time. Enrichment and burnup rate range of the nuclear fuel used in Korea were 2-5 wt%, and 25,000-50,000 MWD/MTU, respectively. Spent nuclear fuel was needed to be stored more 5-7 years in temporary storage facility of wet storage type in order to decrease decay heat and radiation. Therefore, neutron release rate and energy spectra of spent nuclear fuel in consideration of radiological characteristics were calculated using ORIGEN-ARP code.

Evaluation points of shadowing effect were selected for 3 point each KORAD-21 cask (see Fig. 2 and Fig. 3). The KORAD-21 cask developed by Korea Radioactive Waste Agency (KORAD) was selected as dry storage casks for the evaluation. KORAD-21 cask can be classified as the metal cask and concrete cask. It was designed to contain 21 spent nuclear fuel assemblies. The metal cask consists of canister containing the spent nuclear fuel assemblies, the neutron absorber, trunnion, the heat transfer pins, and etc. The concrete cask consists of the neutron absorber, air ducts, top and bottom cover, canister containing the spent nuclear fuel assemblies, and etc. Therefore, geometry and material properties of the spent nuclear fuel assemblies and casks were simulated using MCNP code. It was assumed that the same 21 PWR spent nuclear fuel assemblies were loaded (Ref. 8).

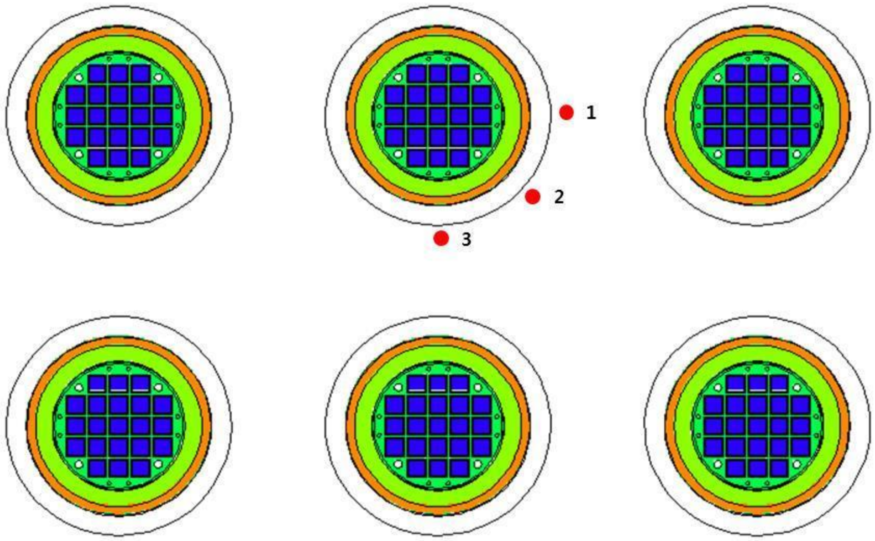

Fig. 2. The flux evaluation points for the shadowing effect among the metal casks

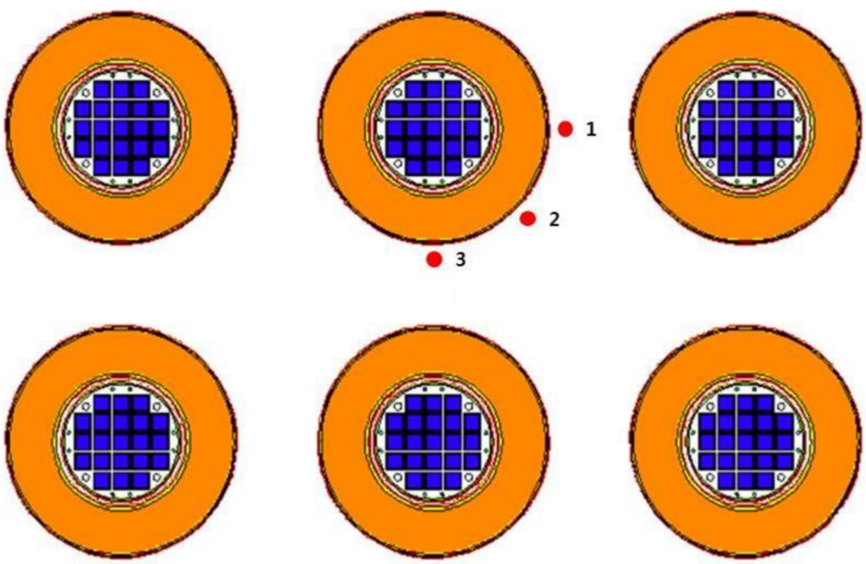

Fig. 3. The flux evaluation points for the shadowing effect among the concrete casks

III. RESULTS AND DISCUSSIONS

Fig. 4 shows the neutron release rate and energy spectra of the PWR spent nuclear fuels. Considering the radiological characteristics of the spent nuclear fuels, the neutron release rate and energy spectra were calculated. The fuel assembly type, enrichment, burnup rate, and cooling time for conservative evaluation were Westing-house (WH) 17x17 assemblies, 4.5 wt%, 45,000 MWD/MTU, and 10 years, respectively. The neutron release rate gradually increased along with neutron energy up to 3 MeV, and the decreased.

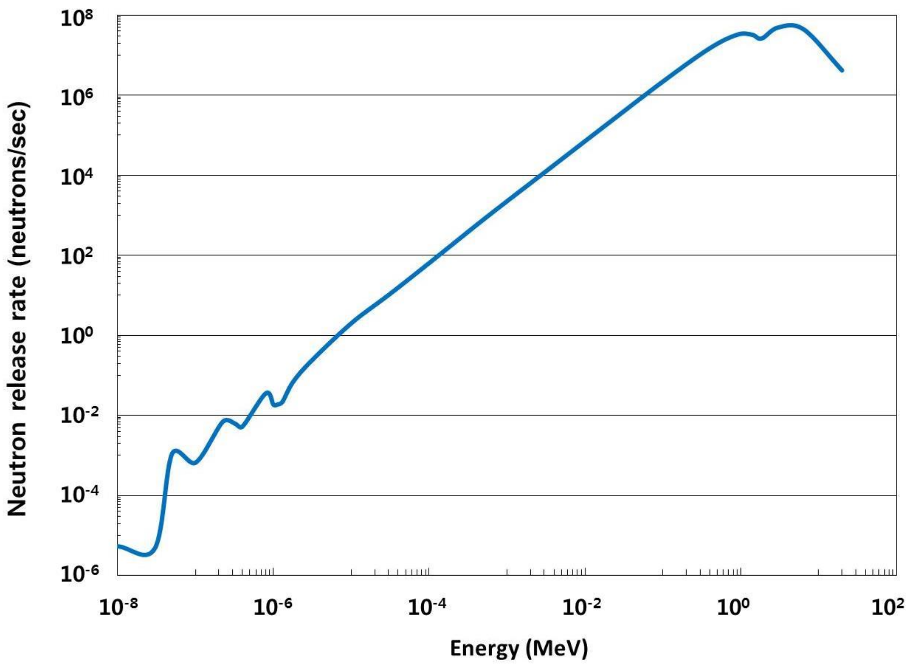

Fig. 4. Neutron release rate and energy spectra of PWR spent nuclear fuels in Korea

Fig. 5 shows the MCNP modeling of the 2x10 array of the metal casks and the concrete casks. The canister contained the 21 spent nuclear fuel assemblies and the neutron absorber was also simulated. The metal cask was simulated by considering trunnion, heat transfer pins, and was also simulated by considering air ducts, top and bottom cover, for the concrete cask. When MCNP modeling was performed, the air-layer outside the casks was simulated in order to consider of the effect of scattered radiation (Ref. 9).

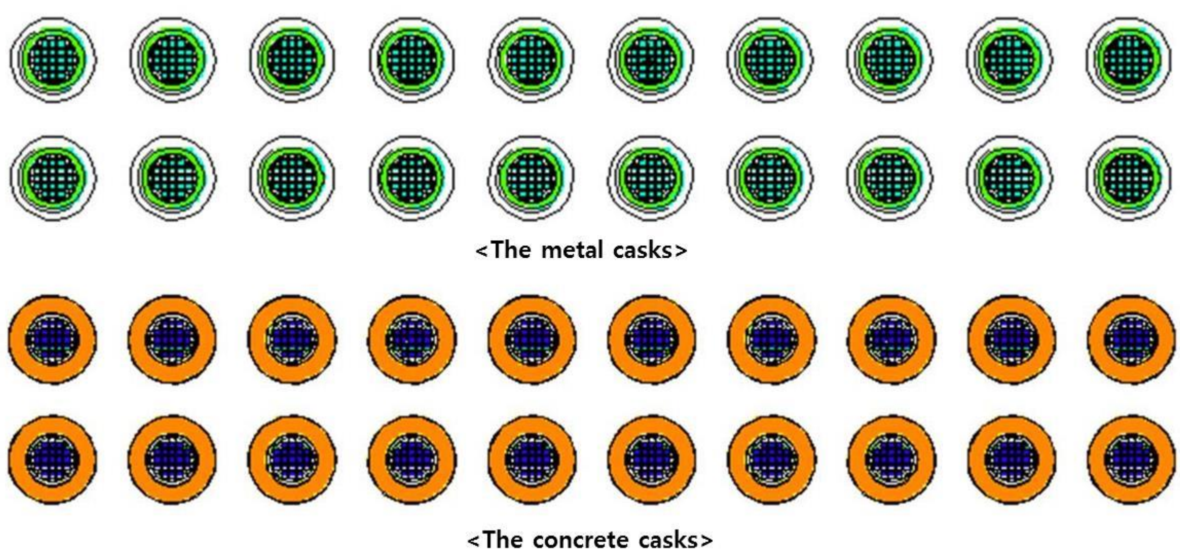

Fig. 5. MCNP modeling of the 2x10 array of the metal casks and the concrete casks

Shadowing effect among the metal casks and the concrete casks is given in TABLE I. For the metal cask, the shadowing effect under the existence and nonexistence of the neutron source term at the center was about 43%, gradually increased toward the center from the outside. For the concrete cask, the shadowing effect at the center under the existence and nonexistence of the neutron source term was about 51%.

TABLE I. The shadowing effect among the KORAD-21 casks according to flux evaluation points

The flux evaluation point	The Shadowing effect among the KORAD-21 casks	
	The metal casks	The concrete casks
1 point	18%	46%
2 point	23%	51%
3 point	43%	51%

Shadowing effect was evaluated through neutron flux under the existence and nonexistence of the neutron source term of spent nuclear fuels (see Fig. 6 and Fig. 7). The shadowing effect of other dry storage casks was the highest at the center of the dry storage facility of the 2x10 array compared with the outside of the cask. The shadowing effect gradually increased towards the center of the dry cask from the outside. For the concrete cask, however, it was not significantly different at each point. This result indicates that shadowing effect is more significant for metal cask compared with concrete cask. This is attributed that neutron shield of the concrete cask is thicker than that of the metal cask.

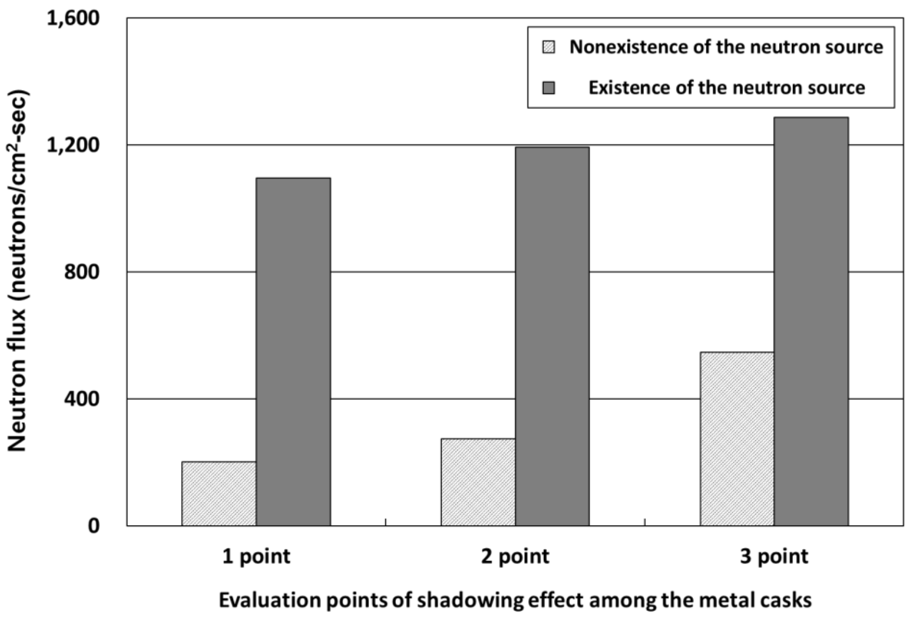

Fig. 6. Neutron flux by evaluation points of shadowing effect among the metal casks

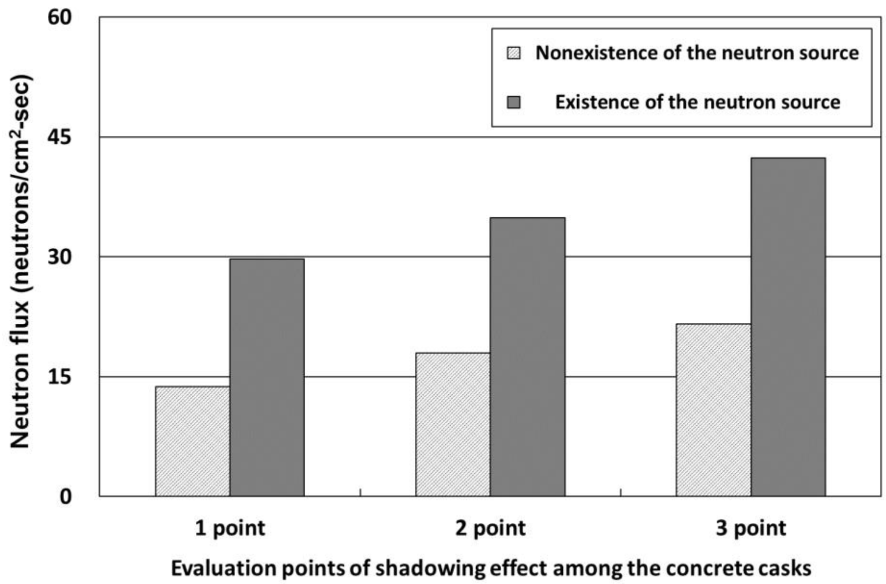

Fig. 7. Neutron flux by evaluation points of shadowing effect among the concrete casks

IV. CONCLUSIONS

Shadowing effect among the dry storage casks was evaluated. The shadowing effect varied depending on the dry storage cask type and evaluation points. For the metal cask, the shadowing effect under the existence and nonexistence of the neutron source term at the center was about 43%, gradually increased toward the center from the outside. For the concrete cask, the shadowing effect at the center under the existence and nonexistence of the neutron source term was about 51%. The shadowing effect gradually increased towards the center of the dry cask from the outside. For the concrete cask, however, it was not significantly different at each point. This result indicates that shadowing effect is more significant for metal cask compared with concrete cask. Therefore, shadowing effect should be considered to design metal cask. The results of this study will be used for comparative analysis of neutron measurement data from PWR spent fuels in dry storage cask. Additionally, this study can be applied to evaluate characteristics of PWR spent nuclear fuels and the neutron flux on the surface of the dry storage cask.

ACKNOWLEDGMENTS

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