Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 18-19, 2017

Effect Analysis of Artificial Rare Earth Compound-based Neutron Absorber in Radiation Dose Rate Distribution

Kyung-O KIM*, Gyuhong ROH, and Byungchul LEE
Korea Atomic Energy Research Institute, 1045 Daedeok-daero, Yuseong-gu, Daejeon, Korea
**Corresponding Author: k5kim@kaeri.re.kr*

1. Introduction

In previous research, a new concept of a neutron absorption material (artificial rare earth compound, RE_2O_3) was introduced for criticality control of a spent fuel storage system, and its neutron absorption cross-section, effective lifetime etc. were analyzed for investigating the application possibility as a neutron absorption material [1]. In this study, some calculations based on the KSC-4 cask [2] are performed to evaluate the practical applicability of the RE_2O_3 compound, and its effect on radiation dose rate distribution around the cask are analyzed by using MCNPX 2.7.0 code [3]. In order to perform a bounding analysis, it is assumed that the four assemblies of WH 17×17 with 3.5 w/o enrichment, 35 GWD/MTU burnup, and 10-year cooling time are loaded in a cask.

2. Methods and Materials

The KSC-4 cask developed by KAERI was used for the transportation of PWR spent fuel assemblies between neighboring nuclear power plants. Until the early 2000s, a total of 106 transports were carried out using two KSC-4 casks, and 424 assemblies of spent fuels were transported at the Kori site. The KSC-4 cask weighs about 37 tons and is capable of loading four PWR spent fuel assemblies with enrichment of 3.2 w/o ^{235}U, burnup of 38 GWD/MTU, and cooling time of three years. Also, the major shielding material against gamma-rays and neutrons are lead and hydrogen rich resin, respectively, while about 150 kg of Boral™ plate is employed around the nuclear fuel assemblies for criticality control. **Figure 1** shows the configuration of KSC-4 PWR spent fuel cask.

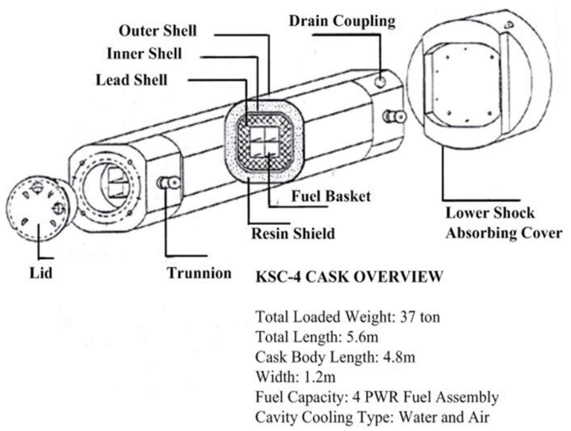


Figure 1. Configuration of KSC-4 PWR Spent Fuel Cask

A computational model of the KSC-4 cask, loaded with PWR fuel assemblies, is developed by using MCNPX 2.7.0 code, and a cross-sectional view of the model is shown in **Figure 2**. In this model, the WH 17×17 assembly with 3.5 w/o enrichment, 35 GWD/MTU burnup, and 10-year cooling time is considered to perform a bounding analysis. Since the KSC-4 cask has horizontal and vertical symmetry with respect to its center, a one quarter model is employed with a reflecting boundary condition on the cutting surfaces.

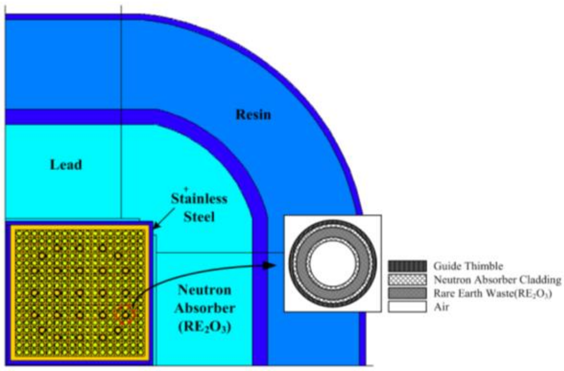


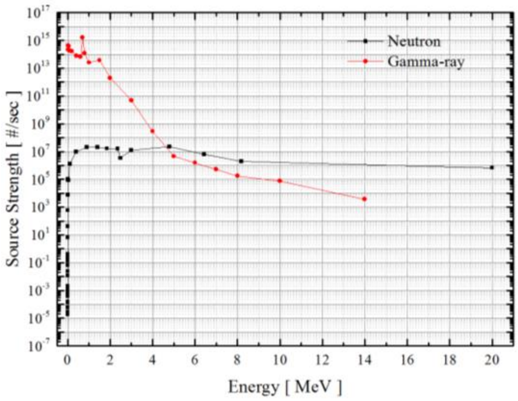
Figure 2. Radial Cross-section of One Quarter of the MCNP Model for the KSC-4 Cask

The radiation shielding of the KSC-4 cask is performed by the thick-walled cask body and the lid. Especially, the resins (NS-S-FR) for neutron shielding are arranged between the lead shells and the outer steel plates positioned in top, side, and bottom parts, and additional shielding is provided by the basket structure. However, the neutrons and gamma-rays generated from various sources should be considered in the design of spent fuel transport/storage cask, and the considerable radiation sources are presented, as follows;

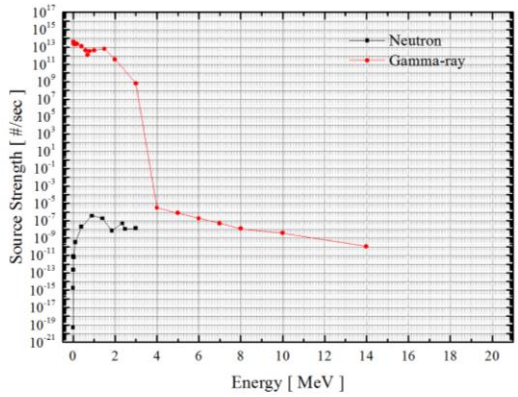
1) Gamma-ray Sources:
- Decay of radioactive fission products
- Secondary photons from neutron capture in fissile and non-fissile nuclides
- Hardware activation products

2) Neutron Sources:
- (α,n) reactions in fuel material
- Secondary neutrons produced by fission from subcritical multiplication
- (γ,n) reactions in fissile and non-fissile nuclides (this source is negligible)

The above-mentioned radiation sources except for the activation source are considered in the effect analysis of the RE_2O_3 compound on surface and external dose rate distribution of a KSC-4 cask. The neutron and gamma-ray source terms are determined using the ORIGEN-ARP module in SCALE 6.0 package code system [4], and the radiation shielding analyses are performed with MCNPX 2.7.0. **Figure 3** shows the energy spectrums for radiation emitted from a unit of spent fuel assembly and a unit mass (kg) of the RE_2O_3 compound, respectively. In addition, the emission rate of radiation is proportional to the burnup value in active fuel regions, and therefore, the radiation peaking factor in axial direction is determined by introducing a limiting axial burnup profile as recommended by the U.S. Department of Energy (DOE). The detector surfaces are placed in two positions, which is subdivided into 30 regions along the fuel height to obtain a maximum local dose rate.



(a) Spent Fuel Assembly (1 FA)

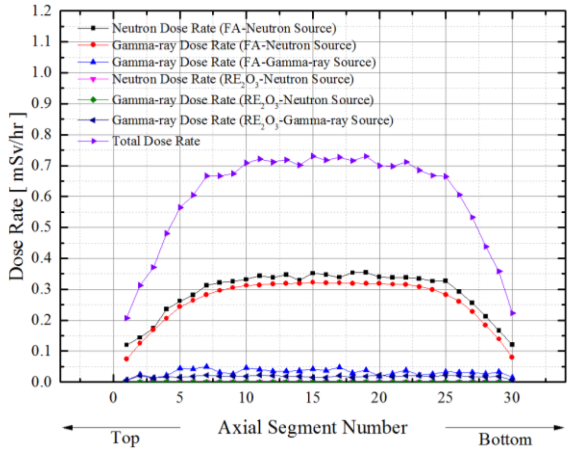


(b) RE_2O_3 Compound (1 kg)

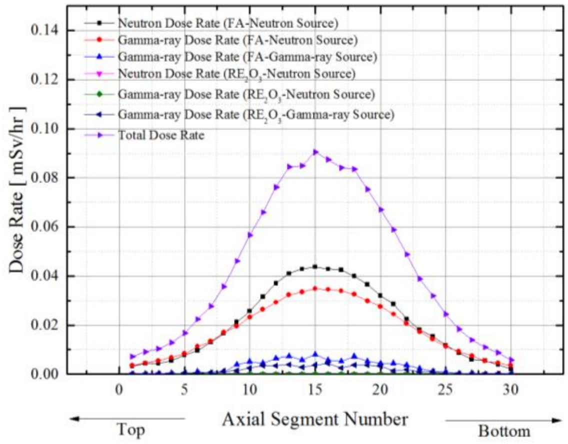
Figure 3. Energy Spectrum for Neutron and Gamma-ray Emitted from Spent Fuel Assembly and RE_2O_3 Compound

3. Results and Discussions

Figure 4 shows the axial dose rate profile at the surface and at a distance of 2 m from the cask. It is found that the maximum surface and external dose rates are within domestic standards (surface dose rate < 1 mSv/hr and external dose rate at 2m distance < 0.1 mSv/hr). The radiation dose rate distribution around the cask, regardless of detection position, is primarily influenced by the neutron source in the active fuel region, whereas the radiations emitted from the RE_2O_3 compound have very little effect on the radiation dose rates around the KSC-4 cask. Therefore, it is possible that the RE_2O_3 compound collected in pyroprocessing could contribute significantly to the criticality control of spent fuel storage systems without having an effect on the radiation dose rate around the system.



(a) Cask Surface



(b) 2m Distance from the Cask

Figure 4. Axial Dose Rate Distribution at the Surface and 2m Distance from the Cask

4. Conclusions

The computational calculations are performed to evaluate the practical applicability of artificial rare earth compound (RE_2O_3) as a neutron absorption material, and the KSC-4 cask used for the transportation of PWR spent fuel assemblies is considered as a reference cask. In these calculations, a one quarter model is used with a reflecting boundary condition because the KSC-4 cask has a symmetric configuration in horizontal and vertical directions, and the WH 17×17 assembly with 3.5 w/o enrichment, 35 GWD/MTU burnup, and 10-year cooling time is employed to perform a bounding analysis. As a result, the maximum surface and external dose rates are satisfied with domestic standards (surface dose rate < 1 mSv/hr and external dose rate at 2m distance < 0.1 mSv/hr), and the radiations emitted from the RE_2O_3 compound have no effect on the radiation dose rates around the KSC-4 cask. On the basis of these results, it is expected that the efficiency of radioactive waste management can be significantly improved by simultaneously keeping the RE_2O_3 compound and spent nuclear fuels in a restricted space.

REFERENCES

[1] Kyung-O Kim and Jong Kyung Kim, "A Study on Artificial Rare Earth (RE_2O_3) based Neutron Absorber," *Applied Radiation and Isotopes*, **105**, 52-, 2015.
[2] IAEA, Operation and Maintenance of Spent Fuel Storage and Transportation Casks/Containers, International Atomic Energy Agency, TECDOC-1532, 2007.
[3] D.B. Pelowitz, MCNPX^{TM} User's Manual, Version 2.7.0, Los Alamos National Laboratory, LA-CP-11-00438, 2011.
[4] B.J. Ade, SCALE/TRITON Primer: A Primer for Light Water Reactor Lattice Physics Calculations, Oak Ridge National Laboratory, ORNL/TM-2011/21, 2012.