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A Study on Radiation-Shielding Performance of Hotcell using High Burnup Spent Fuel Rod

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1. Introduction

Radiation shielding performance of the hotcell facility is the top priority to operate efficiently and safely. The hotcell facility at the Irradiated Materials Examination Facility (IMEF) in Korea Atomic Energy Research Institute (KAERI) has been operating since 1994 and from then on the discharge burnup of fuel has increased steadily and now reaches 60GWD/MTU. Computer code technology has been continuously developed over time.

A preliminary calculation by QAD-CG code[1] was conducted at the time of hotcell design. The standard radiation source terms were set to 1000,000 Ci of 1MeV gamma ray for 120cm-heavy concrete shielding wall and 200,000 Ci of 1MeV gamma ray for 110cm-heavy concrete shielding wall.

Therefore, for safe and effective operation of the hotcell facility, it is necessary to establish a new calculation standard of source term for high burnup fuel.

In this study, radiation dose rates from the above source terms were evaluated with MCNP6 code [2]. Based on the results of dose rates, maximum radiation source capacity of high burnup spent fuel rod for 120cm and 110cm-heavy concrete shielding walls was derived.

2. Methods and Calculation

2.1 Source terms

The source terms used in hotcell design are 1MeV γ-ray, 10^6 Ci for 120cm-heavy concrete wall and 1MeV γ-ray, $2X10^5$ Ci for 110cm-heavy concrete wall and all were assumed to be a point source.

Other source terms for high burnup fuel are calculated using the ORIGEN-S module in the SCALE6.1 code system [3]. The source term is CE 16X16 type of PWR fuel rod with 5wt% of U-enrichment and a cooling period of 6 months.

Depletion of PWR fuel rod was applied as 3 cycle of 3 irradiation and 2 downtime. Irradiation time is 540 days, downtime is 30 days between irradiation, and a cooling period of 6 months was applied after the 3^{rd} irradiation. Even though the actual rod will have a decreasing power history, the constant power was used for each burnup case. The power value are 24.6913, 30.8642, 37.0356, 43.2099 MW for 40, 50, 60, 70 GWD/MTU burnup, respectively. As shown in Fig. 1, gamma spectra for different burnup were calculated, adopting 18 groups of gamma energy range.

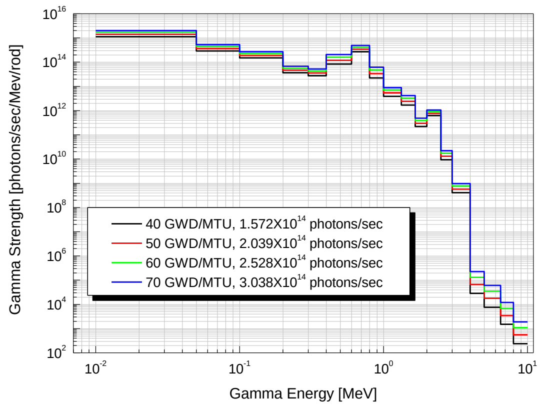

Fig. 1. Gamma Spectra for a fuel rod of PWR 16X16

2.2 Geometry Modeling with MCNP6

Geometry of shielding wall was only consisted of heavy concrete wall ($3.45g/cm^3$). Inside of hotcell was assumed to be dry air ($0.00120479g/cm^3$), as described in Fig.2.

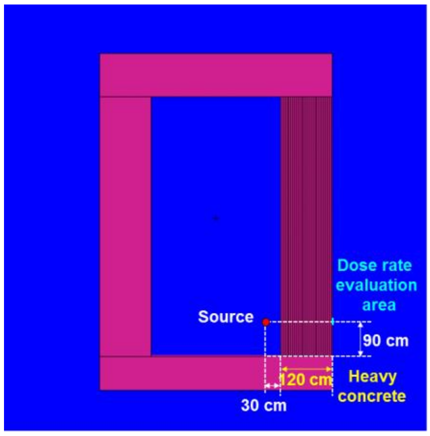

Fig. 2. 120cm-heavy concrete shielding wall modeling in MCNP6 (x-z plane)

In this shielding calculation, the conditions such as source position and dose evaluation area were applied as same as the previous QAD-CG code shielding calculation. The point source is 30cm away from inner shielding wall and 90cm above from the floor considering a working table. The dose evaluation area is defined as $1cm^2$ area of outer surface of shielding wall corresponding to the shortest point of gamma ray from the source. Because of deep penetration of heavy concrete wall, the shield was divided into 4cm thick layers, so that there were 30 such layers for 120cm-heavy concrete wall. The geometry splitting variance reduction technique was used in order to obtain reliable results. The flux to dose conversion factor of ICRP-116 was applied.

3. Results

Table Ⅰ shows radiation dose rates from the hotcell design source term. The results of dose rate satisfy the radiation safety standard, 10 μSv/hr. The radiation dose rates due to the gamma source originated from a PWR fuel rod are listed in TableⅡ. The relative error of MCNP6 calculation is less than 1%.

Table Ⅰ: Dose rates from hotcell design source term

	Source term	Dose rates (μSv/hr)
110cm-wall	1MeV γ-ray, 2X10^5Ci	1.832
120cm-wall	1MeV γ-ray, 10^6 Ci	1.071

Table Ⅱ: Dose rates from the a PWR fuel rod

Burnup (GWD/MTU)	Dose rates (μSv/hr)	
	110cm- wall	120cm- wall
40	0.129	0.029
50	0.158	0.037
60	0.195	0.046
70	0.234	0.052

Based on these dose rate results, maximum capacity of PWR of fuel rod for each shielding wall was derived, as shown in Figure 3. For 60GWD/MTU, only 23 high burnup fuel rods are suggested to use in the 120cm-heavy concrete wall and maximum of 9 high burnup fuel rods can be handled in the 110cm-heavy concrete wall.

Figure 4 shows maximum weight of uranium for each shielding wall. Uranium weight per rod is 1.825kg in CE 16X16 type of PWR fuel so that for 60GWD/MTU, 16.425kg and 41.975kg of uranium can be handled in 110cm and 120cm-heavy concrete wall, respectively.

As the fuel burnup increases by 10GWD/MTU, maximum allowable weight of uranium is reduced by 20% for each burnup case. For the hotcell design source term, the source capacity of 120cm-wall is higher than 110cm-wall by five times. However, in case of PWR fuel rod, 120cm-wall has a source capacity about 2.6 times higher than 110cm-wall.

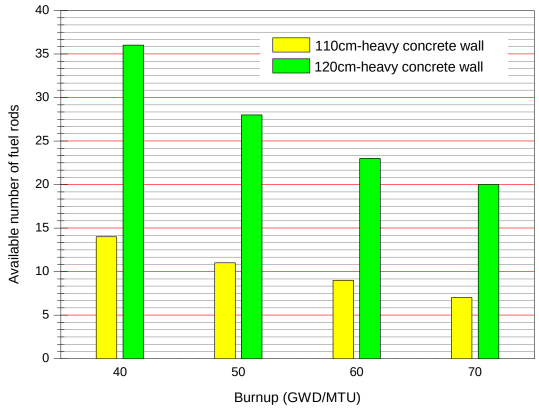

Fig. 3. Available number of fuel rods for 110cm and 120cm-heavy concrete walls

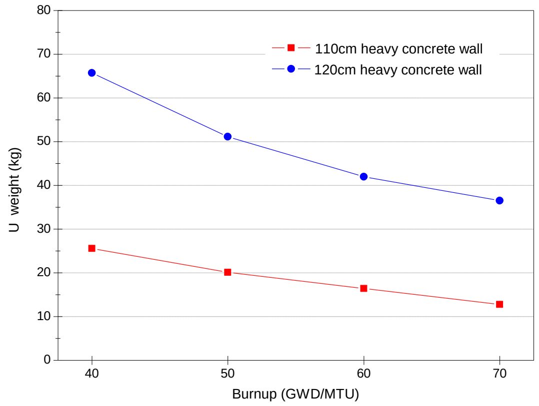

Fig. 4. Maximum uranium weight for 110cm and 120cm-heavy concrete walls

3. Conclusions

The shielding calculations of two kinds of different thickness heavy concrete wall of hotcell were performed with MCNP6. Applying the hotcell design source term and the PWR fuel rod source term in various burnup cases, shielding performance of hotcell was validated with MCNP code. A new calculation standard of source term for high burnup spent fuel rod was established. This result can ensure the safe operation and effective management of hotcell facility.

REFERENCES

[1]U.S. Radiation Information Center, "QAD-CG, a Combinational Geometry Version of QAD-5A, a Point Kernel Code Neutron and Gamma-Ray Shielding Calculation", ORNL, CCC-307.

[2] D.B. Pelowitz, MCNP6 User' s Manual Version 1.0, LA-CP-13-00634, Los Alamos National Laboratory, 2013.

[3]ORNL, SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design, Version 6.1, ORNL/TM-2005/39, Oak Ridge National Laboratory, 2011.