Shielding Assessment for Solid Target Experiment on Ultrashort Quantum Beam Facility Using Monte Carlo Method

Hong-Chul KIM [a], Chang-ho SHIN [b], Hyung Taek Kim [c], Il Woo Choi [c], Do-Kyeong Ko [c], Jongmin Lee [c], and Jong Kyung KIM [a*]
[a] *Department of Nuclear Engineering, Hanyang University, 17 Haengdang, Seongdong, Seoul 133-791, Korea*
[b] *Innovative Technology Center for Radiation Safety, Hanyang University, Seoul 133-791, Korea*
[c] *Advanced Photonics Research Institute, GIST, Gwangju 500-712, Korea*
[*] *Corresponding Author: jkkim1@hanyang.ac.kr*

1. Introduction

The Ultrashort Quantum Beam Facility (UQBF), a petawatt level high power ultra-short pulsed laser facility with peak power over 500 TW, is being constructed by APRI (Advanced Photonics Research Institute) located at Gwangju Institute of Science and Technology. The UQBF is a national user facility to be utilized for pioneering new science and technology in the research areas of intense laser technology and femto-science. As the UQBF will be constructed in near future, it needs to carry out radiation shielding assessment for the facility in order to ensure radiation safety of workers and public as well. In this study, Monte Carlo method was used in the shielding assessment for the secondary radiation by interaction between solid target and the intense laser pulse. After the detailed modeling of the facility using MCNPX code [1], dose calculations were performed at the various positions around the facility.

2. MCNP Modeling and Calculation Method

2.1 Modeling of Main Facility

The MCNP modeling result of the main facility for the UQBF was presented in Figures 1 and 2. Dimensions were 50 m×29 m×12 m for x, y, and z direction, respectively. The laser of which power is up to 100 TW can be used in target area 1. In target area 2, the available power of laser is 500 TW to 1 PW. The thickness of side-wall was 50 cm for target area 1 and 100 cm for target area 2. All walls in this facility were made of a normal concrete and the door consists of lead and polyethylene. Target area 1 consists of 3 experiment rooms, and there is one room for target area 2. The experiments were carried out only in one of rooms and could not be performed in various rooms simultaneously.

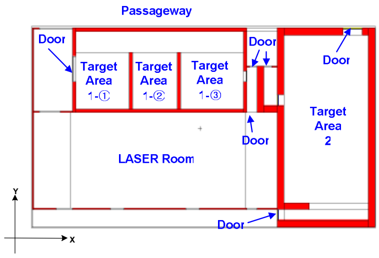

Figure 1. Vertical View of MCNPX Modeling

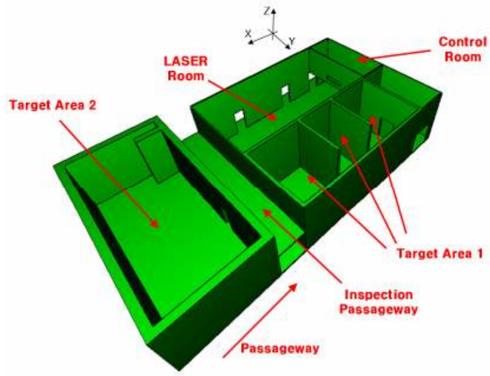

Figure 2. Three-Dimensional View of MCNPX Modeling

2.2 Calculation Method

When a laser beam was focused on a solid target which is made by copper with 5 μm thickness, photons, electrons, and protons were produced. All of these three radiation sources were modeled based on the measurement results by APRI. It was assumed that photons were isotropically emitted with mono-energy of 25 keV, and protons and electrons were emitted toward passageway side with maximum energy of 4 MeV and mono-energy of 2 MeV, respectively. For the conservative safety investigation, we assume that the neutrons energy of 2.45 MeV can be produced and emitted when the deuterium-enriched polymer target was used. The numbers of each radiation emitted per shot were 1.4×10^9 photons/sr/keV, 1×10^3 neutrons, 1×10^{10} electrons and 8×10^{10} protons for the experiment in target area 1. Radiation source for the experiment in target area 2 could not be defined because the experiment was not carried out yet. In this study, 5 times as many number of radiation as the experiment in target area 1 were applied for one in target area 2, since it was known that the number of radiation produced by quantum beam was linearly increased as the quantum beam energy was increased..

The photon, electron and proton fluxes were not converted to dose rate because the radiations leaking from target areas were not observed due to its low penetration ability and energy. Neutron dose rate was calculated as the flux multiplied by the flux-to-dose conversion factors. ANSI/ANS-6.1.1-1991 neutron dose functions for AP direction (Anterior-Posterior) were employed to convert the neutron flux into dose.

Various positions at which radiation shielding assessments were to be made, from A to I, were also shown in Figures 3 and 4.

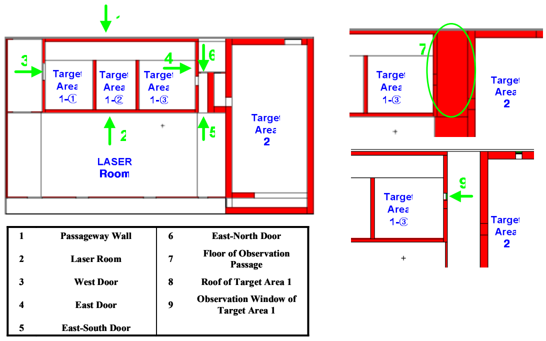

Figure 3. Dose Calculation Positions for the Experiment in Target Area 1

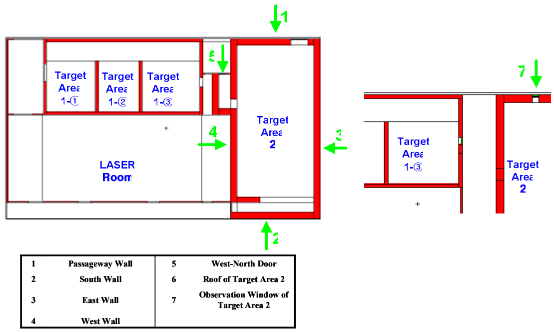

Figure 4. Dose Calculation Positions for the Experiment in Target Area 2

3. Results and Discussions

Dose rates at the interested positions were tabulated in Table 1. It was assumed that the maximum shot rate of quantum beam was 20 shots per hour.

Table 1. Dose Rate Calculation Results

[μSv/hr]

	Position	Max. Dose Rate	Position	Max. Dose Rate
Target Area 1-①	①	2.285E-08	⑥	3.344E-10
	②	5.735E-08	⑦	2.646E-10
	③	8.145E-07	⑧	2.068E-07
	④	3.239E-09	⑨	3.831E-09
	⑤	1.594E-10		
Target Area 1-②	①	2.328E-08	⑥	2.103E-09
	②	5.800E-08	⑦	1.327E-09
	③	6.590E-09	⑧	2.112E-07
	④	2.273E-08	⑨	1.710E-08
	⑤	5.192E-10		
Target Area 1-③	①	2.276E-08	⑥	1.883E-07
	②	5.718E-08	⑦	1.145E-07
	③	1.839E-09	⑧	2.020E-07
	④	2.039E-06	⑨	7.381E-07
	⑤	2.081E-08		
Target Area 2	①	2.208E-07	⑤	1.211E-09
	②	1.650E-09	⑥	1.131E-09
	③	2.165E-09	⑦	5.078E-07
	④	4.865E-07		

From the above results, it is found that the maximum dose was observed at the position 4 when the experiment was performed in target area 1-③. This might be caused by no shielding door at right side wall of target area 1-③.

The Atomic Energy Act in Korea notices that the dose rate per year should be less than the dose limit for the public and the dose rate per week should be less than 0.1mSv on area in which people lives to adjoin radiation facility, based on a criterion for the radiation protection. For Ultrashort Quantum Beam Facility (UQBF), the duration of operation time was 5 days per week and the running time was 4 hours per day. If the facility operated on the conditions above, all calculation results for solid target experiment were sufficiently satisfied within the dose limit.

4. Conclusions

In this study, a radiation shielding assessment was carried out for solid target experiment on Ultrashort Quantum Beam Facility with MCNPX Code. After detailed modeling of the main facility and radiation sources using MCNPX code, dose calculations were performed at the interested positions around the facility. If the dose limit of 0.1 mSv/week, which is a criterion for radiation protection based on the Atomic Energy Act in Korea at present, was applied, all calculation results for solid target experiment would be satisfied with this requested dose limit.

It is noted that shielding assessment for the quantum beam facility such as UQBF was firstly pursued in Korea. It is found that the method to define the radiation source is important when the simulations for shielding assessment was performed for the facility, in which radiation source emitted on experiment have the feature of pulsed type. The results of this study can be applied as a validation tool for the safety regulation and approval for the facility.

Acknowledgment

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REFERENCES

[1] Laurie Waters, Ed., "MCNPX User's Manual, Version 2.4.0," LA-CP-02-408, Los Alamos National Laboratory, September 2002.