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Important Cautions in Shielding Computation by using the FLUKA Code

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1. Introduction

The healthcare facilities using radiations such as high-energy radiation treatment facilities and medical isotope production facilities etc. are ever-increasing in number. Although these facilities can provide much convenience for patients, they accompany a big risk of radiation exposure. Therefore, the radiation safety measures which minimize the radiation exposure but still provide much convenience are the most important for designing these facilities. It is important to consider how efficiently the facility is designed against the shielding and activation problems in order to minimize the radiation exposure. In order to evaluate shielding capability of facility, although the simple calculation with approximate methods were popular until recently, owe to the development of information technology and the advances of computational mathematics, the Monte Carlo codes such as the MCNP, FLUKA, GEANT, and PHITS which can provide accurate answer are popularly used now. Advantage of Monte Carlo code is to perform the correct calculation but takes a long time for computing. More importantly, the exact and precise input data for Monte Carlo codes is essential in order to obtain accurate results. Thus, in this paper, important cautions are presented for shielding computation with the FLUKA code [1][2] because the ignorance of such important cautions makes big troubles.

2. Methods and Results

The Korea Heavy-ion Medical Accelerator (KHIMA) project [3] is performed in Busan, Korea, by the Korea Institute of Radiological and Medical Sciences (KIRAMS). Radiation protection is one of the most important problems in this project. Radiation shielding and activation simulations are performed by using the FLUKA and MCNPX codes for the cross comparison purposes. Preparing the exact geometry input data is one of the most time consuming tasks. A few important cautions in using the FLUKA code were found and reported in this paper. Specifically, the usual multi-process with the FLUKA code showed some unusual aspects.

2.1 Methods – Simulation Concept

The developing heavy-ion medical accelerator is a synchrotron which accelerates the carbon ion up to a total energy of 5GeV. The ion beams are designed to move inside the accelerator but some ion beams leak to the outside area of the accelerator due to the limits of engineering design. The leaked ion beams are passed through surrounding materials which shield the beams, resulting in the generation of secondary particles such as neutron, proton, and photon. In this study, we focused on shielding problem of neutron beams because they are the most harmful among the secondary particles.

2.2 Methods - FLUKA Input: Geometry

Since the important research subject is focused on the shielding problems in the vault area on the first floor where high-energy beam is passing, the complexities of the facility, specifically, those in the areas of the treatment and research rooms, are simplified, and the easy-to-understand technical drawing of the vault is designed (see Figure 1). Because the beam source is a carbon ion released from the accelerator ring to outside, the source hits randomly a part of the accelerator ring. The concentric iron sphere with external radius of 7 cm and internal radius of 2 cm imitates the part of the accelerator ring, from which the secondary particles are generated. To detect the exposed energy, eight detection points (designated by Det_1~8) of water spheres with radius of 25 cm were selected. Their locations were selected according to the pre-estimation of relatively highly exposed areas. The shielding walls are defined as a concrete and the surroundings are defined as an air.

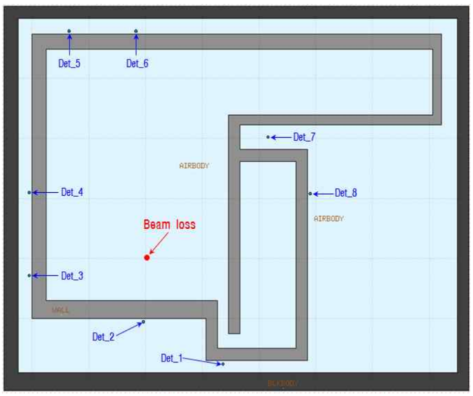

Fig. 1. Accelerator vault geometry for shielding computation

2.3 Methods - FLUKA Input: Beam, Detector

The energy of the source is 430MeV/u and beam direction is defined as a clockwise tangent line along the accelerator ring. USRBIN-DOSE (GeV/g) whit AUXSCORE-NEUTRON option card defined by the FLUKA code is used to evaluate the absorbed dose by a neutron particle and USRBIN-ENERGY option card is used to augment the convergence of the generated second radiation and the detector.

2.4 Methods – Feasible Multiprocessing method

Feasible Multiprocessing method is as follows. (see Table I)

Table I: Feasible Multiprocessing method

Group	Simulation NO	Total History	History/Cycle	Cycle	Used CPU
1	No.1	28E+6	2E+6	14	1
2	No.2	28E+6	2E+6	14	14
3	No.3	28E+6	28E+6	1	1
	No.4	28E+6	28E+6	1	1
	No.5	28E+6	28E+6	1	1
	No.6	28E+6	28E+6	1	1
	No.7	28E+6	28E+6	1	1
	No.8	28E+6	28E+6	1	1
	No.9	28E+6	28E+6	1	1
	No.10	28E+6	28E+6	1	1
	No.11	28E+6	28E+6	1	1
	No.12	28E+6	28E+6	1	1
	No.13	28E+6	28E+6	1	1
	No.14	28E+6	28E+6	1	1
	No.15	28E+6	28E+6	1	1
	No.16	28E+6	28E+6	1	1

All total history of the comparison groups was 28E+6. In group 1, many cycles were calculated one by one with one CPU and an average value of the cycles was estimated automatically. In group 2, each cycle was simultaneously calculated in the different CPUs with different initial random seed and the result was averaged over the different CPUs semi-automatically. In group 3, the computing was the same as group 2 but each cycle has the total number of histories, 28e+6, in group 2.

2.4 Results – Energy Distribution

Figure 2 presents an energy distribution (GeV/cm3) obtained by the USRBIN-ENERGY card. Most of the energy distribution is located in Det_2, 3 and 4 which are expected to be higher energy convergence than other locations.

2.5 Results – Group 1 vs Group 2

Figure 3 presents the results of the comparison of the groups, 1 and 2. The absorbed doses were highest in Det_2, 3 and 4, which is similar to figure 2. Errors were low because of the good convergence. (see Table II)

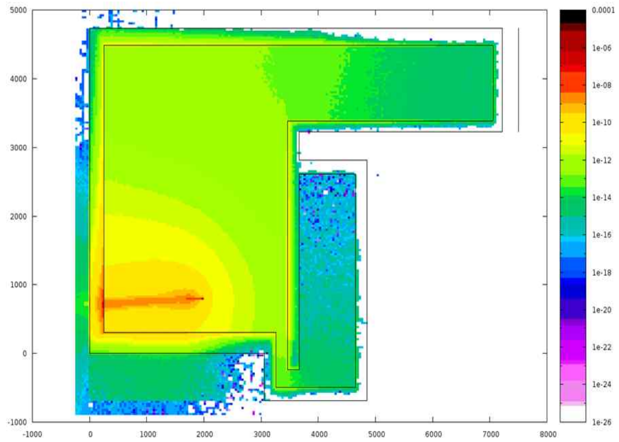

Fig. 2. Energy distribution [X, Y Axis unit: cm]

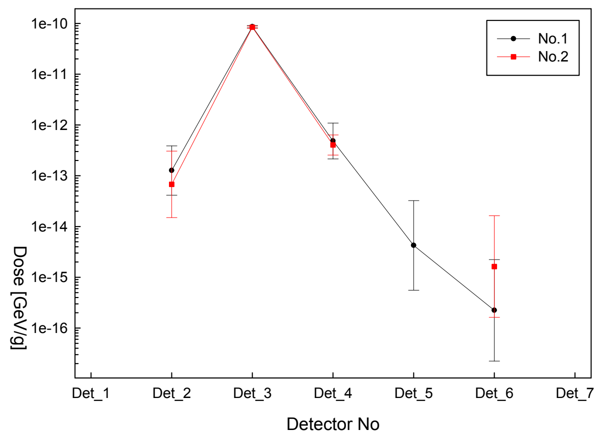

Fig. 3. Simulation result graph [Group 1 vs Group 2]

Table II: Simulation result data [Group 1, 2]

Detector No.	Group 1			Group 2		
	Dose [GeV/g]	Error [%]	Runtime [hour]	Dose [GeV/g]	Error [%]	Runtime [hour]
Det_1	0.00 E+000	0.00 E+000	264	0.00 E+000	0.00 E+000	15
Det_2	1.27 E-013	4.86 E+001		6.76 E-014	6.54 E+001	15
Det_3	8.61 E-011	2.40 E+000		8.44 E-011	2.06 E+000	15
Det_4	4.83 E-013	3.53 E+001		4.03 E-013	1.99 E+001	15
Det_5	4.25 E-015	8.82 E+001		0.00 E+000	0.00 E+000	15
Det_6	2.23 E-016	1.00 E+002		1.63 E-015	1.00 E+002	15
Det_7	0.00 E+000	0.00 E+000		0.00 E+000	0.00 E+000	15
Det_8	0.00 E+000	0.00 E+000		0.00 E+000	0.00 E+000	15

It is confirmed that the absorbed doses and errors of the group 1 and 2 were similar in the detection points with high energy convergences. The simulation time of the group 2 was 17.6 times faster than that of the group 1 because group 2 used the usual multi-processing with the FLUKA code. In group 2, an average value was calculated by merging the data from different CPUs semi-automatically.

2.6 Results – Group3 (No.3~No.16)

The results of the group 3 were obtained by using the different random seeds and the different CPUs. Each history number of the group 3 was equal to the total number of history in group 1 or 2. The purpose of this simulation was to check if the dependency of the result on the number of histories.

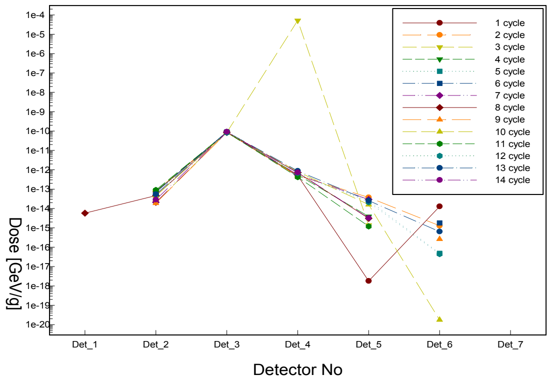

Fig. 4. Simulation result graph [Group 3]

As shown in Figure 4, although the distributions of the absorbed dose in high convergence areas such as the Det_2, 3 and 4 were similar, those in low convergence areas were different. Specifically, Det_5 of No.3 and Det_4 of No.5 were completely different. However, the data are unreliable results because of the error of 99.9% although the number of history in each cycle (28E+6) was the same as the total number of histories in group 1 or 2.

2.7 Results – Group 1 vs Group 2 vs Group 3(No.6, 8, 13)

Figure 5 shows the comparison of No.6, 8 and 13. This result is similar to the comparison of groups, 1 and 2. In the cases of the No.6, 8 and 13, the results show similar to the comparison of the groups, 1 and 2 in spite of the 99.9% error. Thus, the error or average value should be interpreted carefully in the FLUKA code.

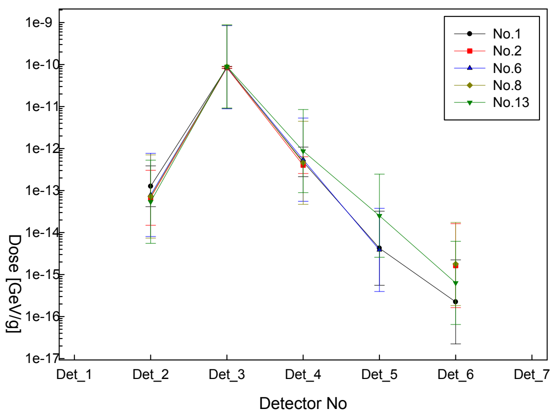

Fig. 5. Simulation result graph [Group 1, 2, 3(No.6, 8, 13)]

3. Conclusions

The absorbed doses and errors show similar tendency in the comparison of groups, 1 and 2. Specifically, the results confirmed the more similar tendency in the high convergence areas. In group 3, although the comparison with groups, 1 and 2, shows the similar absorbed dose in the detectors with high convergences, the results themselves are unreliable because the errors are 99.9%. Thus, we need more careful attention to the average value and error in using the FLUKA code. Simply, it is better for us to have other benchmark tools such as MCNPX. However, it is recommended that the best computing method with the FLUKA code is the same as the computing of group 2, the usual multi-processing with semi-automatic data handling. As shown in group 3, higher number of the cycle is a better method than the higher history to get more reliable result or to reduce errors. However, these values should be carefully evaluated. Although not presented here, the result also confirmed that, in relatively low convergence case, the FLUKA code showed lower average value than that of the MCNPX code. Considering all these various deficiencies appeared in using the FLUKA code, the shielding calculation with the FLUKA code should be augmented with other more reliable Monte Carlo code such as the MCNPX code.

Acknowledgment

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