Application of Kernel-Convolution Method for Photon Dose Estimation in BNCT

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1. Introduction

To plan Boron Neutron Capture Therapy treatment, dose distribution calculation by simulation is necessary. Monte Carlo can be a good method for this. However, Monte Carlo method takes lots of times to get sufficient uncertainty level. In X-ray therapy situation, kernel convolution method can be a substitute because gamma and electron take reaction with only orbital electron [1]. BNCT has other dose components but they have only few µm range. Therefore, other dose components except photon dose can be calculated directly with neutron flux.

In BNCT, photon can be generated wherever neutron flux exists. Also, these photons are isotropic. This situation has similar property with brachytherapy [2]. We have applied brachytherapy collapsed cone convolution to calculate BNCT photon dose. Also, we have compared result of kernel convolution method and FLUKA, the Monte Carlo code, for water phantom and CT head phantom case [3].

2. Methods

There're three reaction that can generate gamma ray 1) B-10 (n, α), 2) H-1 neutron capture, 3) Cl-35 neutron capture. The first two generate 477 keV photon and 2223 keV photon respectively. In Cl-35 neutron capture case, it shows complicate gamma spectrum. We divide this spectrum to four region and calculate with four photon kernels (477 keV, 1 MeV, 2.2 MeV and 6 MeV).

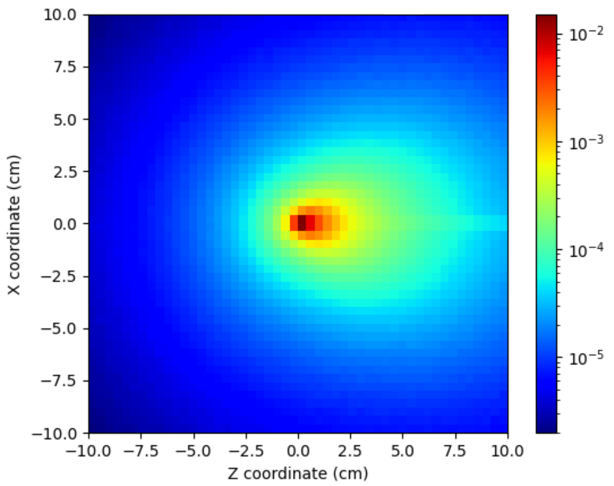

Figure 1. Dose kernel of 477 keV primary photon, unit is MeV/g/cm3.

Dose kernel is calculate by FLUKA usrmed.f subroutine. Figure.1 shows kernel of 477 keV primary photon.

3. Results

Two calculation method is compared, full FLUKA calculation and convolution method. In convolution case, only neutron flux is calculated by FLUKA. Since deterministic method doesn't have uncertainty, neutron flux uncertainty is uncertainty of convolution method.

3.1. Water phantom

The result of water phantom with 13 ppm B-10 background is like figure.2.

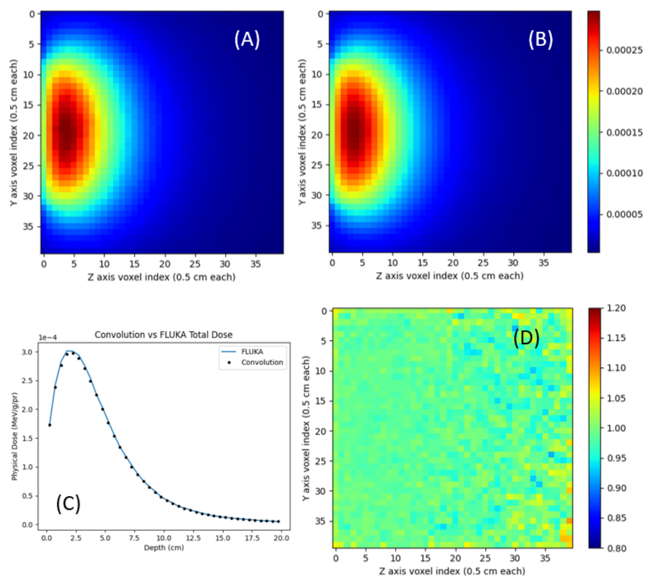

Figure 2. FLUKA-convolution comparison in case of water phantom with 13 ppm boron 10 (A) FLUKA photon dose (B) kernel-convolution photon dose (C) one-dimensional plot at the centerline (D) ratio of convolution/FLUKA. Unit is MeV/g/pr for every case.

Performance comparison of two methods is shows in table.1. Uncertainty is point dose/flux error at the 10 cm depth from neutron beam incident surface.

Table 1

	FLUKA	Convolution
Uncertainty	1.786%	1.783%
# of histories	1.2×10^9	7.2×10^7
Calculation times (FLUKA)	20640 seconds	956 seconds
Voxel build	-	7.6 seconds
Kernel convolution	-	218.5 seconds
Total time	20640 seconds	1182.3 seconds

In this case, kernel convolution method is 17 times faster than FLUKA calculation.

3.2. CT head phantom

The result of CT head phantom with 13 ppm B-10 background is like figure.3.

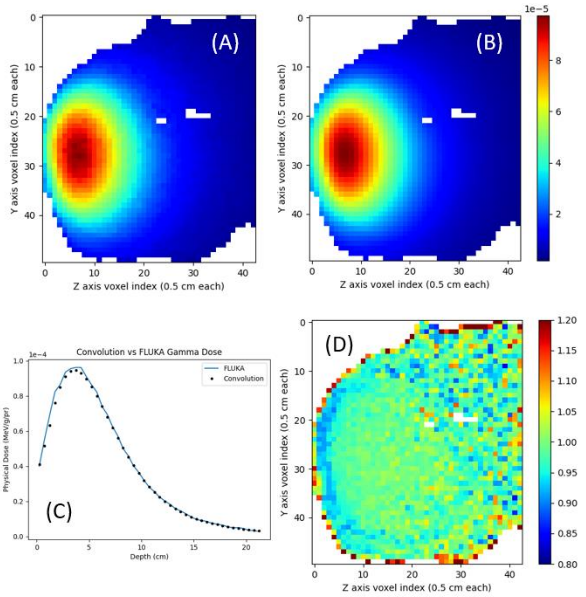

Figure 3. FLUKA-convolution comparison in case of CT head phantom with 13 ppm boron 10 (A) FLUKA photon dose (B) kernel-convolution photon dose (C) one-dimensional plot at the centerline (D) ratio of convolution/FLUKA. Unit is MeV/g/pr for every case.

Performance comparison of two methods is shows in table.2. Uncertainty is point dose/flux error at the 10 cm depth from neutron beam incident surface.

Table 2

	FLUKA	Convolution
Uncertainty	2.036%	0.905%
# of histories	6×10^8	3.6×10^7
Calculation times (FLUKA)	35820 seconds	2130 seconds
Voxel build	-	15 seconds
Kernel convolution	-	300 seconds
Total time	35820 seconds	2445 seconds

In this case, kernel convolution method is 15 times faster than FLUKA calculation.

4. Conclusions

We have developed the system for calculating BNCT photon dose. Compared to full FLUKA calculation, kernel-convolution method is faster 17 times in case of water phantom and 15 times in case of CT head phantom. Kernel convolution can be a good method to reduce the calculation time. In this situation, neutron flux calculation parts consume most CPU time. We developing CUDA based Monte Carlo code system for neutron flux calculation to get more time advantage.

REFERENCES

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