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

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Introduction

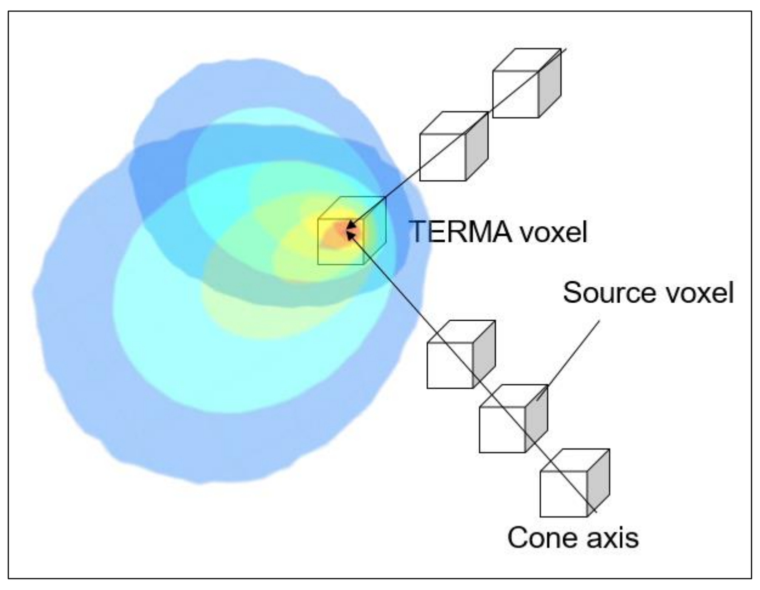
- **Purpose of this work is to reduce the BNCT dose calculation time**
- This method using FLUKA Monte Carlo code to calculate neutron flux distribution, collapsed cone convolution (CCC) to calculate photon dose from neutron flux [1][2].
- Since proton and ion have extremely small range, dose from these particles can be calculated by multiplication of neutron flux and reaction rate.
- We have compare the result of pure FLUKA calculation and this method. The performance of this method also be compared.

Methods

- This work using modified brachytherapy CCC [2].
- Brachytherapy has finite number of gamma source. However, number of BNCT gammas source is the same as the number of voxel.
- **Therefore, our modified algorithm follow two steps.**

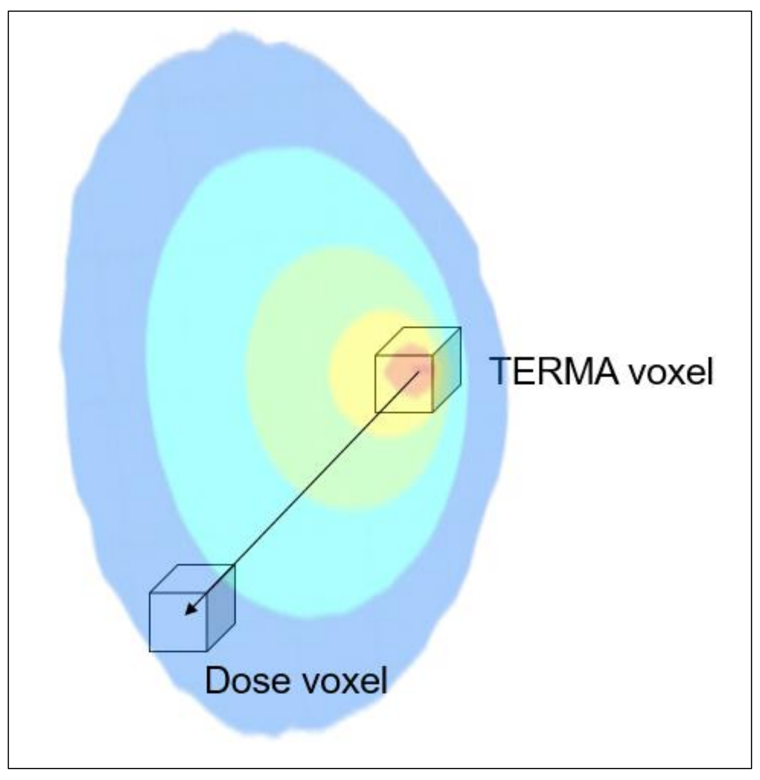
A. Kernel summation

1. Using fixed cone axis that generated by Young-Fibonacci lattice algorithm [3].
2. All gamma sources are isotropic.
3. Calculate effective intensity of every voxel that passing through same cone axis. Consider mass attenuation.
4. Sum kernel for every cone axis.



B. Kernel summation

1. Perform a conventional collapsed cone convolution



- This method can reduce the time complexity.
- Conventional brachytherapy CCC has $M^2 \times N^2$ time complexity for a single source, total is $M^2 \times N^5$.
- This method has $M \times N$ time complexity for a single source and there is two steps, total is $M \times N^4$.

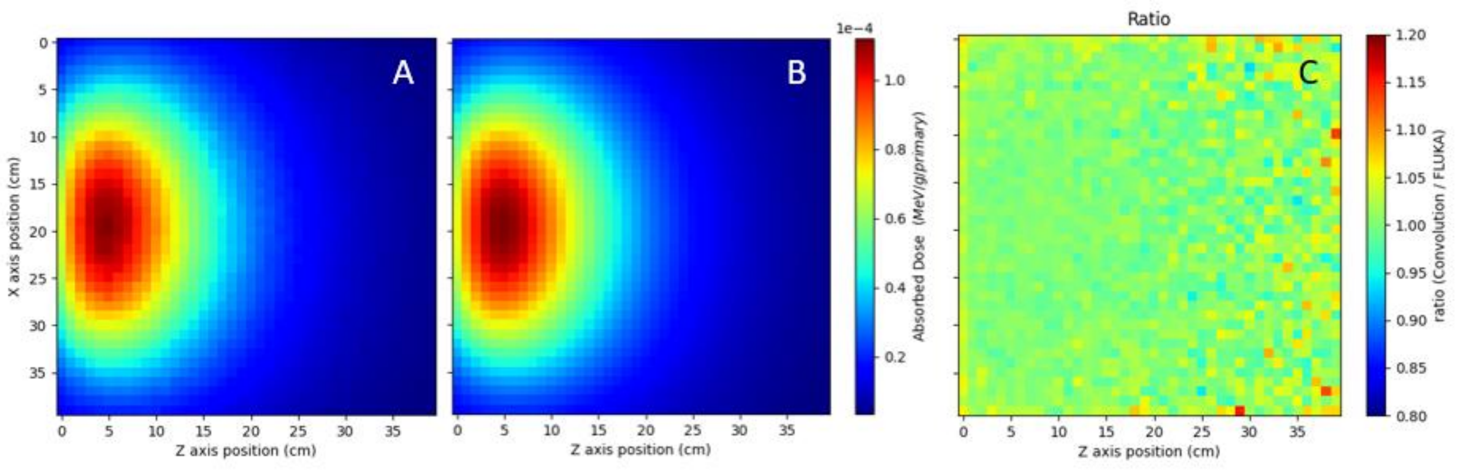
*M is number of cone axis, N is number of voxels on one side

Summary and Future Plan

- **Brachytherapy collapsed cone convolution is modified and applied to BNCT dose calculation.**
- **The difference between FLUKA and convolution is large at the surface and bone.**
- **Average relative difference between FLUKA and convolution code is 2.07% in the case of water phantom and 3.91% in the case of head CT voxel model.**
- **GPU-accelerated neutron flux Monte Carlo code that can substitute FLUKA will be combined.**
- **Full package that can calculate every dose component will be developed.**

Results

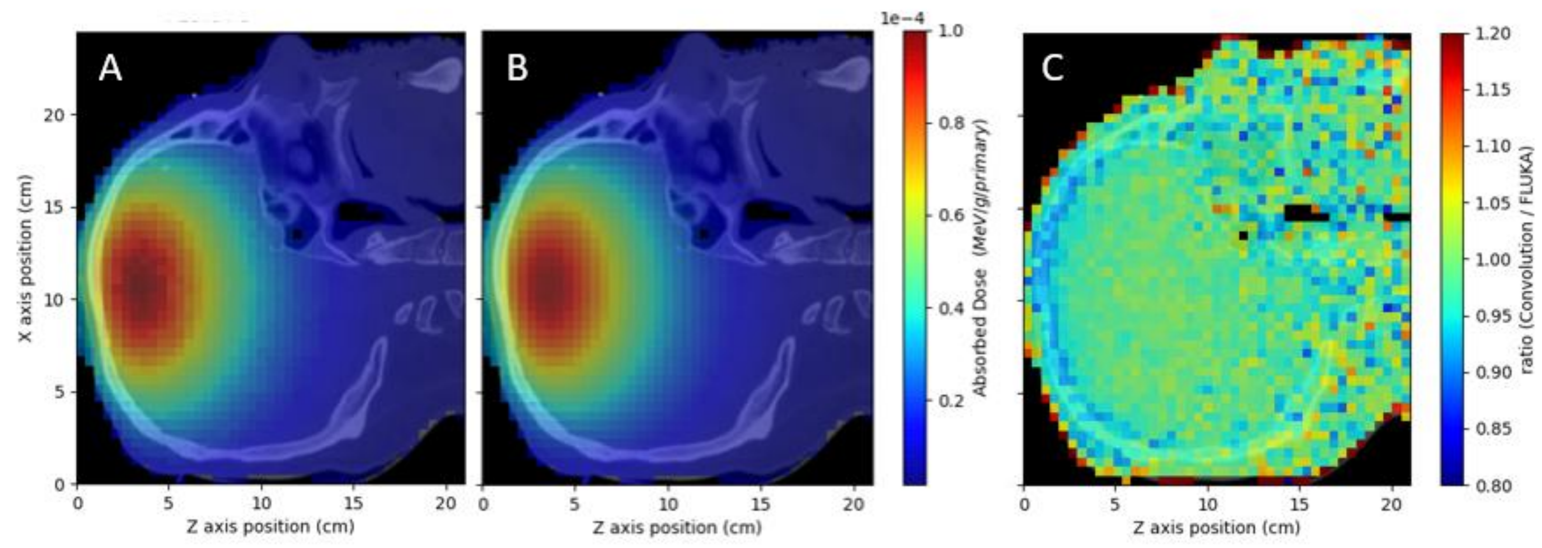
- Both case used FIR-1 research reactor BNCT module neutron spectrum. Beam shape is circular and diameter is 12 cm.
- Both case use hounsfield to material composition table from Schneider et. al. (2000) [4]. Uniformly distributed Boron-10 that has 13 ppm concentration is added.
- Voxel size is $0.5 \times 0.5 \times 0.5$ cm^3
- **20x20x20 cm^3 water phantom**



	Pure FLUKA	This Work
Uncertainty	2.009%	2.700%
# 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

- The uncertainty of FLUKA means average statistical uncertainty of photon dose. Uncertainty of this work means average statistical uncertainty of neutron flux.
- Since kernel convolution is deterministic method, uncertainty of neutron flux propagate to final result.

- **Head CT voxel model**



(A) FLUKA photon dose (B) kernel-convolution photon dose (C) ratio of convolution/FLUKA

	FLUKA	Convolution
Uncertainty	3.479%	3.859%
# 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

References

[1] T.T. Bohlen, F. Cerutti, M.P.W. Chin, A. Fassò, A. Ferrari, P.G. Ortega, A. Mairani, P.R. Sala, G. Smirnov, and V. Vlachoudis, "The FLUKA Code: Developments and Challenges for High Energy and Medical Applications", Nuclear Data Sheets 120, 211-214 (2014).
[2] Carlsson, Åsa K., and Anders Ahnesjö. "The collapsed cone superposition algorithm applied to scatter dose calculations in brachytherapy." Medical physics 27.10 (2000): 2320-2332.
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