*Transactions of the Korean Nuclear Society Autumn Meeting*
*Busan, Korea, October 27-28, 2005*

# Development of BTPS for BNCT Treatment Planning

Sang Hoon JUNG[a], Sung Ho PARK[b], Chi Young HAN[c], Soon Young KIM[c], and Jong Kyung KIM[a]
[a] *Department of Nuclear Engineering, Hanyang University, Seoul, Korea*
[b] *Asan Medical Center, Seoul, Korea*
[c] *Innovative Technology Center for Radiation Safety, Hanyang University, Seoul, Korea*

## 1. Introduction

In BNCT (Boron Neutron Capture Therapy) procedure, the radiation field consists of complex and distinct radiation components with different biological weights in contrast to conventional radiotherapy because incident neutrons induce many different nuclear reactions. This fact has led many research groups to explicit 3D calculations not the conventional semi-empirical approach for treatment planning. Monte Carlo technique has become the major tool for treatment planning of BNCT. Several BNCT research groups have developed their own TPS (Treatment Planning System) for BNCT based on the Monte Carlo simulation technique. Two TPSs, SERA (Simulation Environment for Radiotherapy Applications, INEEL) and NCT_Plan (Havard-MIT), have been specifically developed. JCDS (JAERI Computational Dosimetry System, JAERI) and BDTPS (Boron Distribution TPS, University of Pisa) are under development. In Hanyang University, for the first time in Korea, BTPS (BNCT Treatment Planning System) has been developed and is used for the research on accelerator-based BNCT[1]. This paper describes the various features of BTPS and its good performance compared with the conventional TPS calculation.

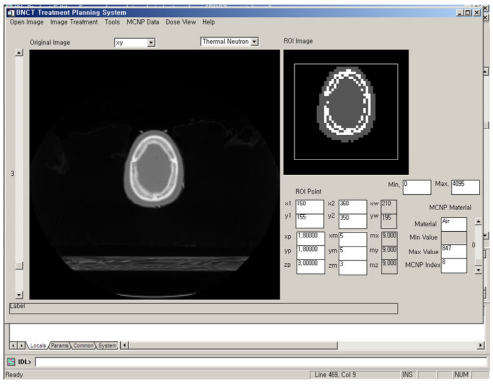
## 2. Brief Description of BTPS

BTPS is a patient-specific treatment planning system for BNCT using common diagnosis images and their geometry reconstruction, and works on the Windows platform. It has been developed based on the voxel reconstruction technique widely used in the fields of diagnostics, nuclear medicine, and dose calculation in radiotherapy. BTPS calculates four dose components (gamma dose, neutron dose, proton dose, and boron dose). They are built with IDL (Interactive Data Language) which is the solution for data visualization and image analysis.

BTPS includes three common modules, 3D voxel phantom modeling, dose calculation, and data analysis.

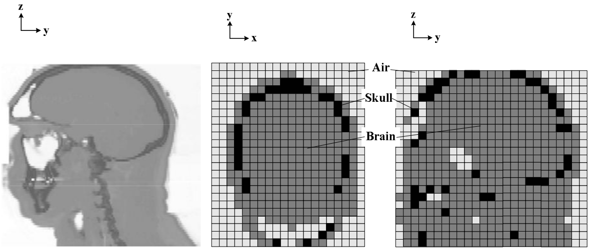
### *2.1 Voxel Phantom Modeling*

BTPS constructs 3D voxel phantoms easily and speedily from CT images of patients such as DICOM, PINNACLE, and VHP [2]. BTPS divides a CT image set into some ROI (Region Of Interest) images and constructs a voxel phantom using them. The voxel phantom can include patient-specific oncological data, such as GTV (Gross Tumor Volume) and CTV (Critical Tumor Volume). Figure 1 shows the main interface of BTPS and Figure 2 shows an example of 3D voxel phantom construction from a VHP image set. The material of each voxel is defined based on the index number of each pixel in CT images.



xy
Thermal Neutron
Min. 0
Max. 4095
x1 150
x2 360
xw 210
y1 155
y2 350
yw 195
xp 1.80000
xm 5
mx 9.000
yp 1.80000
ym 5
my 9.000
zp 3.00000
zm 3
mz 9.000
Material Air
Min Value
Max Value 847
MCNP Index 8

Figure 1. Main Interface of BTPS



(a) CT Image (b) 3D Voxel Phantom

Figure 2. An Example of 3D Voxel Phantom Construction from a VHP Image Set

### *2.2 Dose Calculation*

Dose calculations in the voxel phantom are performed using MCNPX code with the treatment environment including beam irradiation and patient position. In general, voxel phantoms in MCNP are constructed using a geometrical model of 'repeated structure' and therefore dose calculations in the phantoms have been mainly performed using the conventional tally ('lattice tally') in MCNP. However, useful techniques including 'mesh tally' in MCNPX are employed to BTPS in order to reduce computing time as well as to calculate doses in many cells.

The four dose components are calculated using kerma values and combined into background dose, tumor dose, and tissue dose to evaluate therapeutic effect of tumor as follows;

$$D_{\mathrm{Background}} = \mathrm{RBE_n} \cdot D_{\mathrm{n}} + \mathrm{RBE_p} \cdot D_{\mathrm{p}} + \mathrm{RBE}_{\gamma} \cdot D_{\gamma} \qquad (1)$$

$$D_{\text{Tissue}} = D_{\text{Background}} + \text{RBE}_{\text{b}} \cdot D_{\text{b, Tissue}} \quad (2)$$

$$D_{\text{Tumor}} = D_{\text{Background}} + \text{RBE}_{\text{b}} \cdot D_{\text{b, Tumor}} \quad (3)$$

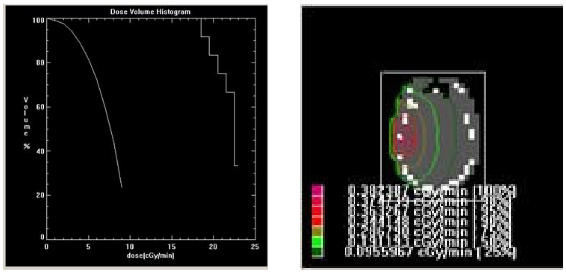
where

$D_{\text{n}}$, $D_{\text{p}}$, and $D_{\gamma}$ = neutron, proton, and gamma doses,

$D_{\text{b, Tissue}}$ and $D_{\text{b, Tumor}}$ = boron doses in tissue and tumor.

### *2.3 Data Analysis*

BTPS converts the results of dose calculation into various indicators widely used in the field of radiation oncology such as dose mapping, dose profile, isodose contour, and DVH (Dose Volume Histogram), to judge therapeutic effect and treatment plan of BNCT. BTPS can also display these indicators in coronal, sagittal, and lateral to show the performance of incident neutron beam. Especially, DVH and isodose contour, as shown in Figure 3, are critical to judge the treatment plan of radiation therapy. A dose mapping for each dose component, including tumor and tissue dose, can be saved after being converted into a text file.



(a) DVH (b) Isodose Contour

Figure 3. Examples of DVH and Isodose Contour in BTPS

## 3. Performance of BTPS

Because the computation time of conventional TPSs using Monte Carlo technique is still relatively large in spite of the development of faster computers, it is very important to reduce the computation time with obtaining a reasonable accuracy.

In order to assess the performance of dose calculation in BTPS improved from the conventional TPS calculation in voxel phantoms using MCNP, the two calculations were carried out using the same head phantom. The phantom was made from a VHP image set using BTPS and consisted of 9×9×9 $\text{mm}^3$ voxels (6233 cells). The epithermal neutron beam for accelerator-based BNCT developed in Hanyang University[3] was used as a neutron beam. These calculations were performed with the same history of $10^5$ in a parallel computing system with 49 nodes (Pentium IV 3.2GHz).

The calculation results of neutron fluxes that are converted into the dose components are summarized and compared in Table 1. In the table, the statistical errors represent RMS (Root Mean Square) values of the error bounds associated with one standard deviation in Monte Carlo calculation.

The results of conventional TPS and BTPS calculations were in good agreement each other with nearly no difference in RMS. The conventional MCNP calculation with the statistical RMS error of 3.08% required a computation time of 340 minutes. However, the BTPS calculation with smaller statistical RMS error needed only 5.35 minutes. In the result, BTPS can provide dose calculation results about 60 times faster than the conventional MCNP calculation.

Table 1. Dose Calculation Results

| | Conventional TPS | BTPS |
|---|---|---|
| Statistical Error in RMS [%] | 3.08 | 2.17 |
| Computation Time [min] | 340 | 5.35 |
| Difference [a] in RMS [%] | - | < 0.001 |

[a] (MCNP-BTPS)/MCNP

## 4. Conclusion

BTPS which was firstly developed in Korea can construct 3D voxel phantoms using CT images from patients, calculate dose components for BNCT using MCNPX, and also provide various indicators for judgment of treatment plan in BNCT. Especially, it shows a good performance of the notably reduced computation time compared with the conventional TPS using MCNP.

In the present, BTPS is used to evaluate therapeutic effect of the epithermal neutron beam for accelerator-based BNCT in Hanyang University.

Further development efforts will include the improvement of interface and database suitable to management of patient treatment on the BTPS. More improvements in convenience and performance of dose calculation are expected to lead BTPS to the application to clinical trials.

## Acknowledgement

This work was supported the SRC/ERC program (R11-2000-067-01001-0) and the long-term research and development program (M20505050003-05A0905-00310) of MOST/KOSEF.

## REFERENCES

[1] J. K. Kim, et al., Core Technology Development for Accelerator-Based BNCT, iTRS/TR-2005-04, Korea Ministry of Science & Technology, 2005.

[2] S. H. Park, C. Y. Han, S. Y. Kim, and J. K. Kim, Use of the CT Images for BNCT Calculation: Development of BNCT Treatment Planning System and Its Applications to Dose Calculation for VOXEL Phantoms, Radiation Protection Dosimetry, Vol. 110, 661-667, 2004.

[3] D. Lee, C. Y. Han, J. K. Kim, and B.-C. Na, Spectrum Shaping of Epithermal Neutron Beam for Accelerator-Based BNCT and Dosimetric Evaluation Using a Brain Phantom, Journal of Nuclear Science and Technology, Supplement 4, pp. 180-183, 2004.