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An In-Phantom Comparison of Neutron Fields for BNCT

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1.0 Introduction

Previously, we have developed the in-phantom neutron field assessment parameters T and D_{Tumor} for the evaluation of epithermal neutron fields for use in BNCT[1]. These parameters are based on an energy-spectrum-dependent neutron normal-tissue RBE[2] and the treatment planning methodology of Gahbauer and his co-workers[3], which includes the effects of dose fractionation.

In this paper, these neutron field assessment parameters were applied to The Ohio State University (OSU) design of an Accelerator-Based Neutron Source (ABNS) (hereafter called the OSU-ABNS) and the Brookhaven Medical Research Reactor (BMRR) epithermal neutron beam (hereafter called the BMRR-ENB), in order to judge the suitability of the OSU-ABNS for BNCT. The BMRR-ENB was chosen as the basis for comparison because it is presently being used in human clinical trials of BNCT[4] and because it is the standard to which other neutron beams are most often compared.

2.0 Methods

The neutron field assessment parameter T, the treatment time, is defined as the total time, including all treatment fractions, required to escalate the normal tissue RBE-dose to the tolerance of the normal brain. The neutron field assessment parameter D_{Tumor}, the high-LET absorbed-dose to the tumor, is the product of the high-LET absorbed-dose rate at the tumor location and the treatment time. These parameters are described in reference 1.

3.0 Analysis

These neutron field assessment parameters were calculated in a 14x14x14 cm^3 Lucite cube phantom located in the irradiation port of each facility. Calculation of T and D_{Tumor} required values for the neutron absorbed dose rate, $\dot{D}_n$, the gamma-ray absorbed-dose rate, $\dot{D}_\gamma$, the specific (*per ppm of* ^{10}B) boron absorbed-dose rate, $\dot{d}_B$, and $\overline{RBE(E_n)_{norm}}$. The OSU-ABNS design is described in reference 1. Values for $\dot{D}_n$, $\dot{D}_\gamma$, $\dot{d}_B$ and $\overline{RBE(E_n)_{norm}}$ as a function of depth in the phantom were calculated using the Monte-Carlo radiation transport code, MCNP4A[5]. The BMRR-ENB is described in reference 6. Values of $\dot{D}_n$, $\dot{D}_\gamma$, $\dot{d}_B$ and $\overline{RBE(E_n)_{norm}}$ as a function of depth in the phantom were calculated for the BMRR using Monte-Carlo based treatment planning software[7]. For both the OSU-ABNS and the BMRR-ENB, the calculated

values of $\dot{D}_n$, $\dot{D}_\gamma$, $\dot{d}_B$ and $\overline{RBE(E_n)_{norm}}$ were fit with curves and the resulting curve fits were used to calculate T and D_{Tumor}.

The evaluation of T and D_{Tumor} requires that some assumptions be made regarding the fractionation scheme and the Estimated Tolerance Dose (ETD) for brain for low-LET ($ETDL_m$) and high-LET ($ETDH_m$) radiation delivered in m fractions. For this analysis, we have assumed that the patient is treated with four fractions (m=4), in five days. According to Gahbauer[8], for treatment with four fractions in five days, $ETDL_4$ = 2300 cGy and $ETDH_4$ = 1000 cGy. Also, according to Gahbauer, for treatment with one fraction, $ETDL_1$ = 1200 cGy and $ETDH_1$ = 600 cGy.

The evaluation of T and D_{Tumor} also requires that some assumptions be made about boron concentrations and localizations. For this analysis we have assumed that the ^{10}B concentration in blood in ppm, [B], equals 30 ppm and that the ratio of ^{10}B concentration in tumor to ^{10}B concentration in blood, $R_{t/b}$, equals 1.3, values which are typical for the B-10 delivery agent BSH[9]. Also, according to a recent evaluation of the BMRR dog data, it was assumed that for BSH the product of the RBE and the compound factor (CF) for the boron absorbed dose ($RBE_B \cdot CF$) is 0.27 for the endpoint of late changes in the magnetic resonance images[10].

4.0 Results

For the calculated absorbed dose rate distributions and with the above assumptions regarding fractionation, tolerances, RBEs, compound factors and boron concentrations, the calculated treatment times (T) were T = 117 minutes for the OSU-ABNS, with a thick Li target and operating at a beam current of 10 mA, and T = 91 minutes for the BMRR-ENB, with the BMRR operating at a reactor power of 3 MW. The corresponding treatment times per fraction were 29 minutes for the OSU-ABNS and 23 minutes for the BMRR-ENB, for a four fraction treatment scheme.

Curves of D_{Tumor} versus tumor depth along the phantom centerline are presented in Figure 1. These curves indicate that the quality of the neutron fields for the OSU-ABNS and BMRR-ENB are comparable. The curves are very similar, with D_{Tumor} slightly larger for the BMRR-ENB for tumor depths ranging from approximately 1 to 4.5 cm, and D_{Tumor} slightly larger for the OSU-ABNS for the other tumor depths.

On the basis of comparison of the calculated values of the in-phantom neutron field assessment parameters, T and D_{Tumor}, for the OSU-ABNS with those for the BMRR-ENB, the neutron field for the OSU-ABNS is judged to be acceptable. The larger value of D_{Tumor} at depth for the OSU-ABNS should not be viewed as indicating that the OSU-ABNS beam has superior beam quality. Rather, it should be viewed as a consequence of the fact that the OSU-ABNS and the BMRR-ENB were compared using the parameters with which the OSU-ABNS was optimized.

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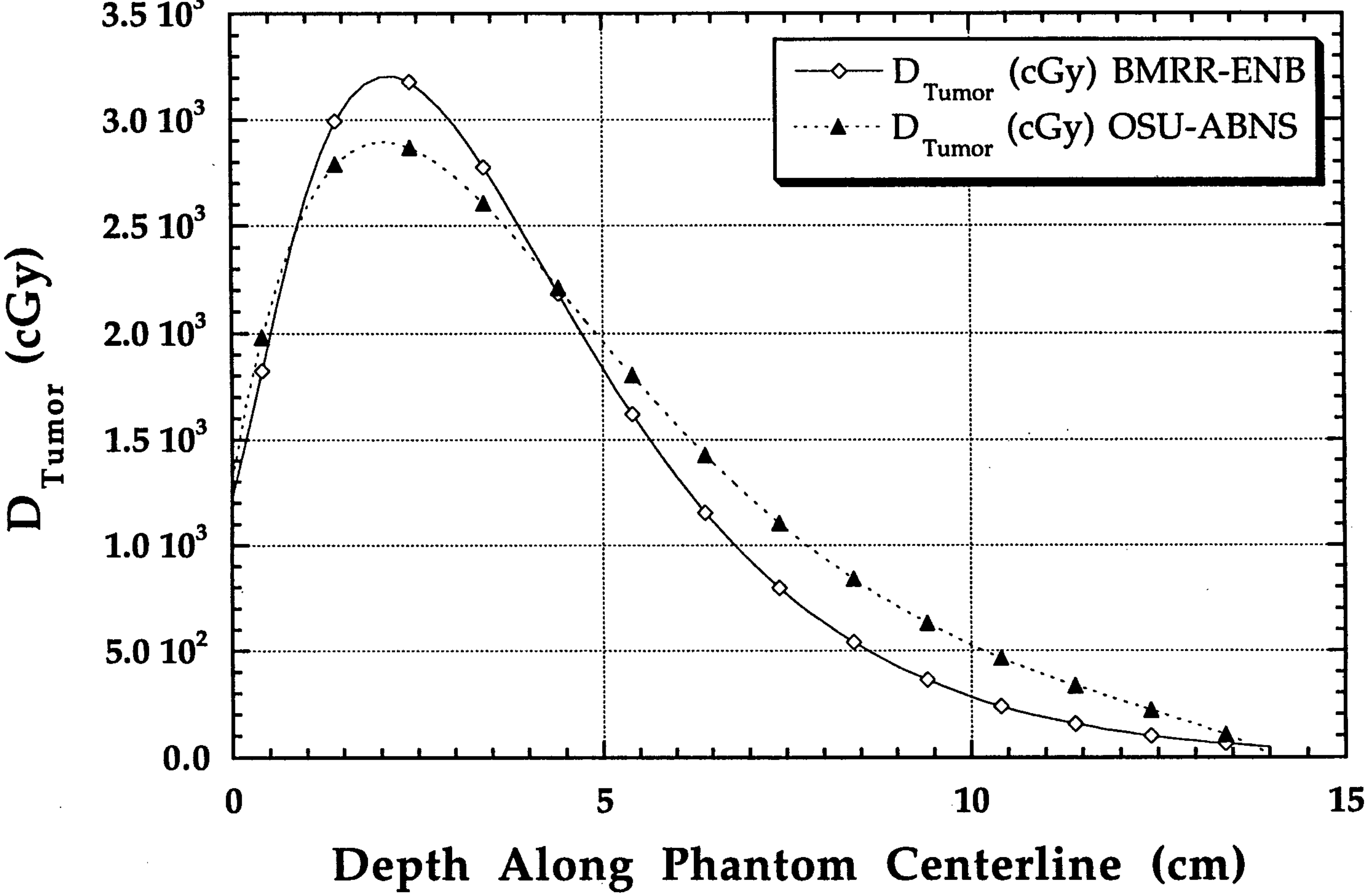
FIGURE CAPTIONS

Fig. 1. Calculated curves of D_{Tumor} vs. depth along the centerline of a Lucite cube phantom for the BMRR-ENB and the OSU-ABNS.

D_{Tumor} vs. Depth Along the Centerline of a Lucite Cube Phantom



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