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SOME RECENT DEVELOPMENTS IN TREATMENT PLANNING SOFTWARE AND METHODOLOGY FOR BNCT

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David W. Nigg, Floyd J. Wheeler, Daniel E. Wessol, Charles A. Wemple
Idaho National Engineering Laboratory, P.O. Box 1625, Idaho Falls, Idaho, USA 83415

Ray Babcock
Montana State University, Bozeman, Montana, USA 59715

Jacek Capala
Brookhaven National Laboratory, Upton, NY 11973, USA

Over the past several years the Idaho National Engineering Laboratory (INEL) has led the development [1-3] of a unique, internationally-recognized set of software modules (BNCT_rtpe) for computional dosimetry and treatment planning for Boron Neutron Capture Therapy (BNCT). The computational capability represented by this software is essential to the proper administration of all forms of radiotherapy for cancer. Such software addresses the need to perform pretreatment computation and optimization of the radiation dose distribution in the target volume. This permits the achievement of the optimal therapeutic ratio (tumor dose relative to critical normal tissue dose) for each individual patient via a systematic procedure for specifying the appropriate irradiation parameters to be employed for a given treatment. These parameters include angle of therapy beam incidence, beam aperture and shape, and beam intensity as a function of position across the beam front. The INEL software is used for treatment planning in the current series of human glioma trials [4] at Brookhaven National Laboratory (BNL) and has also been licensed for research and developmental purposes to several other BNCT research centers in the US and in Europe.

Reconstruction of patient geometry from medical images in BNCT_rtpe is based on the calculation of free-form non-uniform rational B-spline (NURB) surfaces fitted to the various tissue compartments (or any desired subcompartments) of interest. With this method, one first outlines the regions of interest (e.g., skin, skull, brain, target volume, etc.) on each computer-displayed medical image plane. This may be done either manually or in some cases automatically via edge detection algorithms. Figure 1 shows an axial Magnetic Resonance Image (MRI) scan of a glioma patient. In this case the normal anatomical regions as well as the tumor region and a 2-cm margin defining the target volume are outlined on the image planes. Several new features are available for medical image input, manipulation, and display. Additional MR and Computed Tomography (CT) image format translation capabilities are incorporated as needed in response to client requirements. New image colormap, contrast, and brightness tools have been developed along with a vertically and horizontally scrollable image container window.

Once the region outlines for all image slices are established, these representations are then mathematically combined to produce detailed equations describing the 3-D surfaces that enclose each volume of interest. The surface equations generated in the B-spline region reconstructions, in conjunction with appropriate region material descriptions, completely describe the problem and are subsequently used in a Monte Carlo radiation transport calculation performed by a specialized module incorporated into BNCT-rtpe. The ray-trace algorithm for the Monte Carlo calculation is based on searching nested hierarchies of bounding volumes enclosing the points of intersection of particles (neutrons or photons) with each reconstructed geometric NURBS surface describing a particular compartment of the patient anatomy. The spline surfaces can be combined with geometric primitive surfaces to further specify the calculational geometry, if needed. Any type of tomographic medical image data can be input to BNCT_rtpe. The radiation transport computational module within BNCT_rtpe will also accept parallelpiped arrays constructed using the so-called "voxel reconstruction" technique [5], if desired.

Figure 2 illustrates some typical computed total physical dose contours registered on the original MR image of Figure 1, which was used to construct the computational model. These results are based on the assumption that the patient is treated using the Brookhaven Medical Research Reactor (BMRR) epithermal-neutron beam as it was configured at the initiation of human studies in September, 1994. In the display the boron concentration is assumed to be 15 parts per million (ppm), uniformly distributed throughout the brain. The contours are thus representative of what would be seen by the normal tissue. The total dose includes the boron dose at 15 ppm as well as the contributions from the fast neutron component of the beam, the incident and capture photon components, the nitrogen component, as well as a fifth component that includes a few other small contributions from various other neutron interactions. The 100% contour corresponds to approximately 9.1 cGy per minute per megawatt of BMRR reactor power. Although BPA-f is typically present in the normal brain at about the same concentration as in the blood, this agent tends to concentrate in the malignant tissue at a level that is roughly 3-4 times the blood concentration for most patients. Thus the tumor dose includes all of the background components as well as a significantly higher boron dose corresponding to the higher tumor boron concentration. The tumor dose contours can also be displayed since the actual treatment plan is based on tumor dose, constrained by normal tissue tolerance, just as in photon therapy. Dose-volume histograms for each defined volume of interest can also be constructed as needed.

Efforts to include much faster, albeit approximate, dose computation methods in BNCT_rtpe are underway. An algorithm based on multidimensional parameter fitting from precomputed kernel functions (closely-related to the so-called "pencil-beam" methods) has been incorporated and has proven to be quite effective for use in dose optimization studies prior to performing a Monte Carlo calculation for the final optimized plan for each patient. This capability should prove to be especially useful as clinical application of BNCT moves into the more complicated realm of multi-port irradiations. In addition, an informal collaboration has been established with The Ohio State University to explore the utility of incorporating a computational option based on removal-diffusion theory [6]. Finally, it may be noted that the basic physics modules have been significantly upgraded to allow incident

neutron energies up to about 100 MeV, with an explicit treatment of recoil proton transport, expanding the utility of this software into the field of fast neutron radiotherapy, with or without BNCT augmentation.

Acknowledgements

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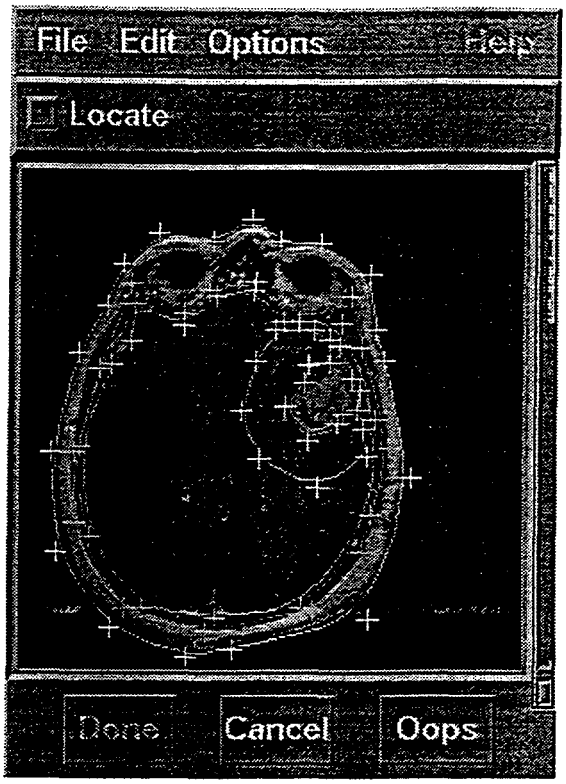
Figure Legends

1. Axial magnetic image image of a glioma patient showing the outlines constructed by BNCT_RTPE for the various regions of interest, including the tumor and target regions.

2. Typical total physical absorbed dose contours in normal tissue that would be produced by the BMRR epithermal-neutron beam for a human glioma patient with a uniform brain-boron concentration of 15 ppm. The 100% dose contour corresponds to approximately 9.1 cGy/min per MW of BMRR power.



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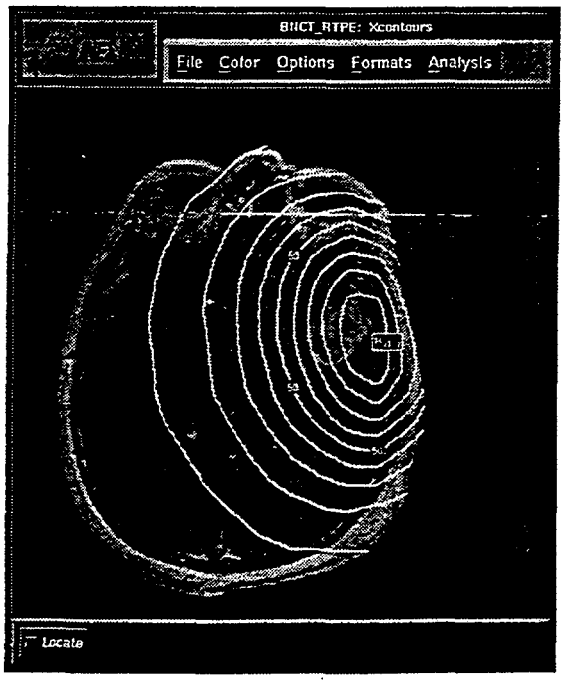
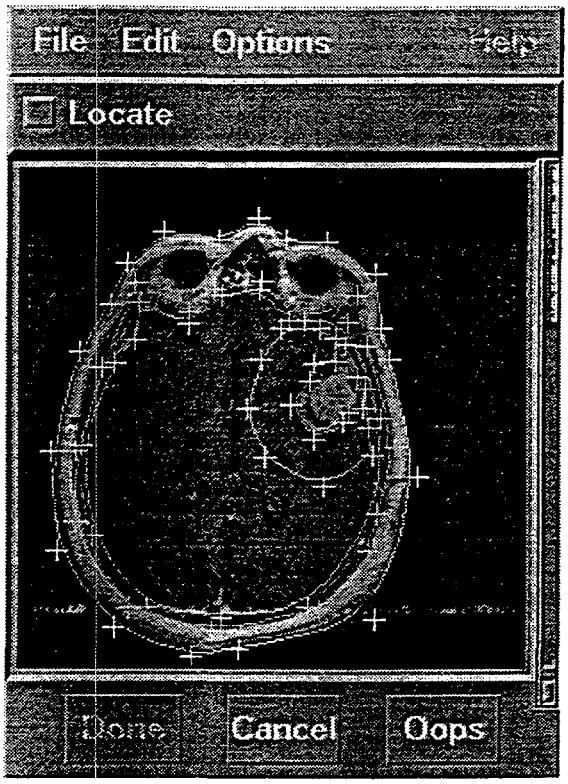


Figure 2. Typical total physical absorbed dose contours in normal tissue that would be produced by the BMRR epithermal-neutron beam for a human glioma patient with a uniform brain-boron concentration of 15 ppm. The 100% dose contour corresponds to approximately 9.1 cGy/min per MW of BMRR power.



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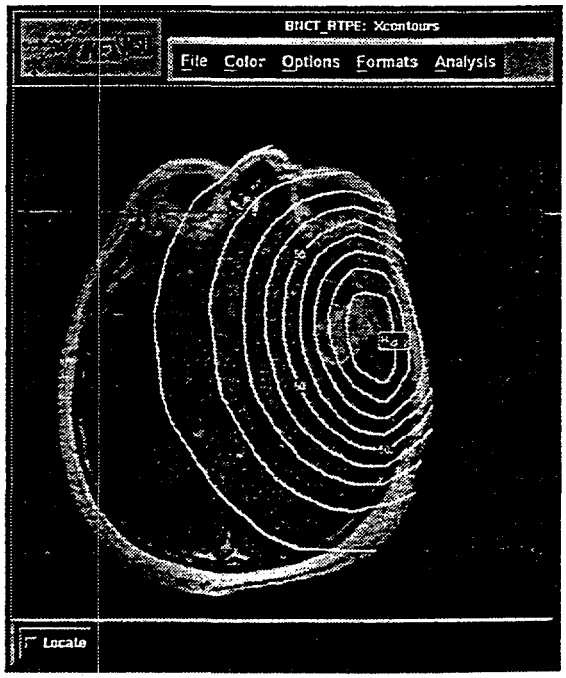

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