Experimental Verification of Neutron Beam Modeling for the LBNL Accelerator-based BNCT Facility

D.L. Bleuel, W.T. Chu, R.J. Donahue, B.A. Ludewigt,
R.J. McDonald, L.W. Phair, A.R. Smith, and G.J. Wozniak

Boron Neutron Capture Therapy (BNCT) is a binary cancer treatment modality in which a drug containing ^{10}B is administered to a patient who is subsequently irradiated with an epithermal neutron beam. Existing studies use reactors as the source of neutrons. The primary cancers being studied for BNCT are glioblastoma multiforme as well as other head and neck cancers and certain melanomas. The ^{10}B-laced drug is preferentially absorbed into cancer cells, leading to a higher concentration in the cancer cells compared to that of the healthy tissue cells. The patient is irradiated by an epithermal neutron beam which, after further moderation in the patient, becomes a thermal distribution in the vicinity of the tumor. The thermal neutrons are captured by the ^{10}B, which has a very high capture cross-section, producing two energetic particles: ^{4}He and ^{7}Li nuclei. These particles have ranges on the order of the size of a cell, and thus deliver nearly all their energy to the cancer cell within which the ^{10}B resides.

An accelerator-based BNCT program is under development at LBNL utilizing the $^{7}Li(p,n)^{7}Be$ reaction at 2.5 MeV. Besides being better suited to a hospital environment, the accelerator-produced neutron spectrum is expected to more effectively distribute the thermal neutron fluence at pertinent depths, particularly in the midbrain. A large effort in modeling, utilizing the MCNP Monte Carlo Program from Los Alamos, has been performed at LBNL to study the $^{7}Li(p,n)$ reaction for various moderator designs. Recently, low-intensity experiments were performed at the 88-Inch Cyclotron to determine the accuracy of these calculations. Although the cyclotron beam is 10000 times less intense than that of a planned treatment facility, it is sufficient to activate Au foils for off-line counting at the LBNL Low-Background Facilities.

Beams of ≈ 5 pμA of protons impinged on a 100 μm thick natural Li target producing neutrons. These neutrons traveled through a Fluental (AlF_3 + Al + LiF) and Teflon moderator to impinge on a Lucite phantom with imbedded Au dosimetry foils. The moderator was surrounded by Pb as a reflector. This arrangement concentrated the neutrons into a narrow spectrum at about 20 keV. Compared to the spectrum from a reactor, centered at about 20 eV, this beam is capable of producing high tumor doses at the center of the brain, which is the hardest point to treat. Preliminary studies indicate a 60% improvement over reactor neutrons for the thermal fluence at midbrain.

Thin Au foils, ≈ 0.5 g each, were distributed in the phantom and exposed for approximately 1 hr. This provided sufficient activity to accurately determine the neutron dose to the foil by counting the ^{198}Au 411 keV gamma rays on a large NaI spectrometer at the LBNL Low-Background Facilities.

In between experiments, a Ge spectrometer was used to measure the 478 keV gamma ray from the ^{7}Be decay in the production target. Since one ^{7}Be atom is produced for each neutron produced, a measure of the number of ^{7}Be atoms gives a measure of the absolute number of neutrons produced. Thus , the ^{7}Be measurement gives the input number of neutrons for the MCNP calculation, and the activation of the Au foils gives the results. At present, the MCNP calculation correctly predicts the depth at which the neutron fluence peaks, but over estimates the fluence by about 30%, depending on how one treats reflections from the walls.

Although the discrepancy between the experiment and calculation is not yet understood, it is clear that these low-intensity experiments are capable of providing direct experimental numbers to compare with calculations, well within limits of the cyclotron and counting systems. Future experiments will provide systematic studies of the reaction and the moderator, to optimize BNCT treatments.