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Neutron-gamma mixed field dosimetry on a child phantom under therapeutic proton irradiation using TL dosimeters

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Introduction:

During proton therapy energetic proton beams deliver a highly conformal dose to the primary tumor mass; thereby, reducing unwanted radiation exposure to the neighboring healthy tissue. These unique characteristics provide significant therapeutic advantages in comparison to the well-established photon-therapy. However, a significant number of secondary particles, predominantly fast neutrons and gamma-rays, are produced by the interaction of the main proton beam with the beam shaping and modifying devices located inside the beam delivery nozzle as well as from the irradiated volume itself. This results in an unwanted increase in radiation exposure of sensitive organs located outside of the treated volume, thereby increasing the risk of second cancer incidence. Children are more vulnerable to 2nd cancer risk than adults due to longer life expectancy, shorter distance between organ at risk and primary radiation source and higher cell differentiation rate of organ tissues of interest. This paper presents the application of twin-TLD (TLD-500 and TLD-700) dosimetry technique developed at WPE for in-situ estimation of the out-of-field neutron and gamma dose equivalents. The TLD pairs were placed on selected organ locations of an anthropomorphic phantom while a simulated 125 cm³ skull based tumor was irradiated with protons in uniform scanning (US) mode. A prescribed dose of 2 Gy in a single fraction was delivered in three fields. The results and dosimetry protocol from this benchmark experiment could be used to estimate the neutron and gamma dose equivalents during proton irradiation of a child phantom, emulating a pediatric cancer patient.

Methods:

Commonly used TLD-700 (7LiF:Ti,Mg) dosimeters are highly sensitive to gamma rays. On the other hand, the high-temperature region (HTP) of the TL-glow curve of TLD-700 is also responsive to fast neutrons, however, contaminated with gamma background. Hence, a method to eliminate the gamma background of the HTP region using primarily gamma sensitive TLD-500 (Al₂O₃:C) dosimeters has been developed. A polystyrene plate phantom (20 cm x 20 cm x 30 cm) was bombarded with 170 MeV protons to produce high-energy neutrons of similar energy distribution like neutrons generated during proton treatment of tumors. A Wide Energy Neutron Detection Instrument WENDI 2 (capable for dose equivalent estimation of neutrons from thermal to 5 GeV energies) was used to cross calibrate the TLD chips. The TLD chips were evaluated using a hospital based TLD reader and annealed thereafter. The annealed pairs of TLD-500 and TLD-700 chips were attached to the location of Left/Right Eye, Thyroid, Left/Right Lungs, Stomach and Gonad of the child phantom. A simulated skull-base tumor (125 cm³) was irradiated with a single fraction 2 Gy proton dose.

Results:

The gamma background correction factor (kG), gamma (fG) and neutron (fN) dose equivalent conversion factors are given as:

$$kG = \text{TLD700AHTP} / \text{TLD500AMP} \quad (1)$$

$$fG \text{ (mSv/nC)} = \text{calibHG} / \text{TLD700AMP} \quad (2)$$

$$fN \text{ (mSv/nC)} = \text{calibHN} / (\text{TLD700AHTP} - kG \times \text{TLD500AMP}) \quad (3)$$

Where, TLD700AHTP and TLD500AMP are the high-temperature peak of TLD-700 and main peak of TLD-500 chips respectively. Furthermore, calibHG and calibHN are the calibration gamma and neutron doses delivered to TLD-500 and TLD-700 chips respectively.

By substituting the numerical values in equations 1, 2 and 3 the gamma (fG) and neutron (fN) dose equivalent calibration factors were evaluated to be 1.68×10^{-5} and 1.22×10^{-4} mSv/nC respectively.

The organ specific out-of-field gamma (OrganHG/DP) and neutron (OrganHN/DP) dose equivalent per delivered proton dose (DP) were calculated as follows:

$$\text{OrganHG/DP (mSv/Gy)} = fG \times \text{TLD700AMP} \quad (4)$$

$$\text{OrganHN/DP (mSv/Gy)} = fN \times (\text{TLD700AHTP} - kG \times \text{TLD500AMP}) \quad (5)$$

Using the TLD readings the organ specific gamma and neutron dose equivalents were estimated explicitly and the results are depicted in Figure 1.

Conclusion:

During proton therapy predominantly high-energy neutrons with energies up to excess of 100 MeV prevail outside the treatment volume. These high-energy neutrons essentially contribute to risk of second cancer at out-of-field organs. The risk is higher in child patients due their smaller physical size and longer life expectancy. The twin-TLD method for explicit estimation of out of field gamma and neutron dose equivalents requires a common hospital/clinic based TLD reader and an annealing oven. Technicians can conveniently sterilize the tiny dosimeter holders sealed in pouches prior to routine clinical applications. The technique is ideally suited for dosimetry procedures where high spatial resolution (i.e. small detector size) and direction-independence of detector response are required, in particular for pediatric proton therapy cases. At West German Proton Therapy Center Essen (WPE) the results of these benchmark measurements have already been implemented to study the second cancer risk of pediatric patients of various cancer indications, ages and genders.

Country

GERMANY

Institution

WPE-UK Essen and IBA Medical Accelerator Solutions

Primary author: MUKHERJEE, Bhaskar

Co-authors: FUENTES, Carolina (Clinical Solutions Manager, IBA Group); MARES, Vladimir (Research Scientist, Helmholtzzentrum Muenchen)

Presenter: MUKHERJEE, Bhaskar

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