Possibility of using a plastic scintillator detector system for quality assurance in proton therapy

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Introduction

• In 1946, Robert Wilson proposed for the first time to use protons for radiotherapy.

• But after 50 years proton therapy still has not become widely available.
  • the cost of a proton accelerator
  • proton therapy was proposed at the same time when megavoltage X-ray therapy was considered, and physicians were already acquainted with X-rays.

• Nowadays, there is a steep rise in clinical research and experience because protons are highly recommended for specific tumour especially in children.
A 5 years old Ashya King (Post operative radiotherapy)
• Proton therapy requires precise knowledge of dose distribution relative to tumor and other organs.
• Imaging is necessary but not sufficient
• The question:
  • Can we monitor emissions from a proton beam to provide 3D dosimetry?
Motivation

• With the high demand of proton therapy worldwide, most of the detector materials and detector system are currently being re-evaluated for use in proton beams dosimetry.

Aim

• Practical low-cost, easy-to-use system for QA and dosimetry based on 3D volume scintillation material in a clinical setting
Scintillation material ??

- ENERGY IN ➔ LIGHT OUT

• Types of materials that scintillate:

1- Non-organic (e.g. NaI)
   + High Z & high density
   + High light output

2- Organic (e.g. plastics, liquids)
   + Nearly equivalent to water & cheaper
   + Fast response
The choice of the organic scintillator

**Scintillating fibre**

**Liquid Scintillator**
- PMMA container $d = 1.18 \text{ g/cm}^3$
- Glass container $d > 2.5 \text{ g/cm}^3$

**Plastic Scintillator**
• 62 MeV Scanditronix cyclotron provides 60 MeV protons (31 mm in water) to treatment room through double scattering.
The setup of the experiment
• Quenching (i.e. electron de-excites in the scintillator without fluorescence) is a related property especially for organic scintillators.
  • The consequences → non-linearity in energy response
Quenching

- Ideally \( \frac{dL}{dx} = S \frac{dE}{dx} \)
- Birks suggest an equation which could solve the issue of quenching.
  - \( \frac{dL}{dx} = S \frac{dE}{dx} \frac{dE}{1+kBdx} \)
- Plotting various \( E \) vs. \( L \) and from the fit we will have the \( kB \) value by which we could simulate the quenched scintillation light.
Proton dosimetry and quenching correction

- Geant4 simulations were used to generate the energy deposited inside the scintillator along with the scintillation light.
  1. The light profile is scored without applying Birks law.
  2. The light profile is scored with applying Birks law.
Correction for Quenching

- Measure scintillation light output vs. depth
- Plot the LET against light output to find \( k_B \) by fitting Birks equation
- Apply \( k_B \) in simulation to find simulated quenched scintillation vs depth
- Obtain LET vs. depth
- Simulate to find dose and scintillation vs. depth
- Generate a correction to be applied to the measured scintillation distribution
Validating the quenching correction

For the 60 MeV proton beam, the simulated Bragg peak range and the range taken from the corrected measured scintillation both agree with the range measured from the ionisation chamber (black crosses), with 0.2 mm accuracy and 3% accuracy for the peak/plateau ratio.
Dose Linearity

Detector response (%)

Dose (Gy)

Dose Linearity

Dose rate dependency

Dose rate (Gy/min)

Relative dose (%)
Conclusion

• The system has the advantages of providing a 2D view of dose distribution for individual radiation fields, while being fast, directly digital and tissue equivalent.
• The measured depth-dose distributions using this system were lower than those measured with an ionisation chamber due to quenching effect occurring in the scintillator. We have proposed a method for correcting for quenching which shows promising results.
• This low-cost, convenient, clinically achievable system builds upon previous work by using a large plastic scintillator, a commercial camera and a completely numeric technique for quenching correction.
• It can be concluded that the detector system has the potential to be translated for use in quality assurance of clinical proton beams. Future challenges include 3D time-varying data acquisition.
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