Microdosimetric Measurements on the Clatterbridge Proton Therapy Beam

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Abstract

The interpretation of RBE studies relating to proton, neutron and ion beams can be aided by a knowledge of the distribution in LET (or lineal energy) of the incident and recoil particles. In order to provide such information for the Clatterbridge proton therapy beam, a programme of microdosimetric measurements is currently under way. Preliminary measurements using a commercial single-wire proportional counter have been followed by the design and use of a planar microdosimetric detector. Details of the planar detector design are presented here, together with some measurements made with it, and comparisons with equivalent measurements made with a silicon diode dosimeter.

1 Introduction

It is well known that charged particles exhibit a dose with depth profile which sharply rises towards the end of the particle track. It is also of course possibile to focus charged particle beams, and these factors, together with the steep slope of the distal edge, combine to allow a much more localised dose to be delivered than is possible with neutrons. For these reasons protons have been exploited for therapy purposes at many centres[1].

At Clatterbridge, proton therapy began last year using the 62 MeV proton beam and concentrating, because of the relatively low penetration of the beam, on tumors of the eye. To this date 73 patients have been treated at this centre and a randomised trial of this form of treatment against others is about to begin.

Microdosimetry has been applied to charged particle beams by many other groups(2–5), generally using "wall-less" detectors[6]. These detectors are almost always spherical, a fact which derives from the need for an isotropic response to particles incident in any direction and is typical of neutron microdosimetry applications. For proton therapy the incident beam is unidirectional and hence we feel that for certain types of measurements a planar detector is more appropriate. This will be primarily for beams which are narrower than the detector entrance window, as discussed below.

2 Initial Measurements.

An initial set of measurements was performed with a standard Far West Technology LET SW$\frac{1}{2}$ filled to 2μm pressure with methane based tissue-equivalent gas. These were designed to give us an introduction to the general area of proton microdosimetry and revealed a few problems.

The first of these was the simple one of detector positioning which is important for narrow beams crossing a spherical cavity, and the second related to the level of noise in the detector which was too high to allow adequate measurement of the full energy (62MeV) beam.

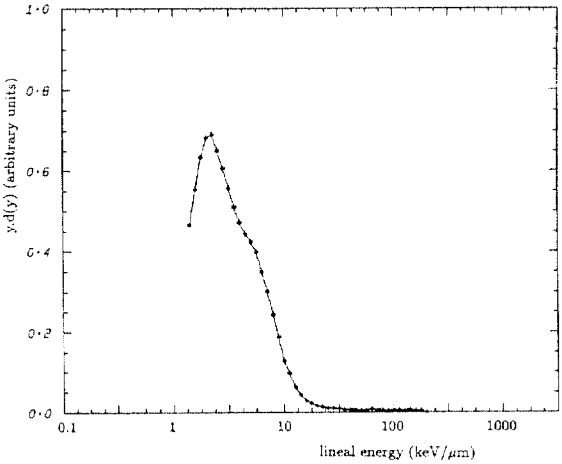

Figure 1: A preliminary measurement of the Clatterbridge beam with the spherical counter.

We were particularly interested in the shape of the y.d(y) curves above the proton edge. Events here must originate in proton reactions with the detector wall materials. Figure 1 shows a typical y.d(y) distribution for a depth equivalent to about 15mm of perspex measured with the Far West detector. Even with this walled counter there are not significant numbers of events above the proton edge, from which we conclude that the proton energy at Clatterbridge is too low to produce the sort of high LET events seen in experiments on the Harvard (160MeV) proton beam[7] This observation does not however preclude the presence of events below the proton edge (140 keV/μm) which are due to particles other than primary protons. These will mostly consist of delta rays and scattered protons produced in the wall, the impact of which are difficult to assess without further measurements.

In conclusion to this section we note that our preliminary experiments gave no reason to suggest that a wall-less counter design was necessary for the work that we intended to do on the Clatterbridge beam.

3 Detector Design and Testing

The general outline of our detector is shown in figure 2. It consists of five 25μm parallel wires 5mm apart to give a total active width of roughly 20mm. The outer pair of wires act as guards to delimit the collecting region with the central wire acting as an anode. It was originally thought that multiple anodes would be required to give a uniform collection efficiency across the full active region and hence the inclusion of an extra pair of wires. This seems not to be the case although further experiments to test the detector are under way.

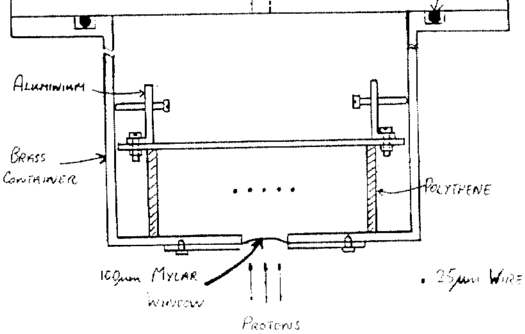

Figure 2: A schematic of the planar detector construction.

The variation in collection efficiency across the detector face was tested at Clatterbridge using a 2mm collimated beam at 3 lateral positions across the detector, and the results are shown in table 1. Normalisation is taken from the integrated beam current falling on the beam central stopper. The d(y) distributions measured at each lateral displacement were identical.

Lateral Displacement (mm)	Relative dose recorded (arbitrary units)
0	23.77±0.5
2	25.19±0.5
4	24.67±0.5

Table 1: Detector uniformity measurement

The maximum collimator diameter used so far in our therapy beam measurements is 5mm and so the primary beam always crosses the detector near its centre and distortions in the detector response due to non-uniform collection will be minimised.

A comparison of the performance of our detector with the commercial one, is shown in figure 3 for a 2mm collimator size. In both cases, these were obtained with +900V on the central anode and used methane based TEG at a pressure of 70mbar for the planar detector and 160mbar for the spherical, to simulate $2\mu m$ of tissue. Measurements were made simultaneously at two amplifier gain settings and combined off-line to give the data presented here. Throughout this paper, different "depths" in perspex are simulated with a perspex wheel which has steps to give variable thicknesses on rotation.

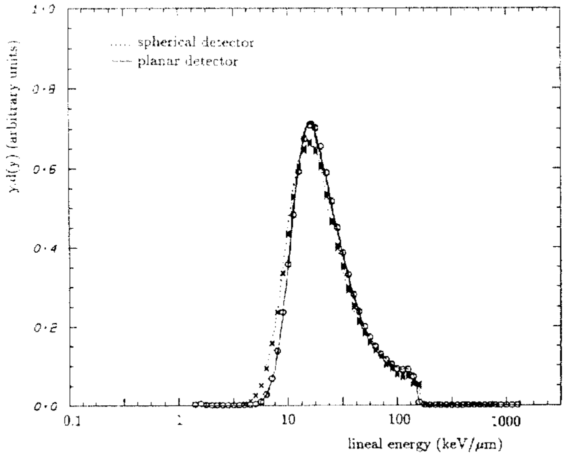

Figure 3: Comparison of the y.d(y) distributions measured at the Bragg peak with two detectors.

The measurements shown in figure 3 were made on the Bragg peak (see below) and are quite similar. The differences between these two curves are believed to be due to differences in the detector characteristics (primarily resolution), rather than different numbers of wall events in each case.

4 Therapy Beam Measurements

4.1 Relative Dose Measurements

As an integral check of our detector performance we have constructed depth/dose profiles for different collimator sizes to compare with those obtained with the Clatterbridge silicon diode dosimeter. This is a 4mm by 4mm by $50\mu m$ Farnell BPW34 silicon diode used for dosimetry purposes in the way reported in the literature[8]. Normalisation is once again taken from the beam central stopper integrated current. A comparison of the two detectors for a collimator diameter of 2mm is shown in figure 4. When correction is made for the layer of material which overlays the diode, the peak and distal edge fall at approximately the same depth for both detectors to within 0.1mm. According to the literature[9] the depth at 90% of the distal edge corresponds to 0.996 of the usually quoted range value for the energy concerned. This gives a range of the Clatterbridge beam in perspex of 27.33mm which agrees well with standard tables.[10]

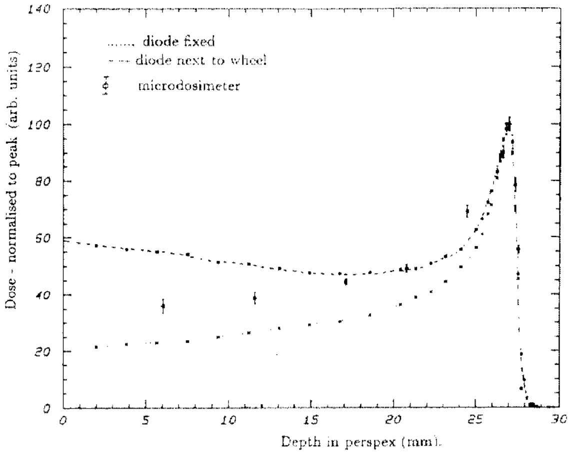

Figure 4: Dose with depth curve for a 2mm collimator diameter as measured with a silicon diode and the planar microdosimetric detector.

This observation has been verified by further measurements with a parallel plate ionisation chamber similar to the one described in reference 11.

The difference in the plateau height in figure 4 is, we believe, explained by the presence of proton scattering in the collimator or the modulating perspex wheel. The diode is much smaller than our microdosimeter, being roughly 4mm by 4mm and hence it would detect a smaller scattered component. This was tested by repeating the diode experiment with it positioned close to the rotating wheel rather than (as above) at a fixed distance from the collimator. A different profile again is obtained as shown by the dashed line in figure 4 and we conclude from these experiments that there is a diverging scattered proton component emerging from the collimator/wheel and that each detector detects an amount which varies with the solid angle that it subtends at the collimator.

We have noted with both microdosimeter and diode measurements, a change in the peak to plateau ratio with collimator size. The trends that we observe are in agreement with calculations reported in the literature[12] although the absolute

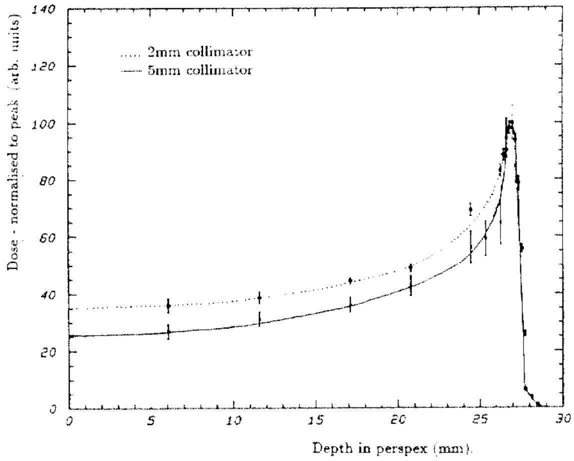

Figure 5: Dose with depth curve measured with the planar microdosimetric detector for 2 and 5mm collimator diameters.

differences seen by us are much smaller than those reported in reference 12. Figure 5 shows our results for 2 and 5 mm diameter collimators. The differences between our measurements and the published data are probably due to differences in the basic parameters describing each situation. Clearly the detector size and position modelled will be important, as will such beam parameters as energy spread and angular divergence. At present we are developing a Monte Carlo code with which we shall repeat the sort of calculations reported in reference 12, using parameters relating to our experiments and the Clatterbridge beam transport system.

4.2 y.d(y) Measurements

Initial measurements have concentrated on small collimator diameters because of the need to avoid high count-rates in the detector. The y.d(y) distributions obtained for a 2mm diameter collimator at four different depths in perspex are shown in figure 6. These curves show clearly the reduced noise-level in the planar detector (measurements go down to 0.3keV/μm). Table 2 shows the change in $\overline{y}_f$ and $\overline{y}_d$[13] with depth in a perspex phantom for different positions. The quoted errors consider only statistical counting uncertainties.

As expected, the most rapid changes in $\overline{y}_d$ occur in the last few mm of the proton tracks. Also in table 2 is the $\overline{y}_d$ value for a ^{22}Na gamma source, measured with a standard spherical neutron microdosimeter at a simulated diameter of 2μm. This can be taken as typical of fast gamma spectra such as ^{60}Co and it can be seen that the $\overline{y}_d$ for the Clatterbridge proton beam ranges from a value which is roughly twice that for fast gammas, to a value which is roughly 25 times.

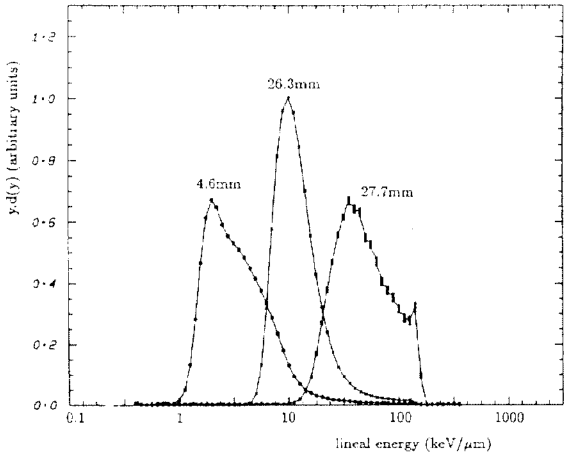

Figure 6: y.d(y) distributions at three depths in perspex measured with the planar microdosimetric detector.

Position (approx.)	Depth in Perspex (mm)	$\overline{y}_f$ (keV/μm)	$\overline{y}_d$ (keV/μm)
PLATEAU	4.58	2.27±0.002	4.75±0.02
PLATEAU	19.82	3.89±0.003	5.79±0.01
PROXIMAL	26.29	10.80±0.01	14.41±0.03
PEAK	27.03	17.76±0.02	26.21±0.05
50% DISTAL	27.35	25.67±0.04	38.65±0.1
5% DISTAL	27.70	29.1±0.2	53.2±0.5
^{22}Na	–	0.53±0.001	1.92±0.01

Table 2: Dose parameters

It should be expected that, as reported in the literature[14], this change in $\overline{y}_d$ will be accompanied by a change in RBE with depth in phantom.

5 Summary and Conclusions

We have built and tested a planar microdosimetric counter for measurements on the Clatterbridge proton therapy beam. The detector has been used to measure depth/dose profiles that are consistent with those measured with the Clatterbridge silicon diode. The y.d(y) spectra measured at different depths in perspex show clearly the wide range of lineal energies that can be produced with this sort of beam, and provides exciting possibilities for radiobiological studies using this beam.

It is worth noting that the experiments that we have performed so far have used collimation to give proton beams which are much smaller in diameter than the detectors used. This was done primarily to reduce the count-rate in the detector, but with the beam passing through the cavity it means that delta-ray events are not detected separately from proton events. We cannot therefore use our measurements so far to infer the real d(y) distribution that will be seen in bulk tissue from this beam; however, experiments to investigate delta-ray effects are planned.

6 References

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