Progress Report on Proton Dosimetry at NPL

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1 Introduction

With the reduced cost of proton therapy it is becoming a viable alternative to conventional radiotherapy treatments. Several dosimetric issues remain, however, not as well investigated as in x-ray beams and primary standards for proton beam dosimetry do not exist.

A Strategic Research project was performed at NPL with the aim of investigating issues and potential improvements for light-ion dosimetry. The objectives of the project were: a literature survey, testing a number of dosimeters in the proton therapy beam of Clatterbridge Centre of Oncology (CCO), measurement of dose distributions, measurement and calculation of detector perturbations, explore the use of Monte Carlo simulations for the calculation of particle spectra, stopping power ratios and detector perturbation factors. All the work performed in this project, including a literature review of around two hundred papers on proton and light-ion reference dosimetry, is prepared for publication as an internal NPL report [1].

The experience from the Strategic Research project has led to new projects on the development of a primary standard level proton calorimeter and the further investigation of ionisation chamber perturbation factors as well as the conversion of dose to graphite to dose to water and evaluation of interaction data for Monte Carlo simulations.

2 Graphite calorimetry in low-energy protons

Graphite calorimetry measurements were performed with the previously existing portable calorimeter [2] but were problematic due to large heat flows. A prototype of a dedicated small-body portable graphite calorimeter (SPGC) was constructed and tested in the proton beam. Simplified construction details are shown in figure 1. Corrections for heat diffusion were calculated using the finite-element method and corrections for the gap effect were calculated using Monte Carlo simulations. The SPGC response was compared with a set of two plane-parallel and two cylindrical ionisation chambers with absorbed dose calibration factors in ^{60}Co and NPL's 19MeV electron beam traceable to NPL. The average value for w_{air}, the average energy required to produce an ion pair in dry air by protons, derived from these measurements varied between 33.6 J/C and 34.9 J/C, with uncertainties that varied between 1.9% and 2.5% depending on the beam type and the calibration modality. The results have been presented at the ABSDOS2003 workshop [3] and at the World Congress on Medical Physics and Biomedical Engineering 2003 and are published [4].

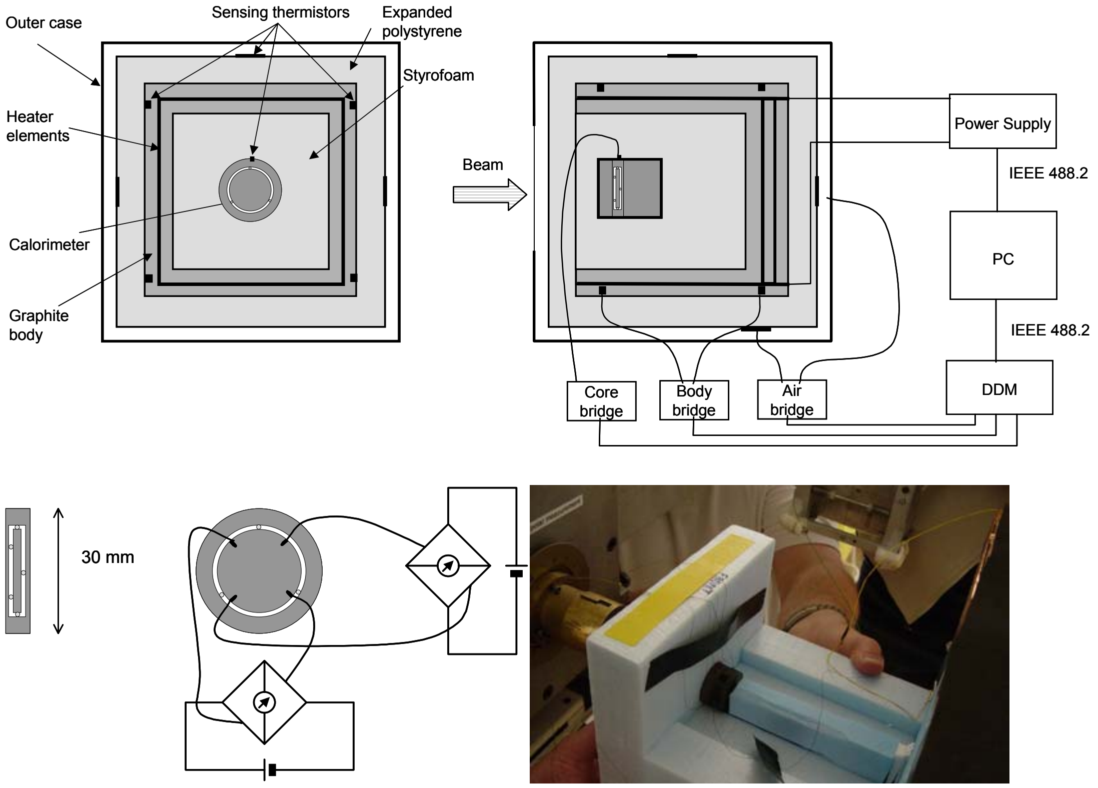

Figure 1. Schematic diagram of the prototype small portable proton graphite calorimeter (top) and its core (bottom left) and a picture during installation at the proton beam line (bottom right, the final collimator of the proton beam line is visible on the left).

2 Ionisation chamber dosimetry

Absolute dose measurements with cylindrical and plane-parallel ionisation chambers in ‘plastic water’, in water and in graphite have been compared, based on two calibration routes: calibrations in ^{60}Co and NPL’s 19MeV electron beam traceable to NPL [5]. The results show that the four ionisation chamber types (NE2561, NACP02, Markus, Roos) perform and agree well in an ocular proton beam. There is, however, a systematic difference in the dosimetry between both calibration routes, which is of concern since for plane-parallel chambers a calibration in electron beams, is generally recommended whereas for cylindrical chambers a calibration in ^{60}Co is generally recommended. With the present information we cannot rule out whether the problem is due to the calibrations or due to the data in the dosimetry protocols and argues for more experimental work in proton ionisation chamber dosimetry.

Perturbation correction factors for ionisation chambers in proton beams are essential for studying the conversion from dose to graphite to dose to water and are also of importance for dosimetry in the presence of gradients such as in a carbon beam and in the measurement of depth dose distributions. Correction factors for the perturbation of the primary proton fluence and the secondary electron fluence have been calculated for all cylindrical ionisation chambers listed in IAEA TRS-398. The effects of the primary proton fluence calculations can entirely be reduced to gradient effects. Perturbations related to secondary electron effects show differences of the level of 1% between chamber types constructed with different wall materials. This indicates that consistency can be improved by taking these perturbation correction factors into account. Correction factors for the perturbation of the secondary proton fluence are at present under investigation.

3 Alanine dosimetry

As in other radiotherapeutic beams, alanine can be used as a potential secondary dosimeter in proton beams. It is known that at low proton energies the dose response of alanine is reduced compared to its response in high-energy photon beams and in the high-energy proton range. A review paper was written on literature data concerning the reduction of the alanine response at low energies [6].

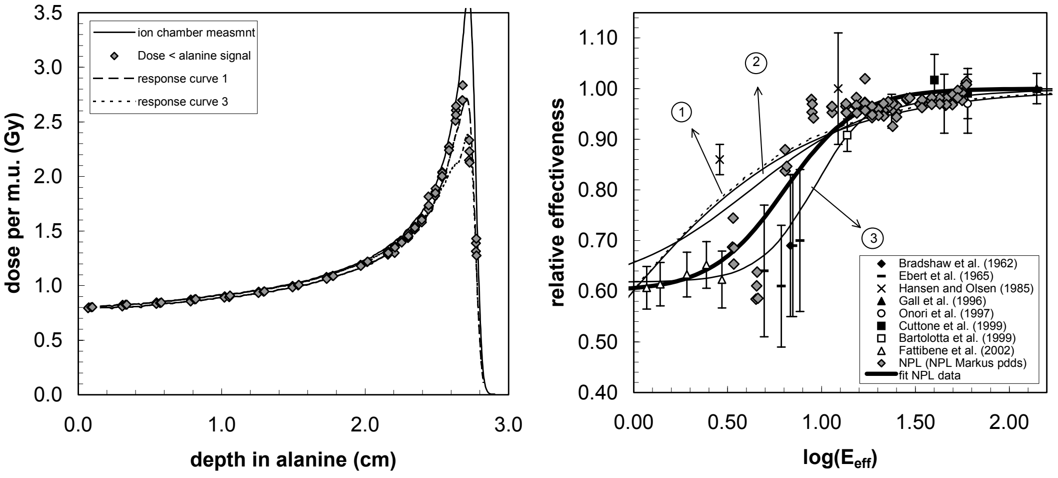

Figure 2. Depth dose curve measured with alanine pellets compared with ionisation chamber measurements and predictions according to two models (left). Derived relative effectiveness of alanine as a function of energy compared with data from the literature and three different models numbered 1 to 3 (right).

Measurements of depth dose curves with alanine pellets in a plastic phantom were performed to derive information on the energy response of alanine. A mono-energetic effective energy, E_{eff}, was assigned to each depth such that the csda range for that energy would equal the residual range. Preliminary results are shown in figure 2.

4 Monte Carlo simulations

Monte Carlo simulations have been initiated using GEANT4, MCNPX, McPTRAN.CAVITY and McPTRAN.RZ (the latter two codes were derived from PTRAN [7]). Simulations have been performed to simulate the CCO beam line, showing a good agreement between MCNPX-results and measurements, whereas GEANT4 and McPTRAN.RZ tend to over predict the Bragg peak by 10% to 15%. Further Monte Carlo simulations were performed to investigate the influence of nonelastic nuclear interactions on depth dose data [8] and for quantifying perturbation correction factors for ionisation chambers and alanine dosimeters.

5 Running projects and ongoing work

In the present programme the development of a primary standard level proton calorimeter is aimed for by the end of 2007. Further investigation of ionisation chamber perturbation factors, the conversion of dose to graphite to dose to water and evaluation of interaction data for Monte Carlo simulations will be conducted.

Acknowledgements

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