Proton beams exhibit better dose characteristics than x-rays for radiotherapy. Proton therapy is not new but has become much cheaper in the last decade. Emerging new accelerator technologies such as laser-induced beams, dielectric wall accelerators and fixed field alternating gradient accelerators promise a further lowering of costs for proton therapy. The NHS has committed £250M for two high-energy proton therapy facilities. In order to make the most out of this modality (highest treatment outcome with minimal side effects) dosimetric accuracy similar to x-ray therapy is required and improved reference dosimetry is needed.

**Key Achievements**

- World's first graphite calorimeter for reference dosimetry of therapeutic proton beams, prospect of world's first primary standard for proton dosimetry.
- Characterisation of alanine as a reference dosimeter and mailed audit tool for proton dosimetry.
- Calculation and measurement of ionisation chamber perturbation factors.
- Developed Monte Carlo simulation capabilities using the PTRAN, MCNPX, GEANT4 and FLUKA codes.
- New research program on novel SQUID-based detector development for microdosimetry of ion beams.

**Aims**

- Establish primary standards for proton dosimetry.
- Improve reference dosimetry.
- Establish correction factors for ionisation chambers.
- Establish energy-response relationships for alanine and radiochromic film and propose procedures to correct measurements with these dosimeters.
- Characterise the water-equivalence of phantom materials and tissue substitutes.
- Define new quantities accounting with the stochastic distribution of energy deposition at the micro- and nano-scale.
- Support dosimetry for proton therapy in UK & abroad.

**Collaborations**

- Clatterbridge Cancer Centre, Wirral, UK
- University of Surrey, Guildford, UK
- University of Birmingham, UK
- University College of London, UK
- University of Liverpool, UK
- University of Århus, Denmark
- University of Stockholm, Sweden
- University of Vienna, Austria
- Université catholique de Louvain, Belgium
- Ion Beam Applications (IBA), Belgium
- German Cancer Research Institute, Heidelberg, Germany
- MedAustron, Wiener Neustadt, Austria
- Slovak Institute of Metrology, Slovakia
- International Atomic Energy Agency, Vienna, Austria

**Advantage of proton therapy**

Below: Blue and green curves show depth dose curves for two opposing beams of a radius (left) and proton spread-out Bragg peaks (right). The sum in red shows that for the same target dose protons deliver much smaller doses outside the target region (delimited by dashed lines).

**Methods**

- Development and characterisation/correction factors, heat transfer, dose to graphite to dose-to-water conversion, graphite calorimeters for proton dosimetry.
- Measurement of relative response of suitable detectors.
- Measurement of energy-response relationships of ionisation chambers on recombination, alanine dosimeters and radiochromic film dosimeters.
- Monte Carlo simulations of beam-maps and beam output.
- Monte Carlo simulations of detector perturbation/correction factors.
- Cavity theory for ionisation chambers.
- Adapting methods for high-dose per pulse regimes (e.g. from laser induced particle beams).
- Design, development and Monte Carlo simulations of SQUID based dosimeters.

**Funding**

- SR-ER project on microbolometry and ROS probes for gold nanoparticles enhanced radiotherapy and SR UoS doctoral.
- NMS.
- EMRP - JRP7, MetrExtRT, BioQuaRT.
- SR-ER project on microbolometry and ROS probes for gold nanoparticles enhanced radiotherapy.
- NIHR i4i projects on microbolometry.

**Publications**

1. A. Lühr, ... H. Palmans, S. Rossomme and N. Bassler, "Fluence correction factors and stopping power ratios for clinical ion beams" Acta Oncol. 50(6) 797-805, 2011.
11. A. Lühr, ... , H. Palmans, S. Rossomme and N. Bassler, "Fluence correction factors and stopping power ratios for clinical ion beams" Acta Oncol. 50(6) 797-805, 2011.
17. A. Lühr, ... , H. Palmans, S. Rossomme and N. Bassler, "Fluence correction factors and stopping power ratios for clinical ion beams" Acta Oncol. 50(6) 797-805, 2011.