The SmartPhantom – A beam profile and dose measuring device.

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Introduction

Radiobiological experiments are important to improve our understanding of the interaction of charged particles with tissue and will lead to improved cancer therapy using particle beams. In order to simulate the effect of irradiating cells at some depth within the body a water phantom is used. The SmartPhantom will significantly improve the way these experiments are done by allowing real time measurements of the dose profile while the biological samples are being irradiated. This is currently not possible using conventional dosimetry methods. Successful testing of the SmartPhantom will deliver a device that will have a big impact on radiobiology experiments, where knowing the dose delivered to the samples is of critical importance, and can improve the way dose calibration is done in clinical particle therapy centres across the World.

For radiobiological experiments, understanding the dose profile is very important in understanding the actual dose received by the biological samples at various depths within the water phantom. Conventional dosimetry methods place detectors at the location of the biological samples to measure the dose. However, this must be done in a separate irradiation to the irradiation of the biological samples and only an integrated dose over the area of the detector can be measured. This means there is an uncertainty in the dose delivered to the cells due to variations in the beam distribution that can occur in the time between dose calibrations. In the case of laser driven ion beams this is a very important issue as there can be orders of magnitude variation from pulse-to-pulse. The SmartPhantom will eliminate this problem by measuring the dose profile in real time as the biological samples are irradiated. By using 250 μm diameter scintillating fibres planes positioned at various depths within the water phantom, in conjunction with detailed simulations, the dose and dose uniformity can be measured. The SmartPhantom will be tested at MedAustron, the Austrian centre for proton and carbon-ion radiotherapy and research, and will enhance their radiobiology programme. This project utilises the expertise within the high-energy physics group in building the MICE scintillating fibre tracker, which was supported by STFC grants ST/P001203/1 and ST/N003357/1, and the development of the SciWire (a low energy ion beam diagnostic device) that was supported by the 2018 STFC IAA grant. Several key aspects of the SmartPhantom builds on the work done for the SciWire including: re-use of the fabrication rigs and procedures; re-use of the fabrication quality assurance equipment; and re-use of the fibre plane radiation source test rig that can be used to measure the response of the fibre plane as a function of position.

The SmartPhantom

Protons and other light ion beams are attractive options for radiotherapy as, unlike conventional x-ray therapy, most of the dose is deposited at the maximum range (i.e. within the Bragg peak) for a given beam energy. This is because the stopping power of a material (or specific ionisation, dE/dx) for charged particles is dependent on the particle energy and increases as the particle slows down. Thus the energy loss peaks at the maximum range of the particle, see Figure 1.

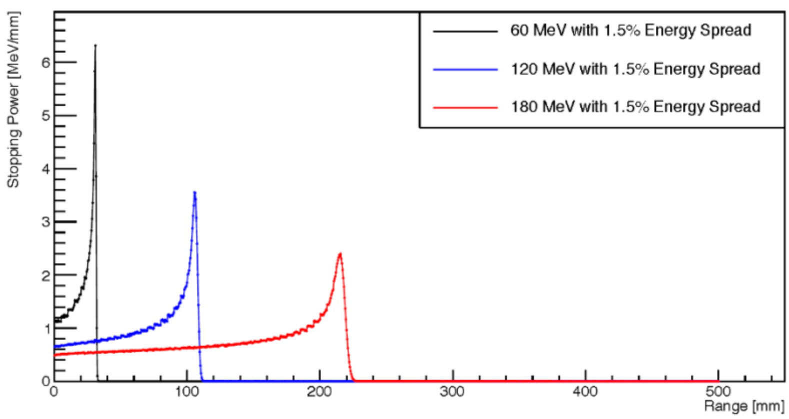

Figure 1: Stopping power of water for 60, 120 and 180 MeV protons. The Bragg peak for each energy shows the maximum range of the particle is dependent on its initial energy.

Experiments to improve our understanding of the radiobiological effect of ion beams use water phantoms to mimic the effect of irradiating a sample that is located deep within the human body. Figure 2 shows a commercially available water phantom that allows the accurate positioning of samples with a volume of water.

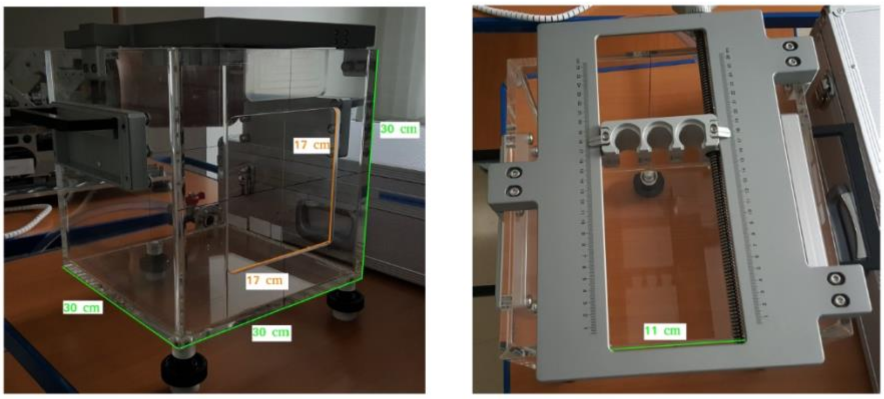

Figure 2: Photographs of a commercially available water phantom.

The SmartPhantom is a water phantom that includes several scintillating fibre stations in front of the sample to be irradiated that will measure energy deposition as a function of position. This can be used in conjunction with simulations to determine the location of the Bragg peak and thus the dose delivered to the cells. Figure 3 shows schematic diagrams of the SmartPhantom. The left panel is the beam's-eye view of the SmartPhantom. The water tank is indicated by the outer solid-green square and the beam window is indicated by the smaller green square. The active area of the scintillating-fibre stations is shown by the shaded rectangle. The direction in which the clear fibre light-guides transport the scintillation light to the photo-sensors is indicated. The orange rectangle indicates the transverse projection of the largest sample flask that will be used with the water phantom. The right panel is the top view of the SmartPhantom. The beam is incident from the left. The water tank is indicated by the green rectangle and the precision support frame located on the water tank is shown in grey. The positions of the five stations are indicated along with the exit routes for the light-guides.

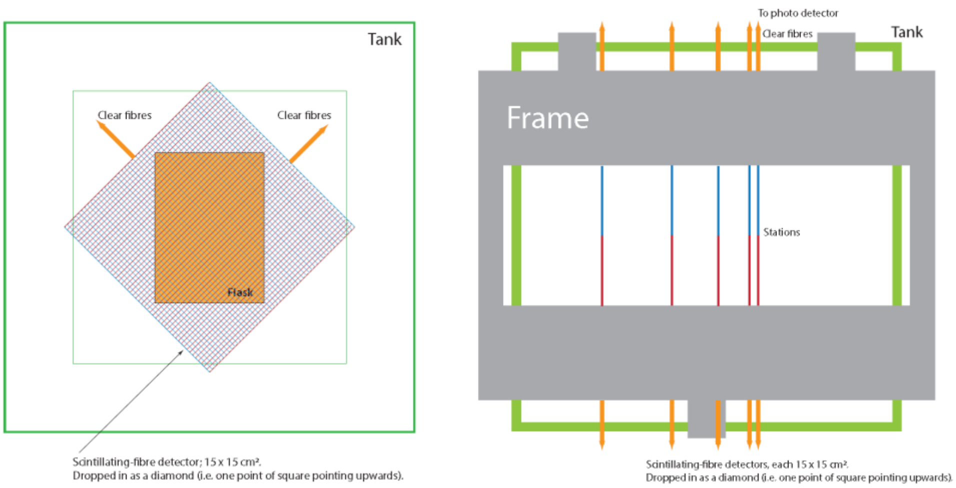

Figure 3: Schematic diagrams of the SmartPhantom. The left panel is the beam's-eye view. The right panel is the top view showing the location of five stations.

These fibre stations will measure the beam intensity profile and energy deposition and, together with simulations, can be used to determine the location of the Bragg peak, thus allowing an accurate determination of the dose delivered to the biological sample. The density of the fibre stations is similar to that of water as the core is made of polystyrene. Thus the shift in the Bragg peak due to the detector material is negligible. Each fibre station consists of two planes of 250 μm diameter fibres at 90 degrees to each other, thus providing x-y intensity profile information about the beam. This means the position of the Bragg peak can be determined for each x-y position, i.e. the dose profile over the area of the sample can be measured with a position resolution better than 250 μm due to the way the fibres are arranged in each layer. Measuring the dose delivered during the irradiation of the biological samples eliminates the uncertainty in the dose due to beam variations. Clear fibres, 750mm in length, will be used to bring the light from the scintillating fibres out of the water to the photo-sensors, digitiser boards and readout located behind the phantom and out of the way of services required by the biological samples.

Objectives and Description of Activities

The key objectives of this proposal and the required activities to deliver these objectives are:

- To construct a fibre station and verify its performance using the manufacturing and testing rig developed for the SciWire.
    - This requires: finalising the fibre layout and support structure; using the SciWire manufacturing rig to construct two planes; assembly of the planes and testing using the test rig developed for the SciWire.
- To construct a five station detector.
    - This requires: finalising the clear fibre coupling and readout design; constructing, assembling and testing eight additional planes; assembling the stations with the clear fibres and readout electronics; and testing the readout.
- To test the SmartPhantom at MedAustron.
    - This requires: transporting the device to MedAustron; installing in the SmartPhantom in the research beam line; commissioning the detector; testing with beam and no biological samples; and testing the SmartPhantom with biological samples.

Deliverables and Milestones

- Constructed and tested first station – **September 2019**.
- Fully assembled five-station detector – **October 2019**.
- Measurements of beam dose profiles with cell irradiation studies at MedAustron – **November 2019**.

Summary and Future Prospects

The requested resources are critical for the deliverables of this project to be achieved. A successful outcome of the tests at MedAustron will enhance their radiobiology programme and demonstrate the suitability of the SmartPhantom for dose calibration at clinical particle beam therapy centres and radiobiology research facilities across the World. The application of this and the viability of a commercial venture will be explored together with options for securing start-up funding.