

Absolute dosimetry of scanned protons with a water calorimeter

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When using ionizing radiation for therapy, the dosimeters have to be traceable to national primary standards. Primary standards for dosimetry exist for photons and electrons, however no direct internationally recognized primary standard exists yet for therapeutic proton beams. This report describes the first results obtained with a water calorimeter exposed to scanned protons in the PROSCAN test area in December 2006.

Dosimetry in proton therapy

In radiotherapy, the absorbed energy in a tissue is defined in terms of the absorbed dose to water D_w (SI units Gy = J/kg). The conventionally used ionizing chambers have to be traceable to a primary standard. A water calorimeter is the preferred primary standard as it measures directly the temperature rise induced by the energy deposited owing to the absorbed dose in water. This approach requires sensitive thermometry as the temperature rise is only 0.238 mK per Gray. In addition, the water has to be ultra pure in order to reduce the major uncertainty of this primary standard: the chemical heat defect owing to irreversible radiochemical processes which will not show up in the temperature rise [1]. METAS has realized a water calorimeter for the Swiss primary standard for therapy dosimeters in conventional high-energy photon therapy [2,3]. As no internationally recognized direct primary standard for D_w in proton therapy exists yet (today the dosimeters used in proton therapy are traceable to Co-60 beam quality with calculated correction factors for protons), PSI and METAS have decided to join efforts in order to realize such a primary standard [4]. Here we report on the first experimental results using a replicate of the standard METAS water calorimeter in the PROSCAN test area in December 2006.

Experimental Setup

The water calorimeter consists of a sealed glass vessel (diameter 6 cm) containing two NTC thermistors (10 k Ω at 4 °C inside a water phantom of 30 cm side length. The water phantom is inside a thermally insulated wooden box

in which cooled air is circulated. The temperature of the water phantom is kept at 4 °C (maximal water density) in order to minimize convection. The water calorimeter has been placed in the PROSCAN test area and homogeneous 3D box dose profiles were deposited in the water phantom. Typically the box was 8 x 8 x 8cm³, centered at a point located 15 cm downstream from the phantom entrance window, the approximate position of the thermistors in the glass vessel. Figure 1 shows schematically the experimental setup.

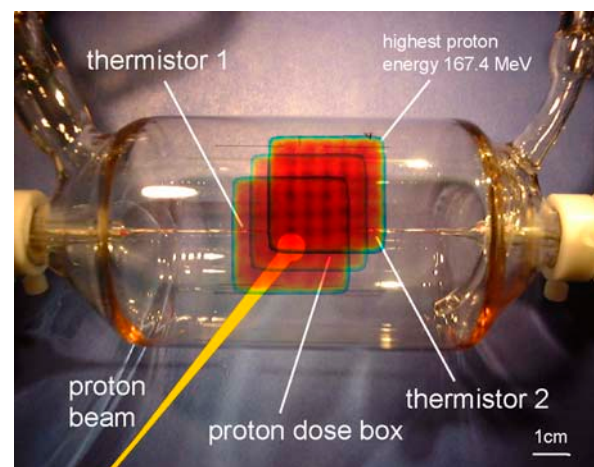


Figure 1: The sealed vessel of the water calorimeter with two thermistors separated by 1 cm. Superimposed is a schematic scanned proton dose profile.

The resistance change of the thermistors owing to the temperature rise induced by the absorbed dose is measured with a Wheatstone bridge and a phase sensitive lock-in amplifier, leading to a temperature sensitivity of 10 μ K.

Experimental Results

Using the spot scanning technique [5], pencil beams with a gaussian width of $\sigma=4.5$ mm were deposited in a plane perpendicular to the beam direction at given water depth determined by the energy of the pencil beam. The distance between the x-y spots in a given water depth was 5 mm. In order to create a homogeneous box with a flat SOBP, the dose of the proton pencil beam corresponding to a given energy plane (water depth) was determined by a calculated weight factor. The distance between the energy planes in the water phantom corresponds to 4.5 mm. Figure 2 shows the individual dose profiles for the 19 energies required to create an 8 cm box with a flat SOBP corresponding to 4.5 Gy. The thermistors recorded a temperature rise for dose deposition of the first six energy planes. No signal was seen for protons with an energy of 153.38 MeV, corresponding to a Bragg peak maximum at 16.4 cm. This indicates that the geometrical 3D dose profile has a rather sharp cut-off in water at 4 °C owing to the small heat conductivity of water of $0.61 \text{ Wm}^{-1}\text{K}^{-1}$. The proton beam current was such that the deposition of a 4.5 Gy in an 8 cm box took 80 seconds. In Figure 3 the temperature rise of the two thermistors is shown for the 4.5 Gy 8 cm box. Although the first energy plane has its Bragg peak at a depth some centimetres larger than the position of the thermistors, a dose is deposited in the proximity to the thermistors owing to the plateau

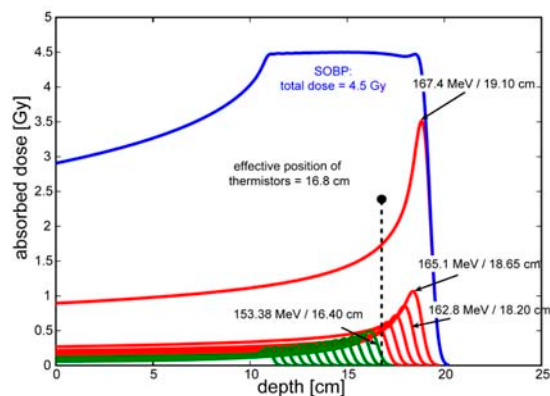


Figure 2: The SOBP of a 4.5 Gy dose box in the water phantom (8cm x 8cm x 8cm box centred at 15 cm).

of the dose profile as shown in figure 2. Because the two thermistors are separated by 10 mm, a time difference of the onset of the temperature rise of 2.6 seconds is to be expected for the deposition of the deepest dose plane produced by the protons with energy of 167.4 MeV. The highest energy has the largest weight factor, leading to the strongest temperature rise. The arrival time of the

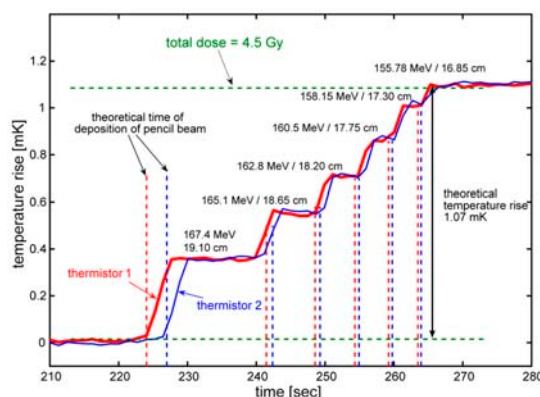


Figure 3: The temperature rise signal of the two thermistors for the cubic dose distribution of 4.5 Gy.

pencil beams corresponding to the smaller proton energies can be calculated from the various weight factors and magnet and energy switching times. As can be seen in figure 3, these times correspond reasonably well with the observed onset of the various temperature rises. A deposition of 4.5 Gy in water at 4 °C leads to a temperature rise of 1.07 mK, a value which is also reasonably well measured by both thermistors. In order to use the water calorimeter as a primary standard for scanned proton beams, the various parameters will now have to be studied systematically, notably the heat defect, which is typically the largest uncertainty in the water calorimeter. The results presented in this report demonstrate that the 3D dose profile produced by the spot scanning technique of PROSCAN is sufficiently long lived in water that absolute dosimetry with a water calorimeter should be feasible.

References

- [1] N.V. Klassen and C.K. Ross, Water Calorimetry: the heat defect, J. Res. Natl. Inst. Stand. Technol. 102 (1997) 63-74
- [2] M. Sassowsky, H. Quintel, R. Schafer and G. Stucki, Primärdosimetrie hochenergetischer Photonenstrahlung, metINFO 11 (2004) 4-8
- [3] J. Medin et al., Commissioning of an NRC-type sealed water calorimeter at METAS using ^{60}Co γ -rays, Phys. Med. Biol. 49 (2004) 4073-4086
- [4] M. Sassowsky and E. Pedroni, On the feasibility of water calorimetry with scanned proton radiation, Phys. Med. Biol. 50 (2005) 5381-5400
- [5] E. Pedroni et al., The PSI Gantry 2: a second generation proton scanning gantry, Z. Med. Phys. 14 (2004) 25-34