Range determination for proton beams. A comparison between luminescence imaging in water and standard ionization chamber based methods

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J Burg[1,2], F Horst[1], J Wulff[4,5,6] H Vorwerk[2], K Zink[1,2,3]
(1) University Medical Center Giessen-Marburg, Department of Radiotherapy and Radiooncology, Marburg, Germany
(2) University of Applied Sciences, Institute of Medical Physics and Radiation Protection, Giessen, Germany
(3) Marburg Ion-Beam Therapy Center (MIT), Marburg, Germany (4) West German Proton Therapy Centre Essen, Essen, Germany
(5) West German Cancer Center (WTZ), Essen, Germany (6) Department of Particle Therapy, University Hospital Essen, Essen, Germany

INTRODUCTION

As recently reported, water emits a weak luminescence when it is irradiated with high energy protons. The light signal is proportional to the absorbed dose in water and no fluorescence dye or other additive is required to obtain this signal. We want to present a detailed comparison of the optical range measurement with standard ionization chamber based methods in terms of resolution and measurement time. Also, we have investigated the influence of perturbations such as scattered radiation and Cerenkov light.

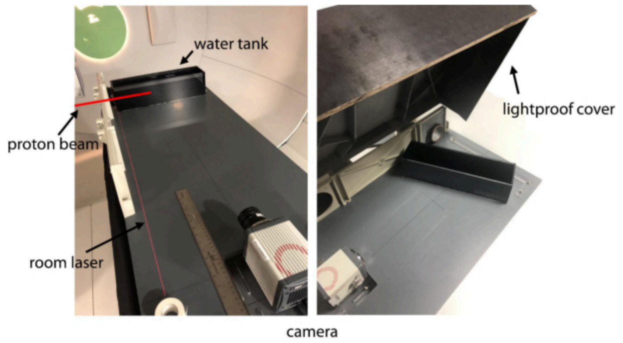
AIM

We would like to examine and present the following questions in detail:

- Is it possible to measure luminescent signals of protons in water in a clinical environment?
- Is it possible to use image processing to suppress disturbing influences on the recorded images?
- Can we use the luminescence signal for range measurement?
- Can range measurements by means of luminescence signal be compared with the conventional measuring methods?

METHOD

Fig. 1 left: Measurement setup in the treatment room without lightproof cover.
Right: With cover and the water tank not in its final position to make the beam entry visible.



We have created a setup for measuring luminescent light, generated during the irradiation of water with photons.
The structure consists of three main parts:

- a sensitive CMOS camera with a fast lens
- a water tank with a translucent side facing the camera
- a base plate for positioning and aligning the components with a light-tight enclosure

The described structure was calibrated with the help of a test sample before the measurement. Afterwards, luminescence images of protons in water in the energy range of about 100 - 220 MeV were generated.
These images were post-processed using a threshold based median filter to reduce interference.
The final Bragg-curves were generated by laterally integrating the signal from the image.

The comparative measurements using a multilayer ionization chamber and a Bragg-peak chamber were made under reference conditions. Detailed information are described by Bäumer et al. [3]

RESULTS

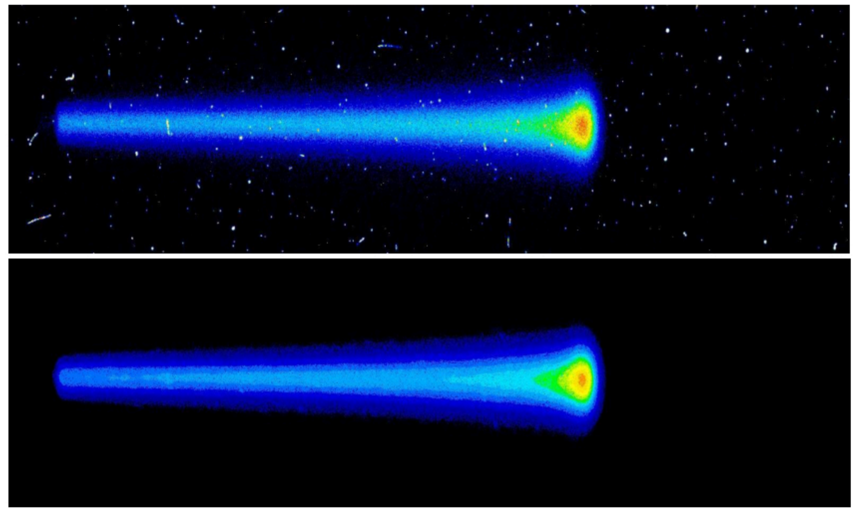
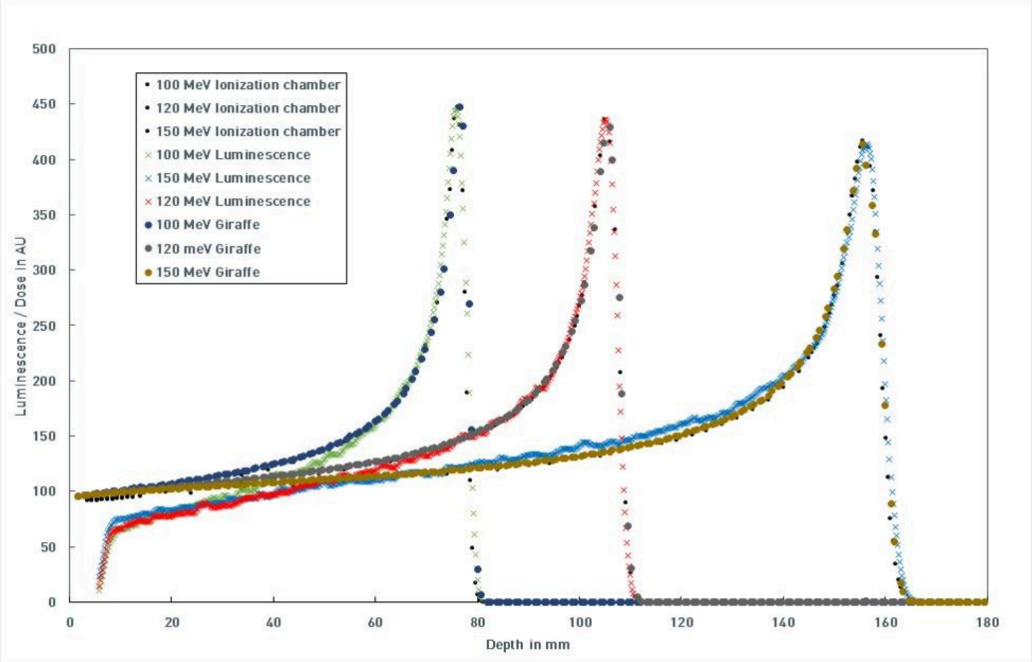


Fig. 2 shows the recorded luminescence images for a proton beam in water with an energy of 150 MeV. The upper image shows the raw image before image processing. Clearly visible are disturbances which are mainly caused by interaction of scattered radiation with the camera chip during the recording. The image below shows the same image after processing. Instead of the original grey scale images, the images are displayed in 16 color lookup table for better visibility.

Fig. 3: shows a comparison of the ranges measured withe different measuring systems. For the proton energies 100, 120, 150 MEV the Bragg-curves are plotted. The Bragg-peak position for the three measuring methods luminescence imaging, multilayer ionization chamber and Bragg-peak chamber is clearly visible. In addition, it can be seen that the sampling rate of the Bragg-curve is particularly high for luminescence measurement.



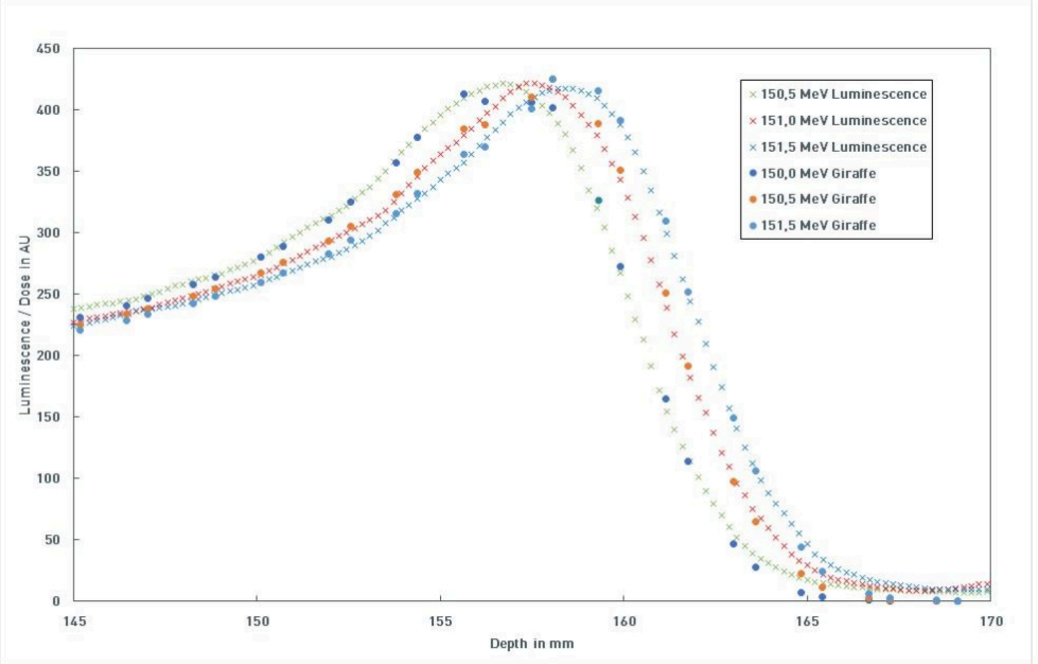


Fig. 4. shows the resolution of the range measurement. For this purpose, Bragg-curves were recorded using luminescence imaging and multilayer ionization chamber measurements.
The energy difference of the recorded Bragg-curves was 500 keV. The chosen energy change corresponds to a range change of 1 mm for protons in water.

CONCLUSION

It could be shown that it is possible to detect luminescence signals of protons in water in the clinically used energy range between 100- 220 MeV.

The particularly weak signal of this luminescence requires a complete shielding of the measurement setup against any stray light.

The operation of a scientific CMOS camera in the radiation field of a clinical proton accelerator is challenging but possible. However, a post-processing of the images is necessary to suppress disturbances caused by scattered radiation.

The luminescence signal is suitable for range determination. The comparison with standard measuring methods showed high agreement for range measurements.

It could be shown that a range change of 1 mm is detectable with the system presented.

Due to the acquisition of the signal using a CMOS chip, a high sampling rate over the entire Bragg-curve is obtained with a single shot.

In detail the method and results are published in Ref. [1]

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CONTACT INFORMATION

Jan Michael Burg
jan.michael.burg@lse.thm.de
University of Applied Sciences, Giessen, Germany
Institute of Medical Physics and
Radiation Protection
Wiesenstrasse 14
D 35390 Giessen