Iodine and gadolinium sulfate solutions were introduced into standard Fricke dosimeter solution for final concentrations of iodine from 2.5 mg I/ml to 50 mg I/ml and gadolinium from 5 mg Gd/ml to 10 mg Gd/ml. Detection of iron (III) ions was performed with spectrophotometer Varian Cary 50. For measurement of iron (III) ions concentration in the presence of iodopride ammonium thiocyanate (Panreac) was used as an indicator because optical spectrum of iodopride interfere with optical spectrum of iron (III) ions. Irradiation of Frickie solutions was performed with 110 kVp x-rays through 3.5 mm Al filter at 0.7 Gy/min dose rate.

Results: Dose enhancement in presence of iodine and gadolinium was expressed as dose enhancement factor (DEF), which is the ratio of absorbed dose value in Fricke water solution containing iodine or gadolinium and in pure Frickie water solution. Measured DEF values and corresponded iodine and gadolinium concentrations are presented in Table.

<table>
<thead>
<tr>
<th>High atomic number element</th>
<th>Concentration, mg/ml</th>
<th>DEF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gadolinium</td>
<td>5</td>
<td>1.3±0.1</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>1.5±0.1</td>
</tr>
<tr>
<td></td>
<td>2.5</td>
<td>1.2±0.1</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>1.3±0.1</td>
</tr>
<tr>
<td>Iodine</td>
<td>10</td>
<td>1.7±0.2</td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>3.1±0.3</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>4.8±0.5</td>
</tr>
</tbody>
</table>

Dose enhancement is proportional to concentration of the element used. DEF value for iodine varies from 1.2±0.1 to 4.8±0.5 for concentration of iodine from 2.5 mg I/ml to 50 mg I/ml respectively.

Conclusion: A new approach for measuring dose enhancement in CERT was proposed. This method can be used as a routing procedure in experimental and clinical practice of CERT dose measurements.

PO-0793
The Advanced Markus ionization chamber is useable for measurements at ultra high dose rates
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Purpose or Objective: The Advanced Markus ionization chamber from PTW (PTW-Freiburg GmbH, Freiburg, Germany) saturates at high dose rates (Ḋ) and/or at a high dose-per-pulse (DPP). According to PTW, the ion collection efficiency is ≥ 99% at continuous Ḋ < 375 Gy/s and at DPP < 5.56 mGy. At a source-to-surface distance (SSD) of 50 cm, our prototype linac produces a mean Ḋ of ~ 500 Gy/s, an instantaneous Ḋ of ~ 2.5 MGy/s, and a DPP of ~ 5 Gy (far above the chamber datasheet range). In order to use the Advanced Markus chamber for determining the absorbed dose in these intense irradiation conditions, we needed to establish a model of its saturation as the D/DPP increases.

Material and Methods: Two independent methods were used to determine the chamber saturation curve. 1) Measurements in a water phantom at different D/DPP by varying the SSD and the linac gun grid tension (pulse amplitude). The hypothesis was that if the linac output varies with grid tension in a reproducible way and if the grid tension was varied by the same factor for every SSD then the relative change in chamber response with grid tension should be the same (for all SSD) if not for the chamber saturation. 2) Simultaneous measurements of chamber and D/DPP independent radiochromic film (Gafchromic™ EBT3, Ashland Inc., Covington, USA), in a solid water phantom (RW3 slabs, PTW) at various D/DPP.

Results: The results show how the chamber saturation increases (the ion collection efficiency decreases) as the DPP increases (Figure). These results also show that the chamber saturation is much more dependent on the DPP than the instantaneous Ḋ, as the ion collection efficiency curves for the different pulse widths (~ DPP/instantaneous Ḋ) are only slightly separated when plotted against DPP. A mathematical model of the saturation curves was established by fitting a logistic function (dependent on DPP) to the data points:

\[
\frac{1}{k_s} = \frac{1}{1 + \left(\frac{DPP}{0.3}\right)^{2}} = k \left(1 + \left(\frac{DPP}{0.3}\right)^{2}\right)^{-a}
\]

Where ks is the saturation (ion recombination) correction factor and where a takes a slightly different value for different instantaneous Ḋ (a = 0.197, 0.192, and 0.184 for pulse widths of 0.5, 1.0, and 1.8 μs, respectively).

Results from subsequent dose measurements at various D/DPP verified that chamber dose values (corrected by the saturation model) were compatible with film and TLD dose values.

Conclusion: We present a saturation model for the Advanced Markus ionization chamber, which was based on dose measurements performed in a water phantom as well as simultaneous film and chamber measurements in a solid water phantom at various D/DPP. Chamber dose measurements corrected by the saturation model were compared to independent film and TLD dose measurements. These measurements verified that the Advanced Markus ionization chamber does not completely saturate up to DPP values of 10 Gy and can consequently be used for accurate dose measurements (within 5%) in ultra high D/DPP irradiation conditions, if the chamber saturation model is applied.

PO-0794
First proton irradiation experiments with a deformable radiochromic 3D dosimeter
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Purpose or Objective: In proton therapy, anatomical changes may cause considerable deterioration of the delivered dose distributions. Transmission-based treatment verification is generally not possible, making three-dimensional (3D) dosimetry a promising tool for verification of the delivered dose. However, solid state 3D detectors have significant problems related to linear-energy-transfer dependent quenching in particle beams – an under-response of the signal in the Bragg peak. A new deformable, silicone-based, radiochromic 3D dosimeter has recently been developed by our group. The aim of this study was to perform the first proton beam experiments with this detector. Special attention was given to the quenching and dose-rate dependencies in general, relating these effects to the chemical composition of the dosimeter.

Material and Methods: Dosimeters (1 x 1 x 4.5 cm³) of varying chemical compositions were produced. They contained leuco-malachite green (LMG) dye as the active component, chloroform and silicone elastomer. Twelve different batches were irradiated with 60 MeV proton beams, using a 40 mm circular collimator, to different doses (0 – 30 Gy). Irradiations were performed with both a low and a high dose rate (0.23 and 0.55 Gy/s). For comparison, depth-dose distributions were measured in water with a Markus-type plane-parallel ionizing chamber. Simultaneously, dosimeters from the same batches were irradiated with 6 MV photon beams in a 10 cm square field on a linear accelerator. Dosimeters from the same batches were irradiated with 6 MV photon beams in a 10 cm square field on a linear accelerator. All dosimeters were read out before irradiation and four hours after, at a wavelength of 635 nm. The read-out was performed with a home-built 1D-scanner with a depth resolution of 0.2 mm for the proton irradiated dosimeters, while a spectrophotometer was used for the photon read-out. The dose-rate dependency was compared for proton and photon irradiations. The ratio of Bragg-peak to plateau response (at 1 cm) was compared between batches.

Results: The effect of lowering the dose rate was similar for proton and photon beams, although the beam qualities were different. The dose response was higher at a low dose rate, but at increasing dye concentration the effect was reduced. Significant under-response was observed in the Bragg peak. The peak-to-plateau ratio was improved from (2.5 ± 0.1) to (3.0 ± 0.04) by increasing the dye concentration from 0.1 to 0.3 % (w/w). By increasing the curing-agent concentration from 5 to 9 % (w/w), the ratio further improved to (3.7 ± 0.4) and (3.5 ± 0.1) for the same respective dye concentrations.

Conclusion: The 3D radiochromic silicone based dosimeter has for the first time been investigated in proton beams, and it was demonstrated that chemical modifications could influence the dosimeter response.

PO-0795
Dose verification of fast and continuous scanning in proton therapy
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2University of Zurich, University Hospital, Zurich, Switzerland

Purpose or Objective: Out of all techniques proposed to mitigate intra-fractional motion in particle therapy, rescanning appears to be the easiest to realize: One simply needs to apply the same field multiple times with proportionally reduced dose to average out interplay patterns (Phillips et al. 1992). However, dead times (e.g. energy changes, spot transitions) accumulate which lengthens the overall treatment time. Thus, efficient rescanning – possibly combined with gating and/or breath-hold – requires fast energy changes (~ 100 ms) and fast lateral scanning. The former is already established at Gantry 2 (Safai et al. 2012). For the latter, we pursue implementing a faster delivery technique called line scanning, in which we scan the beam continuously along a straight line while quickly modulating the speed and/or current (Schätti et al. 2014). In this presentation, we would like to report on the dose verification concept of line scanning.

Material and Methods: With beam current changes in less than 1 ms (Schippers et al. 2010) and lateral scanning speeds of up to 2 cm/ms (Pedroni et al. 2004), the frequency of speed and current modulation along a line can be exceptionally high. This calls for a verification system that can intervene (almost) in real-time to fulfill current safety standards. Thus, we decided to monitor the beam current and position continuously during the delivery of a single element, since errors in those two parameters directly impair the homogeneity of the delivered dose distribution. In addition to these real-time verification measures, we implemented a final, redundant verification step, in which the overall dose profile of the delivered line is validated.

Results: We investigated time-resolved signals from (a) two planar ionization chambers in the gantry nozzle to monitor the beam current and (b) two Hall probes in the sweeper magnets to verify the lateral beam position. Tolerance bands define acceptable fluctuations of all signals. We