# Dosimetry for advanced radiotherapy approaches using particle beams with ultra-high pulse dose rates in the EMPIR UHDpulse project


A. Subiel[1], M. McManus[1], F. Romano[1,2], N. Lee[1], A Lourenco[1], H. Palmans[1,3], R Thomas[1], W. Farabolini[4,5], A. Gilardi[4], A Mascia[1], S. Joseph[6], E. Lee[6], A. Schueller[7]

[1]Medical Radiation Science, National Physical Laboratory, Hampton Road, Teddington, Middlesex, TW11 0LW, UK
[2]Istituto Nazionale di Fisica Nucleare, Sezione di Catania, Catania, Via S Sofia 64, I-95123 Catania, Italy
[3]MedAustron, Marie Curie-Strasse 5, 2700 Wiener Neustadt, Austria
[4]CERN, Geneva 1217, Switzerland
[5]CEA-IRFU, Gif-sur-Yvette, France
[6]University of Cincinnati Medical Center, Cincinnati, OH, USA
[7]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany



National Physical Laboratory

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## INTRODUCTION

The European Metrology Programme for Innovation and Research (EMPIR) UHDpulse project aims to develop the metrological tools needed to establish traceability in absorbed dose measurements of pulsed particle beams with ultra-high dose-rates. Delivery of doses at ultra-high dose-rate has been of particular interest due to remarkable reduction of normal tissue toxicity (known as the FLASH effect) with respect to conventional treatments. Pulses of particle beams with dose-rates orders of magnitude higher than in conventional radiotherapy present significant metrological challenges in dosimetry, which need to be addressed to enable the translation of these novel radiotherapy techniques to clinical practice.

## AIM

The main goal is the development of the metrological tools needed to establish traceability in absorbed dose measurements of UHPDR particle beams, generated by both conventional, (radiofrequency), as well as laser-driven radiation sources. Different types of UHPDR particle beams, investigated in this project are shown below.

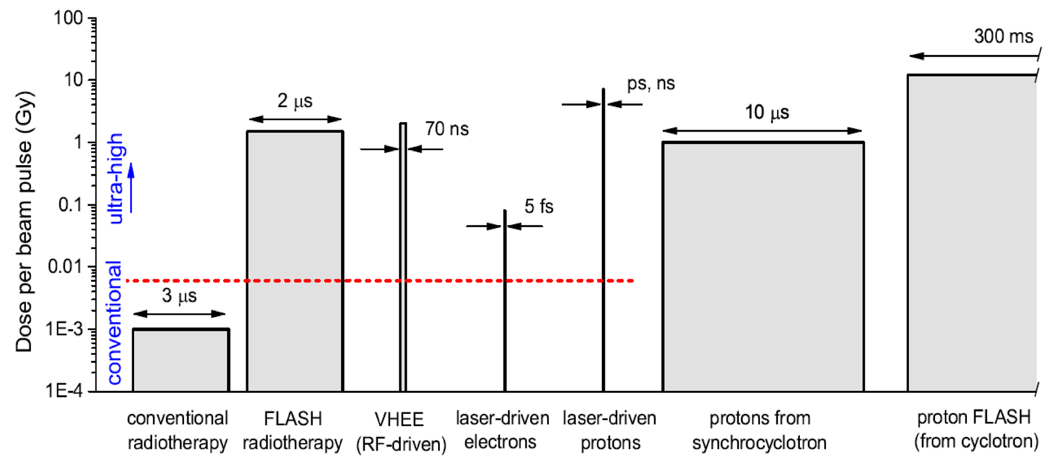


*Figure 1. Illustration of different types of UHPDR particle beams studied within this project [1].*

The metrology tools, which are developed within the project, are a prerequisite for the comparison of radiobiological effectiveness for different irradiation modalities. They are essential to carry out preclinical radiobiological studies to test the efficacy of these beams, and to enable future clinical application of these emerging technologies.

## METHOD

NPL's graphite calorimeter has been employed to measure the dose delivered from a 200 MeV pulsed very high energy electron (VHEE) beam. This was compared to the charge measurements of a plane-parallel ionisation chamber to determine the absolute collection efficiency and infer the ion recombination factor. The dose-per-pulse measured by the calorimeter ranged between 0.03 Gy/pulse and 5.26 Gy/pulse [2].

## OBJECTIVES

The objectives of the project are to be addressed in the four work packages (summarized in Figure 2). These include:

1. The development of a metrological framework, including SI-traceable primary and secondary reference standards and validated reference methods for dosimetry measurements for particle beams with ultra-high pulse dose-rates.

2. Dosimetric characterization of available detector systems in particle beams with ultra-high dose-per-pulse or with ultra-short pulse duration.

3. Development of traceable and validated methods for relative dosimetry.

4. Provision of the input data for development of new Codes of Practice for absolute dose measurements in particle beams with ultra-high pulse dose-rates.

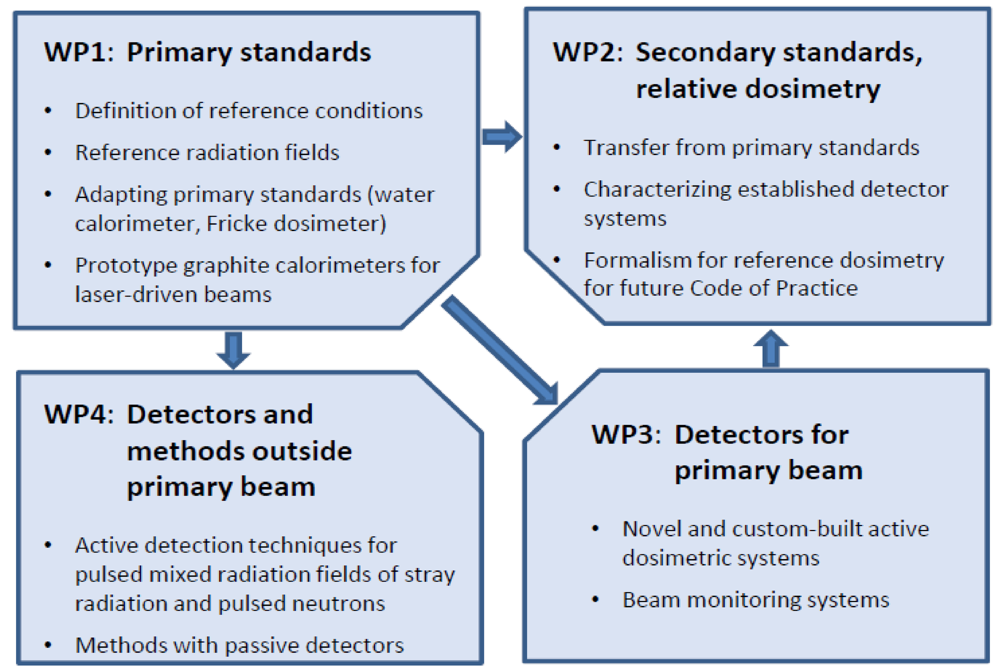


*Figure 2. The structure of WPs within the EMPIR UHDpulse project [1].*

## CONSORTIUM

The multidisciplinary consortium consists of:

- 5 National Metrology Institutes - leading in the field of dosimetry
- 3 academic hospitals - pioneers in FLASH-RT/dosimetry expertise
- 3 universities - experts in detector development /pioneer in laser-driven beams
- 3 national research institutes -pioneer in detector development/stray radiation expert/access to radiation facilities
- 1 European research institute - laser-driven beam research infrastructure
- 5 companies - expert in detector development

## RESULTS

The experimental setup allowed to carry out side-by-side measurements (Figure 3). A PTW 7862 Monitor chamber was placed between the vacuum window and the phantom setup allowing for the normalisation of any beam fluctuations in the measurements.

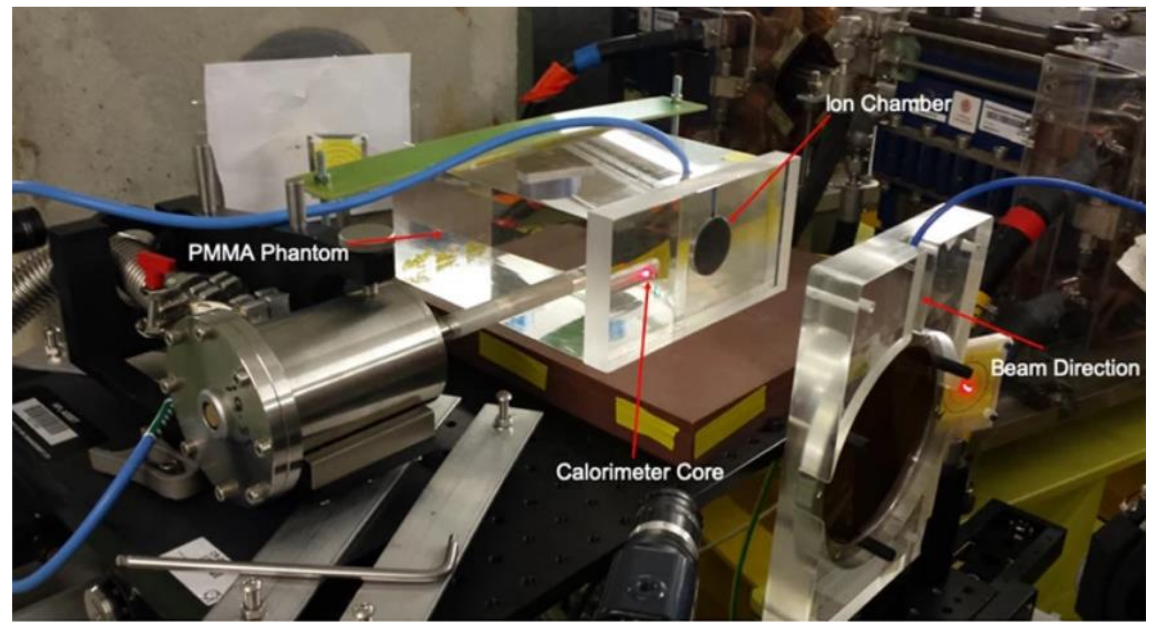


***Figure 3.** The test-stand at the CLEAR facility, with the calorimeter, ion chamber and monitor chamber placed along the beam line with the beam travelling from right to left [2].*

The calorimeter and chamber were exposed to a quasi-monoenergetic pulsed electron beam of approximately 200 MeV at the CLEAR user facility at CERN [3]. Each electron pulse was formed of a variable number of shorter electron bunches, with an adjustable charge-per-bunch range between 0.001 nC to 1.5 nC. Each bunch had a length of approximately 1 ps. By adjusting the charge-per-bunch and the number of bunches-per-pulse, we investigated charge-per-pulse values ranging from 0.05 nC to 11 nC. The collection time of the ion chamber is of the order of µs, therefore the chamber is sensitive to the total macro pulse and not the individual bunches.

The absolute value of the recombination factor was calculated from the ratio of the absolute dose determined from the calorimeter and the dose calculated from the ion chamber:

$$k_{s,abs} = \frac{D_{w,cal}}{M k_{pol} k_{TP} k_{Q,Q_0} k_{Q,Q_0} N_{D,w,Q_0}} \qquad (1)$$

where $D_{w,cal}$ is the dose-to-water measured from the calorimeter, $M$ is the charge reading of the chamber, $k_{pol}$ is the polarity correction factor, $k_{TP}$ is the temperature and pressure correction factor, $k_{Q,Q_0}$ is the beam quality correction factor and $N_{D,w,Q_0}$ is the calibration coefficient of the ionisation chamber in the reference beam quality

The dose-to-water conversion factor, used to convert from the measured dose-to-graphite from the calorimeter into the required dose-to-water, was calculated to be 1.0912. The dose-per-pulse to water and the recombination factors determined from absolute measurements are displayed in Table 1.

| Nominal Beam Charge (nC/pulse) | $D_{w,cal}$ (Gy/pulse) | $k_{s,abs}$ | | | |
|---|---|---|---|---|---|
| | | 75 V | 200 V | 350 V | 600 V |
| 0.05 | 0.03 | 1.3 | 0.98 | 0.89 | 0.78 |
| 0.2 | 0.20 | 3.41 | 1.87 | 1.56 | 1.14 |
| 0.25 | 0.14 | 2.46 | 1.33 | 2.05 | - |
| 1 | 0.67 | 6.00 | 3.07 | 2.12 | 1.58 |
| 2.2 | 1.25 | 8.80 | 4.12 | 2.80 | 1.94 |
| 3 | 1.95 | 11.96 | 5.67 | - | 2.58 |
| 4.5 | 2.63 | 14.99 | 6.87 | 4.59 | 3.07 |
| 6 | 3.66 | 18.94 | 8.54 | 5.63 | 3.81 |
| 7.5 | 4.12 | 19.54 | 8.77 | 5.69 | 3.74 |
| 9 | 4.56 | 21.38 | 9.30 | 5.99 | 4.23 |
| 10.5 | 5.26 | 22.99 | 9.95 | 6.50 | 4.24 |

***Table 1.** Dose-per-pulse and ks,abs values, calculated using Eq.1 [2].*

## CONCLUSIONS

Graphite calorimeter and PTW Roos ionisation chamber were used to determine the absolute recombination factor $k_{s,abs}$ of the ion chamber as a function of dose-per-pulse when exposed to high dose-per-pulse VHEEs. The recombination factor was calculated for chamber collecting voltages of 75 V, 200 V, 350 V and 600 V (Table 1). The value of $k_s$ was found to increase over the investigated dose range for each collecting voltage. The largest recombination factor was found to be approximately $k_{s,abs}$≈23 at a collecting voltage of 75 V and a dose-per-pulse of 5.26 Gy/pulse, corresponding to a chamber collection efficiency of 4% (1/$k_{s,abs}$). The highest collection efficiency was measured at 0.03 Gy/pulse, which is similar to what would be expected in a standard clinical radiotherapy beam. This significant decrease in collection efficiency indicates that understanding the process of ion collection in the chamber will be fundamental in the translation of FLASH therapy and laser-driven sources into clinical practice.

Behaviour of ion chambers and other dosimeters needs to be well-understood before implementing them as secondary standard detectors in new radiotherapy applications such as FLASH and high dose-per-pulse VHEE RT. This work is a foundation towards development of metrology and tools traceable to national standards for these novel radiotherapy approaches.

This work has been carried out within the framework of the EMPIR UHDpulse project, which aims to develop the metrological tools needed to establish traceability in absorbed dose measurements of pulsed particle beams with ultra-high dose-rates.

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EMPIR EURAMET

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## CONTACT INFORMATION


anna.subiel@npl.co.uk