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Metrology Research Centre

Absolute dosimetry of UHDR radiation beams in real time

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Progress in **FLASH radiation therapy using electron beams** is currently blocked because we lack **Appropriate beam monitoring and fast accelerator control systems**, which prevents **Accurate implementation of UHDR beam delivery**.

Acknowledgements

I acknowledge that where I live and work in Ottawa is situated on the unceded and unsurrendered territory of the Anishinabe Algonquin Nation, whose presence there reaches back to time immemorial.

I also acknowledge that this is but a small, first step towards reconciliation between indigenous peoples and newcomers to the continent, with the endpoint being the liberation of all.

This is the work of a diverse team combining researchers, engineers and students: James Renaud, Jean Dessureault, Zaki Gardezi, Victoria Howard, Bryan Muir

FLASH-RT is all about the temporal structure of the dose delivery

What qualifies as a UHDR (ultra-high dose rate) beam is not very well defined

- For continuous beams a mean dose rate of around **40 Gy s^{-1}** is quoted
- For pulsed beams the average dose per pulse is said to be **5-10 Gy**
- There does not appear to be a required pulse structure
- The delivery PRF (pulse repetition frequency) is <u>not</u> a key parameter

Electron UDHR, delivered using linear accelerators, is the most commonly studied FLASH RT system, because:

i) A conventional linac can be modified (either ‘hacks’ of standard machines or vendor-approved modifications)

ii) Custom devices are available from a range of manufacturers

Problem #1: dosimetry of UHDR beams

‘Standard’ electron FLASH is delivered using high dose-per-pulse linacs

Three dosimeters have been shown to be insensitive to dose per pulse:

i) Calorimeter

ii) Alanine

iii) Radiochromic film

Note no mention of ion chambers!

Each has a different response and provides complementary information:

Calorimeter – real-time response, potential for absolute dose determination

Film – 2-D dose distribution in a single measurement

Alanine – direct traceability to primary standards, low uncertainty

No universal dosimeter!

Problem #2: beam monitoring of UHDR beams

FLASH beam deliveries are typical a few pulses, with each pulse around 1μs to 5 μs

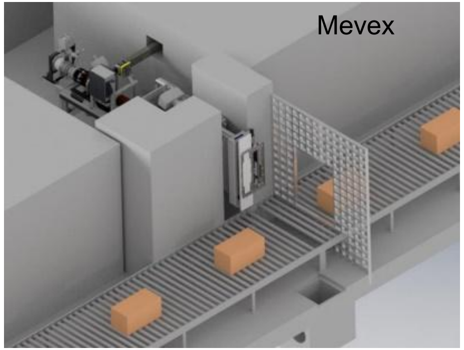
Monitoring of each individual pulse is now important (compared to conventional doserates, where one averages over a large number of pulses)

- **Ionization chambers are not fast enough to accurately measure a single electron pulse**
- **Reverse-biased diodes have been used for decades for pulse detection (and dosimetry) but will perturb the radiation field**
- **Faraday cups can be monitor individual pulses and integrate over a complete delivery, but they totally stop the beam**

Toroidal beam current monitors (integrating current transformers) provide the necessary fast response, can be calibrated in terms of absolute beam current, and do not intercept the radiation beam

UHDR beams are <u>not</u> new

Sterilization of medical goods



Radiation sterilization using high energy electron or x-ray beams requires the delivery of ~ 25 kGy in < 10 s

This requires a dose per pulse in the UDHR region

Industrial users of ionizing radiation have been doing FLASH dosimetry for decades, but for them it was just dosimetry!

Alanine, calorimetry, film – ALL have been used in industrial dosimetry for decades

Many industrial accelerator producers now offer a single-pulse capability for their devices.

Calorimetry

$$D_{\mathrm{core}} = \frac{\Delta E_{\mathrm{rad}}}{m_{\mathrm{core}}} = c_{p,\mathrm{core}} \cdot \Delta T \cdot \prod k_i$$

Need material with well-known specific heat capacity

Measure radiation-induced temperature rise

Portability provides additional constraints:

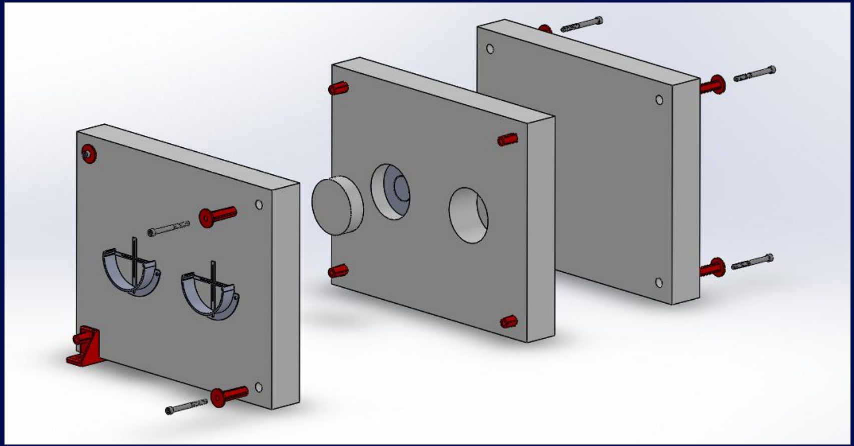
i) Small

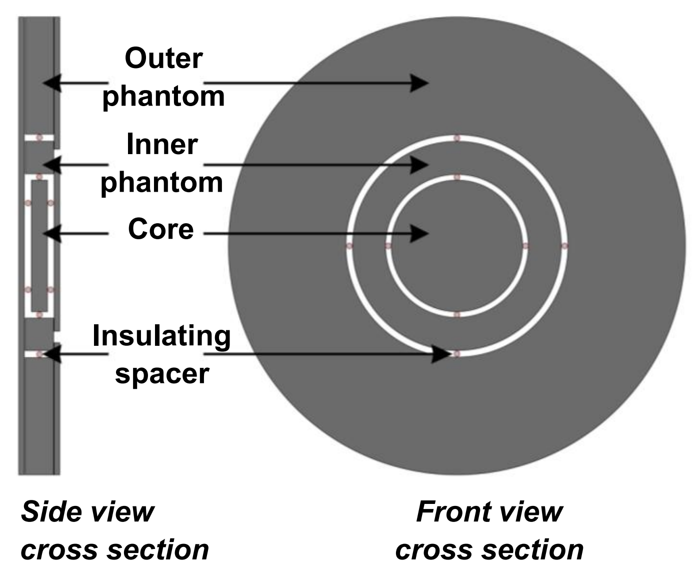
ii) Robust

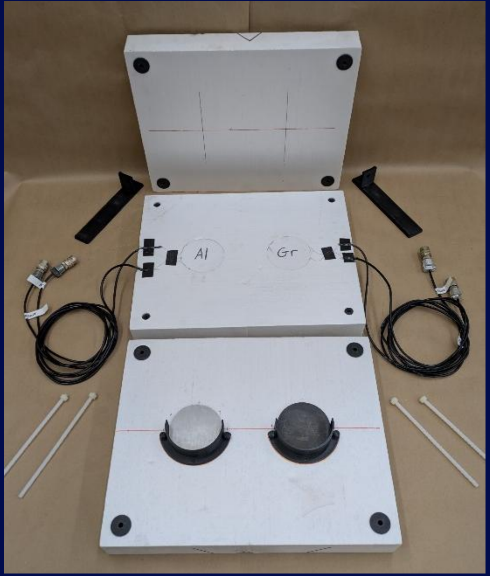
iii) Simple

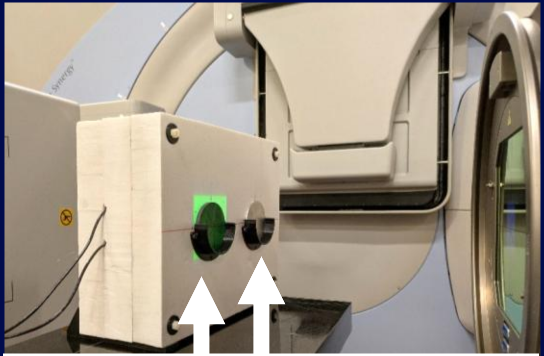
Twin-calorimeter system based on graphite and pure aluminum within a compact polystyrene enclosure.

2 cm wide sensitive volume
7.5 cm wide absorber assembly









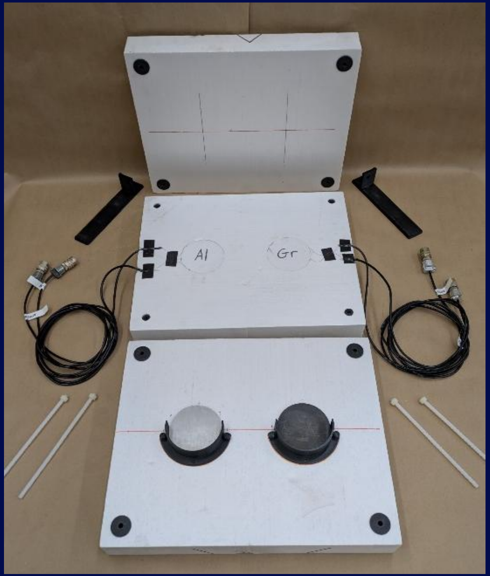
Holders for external build-up plates (*left*) graphite; (*right*) aluminum

Dual-materials provide independent dose measurements and cross-verifies system performance in remote settings.

Effective depth of measurement is adjustable using front build up.

~35 cm wide overall & < 2 kg total weight

Rugged design is easy to ship and set up on couch



Data acquisition system

Need to measure the temperature rise

Typically a complex resistance bridge is used

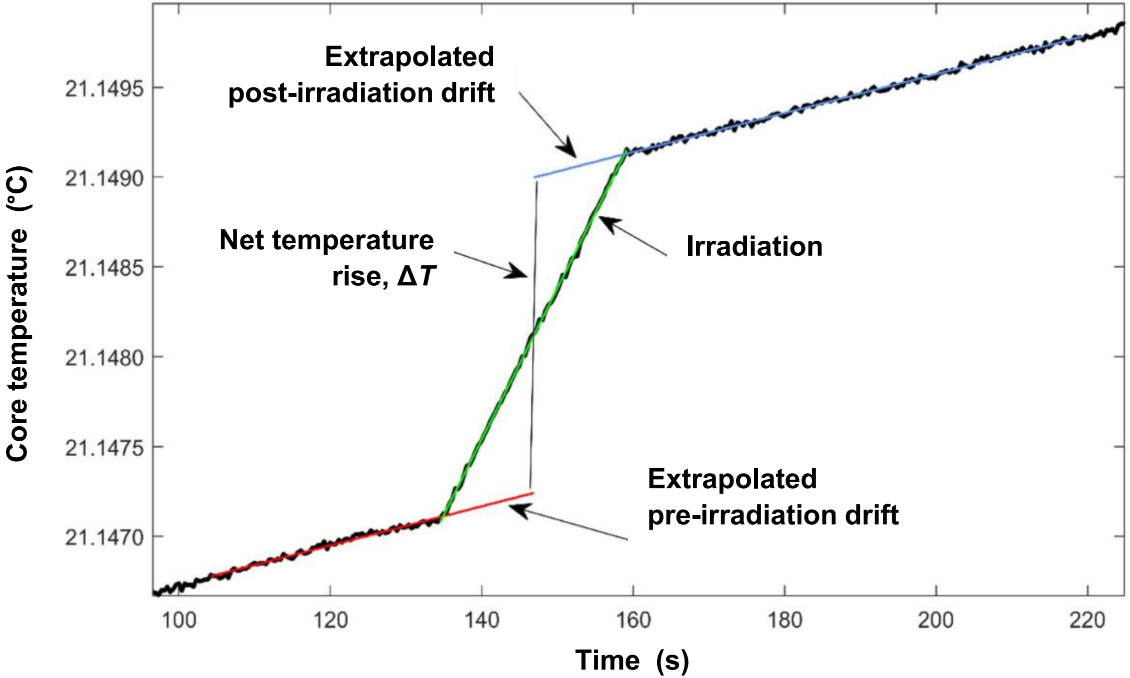
What do we need for conventional RT?

6 MV photon beam, WFF ~ 5 Gy/min gives:

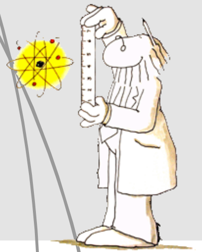
- **1 mK/min** temperature rise for water
- **6 mK/min** temperature rise for graphite

Can we simplify data acquisition with the increased sensitivity of a solid calorimeter?

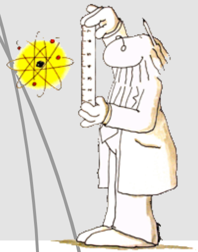
Data acquisition system



HP 3458A
8.5 digit DMM
high-precision option



Dose to water formalism



Heat flow correction

Finite element thermal modelling

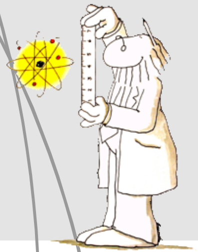
$$D_w = \underbrace{\Delta T_{\mathrm{med}} \cdot c_{p,\mathrm{med}}(T)}_{\text{Measured}} \cdot k_c \cdot f_{w,\mathrm{med}}$$

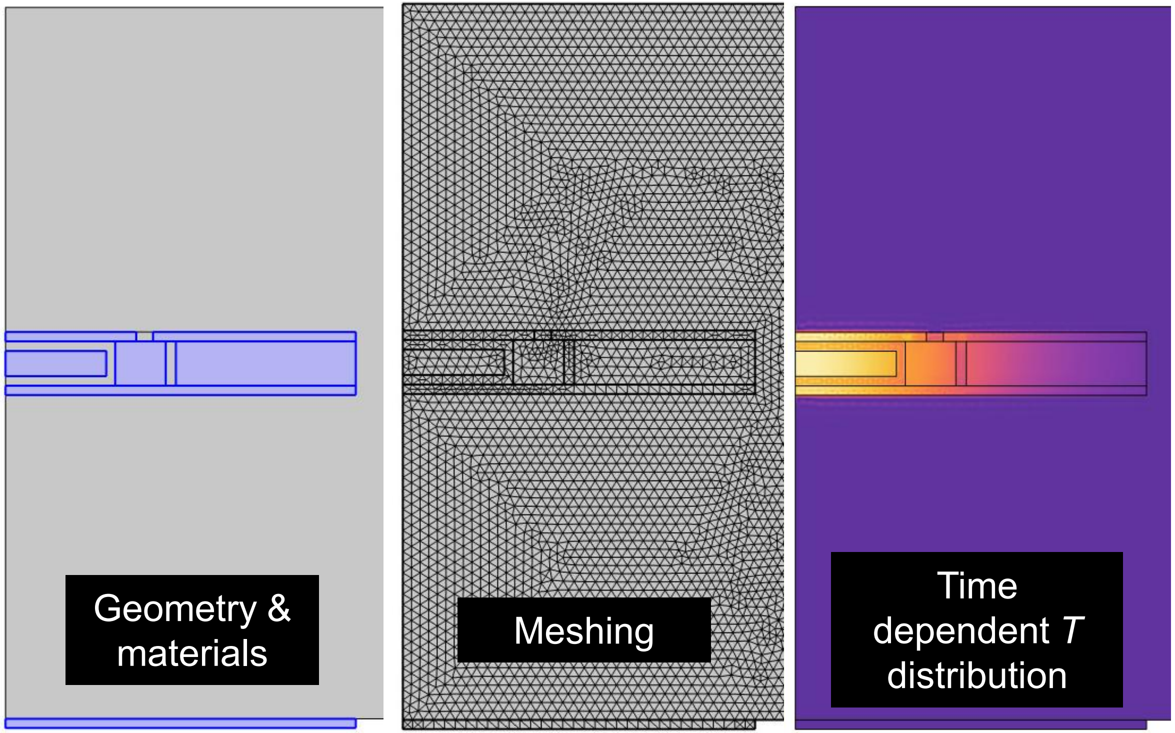
Dose conversion factor

Monte Carlo radiation transport simulation

Simulation is a key component of the standard

Finite element thermal modelling



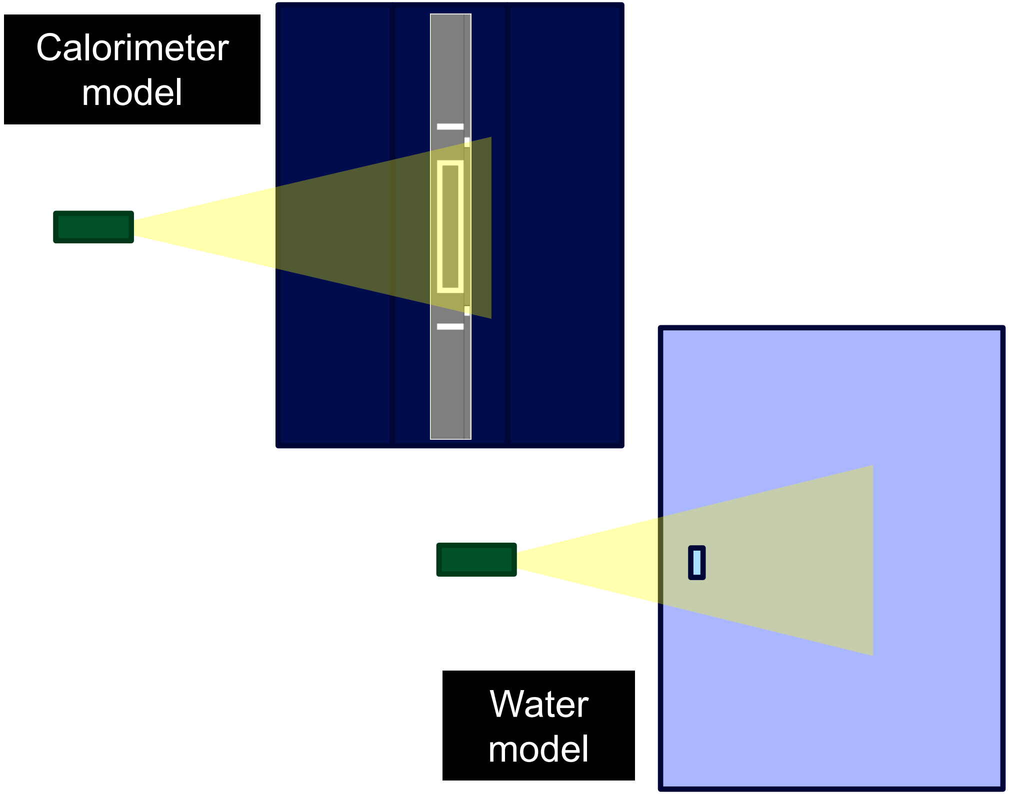


Heat flow correction

k_c

Only need to consider heat transfer via conduction

Monte Carlo radiation transport modelling



Dose conversion factor

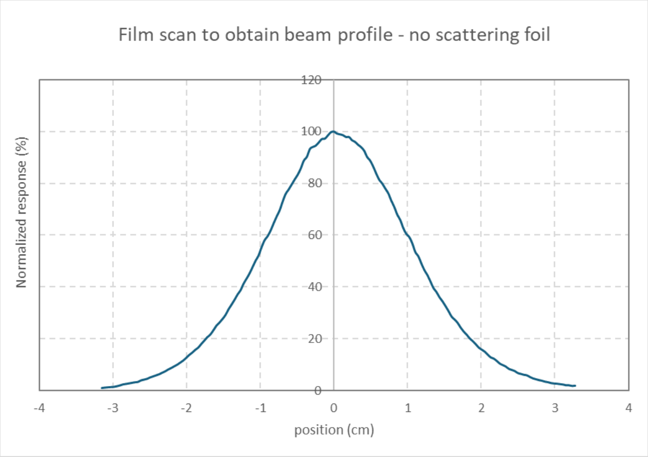
$$f_{w,\mathrm{med}}$$

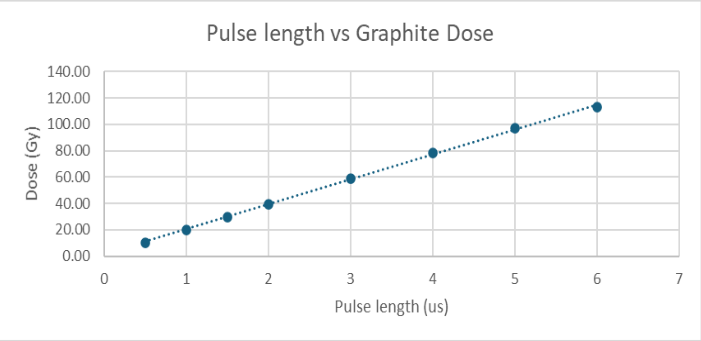
Modern, accurate MC systems mean:

i) the calorimeter measurement depth does not have to match final depth in water

ii) an inhomogeneous phantom is OK

Initial Results – UHDR calorimetry

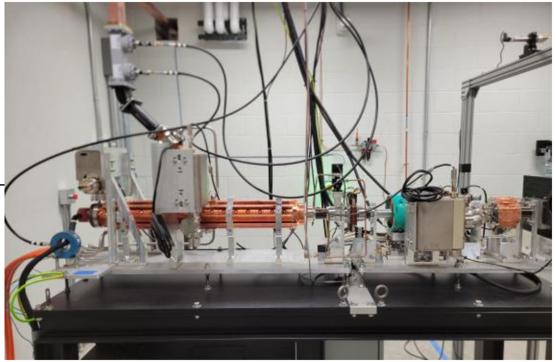


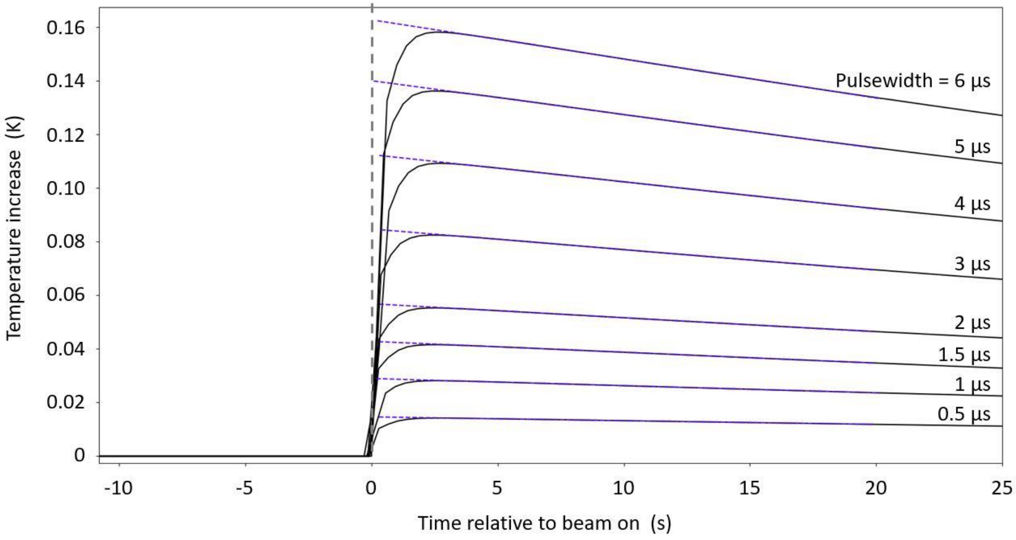


Precision ~ 0.2%

Graphite and aluminum calorimeters agree at 0.8 %

Narrow beam characterization possible





3. Future work

- Calorimeter design has not been optimized
- Is there an ideal geometry for UHDR beams or should there be a suite of calorimeters?
- Can data acquisition system be further miniaturized to simplify shipping?
- Biggest time requirement is accurate thermal and radiation simulations – can corrections be pre-calculated based on typical beam geometries?
- What about other radiation beams – MV operation has been demonstrated but what about kV FLASH and proton beams?

150 YEARS OF SIENCE

Thank you

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