Calorimetry-based absolute dosimetry in MR-Linac

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WHY DO CALORIMETRY??

AAPM's TG-51 protocol for clinical reference dosimetry of high-energy photon and electron beams

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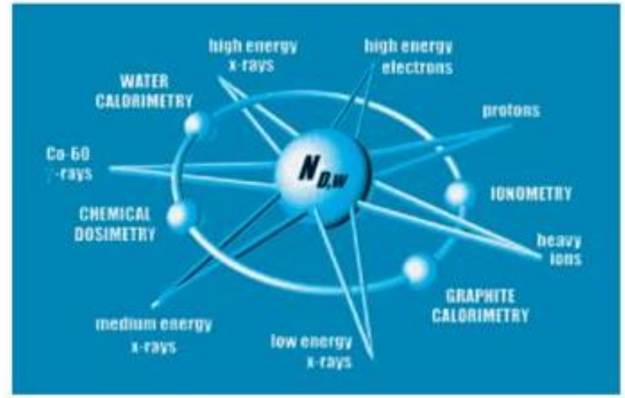
A protocol is prescribed for clinical reference dosimetry of external beam radiation therapy using photon beams with nominal energies between ^{60}Co and 50 MV and electron beams with nominal energies between 4 and 50 MeV. The protocol was written by Task Group 51 (TG-51) of the Radiation Therapy Committee of the American Association of Physicists in Medicine (AAPM) and has been formally approved by the AAPM for clinical use. The protocol uses ion chambers with absorbed-dose-to-water calibration factors, $N_{D,w}^{^{60}\mathrm{Co}}$, which are traceable to national primary standards, and the equation $D_w^Q = M k_Q N_{D,w}^{^{60}\mathrm{Co}}$, where Q is the beam quality of the clinical beam, D_w^Q is the absorbed dose to water at the point of measurement of the ion chamber placed under reference conditions, M is the fully corrected ion chamber reading, and k_Q is the quality conversion factor which converts the calibration factor for a ^{60}Co beam to that for a beam of quality Q. Values of k_Q are presented as a function of Q for many ion chambers. The value of M is given by $M = P_{\mathrm{ion}} P_{\mathrm{TP}} P_{\mathrm{elec}} P_{\mathrm{pol}} M_{\mathrm{raw}}$, where M_{raw} is the raw, uncorrected ion chamber reading and P_{ion} corrects for ion recombination, P_{TP} for temperature and pressure variations, P_{elec} for inaccuracy of the electrometer if calibrated separately, and P_{pol} for chamber polarity effects. Beam quality, Q, is specified (i) for photon beams, by $\%dd(10)_x$, the photon component of the percentage depth dose at 10 cm depth for a field size of 10×10 cm^2 on the surface of a phantom at an SSD of 100 cm and (ii) for electron beams, by R_{50}, the depth at which the absorbed-dose falls to 50% of the maximum dose in a beam with field size $\geqslant 10\times 10$ cm^2 on the surface of the phantom ($\geqslant 20\times 20$ cm^2 for



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Absorbed Dose Determination in External Beam Radiotherapy

An International Code of Practice for Dosimetry Based on Standards of Absorbed Dose to Water

Sponsored by the IAEA, WHO, PAHO and ESTRO

Protocols

$$D_{w,Q} = M_Q \cdot N_{D,w}^{Q}$$

$$D_{w,Q} = M_Q \cdot N_{D,w}^{Q_o} \cdot k_{Q,Q_o}$$

Reference Dosimetry

$$D_{w,Q} = M_Q \cdot N_{D,w}^{Q_o} \cdot k_{Q,Q_o}$$

HOW?
-by cross calibrating user detector against a primary standard (e.g. calorimeter) in some reference beam/conditions

Reference Dosimetry

$$D_{w,Q} = M_Q \cdot N_{D,w}^{Q_o} \cdot k_{Q,Q_o}$$

Can be determined through:
Simulations
OR
Measurements

Reference Dosimetry

$$k_{Q,Q_o}$$

- Through Simulations:
  - Model detector accurately, in reference (Q_o) and clinical (Q) beam quality.

- Through Measurements:
  - Measure dose to water using an absolute dosimeter in clinical (Q) beam quality

- So far, for MR-linac, we have mainly *calculated* beam quality and magnetic field-based corrections factors (O'Brien et al; Malkov et al; Spindeldreier et al, …)

- Show feasibility of performing calorimetry in MRL

- This paves way for future development of calorimetry based standards at the std labs, as well as experimental verification of k_Q

- We looked at Water Calorimetry, Graphite Calorimetry, as well as chamber dosimetry

Purpose

BACKGROUND

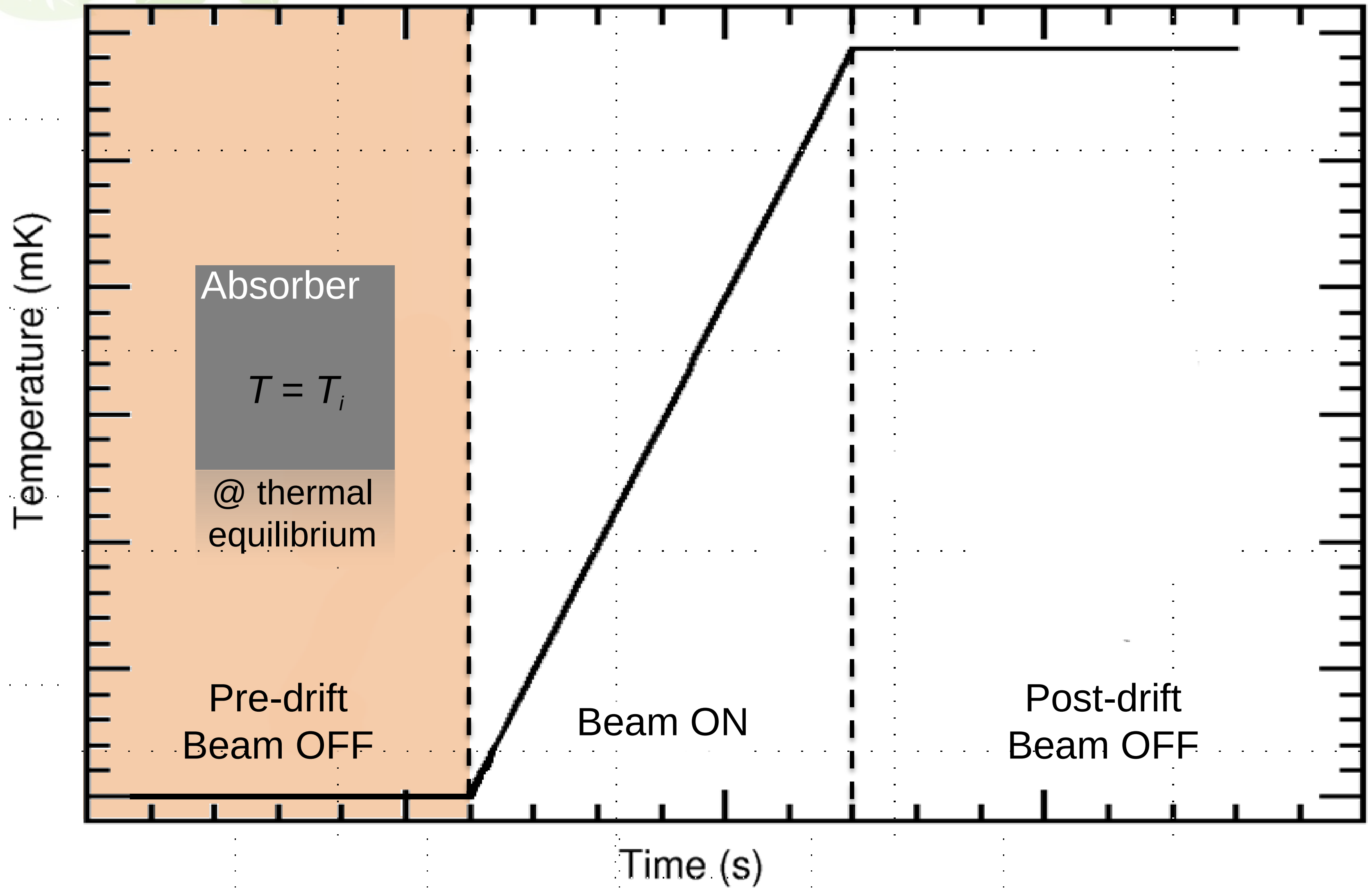
- Calorimetry is the only true primary standard for absorbed dose measurement

$$D_w(\vec{r}) = c_w \cdot \Delta T(\vec{r})$$

- Calorimetry is the only true primary standard for absorbed dose measurement

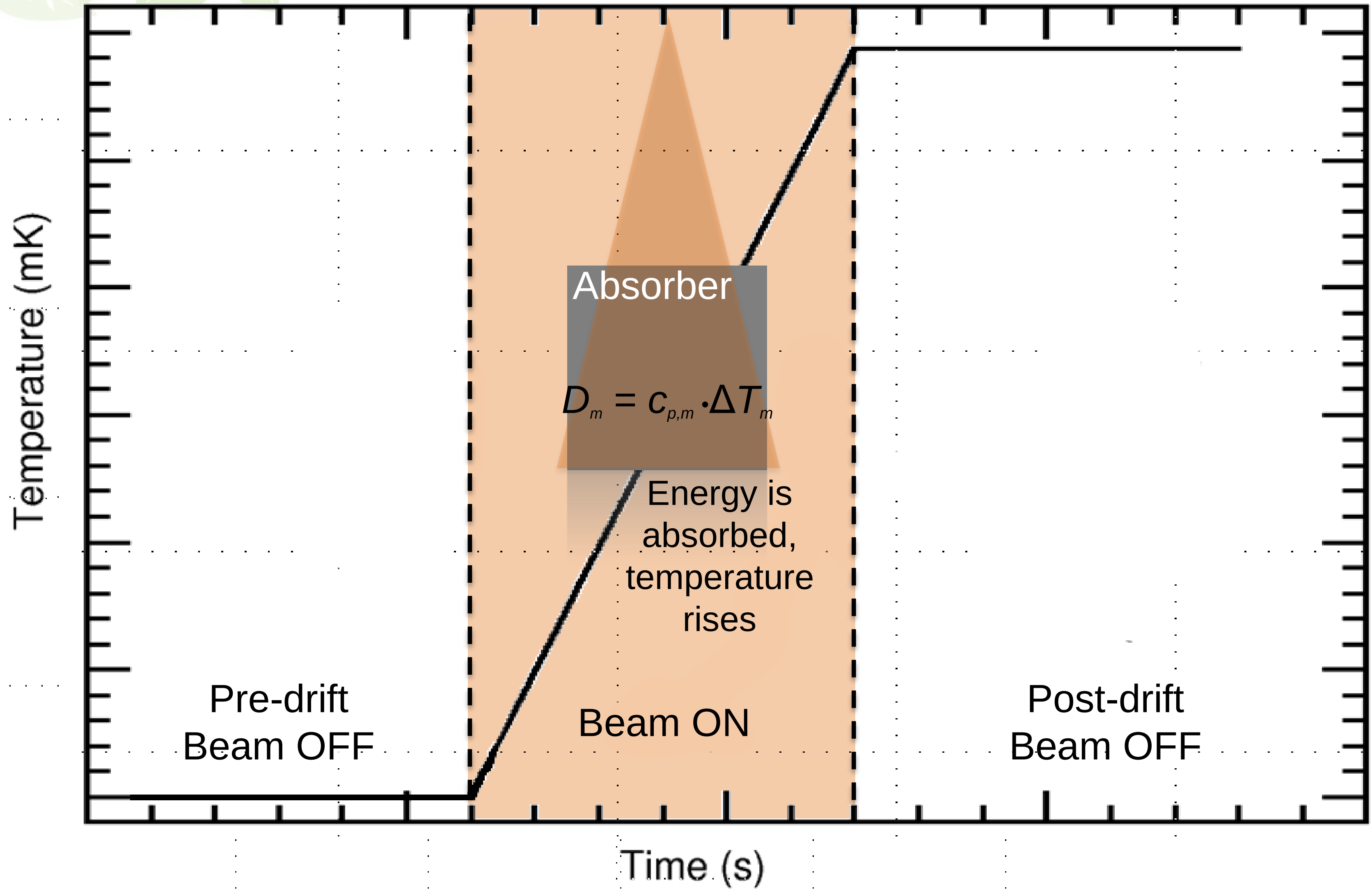
$$D_w(\vec{r}) = c_w \cdot \Delta T(\vec{r}) \cdot \prod k_i$$

- Advantages:
  - Measure *Absorbed Dose* directly and absolutely
  - Theoretically independent of energy, dose rate, *etc*



Slide Courtesy of J. Renaud

Quasi-Adiabatic Mode



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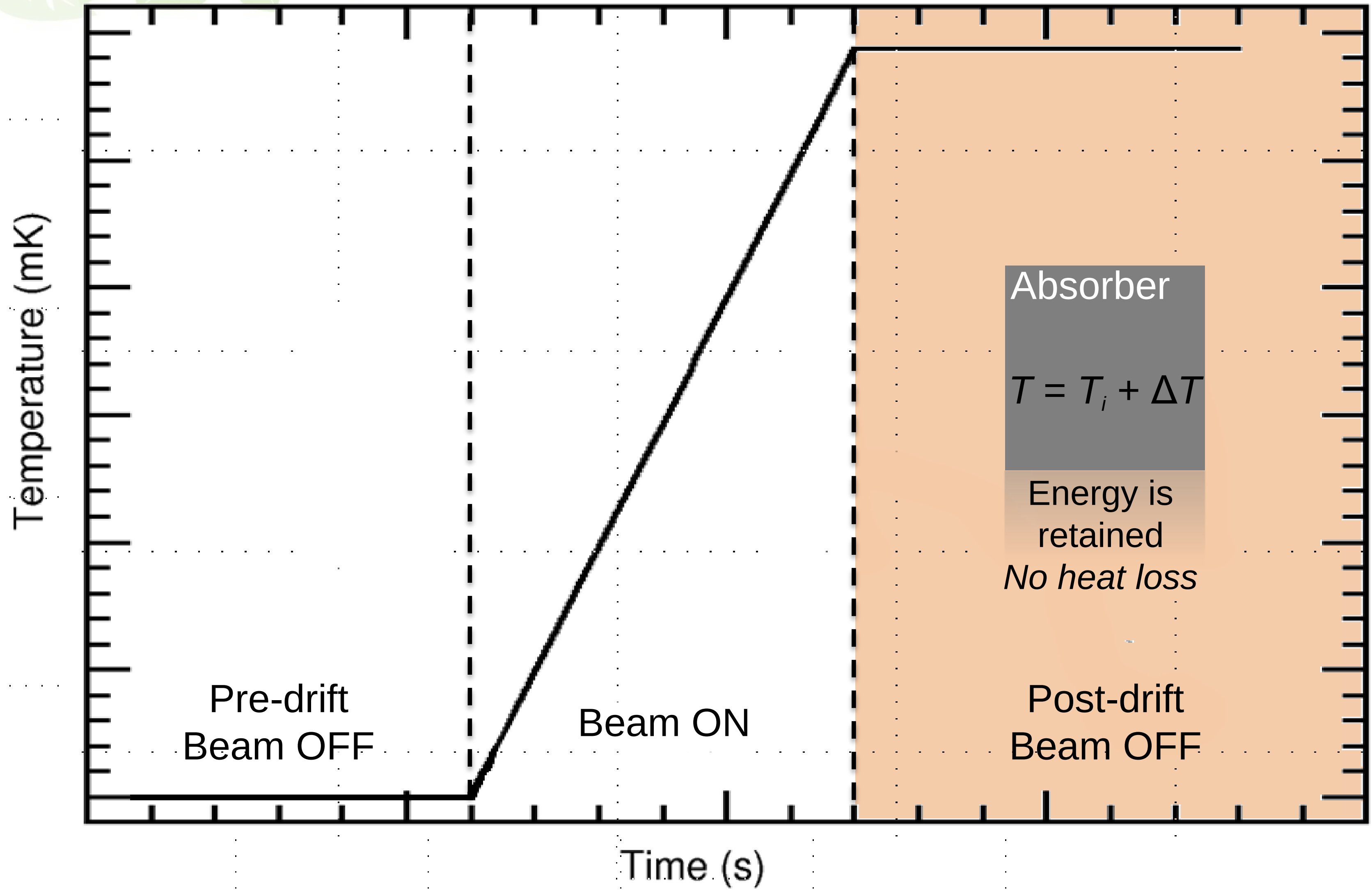
Quasi-Adiabatic Mode



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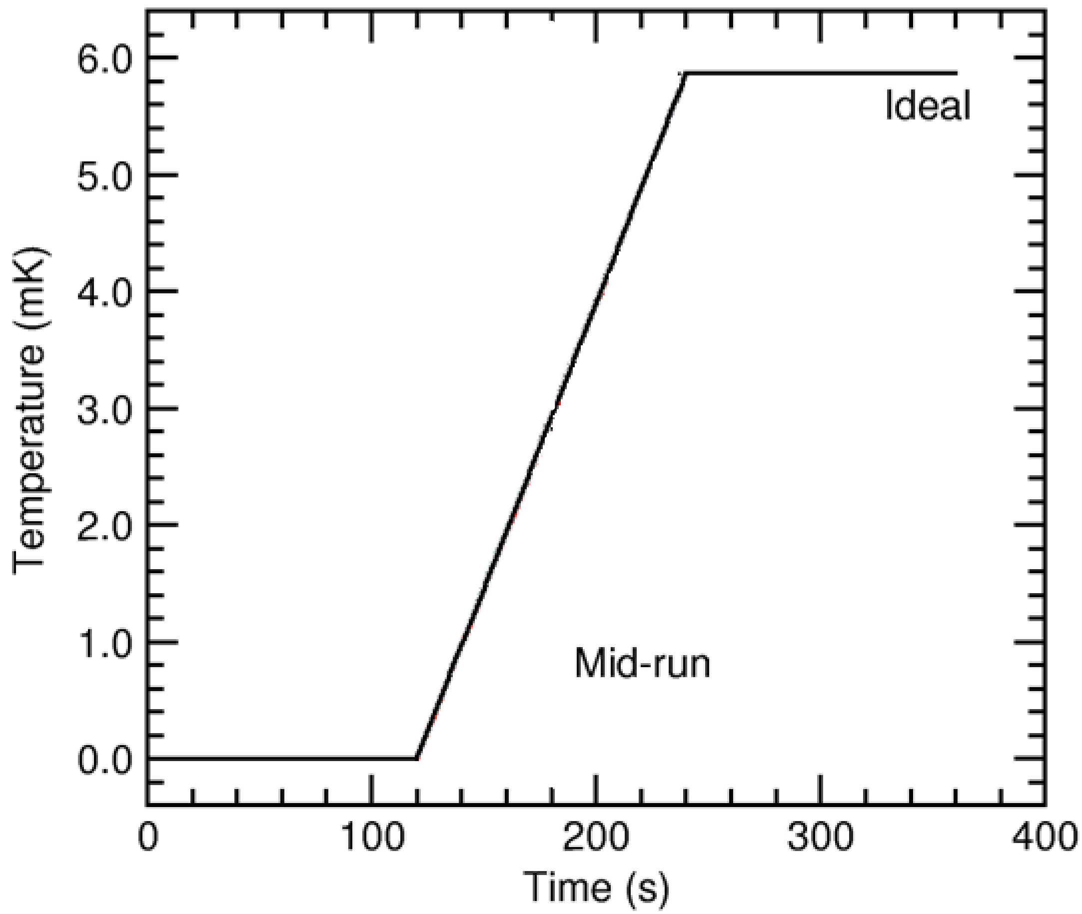
Quasi-Adiabatic Mode



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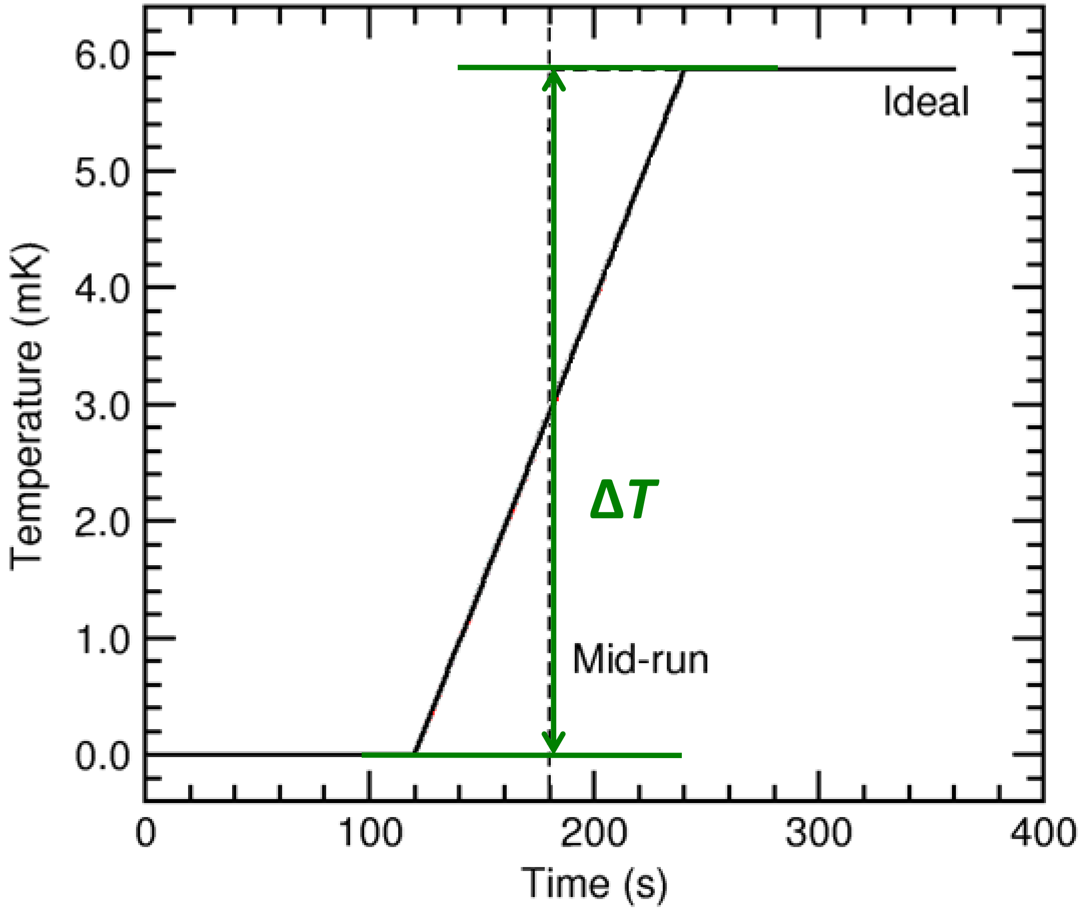
Temperature rise - ideal



Courtesy: Carl Ross, National Research Council Canada

Temperature rise - ideal

- The reality is slightly different:
  - Small SNR
  - Heat transfer
  - Heat defect

Challenges

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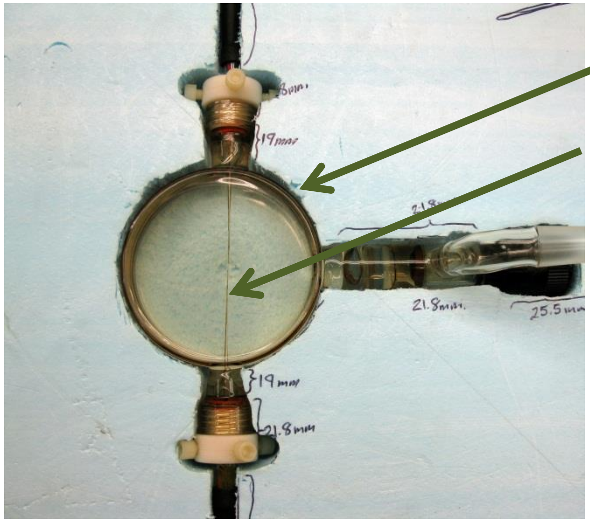
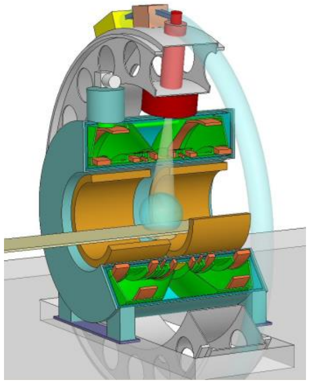
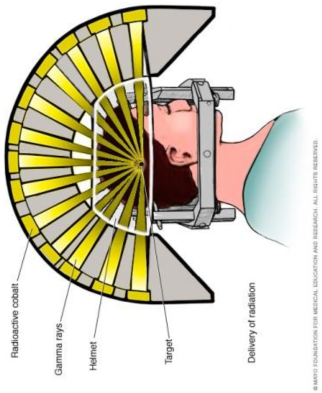
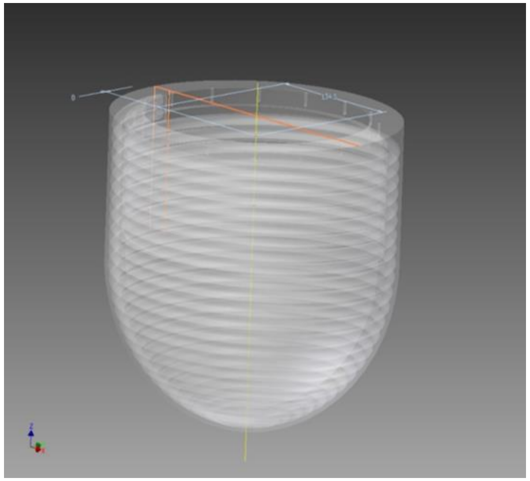


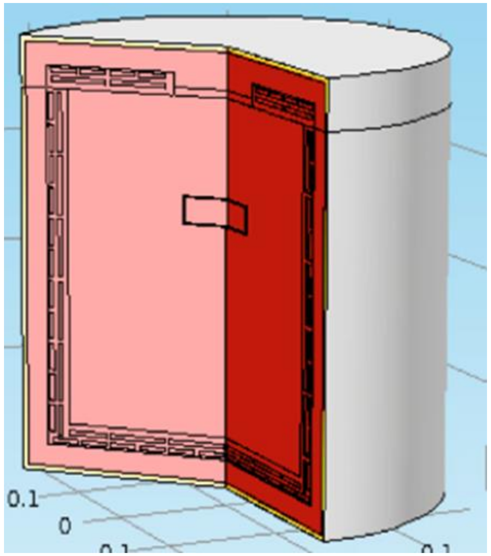
- To design and construct a water calorimeter that is:
  - Fully MRI-compatible
  - Accommodates measurements in MRL and GK
  - Positioning can be verified through imaging

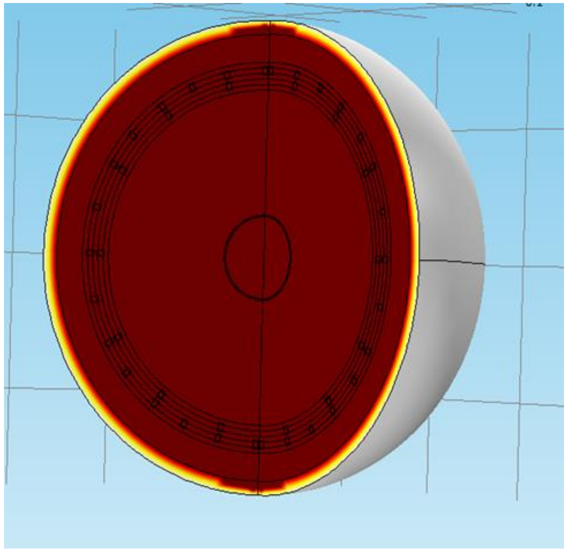
Purpose

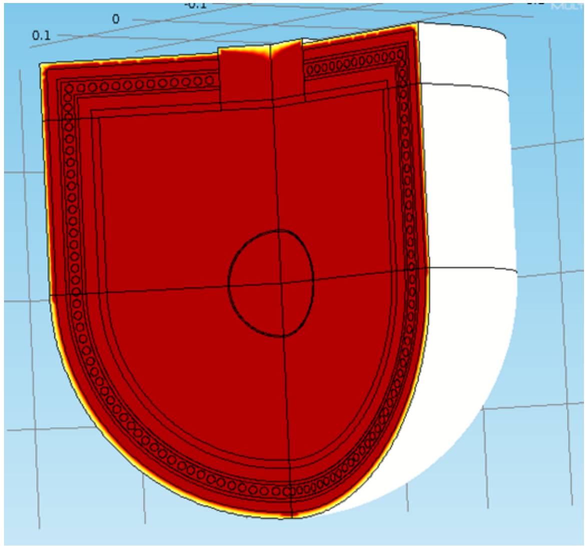






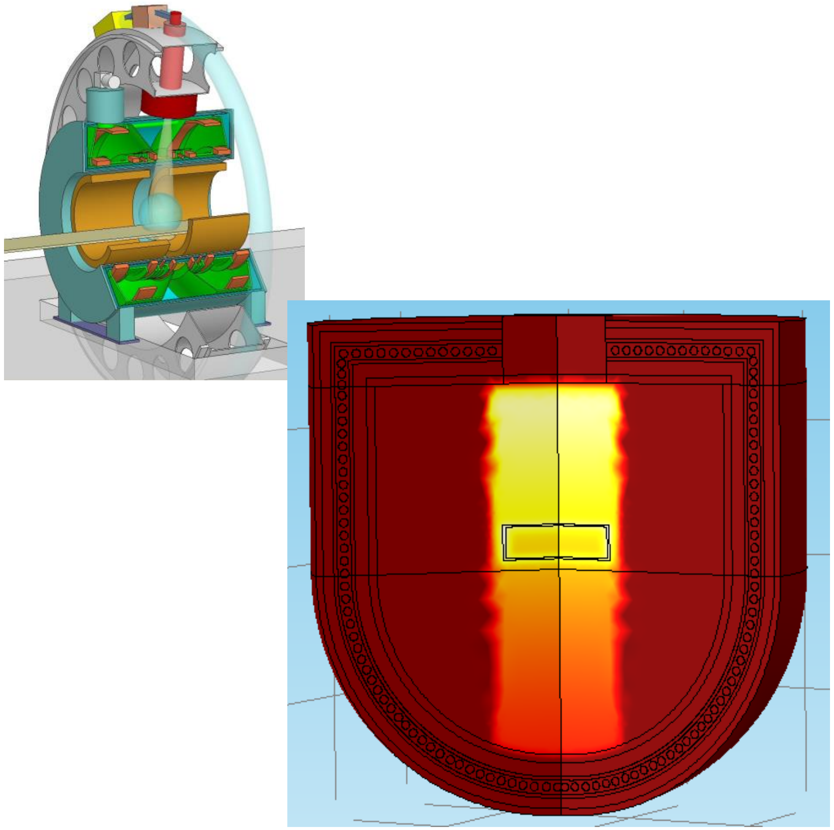




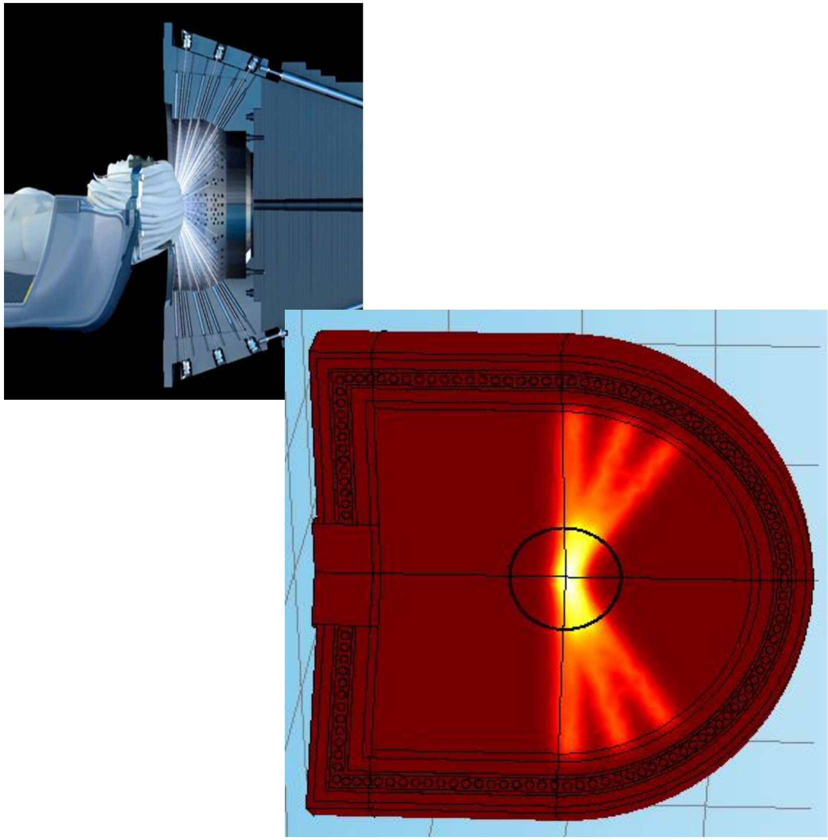


MRL/GK Water Calorimetry

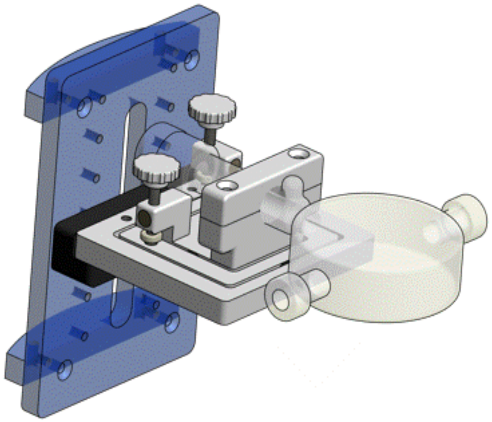
WC in MR-Linac

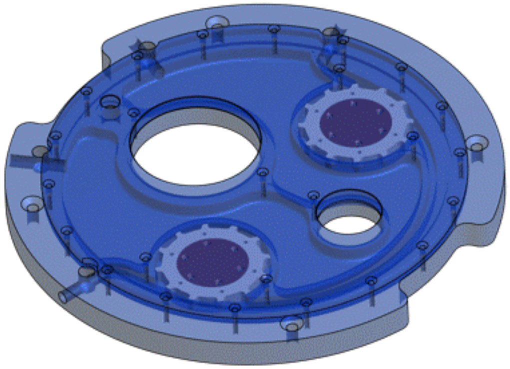


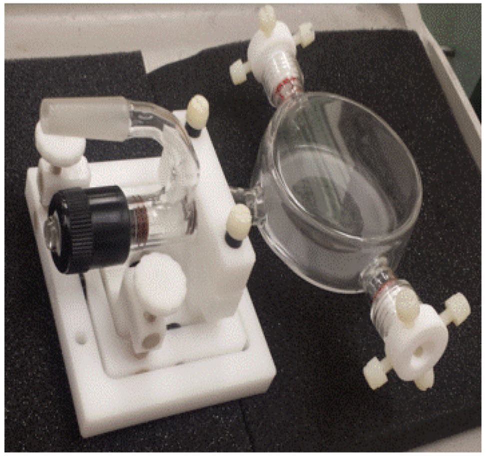
WC in Gamma Knife®

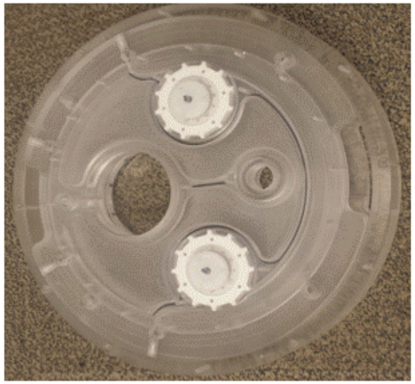


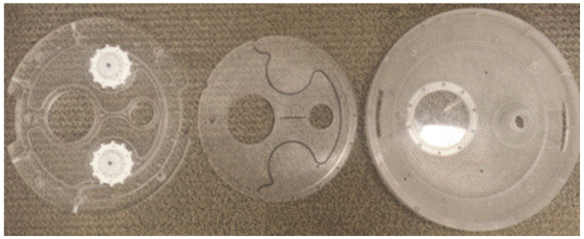
CONSTRUCTION



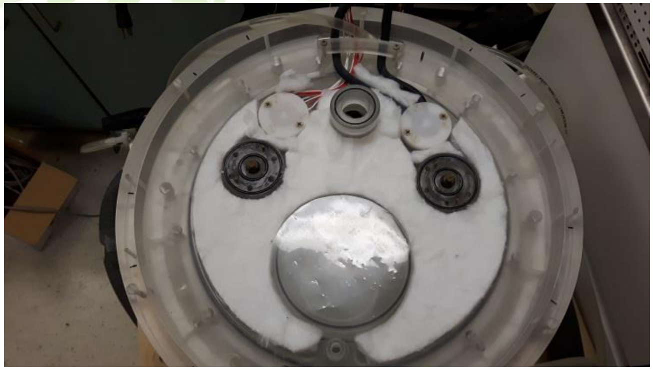


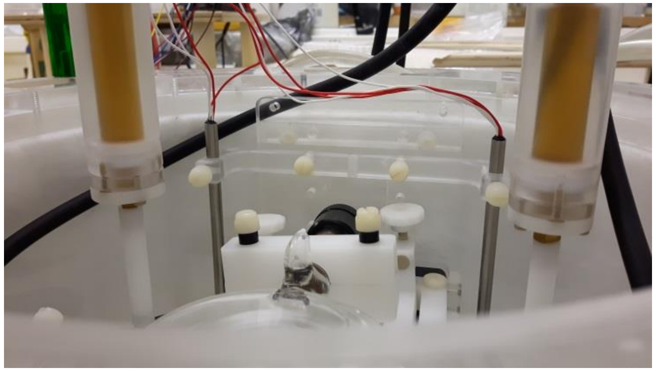






Tank / Holder / Lid Construction



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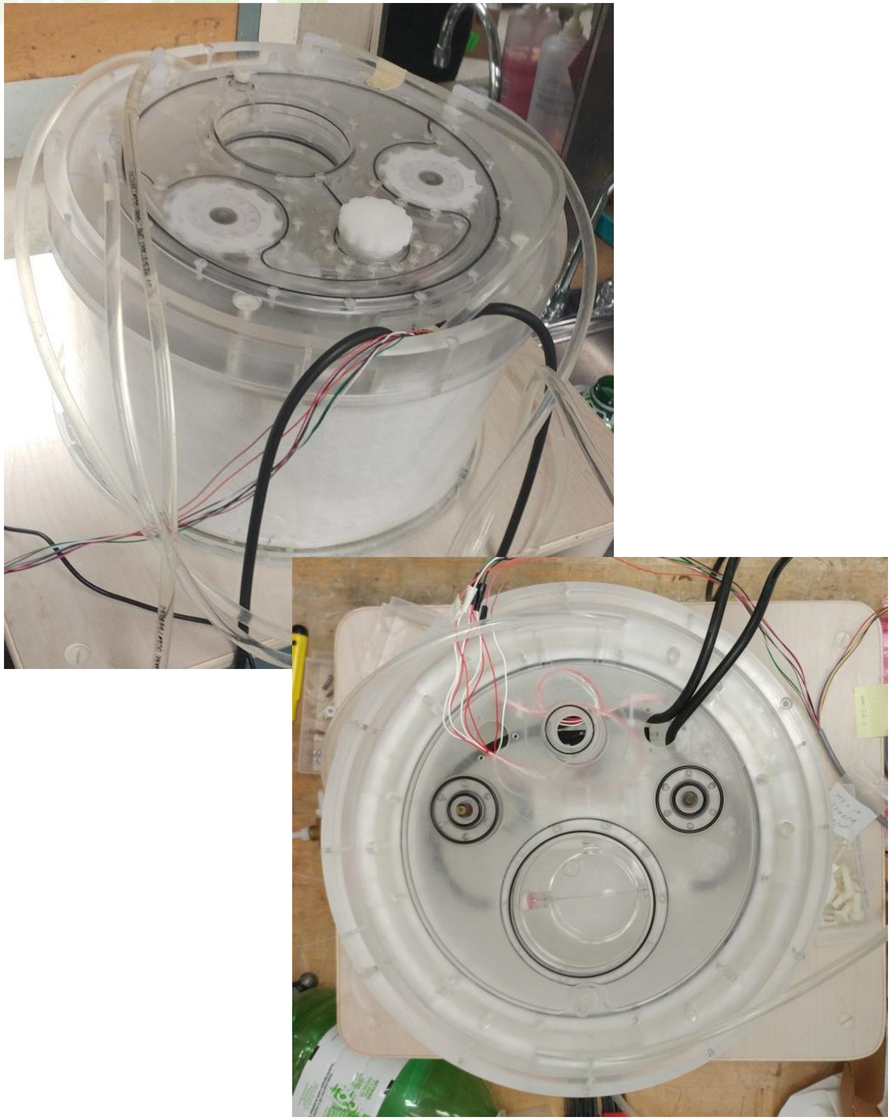
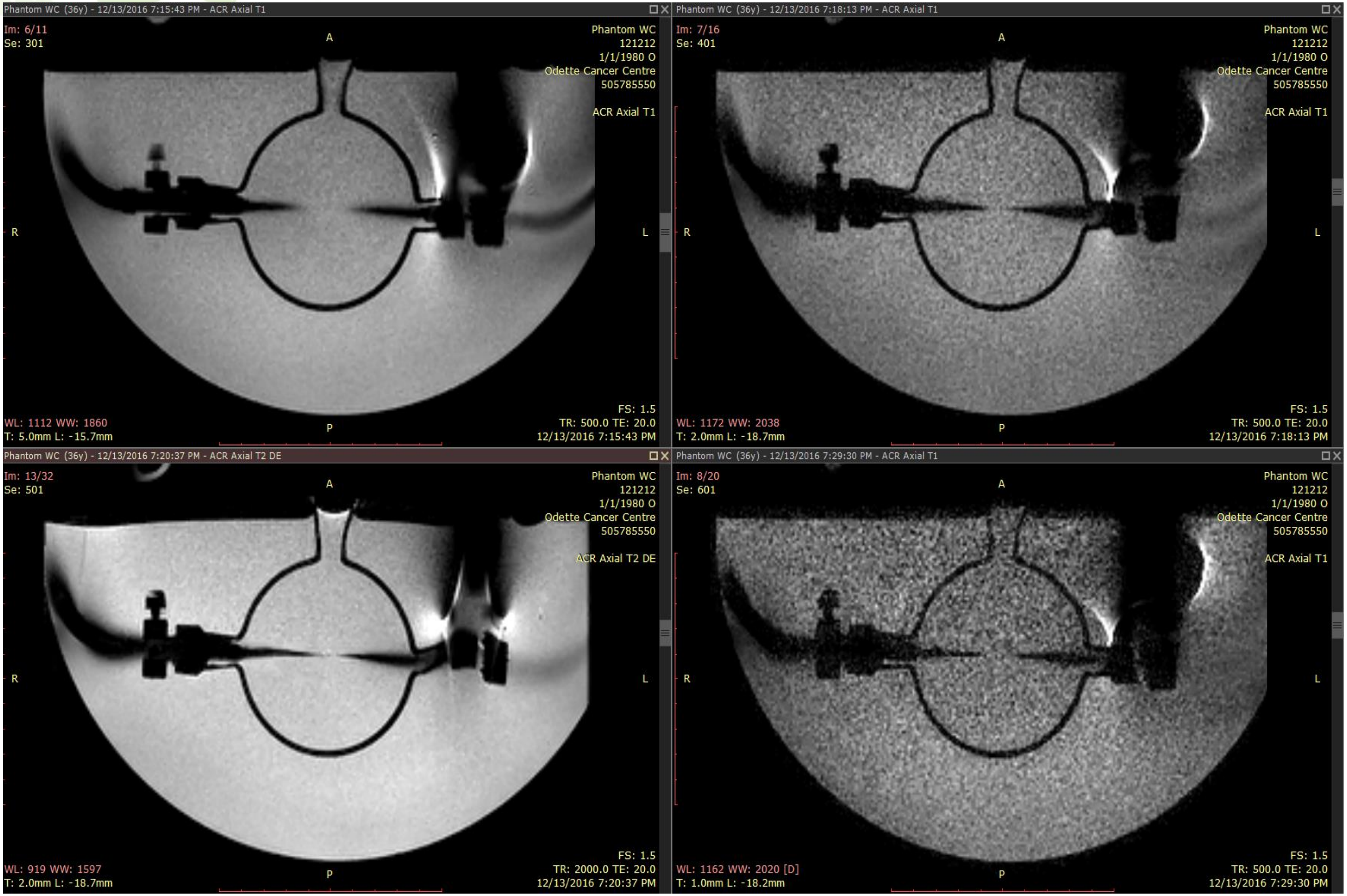
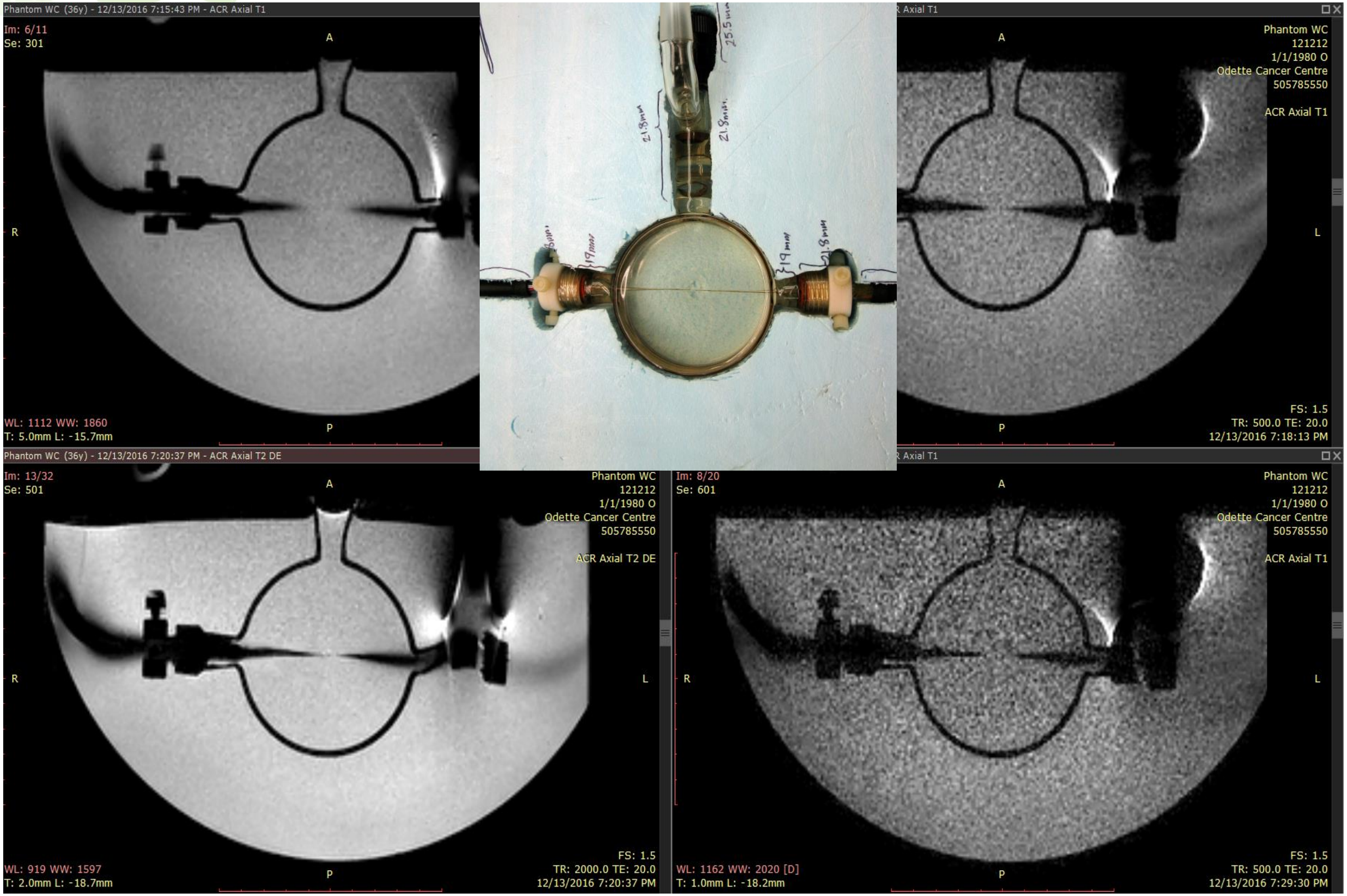


MR Sim Imaging



MR images of Calorimeter

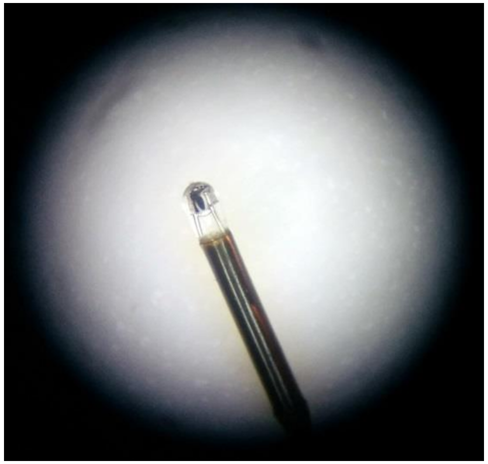


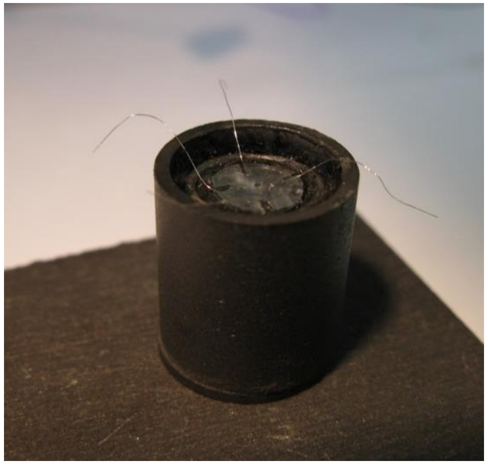
MR images of Calorimeter

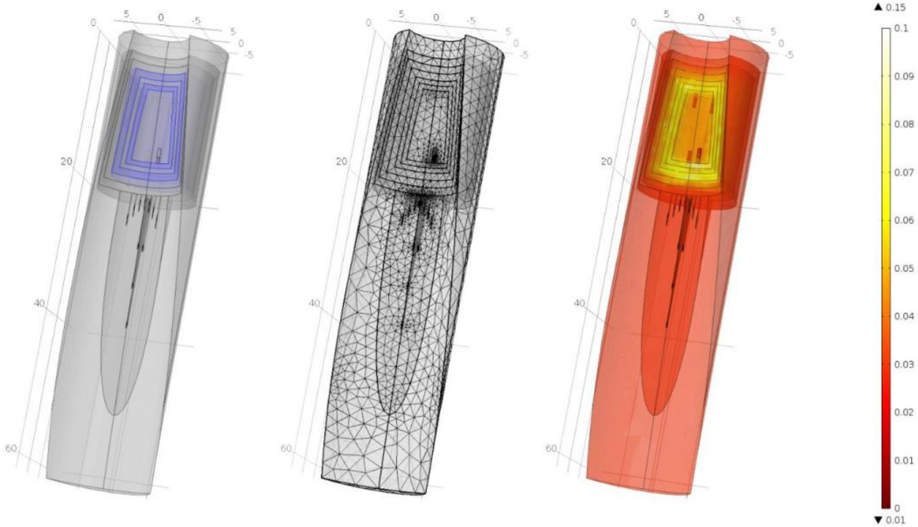
Graphite Calorimetry

- Pros: Much Higher SNR; Easy to work with
- Cons: Absorbed dose averaged over a volume in graphite

Graphite Probe Calorimeter







Patented Technology



ROBUST

EASY TO USE

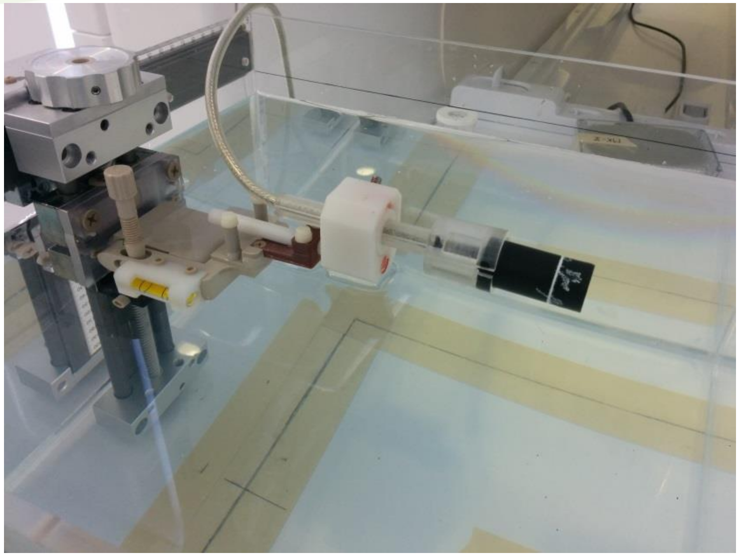
MR COMPATIBLE

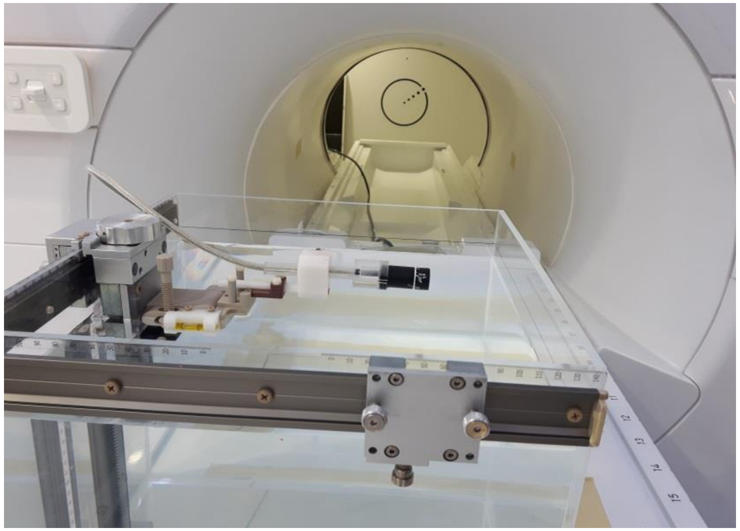
SELF CALIBRATING

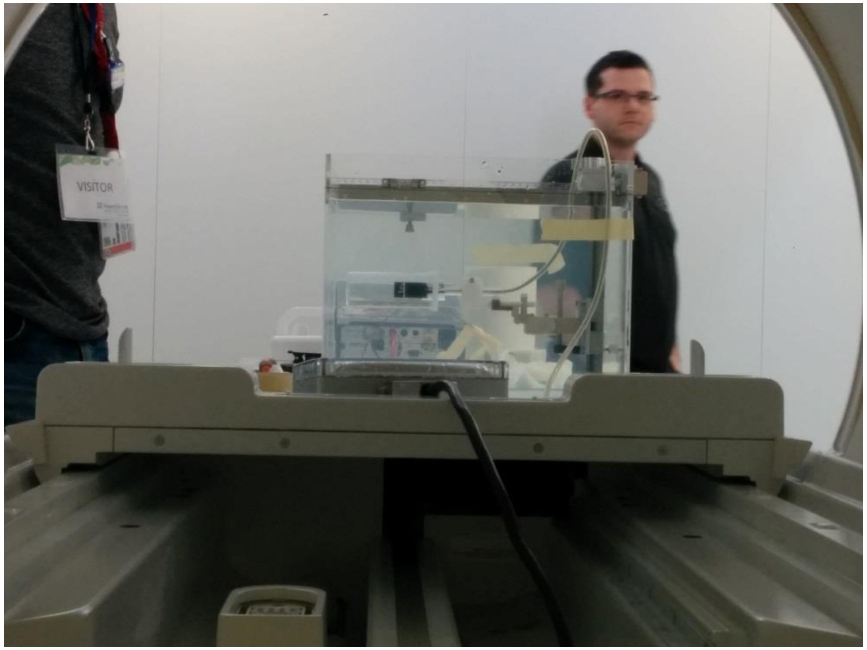

Graphite Probe Calorimeter

MEASUREMENTS

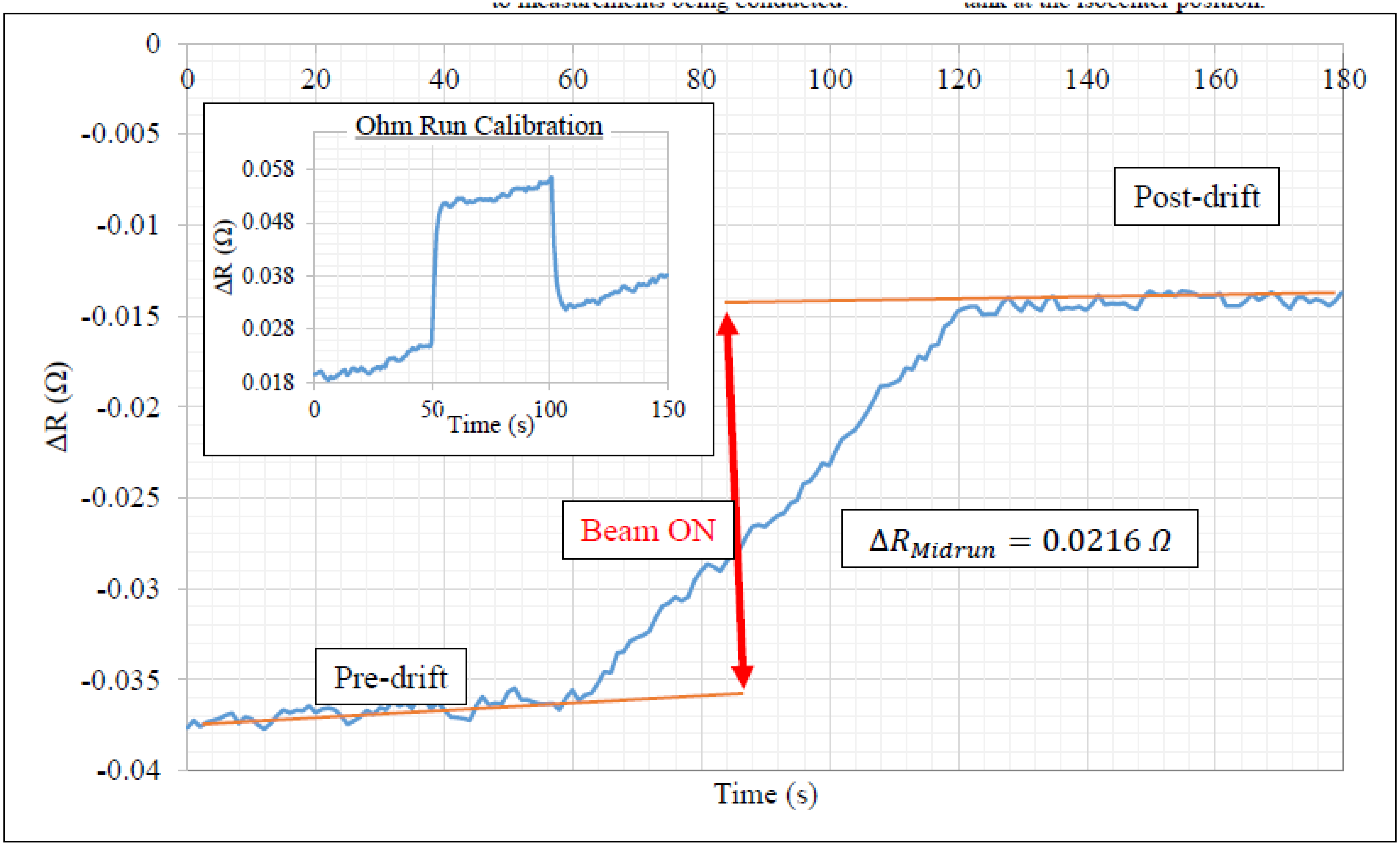
WCal Setup



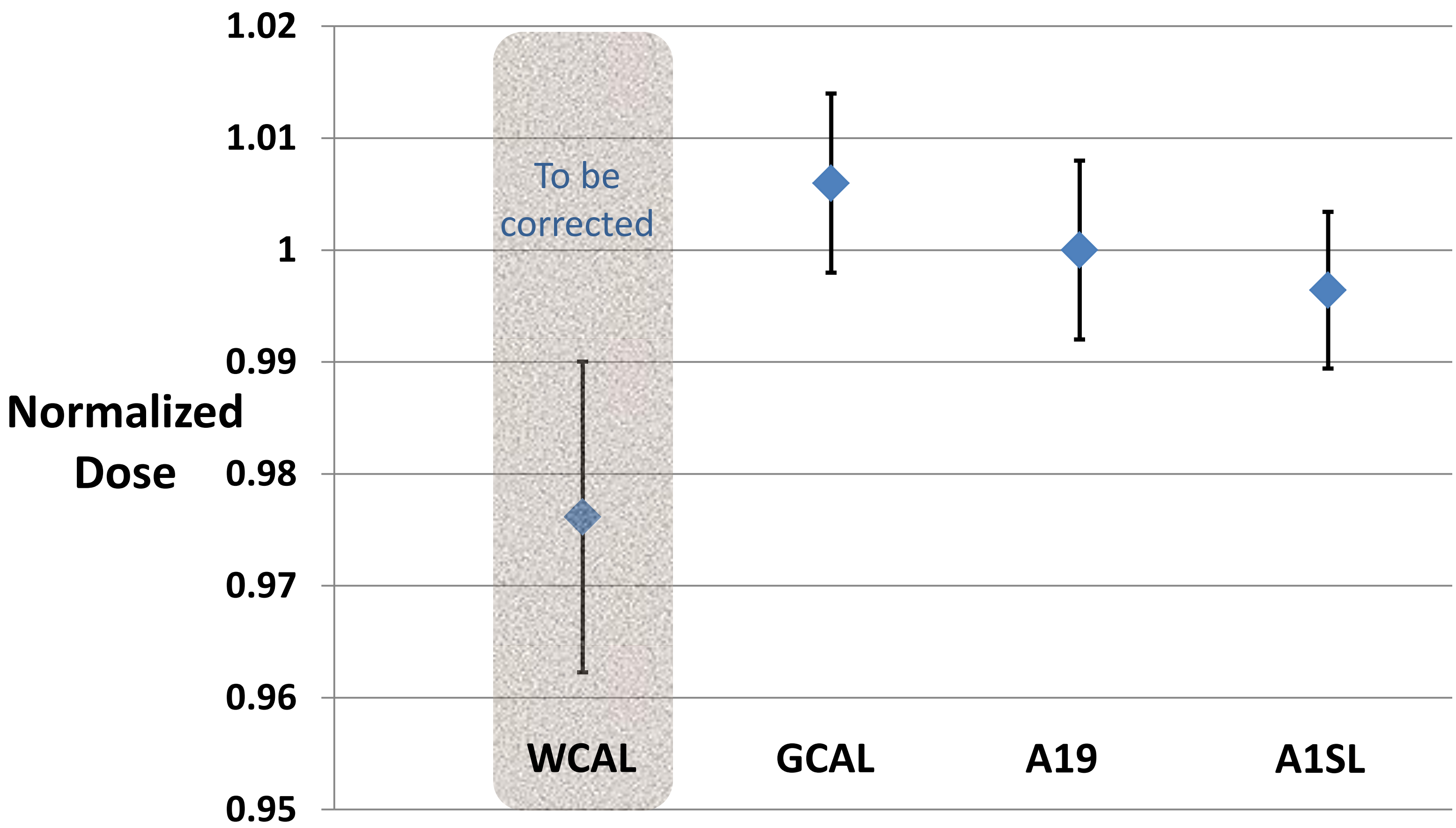




GCal Setup



Typical drifts


1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
Normalized Dose
To be corrected
WCAL
GCAL
A19
A1SL

Results

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