# Optimization and design of a glass vessel and MR-compatible water calorimeter for use in clinical photon and electron beams

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## INTRODUCTION

- Water calorimetry is a method to obtain absolute dose to water directly[1]
- In water calorimetry, the dose is obtained by measuring the radiation induced temperature change
- To minimize the presence of impurities in water that could in turn affect heat defect, the point of measurement is surrounded with a glass vessel filled with pure water[2-4]
- In calorimetry, the heat transfer correction ($k_{ht}$) accounts for additional heat loss/gain at the point of measurement

## AIMS

- To optimize the design of a water calorimeter so that it can be used in convectional linacs, MR-integrated linacs, as well as any volumetric delivery techniques
- To construct the calorimeter from materials that will enable its positioning using onboard imaging alone
- To optimize the design of a glass vessel so that it can be used for both photon and electron beams
- To use our calorimeter in a conventional linac as well as an MR-integrated linac

## METHODS

- Finite element method (FEM) analysis was used to optimize the overall design of the calorimeter (FIG 1)
- Different designs were evaluated by comparing the overall thermal stability at the point of measurement
- FEM analysis was used to optimize $k_{ht}$ for a cylindrical glass vessel
- Simulations varied vessel dimensions (front/back glass thickness) under different energies (6 MV, 7 MV-MRL, 6 MeV, 9 MeV, 18 MeV)
- Position of the vessel with respect to the measurement point was also varied
- The final designed calorimeter was completely MR-compatible and can be positioned using MR, MV, CT, and kV CBCT
- Initial measurements were taken in an Elekta Versa HD under a 6 MV FFF beam
- Measurements were also acquired in an Elekta Unity MR-linac with a 7 MV beam and 1.5 T Magnet

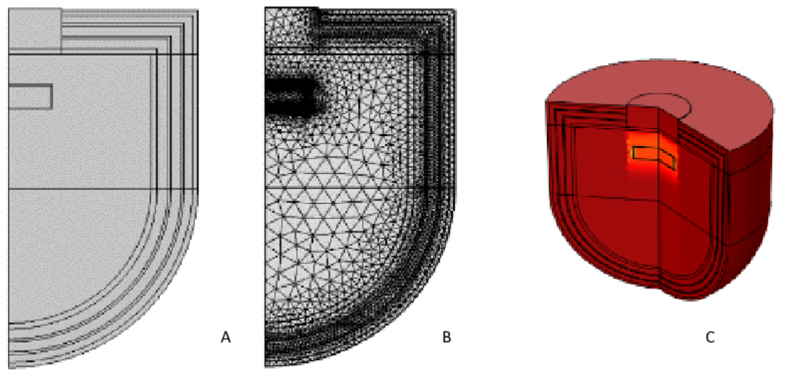


**Figure 1** - FEM analysis model showing: Geometry (A), mesh discretization (B), and thermal distribution solution (C) inside the modeled water calorimeter tank

## RESULTS

- FEM analysis showed that a three shell acrylic water tank with Aerogel acting as insulators between the shells provided the most effective insulation (FIG 2)
- The walls of the calorimeter also contain pathways for coolant to flow
- It has a cylindrical top to allow for direct beam incidence from the top, as well as a hemispherical bottom to accommodate for volumetric delivery methods
- The calorimeter lid was further insulated with a removable 38 mm piece of Styrofoam

- Glass vessel analysis showed that temperature fluctuations were most sensitive to changes in vessel glass window thickness
- For a 6 MeV beam, $k_{ht}$ was most sensitive to changes in top vessel thickness varying by as much as 8.9 % with a 1 mm change in top thickness
- For thermistor detectors positioned at distances beyond 6 mm from the top surface of the vessel $k_{ht}$ reaches a steady state for all designs (FIG 3)
- Results were used to design a glass vessel (FIG 4) with bottom and top thicknesses of 0.7 mm, with 22.66 mm between the surfaces
- This vessel can thus be used for both photon and electron beams

- The calorimeter design allows for full imaging of the tank and vessel for positioning with MRI, CT, and CBCT, enabling very rapid setup in <1h
- Measurements (n = 30) inside a 6 MV linac yielded a 0.06 % standard error with the dose agreeing to within 0.25 % of an NRC calibrated ionization chamber
- Absolute absorbed dose was successfully measured in an Elekta Unity MR-linac

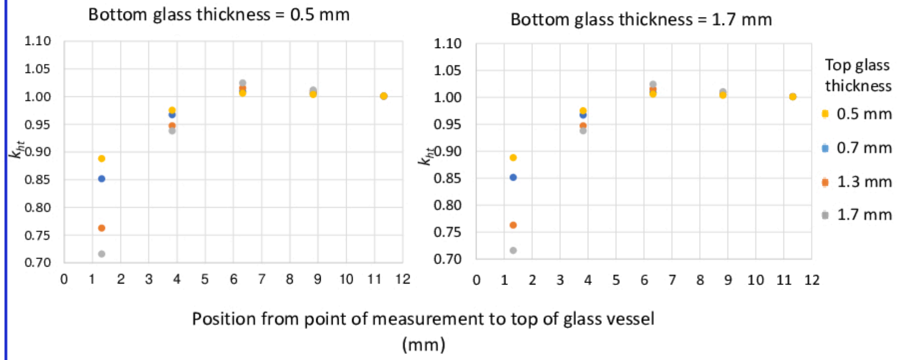


**Figure 3** - Graphs showing $k_{ht}$ vs position of measurement point for a 6 MeV beam. The color represents the thickness of the top glass plate while each graph represents a fixed bottom plate thicknesses. We can see that both graphs have the same shape regardless of bottom thickness

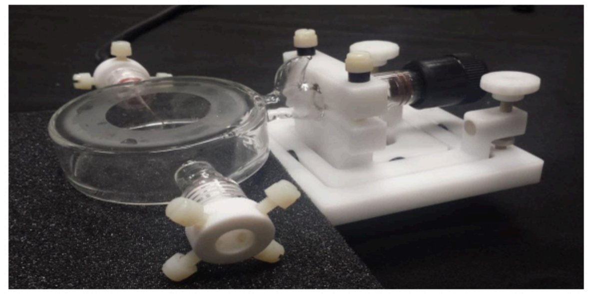

**Figure 4 –** Final constructed glass vessel inside a glass vessel holder

A. Beam window
B. Coolant pathway
C. Hydraulic stirrer
D. Cryogel®
E. Cryogel®
F. Lucite®
G. Glass vessel
H. Vessel Holder
I. Vessel holder backing plate
J. Superthane-ether tubing
K. Lucite®
L. Stirrer

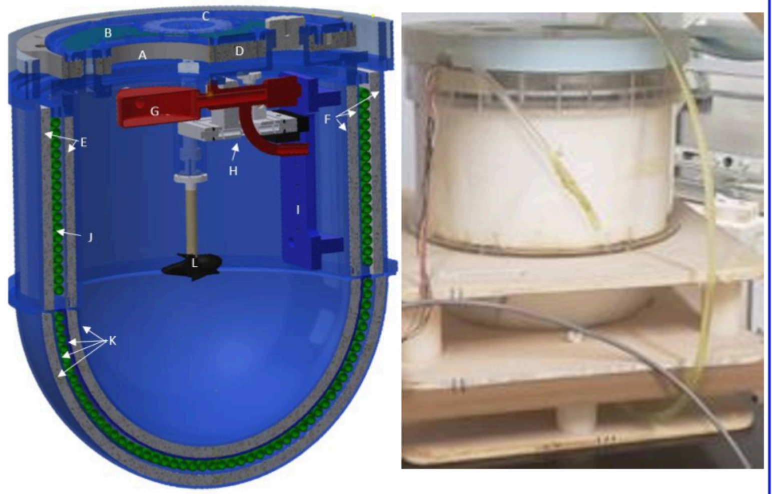


**Figure 2** - AutoCAD® generated cross-section of entire water calorimeter along with fully assembled calorimeter

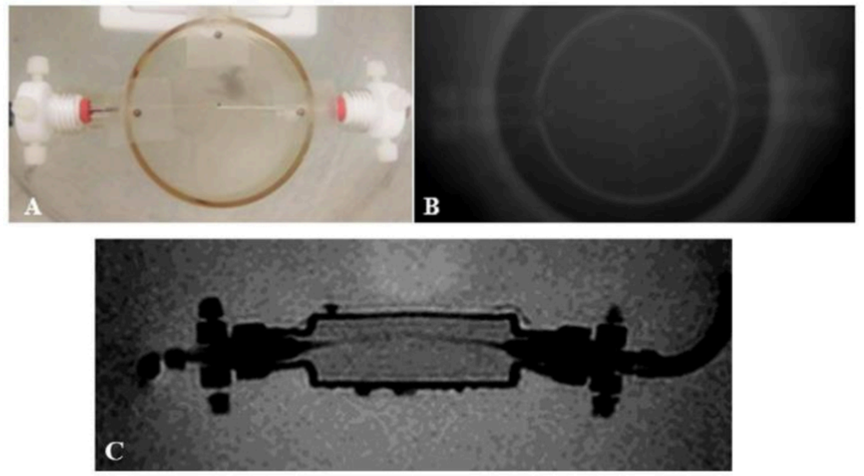


**Figure 5** A) Glass vessel in calorimeter with copper markers placed on the base of temperature detectors and at back of vessel, B) corresponding EPID image taken in MR-linac, and C) T1-weighted image of vessel taken in MR-linac showing the temperature detectors

## CONCLUSIONS

- An MR compatible water calorimeter was designed and constructed using FEM analysis
- A glass vessel that can be used for both photon and electron beams was designed using results from FEM analysis
- The calorimeter is the first of its kind that can be positioned using imaging alone

- Measurements in a 6 MV beam showed that the calorimeter can be used to accurately measure absolute absorbed dose
- The calorimeter was successfully used to measure absorbed dose in an MR-integrated linac
- Future work will focus on performing measurements in electron beams as well as volumetric delivery methods

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## REFERENCES

1. McEwen M. Primary standards of air kerma for 60Co and x-rays and absorbed dose in photon and electron beams. In: Rogers DWO, Cygler JE, eds. *Clinical Dosimetry Measurements in Radiotherapy*. Madison, WI: Medical Physics Publishing; 2009
2. Domen SR. A sealed water calorimeter for measuring absorbed dose. *J Res Natl Inst Stand Technol.* 1994;99(2):121. doi:10.6028/jres.099.012
3. Klassen N V., Ross CK. Water calorimetry: The heat defect. *J Res Natl Inst Stand Technol.* 1997;102(1):63-74. doi:10.6028/jres.102.006
4. Ross CK, Klassen N V., Smith GD. The effect of various dissolved gases on the heat defect of water. *Med Phys.* 1984;11(5):653-658. doi:10.1118/1.595547

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