UHN Princess Margaret Cancer Centre

Radiation Oncology UNIVERSITY OF TORONTO

Monte Carlo Modelling of Well Chamber Response for Calibration of Diffusing Alpha-Emitter Radiation Therapy Brachytherapy Seeds

Helena Koniar[1,2], Akbar Beiki-Ardakani[1], Jette Borg[1], Hossein Afsharpour[1,2]

1. Radiation Medicine Program, Princess Margaret Cancer Centre, University Health Network
2. Department of Radiation Oncology, University of Toronto

Introduction

Diffusing Alpha-emitter Radiation Therapy ('Alpha DaRT') is a novel brachytherapy technique that leverages the high LET of alpha particles for the treatment of solid tumours. Alpha DaRT seeds are coated with ^{224}Ra which undergoes a total of four alpha emissions throughout its decay chain to cause effective cell killing in the implanted tumour. There remains a clinical need for independent source strength verification prior to treatment delivery. Well type ion chambers are well suited for this purpose based on the energy range of photons emitted by ^{224}Ra and by preserving the sterile packaging required for pretreatment measurements.

Objective

In this work, we aimed to model well chamber response to Alpha DaRT seeds to enable simple and rapid source strength verification with readily available brachytherapy dosimetry equipment.

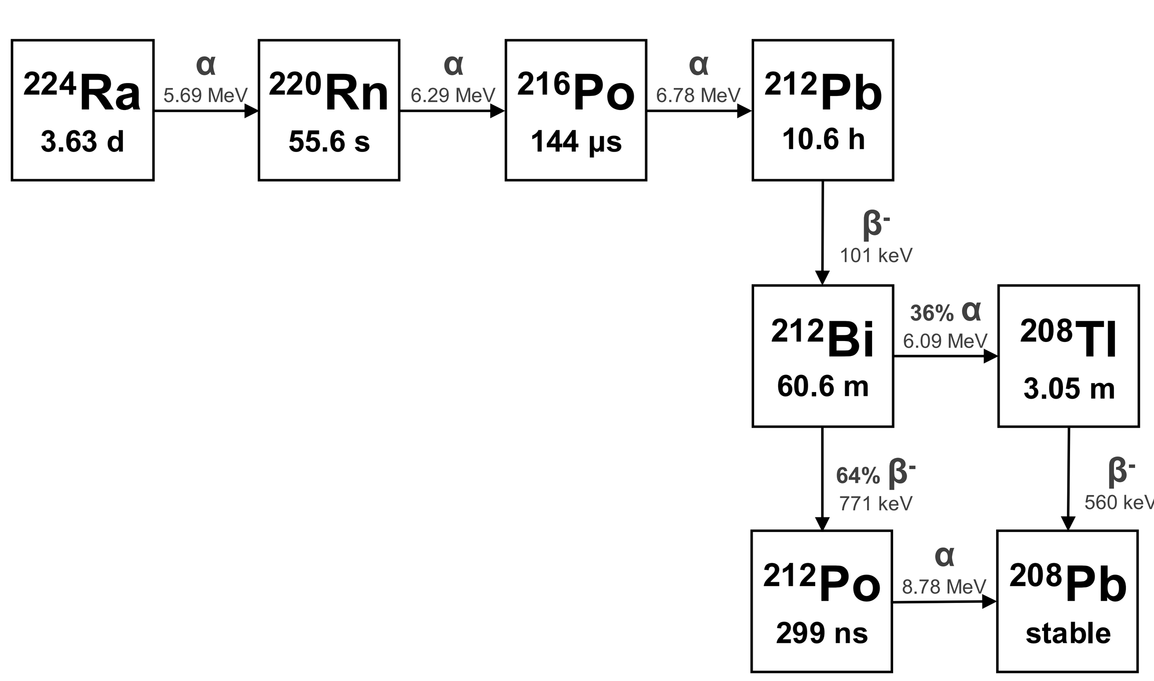

Figure 1: ^{224}Ra decay chain to stable ^{208}Pb.

Methods

Monte Carlo (MC) simulations were performed with the Geant4-based GATE toolkit to derive activity calibration coefficients in a Standard Imaging HDR 1000 Plus well chamber. Preliminary validation of the MC physics and well chamber geometry was conducted with monoenergetic photon sources ranging from 10 to 500 keV. Additionally, two clinical sources were validated, the ^{125}I IsoAid Advantage and the ^{192}Ir Flexisource, with their corresponding source holders. To model the Alpha DaRT source, decay emissions from each radionuclide in the ^{224}Ra decay chain were simulated individually and summed according to equilibrium activity conditions. Needle applicators loaded with Alpha DaRT seeds were measured experimentally and compared against MC simulations. The number of primaries was determined such that the energy deposited in the active volume of the well chamber was scored with statistical uncertainty < 0.5% for all simulations.

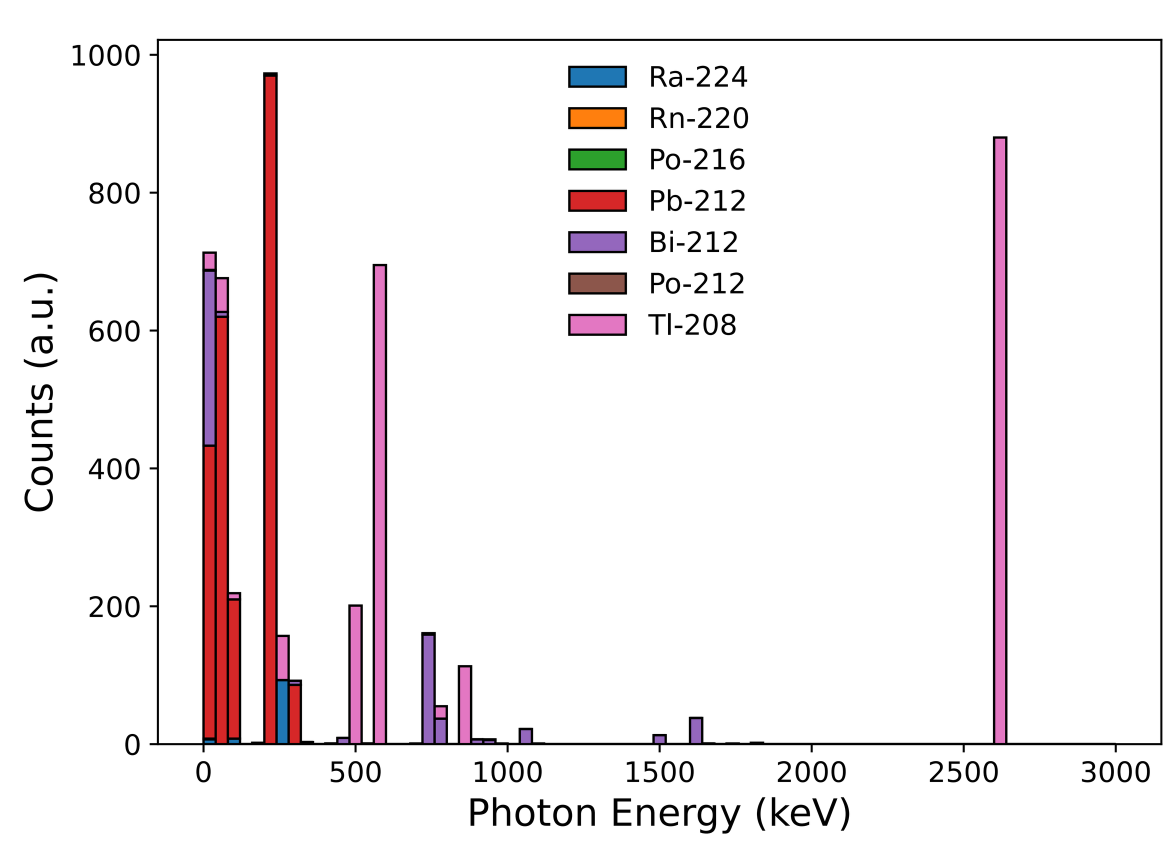

Figure 2: Gamma and x ray photon emissions from ^{224}Ra decay chain under decay equilibrium.

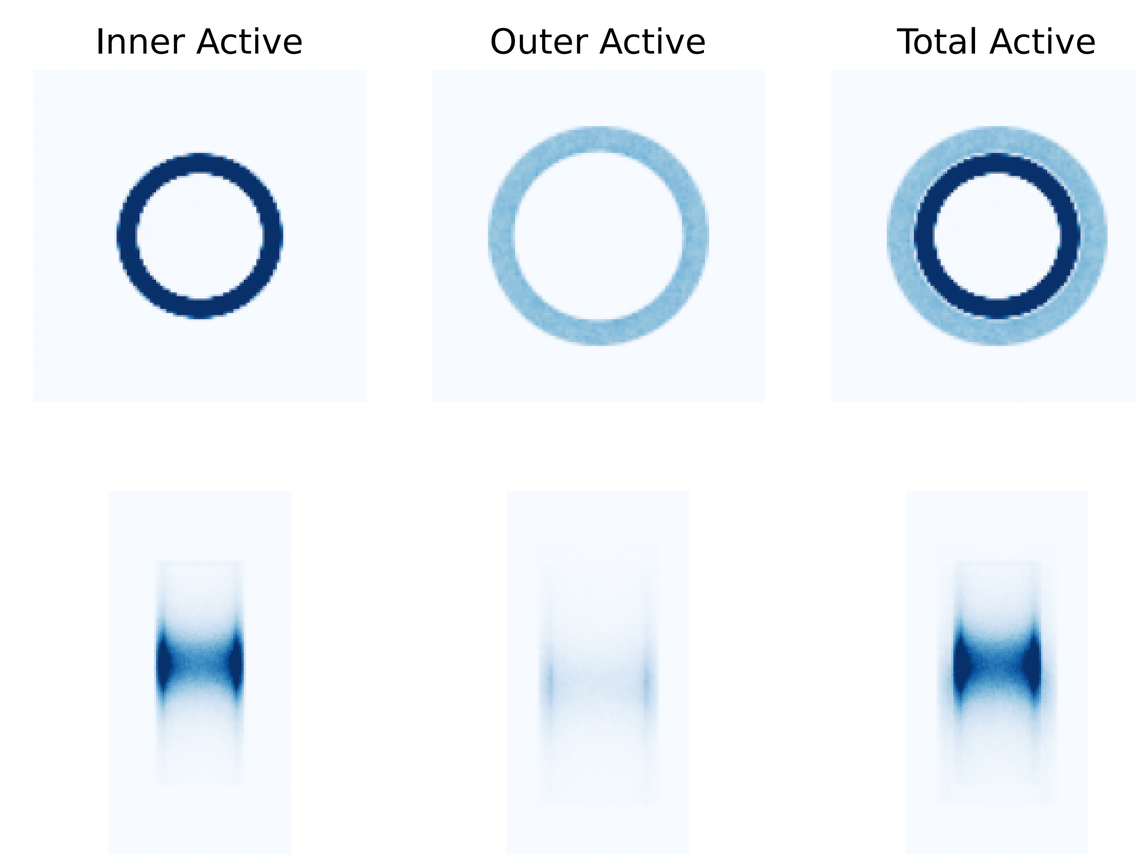

Figure 4: Axial and transverse projections of MC derived well chamber response to one Alpha DaRT seed located in the central sensitive region scored as energy deposited in the air-filled active volume per unit activity of ^{224}Ra.

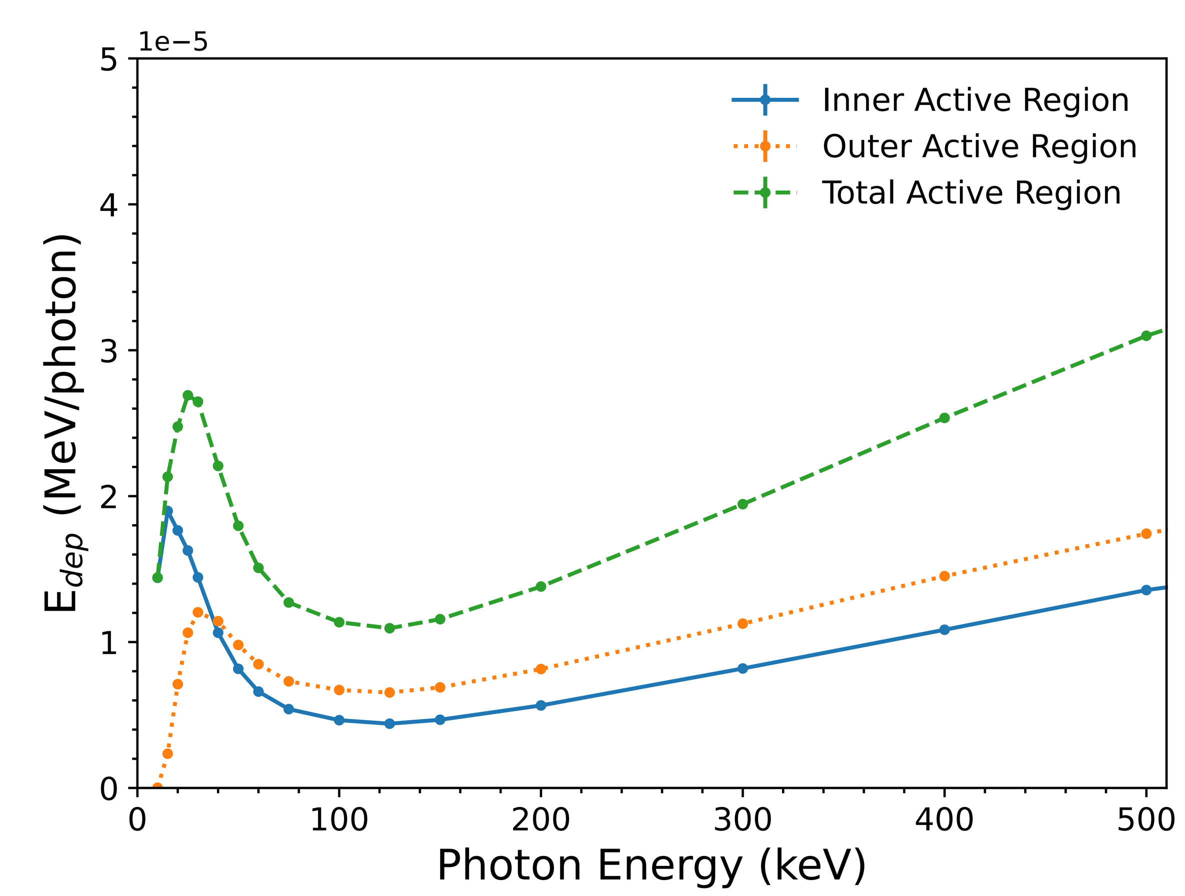

Figure 3: MC derived response of the HDR 1000 Plus well chamber to a monoenergetic photon source scored as energy deposited in the air-filled active volume per photon primary.

Results

Well chamber response to the monoenergetic photon source was consistent with the literature. MC derived air kerma strength calibration coefficients for the ^{125}I IsoAid and ^{192}Ir Flexisource clinical sources were within < 5% of calibration certificate values. Under decay equilibrium conditions, the single Alpha DaRT seed produced 0.0510 pC/kBq in a 30 s collection time. This activity calibration coefficient varied by < 1% for needles loaded with one, three, or six Alpha DaRT seeds. The MC derived calibration coefficients were consistent with experimental measurements within < 3% variation.

Discussion

We present for the first time, to the best of our knowledge, a method for independently verifying the source strength of Alpha DaRT seeds prior to treatment. These MC derived activity calibration coefficients provide an important tool for quality control in active clinical trials investigating Alpha DaRT efficacy for various solid tumour indications.

Conclusion

MC derived activity calibration coefficients were determined to correlate the charge collected by the well chamber to the total ^{224}Ra activity. Our results demonstrate the utility of well chamber measurements for pre-treatment verification of Alpha DaRT source strength.