Proton Physics Research and Implementation Group Workshop
November 2023

Model for out-of-field doses in proton beam therapy for paediatric abdominal neuroblastoma

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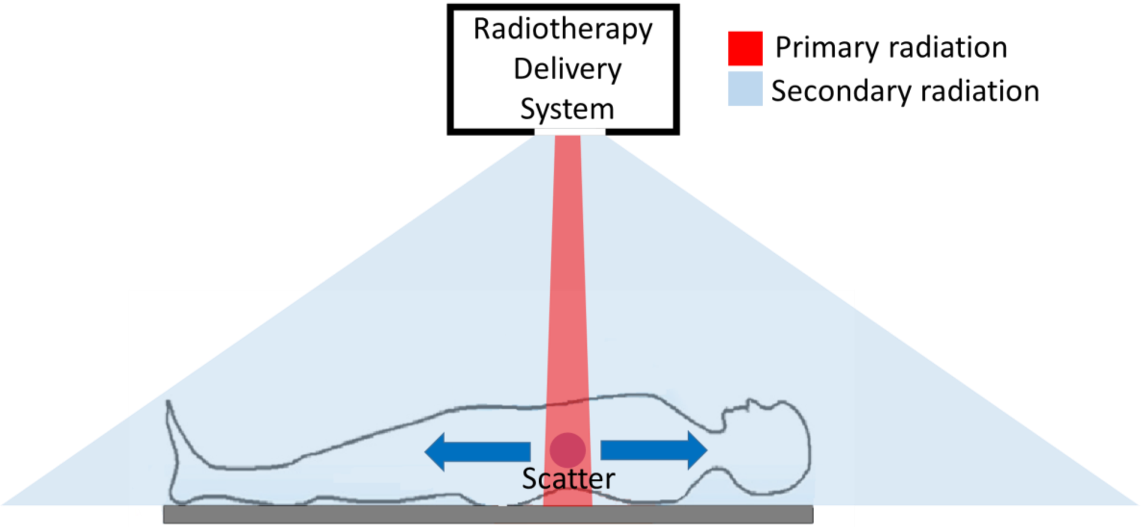
Introduction

- Each year, more **than 300 000 children** are diagnosed with cancer around the world
- More than 50% of patients receive radiotherapy (any form)

In the UK, 76% of paediatric patients survive for more than 10 years

What is the risk to develop radiotherapy treatment induced late effect?

- **Second cancers:**
  - 19% of all cancers are second cancers
  - main cause of mortality amongst the population of long-term survivors



(adapted from Newhauser et al, 2016, Frontiers in Oncology)

Tumour response → **Dose in-field**

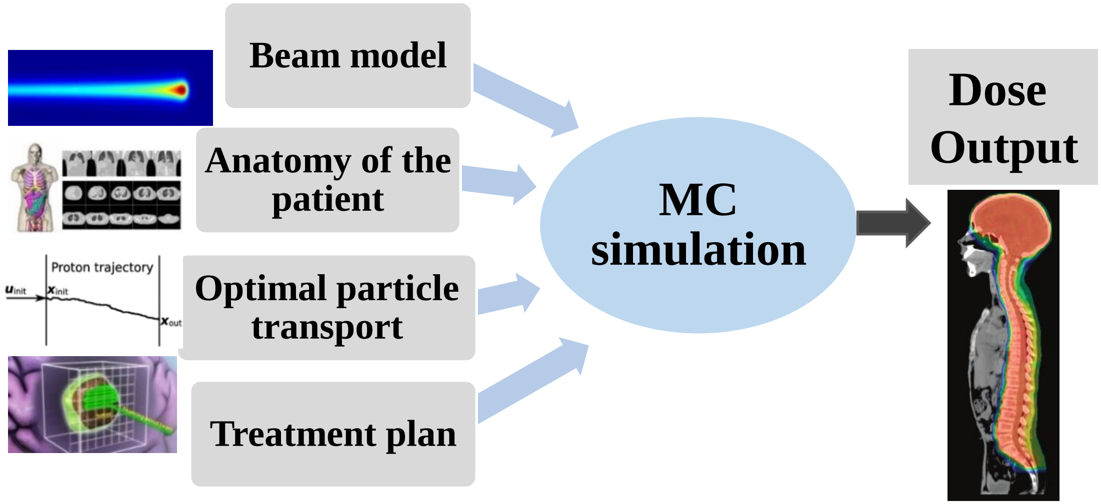
Late effects → **Dose in-field**, **Dose out-of-field**

Aims and motivation

- Patient dose distribution maps recorded within the clinics present uncertainties:
  - out-of-field dose
  - no anatomical information
- **Full-body dosimetry is required for epidemiological studies of radiotherapy-induced second cancers**

<u>The aims of this work were:</u>

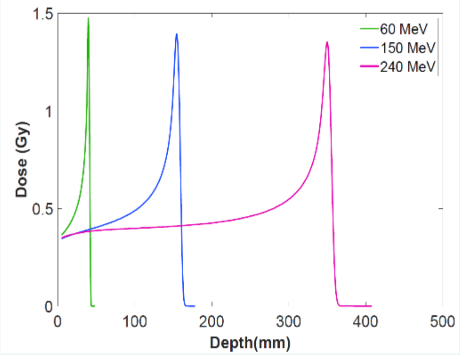
1. Develop a parametrised Monte Carlo (MC) beam model of the proton beam scanning system at UCLH
2. Calculate out-of-field neutron equivalent doses using the clinical model for a cohort of abdominal neuroblastoma patients
3. Compare the MC neutron dose to analytical neutron dose models in the literature



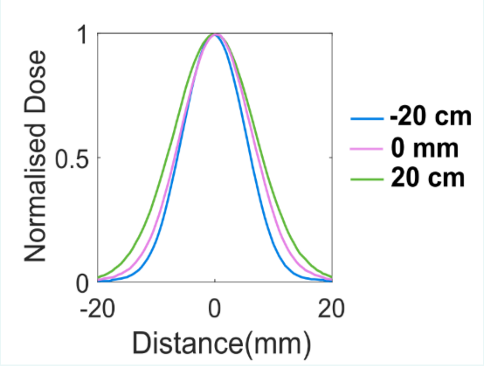
Beam model: in-field dose validation

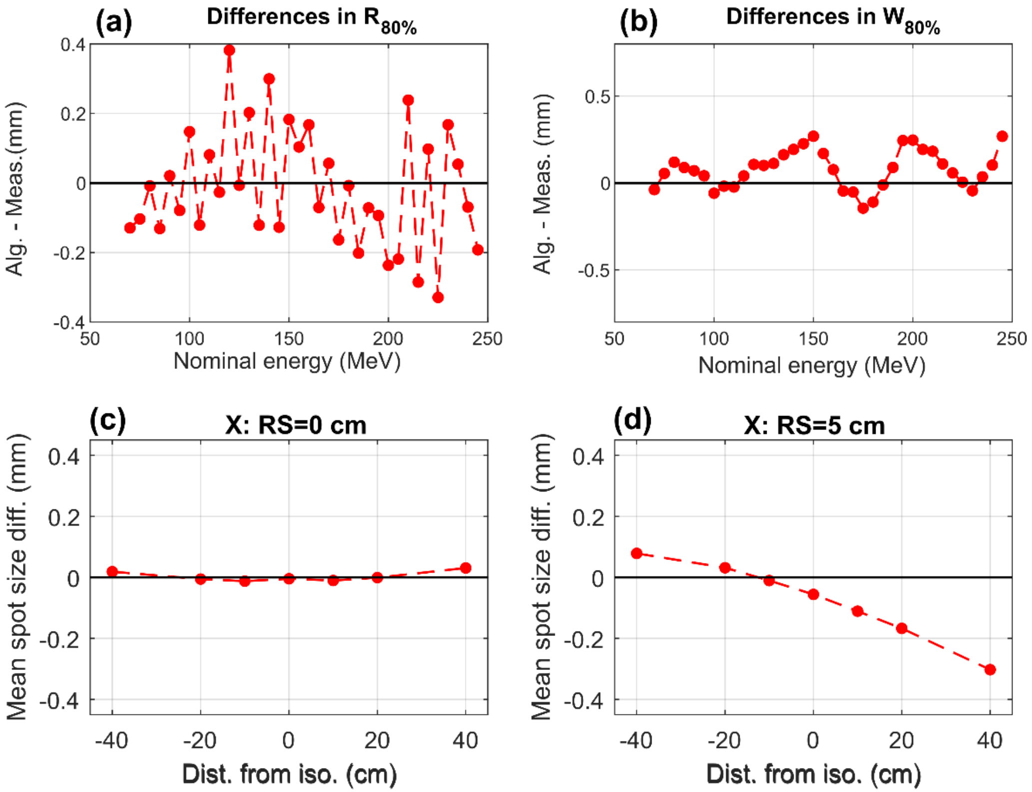
- GATE Monte Carlo code
- **The beam energy and optical properties of the source are tuned to match the beam commissioning data, through an iterative process**

Integral depth dose (IDD) in water

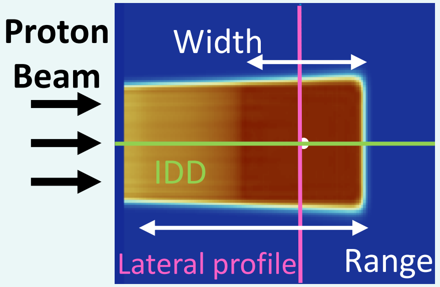


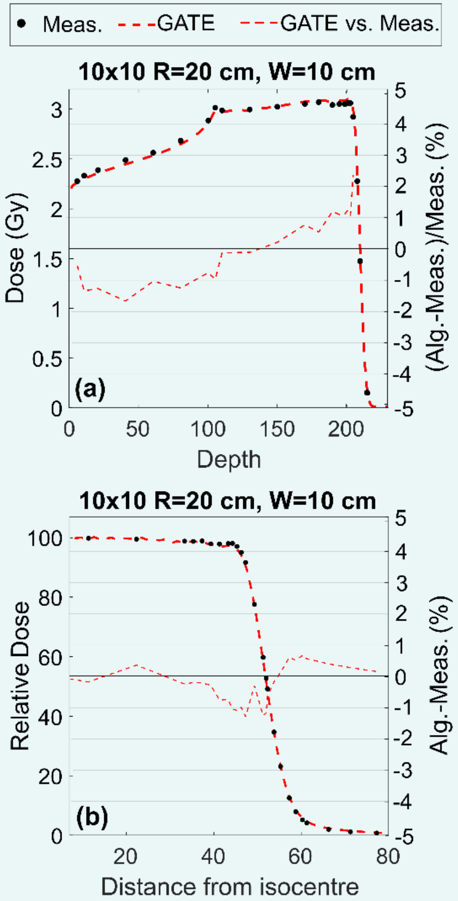
Transverse profiles in air





Botnariuc et al, 2023, PMB (under revision)



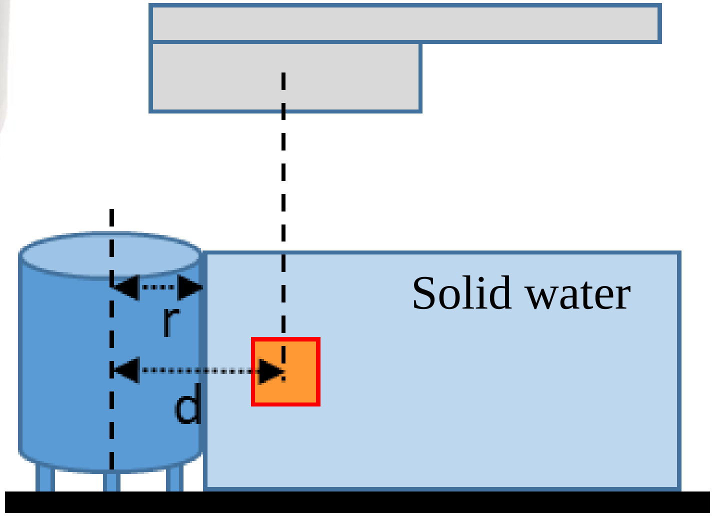


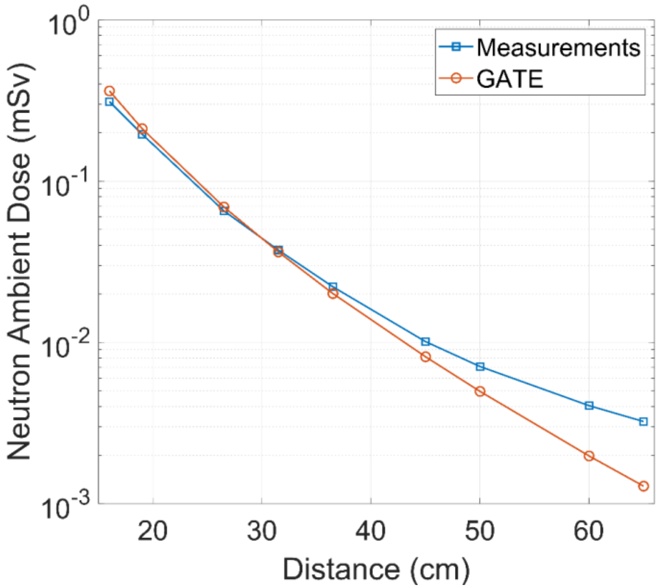
Beam model: out-of-field neutron dose validation

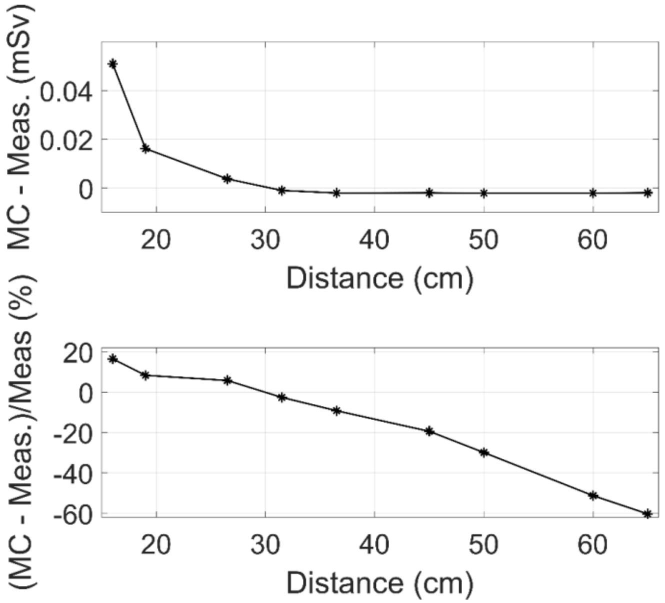
- Neutron ambient dose using the WENDI 2 detector
- 5×5×5 cm^3 field (energies 150 MeV – 90 MeV)
- 10 distances, d

- Dose decreased with increasing distance from the field
- Absolute differences were within 50 μSv
- Percentage differences within 60% for the larger distances

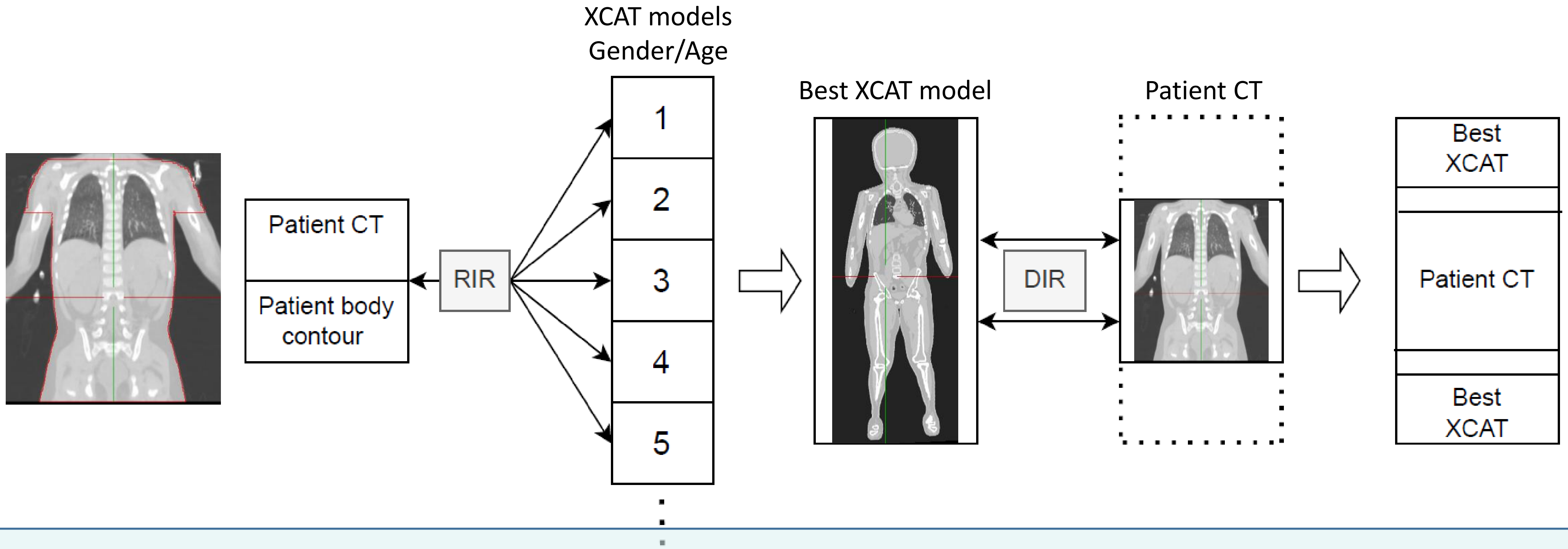
Thermo Fisher Scientific Inc.







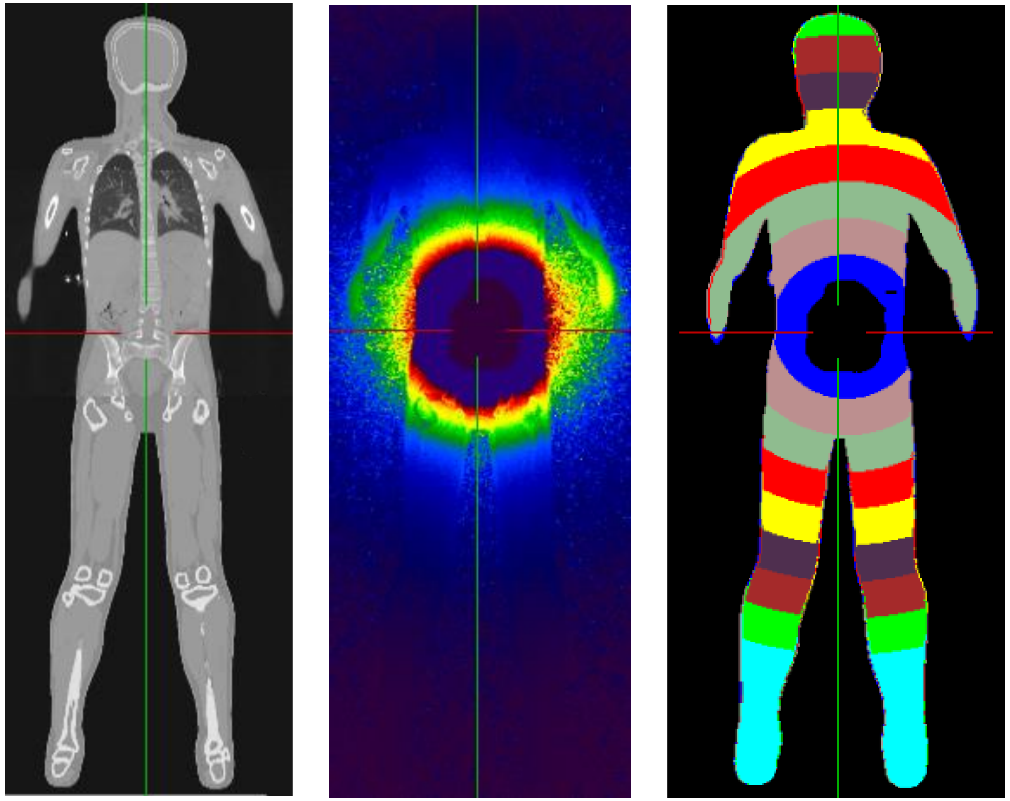
Anatomy of the patient: Hybrid Phantom (HP)



- 5 neuroblastoma cases: CT image contains thorax and abdomen
- Extend the CT images of the patients to full body phantoms using XCAT computational models – hybrid phantom
  - Find the best matching XCAT model for each patient
  - Use deformable image registration to create the hybrid phantoms
  - Organ contours: contained within the CT image + contained within the XCAT model + merged organ contours

HP: neutron dose as a function of distance

Hybrid phantom | Neutron dose map | Distance map



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/gate/actor/np/addFilter particleFilter
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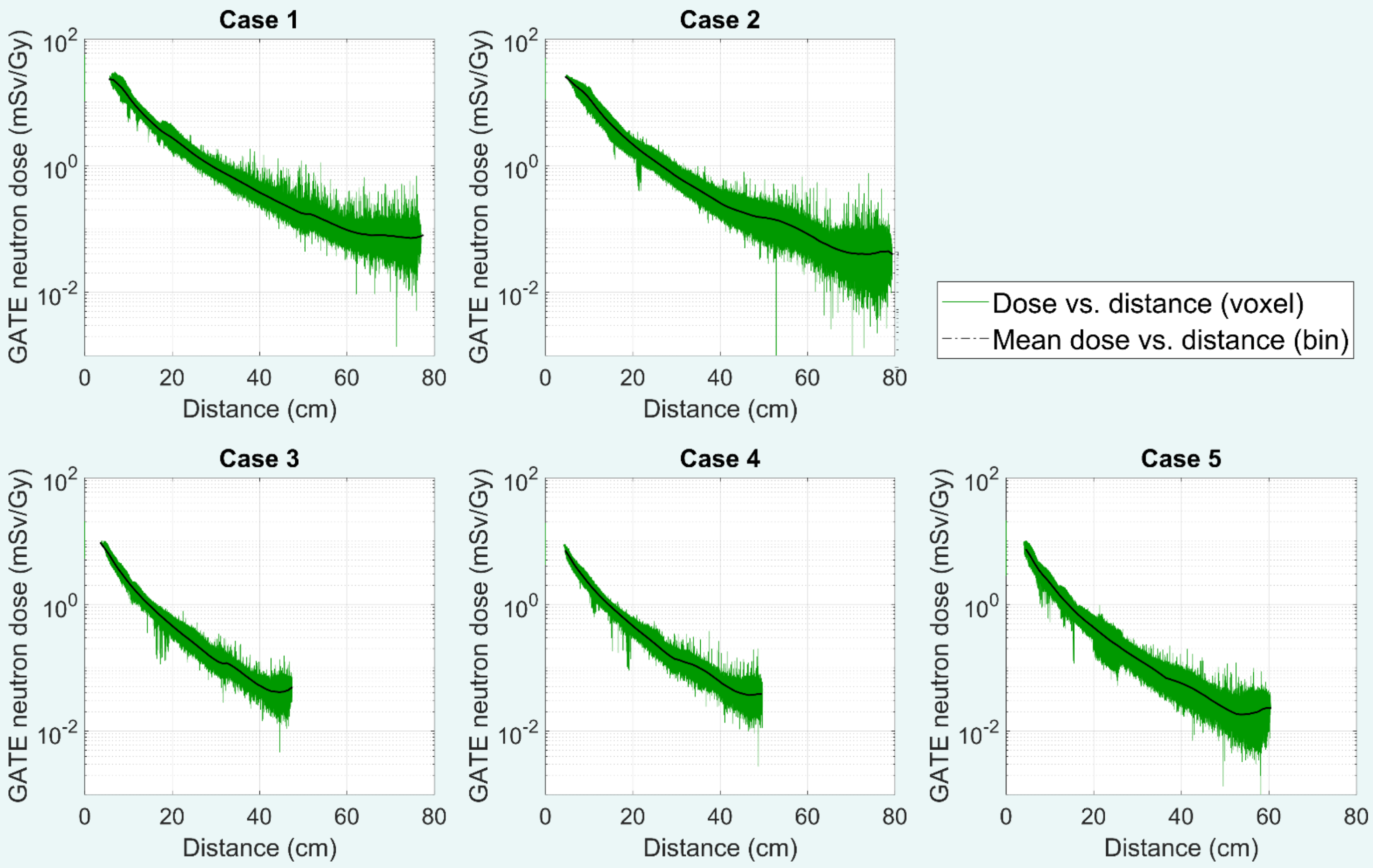
Neutron radiation factor: 10

- Case 1 and case 2: older patients, larger fields, higher energies
- Cases 3, 4 and 5: younger patients, smaller fields, lower energies



Analytical models of neutron dose

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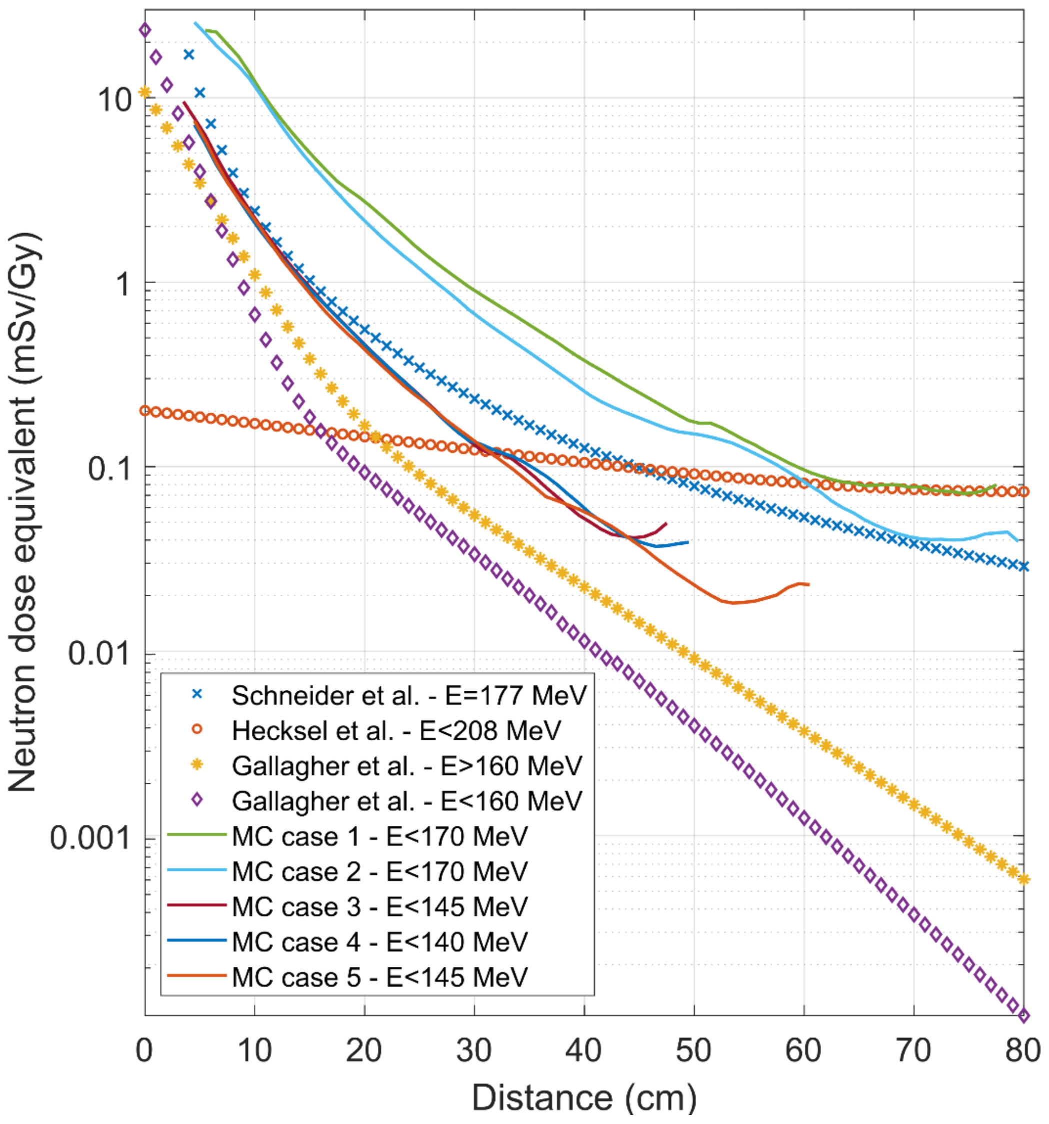
	Model setup	Phantom	Beam type	Gantry angle	Energy	w_n
Schneider et al.	Measurements Bonner Sphere and Etch detectors	Water phantom	Pencil Beam	270°	E = 177	7
Hecksel et al.	Measurements with NRD (Thermo Fisher) Prostate field	Anthropomorphic Phantom Patient™	1 field	0°	E<208	-
Gallagher et al. – High Energy	Monte Carlo Brain treatment	Real patient (9-year-old female)	1 field	180°	E > 160	7.9
Gallagher et al. – Low Energy	Monte Carlo Brain treatment	Real patient (9-year-old female	2 fields	97° and 263°	E ≤ 160	7.9

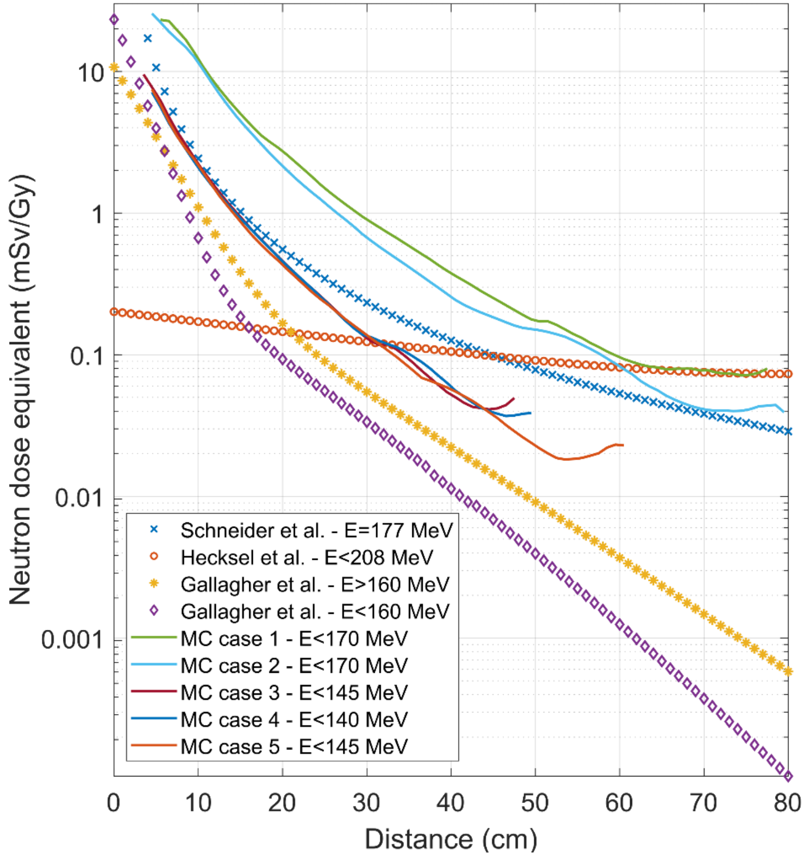
- All models except Hecksel et al. showed similar trends with distance
- GATE doses for cases 1 and 2 were higher across all distances
  - Higher treatment energies and larger field sizes used for larger patients
- The Schneider et al. model presented maximum differences of a factor of 5 against GATE
- The Gallagher et al. model underestimated the dose by a factor of 100 for distances higher than 50 cm in comparison to GATE

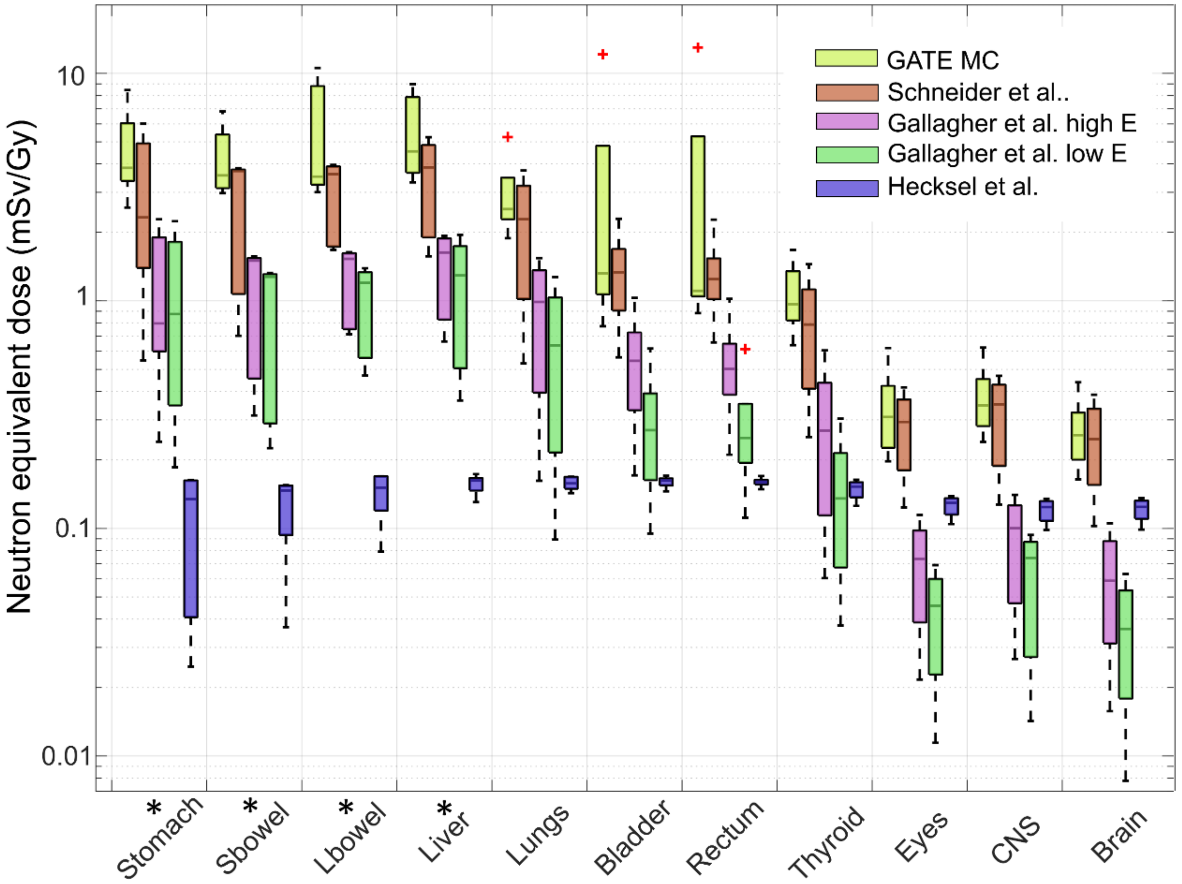


Analytical models of neutron dose

- MC and Schneider et al. models had the highest doses for all organs
- Gallagher et al. presented the lowest doses for organs further away from the PTV
- The Hecksel el al. model showed similar dose values for all organs

*Organs partially-in-field.





Conclusions and future work

- We developed a MC-based framework to simulate full-body neutron dose in proton beams using our clinical beam model
- The MC model appears consistent with literature models despite different beam configurations used
- Analytical models may be suitable for preliminary second cancers risk estimation

Explore further:

- Understand the impact that the differences in neutron dose (MC vs. analytical models) have on second cancer risk estimation
- Further validate the MC neutron dose against experiments:
  - Longitudinal beam direction
  - Field size impact
  - Range shifter impact

A lot of variability in the literature upon reporting neutron doses:

- Physical dose
- RBE dose
- Equivalent dose (w_R)
- Normalised by prescribed physical or RBE dose
- Ambient dose equivalent (WENDI detector)

Acknowledgements

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QUESTIONS?

cmic
Centre for Medical Image Computing

NHS
University College London Hospitals
NHS Foundation Trust

rtic

PRT

Royal Academy of Engineering

FCT Fundação para a Ciência e a Tecnologia
SFRH/BD/145287/2019