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BestMasters
ISBN 978-3-658-13167-8 ISBN 978-3-658-13168-5 (eBook)
DOI 10.1007/978-3-658-13168-5

Library of Congress Control Number: 2016932889

Springer Spektrum

Printed on acid-free paper

This Springer Spektrum imprint is published by Springer Nature
The registered company is Springer Fachmedien Wiesbaden GmbH

Acknowledgments

This thesis would not have been possible without the help and support of many people.

Above all, I would like to show gratitude to my supervisor, Prof. Dr. Katia Parodi, who has supported me throughout this entire project. Japan, Texas, Heidelberg or in the office - no matter how far away, I could always count on immediate and certainly valuable help. Her way of asking questions always made me think twice about things that seemed clear to me. I am glad to have the opportunity to work at her chair for the next few years.

I express my warm thanks to my external supervisor, Dr. Martin Hillbrand, from the Rinecker Proton Therapy Center for his invaluable and kind support and for making this work possible. Hundreds of e-mails and hours of talking provided me a deep insight into clinical practice in proton therapy. It was a true pleasure to perform the PET activation experiments together, although probably many employees of the RPTC wondered about our "early morning exercises".

Furthermore, I would like to thank the team of the RPTC, which was directly or indirectly involved in my research project. Especially Andrea Schieh-Schneider, Želka Geočelović and Cornelia Mühler made the time I had to wait for the PET reconstructions to be ready, appear significantly shorter.

Many problems and questions I had within this project could be answered with the help of scientists from our chair or from HIT. I would like to express gratitude to Dr. Georgios Dedes and Dr. Guillaume Landry for helping me with Monte Carlo and computational issues, as well as Dr. Julia Bauer for her help concerning the PET activation studies. Moreover, I want to thank Franz Englbrecht for the fruitful discussions and the wonderful teamwork - I am looking forward to the next three years...

I would also like to thank the mechanical workshop of our faculty here in Garching, represented by Rolf Oehm for making the phantoms I used in this work.

In the beginning of this project, the PET/CT scanner used for the experiments was a closed book to me. I therefore want to thank Cataldo Tarantino from the Philips customer support and Dr. Christian Zach from Klinikum Großhadern for giving me useful hints and information on this scanner.

Garching would be a really boring place without the presence of my (former) colleagues Eva, Susanne, Ben, Konstantin, Jonas, Michael, Andreas, Daniel, Basti, Tiago, Hugh, Kathrin, ... Thank you very much for the time we spent here and outside the campus.

Finally, I want to thank all the people that supported me within the last two years and on which I could always count. I want to say thank you to my parents, to my sister Michaela and my brother Thomas, to my friends Tom, Clara, Markus, Jakob, Jonas, Claus, Martin, Tobias, Santiago, Johnny, ... and especially to Jennifer, for always supporting me and trying to understand my work ;-).

Matthias Würl

Abstract

For the full clinical exploitation of the ballistic advantages of proton beams for radiation therapy, accurate knowledge of the location of dose deposition in tissue is necessary. A dedicated tool for monitoring the dose deposition in-situ and in vivo is positron emission tomography (PET). The implementation of this method requires a detailed Monte Carlo model of the clinical proton beamline for the exact dose calculation and β^+-activity prediction. For the latter, reliable cross-section data of the β^+-emitter production channels is needed.

The purpose of this work was therefore to perform two fundamental steps towards the implementation of offline PET monitoring at the Rinecker Proton Therapy Center (RPTC). First, a correct modeling of the proton beam spot scanning and the absolute dose output was established. This included a study of the influence of the low-dose envelope of scanned proton beams on the total dose output. Monoenergetic square fields, as well as homogeneous dose spheres of different sizes were planned with the treatment planning system (TPS) XiO®, and its predicted dose compared to measurements and simulations. Simulated doses agreed nicely with measurements for all square and sphere sizes, but for small squares and spheres the dose predicted by the TPS significantly differs. For treatment plans including small fields it is therefore recommended to verify planned doses by measurements or MC simulations prior to patient irradiation.

The second step towards offline PET monitoring was to validate an experimental cross-section data set at the RPTC for the most relevant β^+-production channels. For this purpose, 3 phantom materials (PE, gelatine and PMMA) were irradiated and the proton-induced activity was measured by a full-ring PET/CT scanner. Production yields were extracted from the measured activities and compared to calculated yields from FLUKA MC simulations and data from HIT and GSI. Integral positron emitter yields measured at the RPTC are comparable to simulated yields using experimental cross-sections. Comparison to simulation results using the internal hadronic model of FLUKA for calculating β^+-emitter yields confirms the findings of previous publications, which recommend to use experimental cross-sections instead. The largest difference to the data from HIT is 18.3 %, whereas yields are heavily overestimated at GSI. The scatter correction applied by the relatively old scanner during PET image reconstruction displaces a significant amount of activity at locations far beyond the proton penetration depth. Therefore, no fine-tuning of the production cross-sections could be performed due to the unreliability of the reconstructed activity spatial distributions for the considered irradiation scenarios.

In order to check the linearity of the PET scanner with the activity level, further irradiations and measurements were performed with different numbers of delivered protons. These data could confirm that due to dead time losses, the scanner underestimates measured activities with increasing level of phantom activation. This resulted in an underestimation of production yields by up to 8 % for the PE phantoms. Instead of delivering as much protons as possible for the sake of good statistics in the dynamically evaluated PET images, a trade-off between high count-rate and dead time losses has to be made when performing thick phantom experiments to validate and fine-tune cross-sections for PET monitoring.

Munich, December 2015
Matthias Würl

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