Development of proton range verification by use of titanium implants and PET

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Background and Objective

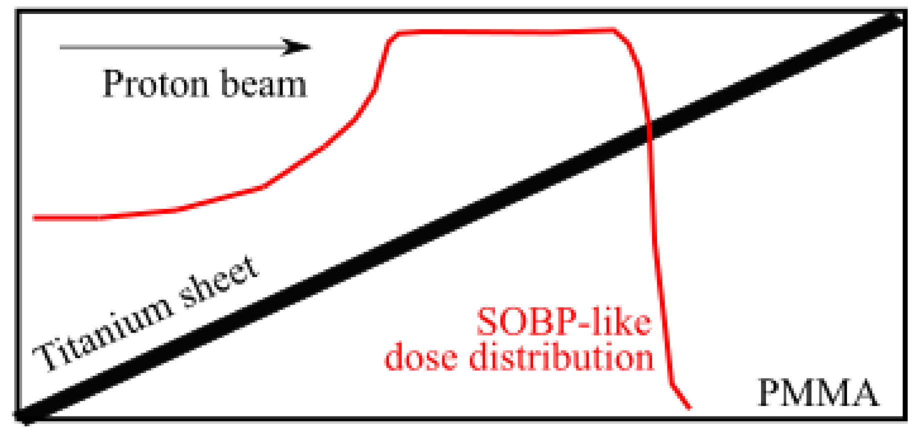
Proton beam range verification by positron emission tomography (PET) has been discussed in several publications in the past. As in off-line PET imaging, the activity in the tissue is subjected to the biological wash-out, implanted markers are supposed to avoid this limitation [1]. This study investigates the activation of titanium-based implants which are used in surgical resection prior to the proton therapy because of their biocompatibility and can be found especially in CT images of brain tumor patients.

Methods

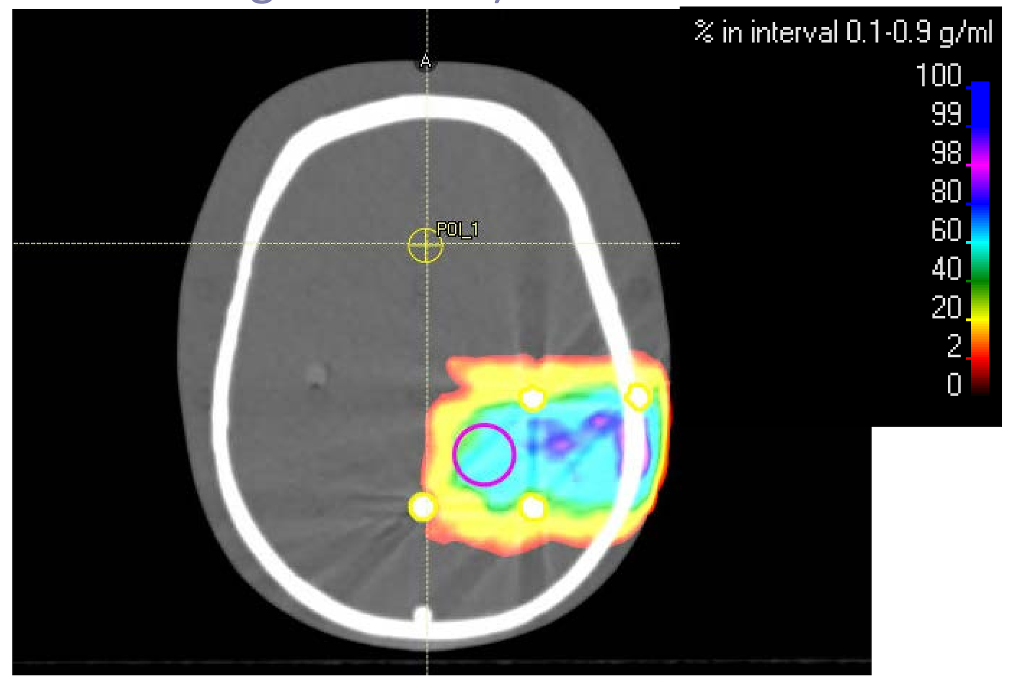
The general potential of titanium implants for field verification has been demonstrated with the irradiation of a slanted angle phantom and a PET scan of the titanium sheet in a small animal PET [2].

Transfer to clinically geometries

- Using a human PET scanner (Siemens Biograph64 Vision600) for the activation study and scanning the complete phantom (not only titanium parts) while 4 h after irradiation
- Irradiation of the slanted angle geometry with two different proton fields
  1. Quasi-monoenergetic field which stops inside the phantom (10 CGyE to the Bragg peak)
  2. SOBP-like dose distribution on a cubic target volume (5 CGyE to the target volume)
- Irradiation of a second phantom with four dedicated implants (sheets) with a SOBP-like dose distribution to a virtual target volume (2 CGyE to the target volume)
- Irradiation of an anthropomorphic head phantom with one single proton field (2 CGyE to the virtual target volume)



Slanted angle geometry with titanium sheet (black) in the PMMA phantom

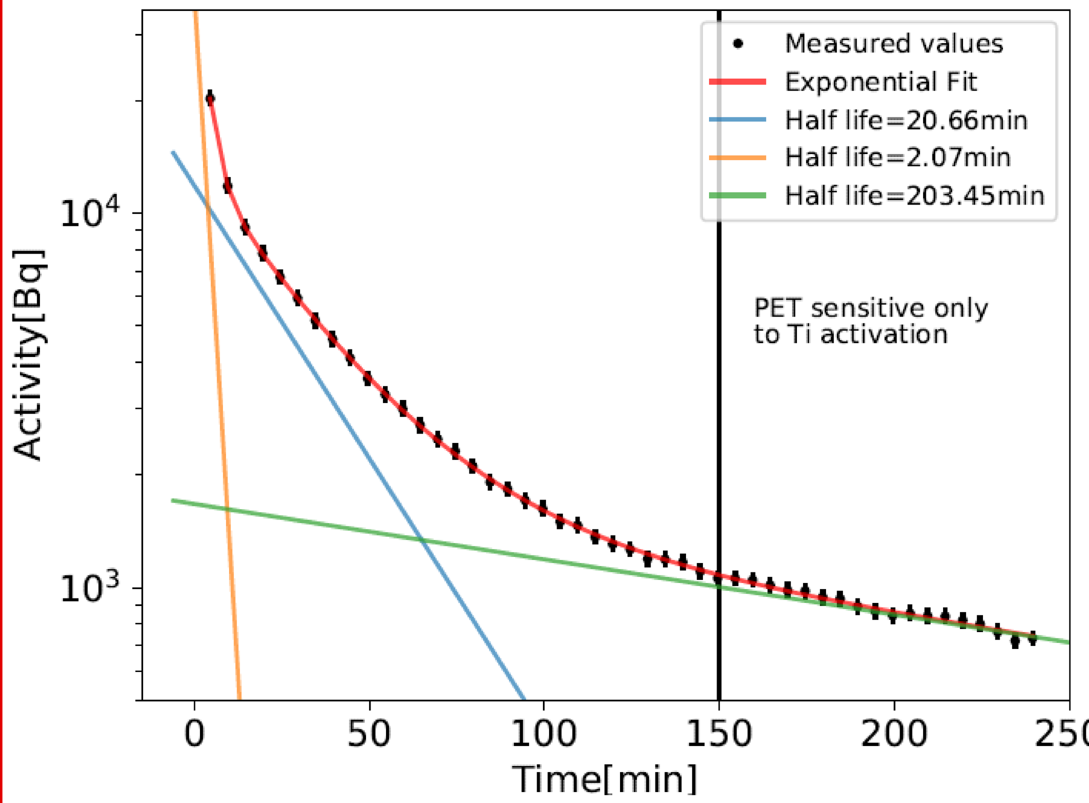


Planning CT matched with a 4 h PET scan of an irradiated head phantom. The implants give a signal after 3 h (work in progress).

Results and Discussion

Activity over time

- PET scan in time intervals of 5 min
- Fitting an exponential model for the decay in the complete phantom, the PMMA and the titanium sheet in the slanted angle geometry
- Identify three half-lifes: 2.07 min, 20.66 min and 203.45 min
  Short-lived: O-15 and C-11, **long-lived from titanium** (not in PMMA areas)
- **Titanium activation gives signal after 3 hours**



Half-life analysis of the obtained activity in the titanium sheet.

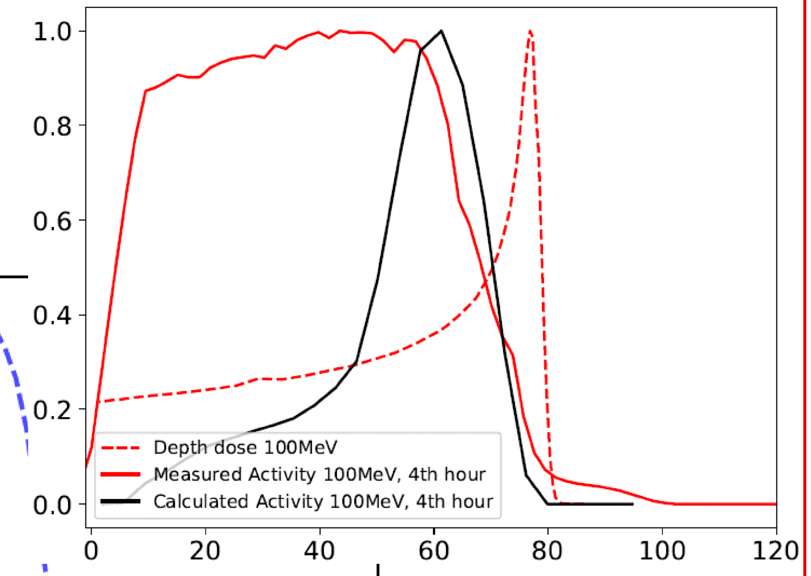
Dose reduction and absolute activities

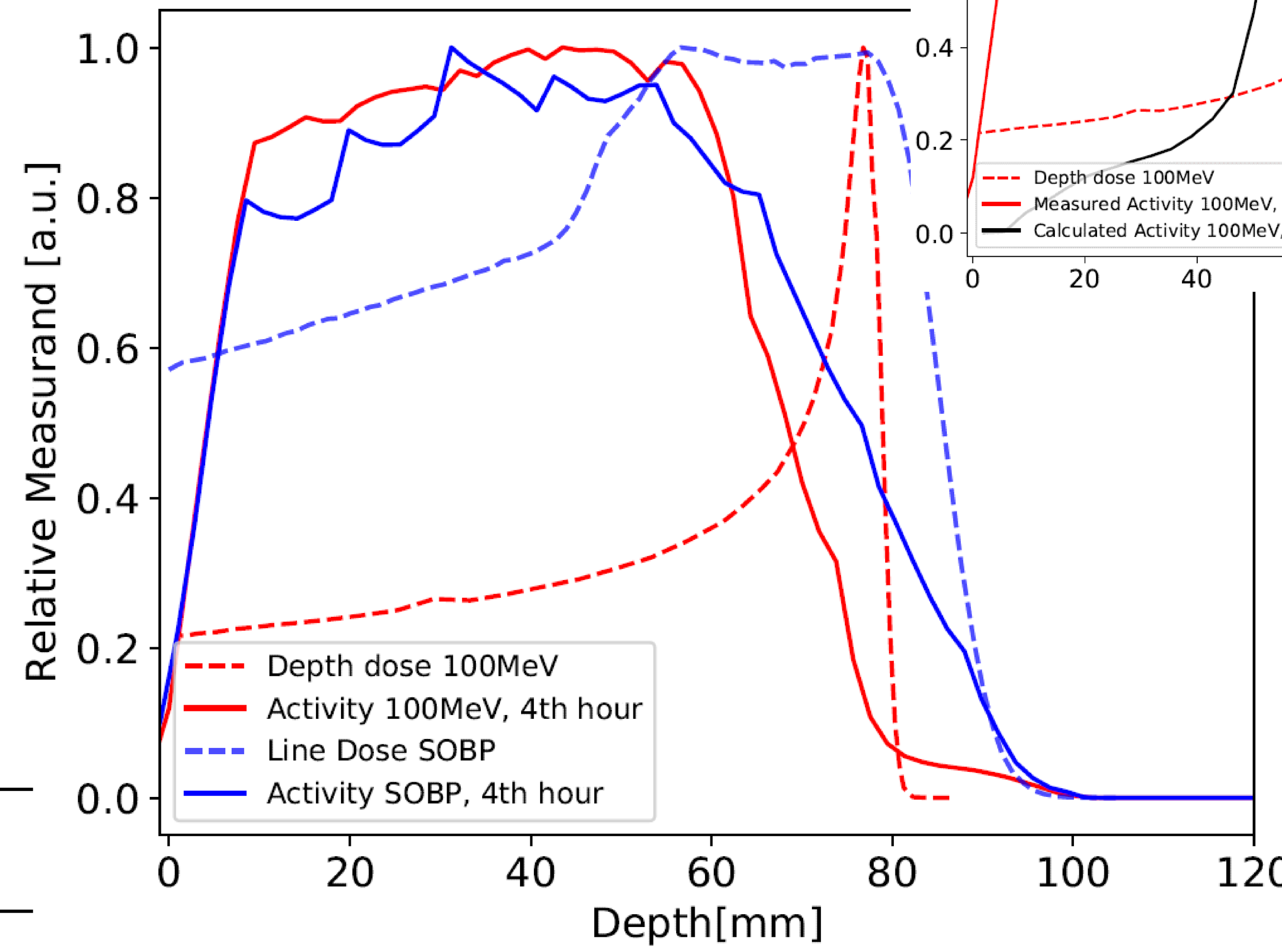
- Dose reduced to clinical fraction doses (approx. 2 CGyE)
- **Titanium gives signal** in an anthropomorphic phantom without statistical limitation

Position	Plateau	Proximal SOBP	Distal SOBP
$Activity^{PET}$ [kBq/ml]	1.52	1.51	0.89

Depth profile of activity in the slanted angle phantom

- Plateau area in activity distribution
- Distal fall-off of the activity distribution proximal to the dose fall-off
- Different radionuclides (longer half-life) compared to Ref. [2] peak proximal compared to the observation from the Ref.
- With cross sections from the EXFOR database, **distal fall-off can be calculated**





Comparison of the depth dose curve (dashed), the obtained activity over time (line). The monoenergetic field is red, the SOBP-like is blue. Small plot: calculated activity (black) with measured activity.

Conclusions

- PET imaging based on **titanium implants** has a potential for **proton beam range verification and absolute dose verification**
- PET scan should be taken **several hours after treatment** due to the tissue activation
- Future steps: multiple treatment fields and sensitivity tests, Monte Carlo predictions of the activity (distributions)

References

[1] CHO, J. et al., Feasibility of proton-activated implantable markers for proton range verification using PET, Phys. Med. Biol. 58 (2013) 7497-7512.
[2] BÄCKER, C.M. et al., Proton Beam Range Verification with Secondary Radiation from Titanium Implants, Proceedings of the 2019 IEEE Nuclear Science Symposium and Medical Imaging Conference, Manchester (2019).