Monte Carlo optimization of a neutron beam from 5 MeV ^{9}Be(p,n)^{9}B reaction for clinical BNCT

I.Postuma[1,*], S.Bortolussi[2], N.Protti[1] , S.Fatemi[1,2], S.J. González[3,4], L. Provenzano[3,4], G.Battistoni[5] and S.Altieri[1,2]

1) Istituto Nazionale Di Fisica Nucleare (INFN), Unit of Pavia, Italy. 2) Department of Physics, University of Pavia, Italy. 3) Comisión Nacional de Energía Atómica (CNEA), Argentina. 4) CONICET, Argentina. 5) Istituto Nazionale Di Fisica Nucleare (INFN), Unit of Milan, Italy.

Objectives

Tailor a neutron beam for **clinical** Boron Neutron Capture Therapy (BNCT) from 5 MeV protons interacting on a beryllium target :

- By following the IAEA guidelines, select the material that best modifies the initial neutron energy spectra for clinical BNCT.
- Pick the Beam Shaping Assembly (BSA) that best suits the IAEA parameters and the dose evaluation in Snyder phantom.
- Test the BSA on a real clinical case with a Treatment Planning System and choose the most performing neutron beam.
- Finally, investigate the dose distributions due to the neutron beam in the whole treatment room.

1 - Introduction

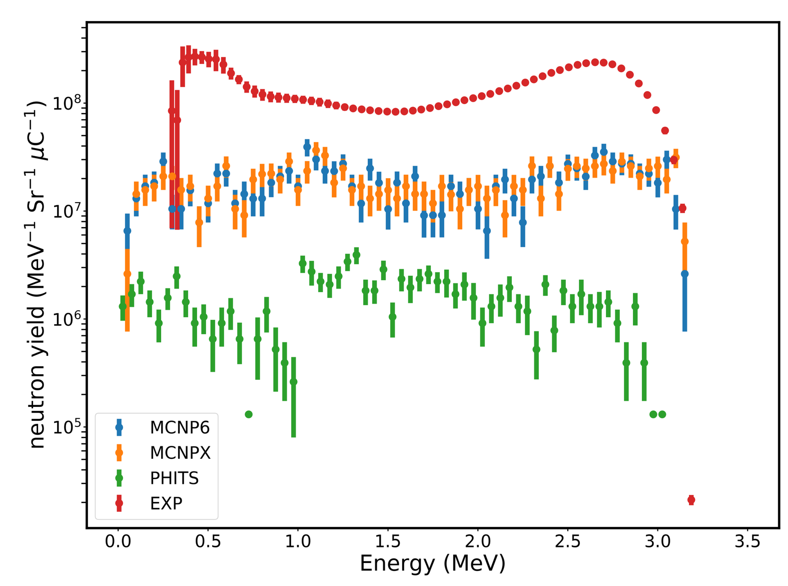
Boron Neutron Capture Therapy (BNCT) is an experimental radiotherapy that uses the combination of neutron irradiation and ^{10}B to treat neoplasms. Many clinical trials were performed worldwide with promising result using research nuclear reactors as neutron sources. Anyhow, these machines are very difficult to be installed in hospitals. This issue can now be overcome by using intense-current proton accelerators, which coupled with beryllium or lithium targets yield more than 10^{14} neutron per second. These accelerators are more compact, easy to operate and maintain, and can boost the development of dedicated BNCT clinical centers.

The Italian National Institute of Nuclear Physics (INFN) designed and manufactured a Radiofrequency Quadrupole proton accelerator (RFQ), which delivers 5 MeV protons with 30 mA current in a Continuous Wave (CW) mode and it is coupled to a beryllium target. This accelerator could be installed at Centro Nazionale di Adroterapia Oncologica (CNAO) in Pavia.

In this work, with the aid of Monte Carlo (MC) simulations, we show the design of the neutron moderator that couples the INFN-RFQ to a clinical BNCT facility.

2 - Neutron Source

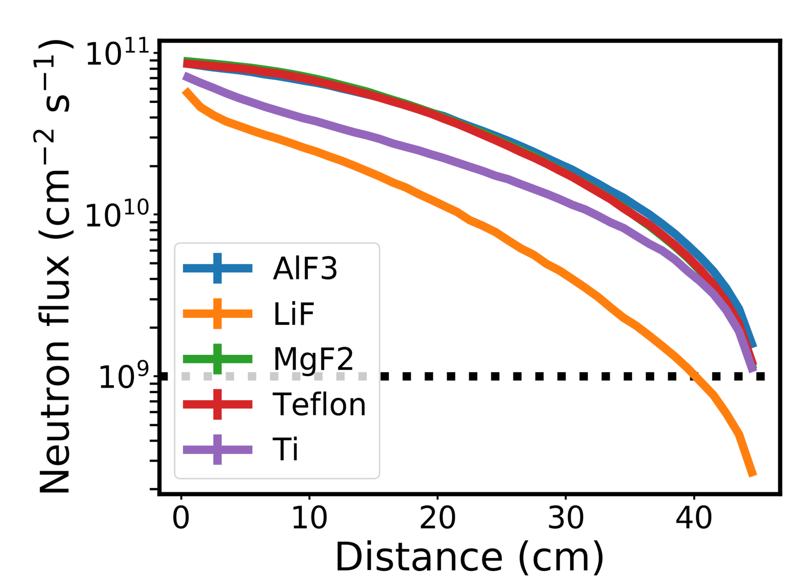
We tested MCNP and PHITS models and libraries for the reaction ^{9}Be(p,n)^{9}B. The results were then compared with experimental results [1]:



Consequently, **we implemented a neutron source distributed in the target**, based on experimental double differential spectra [1].

3 - Moderating material

We want an epithermal neutron beam with a flux greater than 10^{9} cm^{-2} s^{-1}. The neutron flux along the beam axis of various bulk material is:



It resulted that the **most performing material is AlF$_3$**. Further checks on fast neutron and photon contamination confirmed AlF$_3$ as the best bulk material for our set-up.

Important Result

To tailor an epithermal neutron beam, one starts by using IAEAs parameters as guidelines. Then it is important to *test the neutron beam on real clinical cases.* Finally, the optimization *must take into account the dose distribution in the environment and the radioprotection issues.*

4 - Physical parameters

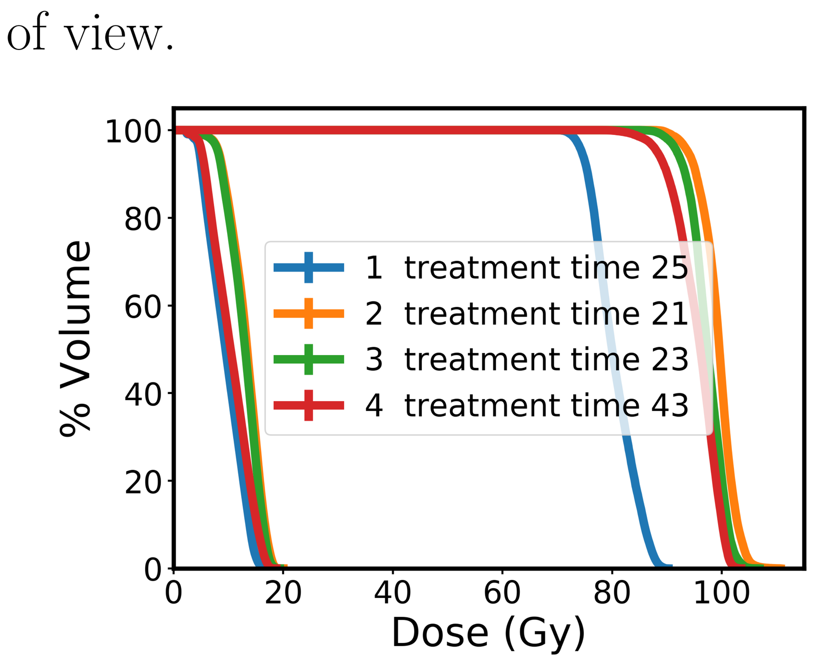
The *IAEA-TECDOC-1223* proposes three physical parameters to evaluate the quality of an epithermal neutron beam: epithermal flux ϕ_{epi}, fast neutron contamination $\dot{D}_n/\phi_{epi}$ and gamma photon contamination $\dot{D}_g/\phi_{epi}$. In the table below IAEA recommendations are compared to the figures of merit of 4 different BSA geometries, containing AlF$_3$ as bulk moderating material.

#	ϕ_{epi} (10^{9} cm $^{-2}$ s^{-1})	$\frac{\dot{D}_n}{\phi_{epi}}$	$\frac{\dot{D}_\gamma}{\phi_{epi}}$
		(10^{-13} Gy cm ^{2})	
1	2.6	7.1	6.3
2	2.8	8.9	3.7
3	2.6	9.0	3.9
4	1.6	7.6	2.8
IAEA	> 1	< 2.5	< 2.5

The results shows that none of the beams strictly comply with IAEA guidelines. However, **these beams have been tested in treatment planning simulations to evaluate their dosimetric performance**.

5 - Clinical comparison

We used NCTPlan [2] Treatment Planning System (TPS) on a real clinical osteosarcoma case. The figure below shows Dose Volume Histograms (DVH) for the tumor and for the organ at risk (skin) due to the 4 beams. The DVH plot tells us that the BSA delivering the highest dose to the tumor *prescribing the same maximum skin dose* is number 2. The next step is to test this beam from the radio-protection point of view.

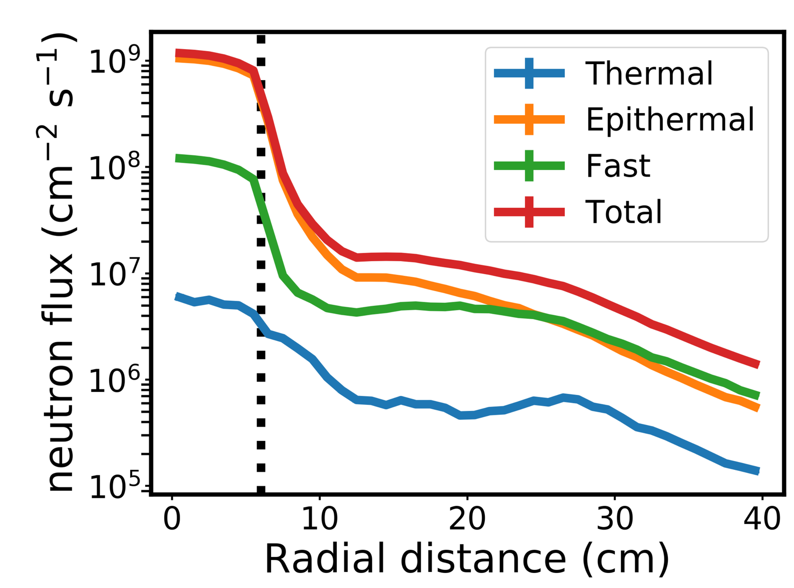


Contact Information

- Web: www2.pv.infn.it/∼postuma/
- Email: ian.postuma@pv.infn.it
- Phone: +39 0382 987635

6 - Radio-protection

Beam number 2 was used to simulate dose distribution in air in the whole treatment room and it was proven to have a high radial neutron contamination. Consequently, the BSA was further modified to better collimate the beam, providing an acceptable result. The final beam thus obtained was again tested on the clinical case to prove that its performances at clinical level have not changed dramatically



7 - Conclusioni

This work shows that the tailoring of a BNCT beam for clinical application is a very complex task, that cannot be completed only by the calculation of IAEA figures of merit in air. Treatment planning calculations and dosimetric evaluation outside the clinical target are important because they can have a strong influence on the final beam. These calculations led to a BNCT epithermal neutron beam that show optimal performance in the tumour and satisfies many dosimetric requirements.

References

[1] S Agosteo, P Colautti, J Esposito, A Fazzi, MV Introini, and A Pola. Characterization of the energy distribution of neutrons generated by 5mev protons on a thick beryllium target at different emission angles. *Applied Radiation and Isotopes*, 69(12):1664–1667, 2011.

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INFN Istituto Nazionale di Fisica Nucleare
UNIVERSITÀ DI PAVIA
Ministero degli Affari Esteri e della Cooperazione Internazionale

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