INFN
Istituto Nazionale
di Fisica Nucleare
Laboratori Nazionali di Frascati

www.lnf.infn.it

Dr. Catalina Oana Curceanu
tel. + 39 06 9403 2321
fax + 39 06 9403 2559
email: catalina.curceanu@lnf.infn.it

Frascati, 15/05/2022

To: *Faculty of Physics, Astronomy and Applied Computer Science*
Jagiellonian University in Krakow

Evaluation of the doctoral thesis of Vahagn Ivanyan

I had the pleasure to review and evaluate the doctoral thesis of Vahagn Ivanyan, entitled "*Design and optimization of beam shaping assemblies for boron neutron capture therapy based on accelerators and DD/DT neutron generators*", realized under the supervision of Prof. dr. hab. Pawel Moskal, and auxiliary supervision of Dr. Michal Silarskiand presented to the Department of Experimental Particle Physics and Applications Faculty of Physics Astronomy and Applied Computer Science, Jagiellonian University in Krakow.

The thesis reports the results of an original and important study aiming to design and optimize neutron beam shaping assemblies (BSA) for adapting neutron beams produced by Deuterium-Deuterium (DD) and Deuterium-Tritium (DT) neutron generators, as well as by Cyclotron C18/18, for application in boron neutron capture therapy (BNCT).

In the first part of his thesis Vahagn Ivanyan presents the BSA design and GEANT4 simulations for the cyclotron C18/18 based BNCT project. He is discussing the way in which he realized virtual models of the experiment by means of extended Monte Carlo calculations for the optimal selection of thicknesses and materials of the target for a 14.8 MeV proton beam. Based on the simulation results the optimal solution is the use of 2.5 mm thick 9Be target with 9Be (p, Xn) multibody reactions as source of neutrons. Then Vahagn Ivanyan discussed the C18/18 modified cyclotron of the IBA which was installed in Armenia at the A. Alikhanian National Laboratory (AANL) for the medical purposes, especially for the development of the accelerator based BNCT. In this regard, Vahagn Inanyan presents original simulation results obtained by him, which are discussed in Chapter 3 and 4 of his thesis, as well as a series of articles co-authored by him. The methodology of the optimization and designing of the BNCT applicable BSA was prepared by the candidate in

two different ways. In a first one, as Ivanyan discusses in his thesis, two materials were used as moderator, which served also as fast neutrons filters. In a second method multipliers, such as nat-Bi or nat-Mo, were used and the simulations gave very significant results, in agreement with IAEA recommendations for BNCT. In the second and third parts of the thesis, Vahagn Ivanyan presents original calculations aiming to the designing and optimization of the beam shaping assemblies (BSA) for DD and DT neutron generator based BNCT, discussing the way in which many types of BSAs were designed to achieve 10 keV energetic peak of neutrons, needed for the most aggressive malignant brain tumor Multiform Glioblastoma, when also located in the central part of the human brain. In the fourth part of his thesis the author shows results of GEANT4 for the estimation and elaboration of the wide energy range (0.01 eV - 1 MeV) neutron reactions with the soft tissue, showing that the 10 keV neutron beam has the best penetration ability through the tissue with the lowest number of gamma rays and additional nuclear reactions.

The presented work augment the existent knowledge in the field and opens future scenario for the boron neutron capture therapy (BNCT).

The results which Vahagn Ivanyan obtained during his work for the Ph. D. thesis has also produced several publications in refereed journals.

The description of the results in the thesis is clear, with good linguistic expression and with a proper citation of references.

The methods and the approach are very well presented, proving that Vahagn Ivanyan is able to provide original contributions in the field related to the boron neutron capture therapy.

The results of his work are important for the community working in the field, a growing community which aims to find and use new methods for applying the neutron therapy of tumors.

I consider the results of the thesis and its presentation as being excellent and propose to assign to Vahagn Ivanyan the Ph. D. with the highest grading and distinction.

Dr. Catalina Oana Curceanu

Laboratori Nazionali di Frascati
dell'Istituto Nazionale di Fisica Nucleare
(LNF-INFN)