

REFeree REPORT

on the dissertation work for awarding the educational and scientific degree "Doctor" in the professional field 4.1 "Physical Sciences" for defense procedure at the Faculty of Physics of St. Kliment Ohridski University of Sofia

The report is prepared by **Roumen Vassilev Tsenov, Professor Emeritus, Doctor of Sciences** in his capacity as a member of the scientific jury according to Order № RD 38-355/16.07.2021 of the Rector of the University of Sofia.

Title of the dissertation:

Studies on the application of the triple-to-double coincidences ratio method for primary activity standardization using liquid scintillation counting

Author: Chavdar Chavdarov Dutsov

I. General description of the submitted materials

1. About the submitted documents

The candidate Chavdar Chavdarov Dutsov has presented a dissertation in English, an abstract in Bulgarian, an abstract in English and the obligatory tables for the Faculty of Physics, required by the Regulations on the terms and conditions for acquiring scientific degrees and holding academic positions at St. Kliment Ohridski University of Sofia. Eight other documents were also presented, namely professional CV, bachelor's and master's diplomas, order for enrollment in doctoral studies, declaration of authorship of the dissertation, protocol for verification of the originality of the dissertation and opinion to him by Assoc. Prof. K. Mitev, supervisor of the doctoral student. A list of 9 publications of the doctoral student on the topic of the dissertation, 2 other publications and 10 talks and posters presented by the candidate at conferences are presented.

I have no comments on the documents.

The documents submitted for the defense by the candidate comply with the requirements of the Law on career development of the academic staff in Republic of Bulgaria, the respective national Regulations, the Regulations on the terms and conditions for acquiring scientific degrees and holding academic positions in St. Kliment Ohridski University of Sofia.

2. Biographic details of the candidate

Chavdar Dutsov was born on October 2, 1993 in Sofia. In 2021 he graduated from the National High School of Natural Sciences and Mathematics "Acad. Lyubomir Chakalov" in Sofia with a profile in Physics and Astronomy. He then studied at the Faculty of Physics of Sofia University and in 2016 received a Bachelor's degree in Medical Physics. He continued his education and in 2018 received the degree of Master of Medical Physics. During his studies Chavdar Dutsov was an excellent student. His average grade from the semester bachelor's exams is 5.77, and from the master's - 5.89. In July 2018 he was enrolled as a full-time doctoral student in the Department of Atomic Physics at Sofia University and completed his doctoral studies within the regular three-year period, which is a rare achievement among the doctoral students in Physics.

3. General considerations on the candidate's scientific achievements

The main achievements of the candidate are in the field of liquid scintillation dosimetry and they are reflected in the presented dissertation and the 9 publications on which it is based. These publications fully cover and significantly exceed the minimal national requirements (under Art. 2b, para. 2 and 3 of the Law on career development of the academic staff in Republic of Bulgaria) and the additional requirements of St. Kliment Ohridski University of Sofia for acquiring the educational and scientific degree "Doctor" in the professional field 4.1 "Physical Sciences". In 4 of these publications he is the first co-author, and in one - a co-author for correspondence. According to the definitions in the requirements of the Faculty of Physics of Sofia University, this means that he has a significant contribution in 5 of the presented publications. The minimal requirement is for one such a publication.

The candidate has not participated in other procedures for awarding the doctoral degree or for holding an academic position. The works are original, there is no proven plagiarism in the dissertation and the abstract.

The doctoral student's scientific achievements described in his dissertation will be discussed in more detail below. Here I want to note that in addition to the 9 papers included in the dissertation, the doctoral student is a co-author of 2 more publications in journals with impact factor and 10 talks and poster presented at conferences. They show that, in addition to his main activities in liquid-scintillation dosimetry, Ch. Dutsov has entered the field of radon dosimetry, as well as design and construction of the necessary dosimetric devices for the measurements presented in the dissertation.

4. Characteristics and assessment of the teaching activity of the candidate (if there is a requirement for this)

There is no information in the candidate's documents about his teaching activities, if any. Teaching activities are not required for obtaining the scientific and educational degree "Doctor".

5. Analysis of the scientific achievements of the candidate, presented in the materials for the defense procedure

The main scientific achievements of the doctoral student are in further development of the liquid-scintillation method for measuring the absolute activity of a radioactive sample. The contributions are both in the development of new mathematical models and in the improvement of the methodology of the measurements. The candidate focused on improving the triple-to-double counting ratio method (TDCR) in a liquid scintillation system with three photoelectron multipliers (PMT). The achieved improvement is in two directions: the establishment of new dependencies between the measured values and the development of the methodology.

In the first direction, new methods for evaluation of the random coincidences in the TDCR measurements are proposed and the cross-correlation distribution of times between the detected scintillation events is derived. It is demonstrated how it can be used to calculate the detection efficiency and the activity of the sample.

In the methodological direction the influence of the delayed fluorescence on the activity calculated by the TDCR method is demonstrated, a comparison of two algorithms for imposing prolonged dead time in TDCR measurements is made and their advantages and disadvantages are demonstrated, the possibility of using liquid-scintillation technique for precise determination of the half-life of short-lived (~ 10 ns) nuclear excited states is shown. For some states, half-lives were obtained with an uncertainty better than of the measurements made so far (for example, for the 59.5 keV isomeric state of ^{237}Np , as well as for the 14.4 and 136.5 keV levels in the ^{57}Fe isotope). In the course of the research, several software applications have been developed that facilitate and clarify the applied methods of data analysis.

The contributions presented are based on results published in 9 papers, where the candidate is a co-author, all in journals with impact factor. As I noted above, in 5 of them he has a significant contribution. The doctoral student has presented two talks at international conferences, published in full text and has personally presented two posters at such conferences, and in another 6, presented by his colleagues, he is a co-author. All this leaves no doubt in the significant personal contribution of Chavdar Dutsov in the obtained and published results. According to additional information received from the author, there are already citations of some of the articles. For articles [P1] and [P7] published in 2020, one independent citation of each was observed, and for article [O2] from the supplementary list, published in 2019, two independent citations have been found. This shows that the doctoral student's work is already visible in the world literature.

I want to open a bracket here. The dissertation is quite big in volume. The main text (excluding the content, bibliography and appendices) consists of 178 pages in 12 pt font. I think the thesis content could be presented much more succinctly. In addition, as far as the contributions do not include the results of the application of the TDCR method in radon dosimetric measurements described in

Chapter 11 these results could be dropped from the dissertation and the work [P9] from the list of main publications to be moved to the list of other publications. The merits of the dissertation are already completely sufficient to achieve the goal - to obtain the degree of "doctor" without those results.

6. Critical remarks and recommendations

I have no particular critical remarks. The dissertation (in English) and the abstracts (both in Bulgarian and English) are very well designed graphically, in a refined and elegant style. The abstracts fully reflect the content of the dissertation. The many punctuation errors in the Bulgarian text could have been avoided with a last careful proofreading.

While reading, I came across a terminological problem that I want to point out here. In equation (1.7), in the abstract in Bulgarian - (1.2), the quantity dE/dx is introduced and it is called "particle's stopping power". The relation of possession here is misleading as this quantity is not a characteristic of the particle, but of the medium through which the particle moves. Of course, it also depends on the properties of the particle (velocity and charge), but it characterizes the medium and is not a property of the particle itself. By definition, *stopping power* is the average energy loss per unit path length (in a given medium and for a given particle). On page 16 of the dissertation, such a definition is just used to introduce the definition equality (1.13) few lines below, but in the next sentence, and throughout the following text, the use of "stopping power of a particle" continues...

Another small detail. With the relation (2.18), in the abstract in Bulgarian - (1.9), the quantity φ is introduced, defined as "the average effective energy (after taking into account the ionization quenching function) that is needed to create a photoelectron at the photocathode of the PMT".

From the relation itself it can be seen that its meaning is exactly the opposite - this is the average number of photoelectrons created on the photocathodes of all PMTs when an energy E is released in the scintillator. Further down in the equations the quantity φ is used correctly, but its incorrect naming continues.

The observed discrepancies do not influence in any way the high merits of the dissertation.

7. Personal impressions about the candidate

I have scarce but excellent personal impressions about the candidate. In my opinion, he is a well-educated, hard-working and talented young scientist, who will have a successful scientific career if he decides to follow this thorny path.

8. Conclusion

After getting acquainted with the presented dissertation, abstract and other materials and based on the analysis of their significance and contained in them scientific contributions, **I confirm** that the scientific achievements meet the requirements of the Law on career development of the academic staff in Republic of Bulgaria, national Regulations for its application and the respective Regulations of St. Kliment Ohridski University of Sofia **for acquiring the educational and scientific degree “Doctor”**. In particular, the candidate satisfies the minimal national requirements in the professional field 4.1 "Physical Sciences" and no plagiarism has been established in the dissertation, abstract and scientific papers submitted for the procedure.

I give my **positive** assessment of the dissertation.

II. OVERALL CONCLUSION

Based on the above, I recommend the scientific jury to award **the educational and scientific degree "Doctor"** in professional field 4.1 "Physical Sciences" to **Chavdar Chavdarov Dutsov**.

August 18, 2021.

Referee: Prof. Roumen Tsenov, Doctor of Sciences