OPINION

On the dissertation for acquiring the educational and scientific degree

DOCTOR

in a professional direction 4.1 Physical Sciences Nuclear Physics.

Author of the dissertation: Chavdar Chavdarov Dutsov, full-time doctoral student, Sofia University "St. Kliment Ohridski ", Faculty of Physics, Department Atomic Physics

Topic of the dissertation: " Studies on the applications of the Triple-to-Double Coincidences Ratio method for primary activity standardization using liquid scintillation"

Member of the Scientific Jury: Assoc. Prof. Dr. Plamen Stoianov Iaydjiev, Institute for Nuclear Research and Nuclear Energy - BAS

1. General description of the dissertation and the presented materials:

The dissertation presented by Chavdar Dutsov is for acquiring the educational and scientific degree "Doctor" and contains 12 chapters divided into 3 parts. 3 additional parts have been added with explanations of the simulation codes used in the analyzes and their comparison with the data. The text contains 215 pages, 69 figures and 12 tables. The list of used literature includes 159 titles cited in the text. Chapter 12 provides information about the scientific and methodological contributions of the doctoral student and the publications on which the dissertation is based.

The topic of the dissertation is " Studies on the applications of the Triple-to-Double Coincidences Ratio method for primary activity standardization using liquid scintillation".

There is a difference in the structure of the abstract and the dissertation. In the abstract, chapter 1 combines chapters 1 and 2 in the dissertation, chapter 3 combines 3,4,5,6 of the dissertation and chapters 4 to 9 of the abstract correspond to chapters 7-12 of the dissertation.

The first chapter of the dissertation is devoted to the method of measuring activities using liquid scintillators. The method of triple to double coincidences is described and the relevance of the dissertation for the evaluation of random coincidences in this method, the calculation of the efficiency for registration and the activity of the sample is presented.

The second chapter describes precisely the method of triple to double coincidences (TDCR). Chapters 3,4,5,6 describe in detail the distribution of scintillation events in time and different algorithms for registration and evaluation of the corresponding methods, using liquid scintillators, are compared precisely. The cross-correlation distribution and the application in TDCR are discussed in detail.

Chapters 7-11 describe the use of time distribution information in the TDCR method. The possibility for measuring the half-life of excited nuclear states by analyzing the time distributions from liquid-scintillation measurements is shown. Methods have been developed for estimating the contribution of random coincidence in a liquid scintillation detector with 3 photomultiplier tubes. The contribution of the delayed scintillation component to the evaluation of the activity calculated by the TDCR method was investigated. The development of a new Compton-TDCR detector system for primary standardization of liquid scintillation samples is also described. The system was used to study the response of commercial liquid scintillators when irradiated with electrons with energies in the range from 2 keV to 8 keV.

Chapter 12 describes the dissertation's contributions.

2. Purpose of the dissertation and relevance of the topic:

The scientific part of the thesis is focused on the primary measurement and standardization of radioactivity by liquid-scintillation method - TDCR, used for absolute measurement of activity of many radionuclides, decaying by α-decay, β-decay or electron capture.

The relevance of the study is determined by the proposed methods of random coincidences in TDCR measurements and the resulting cross-correlation time distribution between detected scintillation events.

The dissertation has a significant contribution to the methods for estimating the percentage of random coincidences in TDCR, the study of cross-correlation distribution, the comparison of counting algorithms for TDCR measurements, the use of digitized liquid scintillation measurements to accurately determine the half-life of excited nuclear states, software for data analysis from a digitizer with applications for TDCR measurements, Monte Carlo code for simulation.

3. Critical remarks and recommendations

The text of the dissertation is well written and the graphic layout is up to standard, but still a minor drawback is the difference in the design of the abstract and the dissertation in the distribution and name of the individual parts.
In general, I have no critical remarks that would negatively affect my overall conclusion about the dissertation.

4. **Contributions to the dissertation**

In this case, these contributions can be classified as scientific and methodological. The contributions described so far in the dissertation are the following:

4.1 Scientific contributions to new knowledge in the field of activity measurement using liquid scintillation counting:

• For the first time, methods for estimating the census rate have been proposed random coincidences in TDCR [1].
• The cross-correlation distribution of the time intervals between scintillation events is derived and is shown how it can be used for determination of the registration efficiency and sample activity [2].

4.2 Methodological contributions in the field of liquid scintillation counting:

• The effect of delayed fluorescence on activity has been demonstrated and calculated using TDCR [3].
• A comparison of two counting algorithms for TDCR measurements was performed [4].
• The possibility of using digitized liquid scintillation measurements is demonstrated and is applied in accurate measurement of the half-life of some excited nuclear states [5].
• Software for data analysis from a digitizer with applications has been developed for TDCR measurements, cross-correlation measurements and Compton-TDCR method.
• Monte Carlo code has been developed to simulate the time distribution and number of scintillation events in liquid scintillation counting.

5. Scientific publications on the topic of the dissertation

The main contribution of the dissertation are 9 publications (one is accepted for publication):

1. Dutsov, C., Cassette, P., Sabot, B., & Mitev, K. (2020). “Evaluation of the accidental coincidence counting rates in TDCR counting”. Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 977, 164292.
2. K. Mitev, Ch. Dutsov, Ph. Cassette, B. Sabot, “Time-domain based evaluation of detection efficiency in liquid scintillation counting”, Scientific Reports 11, 12424 (2021).
3. Dutsov, C., Cassette, P., Mitev, K., & Sabot, B. (2021). “In quest of the optimal

coincidence resolving time in TDCR LSC". Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, 987, 164846.
4. Dutsov, C., Mitev, K., Cassette, P., & Jordanov, V. (2019). "Study of two different coincidence counting algorithms in TDCR measurements". Applied Radiation and Isotopes, 154, 108895.
5. Ch. Dutsov, B. Sabot, Ph. Cassette, K. Mitev, "Measurement of the half-life of excited nuclear states using liquid scintillation counting", submitted to Applied Radiation and Isotopes.
6. Cassette, P., Arinc, A., Capogni, M., De Felice, P., Dutsov, C., Galea, R., Garcia-Torano, E., Kossert, K., Liang, J., Mitev, K., & others (2020). "Results of the CCRI (II)-K2. H-3 key comparison 2018: measurement of the activity concentration of a tritiated-water source". Metrologia, 57(1A), 06004.
7. V. Jordanov, P. Cassette, C. Dutsov, and K. Mitev, "Development and applications of a miniature TDCR acquisition system for in-situ radionuclide metrology", Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 954, 161202 (2020).
8. Hamel, M., Sabot, B., Dutsov, C., Bertrand, G., & Mitev, K. (2021). "Tuning the decay time of liquid scintillators". Journal of Luminescence, 235, 118021.
9. S. Georgiev, K. Mitev, C. Dutsov, T. Boshkova, and I. Dimitrova, "Partition coefficients and diffusion lengths of Rn-222 in some polymers at different temperatures", International journal of environmental research and public health 16, 4523 (2019).

6. Conclusion

In conclusion, I think that the largeness and quality of the research and the achieved results meet the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria, the rules for application of this law, the rules for the acquisition of scientific degrees and academic positions in Sofia University, as well as the recommended requirements to the candidates for acquiring the scientific degrees and holding the academic positions in the Faculty of Physics of Sofia University "St. Kliment Ohridski ".
Chavdar Dutsov has in-depth theoretical knowledge and practical skills for conducting independent research.

Based on everything written so far, convinced and without reservations, I recommend to the respected scientific jury to award Chavdar Chavdarov Dutsov the educational and scientific degree "Doctor".

August 22, 2021.
Sofia

Signature: .....
/ Assoc.prof. Dr. Plamen Iaydjiev /