REVIEW

of a dissertation submitted for acquiring the educational and scientific degree
Doctor

in the Professional Field 4.1 Physical Sciences

(Doctoral program “Neutron Physics and Physics of Nuclear Reactors”)

Author of the dissertation: Srebrin Toshkov Kolev**,** Doctoral student in independent preparation at the Faculty of Physics of St. Kliment Ohridski University of Sofia

Topic of the Dissertation: A time-dependent formulation of the HEXNEM3 nodal method for solving the neutron transport equation in diffusion approximation

Reviewer: Prof. D.Sc., INRNE, member of the Scientific Jury by the appointment of the Rector of Sofia University

1. Biographical data

The candidate Srebrin Toshkov Kolev was born on November 9, 1992 in the city of Plovdiv, where he completed his secondary education and graduated with honors from the Acad. Kiril Popov Mathematical High School in 2011. In the period 2011–2015, he was a student of physics at the Faculty of Physics (FzF) of St. Kliment Ohridski University of Sofia. He graduated with honors with BS “Engineering Physics”; the topic of his thesis was "Cathodoluminescence and applications for characterization of materials and structures." In 2017, he completed a regular course of education in the master's program "Nuclear Energy and Technology" of FzF-SU. He graduated with honors and received a master's degree in "Nuclear Engineering and Nuclear Energy". The topic of his dissertation was "Non-stationary diffusion problem in the physics of nuclear reactors".

His development as a specialist in the field of computational methods in reactor physics continued under the guidance of Assoc. Prof. Dr. Ivaylo Christoskov of the Department of Nuclear Engineering and Nuclear Energy of FZF-SU. On April 1, 2019, he was enrolled in the doctoral program "Neutron Physics and Physics of Nuclear Reactors" as a doctoral student in a self-preparation form of study with a scientific adviser Assoc. Prof. Christoskov, PhD. After passing an exam with an excellent mark (5.50) in "Reactor Analysis" (exam in the specialization), on 21.04.2020 he was disenrolled from the doctoral program and was given the right to defend his dissertation ahead of schedule.

2. Relevance of the problem

In my opinion, the title of the dissertation "A time-dependent formulation of the HEXNEM3 nodal method for solving the neutron transport equation in diffusion approximation" correctly reflects its content. The research in the work presented is focused on the development and application of numerical methods and algorithms to neutron-physical calculations. The problems studied are related to improving the nodal methods for solving the neutron transport equation in a two-group diffusion approximation in order to model the neutron-physical behavior of WWER-type nuclear reactors. A new formulation

of the nodal method HEXNEM3 for solving the neutron transport equation in the diffusion approximation is developed and tested, aimed at efficiently solving nonstationary problems.

The modeling of complex processes in nuclear reactors requires overcoming many computational difficulties and, therefore, the topic of Srebrin Kolev's dissertation devoted to neutron-physical calculations of stationary and transient processes is undoubtedly relevant. The work in this field of development and application of numerical methods in physics is directly related to modern fields of research and to the real necessities of the nuclear power generation by creating opportunities for scientific solutions and for formulating useful practical recommendations in symptom-oriented instructions for the operator's action.

3. Content and structure of the dissertation

The dissertation contains a total of **155** pages, covering the *title page*, *Contents* (**2** pages), *Abbreviations and notation* (**1** page), *Subject and scope* section (**2** pages), *Introduction* (**3** pages), three main sections (total **107** pages), *Appendix* (**34** pages), *Conclusion*s (**1** page), *References* of 59 titles (**4** pages) and *Bibliography* (**1** page), containing the list of author's publications and reports. 36 figures and 37 tables are included.

The sections *Subject and Scope* and *Introduction* give a brief critical review of the main methods for numerical solution of neutron transport equations, focusing on the small-group diffusion approximation using large cell nodal methods, the nonstationary diffusion equation and commenting on the features of the modal approach developed in the dissertation. The three *main sections* of the dissertation and the *Appendix* present the algorithms used or improved with the participation of the candidate and the results of the research. Section I and the Appendix substantiate the algorithm of the modal ACMFD variant of HEXNEM3 for solving conditional critical problems, give exemplary implementations of the developed ACMFD scheme and present an updated algorithm for solving the three-dimensional stationary diffusion problem. Section II contains the mathematical derivation of the basic expressions and equations used to solve the nonstationary two-group diffusion problem. Of practical interest is the construction of ACMFD schemes for modes, with the derivation of working expressions given in the Appendix. Section III contains a detailed explanation of the features of the software implementation of the new modal ACMFD formulation of the HEXNEM3 method named H3CM and results of the advanced software package verification via solving stationary and non-stationary benchmark tasks for WWER-440 and WWER-1000. It is shown that the good accuracy of HEXNEM3 for large hexagonal nodes is preserved, but H3CM has a significant advantage in computational efficiency compared to the algorithm based on iteration by energy groups characteristic of HEXNEM3.

4. Mastering by the doctoral candidate of the state of knowledge on the topic of the dissertation

The doctoral candidate shows in the exposition a good knowledge of the facts and results of other authors, together with a critical comprehension and interpretation pf the necessary information. No redundant numerous references to literary sources are made, resulting in a a relatively short list of cited literature - a total of **59** titles, including 3 of the student's articles

on the topic and 3 reports with the participation of the scientific consultant under contracts with Kozloduy NPP on the introduction of a new nuclear power plant (by 2013) software package for stationary mode calculations.

Special attention is paid to the contributions to the methods for reactor-physical calculations of WWER reactors that are achieved in scientific works of established Bulgarian specialists in this field such as Assoc. Prof. P.T. Petkov and Assoc. Prof. I. Christoskov from FzF-SU, Assoc. Prof. N.P. Kolev (INRNE-BAS).

The doctoral student defines the main goal of his thesis as development and study of a new formulation of the nodal method HEXNEM3 (Christoskov and Petkov, 2013), designed for computationally efficient solution of nonstationary problems in two-group diffusion approximation. The practical motivation for such development is related to the use of the original version of HEXNEM3 (2013) in two nodal reactor-physical programs: the Bulgarian HEX3DA (Christoskov, 2013), which is part of the HELHEX software package (Petkov and Christoskov, 2013) for stationary calculations of WWER-1000, and the German DYN3D of FZDR-Rossendorf (Bilodid et al, 2018).

The cited literature is relevant, but I have a remark (in item 8 below), because there is no mention of other existing and tested nodal methods for hexagonal geometry using approaches with the modal decomposition of the scalar flow, analytical solutions in schemes, analytical coarse-cell finite difference method (ACMFD). Among them are HEXTRAN (transient solutions, 1997) of VTT, Finland and COBAYA (2007) of the Madrid Polytechnic University, which are applicable to WWER reactors. Concerning the validation of COBAYA-Hex for WWER, I am aware of its having been implemented by Bulgarian groups under various projects in the period 2009-2020.

5. Publications on the dissertation and candidate's personal contribution

The dissertation is based on 5 publications co-authored only with Assoc. Prof. Ivaylo Christoskov. Two articles are in impact journals (Annals of Nuclear Energy - 1, C.R. Acad. Bulg. Sci. – 1). Three articles are papers published in full in the Proceedings of international scientific forums, including the traditional symposium on WWER reactor technology, held in 2018 in the Czech Republic. One of the papers was published in the AIP Conference Proceedings and has an SJR.

Srebrin Kolev is the first author in the publications and the results were presented at the conferences by him personally. This gives me reason to conclude that S.T. Kolev has a significant share in the results obtained and has had an at least equal contribution to the joint publications and preparation of materials for scientific events.

6. Scientific contribution

I accept the candidate's scientific contributions as formulated on page 116 of Section V. Conclusion, namely, contributions to the development and application of numerical methods and algorithms for neutron physical calculations. I believe that they are of applied science nature and are described correctly. The developed algorithms, their mathematical derivation and application are described in detail and logically clearly, and in their verification the dissertation is a testimony of creative in-depth knowledge and skills. It is convincingly proven

that the successful development of accelerated computational schemes makes a significant contribution to the creation of a new generation of software products.

The contributions can be categorized as enriching the existing knowledge in the field of reactor physics and as a futher development of the methodology for a deterministic approach to the safety analysis of light-water pressurized reactors.

The doctoral student does not provide information on found citations by other authors of results in the dissertation.

7. Extended abstract

The extended abstract is presented in Bulgarian (41 pages) and translated into English (40 pages). The numbering of the sections in the dissertation in both versions of the extended abstract is observed, but section V. *Conclusion* is renamed in the abstract as V. *Contributions of the dissertation*, respectively V.*Contributions.* I believe that the extended abstract in original and in translation accurately reflects the content, conclusions and formulated contributions to the dissertation topic.

8. Critical remarks

I have no objections to the reliability of the presented results and conclusions in the dissertation. During the preliminary defense, the panel members asked specific questions and requested additional information, which the doctoral candidate reflected essentially in the present dissertation submitted for review.

In general, the dissertation is written competently. It is carefully formatted and the information is correctly presented with appropriate figures and in tabular form. The exposition is concise, but in some places the statements are set out in very long sentences.

I have the following comments and questions:

1. It is interesting to hear the doctoral candidate's comments on the possibilities of the COBAYA reactor-physical computing software package, which are not reflected in the literature review.

2. The abbreviation ACMFD is entered in English, but is not entered / translated into Bulgarian.

3. The reactivity and the corresponding units of measurement are not introduced and defined.

The listed omissions are technical and do not impair in essence the doctoral thesis' results in the field of reactor physics.

9. Conclusion

The presented doctoral dissertation and the extended abstract comply with the criteria adopted by the Law for the Development of the Academic Staff in Bulgaria and the additional requirements of the Faculty of Physics of St. Kliment Ohridski University of Sofia for acquiring the educational and scientific degree "Doctor". I participated in the discussion of the dissertation during the preliminary defense of MS Srebrin Kolev and personally made sure of the excellent preparedness of the doctoral student, shown in the modeling of the physical processes investigated and in his analytical approach to solving

specific computational problems. The research of the doctoral candidate on the presented thesis has been carried out mainly in The Faculty of Physics of Sofia University. In this regard, I will note that a contemporary educational and research program has been implemented. The doctoral candidate has acquired specialized knowledge in the neutron-physical analysis of nuclear reactors; his dissertation is distinctly of applied scientific character and is significant in terms of topicality.

Based on the above, I give a positive assessment of the dissertation and with full conviction recommend that the esteemed members of the Scientific Jury vote for awarding the educational and scientific degree "Doctor" to M.Sc. Srebrin Toshkov Kolev.

Sofia, 15.09.2020

Reviewer:

/Prof. D.Sc. Kiril A. Krezhov/