REVIEWER'S COMMENTS

on the dissertation submitted by Srebrin Kolev in fulfillment of the requirements
for the educational and scientific degree "Doctor"
(Physical sciences - Neutron physics and nuclear reactor physics)
in the University of Sofia, 2020

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

Reviewer, member of the scientific committee: Nikola Kolev, Associate Professor, PhD, INRNE – Bulgarian Academy of Sciences

1. The dissertation consists of an introduction, an overview section, three main sections, conclusions and an appendix with mathematical derivations. The overall size is 155 pages, including 34 figures and 37 tables. The list of references contains 59 titles.

The thesis presents R&D results in the field of computational reactor physics. The main objective of the study is to develop and test a new time-dependent formulation of the HEXNEM3 nodal method intended for accurate and computationally efficient solving of transient problems.

2. The original HEXNEM3 method (Christoskov and Petkov, 2013) is an improved variant of the HEXNEM (Hexagonal Nodal Expansion Methods) series of methods. The HEXNEM computational mesh is a lattice of hexagonal prisms. These methods use an expansion in suitable basic functions for the scalar flux within each homogenized node and transverse integration techniques. Compared to the preceding versions the HEXNEM3 shows an improved accuracy for large fuel assemblies such as in VVER-1000 but its algorithm is designed primarily for steady-state problems and has limitations in case of transient calculations needed for reactor safety analysis. To obtain the neutron fluxes in each energy group it uses separate solving of mono-group equations and iteration on the energy groups. The iteration process is slowly converging and does not conform well with the limitations of implicit differencing in time which is needed to solve the stiff equation system of the neutron kinetics. This motivates the development of a new time-dependent formulation of HEXNEM3 which preserves the good accuracy and allows non-iterative and computationally efficient solving of the two-group diffusion problem. A practical motivation is the use of the original HEXNEM3 (2013) in two nodal core physics codes: HEX3DA (Christoskov, 2013) which is part of the code package HELHEX (Petkov and Christoskov, 2013), and DYN3D of FZDR-Rossendorf (Bilodid et al, 2018).

3. The dissertation presents an approach based on the use of modal decomposition of the scalar fluxes and analytical coarse-mesh finite-differencing (ACMFD) scheme in the HEXNEM3 method. This approach offers a number of advantages especially for time-dependent problems and freedom of choice of algebraic solvers for the resulting set of equations.

The methodology of the study is correctly chosen, in compliance with the declared subject and scope, and well described in the dissertation as well as in the author's publications. The code implementation of the new modal ACMFD version of HEXNEM3 has been tested for stability, convergence and accuracy by solving a series of steady-state and transient mathematical benchmark problems for VVER-440 and VVER-1000, and by comparing the solutions vs. reference diffusion theory solutions for homogenized nodes. This corresponds to code *verification.* The validation of problem-oriented calculation models using the new formulation of the method, in the context of specific applications is declared beyond the scope of this dissertation.

4. The introduction outlines the motivation, the objectives and the scope of the presented research. The overview gives a short survey of the main approaches to the numerical solution of the neutron transport problem, with emphasis on the time-dependent diffusion equation and on the approach used in the dissertation. The content of the overview allows to assume that the author has a good general view of the principal methods used in this field.

5. Sections I, II and III of the dissertation and the Appendix present the description of the algorithms and the results of the study. Section I describes the algorithm of the modal ACMFD variant of HEXNEM3 for steady-state problems, and Section II contains the mathematical derivation of the principle expressions and equations for solving the time-dependent two-group diffusion problem. Section III presents results from the assessment of the new formulation of the HEXNEM3 method through solving steady-state and transient mathematical benchmark problems for VVER-440 and VVER-1000. The results demonstrate that the modal ACMFD variant when using the BiCGSTAB algebraic equation solver preserves the original good accuracy and has a significant advantage in computational efficiency compared with the algorithm using the standard iteration on the energy groups in HEXNEM.
The conclusions of the dissertation are in compliance with the obtained results. The description of the developed algorithms and their mathematical derivation is clear and detailed which indicates that the author has acquired solid knowledge and skills in this field.

6. The presented dissertation is a useful and innovative R&D work on the computational methods in reactor physics. The results and contributions, which include development and research of advanced methods and algorithms, have a scientific-applied nature. They are of methodological value for the specialists in reactor physics and nuclear engineers, and provide useful information for the method and code developers. They also contribute to the buildup and maintaining competence in this field in Bulgaria.

7. The dissertation is based on 5 publications with I. Christoskov as a co-author:

a) Author's publications included in the dissertation
- Article in C.R. de l'Academie bulgare des sciences, 2018 IF 0.32, Q2
- Article in Annals of Nuclear Energy, 2019 IF 1.38, Q1
- Publication in AIP Conference Proceedings, 2019 SJR 0.18

b) Conference papers on the topic of the dissertation

- Paper in Proc. of the AER Symposium on VVER Reactor Physics and Reactor Safety, Olomouc, Czech Republic, 2018
- Paper presented at the 10th Jubilee Conference of the Balkan Physical Union, Sofia, 2018

First author of all the above publications is S. Kolev. The authors declare equal participation in the presented research. The PhD candidate has sufficient personal contribution in the presented results.

8. The extended abstract of 41 pages is available in Bulgarian and English, and summarizes correctly the main content and the results of the dissertation. The declared contributions in the abstract and in the full text are in compliance with the dissertation content and its objectives.

9. My conclusion is that the presented results as well as the science metric data for the publications on which the dissertation is based, meet all applicable requirements (including those of Art. 64 of the Rules on the terms and conditions for obtaining scientific degrees and holding academic positions in Sofia University and the specific requirements of the Faculty of Physics at the Sofia University) for obtaining the educational and scientific degree "Doctor" in the field of computational reactor physics.

Sofia, 14.09.2020

Reviewer:

(N. Kolev)