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Report on the dissertation:

Neutronics analysis of demonstration and experimental fast reactors with transport methods

by

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Presented to the Budapest University of Technology and Economics, Institute of Nuclear Techniques

Report delivered by: Piero Ravetto, Politecnico di Torino, Italy

The neutronic simulation of fast spectrum nuclear reactors is nowadays relevant for the assessment and design of advanced generation IV systems. The PhD work by **Zoltán István Böröczki** is focused on the application of a transport approach for sensitivity and uncertainty evaluations and transient simulations of such reactors. A code named SEnTRi, based on a coupling with the discrete ordinate PARTISN transport code, is developed. Therefore his work constitutes an up-to-date contribution to the field of nuclear reactor physics and engineering of advanced reactors.

The introduction of the thesis (chapter 1) aims at giving the motivations for the work performed by the candidate, in view of the current needs for the neutronic simulation of generation IV fast reactors. A good review of the existing literature in the field is reported, with special reference to the works highlighting the limitations of diffusion theory and the need of more accurate transport methods.

The second chapter introduces the neutron transport model in the various approximations that are used in the deterministic approaches for its solution in reactor physics problems. The transport equation is presented in its integro-differential form for both the time-dependent and the steady-state eigenvalue formulations. The multigroup approach to deal with the energy variable is briefly illustrated, together with the procedure for the cross section generation. The treatment of the angular variable is also discussed, introducing the spherical harmonics expansion and the discrete ordinate methods, including also diffusion. Afterwards, the basics of perturbation theory and of its application for the definition of the sensitivity coefficients is presented. The chapter is concluded with a discussion of the methods for the solution of time-dependent problems, introducing both the direct time discretization and the quasi-static approaches. The predictor-corrector quasi-static method is then chosen for the implementation in the time-dependent solver. All the various analytical aspects are synthetically presented and briefly discussed.

The following chapter is a very interesting analysis of the drawbacks connected to the process of group constant generation using a scalar flux averaging. It is shown by comparison with reference Monte Carlo results obtained by the Serpent code that flux distributions for a VVER-440 benchmark can be significantly improved once linearly anisotropic cross section

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matrices generated through the transport cross section formalism are used. To analyse more in detail the effect of the flux-weighting approach, sets of group constants are generated using Serpent and the ERANOS-ECCO system for a given infinite lattice, which employs a current weighting. Afterwards three cores of different sizes are simulated in S_{12}, SP_3 and diffusion. The comparisons with reference values of multiplication factors and power distributions prove the relevant role played by the anisotropy effects.

Also chapter 4 presents interesting results. It is devoted to investigate the effect of the angular approach used in the transport model (discrete ordinates and spherical harmonics of various orders) and the spatial discretization on the accuracy of perturbation theory to predict reactivity effects. The exercise is carried out on a benchmark configuration.

Sensitivity and uncertainty analyses are the scope of chapter 5. The evaluations are performed using three different approaches, as applied in the Serpent, TSUNAMI and SEnTRi (coupled with PARTISN) codes. Results are presented for the COMET Critical Assembly and for the ALFRED core and the differences detected are discussed.

At last, chapter 6 focuses on time-dependent simulations. Transient experimental data obtained at the BME training reactor are used for validation purposes. The comparisons show that the simulations (deterministic and Monte Carlo) can capture the general trend of the power evolution measured in the experiment, and some discrepancies can be evidenced. Although the full coupling of the SEnTRi code with a thermal-hydraulic solver is not yet complete, all the same the code is used to evaluate an unprotected rod withdrawal for the ALLEGRO reactor using the thermal data evaluated independently by the coupled KIKO3DMG/ATHLETE 3.0 code. The results of the KIKO3DMG/ATHLET 3.0 and SEnTRi/PARTISN calculations appear to be in good agreement.

The dissertation is concluded by an extended summary and by six statements that highlight the innovative aspects of the conducted research. An extended bibliography on basic literature and on specific references for the work is included. A list of nine publications, authored or co-authored by the candidate, on the work carried out is presented.

From the reading of the dissertation and of its published papers, it clearly appears to me that the candidate has reached an excellent mastering of many of the computational tools nowadays available and currently employed for reactor physics simulations. The amount of calculations carried out in the work and of the body of results presented is really impressive.

The dissertation is written in a clear and pleasant style, although at some points it appears to be too synthetic. The material is well-organized and clearly presented with comprehensive discussions of the results. After having read the dissertation, I can conclude that the candidate fully demonstrates the scientific maturity that is expected for a doctor of science.

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In conclusion, **the dissertation by Zoltán István Böröczki is suitable for the public defence** and I judge his work of a standard certainly adequate for the granting of a doctoral degree.

Torino, 17 October 2022

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Some questions and remarks on the work:

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1. It would be interesting to have some details on the interface coupling the SEnTRi code with PARTISN and to know how this interface could be adapted to the coupling with other codes. This may be relevant for extending the potentialities of the code.
2. What is the guide to choose micro and macro time steps in the application of the quasi-static procedure? How can the choice be adapted to the features of the transient?
3. In Fig. 4.9 the results for the reactivity difference show a decreasing trend while the order of angular detail is increasing: is there any explanation?

Suggestion for further work: it would be nice to more deeply investigate the effect of higher-order anisotropy in the simulation of fast-spectrum systems and of the corresponding order of angular discretization.

Remarks

In section 2.1.2 "associated Legendre polynomials" are mentioned, while referring to the "associated Legendre functions".
In equations (2.66) and (2.67) the symbol of total rather than partial derivative should be used.

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