UOIT – Eleodor Nichita CRD

CRD Title: Improved CANDU Core Homogenization and Benchmark Models

Overview

With concerns about climate change ever present, nuclear energy continues to be an attractive source of electricity which has minute CO2 emissions and is stable, reliable, and almost inexhaustible. In Ontario, the CANDU-reactor fleet has been providing approximately 50% of the provincial electricity supply. For CANDU reactors to continue to be an important contributor to the provincial energy supply they have to satisfy ever increasing economic and safety demands. In particular, increasingly accurate and detailed simulation models are required for the safety analysis of existing, as well as future, CANDU reactors. The broad objective of this proposal is twofold: To develop a new, more accurate, method for calculating the neutron power distribution in a nuclear reactor by using advanced homogenization methods and to develop detailed CANDU-specific benchmark problems to test the newly-developed method, as well as other methods and codes in current use in the Canadian nuclear industry. As a result of the proposed research, the Canadian nuclear industry will enjoy improved capabilities of its computer simulation tools. For its part, the University will increase its expertise in the area of advanced nuclear reactor simulation tools and its graduate students trained as part of this project will enjoy sound knowledge of nuclear engineering and experience working on a challenging engineering problem. New knowledge will be generated and advancements will be made in the area of nuclear engineering related to CANDU reactors.

Program Results /Highlights

1. *Global-local iterations using discontinuity factors*
   As part of this project, a new global-local iteration model was developed for CANDU lattices, whereby cross sections and discontinuity factors are generated using non-reflective node-boundary conditions. The node boundary conditions are determined by performing iterations between the core calculations and the single-node (cell) calculations. At each iteration, node boundary conditions from the previous core calculation are used in a single-node (cell) calculation to calculate updated cross sections and discontinuity factors which are used in the subsequent core calculation. The iterative process continues until convergence. Single-cell (lattice) calculations are performed using the lattice code DRAGON and core calculations are performed using the DISDIF3D diffusion code developed at UOIT, which is a finite-difference diffusion code that allows the use of discontinuity factors. Additionally, the method also allows the direct calculation of individual pin powers.

   A 3x3-cell, two-dimensional, test model was developed to test the global-local iteration method and pin-power reconstruction for CANDU configurations. Results for the 3x3 model show pin power errors below 0.5% when diffusion calculations are compared with transport (DRAGON) calculations. This work generated three publications so far (3, 8, 9).

2. *Investigation of a partial-cell homogenization model*
   One potential way to reduce homogenization-related errors for neutronics calculations is to use smaller homogenization regions which can be homogenized either using simple flux weighting or using the superhomogenization (SPH) approach. Such a partial-cell homogenization method, which does not rely on discontinuity factors, has the advantage of not requiring any changes to be made to the existing full-core diffusion codes and only requires a change in the procedure for generating cell-averaged cross sections. The possibility of using partial-cell homogenization was therefore investigated. A CANDU cell was divided into rectangular sub-regions and homogenized cross sections were generated for the sub-regions using both simple, flux-weighted cross sections and SPH-corrected cross sections. Additionally, lattice calculations were performed using both single-cell models and multi-cell models. DRAGON models for CANDU bundles were developed and used to generate homogenized cross sections for parts of the cell. Diffusion calculations were performed using DONJON. A partial-core benchmark model was used to compare transport results with results obtained using full-cell homogenization and with results obtained using partial-cell homogenization, to assess the efficacy of the latter.

   Some results were published in the Transactions of the American Nuclear Society (4, 7) and additional results will be presented at the 8th CNS Conference on Simulation Methods for Nuclear Engineering (2).

3. *Development of CANDU benchmarks*
   Possible concepts, configurations and size for full-core and partial-core benchmarks have been discussed with the technical advisory committee and two benchmark models have been developed. This work generated three publications (1, 5, 6).

<u>Cases with Realized outcomes to Industry</u>

The advanced homogenization based on global-local iterations (track 1) has the potential to allow better accuracy of full-core neutronics calculations and allows the computation of individual pin powers.

The developed benchmarks (track 3) will be very useful for industry code verification, as will the newly-implemented DONJON capacity to account for position-dependent delayed-neutron fractions.

<u>Research Facilities and Equipment</u>

N/A

<u>Current HQP</u>

2 Ph.D. Students

HQP that Graduated

2 M.A.Sc. Students
1 PDF

Publications /Journal Papers

1. Q. Liu and E. Nichita, "Position-Dependent Delayed-Neutron Fractions for IQS Calculations and Application to PHWR Kinetics Calculations", accepted, Nuclear Engineering and Design, (2018)
2. T. Ferguson and E. Nichita, "A Study of Superhomogenization Applied to PHWR Lattices", accepted, the 8th CNS Conference on Simulation Methods for Nuclear Engineering, Oct 9-11, 2018, Ottawa, ON
3. P. Schwanke and E. Nichita, "A Global-Local Approach for Time-Dependent Lattice Homogenization", accepted, PHYTRA4 – The Fourth International Conference on Physics and Technology of Reactors and Applications, Marrakech, Morocco, September 17-19, 2018
4. T. Ferguson and E. Nichita, "Application of Multi-Node SPH Factor Generation to PHWR Lattice Homogenization", Trans. Am. Nucl. Soc., 118, (2018)
5. P. Schwanke, Q. Liu and E. Nichita, "A Multi-Purpose Homogeneous-Node Benchmark for PHWR Configurations", Trans. Am. Nucl. Soc., 116, (2017)
6. P. Schwanke and E. Nichita, "Analytic Benchmark for Fuel-Reflector PHWR Configurations". Proc. 37th Annual Conference of the Canadian Nuclear Society, June 4 – June 7, Niagara Falls, ON, Canada, (2017)
7. E. Nichita and S. Mohapatra "Application of SPH Factors to PHWR Lattice Homogenization", Trans. Am. Nucl. Soc., 114, (2016)
8. E. Usalp and E. Nichita, "Leakage-Corrected Discontinuity Factors for PHWR Lattices – A simple Test", Proc. 7th International Conference on Modelling and Simulation in Nuclear Science and Engineering, Ottawa, Ontario, Canada, October 18-21, (2015)
9. E. Nichita and E. Usalp, "Pin Power Reconstruction for PHWR Reactors Using Leakage-Corrected Discontinuity Factors", Trans. Am. Nucl. Soc., **112**, (2015)

Interactions /Consultations to Industry

Regular meetings were held with the OPG collaborator and two additional meetings with the full advisory committee. Additionally, the research team participated in three two-day meetings of the UNENE RAC.