SAFIR2018 / MONSOON

SAFIR2018 Interim Seminar 23.-24.3. 2017
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Outline

Background

MONSOON project plan

Specific topics:
  ► International collaboration
  ► Serpent-ARES calculations

MONSOON 2017-2018
Background

The primary goal in reactor physics:

*To solve the neutron-induced reaction rate distribution in the reactor core*

Major challenges:

(i) Neutrons are not uniformly distributed in the fuel (heterogeneous geometry)

(ii) Reaction probabilities are strongly dependent on neutron energy (complicated cross sections)

(iii) Strong coupling to reactor operating conditions and fuel burnup (non-linear problem)

Any transport method used for obtaining the neutronics solution needs to be able to cope with the spatial heterogeneity and energy dependence of cross sections

Fuel cycle simulations and transient analyses involve a coupled problem between neutronics, heat transfer, coolant flow and fuel burnup
Background

Obtaining a direct (“high-fidelity”) solution to the coupled problem is not a viable option because of limited computer capacity.

Instead, the traditional approach to apply reduced-order methods and divide the calculation in parts.

The scale of the modeled system is gradually increased, while simultaneously moving towards more simplified description of transport physics.

The calculation scheme relies on a procedure called spatial homogenization:

- Solution of the local heterogeneous transport problem
- Traditionally performed in 2D at the fuel assembly level
- Repeated for all assembly types and reactor operating conditions

Spatial homogenization essentially provides the “building blocks” for full-core calculations carried out using codes like HEXBU, TRAB3D or Apros.
Background

Spatial homogenization is traditionally performed using deterministic transport codes (e.g. CASMO), but during the past decade also the Monte Carlo method has become a viable option for this task.

Advantages of the Monte Carlo method:

- Capability to handle complicated 3D geometries without major approximations
- Capability to use the best available knowledge on neutron interaction physics without major approximations
- Applicable to any fuel or reactor type
- Scalable to small- and large-scale problems → ideal for producing reference solutions for reduced-order methods

The main drawback is the high computational cost

*The Serpent code developed at VTT since 2004 is one of the first Monte Carlo code specifically designed for spatial homogenization*
SAFIR2018 / MONSOON project plan

Spatial homogenization using the Monte Carlo method was the main topic of the KÄÄRME project in SAFIR2014, and the work was recognized in the SAFIR2018 framework plan:

“The development of the open-source\(^1\) reactor physical code (SERPENT) has proven to be an international success. This development should be continued, and the range of application targets should be broadened. It is also a matter of a larger concept where the goal is a fully independent reactor calculation system and a fundamental, source-code level understanding of the methods used.”

The MONSOON project continues the development with ambitious goals:

- Complete the methodological development started in SAFIR2014
- Demonstrate the practical feasibility of Monte Carlo based spatial homogenization
- Validate the calculation sequence for all transient and core simulator codes used at VTT
- Expand the international user basis
- Study new methods for spatial homogenization and full-core calculations

Develop Serpent into a practical and comprehensively validated calculation tool for spatial homogenization that forms the basis of independent safety analyses of Finnish power reactors

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\(^1\)To be precise, even though Serpent is publicly distributed, it is technically not an open-source code
SAFIR2018 / MONSOON project plan

MONSOON project in 2015-2016:

- Original volume and applied funding: 23.5 pm / 275 k€
- Realized volume and funding in 2015: 12.7 pm / 148 k€
- Realized volume and funding in 2016: 7.8 pm / 100 k€

The significant reductions in project volume meant that most of the original goals had to be dropped altogether.

In addition, two young members of the project group left VTT in 2016.

Revised plan:

- Complete work carried over from SAFIR2014
- Demonstrate practical feasibility
- Expand international collaboration
- Study fuel performance code coupling with spatial homogenization

Additional funding was obtained from Fennovoima in late 2016 to perform preliminary validation of the Serpent-HEXBU code sequence.
International collaboration

Serpent user community:

- 650 users from 173 organizations in 37 countries around the world
- User organizations are mostly universities and research laboratories, but in recent years the code has also been adopted by the nuclear industry
- 440 peer-reviewed scientific journal articles and conference papers and 120 theses on Serpent-related topics worldwide
- 5 doctoral and 26 M.Sc. and B.Sc. theses and special assignments at Aalto University and Lappeenranta University of Technology

Interaction with user community:

- Serpent website - http://montecarlo.vtt.fi
- Serpent discussion forum - http://ttuki.vtt.fi/serpent
- Serpent Wiki - http://serpent.vtt.fi/mediawiki/
- Annual international Serpent User Group Meetings since 2011
- Active participation in large international conferences
MONSOON 2015-2016: International collaboration

Figure 1: Number of registered Serpent users since 2011 and publications since 2005.
MONSOON 2015-2016: International collaboration

Benefits of active international collaboration:

▶ Large user basis provides invaluable feedback for Serpent development
▶ Close contacts with top-ranking universities, research organizations and the industry
▶ Significant validation efforts by Serpent users
▶ Joint publications and collaboration in research projects

Practical examples:

▶ Methodological development in close collaboration with Helmholtz-Zentrum Dresden-Rossendorf (HZDR)
▶ Significant validation efforts for Serpent-DYN3D and Serpent-PARCS code sequences
▶ Future collaboration planned with Westinghouse (Sweden) and RPA Impulse (Ukraine)

Many of the tasks that had to be dropped from the project plan because of budget cuts have been accomplished in collaboration with Serpent users
MONSOON 2015-2016: Serpent-ARES calculations

First full-scale tests for using Serpent for spatial homogenization were carried out in the KÄÄRME project in SAFIR2014:

- Homogenized group constants were calculated for the ARES core simulator
- 1000 MW Westinghouse PWR was used as the test case (MIT BEAVRS benchmark)
- Initial core hot-zero power (HZP) calculations, comparison to experimental results and reference Serpent 3D calculations

The calculations were continued in the MONSOON project:

- Calculations were expanded to hot full-power state (HFP) and fuel cycle simulation
- Spatial homogenization covering the full scope of burnups and operating conditions

The 2016 study demonstrated that the Monte Carlo method is a practical option for spatial homogenization

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### MONSOON 2015-2016: Serpent-ARES calculations

**Table 1**: Critical boron concentrations (in ppm) for different control rod bank configurations. Comparison between Serpent-ARES and experimental reference results.

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<th>Configuration</th>
<th>ARES</th>
<th>Ref.</th>
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**Table 2**: Control rod bank worths (in pcm). Comparison between Serpent-ARES and experimental reference results.

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**MONSOON 2015-2016: Serpent-ARES calculations**

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**Figure 2:** Left: Radial power distribution in the hot full-power state of the initial core (assembly powers in MW). Top value shows the reference Serpent 3D result and bottom value the Serpent-ARES result. Right: Relative differences in the radial power distribution (in percent).
MONSOON 2015-2016: Serpent-ARES calculations

Figure 3: Axial power profiles averaged over all radial nodes. Serpent-ARES compared to the reference Serpent 3D result. The small dips in the Serpent 3D result are caused by fuel spacers, which are omitted in the ARES core model.
MONSOON 2015-2016: Serpent-ARES calculations

Figure 4: Boron let-down curve for cycle 1 calculated by Serpent-ARES compared to experimental reference data.
MONSOON 2015-2016: Serpent-ARES calculations

Figure 5: Wall-clock running times of the 9 history cases (including branch variations) of the 9 assembly types. The longest histories were submitted first and therefore started immediately, while the remaining cases were left in the queue waiting for more computer nodes to become available. Cases with the largest number of branches (all state-point variations + control rod insertion) were run with 20 and the remaining cases with 10 CPU cores. The Monte Carlo transport simulation was run 11,868 times, not counting the transport solutions during fuel depletion.
MONSOON 2017-2018

Project volume was increased to 11.5 pm / 146 k€ in 2016, which allows catching up with some of the tasks that had to be dropped in 2015-2016

Topics for 2017-2018:

▶ Continue development of methodology for spatial homogenization in Serpent 2
▶ Expand validation studies from steady-state and fuel cycle simulations to transient analysis
▶ Include BWR core calculations in the validation studies
▶ Study new methodologies for spatial homogenization, parametrization of group constants and nodal diffusion calculations
▶ Enhance collaboration with Serpent users
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