Kraken

– the upcoming Finnish reactor analysis framework

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History

- VTT has a long and strong history of conducting independent deterministic safety analyses for Finnish reactors.
- This is achieved with Finnish reactor analysis tools, developed by VTT.
- Most of our current production tools were developed in the 80's and 90's educating a whole generation of experts into the field of reactor analysis.
- The aging of both tools and expertise leads to challenges.
- New reactor types (e.g. small modular reactors) are expected to enter the market.
- How to ensure expertise and tools needed for future safety analyses?

The next generation of Finnish tools

The development of several next generation tools has been underway at VTT.

- Serpent Monte Carlo code (2004 –)[1].
- FINIX fuel behavior module (2012 –)[2].
- Ants nodal neutronics code (2017 –)[3],[4].

The revitalization in code development and expertise building is taken one step further through the development of a whole new computational reactor analysis framework, Kraken.

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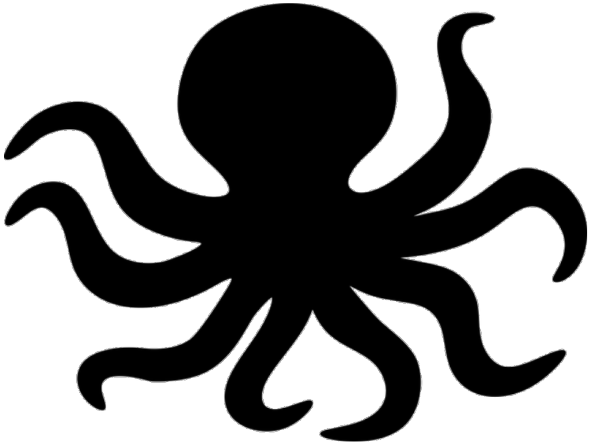
[1] J. Leppänen et al. "The Serpent Monte Carlo code: Status, development and applications in 2013". In: *Annals of Nuclear Energy* 82 (2015), pp. 142–150. ISSN: 0306-4549. DOI: 10.1016/j.anucene.2014.08.024.

[2] T. Ikonen et al. "Module for thermomechanical modeling of LWR fuel in multiphysics simulations". In: *Annals of Nuclear Energy* 84 (2015), pp. 111–121. DOI: 10.1016/j.anucene.2014.11.004.

[3] V. Sahlberg & A. Rintala. "Development and first results of a new rectangular nodal diffusion solver of Ants". In: *Proc. PHYSOR 2018*. Cancun, Mexico, Apr. 2018.

[4] A. Rintala & V. Sahlberg. "Extension of nodal diffusion solver of Ants to hexagonal geometry". In: *Kerntechnik* 84.4 (2019), pp. 252–261.

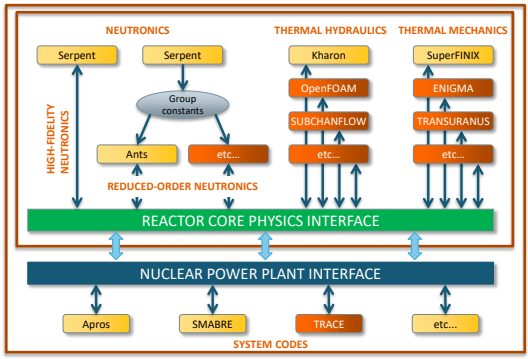


The Kraken framework

Kraken

The development of the Kraken framework [5] has started in earnest in 2019:

- The Kraken framework couples together single physics solvers in a modular fashion.
- Coupling is designed to work both with self developed tools and state-of-the-art third-party codes.
- Core physics solvers are coupled together via a dedicated multi-physics driver module.
- The reactor core solver will be coupled with system codes in the future for the modeling of plant-level transients.

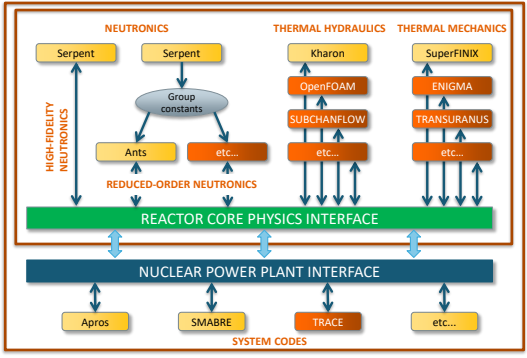


[5] V. Valtavirta et al. "Kraken – an Upcoming Finnish Reactor Analysis Framework". In: *Proc. ANS MC2019.* Portland, OR, USA, Aug. 2019.

Kraken

Serpent gives a strong backbone to the Kraken framework:

- Serpent serves a dual role in the framework.
- Group constant generation for Ants.
- Direct solutions to the multi-physics problem via coupling to thermal hydraulics and mechanics.
- Can produce the best possible reference solution for Ants in CZP, HZP and HFP.



Long term plans

- In the future, all of VTT's deterministic safety analyses can be conducted with Kraken.
- Focus on being able to evaluate fulfillment of design bases according the YVL-guides and NUREG-0800 [6].
- Requirements from regulations need to be translated to features to be implemented.
- A SAFIR2022 project LONKERO aims to set up the basic capabilities.
- Rapid development pace set for the foreseeable future.

[6] "*Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition.* Technical report NUREG-0800, previously issued as NUREG/75-087. US-NRC, 1989.

Long term plans

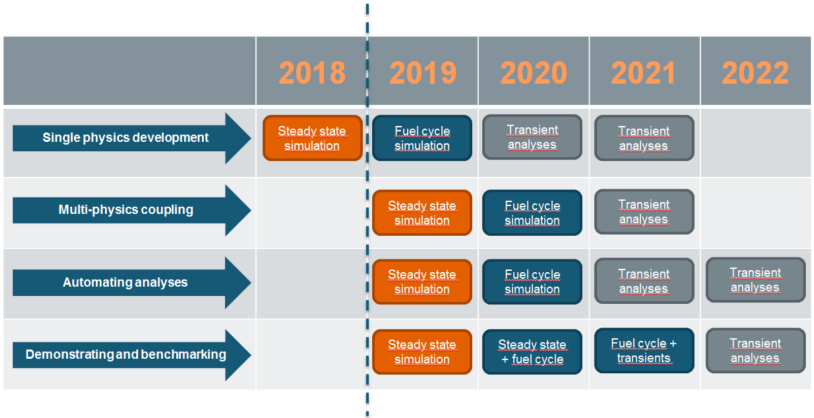
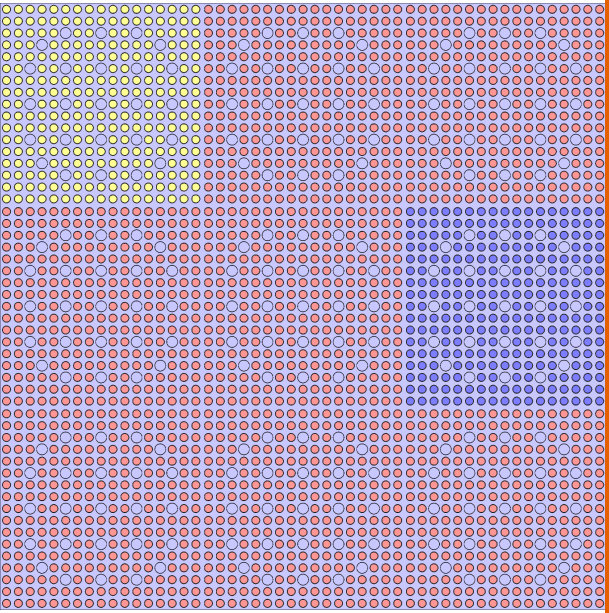
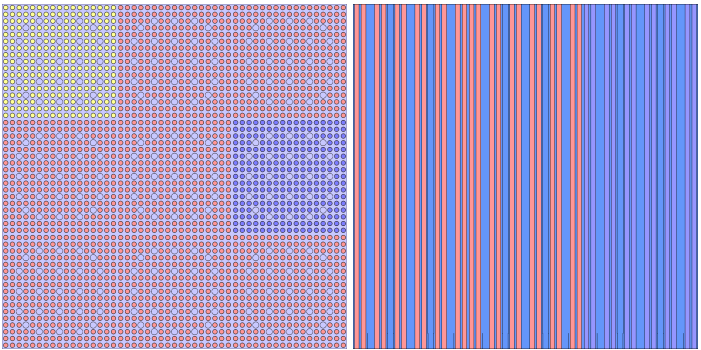


Figure: High-level timetable for the LONKERO project that focuses on Kraken development.



Topical work in 2019

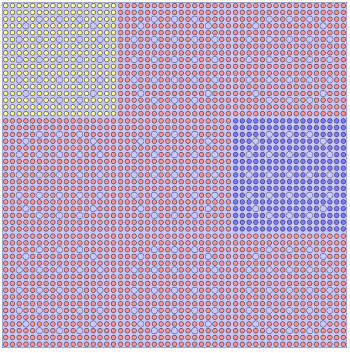
The first coupled problem[5]

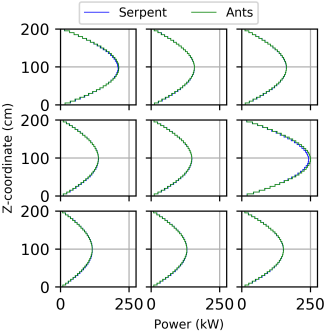


A simple 3D colorset problem to test the coupled solution.

[5] V. Valtavirta et al. “Kraken – an Upcoming Finnish Reactor Analysis Framework”. In: *Proc. ANS MC2019*. Portland, OR, USA, Aug. 2019.

The first coupled problem[5]





Code coupling works as intended, hot full power solutions obtained with both high-fidelity (Serpent) and reduced-order (Ants) methods.

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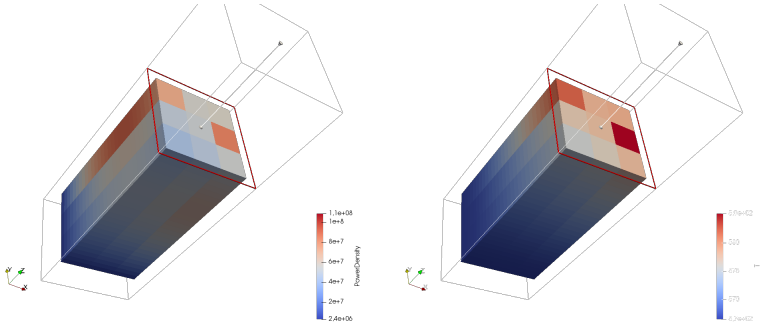

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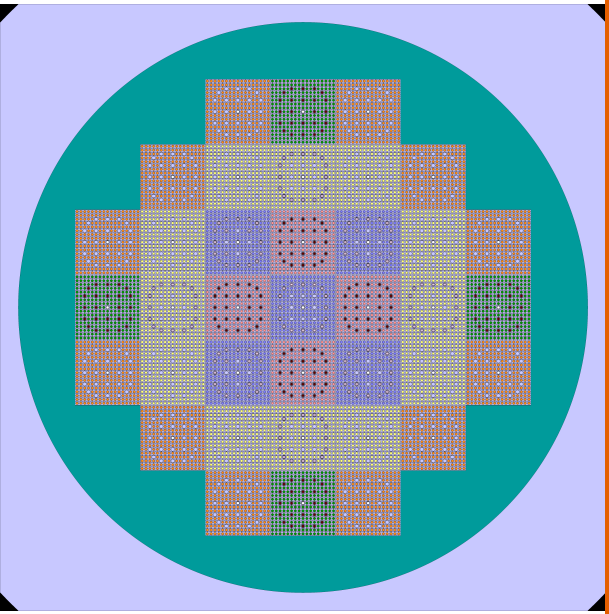

SMR scale progression problem

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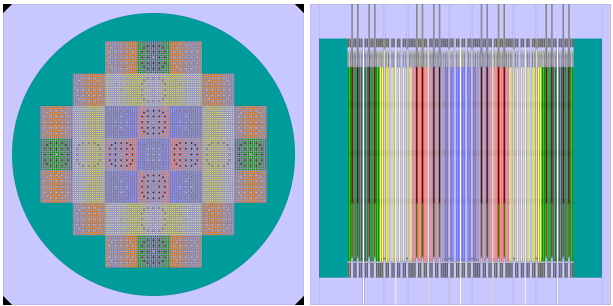
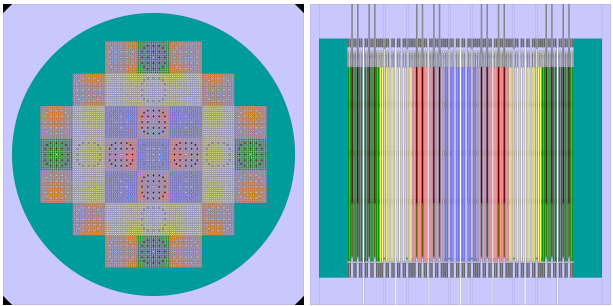


An SMR sized PWR core based on a combination of NuScale [7] and BEAVRS [8] data.

[7] *NuScale Standard Plant Design Certification Application, Part 2, Final Safety Analysis Report, Rev. 2, Chapter 4: Reactor*. NuScale Power LLC. 2018.

[8] N. Horelik et al. "Benchmark for Evaluation and Validation of Reactor Simulations (BEAVRS), v1.0.1". In: *Proc. M&C 2013*. Sun Valley, ID, May 2013.

Second progression problem



- The first real reactor geometry to be modelled.
- Evaluation of control group worths, shutdown margins and reactivity coefficients.

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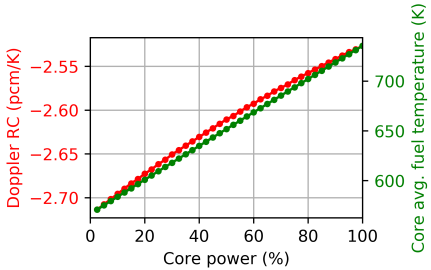

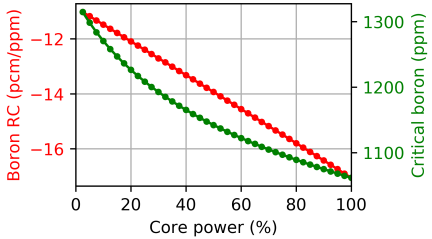

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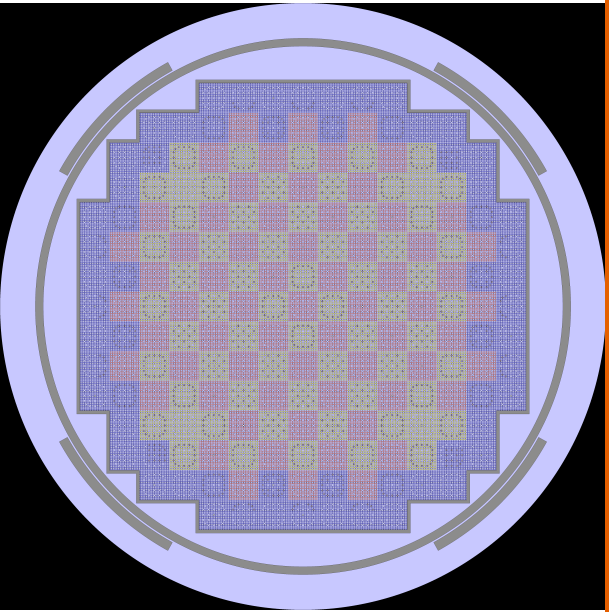
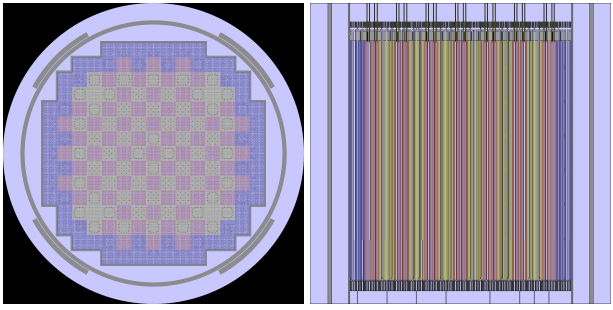


First validation problem

Current work



- Commercial PWR core from the US.
- Boron letdown, axial flux profiles in various assemblies during cycles 1 and 2.
- Detailed benchmark description[8].

Steady state in 2019, fuel cycle simulation planned for 2020.

[8] N. Horelik et al. "Benchmark for Evaluation and Validation of Reactor Simulations (BEAVRS), v1.0.1". In: *Proc. M&C 2013*. Sun Valley, ID, May 2013.

Future

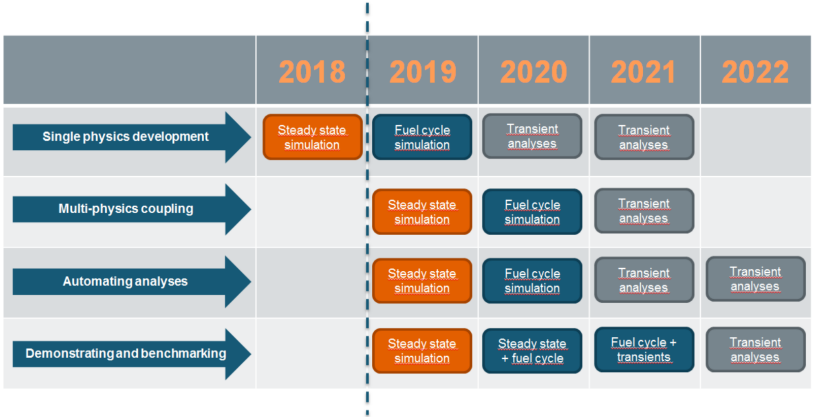


Figure: High-level timetable for the LONKERO project that focuses on Kraken development.

Summary

Summary

- VTT has a long and strong history in the analysis of Finnish reactors with self developed tools.
- The development of the Kraken framework will provide VTT with the next generation of tools for deterministic safety analyses and the experts to use them.
- Kraken tackles topical challenges (e.g. SMRs) with new state-of-the-art (and beyond) approaches.
- A rapid development pace has been set for the next few years.
- Kraken has been applied to an SMR level core problem and the validation will start with the BEAVRS benchmark.

Thank you!

beyond
the obvious

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