Kraken in 2022

An update on the new Finnish reactor analysis framework

Ville Valtavirta and others
SYP 2022

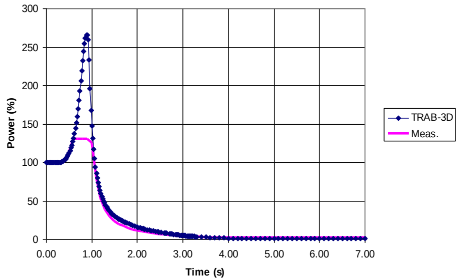
Outline

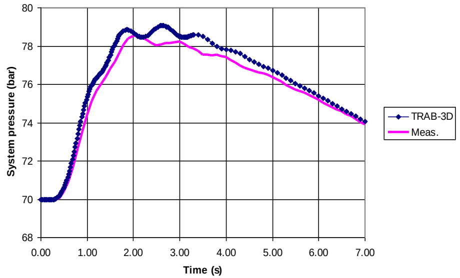
- Motivation for the Kraken development.
- Kraken on one slide
- Highlights of recent work.
- Current status.
- Future plans.

Motivation

Motivation for Kraken development

- VTT has a long and strong history of conducting independent deterministic analyses for Finnish reactors.
- This has been achieved with Finnish reactor analysis tools, developed at VTT.
- Most of the previous tools were developed in the 80’s and the 90’s educating a whole generation of experts into the field of reactor analysis.
- The aging of both tools and expertise led to challenges.
- New reactor types (e.g. small modular reactors) were expected to enter the market.
- **Q: How to ensure expertise and tools required for future safety analyses?**
- **A: Start building up the next generation of tools and experts by developing a new reactor analysis framework, Kraken.**





Reactor power (top) and system pressure (bottom) in the OL1 overpressurization transient (22. 2. 1987). Measured data and prediction by TRAB-3D.
A. Daavittila, E. Kaloinen, R. Kyrki-Rajamäki and H. Räty, *Validation of TRAB-3D against real BWR plant transients,* In Proc. BE-2000, Washington DC, November, 2000

Kraken on one slide

Kraken on one slide

VTT is replacing its legacy reactor analysis toolchains (HEXTRAN, TRAB-3D) with a new set, **Kraken**, building largely on VTT's own modern solvers.

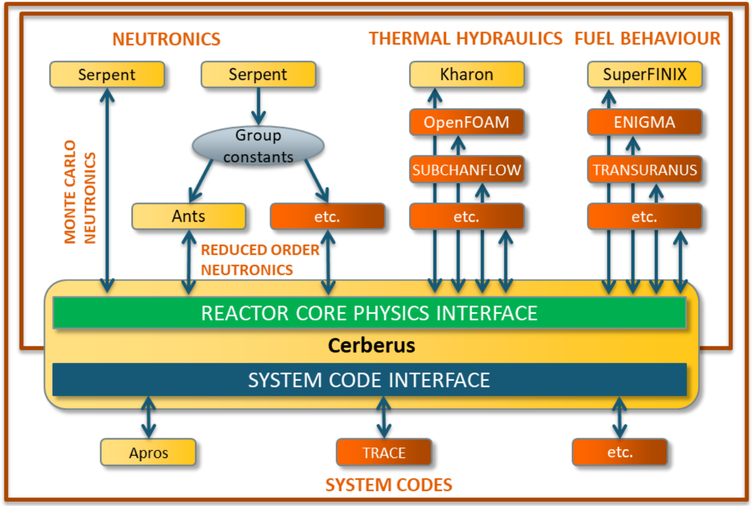
Kraken will provide VTT with the **tools** required for future safety analyses and the **expertise** to use those tools in a proper manner.

Kraken is designed both for **independent determinist safety analyses**, **evaluation of new reactor concepts** and as a **general research tool**.

Basic capabilities for **steady state**, **fuel cycle** and **transient** analyses implemented during 2019-2021.

Validation effort ongoing with focus on demonstrating capabilities required for deterministic safety analyses.

A **non-commercial user license** has been drafted with **international distribution** planned through OECD/NEA data bank and RSICC.



A schematic representation of the plans for the completed Kraken framework. Finnish solver modules developed at VTT are shown in yellow, while potential state-of-the-art third party solvers to be coupled are shown in orange.

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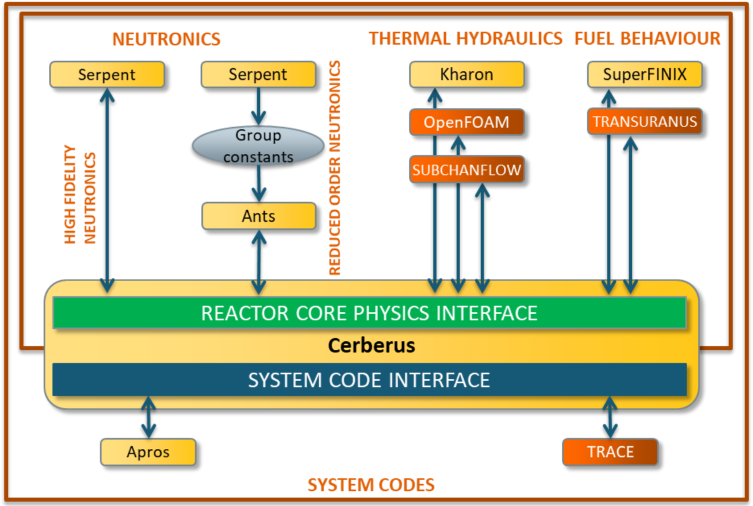
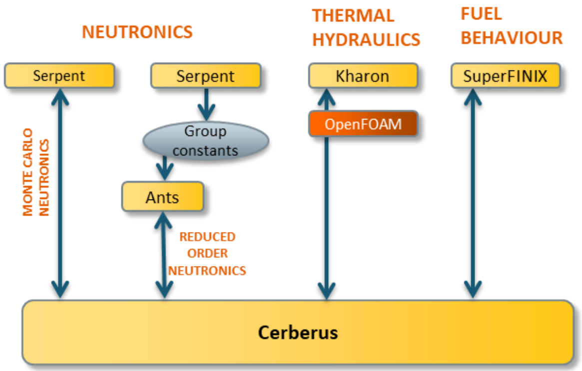


The current couplings in the Kraken framework. Finnish solver modules developed at VTT are shown in yellow, while potential state-of-the-art third party solvers to be coupled are shown in orange.

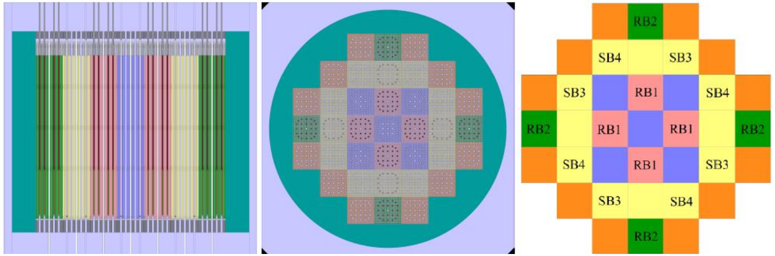
Highlights of recent work

2019: Initial couplings and stationary analyses

- Coupling of the three core level physics through Cerberus.
- Capability to run stationary analyses with two options for neutronics solver:
  - Serpent Monte Carlo code.
  - Ants nodal neutronics program.



- Highlight:
  Demonstration of modularity and capability of Kraken for stationary SMR analyses:



Serpent geometry plots of the modelled SMR core and the naming of different control rod groups.

- Modelled the SMR core at CZP, HZP and HFP with Kraken using **Ants** and **Serpent**.
- Evaluated rod worth curves and feedback coefficients at different power levels.

Valtavirta, V., Lauranto, U., Hovi, V., Peltonen, J., Rintala, A., Tuominen, R., Leppänen, J.
“High fidelity and reduced order solutions to an SMR-level progression problem with the Kraken computational framework”
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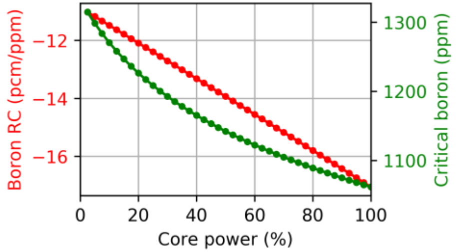
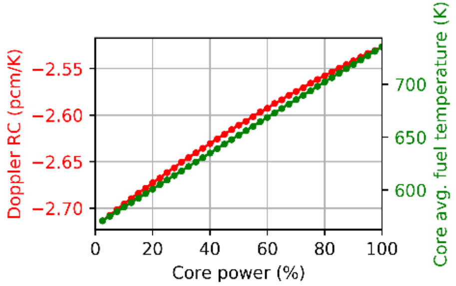
	CZP			HZP			HFP		
	Ants	**Serpent**	**A–S**	**Ants**	**Serpent**	**A–S**	**Ants**	**Serpent**	**A–S**
RB1	861	874	–13	1974	2012	–38	2084	2221	–137
RB2	2094	2092	+2	2218	2161	–57	2290	2285	+5
SB3	2592	2597	–5	3547	3559	–12	3612	3697	–85
SB4	2592	2596	–4	3547	3560	–13	3612	3703	–91

Using high-fidelity solver to verify reduced order solver performance also in coupled calculations: Control rod group worths in an SMR core evaluated by Ants and Serpent based coupled calculation sequences in cold-zero-power (CZP), hot-zero-power (HZP) and hot-full-power (HFP) conditions.

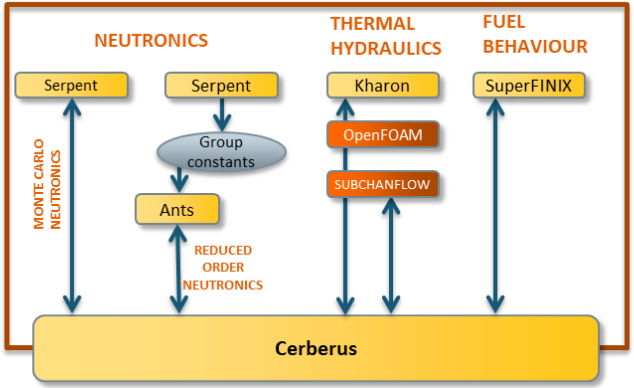




Evaluating licensing relevant data:
Two reactivity coefficients calculated with Ants-Kharon-SuperFINIX for the SMR core at various power levels:
Top: Boron reactivity coefficient (red) and critical boron (green).
Bottom: Doppler reactivity coefficient (red) and core average fuel temperature (green).

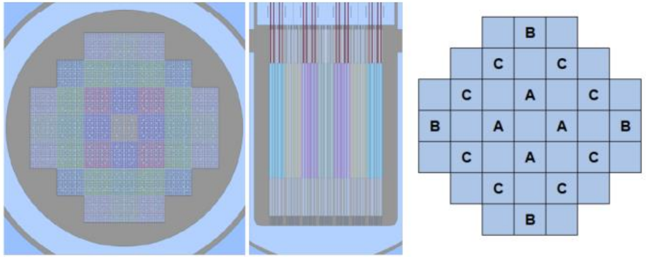
2020: Moving to burnup problems

- Implementing burnup capabilities to Kraken.
- A separate reactor core simulator module created to simplify fuel cycle analyses



Highlights:

1. Demonstration of modularity and capability of Kraken for SMR fuel cycle analyses.



Serpent geometry plots of the modelled SMR core and the naming of different control rod groups.

- Modelled one fuel cycle for the SMR core at full power operation with Kraken using **Ants** and **Serpent**.
- Evaluated rod worths, feedback coefficients, shutdown margins etc. during the fuel cycle.

Valtavirta, V., Tuominen, R.
A simple reactor core simulator based on VTT's Cerberus Python package
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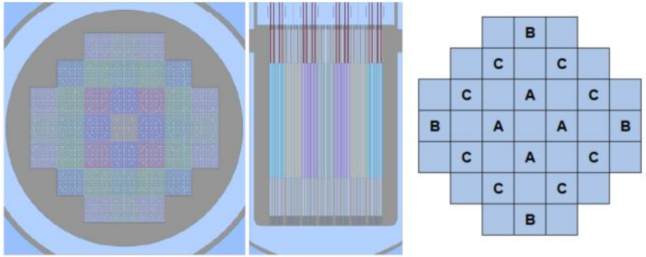

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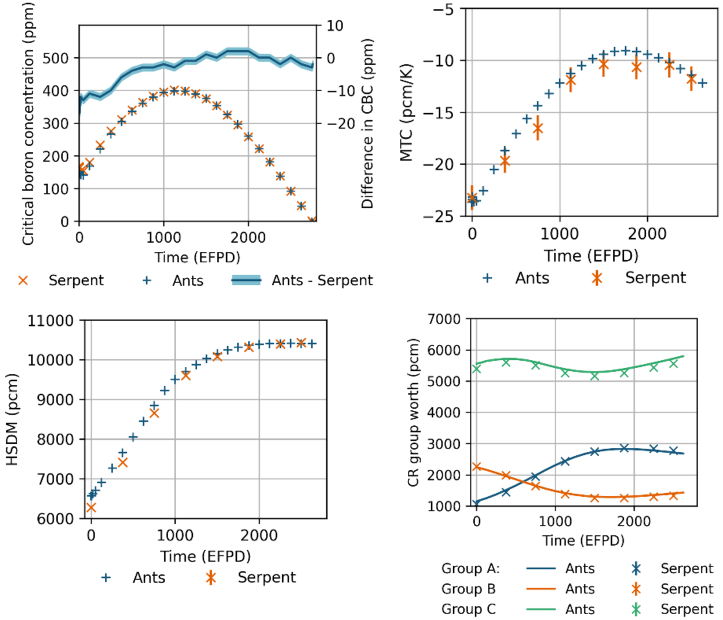

Automatic evaluation of licensing relevant data during the simulation of an SMR operating cycle. Verification of Ants solution with Serpent.
Top left: Boron letdown curve.
Top right: Moderator temperature reactivity coefficient.
Bottom left: Instantaneous hot shutdown margin.
Bottom right: Control rod group worths.

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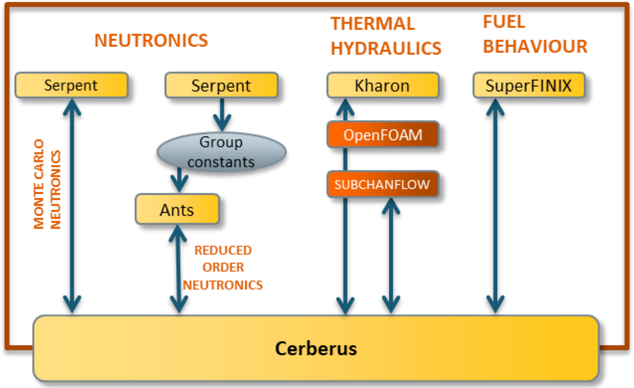
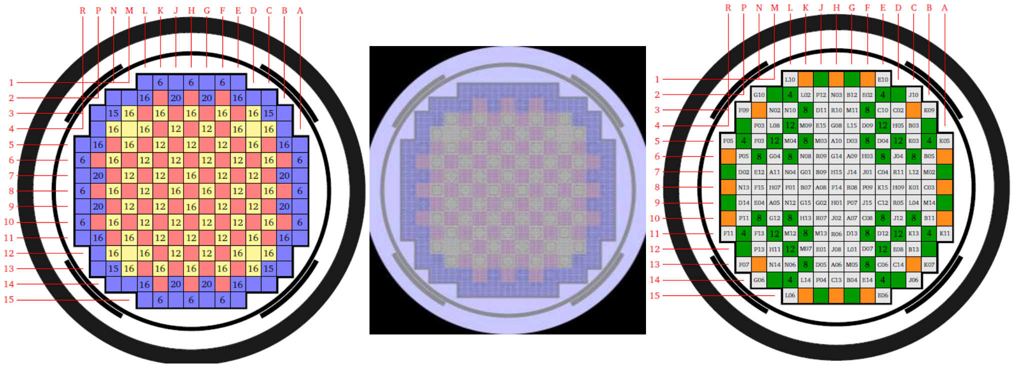


Highlights:

1. Demonstration of modularity and capability of Kraken for SMR fuel cycle analyses.
2. Modelling the BEAVRS benchmark (two cycles for a full sized PWR from the US).



BEAVRS initial core, Serpent model and fuel reload scheme after first cycle.

- Modelling two first fuel cycles for a Westinghouse PWR.
- Shuffling and reload in Ants and SuperFINIX.
- Comparison against measured data:
  - Boron letdown.
  - Fission chamber detector sweeps.

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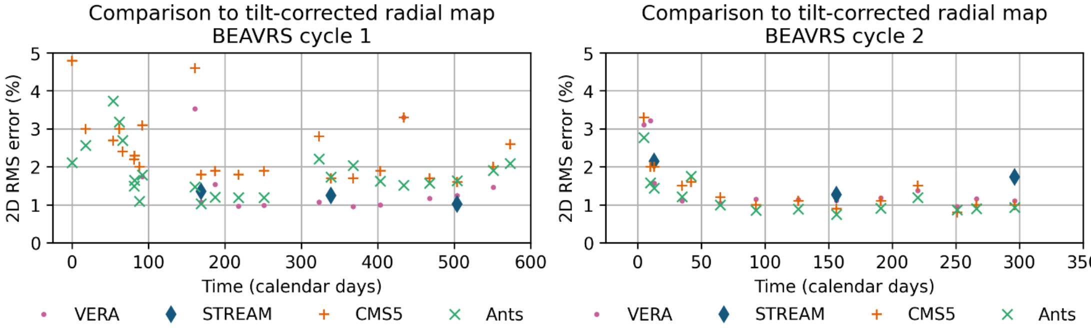
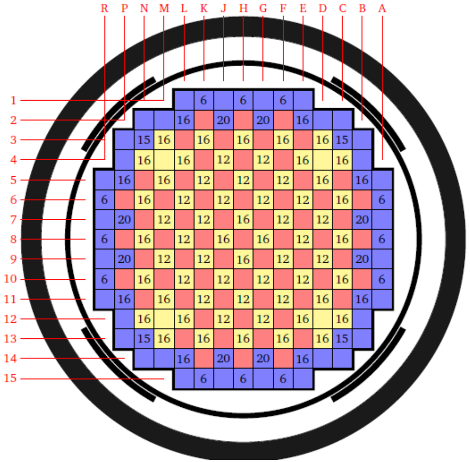
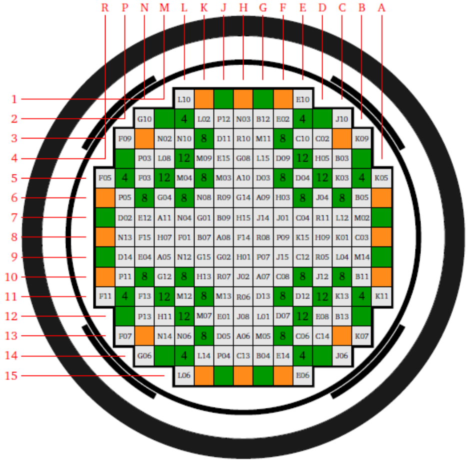


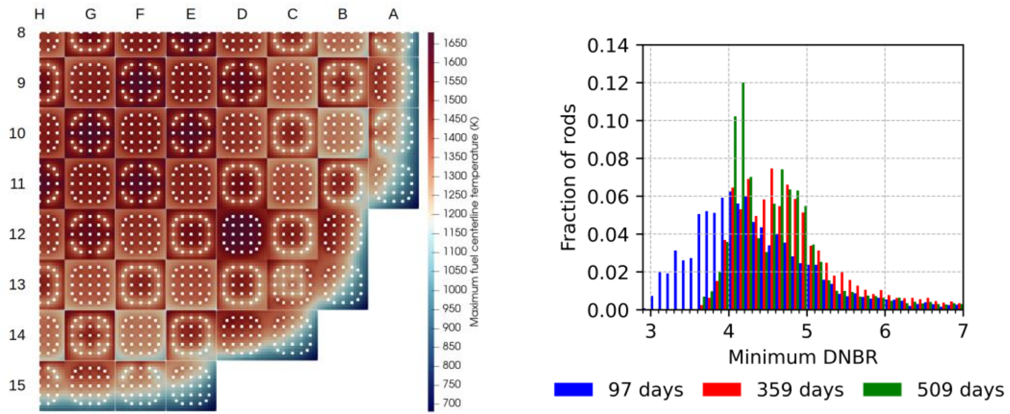
Validation: 2D RMS errors when comparing calculated results to measured detector maps during the two operating cycles of the BEAVRS benchmark. Various industry and scientific leaders and Kraken (Ants).



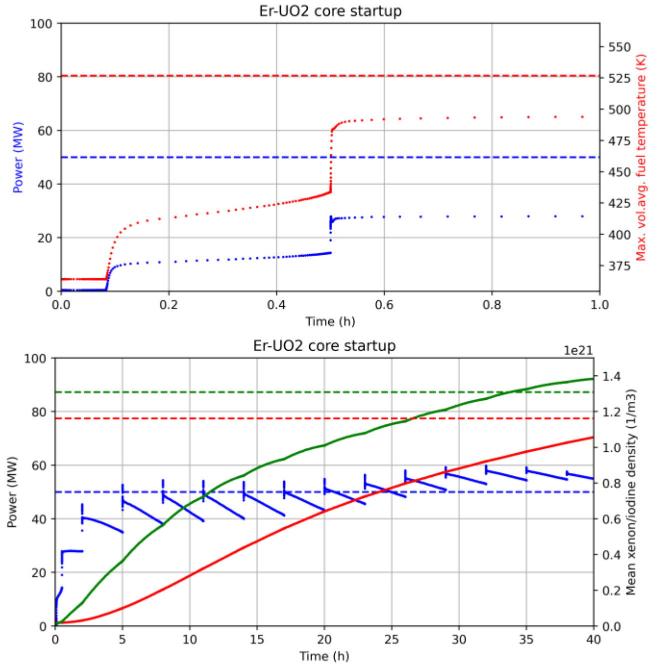


2021: Transient solutions

- Extending the solvers and coupled solution to **time dependent simulations**.
- Verification of Ants neutron kinetics and dynamics.
- Verification of the Serpent-Ants chain in hexagonal lattice neutronics.
- Advanced methods for in-line thermal margin evaluation.



Rod resolved operating cycle analyses: PWR operating cycle modelled with Ants (pin power reconstruction) - SUBCHANFLOW (subchannel resolved) - SuperFINIX (rod resolved): **Left:** Maximum fuel centreline temperatures at 97 days. **Right:** Rod minimum DNBR distributions at 97, 359 and 509 days.



Starting an SMR from hot zero power to full power over several days. Modelled with Ants-SUBCHANFLOW.

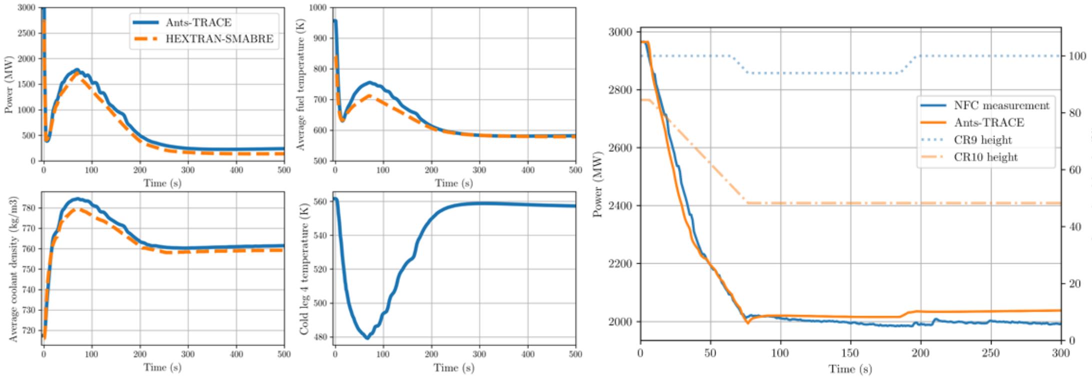
Top row: Reactor power and maximum volume averaged fuel temperature during the first hour of the startup

Bottom: Reactor power and concentrations of ^{135}I and ^{135}Xe during the first 40 hours of the startup process.

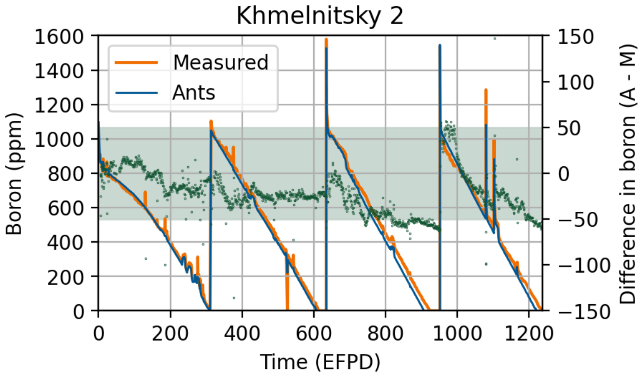
Dashed lines indicate hot full power steady state values.

2022: Further capabilities and V&V

- Verification of Kraken in system scale transients:
  - Ants-TRACE simulations of VVER-1000 coolant transients.
- Verification of Kraken in hexagonal lattice PWR fuel cycle simulations:
  - First four fuel cycles of Khmelnitsky 2 VVER-1000 reactor.
- Prediction of spent nuclear fuel compositions with Ants.
- Further work on thermal margin evaluation.



Verification of Ants-TRACE with VVER-1000 coolant transient benchmarks.
Left: V1000CT-2 MSLB transient, pessimistic scenario. **Right**: Kalinin 3 pump trip.
Ongoing work by U. Lauranto *et al.*



Boron letdown curves for first four operating cycles in Khmelnitsky 2. Measured data and Kraken prediction.
Ongoing work by V. Valtavirta *et al.*

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J. Leppänen *et al.* “A Finnish district heating reactor: Neutronics design and fuel cycle simulations”. Proceedings of ICONE-28, August 4-6, 2021, Virtual Conference, USA.

Valtavirta, V., Tuominen, R. “A simple reactor core simulator based on VTT's Cerberus Python package” ANS M&C 2021, April 11-15, 2021, Raleigh, NC

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Current status

Current status of Kraken

- Capabilities ready for stationary, operating cycle and transient analyses.
- Modular structure with several options for different solver modules.
- Validation work for safety analyses starting (a large future topic).
- Widely used in the core design of VTT‘s district heating reactor concept LDR-50.
  - Equilibrium cycle simulations, load follow simulations.
- Applied in EU-McSAFER to REA and MSLB analyses of the NuScale concept.
  - Serpent or Ants based neutronics, TRACE, SUBCHANFLOW or OpenFOAM based TH.

Future plans

Future plans for Kraken (1/2)

SAFETY ANALYSES OF FINNISH REACTORS

- **Validation**
  - **Fuel cycle simulations and transient analyses for Finnish NPPs.**
  - **Some VVER-440 and BWR specific capabilities need to be implemented.**
- Further development of the nodal neutronics code Ants.
- Further integration of TRACE and Apros to the core level solution.
  - Including coupling to OpenFOAM.
  - Including coupling to separate fuel performance solver.
- Evaluation of fuel rod level thermal margins in transients.
  - Direct evaluation during transient calculation.
  - Separate hot channel / hot pin methodology.
- Sensitivity analyses and uncertainty propagation.

Much of this is planned for SAFER DECAPOD.

Future plans for Kraken (2/2)

- Predicting spent fuel compositions with Ants.
  - Full core spent fuel compositions from fuel cycle simulations.
  - For decay heat, shielding etc. secondary analyses.
  - Work already ongoing as MSc thesis project of T. Kähkönen.
- Distributing Kraken via OECD/NEA data bank and RSICC.
  - Distribution agreement signed with OECD/NEA data bank.
  - Export control permit granted for NEA distribution.
  - Preparation of the first publicly distributed version follows.
- Kraken and advanced reactors.
  - HTGR applications for high temperature heat production.

beyond the obvious

Ville Valtavirta
Ville.Valtavirta@vtt.fi

@VTTFinland

www.vtt.fi