8th International Serpent UGM, Espoo, Finland

Utilization of Serpent for practical applications at Fortum

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Fortum Power and Heat Oy

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Content

- Intro
- Comparison of decay heat between Studsvik's tools and Serpent
- Evaluation of rod bowing effect on the radial power distribution
- Serpent cross sections for Loviisa
- Axial boundary conditions of the reactor core
- Criticality safety calculations
- Potential future applications

Nuclear power plays an important role in our energy production

Nuclear power plays an important role in Fortum's energy production. As a **CO2-free and reliable base-load source**, nuclear power is needed to secure the supply of energy and to mitigate climate change.

Our two VVER-440 (507 MW_e) power plants in Loviisa, Finland, are unique and exemplary. Loviisa NPP has provided clean and reliable base production of energy for the last **40 years**.

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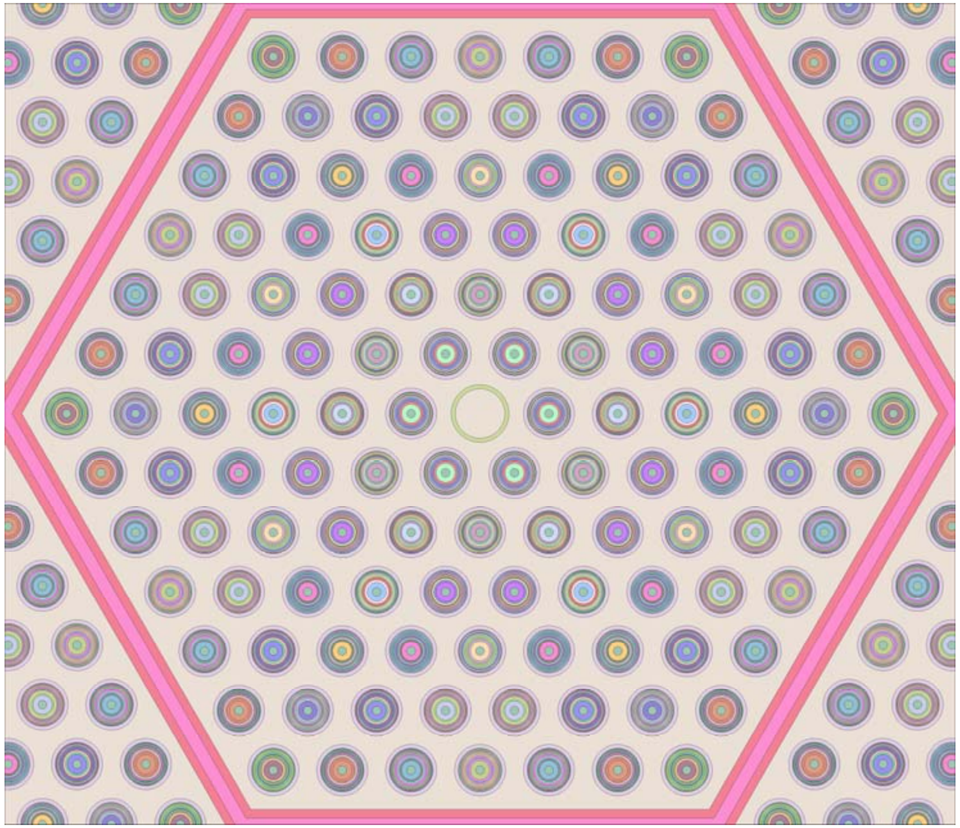
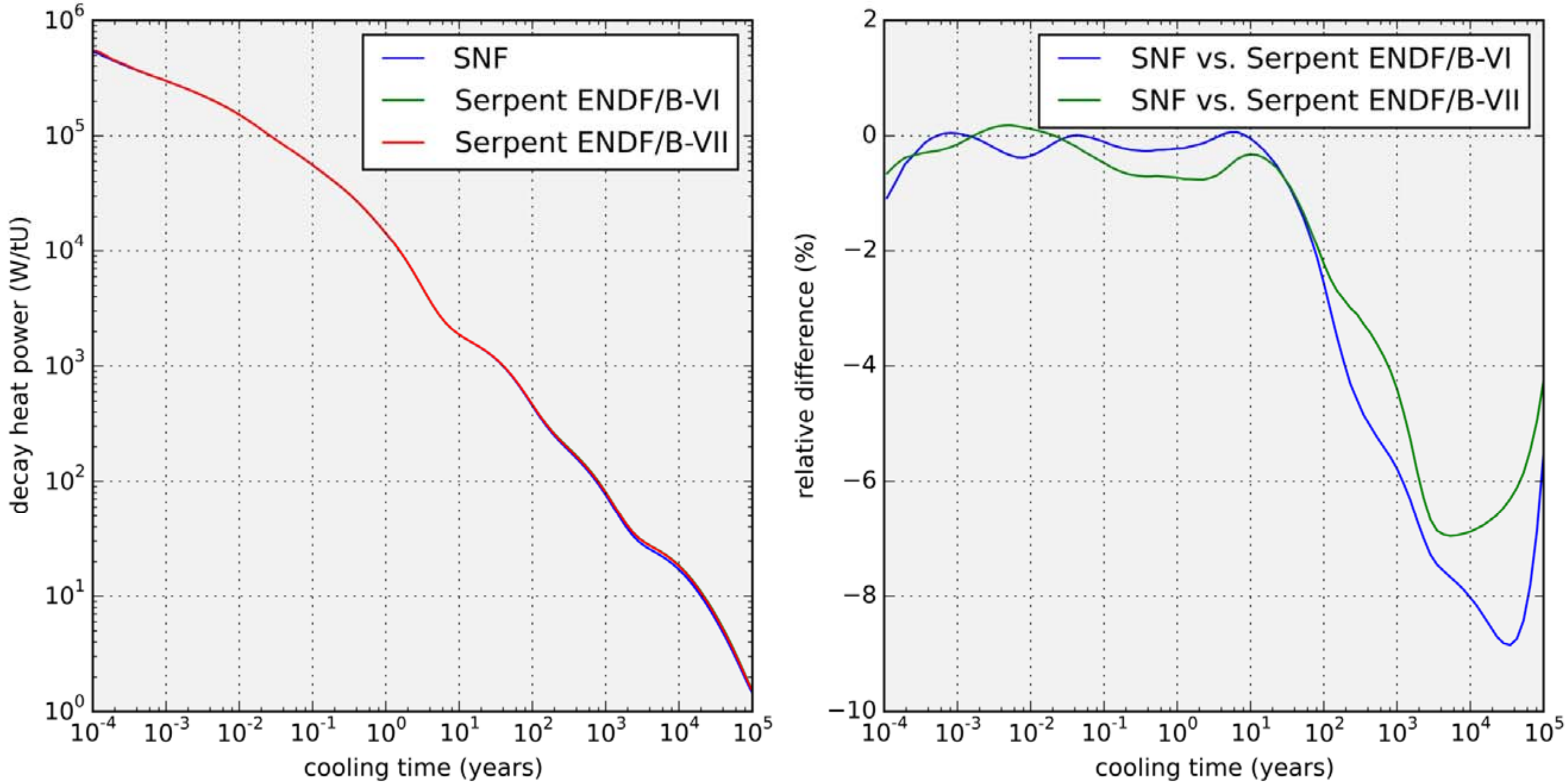
Comparison of decay heat between Studsvik's tools and Serpent

- Single non-profiled 4.0 wt-% VVER-440 fuel assembly.
- EOL burn-up = 50 MWd/kgU.
- Periodic boundary condition on the outer boundary (assembly pitch = 14.7 cm).
- Some simplifications in order to ensure full consistency between CASMO/SNF and Serpent:
  - Axial effects excluded.
  - Thermal expansion switched off (CASMO).
  - Fundamental mode calculation switched off (CASMO).



Comparison of decay heat between Studsvik's tools and Serpent



ENDF/B-VI library with CASMO/SNF (e60201)

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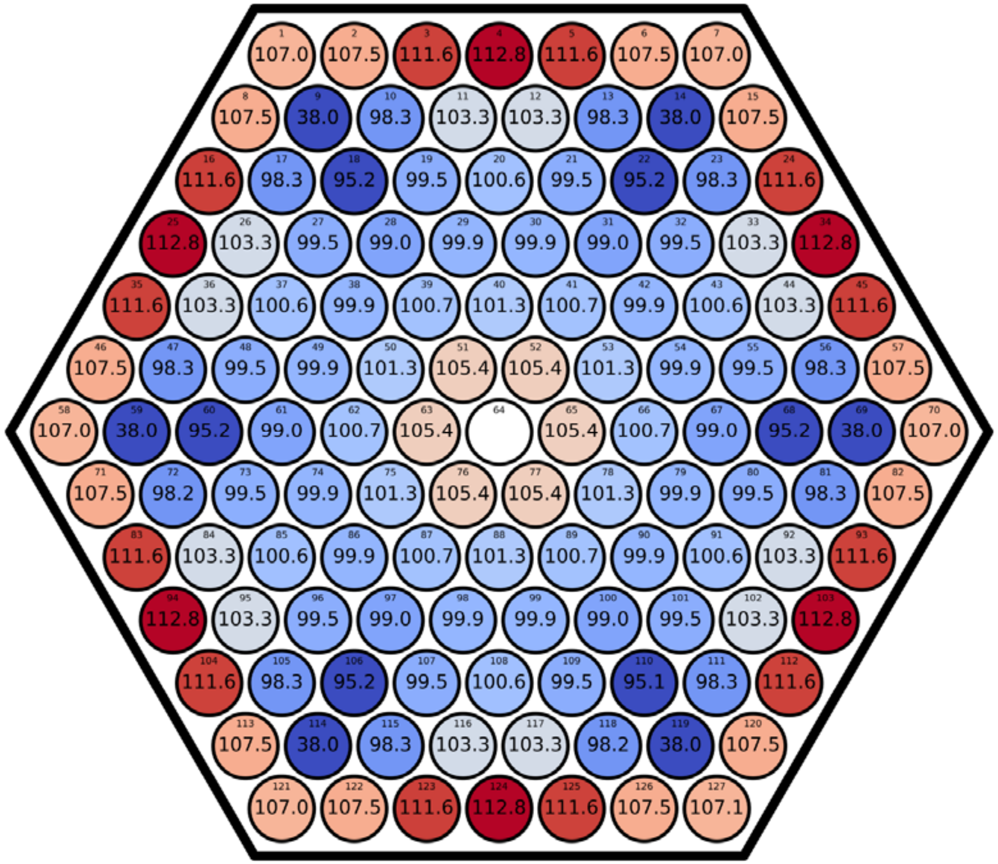
Comparison of mass densities for $Z = 92 \ldots 96$ nuclides SNF vs. Serpent ENDF/B-VI.8 at $t = 10^{-1}$ years

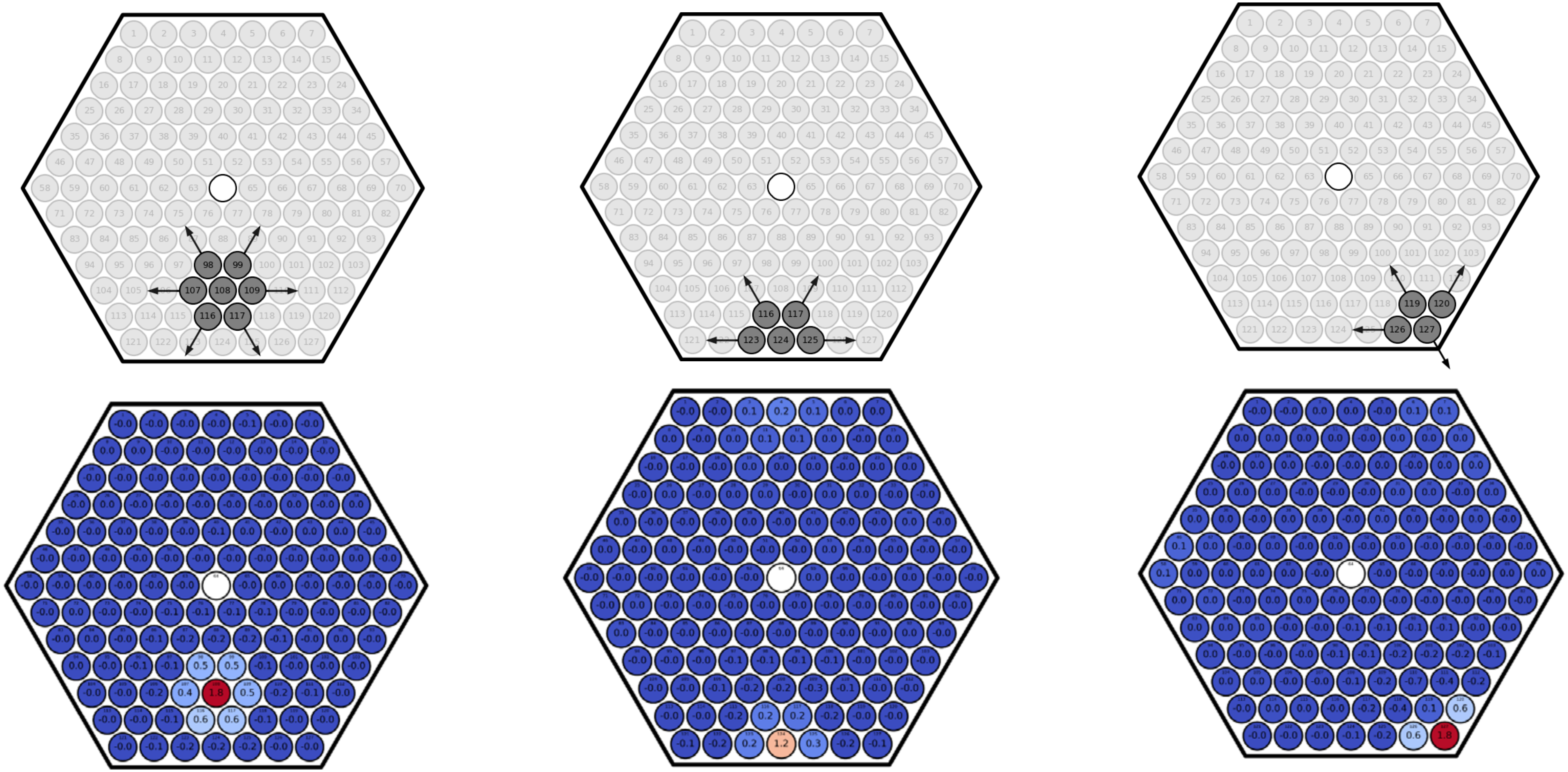
	nuclide	SNF [g/tU]	Serpent [g/tU]
Z=96	Cm-238		1.9e-22
Z=96	Cm-239		2.5e-18
Z=96	Cm-240		5.3e-09
Z=96	Cm-241		2.2e-06
Z=96	Cm-242	2.6e+01	2.6e+01
Z=96	Cm-243	7.0e-01	7.7e-01
Z=96	Cm-244	1.1e+02	1.1e+02
Z=96	Cm-245	6.7e+00	9.2e+00
Z=96	Cm-246	8.8e-01	1.1e+00
Z=96	Cm-247		1.8e-02
Z=96	Cm-248	9.2e-04	1.5e-03
Z=95	Am-238		3.3e-16
Z=95	Am-239		3.4e-09
Z=95	Am-240		2.8e-06
Z=95	Am-241	5.5e+01	5.9e+01
Z=95	Am-242	1.7e-01	1.7e-01
Z=95	Am-243	2.2e+02	2.5e+02
Z=95	Am-244	2.4e-01	1.6e-02
Z=95	Am-245		5.3e-06
Z=95	Am-246		3.0e-19
Z=94	Pu-234		3.7e-16
Z=94	Pu-235		5.3e-15
Z=94	Pu-236	3.7e-08	8.7e-05
Z=94	Pu-237		8.7e-04
Z=94	Pu-238	3.1e+02	3.1e+02
Z=94	Pu-239	6.1e+03	6.5e+03
Z=94	Pu-240	2.7e+03	2.9e+03
Z=94	Pu-241	1.8e+03	1.9e+03
Z=94	Pu-242	8.8e+02	9.1e+02
Z=94	Pu-243	2.3e-01	2.6e-01
Z=94	Pu-244		9.1e-02
Z=94	Pu-245		5.4e-06
Z=94	Pu-246		1.2e-16
Z=93	Np-233		2.9e-19
Z=93	Np-234		5.5e-12
Z=93	Np-235		1.2e-05
Z=93	Np-236		3.3e-03
Z=93	Np-237	6.7e+02	7.0e+02
Z=93	Np-238	2.5e+00	2.4e+00
Z=93	Np-239	1.0e+02	1.1e+02
Z=93	Np-240	0.0e+00	8.7e-04
Z=93	Np-241		3.8e-10
Z=93	Np-242		4.4e-16
Z=92	U-232	7.7e-04	3.8e-04
Z=92	U-233	2.2e-08	3.7e-03
Z=92	U-234	1.5e+02	1.6e+02
Z=92	U-235	6.8e+03	6.9e+03
Z=92	U-236	5.5e+03	5.4e+03
Z=92	U-237	1.4e+01	1.4e+01
Z=92	U-238	9.2e+05	9.2e+05
Z=92	U-239	1.5e-01	1.6e-01
Z=92	U-240		2.1e-04
Z=92	U-241		8.2e-13
Z=92	U-242		2.9e-15

Evaluation of rod bowing effect on the radial power distribution

- Analyzes utilized in the re-evaluation of the linear heat rate engineering safety factor.
- Rod bowing causes pin irregularities, which in turn causes uncertainties in the linear heat rates of the fuel rods.
- For 2nd generation TVEL Gd-fuel assembly, the maximum measured rod bowing was **0.338 mm** between two spacer grids.
- Considered phenomena is very localized. In order to acquire a sufficient statistical accuracy, a large neutron population was utilized.
  - Required population was determined by demanding a perfect symmetry for the reference case (statistical error estimates were ignored).
  - 1 000 000 x 10 000 (x 500) neutrons was utilized.



Maximum effect of the rod bowing is about 2 %



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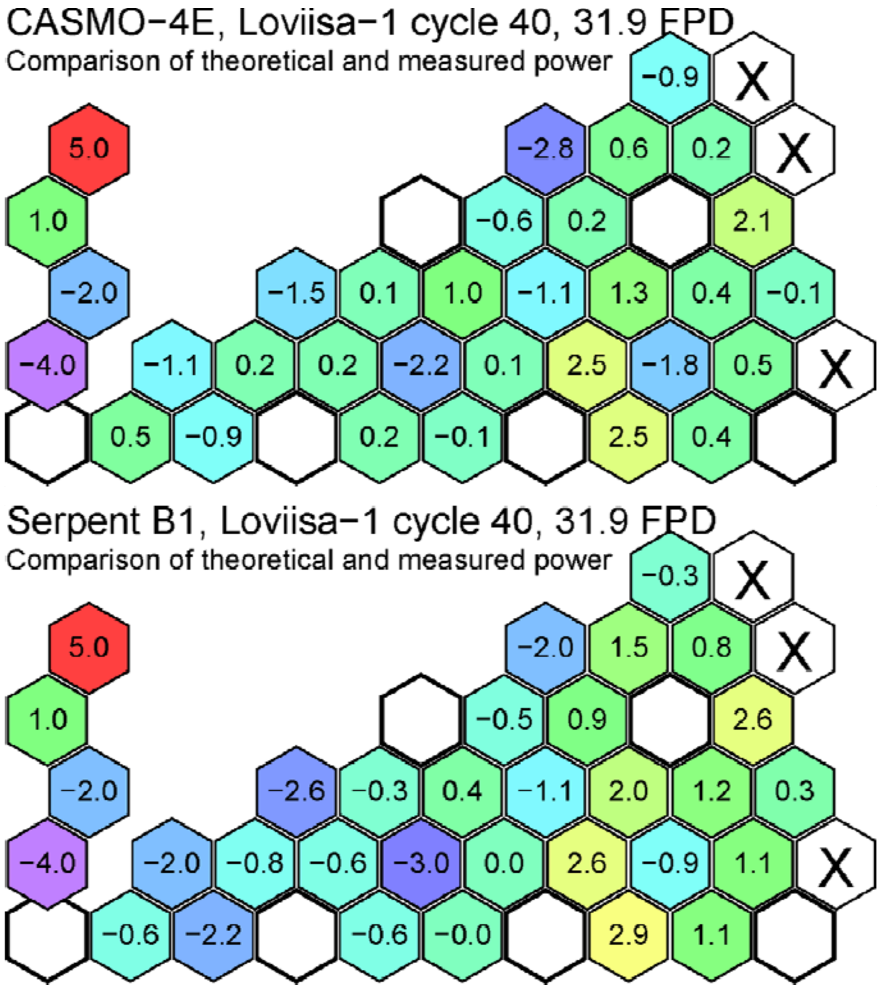
Serpent cross sections for Loviisa*

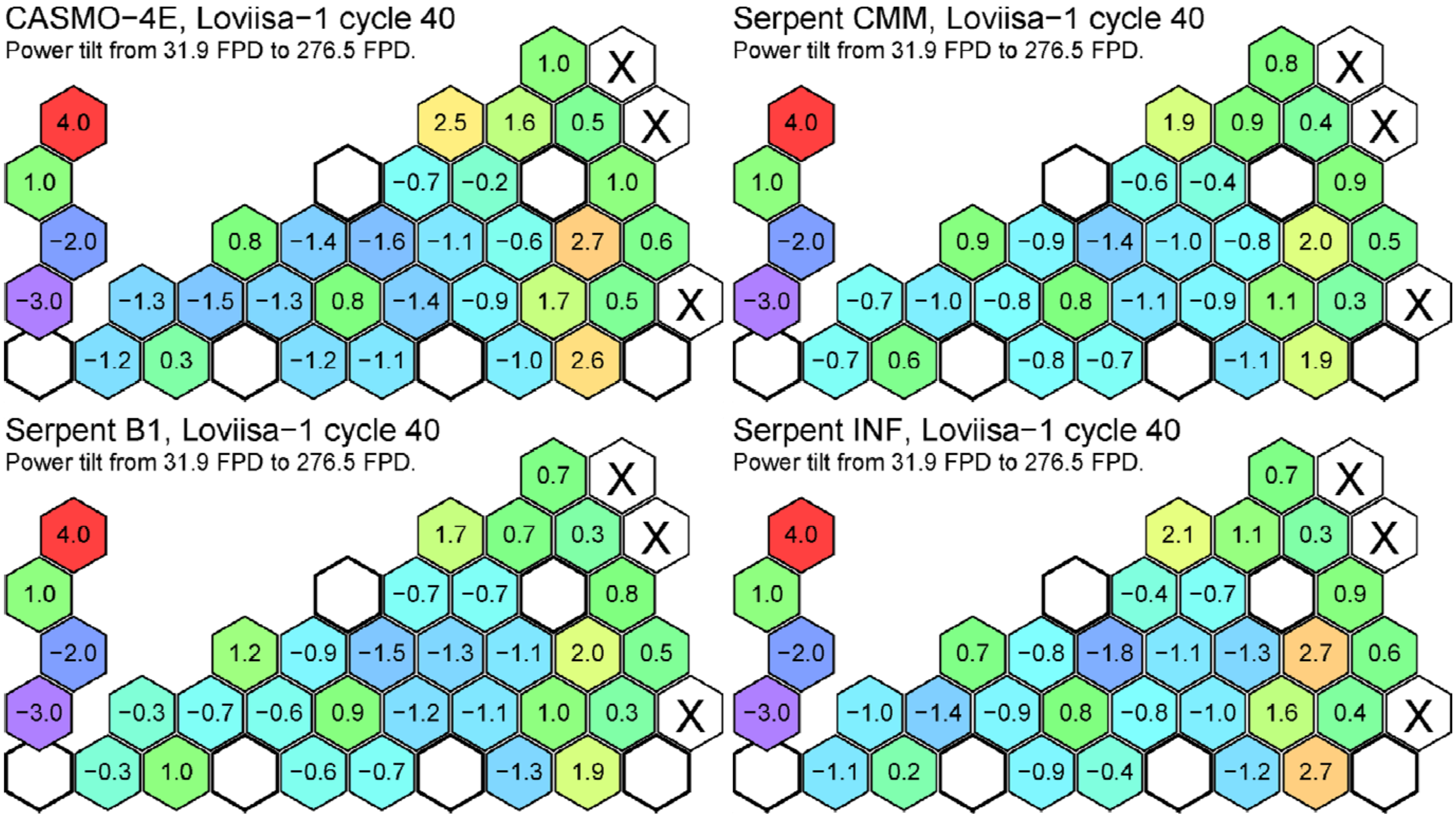
- HEXBU-3D cross sections (MOD5) were calculated with Serpent.
  - Same calculation methods as with CASMO-4E (Studsvik). Thermal expansions of the dimensions were taken into account.
- Three different Serpent cross sections were calculated:
  - no leakage correction, B_1 leakage correction, Cumulative Migration Method (CMM) for diffusion coefficients + B_1 for other parameters
- Comparisons of the theoretical power distribution to the in-core instrumentation measurements were performed.
  - Utilizing the large amount of VVER-440 in-core instrumentation, it is possible to determine the measured power distribution.
- Serpent cross sections were assessed to perform well in the test scenarios.

* For more information, see proceedings of the PHYSOR 2018 (track 3, file 65)

Serpent cross sections for Loviisa



Serpent cross sections for Loviisa



Axial boundary conditions of the reactor core

- Axial boundary conditions of the reactor core are modelled by albedos in HEXBU-3D and Apros programs.
- Serpent is able to calculate the albedos for any defined surface directly using the ‘set alb’ –card.
- Realistic division of axial material areas according to the drawings of the fuel and core.
  - Higher detail near the active fuel.
  - Reflective boundary conditions radially and black axially.
- Albedos calculated as a function of boron concentration and coolant density.
- Realistic coolant density profiles for hot conditions.
  - No axial temperature profile in cold reactor conditions.
- Testing of the albedos will be performed later this year.

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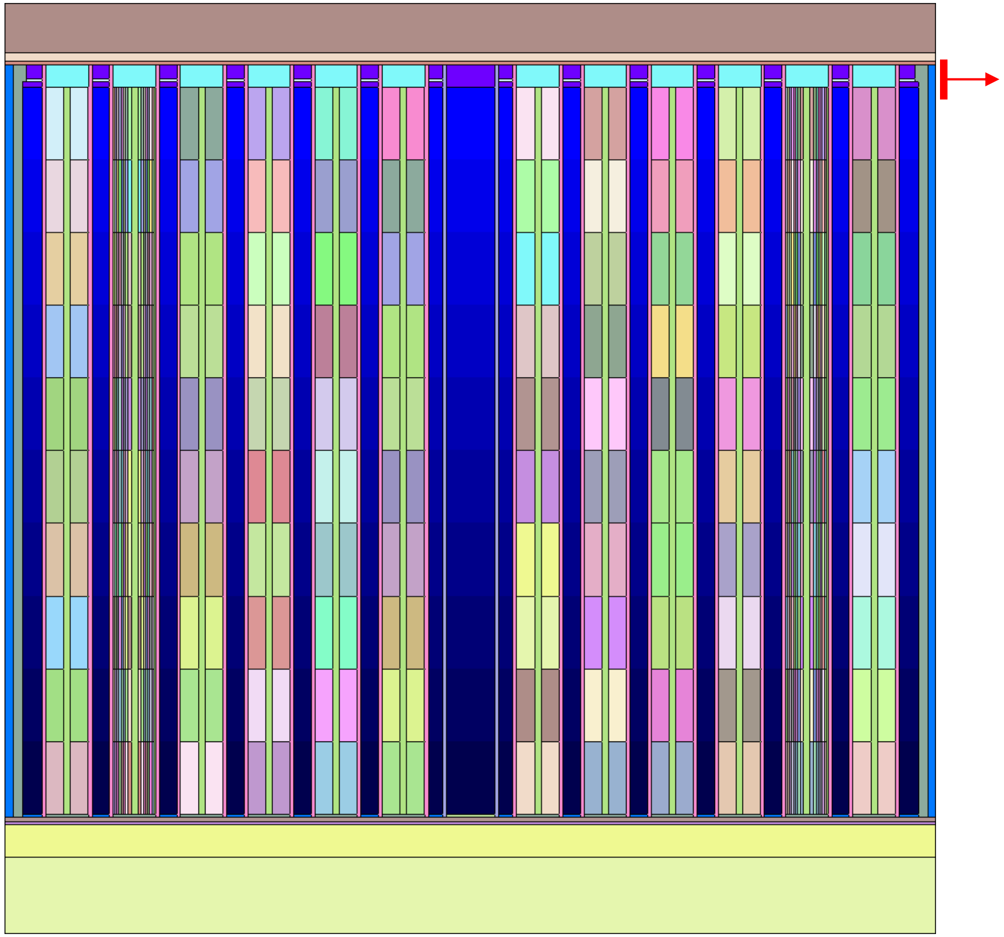
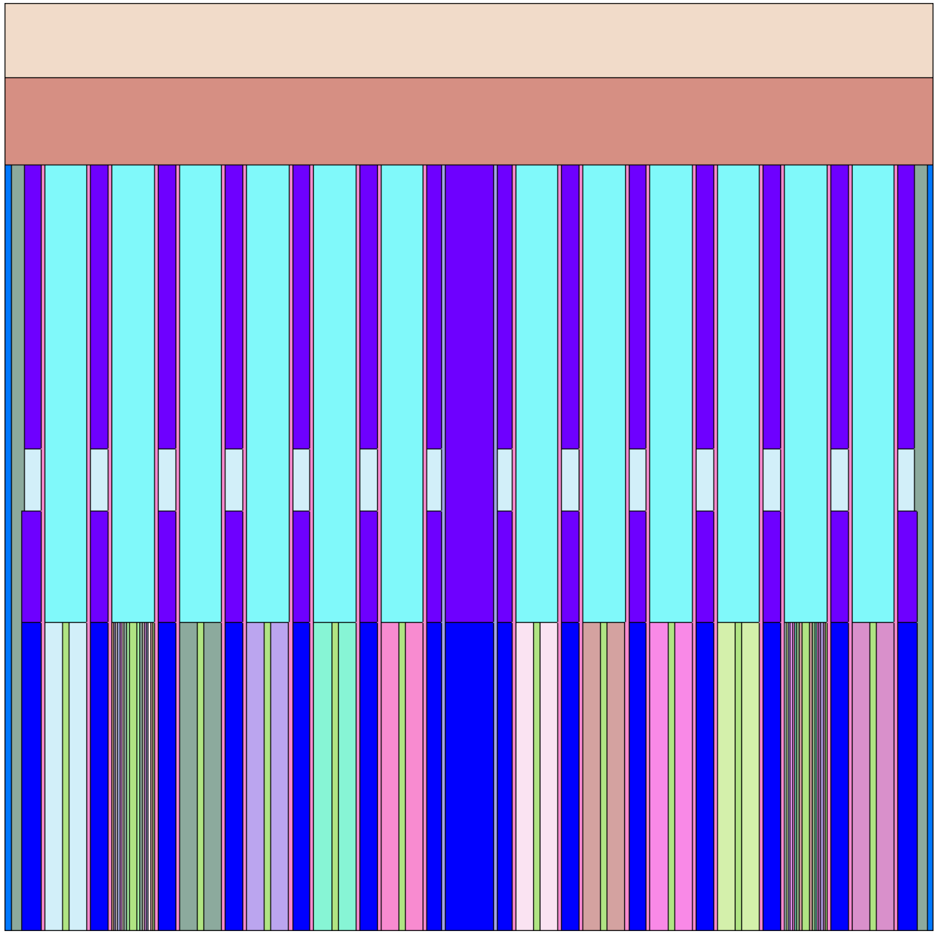
Axial boundary conditions of the reactor core

Total geometry

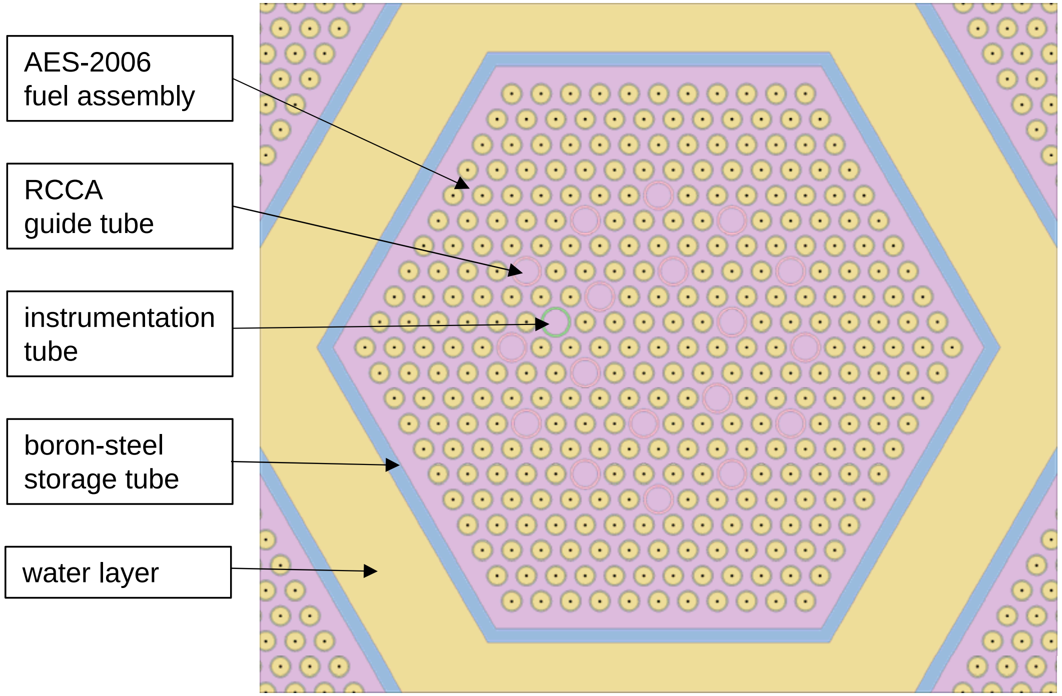


Upper reflector area in more detail (red arrow)



Criticality safety calculations

- Serpent has also been utilized for preliminary criticality safety calculations of Fennovoima's interim spent fuel storage facility.
- The study shows that the storage pool rack fulfills the subcriticality-concerning regulatory requirements.



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Potential future applications

- Calculation of the radial boundary conditions of the reactor core.
  - Detailed model for the radial reflector.

- Calculation of the weighting factors for the pressure vessel neutron dose calculations.

- 3D whole core model of Loviisa NPP using realistic data.
  - Asymmetric burnup distribution effects.
  - Assembly bow effect calculations.
  - etc

- Further development of assembly design.


Thank you for listening!