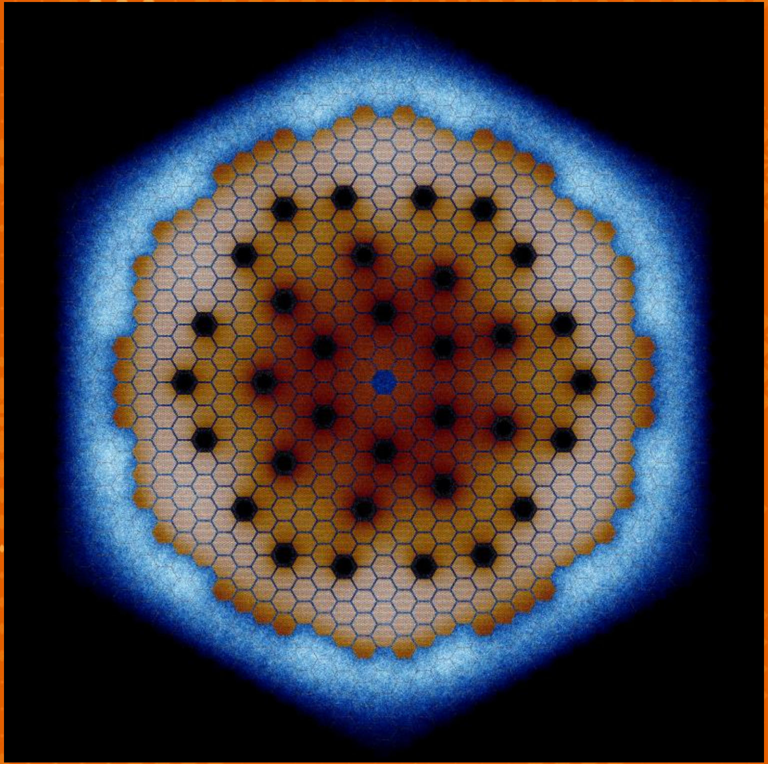

SFR calculations with Serpent and Ants

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9^{th} Serpent UGM
Georgia Tech, Atlanta, GA, USA

October 16^{th}, 2019

Contents

- SFR benchmark with Serpent
- 2D XS generation for fast systems
- Ants neutronics code
- Benchmark with JŌYŌ MK-I

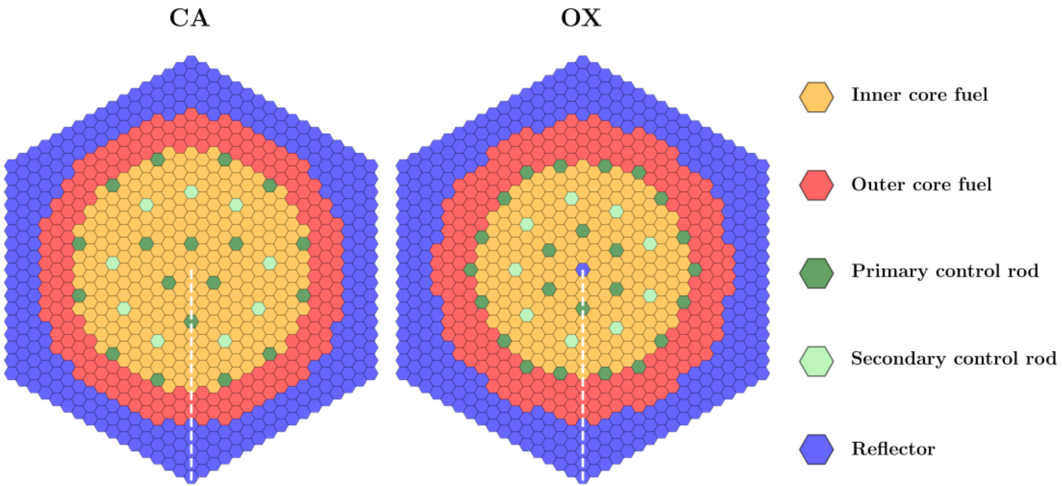
SFR benchmark with Serpent

- Two core configurations utilizing carbide and oxide fuel [1]

- Benefits and disadvantages
  - CA - low linear power rate i.e. enhanced margins to fuel melting
  - OX - self breeding without fertile blanket

- Comparison with collected benchmark data [2]

- Ultimate goal: reliable XS generation for nodal solver

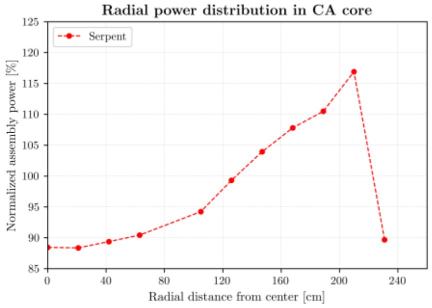


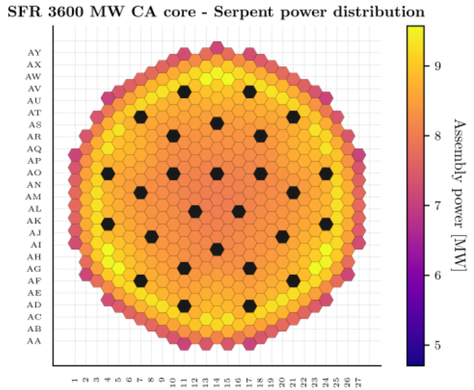
[1] D. Blanchet, L. Buiron, N. Stauff, T. K. Kim, T. Taiwo: Sodium Fast Reactor Core Definitions, v1.2, AEN-WPRS, September 2011.
[2] L. Buiron et al.: Evaluation of Large 3600 MWth Sodium-Cooled Fast Reactor Neutronic OECD benchmarks, Proceedings of PHYSOR 2014, Kyoto, Japan, September 28 - October 3, 2014.

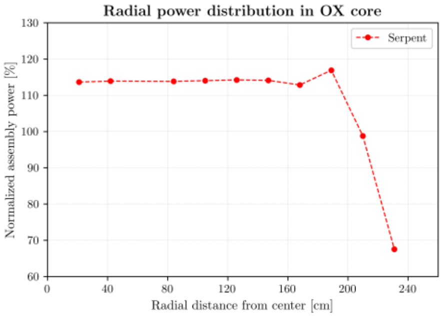
- With JEFF-3.1.2 library, BCs from [1]
- Pressure in gas plugs (10 bar) [3]
- Doppler-effect: +1000 K perturbation (mind fuel properties)
- SVR: large deviation in benchmark data + self-shielding effect
- CRW: comparable results

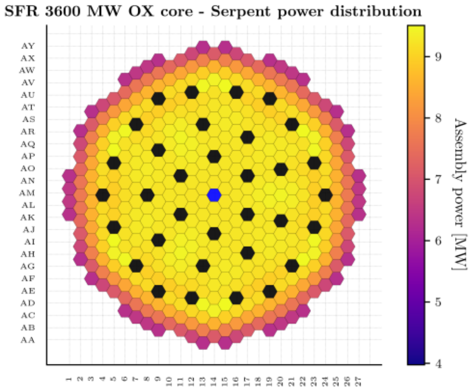
*CA/OX

Ref.	k_{eff}	K_D	SVR	CRW
Serpent	1.0031/1.0083	-945/-940	1461/1221	-4217/-6127
[2]	1.0136/1.0096	-1002/-895	2048/1932	-4326/-6092

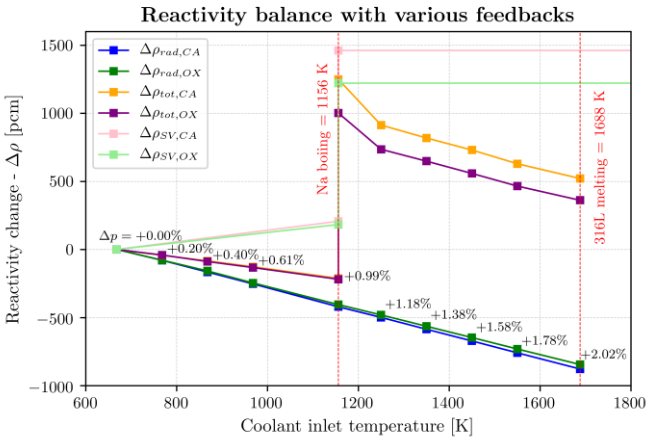






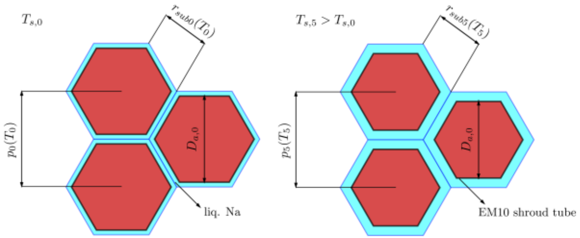


[3] Terje Tverberg: Mixed-oxide (MOX) fuel performance benchmark, Summary of the results for the Halden Reactor Project MOX Rods, NEA/NSC/DOC(2007)6, OECD HRP, 2007



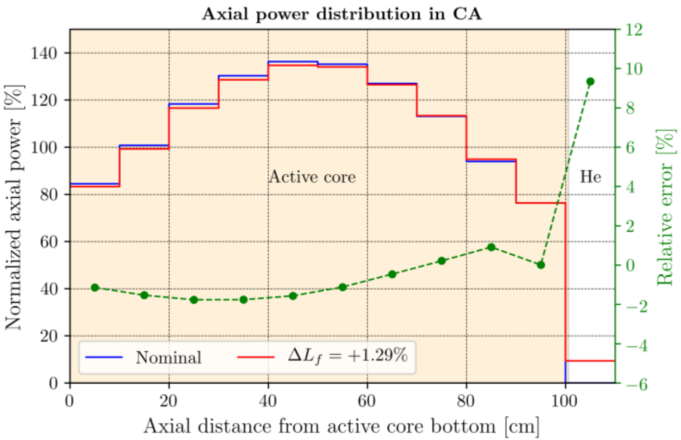
*CA/OX

Ref.	$\Delta\rho_{rad}$
Serpent	-421/-405
[4] (OX)	-429

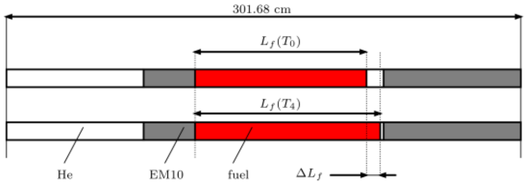


- Simple 1D expansion model
- 316L SS diagrid material

$$p_1(T_1) = p_0(T_0)[1 + \alpha_{rad}(T_1 - T_0)]$$



Ref.	$\Delta\rho_{rad}$
Serpent	-179/-106
[5] (OX)	-120



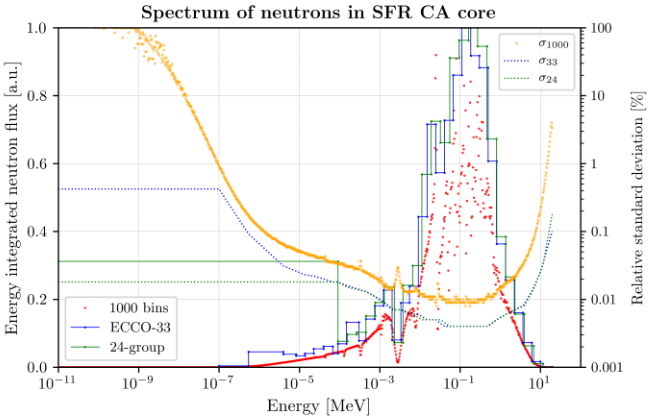
- Axial expansion has smaller impact on reactivity balance than radial expansion
- Yet top of active core highly affected

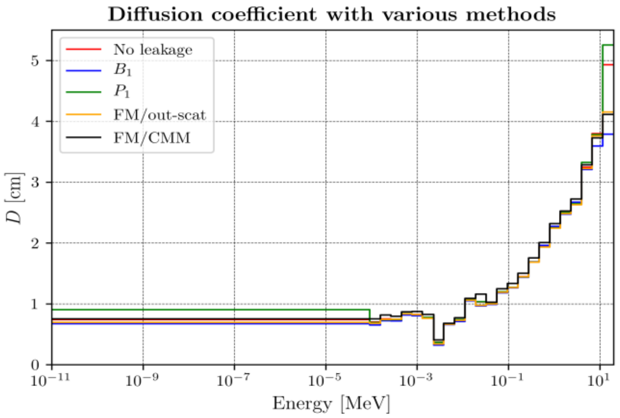
$$L_f(T_1) = L_f(T_0)[1 + \alpha_f(T_1 - T_0)]$$

[4] E. Nikitin, E. Fridman, K. Mikityuk: Solution of the OECD/NEA neutronic SFR benchmark with Serpent-DYN3D and Serpent-Parcs code systems, Annals of Nuclear Energy, vol. 75, pp. 492-497, 2014
[5] E. Nikitin, E. Fridman: Extension of the reactor dynamics code DYN3D to SFR applications - Part I: Thermal expansion models, Annals of Nuclear Energy, vol. 119, pp. 382-389, 2018

2D XS generation for fast systems

- Lab mouse: CA inner FA infinite lattice
- SCALE-238 micro-structure*
- 24-group equal lethargy bin structure condensed from ECCO33, mind statistics [6]
- CMM is deployed in hard spectrum for single fuel assembly [7]
- With CMM ~6 % larger values for diffusion coefficient compared to no-leakage methods





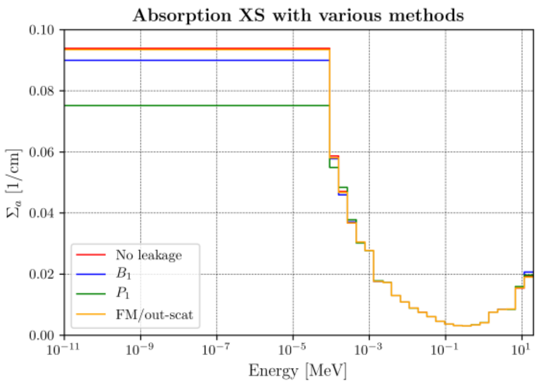
[6] E. Fridman: Generation of few-group constants with Serpent: Application examples, Proceedings of PHYSOR 2014, Kyoto, Japan, September 28 - October 3, 2014
[7] Z. Liu et al.: A Cumulative Migration Method for computing rigorous transport cross sections and diffusion coefficients for LWR lattices with Monte Carlo, Proceedings of PHYSOR 2016, Sun Valley, ID, USA, 1-5 May, 2016

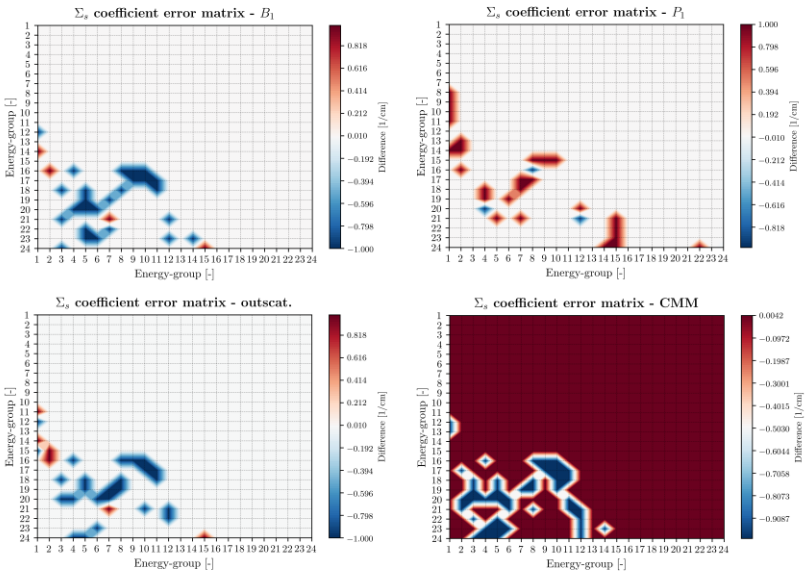
- P_1, B_1 - results confirm earlier observations [8] as a new leakage term does not affect the local multi-group flux within a macro-group

- FM, out-scat. - practically similar results

- Scattering matrices (corrected vs. no-leakage)
  - B_1 and out-scattering - very similar
  - P_1 shifted slightly towards larger differences
  - CMM - smaller overestimates

$$\Sigma_s = \begin{bmatrix} \Sigma_{s,g\to g} & \Sigma_{s,g+1\to g} & \cdots & \cdots & \Sigma_{s,n\to g} \\ \Sigma_{s,g\to g+1} & \Sigma_{s,g+1\to g+1} & \cdots & \cdots & \Sigma_{s,n\to g+1} \\ \Sigma_{s,g\to g+2} & \Sigma_{s,g+1\to g+2} & \Sigma_{s,g+2\to g+2} & \cdots & \Sigma_{s,n\to g+2} \\ \vdots & \vdots & \ddots & \ddots & \vdots \\ \Sigma_{s,g\to n} & \Sigma_{s,g+1\to n} & \cdots & \Sigma_{s,n-1\to n} & \Sigma_{s,n\to n} \end{bmatrix}$$

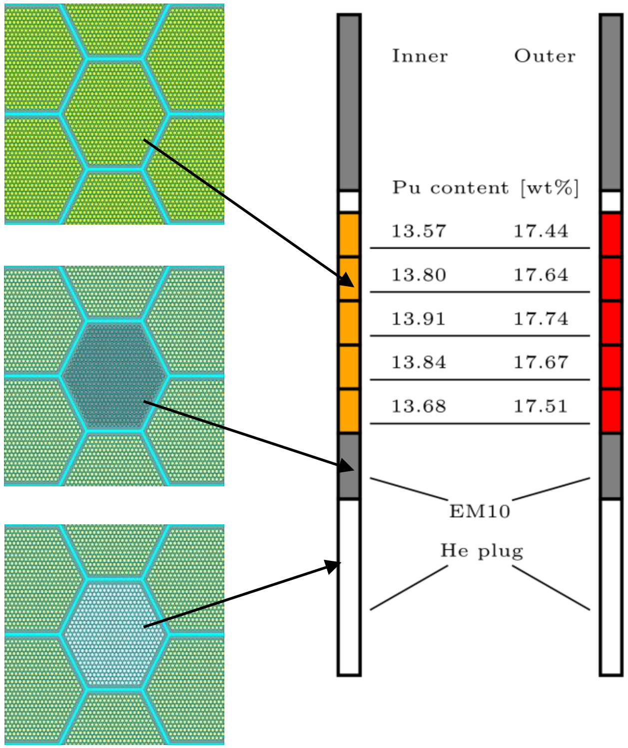




[8] B. Faure, G. Marleau: Simulation of a sodium fast core: Effect of B_1 leakage models on group constant generation, Annals of Nuclear Energy, vol. 99 pp. 484-494, 2017

Ants neutronics code

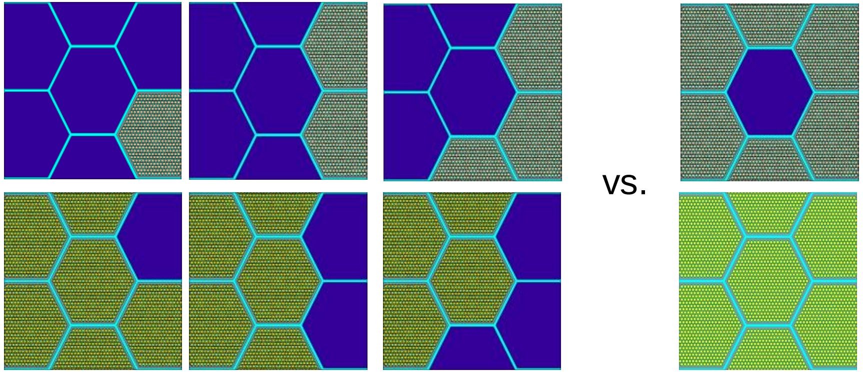
- Reduced order nodal diffusion solver, based on AFEN/FENM approach [9]
- The algorithm solves nodal variables without transverse integration
  - (+) for hexa geometry
  - (-) for solver speed
- Has been tested in PWR, BWR and 2D homogenization cases [10,11]
- Required: XSs, geometry, convergence criteria
- Goal: validation + development



[9] N. Z. Cho, J. M. Noh: Analytic function expansion nodal method for hexagonal geometry, Nuclear Science and Engineering, vol. 121, pp. 245-253, 2014
[10] V. Sahlberg, A. Rintala: Development and first results of a new rectangular nodal diffusion solver of Ants, Proceedings of PHYSOR 2018, Cancún, Mexico, 22-26 April, 2018
[11] A. Rintala, V. Sahlberg: Pin power reconstruction method for rectangular geometry in nodal neutronics program Ants, NENE 2019, Reactor Physics Poster 608, Portorož, Slovenia, 9-12 September, 2019

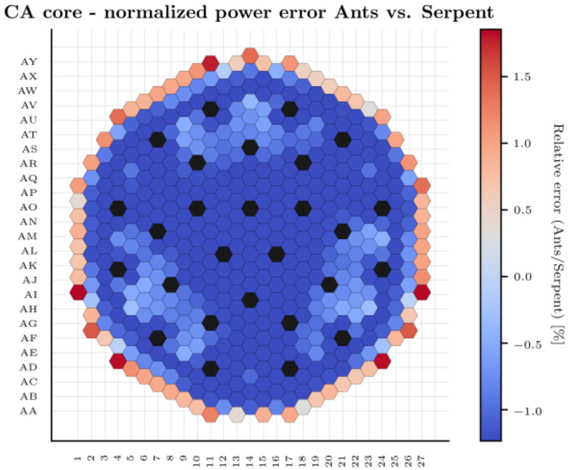
- 3D SFR inputs - same BCs as for Serpent

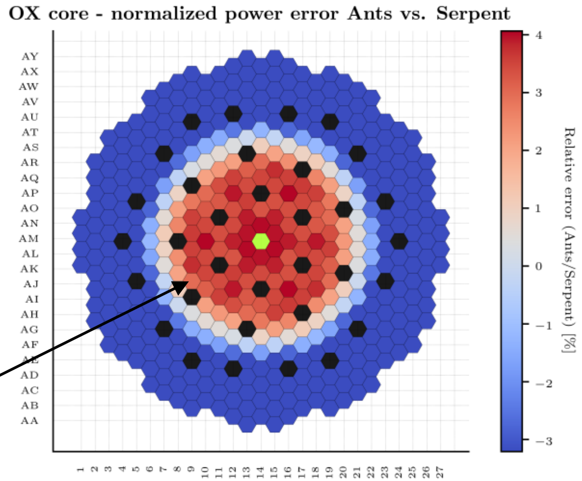
- Fine/simplified mesh on outer core-radial reflector interface in order to assess flux sensitivity on fissile/non-fissile volume interface



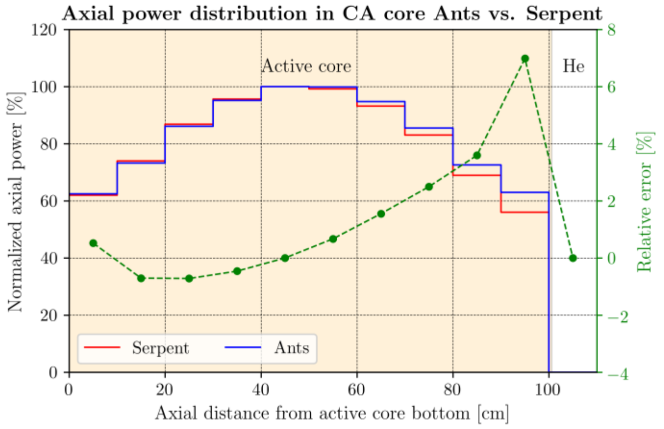
- CA results under review, OX core calculations are in progress…

- Asymmetry from incorrect OX gas plug XSs
  - with CA gas XS the solution is tilted but symmetric

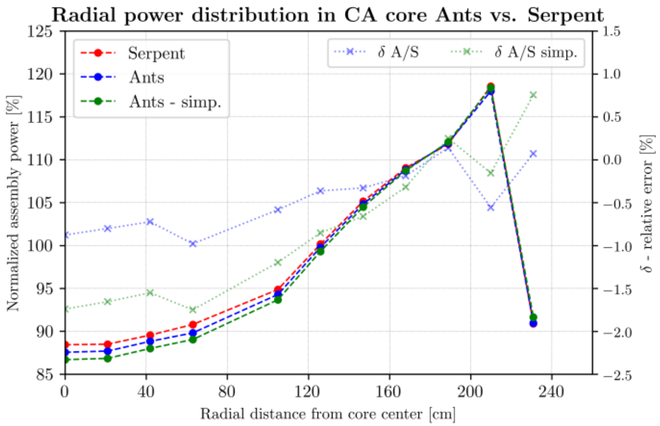




- Axial power distribution
  - Discrepancy increases in the upper section
  - CR/SR assemblies are sitting over active core → absorber XSs have to be revised
  - < 0.5 % deviation in lower core

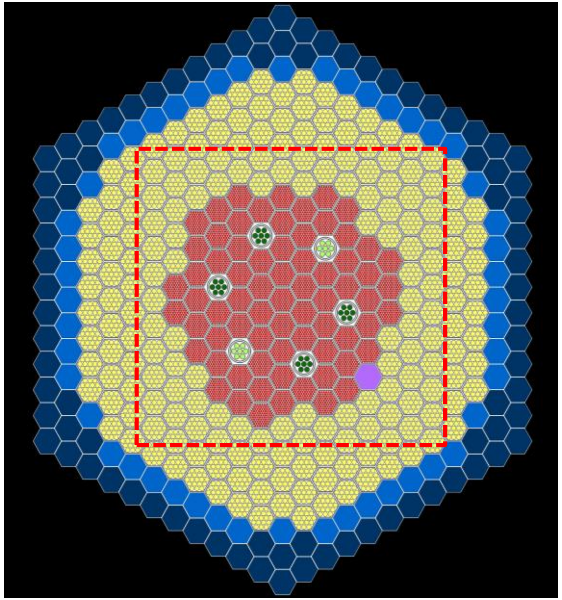


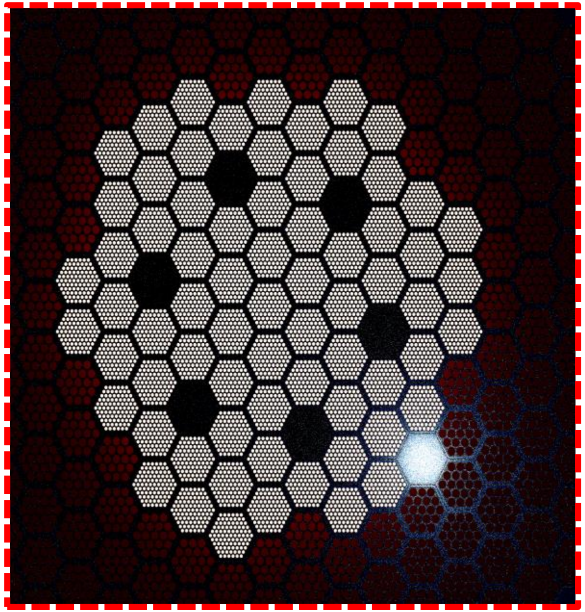
- Radial power distribution
  - (blue) fine case error {-0.98;0.14} %
  - (green) simplified case error {-1.75;0.75} %
  - Slight underestimate in the inner core
  - Growing discrepancies with coarser mesh



Benchmark with JŌYŌ MK-I

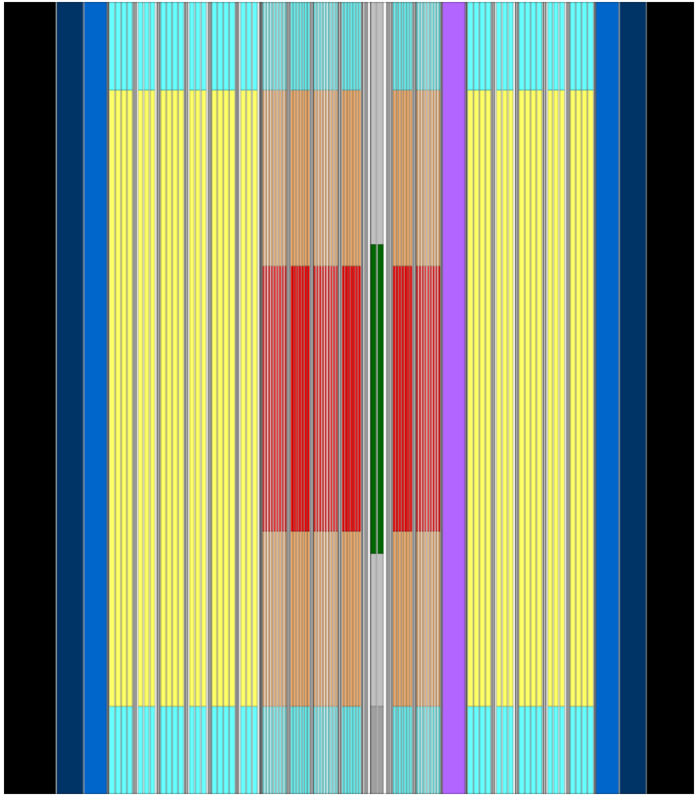
- Based on Jōyō MK-I reactor's experimental data published by JAEA [12]
- 3D Serpent models for criticality, CRW and SVR tests
- 3D and 2D solution comparison with MVP code (in progress)
- Study of few-group XS generation methods e.g. different CMM methods



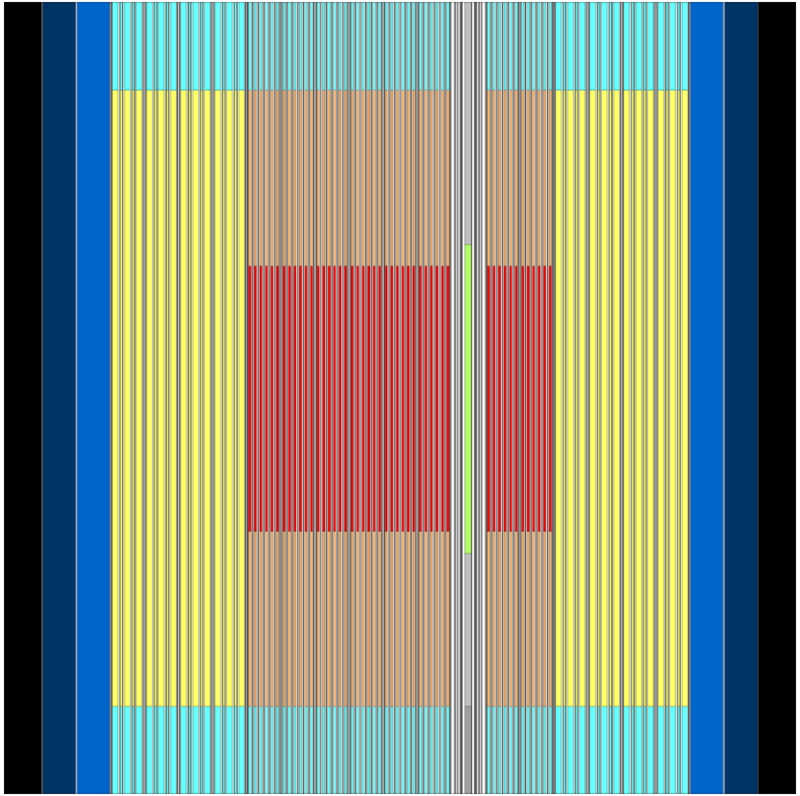


[12] 高速実験炉「常陽」MK-I性能試験の再評価 と最新炉物理解析手法に基づく解析評価, JNC TN9400 2005-24

XZ-plot with neutron source (^{9}Be) and SR2



YZ-plot with RR1

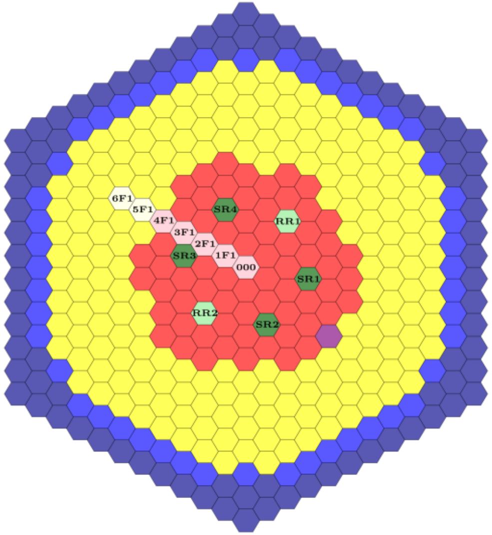


VTT

Criticality case

Ref.	$k_{eff} \pm \sigma$ [-]
Benchmark [12]	0.9981 ± 1.8E-3
Serpent	0.9998 ± 1.5E-4
Avg. diff. [%]	+ 0.17

Jōyō MK-I benchmark SVR core

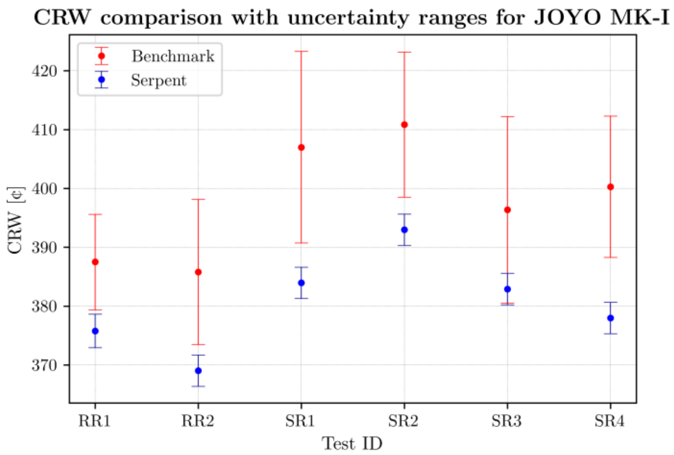


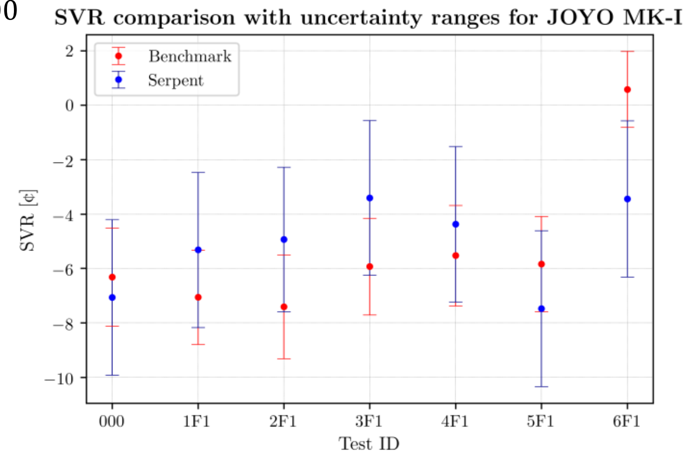
Serpent vs experiment:

- CRW diff.: -4.4 %
- β_{eff} diff.: +0.33 %

$$SVR/CRW = \frac{k_1 - k_2}{k_1 k_2} \frac{1}{\beta_{eff}} \cdot 100$$

- SVR diff.: -7.8 %
- β_{eff} diff.: +0.21 %





The road ahead…

- Building fast reactor expertise
- Group-constant generation validation (SFRs, JŌYŌ, ?) with focus on colorset models
- Ants studies and development (homogenization, ADFs)
- Higher level of automatization in pre- and post-processing for reduced order solver
- Publications…

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Thank you for your attention!