SMART Rod Ejection Accident (REA) Analysis using Different Simulation Approaches

Kanglong Zhang

Institute for Neutron Physics and Reactor Technology (INR)

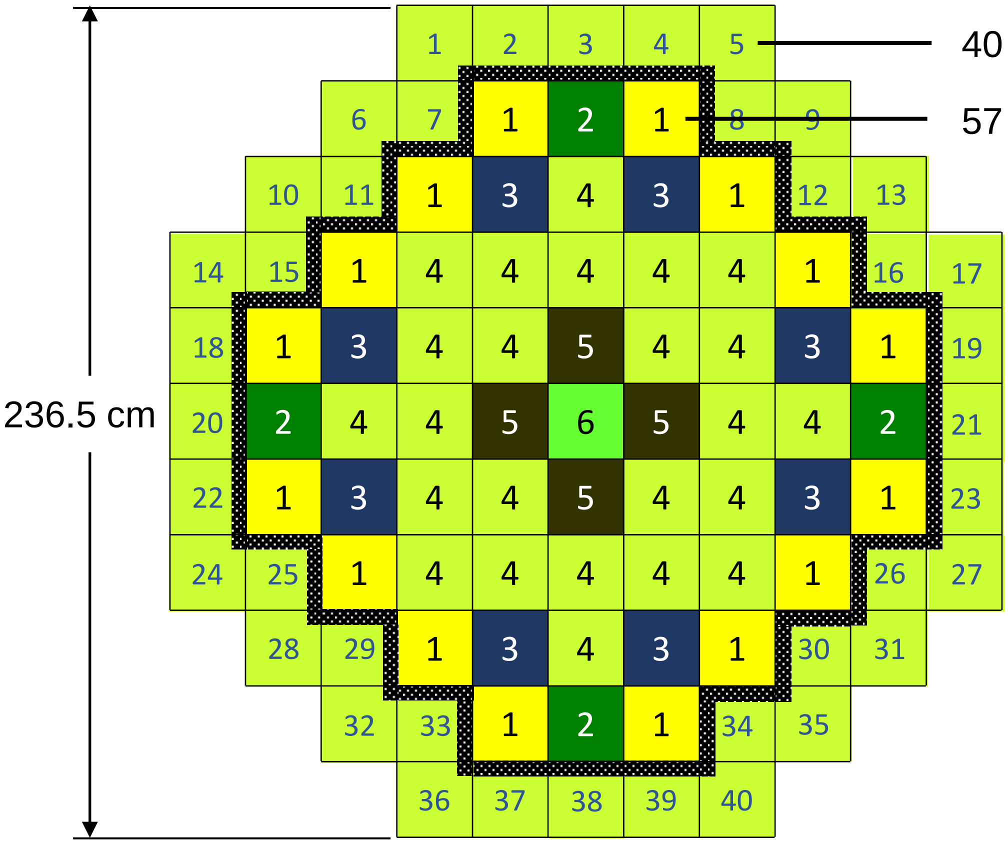
Outlines

SMART *Rod Ejection Accident (****REA****) Analysis using* ***Different Simulation Approaches***

- KSMR Core – a concept based on SMART core
- REA transient sequence (+ steady-state parameters)
- Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF (SCF-SubChanFlow)
  - Codes and methodologies
  - Modeling
  - Steady-State (SS) results
  - Transient (TS) results
- Conclusion and Outlook

KSMR Core – a concept based on SMART core

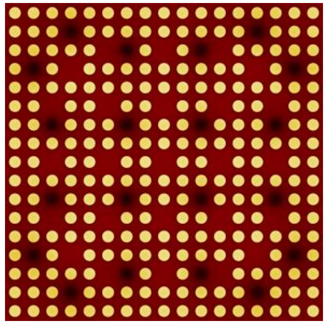
KSMR – KIT-SMR – assembly configuration:



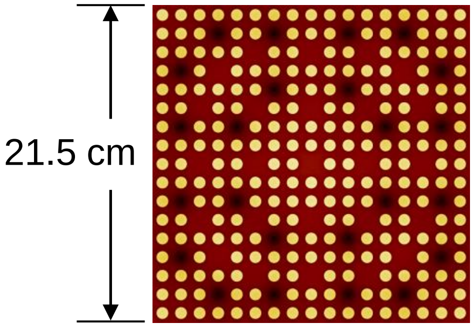
40 radial dummy reflectors

57 fuel assemblies, 6 types, 2 poison types

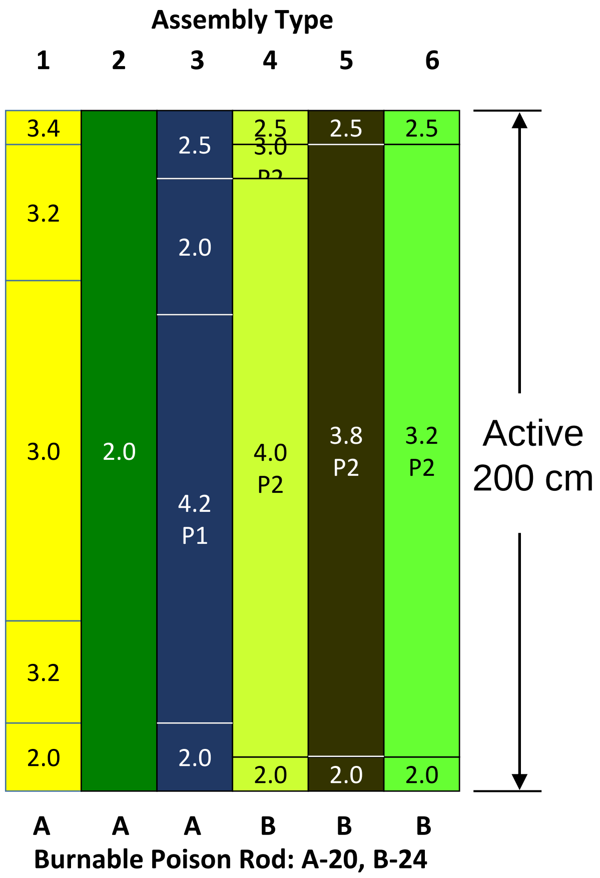
Radial configuration



P1 – Type A 20 poison rods



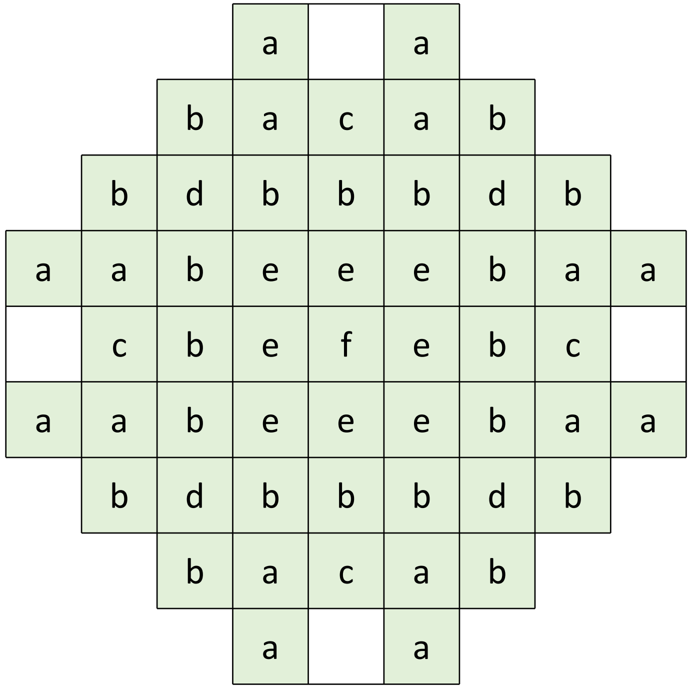
P2 – Type B 24 poison rods



Axial configuration

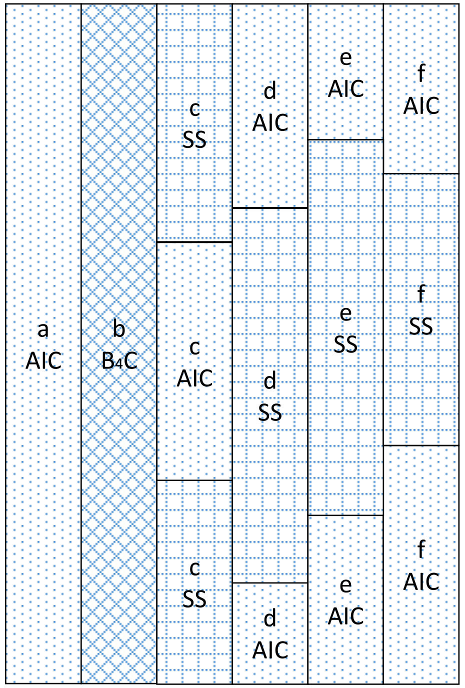
KSMR Core – a concept based on SMART core

KSMR – KIT-SMR – control rods configuration:



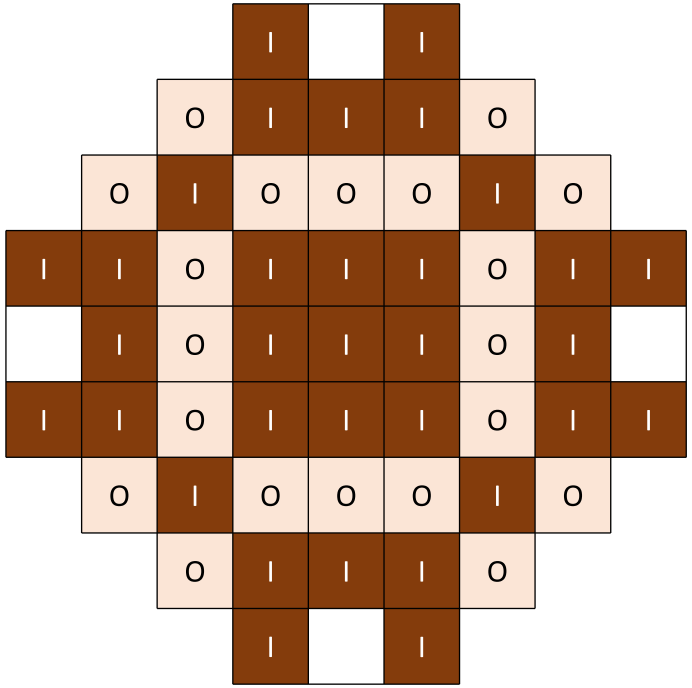
Radial configuration

- 6 types



Axial configuration

- AIC – AgInCd
- SS – Stainless Steel
- B4C



HZP Critical configuration

- I – fully inserted
- O – fully withdraw

REA transient sequence

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REA – Rod Ejection Accident from a Hot Zero Power (HZP) state

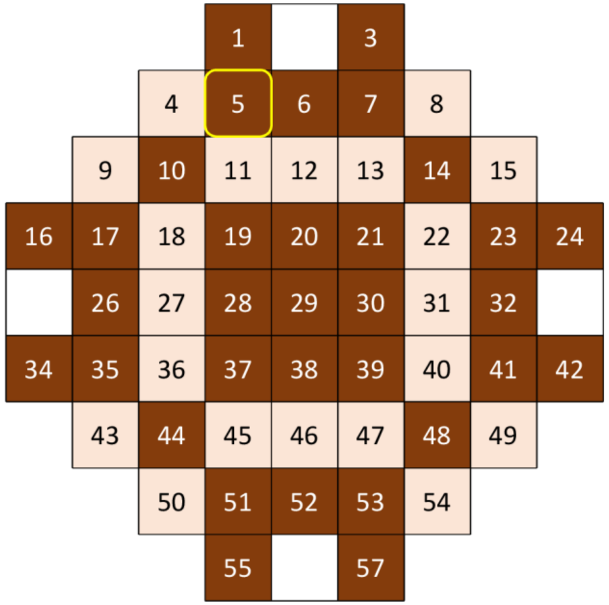
- HZP SS main parameters.

Initial core power	Inlet mass flow	Inlet temperature	Outlet pressure
330 W (10^{-6} nominal power)	2006.4 kg/s	569.15 K	15 Mpa

- REA transient scenario.

Ejected control rod	Ejection time
# 5	0.05 s

Ejected duration	Ejection velocity
3.0 s	constant



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Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

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Codes *and* ***methodologies***

- **Serpent** – Monte Carlo neutronic code by VTT.
- **SCF** – Subchannel thermal-hydraulic code by KIT.
- **PARCS-ass** – Deterministic neutronic code by NRC U.S. (*assembly-level simulation*).
- **PARCS-pin** – PARCS variant at KIT with the pin ability for nodal solvers (*pin-level simulation*).
  - Further-development of PARCS enabling it to process "*thousands x thousands*" geometry matrix
- **Pin-XS optimization** system based on the Super-Homogenisation (**SPH**) method:

Σ_R^{Homo} → PARCS Calculation → $\phi_{tot}^{PARCS,0}$

$$\Sigma_R^{Homo} \times \frac{\phi_{tot}^{Serpent}}{\phi_{tot}^{PARCS,0}} = A_{tot-R}^{Serpent}$$

$$\phi_{tot}^{PARCS,0} \neq A_{tot-R}^{Serpent}$$

$$\Sigma_R^{Homo} \times \phi_{tot}^{PARCS,0} \times \mu^1 = A_{tot-R}^{Serpent}$$

XS update: $\mu^1 \cdot \Sigma_R^{Homo}$ → PARCS Calculation → $\phi_{tot}^{PARCS,1}$

$$\frac{\phi_{tot}^{Serpent}}{\phi_{tot}^{PARCS,1}}$$

$$\phi_{tot}^{PARCS,1} \neq A_{tot-R}^{Serpent}$$

$$\Sigma_R^{Homo} \times \phi_{tot}^{PARCS,1} \times \mu^2 = A_{tot-R}^{Serpent}$$

⋮

If μ converges, we can conclude that SPH corrected PARCS to preserve the total reaction rate as Serpent.

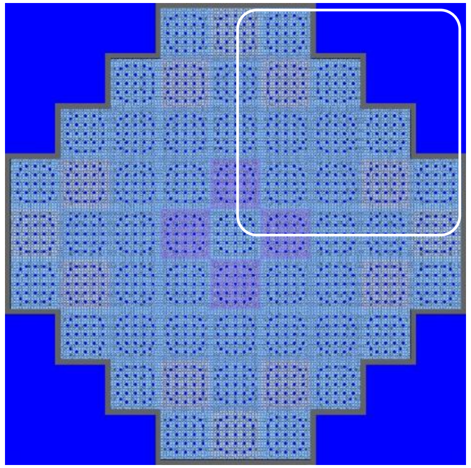
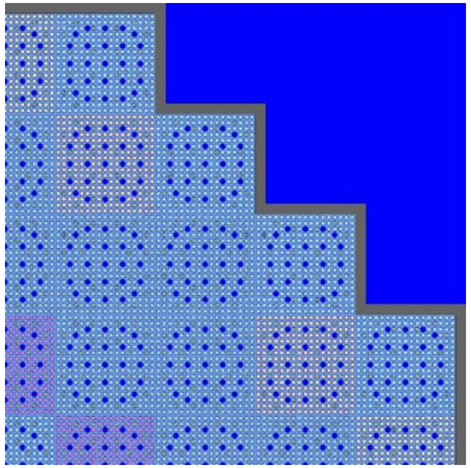
Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Modeling

- **Serpent**

  Reflect the real core, assembly, and rod geometry

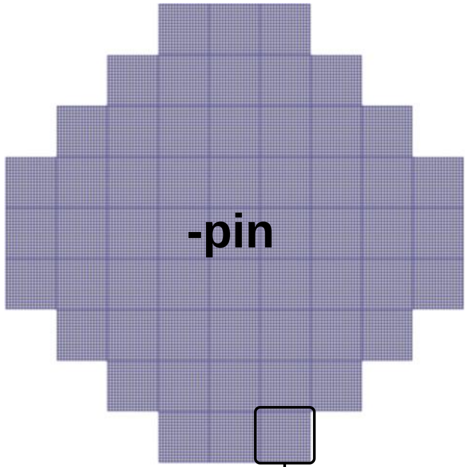
  20 axial nodes

- **SCF**

  Coolant channel centered

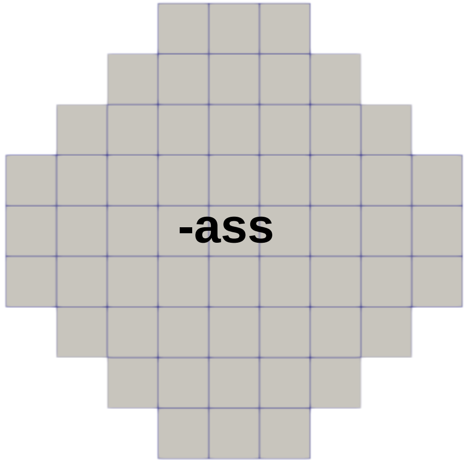
  20 axial nodes

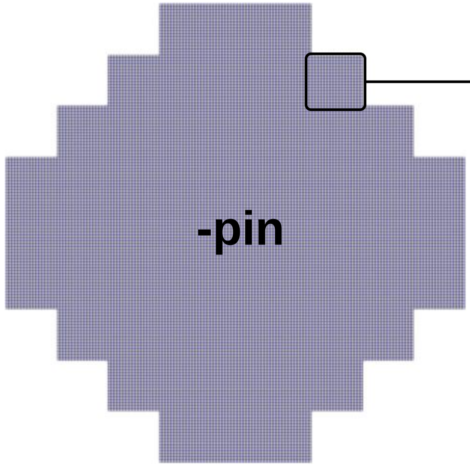


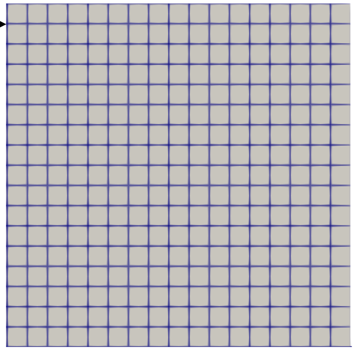
- **PARCS**

  XS homogenized at the assembly, and pin level

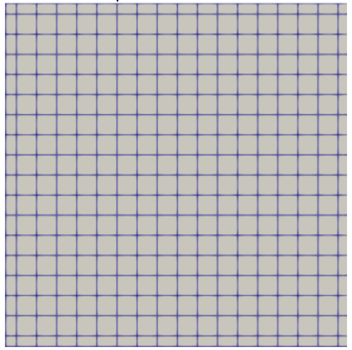
  20 axial nodes







Rod Centered

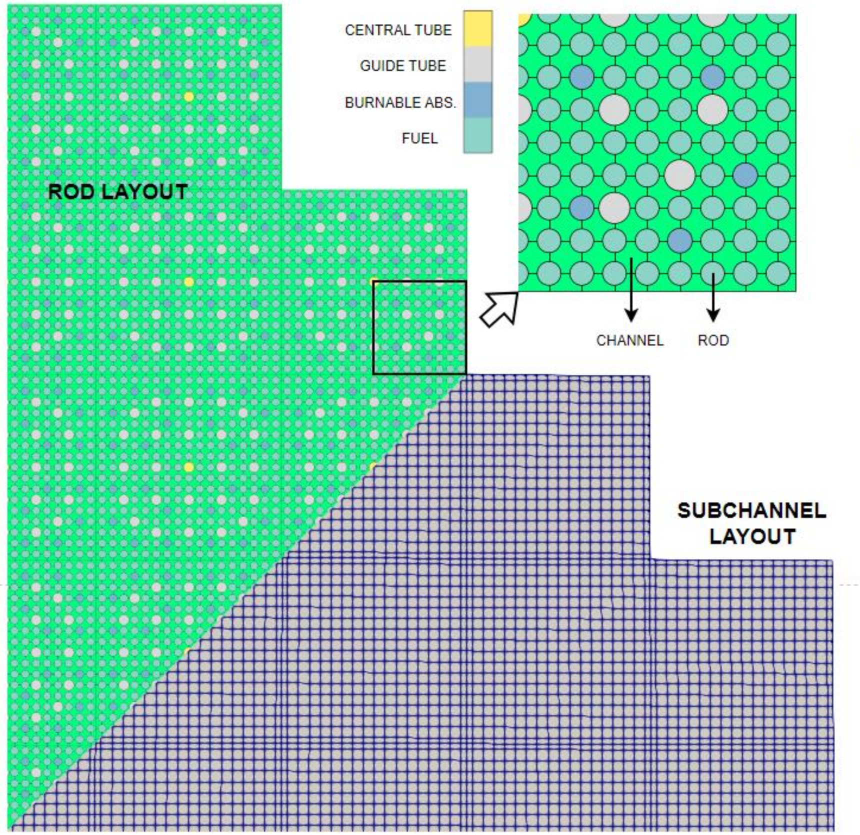


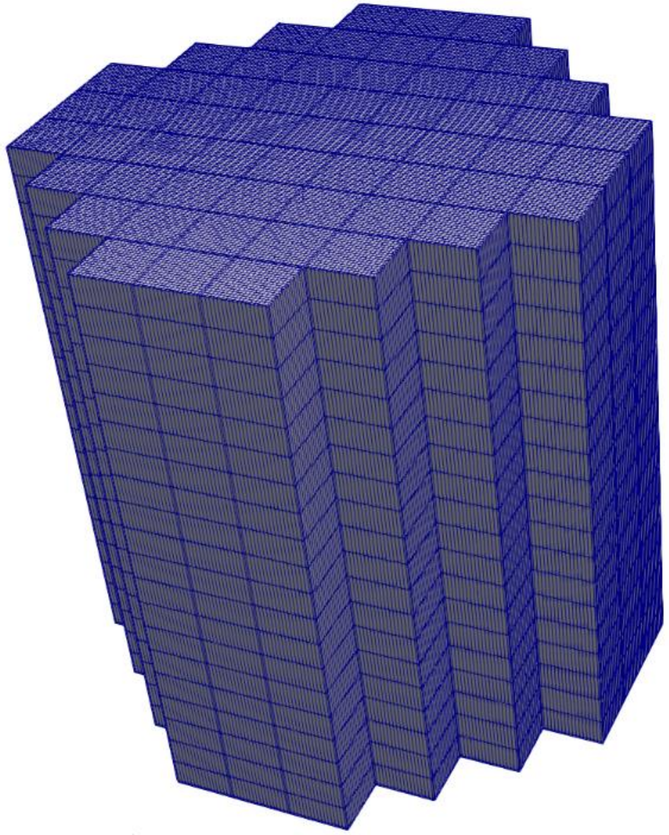
Channel Centered

Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Modeling

- Relations between the rod-centered and channel-centered layouts and the 3D view of the SCF mesh.





Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

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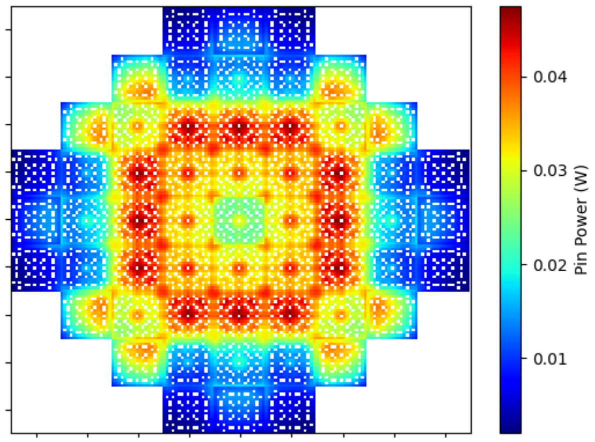
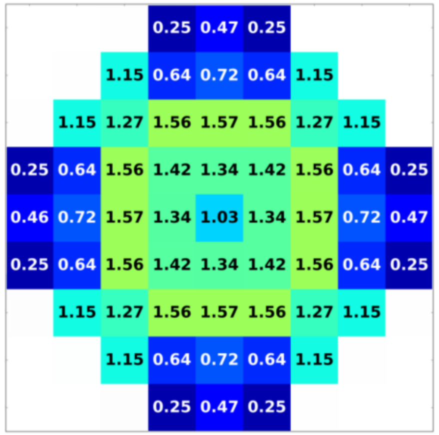
Steady-State (SS) *results*

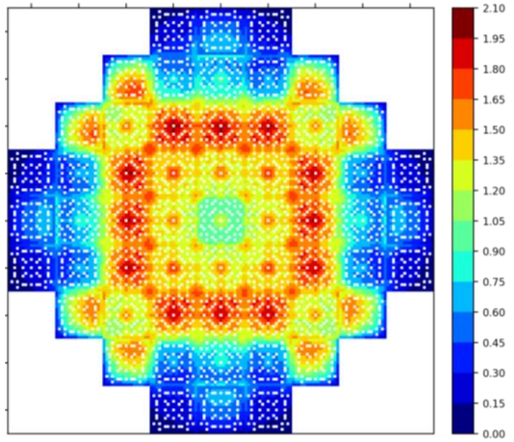
- Power distribution of **Serpent** as a **reference** and the other solutions.



Serpent Power (P)



PARCS-ass normalized P



PARCS-pin normalized P

- PARCS-ass/SCF and PARCS-pin/SCF predict similar power distribution as Serpent/SCF.
- The pin-level XS for PARCS-pin is optimized by our SPH system.
- How is the performance of the SPH optimization?

Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

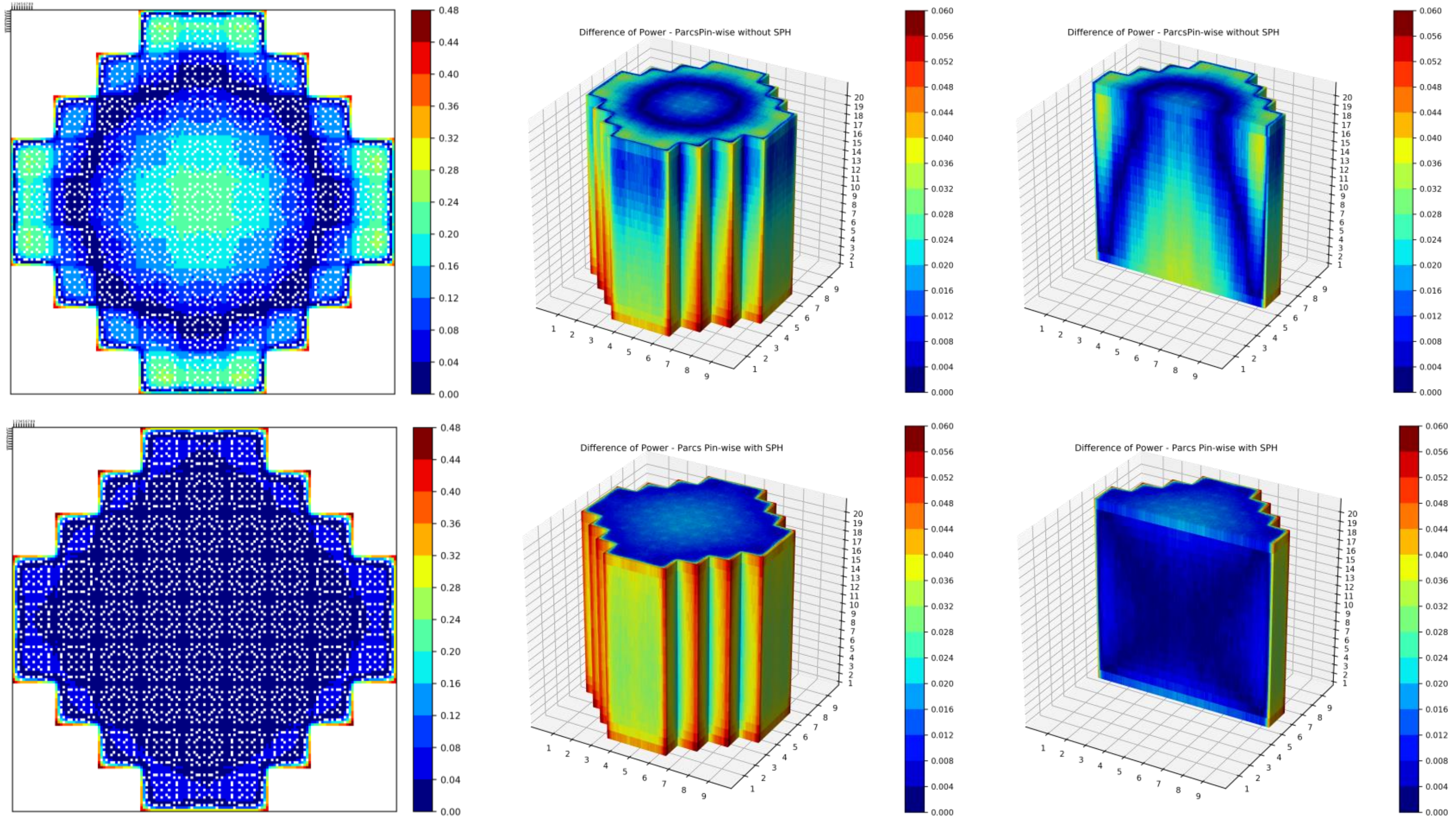
Steady-State (SS) *results*

- PARCS with SPH-optimized pin-XS gives closer power map compared with that with raw pin-XS.

Power diff
no-SPH

SPH optimization is necessary

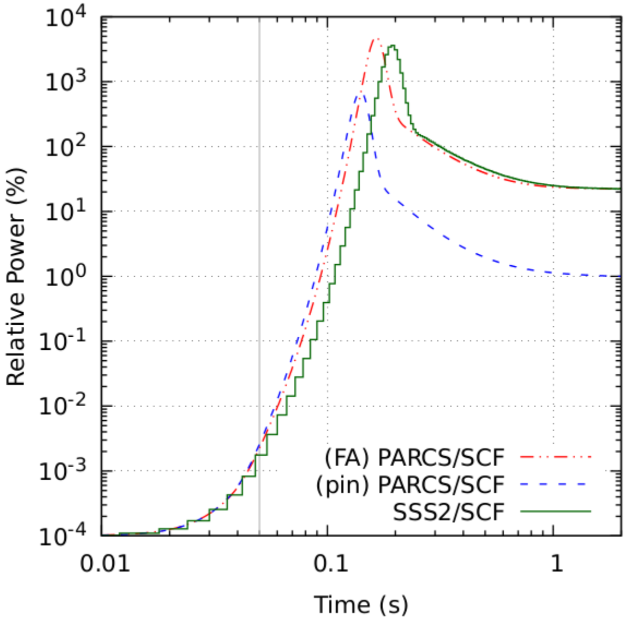
Power diff
on-SPH



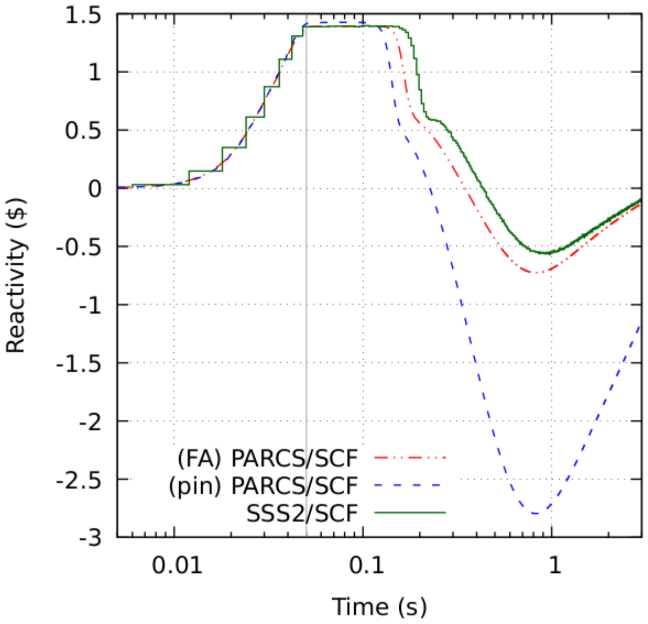
Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Transient (TS) *results*

- The transient starts from HZP SS, the REA initiates at 0.05s.



Core Power in time



Reactivity in time

Parameter	PARCS-ass/SCF	PARCS-pin/SCF	Serpent /SCF
Peak power (ratio to nominal power)	48.3	7.1	36.2 ± 4%
Time to peak power	0.1645 s	0.14 s	~ 0.195 s
Power at end of transient (ratio to nominal power)	0.23	0.01	0.22 ± 4%
Peak reactivity	1.395 $	1.423 $	1.39 $

Key neutronic results

- PARCS-ass/SCF predict similar power/reactivity evolution as Serpent/SCF.
- PARCS-pin/SCF show significant deviation as Serpent/SCF.

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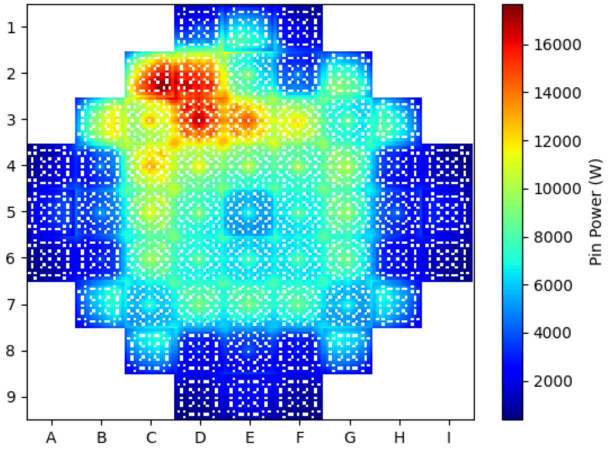
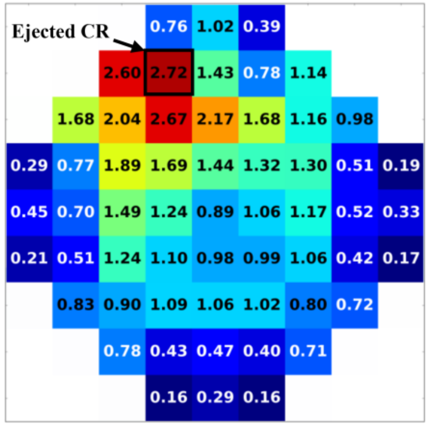
Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Transient (TS) *results*

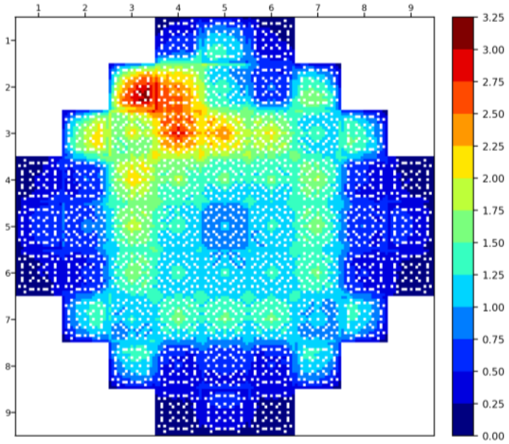
- The power distributions at the peak power time point.



Serpent Power (P)



PARCS-ass normalized P



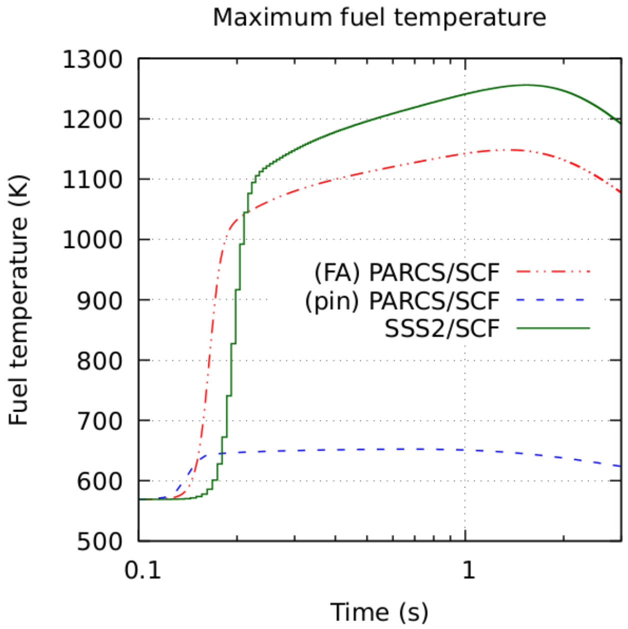
PARCS-pin normalized P

- PARCS-pin/SCF predict finer power profile than PARCS-ass/SCF, but lose in absolute value.
- Possible reasons for the large deviation between PARCS-pin/SCF and Serpent/SCF:
  - The average temperature is passed from SCF to PARCS;
  - Errors in the XS files.

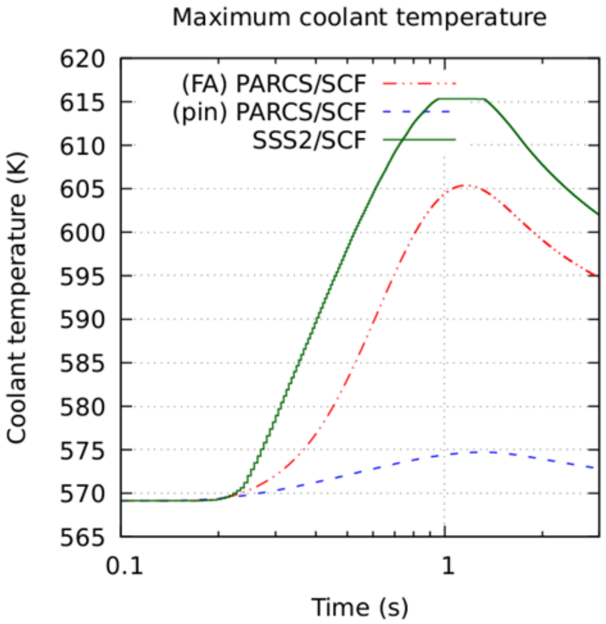
Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Transient (TS) *results*

- Thermal-hydraulic fields.



Maximum fuel Temperature in time



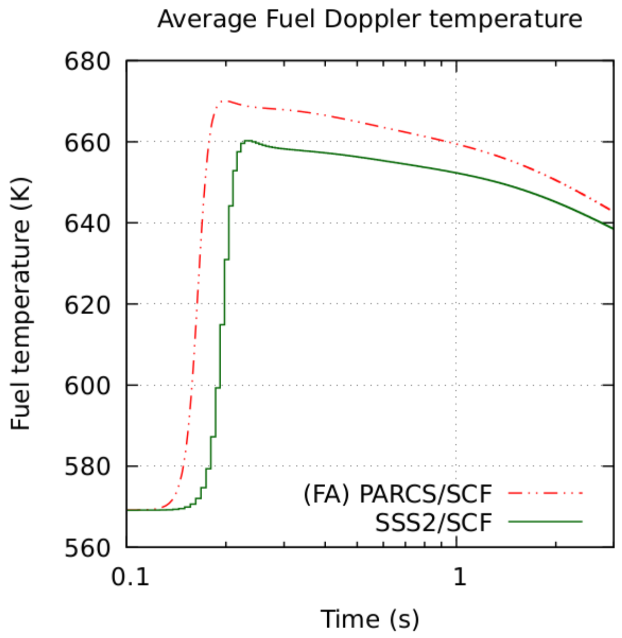
Maximum coolant Temperature in time

- PARCS-ass/SCF predict closer results as Serpent/SCF while PARCS-pin/SCF give large deviation.
- So, we further compare PARCS-ass/SCF and Serpent/SCF only.

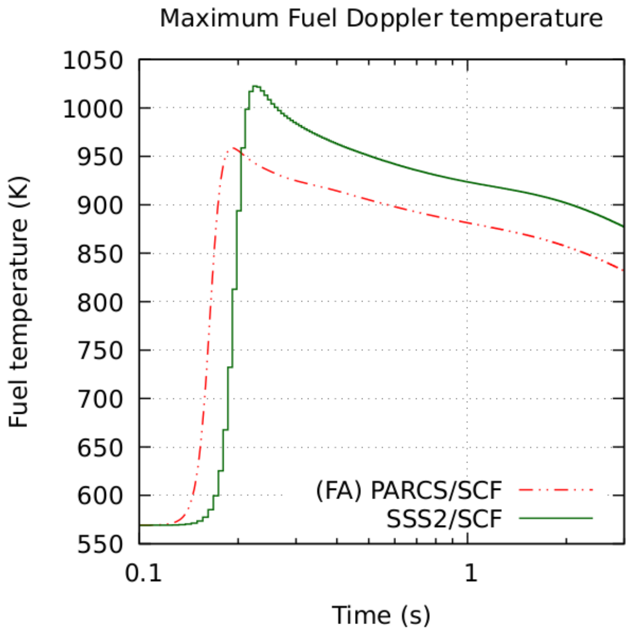
Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Transient (TS) *results*

- Fuel Doppler temperature.



Average fuel Doppler Temperature in time



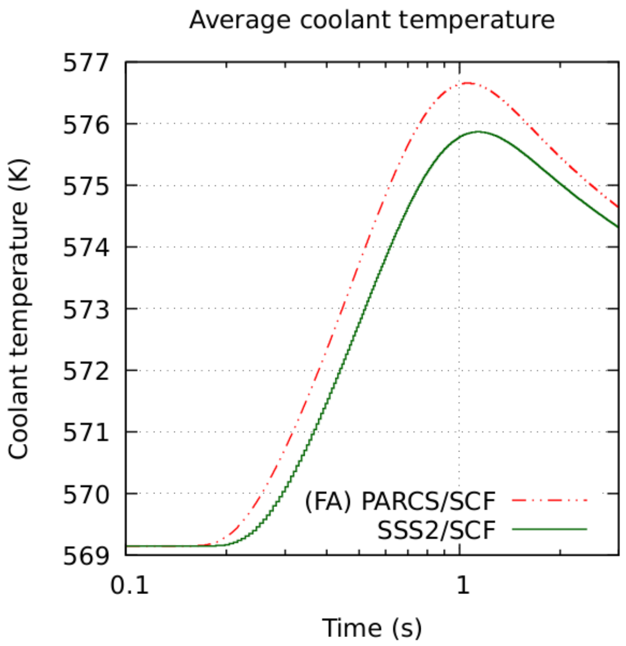
Maximum fuel Doppler Temperature in time

- PARCS-ass/SCF predicts higher average fuel Doppler T because of its higher peak power.
- Serpent/SCF predicts higher maximum fuel Doppler T because of its higher detailed model.

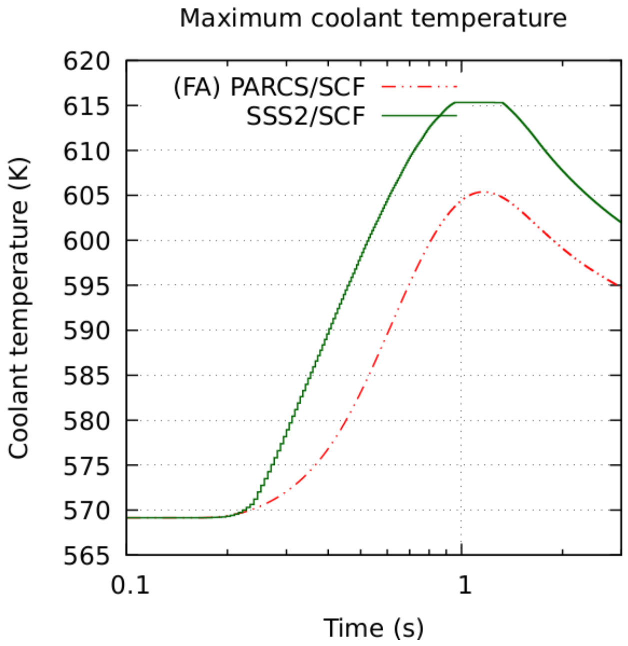
Serpent/SCF, PARCS-ass/SCF, and PARCS-pin/SCF

Transient (TS) *results*

- Coolant temperature.



Average coolant Temperature in time



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Conclusion and Outlook

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Conclusions in the physical viewpoint:

- During a sudden Rod Ejection Accident (REA):
    - The core power can reach up to a peak value around 40 times nominal power;
    - The maximum/average fuel temperature and coolant temperature increase due to power increase;
    - The core power decrease thanks to negative temperature feedback.
- The reactor core **stay safe** in and after an REA.

Conclusions from the three solutions:

- PARCS-ass/SCF predicts “consistent” results as Serpent/SCF.
- PARCS-pin/SCF predicts “similar” power profiles as Serpent/SCF:
    - It works well in SS, thanks to the SPH optimization system;
    - It produce large deviation in absolute values of power, fuel/coolant temperatures.

Future work:

- Pass Doppler T from SCF to PARCS-pin and check XS.

Acknowledgements

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McSAFER project has received funding from the **Euratom research and training program** 2019-2020 under the grant agreement No 945063.

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Thanks for your attention.