Multi-physics Coupled Reactor Core Analysis System of RAST-K2.0 with CTF and FRAPCON

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Contents

Introduction

Introduction

- **In the past decades, the importance of best estimate analysis of nuclear reactors has increased for nuclear safety analysis licensing in nuclear engineering**

- **Recently, performance of computer has been increased**

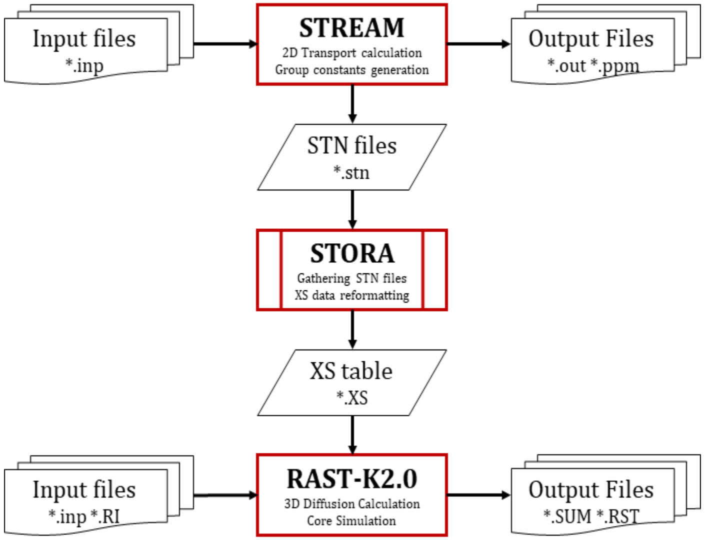
- **MPACT code has been coupled with CTF as a framework of CASL project and nTRACER has been coupled with CTF in SNU**

- **UNIST has developed two-step nuclear reactor core system called STREAM/RAST-K**

Computational Codes
& Coupled Calculation Scheme

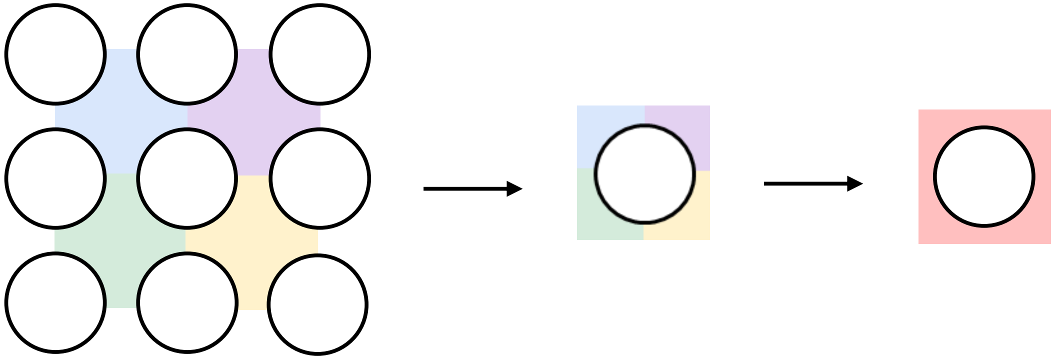
Neutronics code

- **STREAM**
  - **Method Of Characteristic (MOC) code for lattice calculation**
  - **Pin based Slowing down Method (PSM) for resonance treatment**
- **RAST-K2.0**
  - **Reactor core analysis code being developed at UNIST**
  - **3-dimensional 2-group UNM solves a nodal diffusion equation**
  - **Functionalized cross section model for cross section feedback**



Subchannel T/H code

- **Coolant-Boiling in Rod Arrays: Two Fluid (CTF)**
  - **Sub-channel T/H code designed for LWR analysis**
  - **Crossflow can be considered**
  - **Coupling interface make easy to couple with neutronics code**
- **Output quantities from CTF**
  - **Coolant temperature, density for cross section feedback**
  - **Coolant temperature, pressure for FRAPCON B.C.**



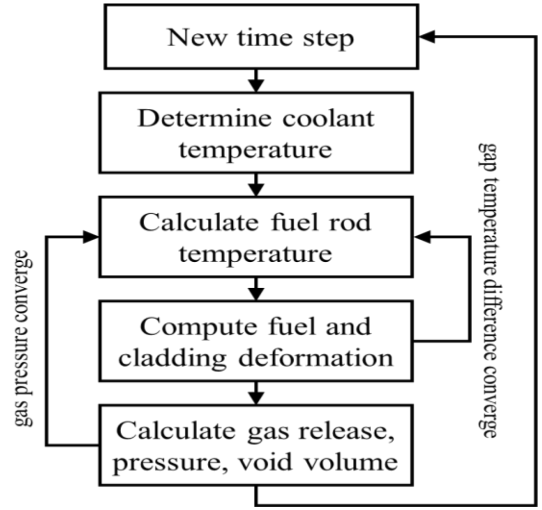
Channel centered

Pin centered

[6] M.N. Avramova, R.K. Salko, CTF–A Thermal Hydraulics Subchannel Code for LWRs Transient Analyses, User's manual, CASL-U-2015-0055-000, March 10, 2015.

Fuel Performance code

- **FRAPCON-4.0**
  - **Steady-state fuel performance code**
  - **Pellet deformation, fission gas release models**
  - **Predict fuel behavior over burnup from 0 to 62 GWd/MTU**
- **Output quantities from FRAPCON**
  - **Fuel temperature for cross section feedback**
  - **Fuel parameters such as oxide thickness, hoop stress, hoop strain, …**



[7] K. J. Geelhood, et al., FRAPCON-4.0: A Computer Code for the Calculation of Steady-State, Thermal-Mechanical Behavior of Oxide Fuel Rods for High Burnup, PNNL-19418, Vol. 1, Rev. 2, September 2015

Comparison of CTF and FRAPCON

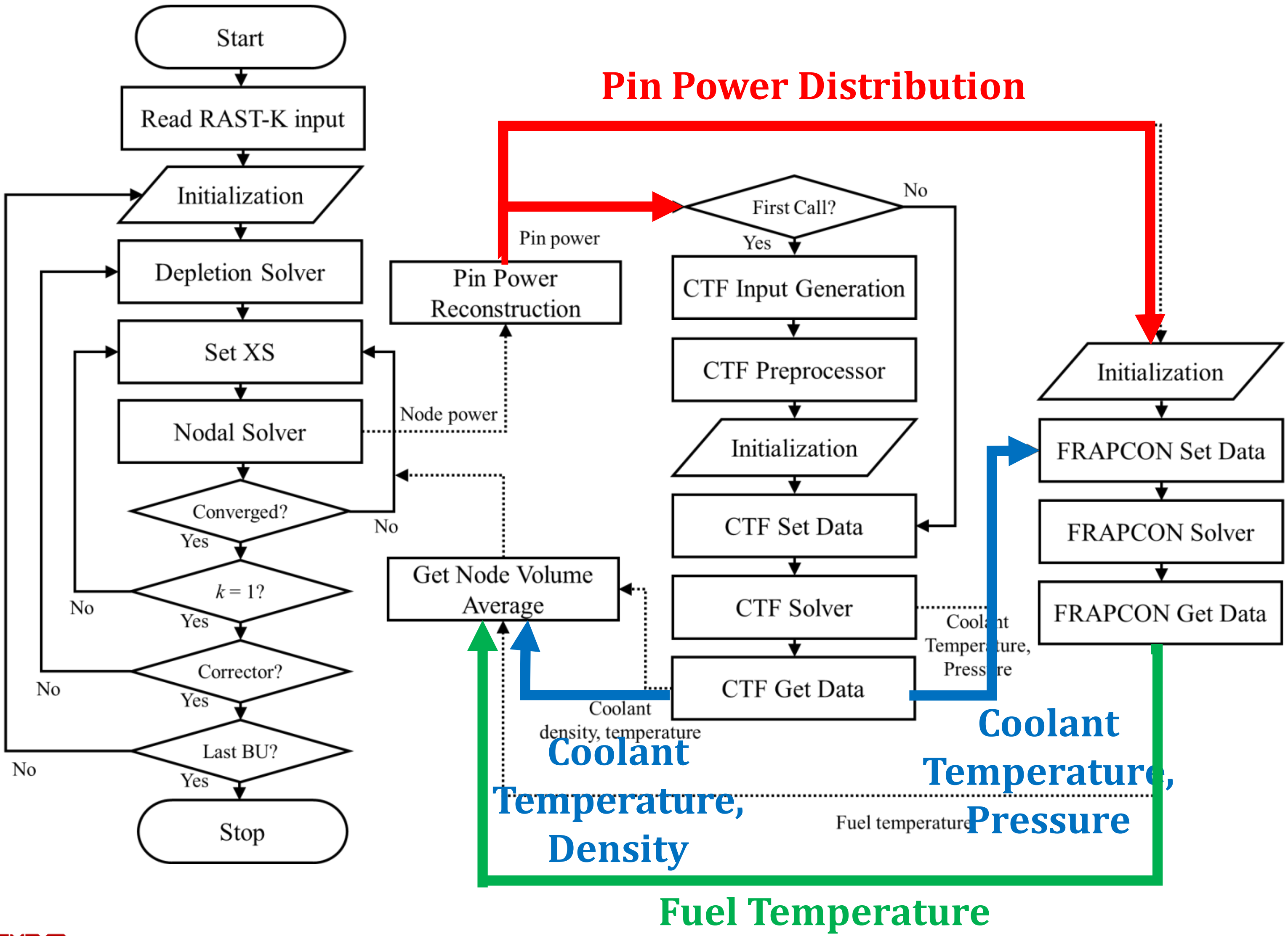
▪ T/H model and Heat conduction model in fuel rod

	T/H model	Conduction model
CTF	• Multi channel model with cross-flow • **Detailed modeling**	• User-defined gap conductance • **Simple modeling**
FRAPCON	• 1D model with single, closed coolant channel • **Simple modeling**	• Deformation, fission gas release model • Dynamic gap conductance • **Detailed modeling**

Aaron Wysocki, et al., L2:PHI.P17.02 Improvement of CTF for RIA Analysis, CASL-U-2018-1608-000, April 30, 2018.

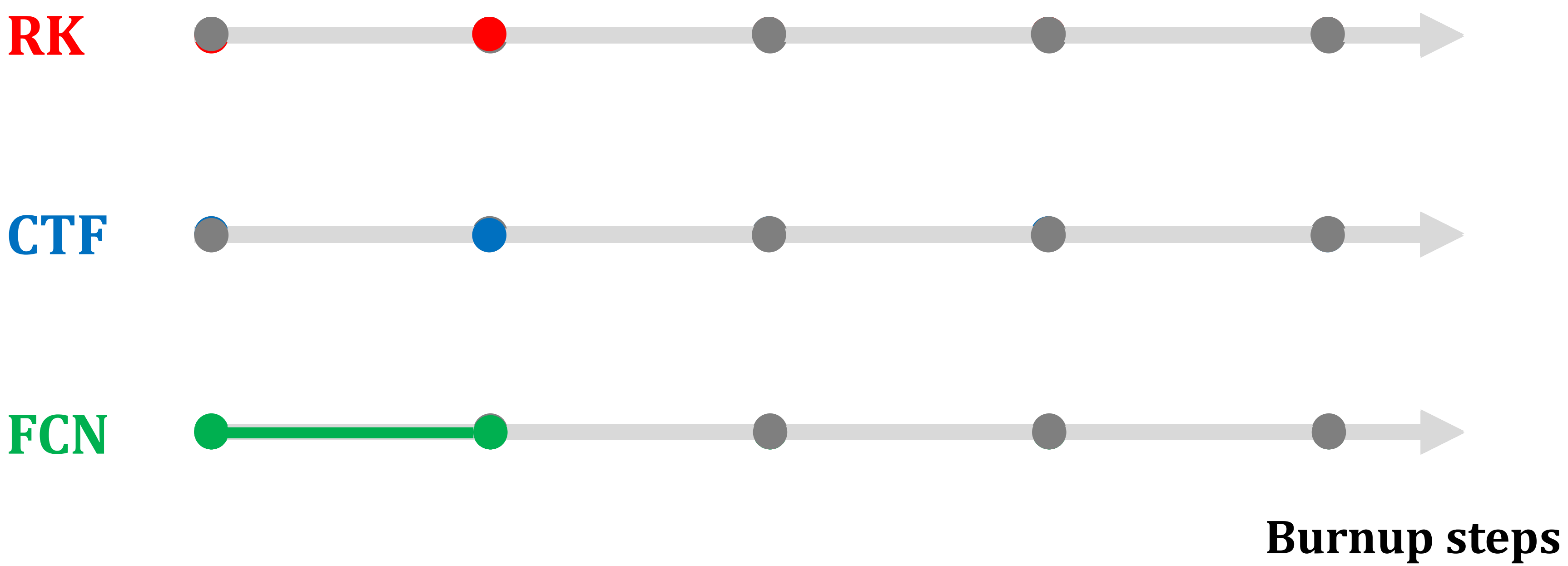
Flowchart of Coupled Calculation

- **RAST-K + CTF + FRAPCON Coupled Flowchart**



Coupled Calculation Scheme of FRAPCON

- **Current coupling of RAST-K and FRAPCON**
  - **FRAPCON has its own Burnup model**
  - **Every burnup, FRAPCON performs burnup calculation from 0 burnup**



Numerical Test

Numerical Test Description

- **OPR1000 type reactor Cycle 1**

-Loading Pattern

A0	A0	A0	B1	A0	A0	B1	C0	RF
A0	A0	C1	A0	C1	A0	C1	B0	RF
A0	C1	A0	B1	A0	B2	C1	B0	RF
B1	A0	B1	A0	B2	A0	C0	RF	RF
A0	C1	A0	B2	B1	C1	B0	RF	
A0	A0	B2	A0	C1	C0	RF	RF	
B1	C1	C1	C0	B0	RF	RF		
C0	B0	B0	RF	RF	RF			
RF	RF	RF	RF					

	Twice Burned
	Once Burned
	Fresh Fuel
	Reflector

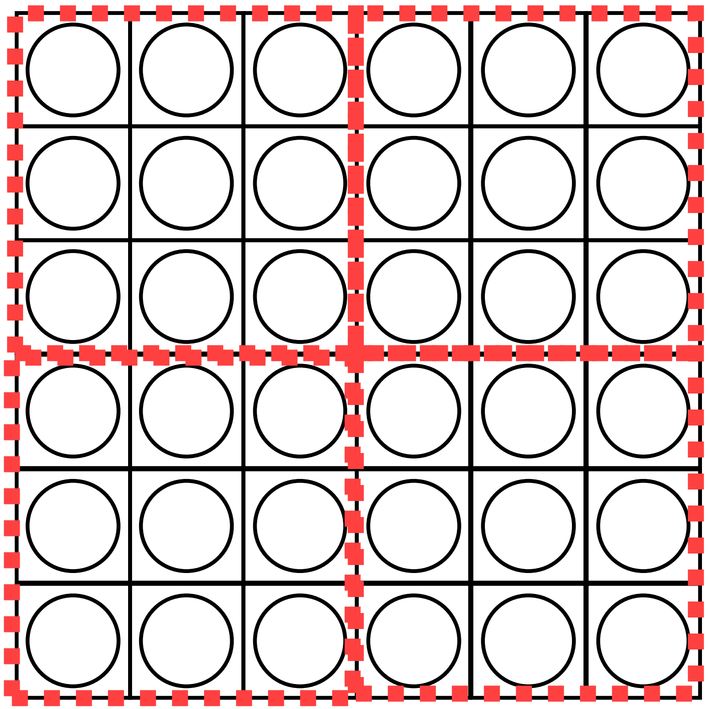
-Calculating condition

- **Quarter core**
- **Power: 2,815 MW**
- **Flow rate: 16,315 kg/s**
- **Burnup: 0~13.8 GWd/MTU**
  - With 17 Burnup steps
  - BOC (0.0 GWd/MTU)
  - MOC (6.0 GWd/MTU)
  - EOC (12.0 GWd/MTU)

Numerical Test Description

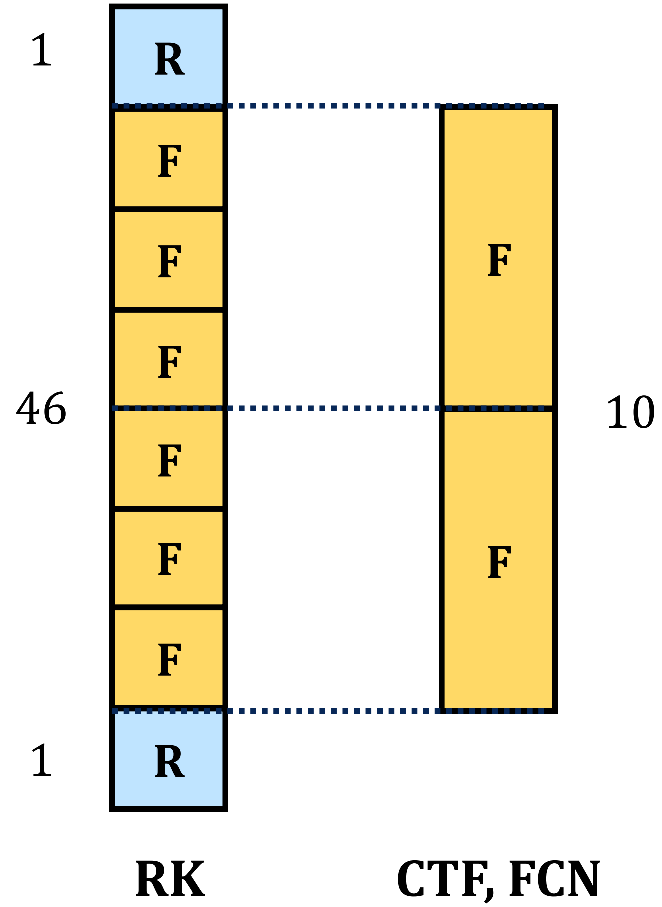
- **RAST-K + CTF + FRAPCON modeling condition**

Radial mesh mapping



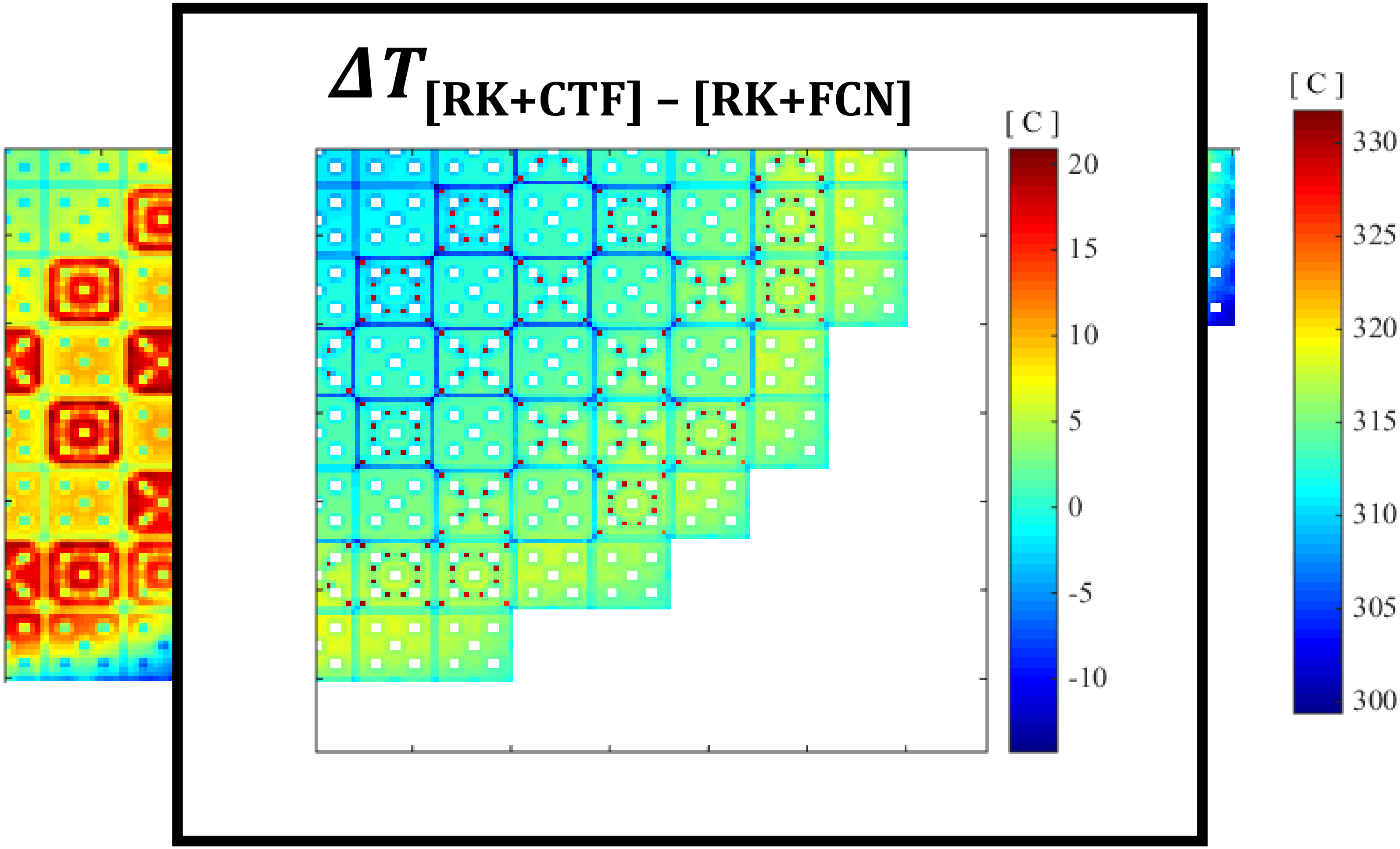
Nodal(XS) mesh

Axial mesh mapping



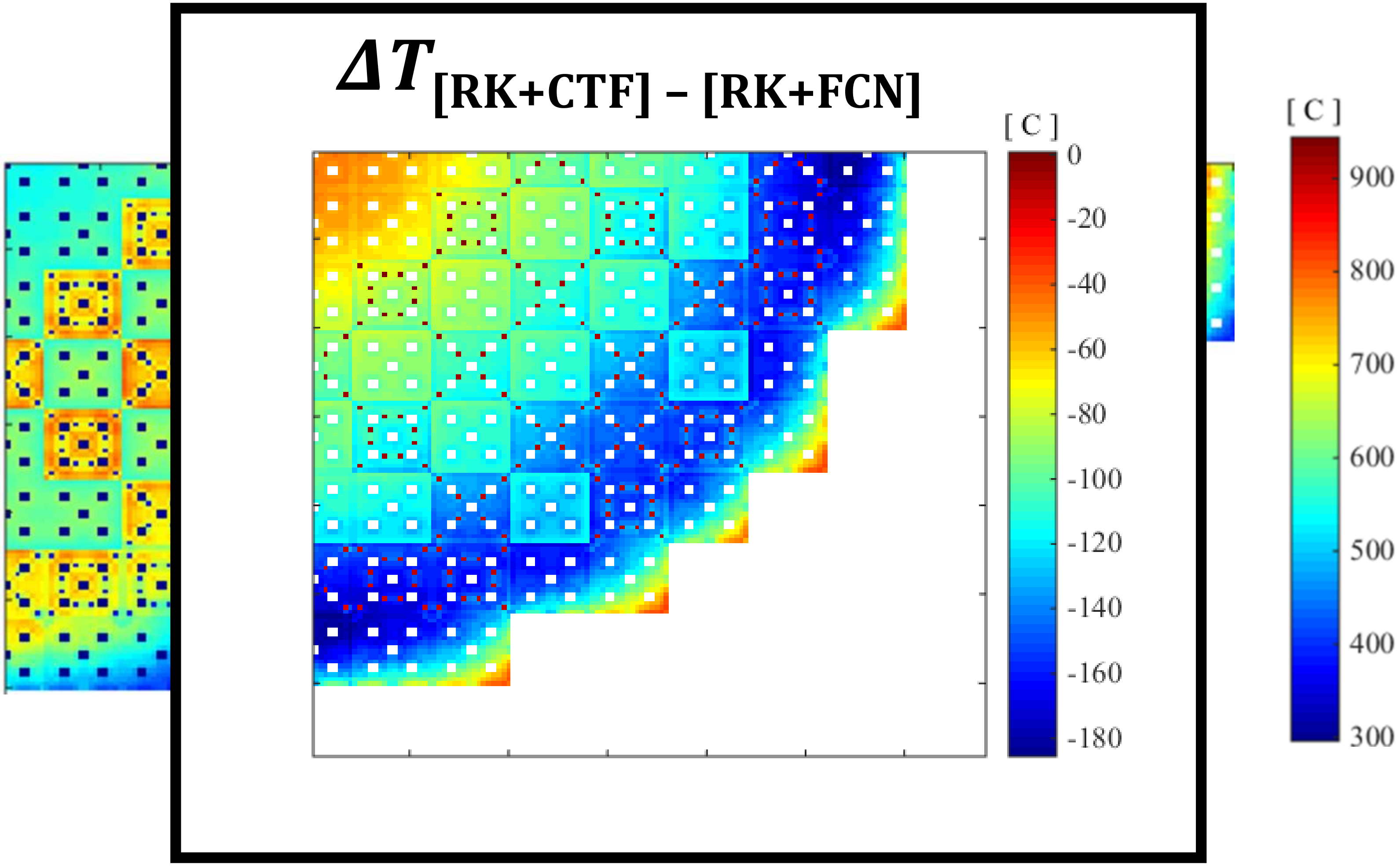
Numerical Test Results: RK+CTF vs. RK+FCN

- **Coolant temperature distribution [°C]**
- **7th axial level from bottom at BOC**



Numerical Test Results: RK+CTF vs. RK+FCN

- **Fuel temperature distribution [°C]**



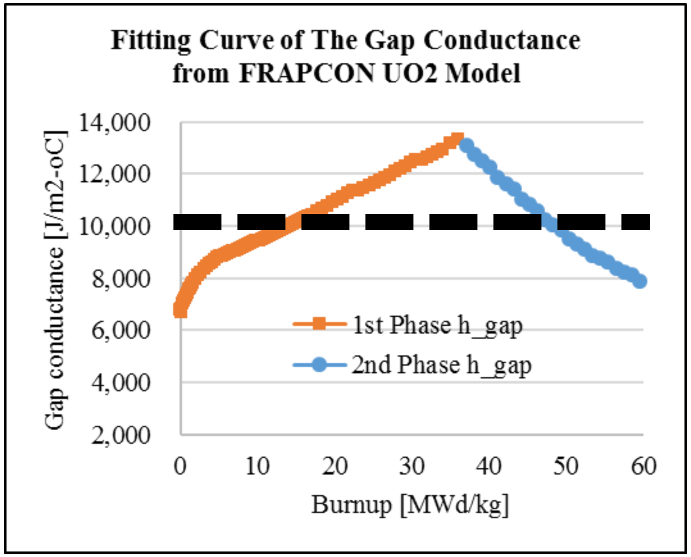
Numerical Test Results: RK+CTF vs. RK+FCN

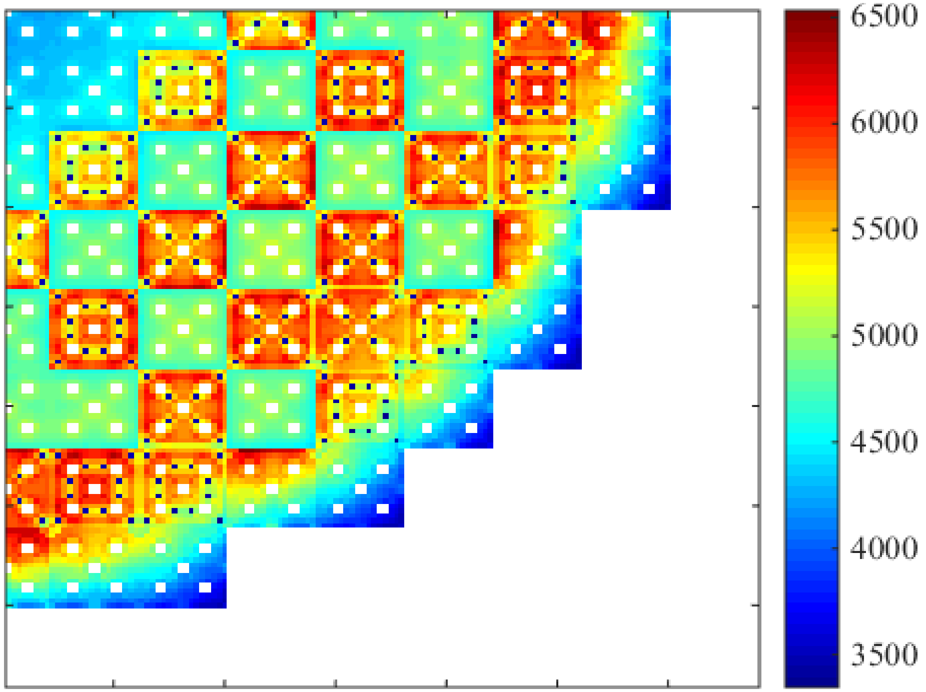
- **Gap conductance [W/m²K]**

RK+CTF

RK+FCN

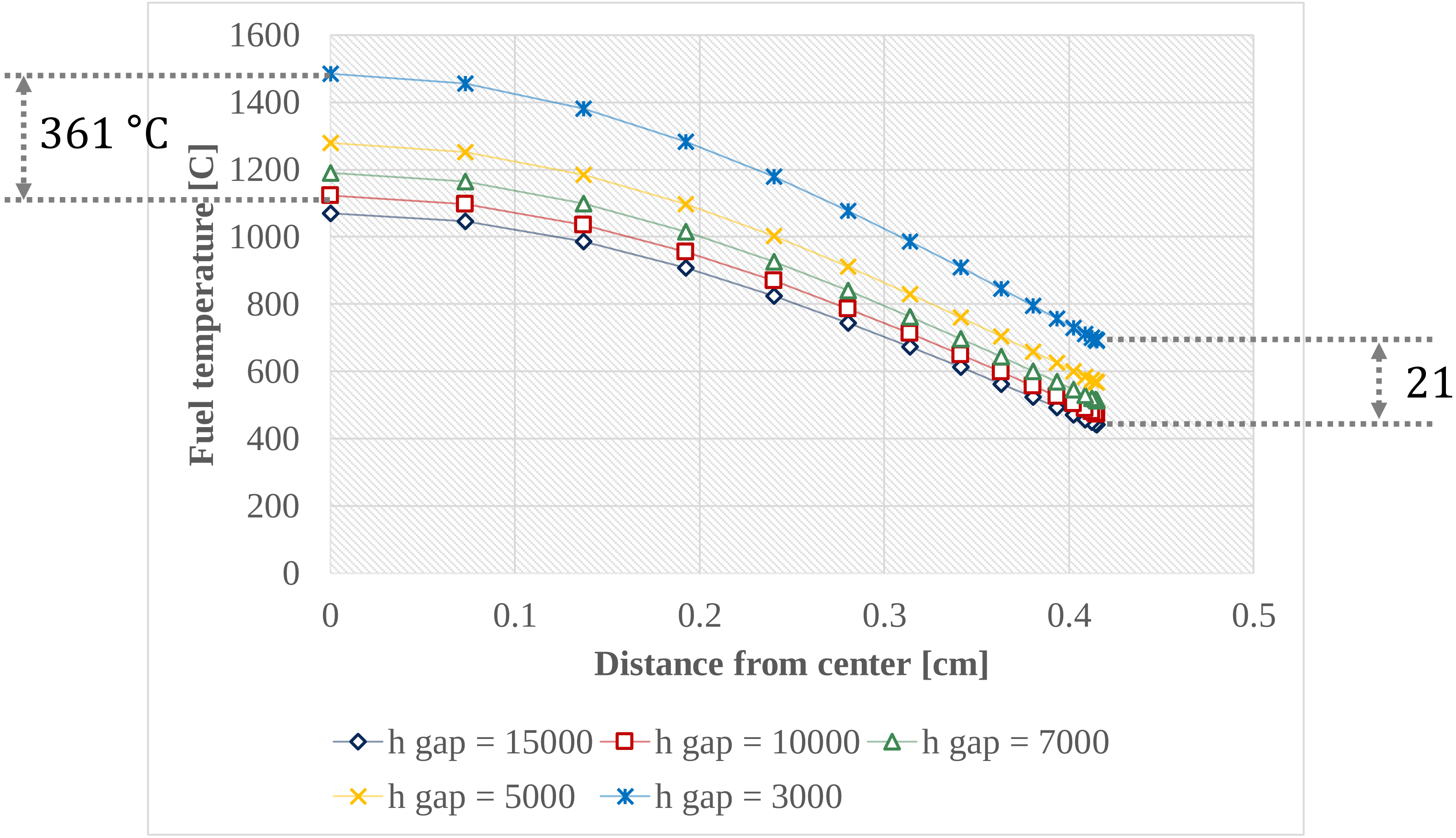
10,000 W/m²-K





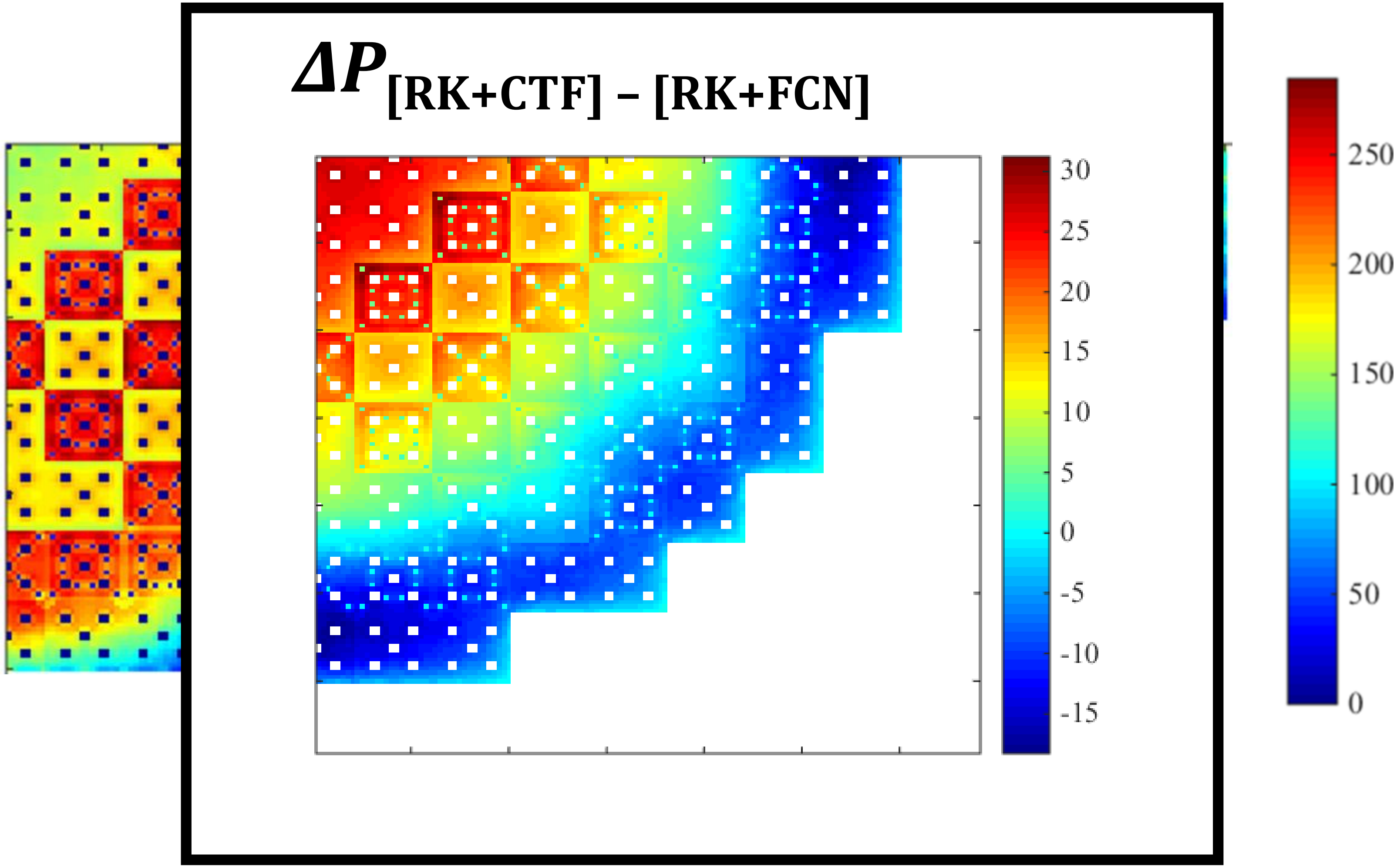
Numerical Test Results: RK+CTF vs. RK+FCN

- **Effect of gap conductance [W/m²K]**
  - **Single rod calculation by FRAPCON**
  - **coolant inlet temperature 306.77 C**
  - **pin power: 0.071030 MW,**



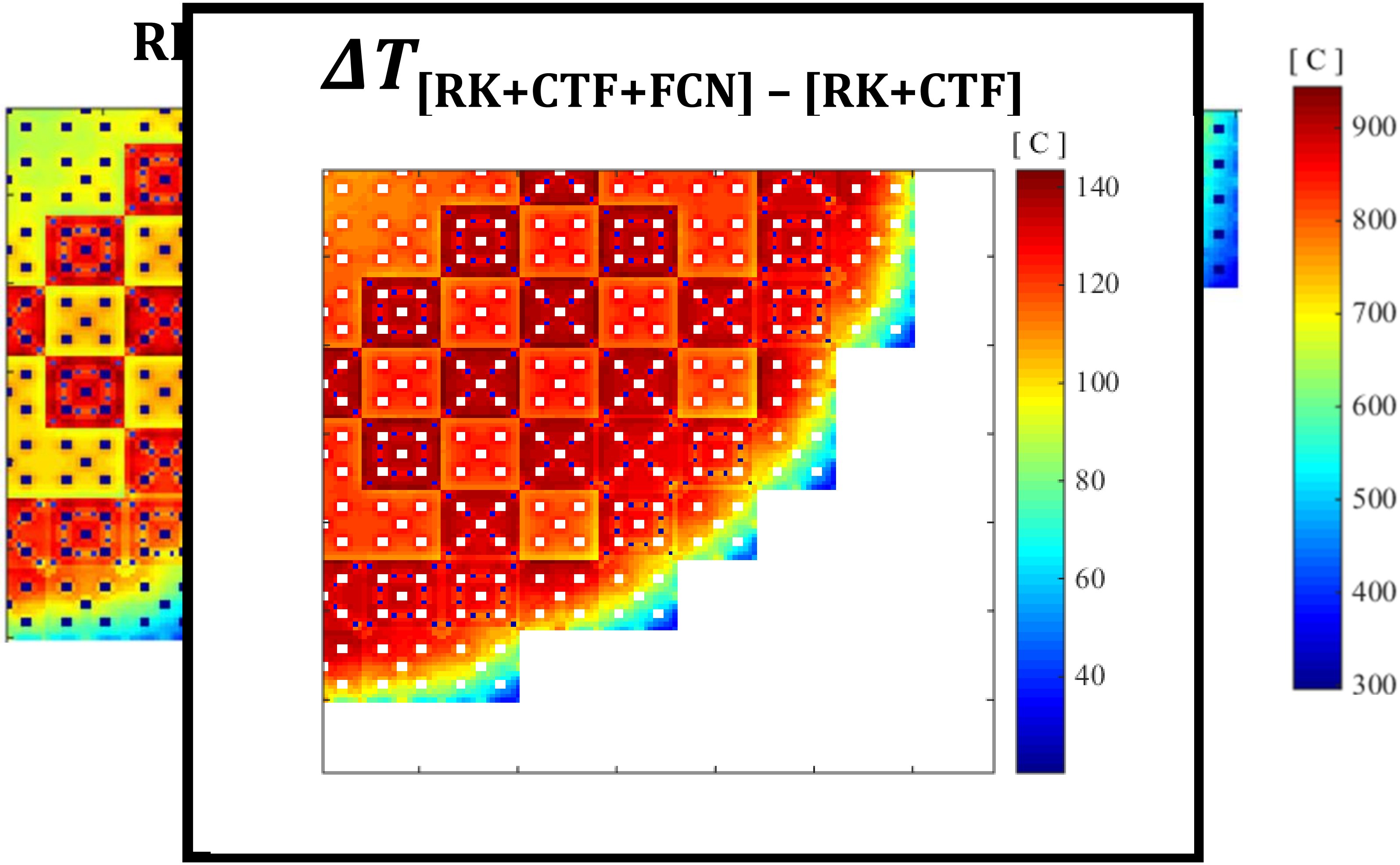
Numerical Test Results: RK+CTF vs. RK+FCN

- **Linear power distribution [W/cm]**



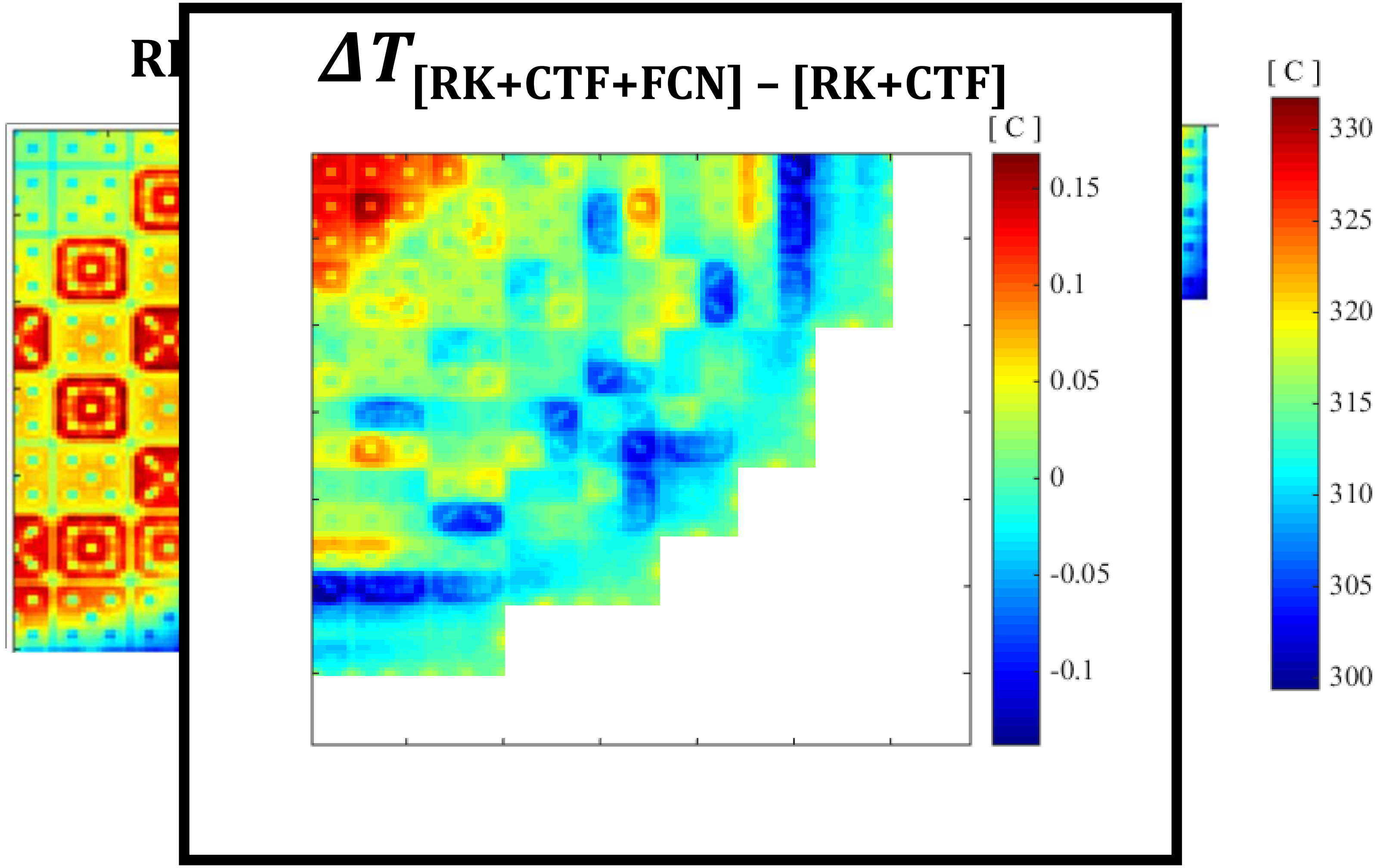
Numerical Test Results: RK+CTF+FCN vs. RK+CTF

- **Fuel temperature distribution [°C]**



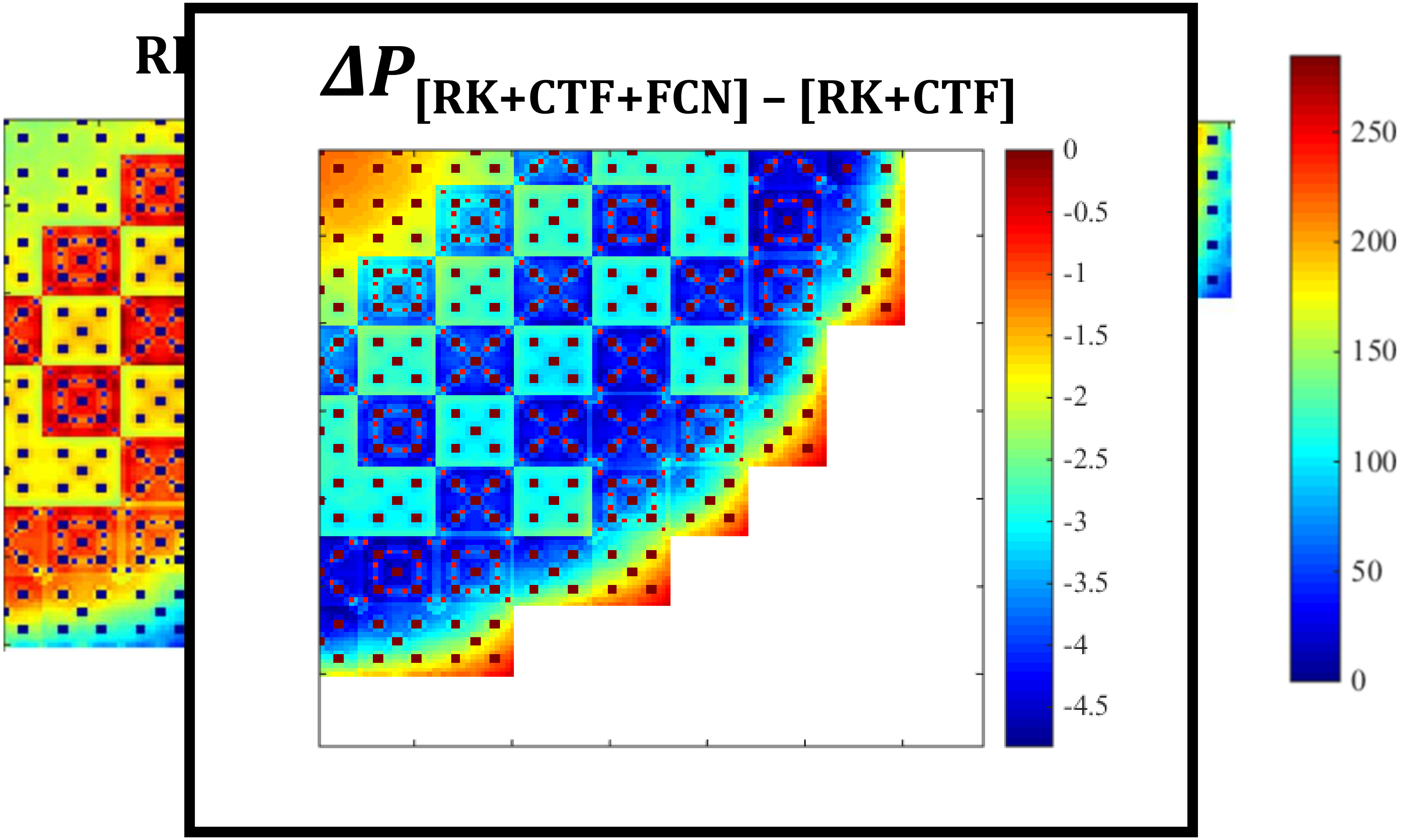
Numerical Test Results: RK+CTF+FCN vs. RK+CTF

- **Coolant temperature distribution [°C]**



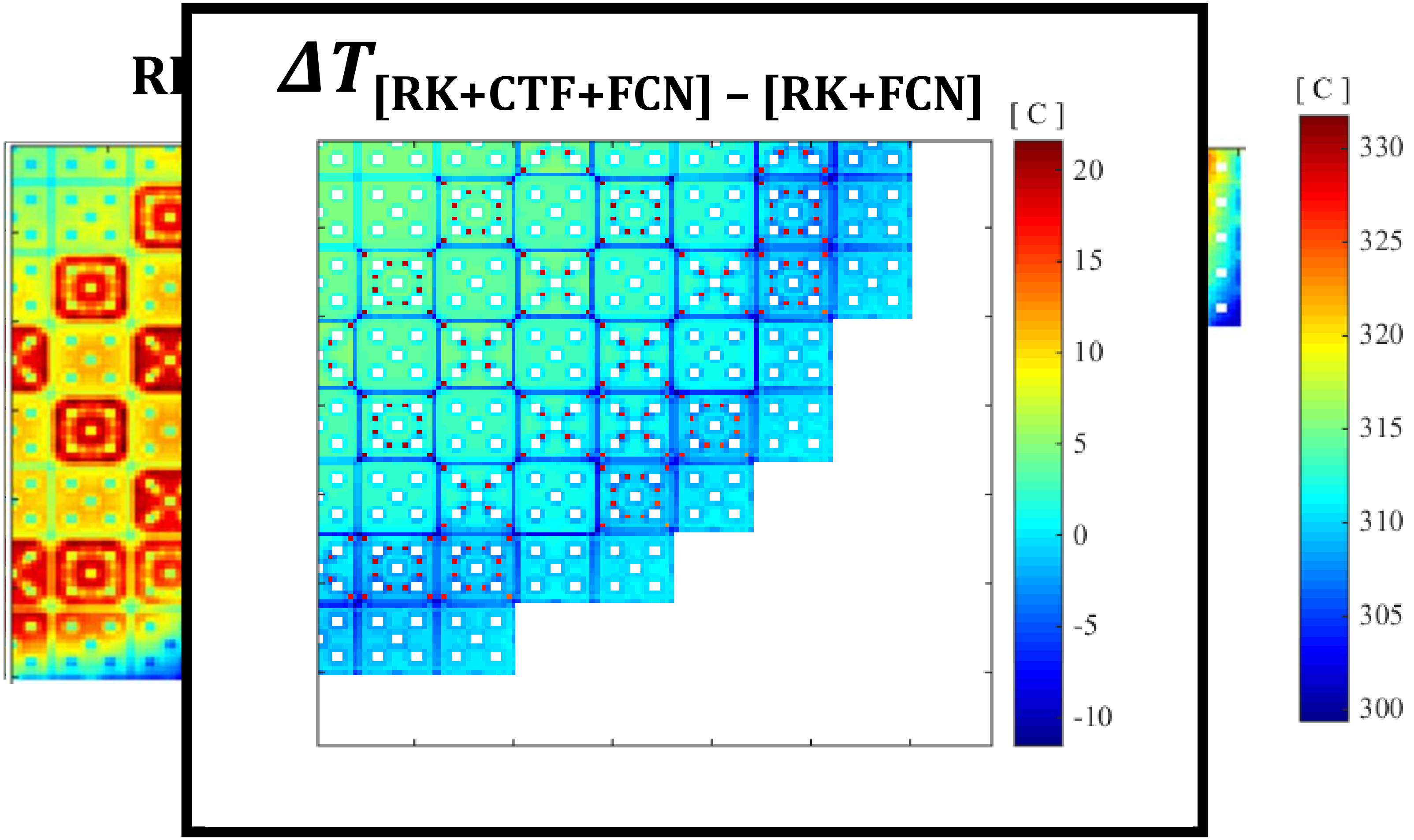
Numerical Test Results: RK+CTF+FCN vs. RK+CTF

- **Linear power distribution [W/cm]**



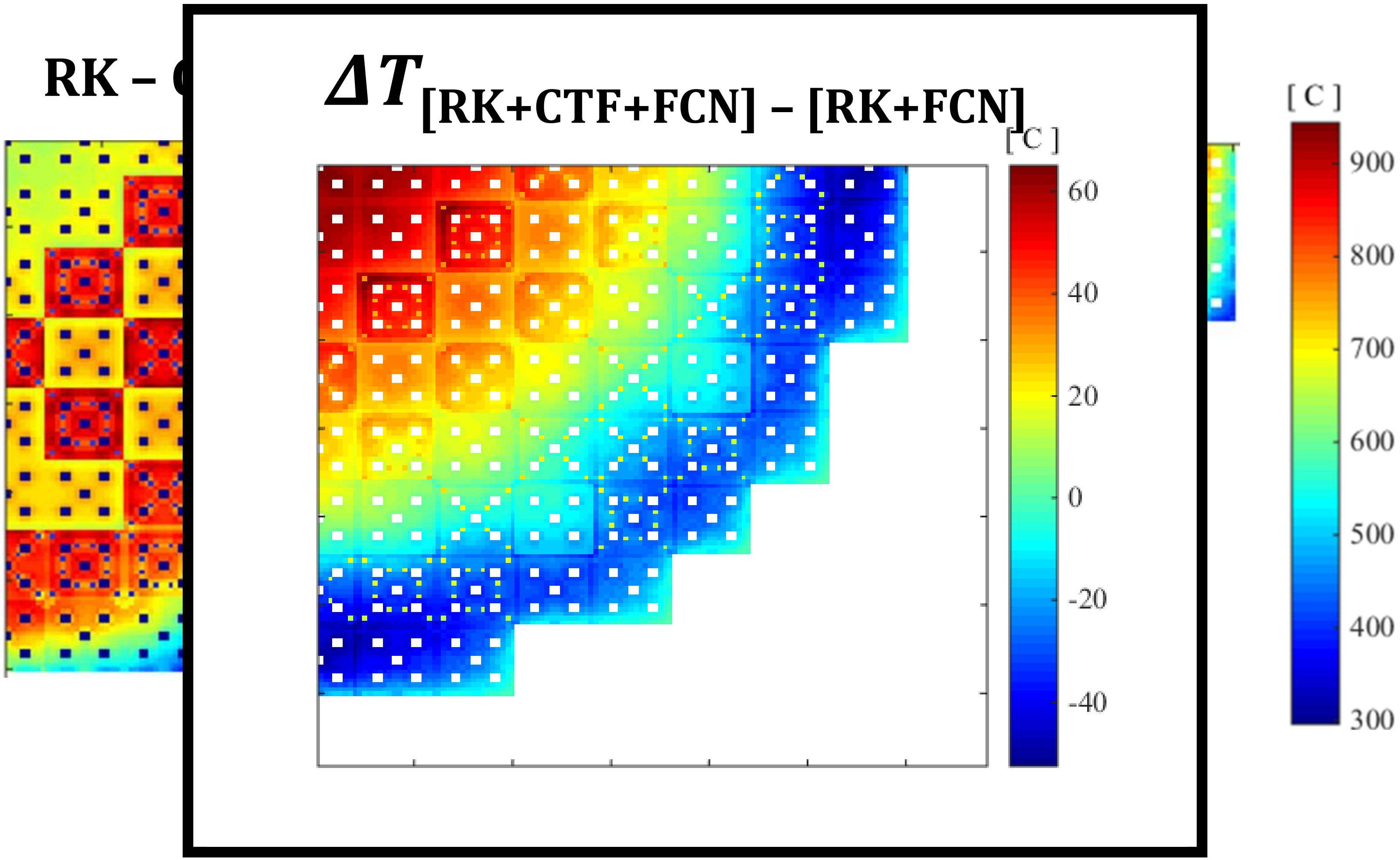
Numerical Test Results: RK+CTF+FCN vs. RK+FCN

- **Coolant temperature distribution [°C]**



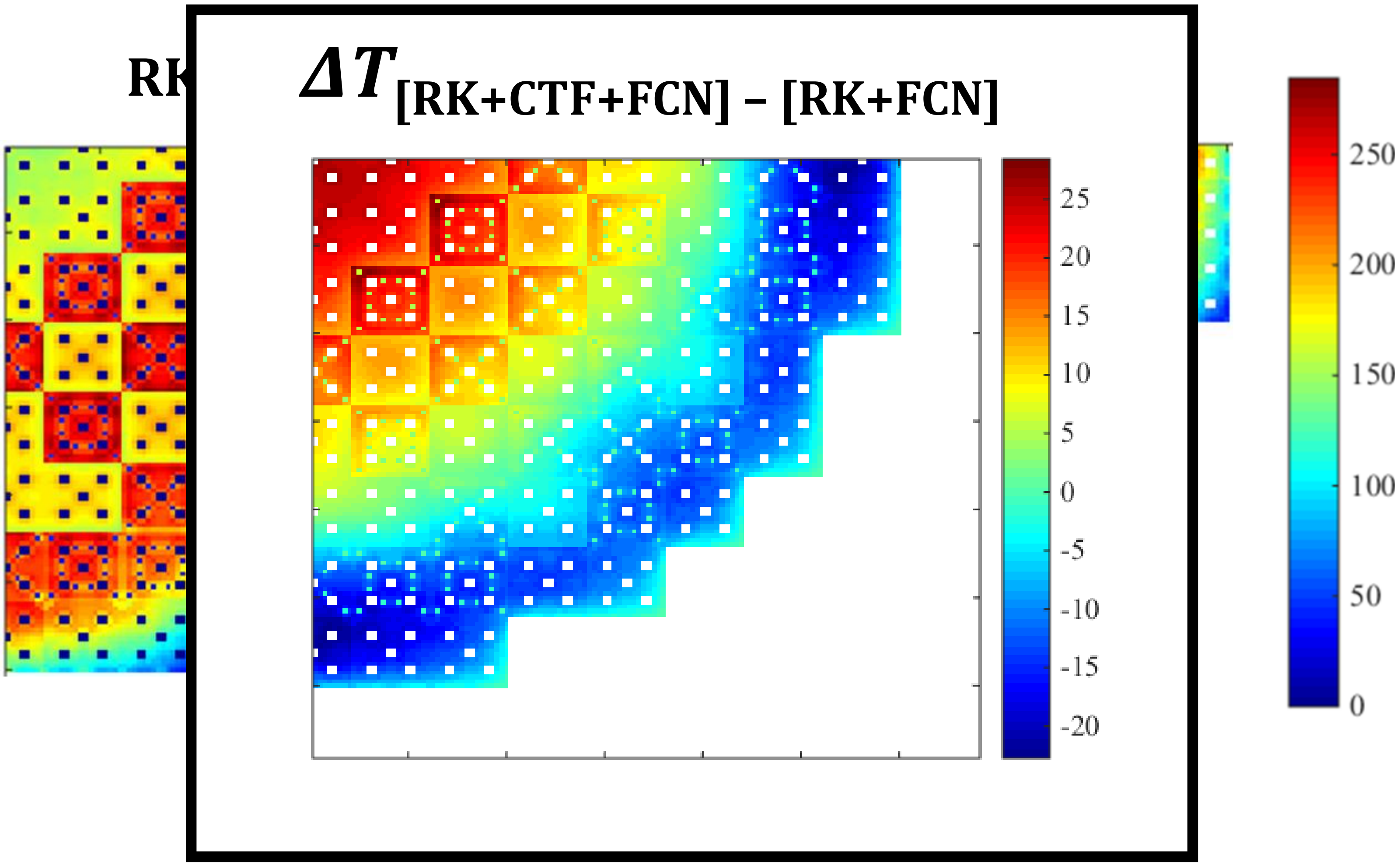
Numerical Test Results: RK+CTF+FCN vs. RK+CTF

- **Fuel temperature distribution [°C]**



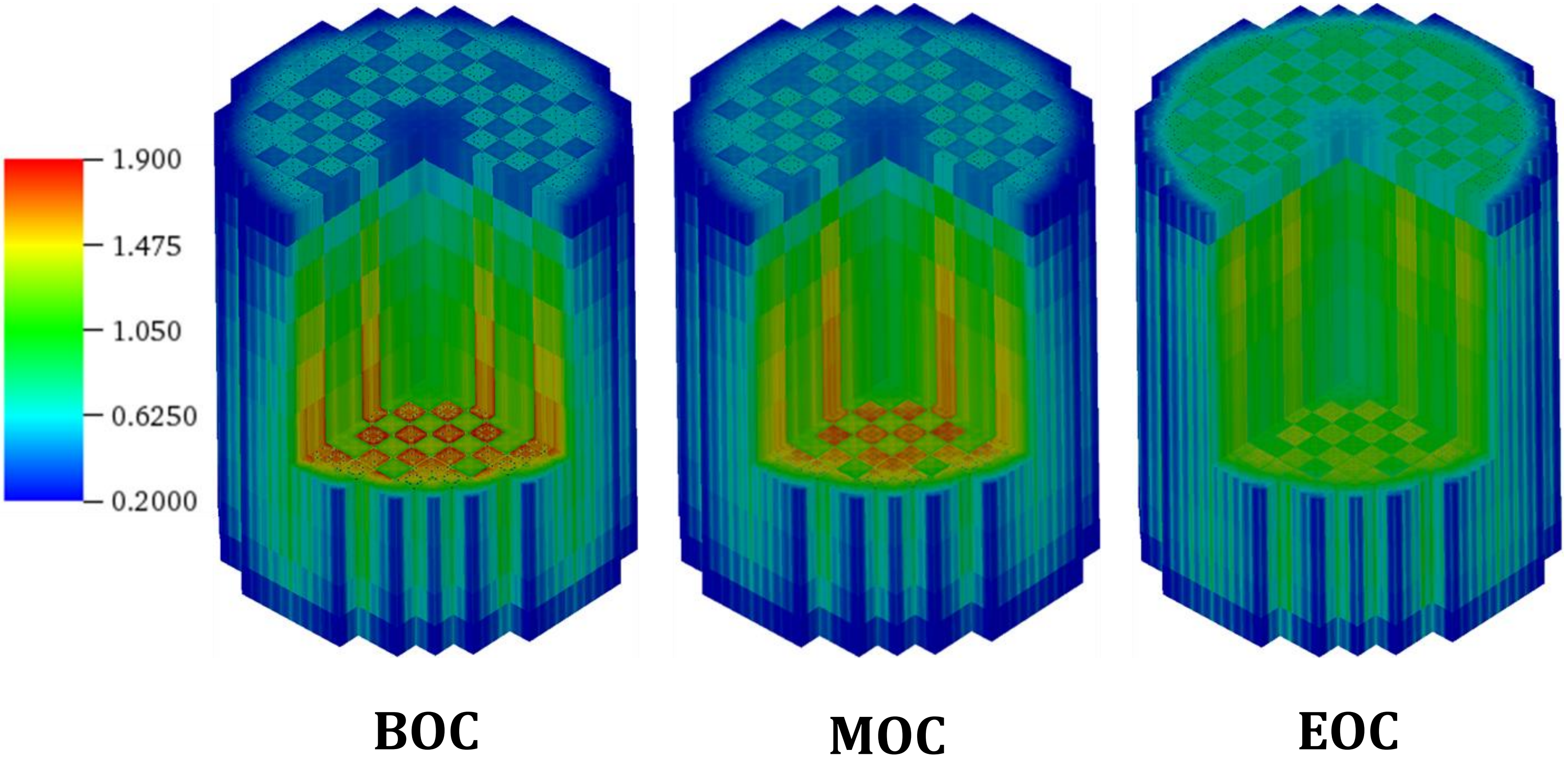
Numerical Test Results: RK+CTF+FCN vs. RK+CTF

- **Linear power distribution [W/cm]**



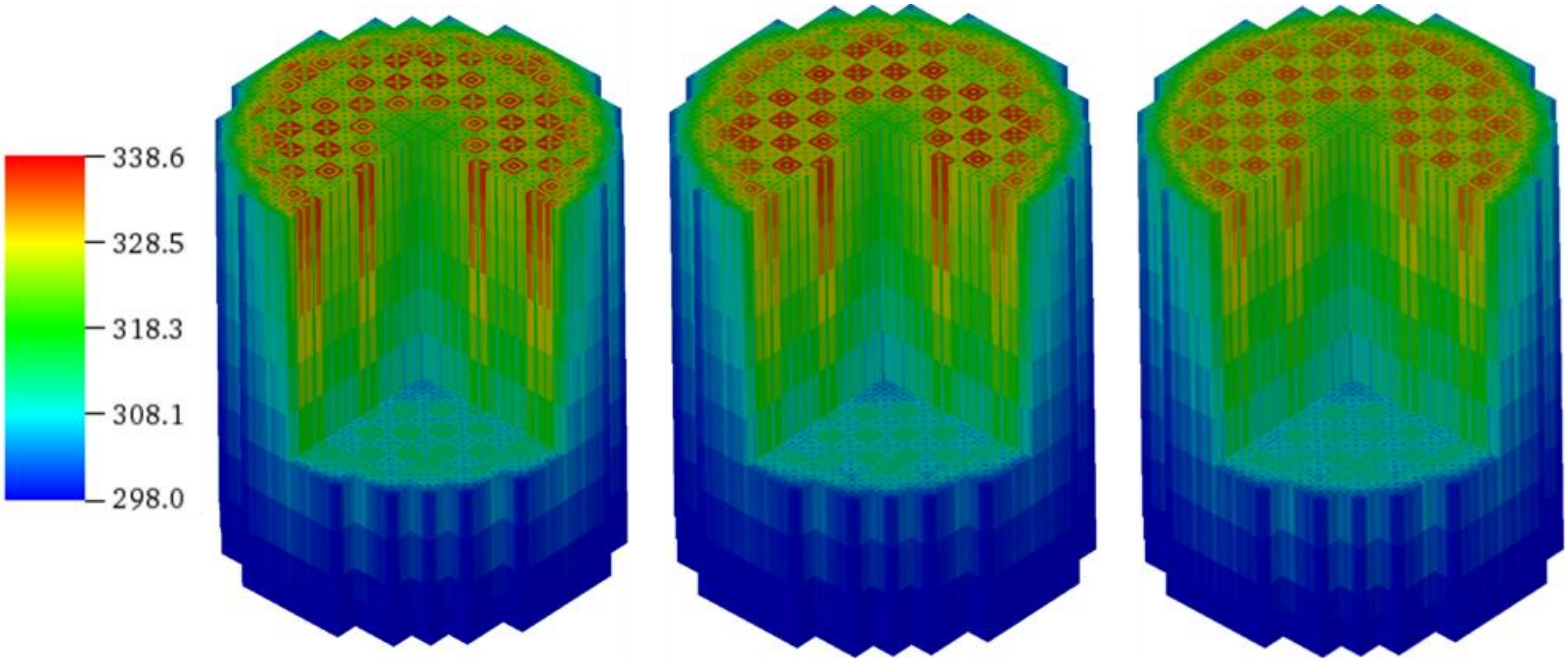
Numerical Test Results: Coupled Parameters

- **RAST-K + CTF + FRAPCON Coupling Result**
  - **Normalized pin power [-]**



Numerical Test Results: Coupled Parameters

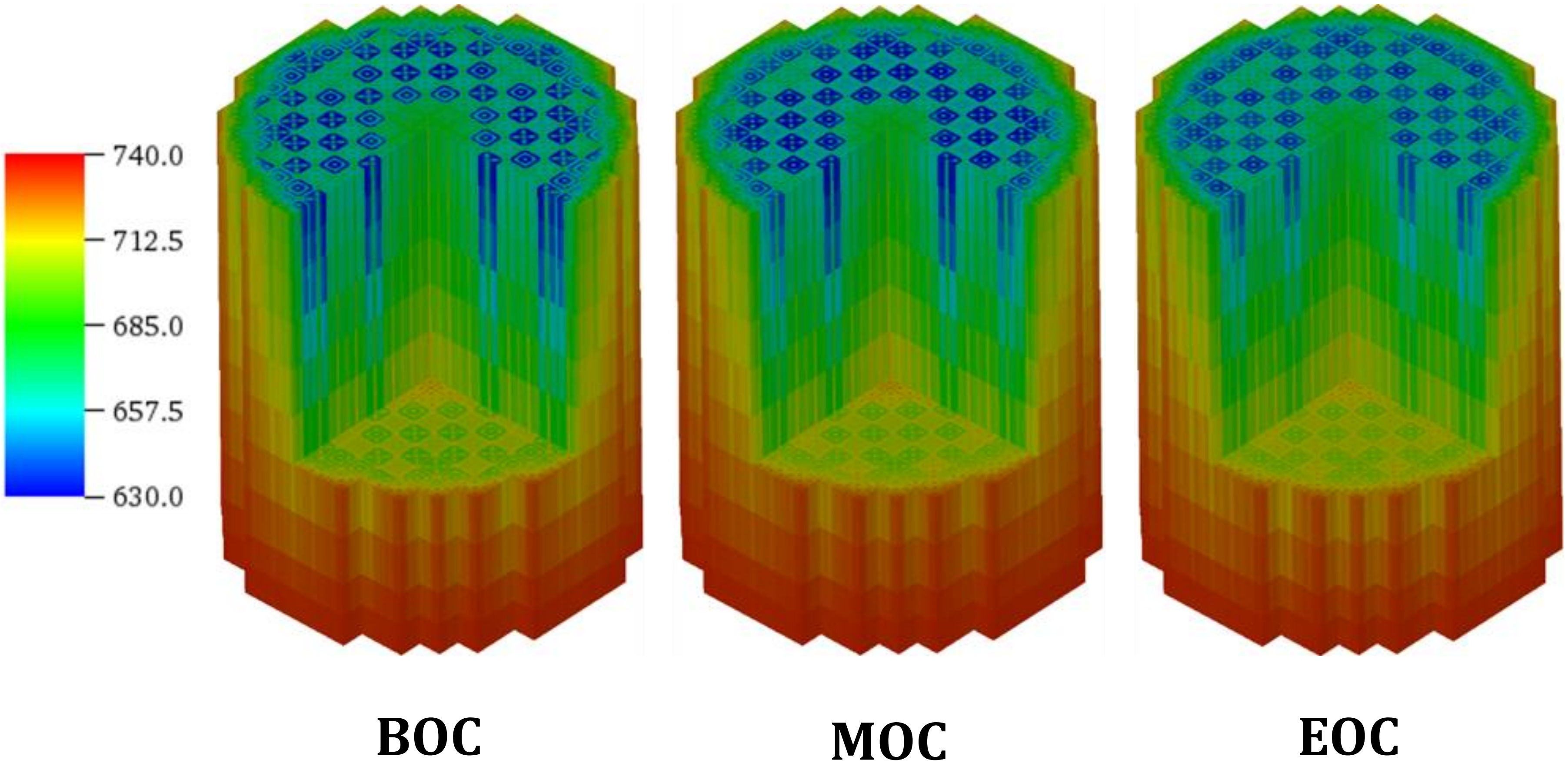
- **RAST-K + CTF + FRAPCON Coupling Result**
  - **Coolant temperature [°C]**



BOC **MOC** **EOC**

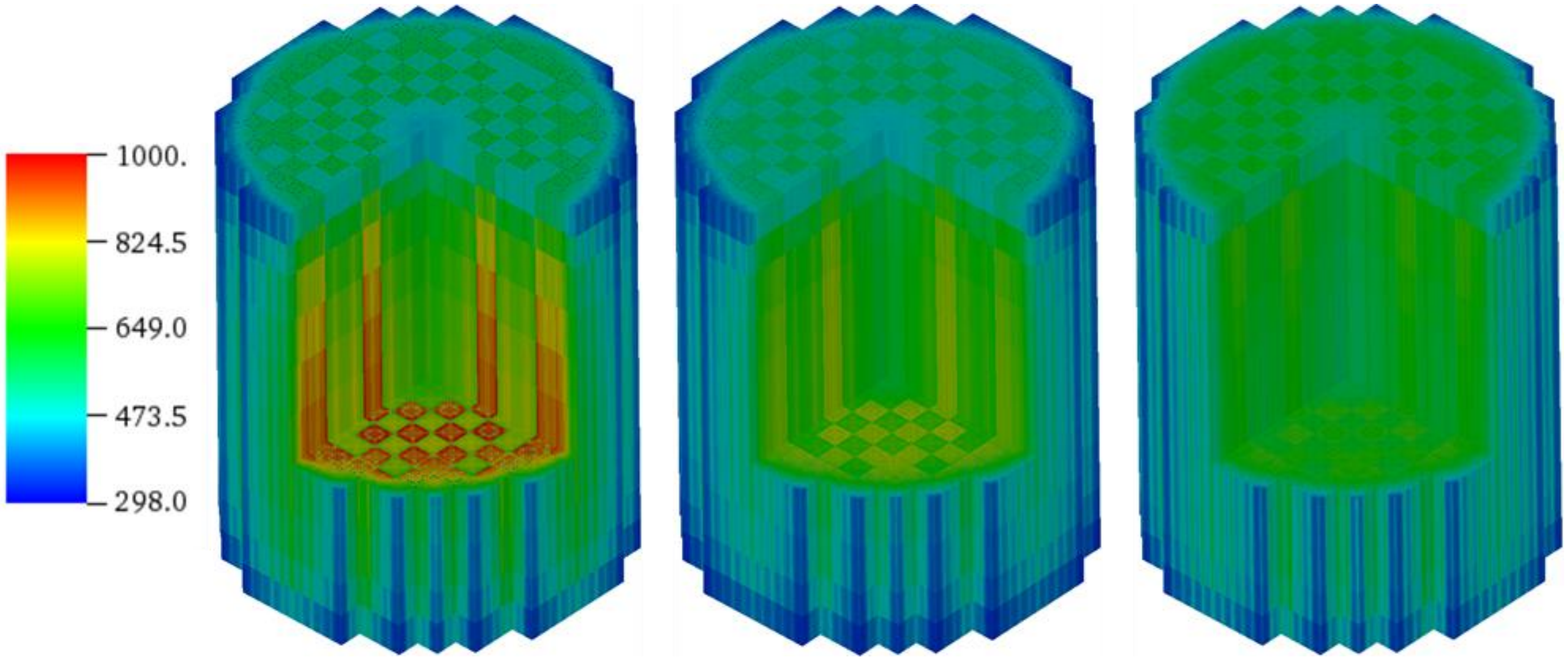
Numerical Test Results: Coupled Parameters

- **RAST-K + CTF + FRAPCON Coupling Result**
  - **Coolant density [g/cc]**



Numerical Test Results: Coupled Parameters

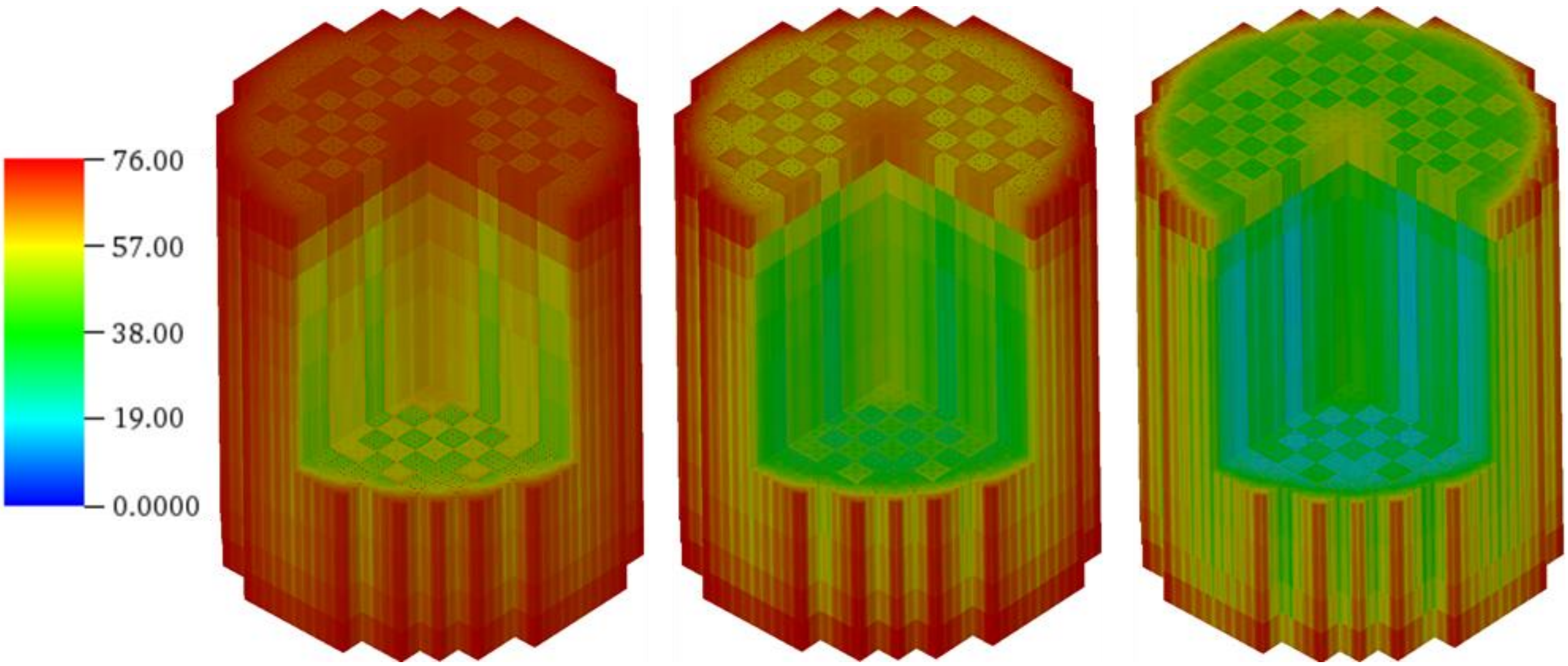
- **RAST-K + CTF + FRAPCON Coupling Result**
  - **Fuel temperature [°C]**



BOC **MOC** **EOC**

Numerical Test Results: Fuel Properties

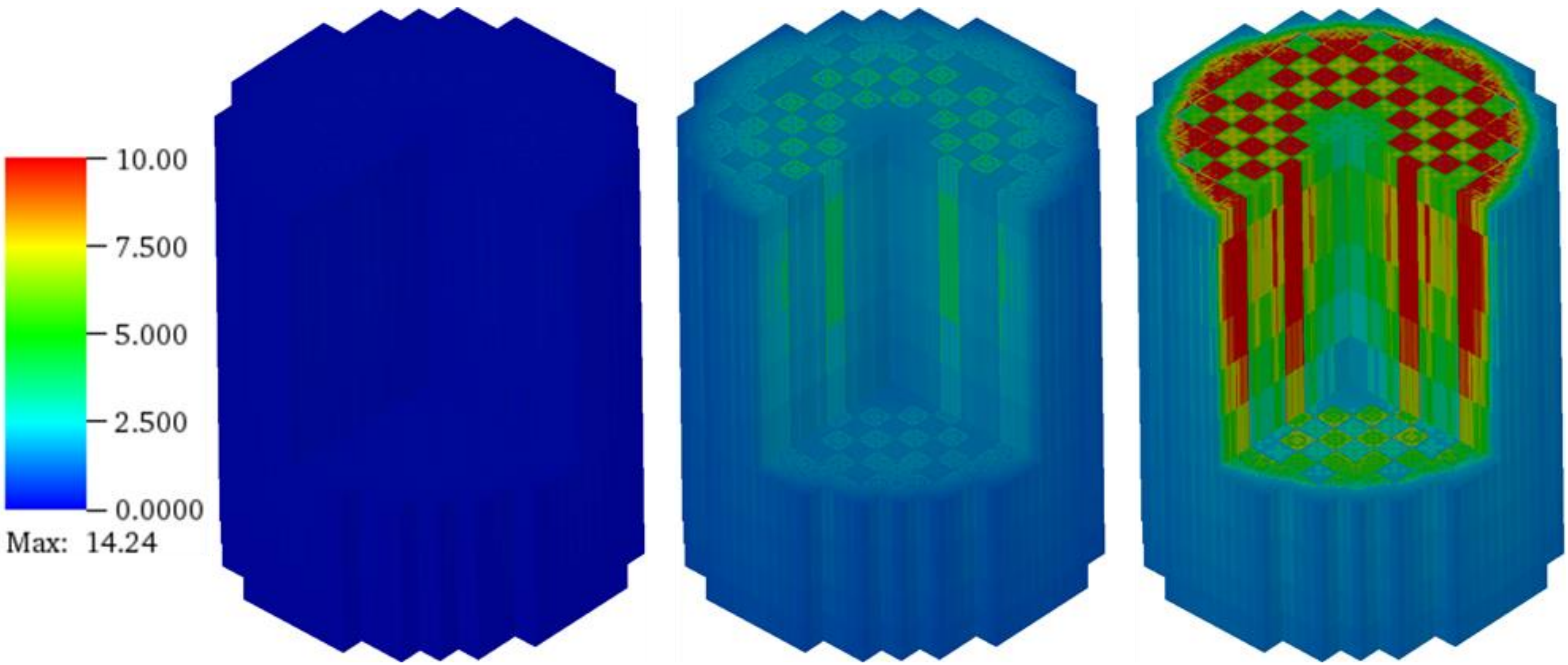
- **RAST-K + CTF + FRAPCON Coupling Result**
  - **Gap thickness [micron]**



BOC **MOC** **EOC**

Numerical Test Results: Fuel Properties

- **RAST-K + CTF + FRAPCON Coupling Result**
  - **Oxide thickness [micron]**



BOC **MOC** **EOC**

Conclusion & Future work

Conclusion

- **Neutronics code RAST-K2.0 has been coupled with sub-channel T/H code and fuel performance code (CTF, FRAPCON) for normal operation calculation**
- **Numerical test is performed on quarter core of a typical OPR1000 type reactor**
- **Pin power distribution, coolant temperature and density distribution, fuel temperature distribution (coupled parameters), gap thickness, and oxide thickness (fuel properties) are calculated by the coupled calculation**
- **Gap conductance has significant effect on fuel temperature**
- **Power distribution is more affected by coolant property**

Future Work

- **Pin-by-pin SP3 kernel will be implemented in RAST-K to calculate pin power distribution directly**

- **Feedback between CTF and FRAPCON is under consideration**

- **RASTK + CTF + FRAPTRAN coupling for accident analysis**

- **Parallel, JFNK ... for better performance**

UNIST CORE