Validation of Neutronic and Thermal-hydraulic Multi-physics Calculations for SMRs Rod Ejection Accident with PARCS/TWOPORFLOW

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PARCS Code: Key Aspects

- Steady-state eigenvalue calculations
- Transient calculations
- Diffusion or low-order transport solution
- Multi-group solver
- Several boundary condition options
- Xenon/Samarium calculations
- Decay heat calculations
- Pin power reconstruction

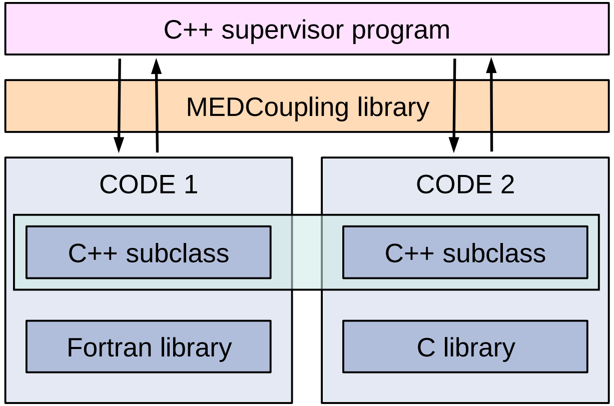
TWOPORFLOW (TPF) Code: Key Aspects

- Porus-media (FAVOR technique)
- Steady-state and transient solution
- Two-phase flow (6 equations)
- 3D conservation equations
- 2D heat conduction model for fuel rods
- Coarse Cartesian grids

Methodology for Code Coupling: ICoCo Approach

- Interface for Code Coupling (ICoCo): provides a standard **frame** for code coupling.

Define methods for:
- Initialization and termination
- Time advance
- Save and restore state
- Getting and setting fields



- **Code split** in funtional pieces.
- ICoCo framework MED format **mesh** is compulsory.
- Inherently bound with **MEDCoupling** library.

Methodology: PARCS ICoCo Implementation

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v3.3.1

- Executables
- GenPMAXS
- ICoCo ← *ParcsProblem.cxx*, *ParcsProblem.hxx*
- Manuals
- Sample
- Source
  - parcslib ← all files listed below

libParcsICoCo.so

Initialization and termantion

parcs_set_data_file.f90
parcs_set_mpi_rank.f90
parcs_initialize.f90
parcs_terminate.f90

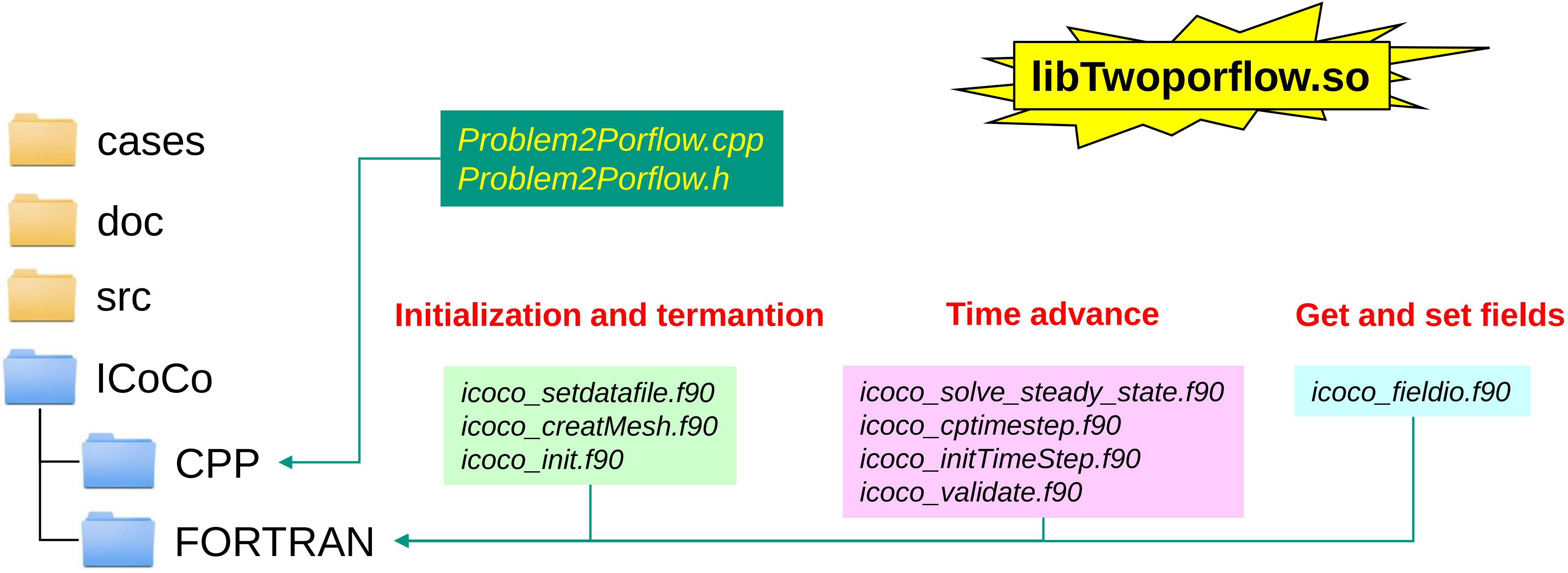
Time advance

parcs_solve_steady_state.f90
parcs_get_present_time.f90
parcs_compute_time_step.f90
parcs_init_time_step.f90
parcs_solve_time_step.f90
parcs_terminate_time_step.f90

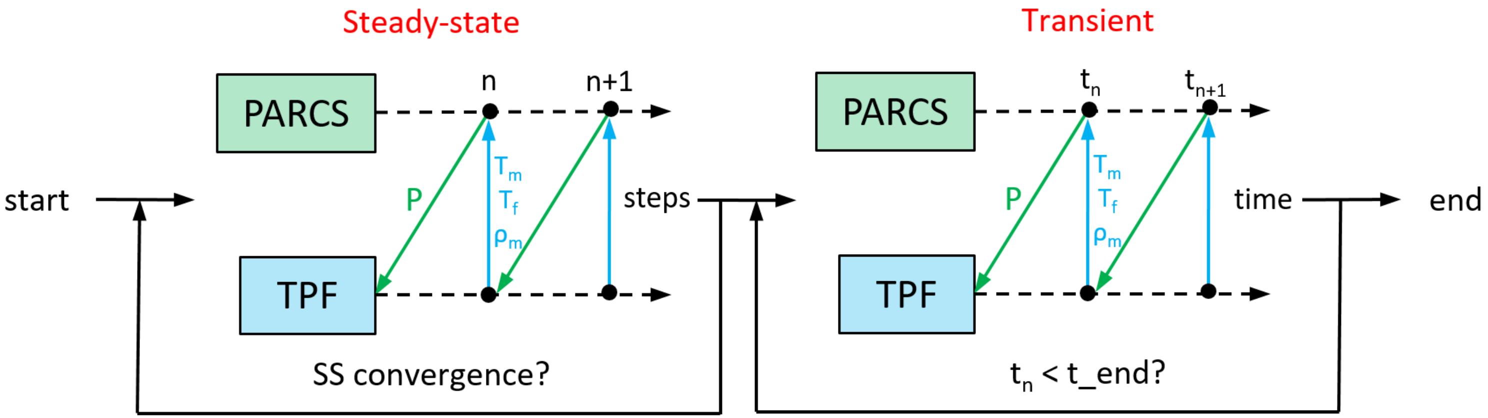
Get and set fields

parcs_set_field.f90
parcs_get_field.f90

Methodology: TPF ICoCo Implementation

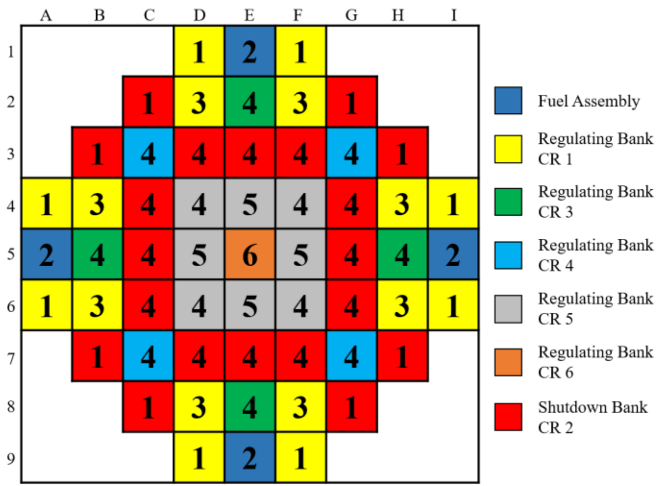


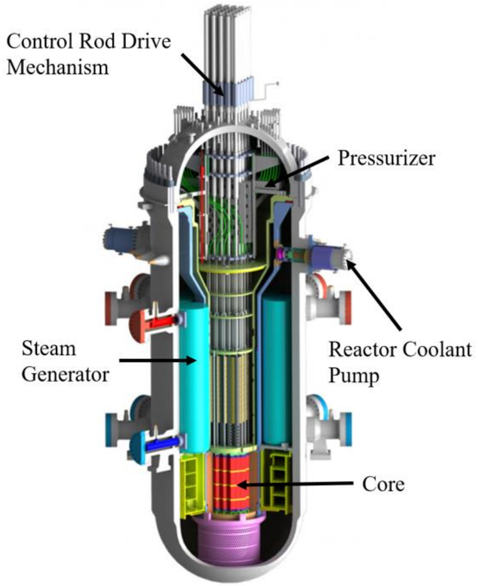
Methodology: Coupling Iterative Scheme PARCS/TPF



KSMR: Core Features

Parameter	Value
Total power	330 MW_{th}
System pressure	15 MPa
Inlet temperature	296 C
Core mass flow	2006.4 kg/s





KSMR: Rod Ejection Transient Definition

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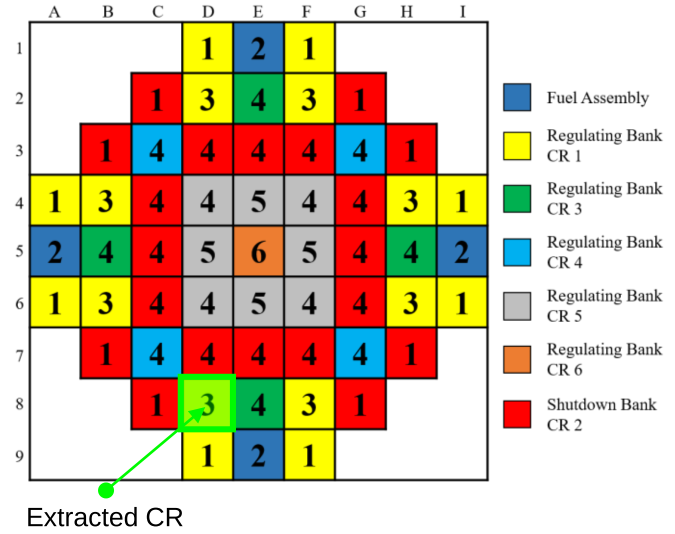
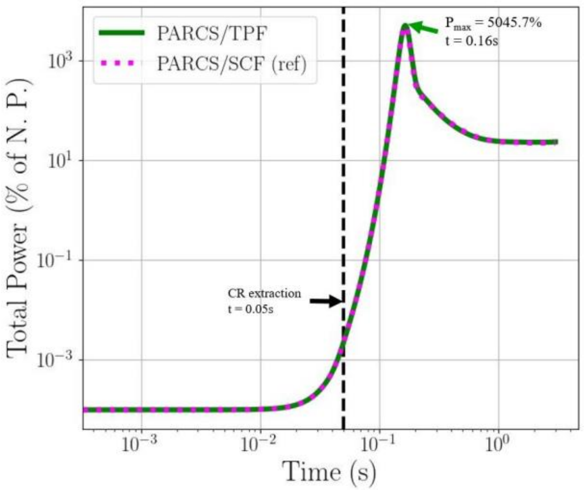
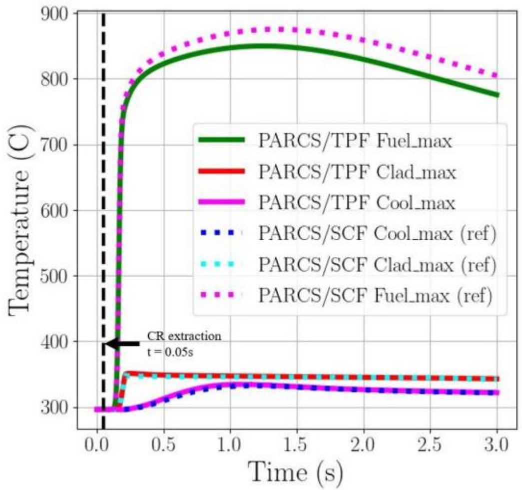
Parameter	Value
Initial core power	1.0E-4%
Highest CR worth	1.45 $
Ejection duration	0.05s
End of transient simulation	3.0s
Time step	0.0005s
Scram	NO



KSMR: Selected Results

KSMR	PARCS/TPF	PARCS/SCF (ref)	Error
Max. Power (%)	5045.7	4834.6	4.36*
Max. Reactivity insertion ($)	1.39	1.39	0.0*
Max. Fuel Temperature (C)	849.79	875.34	25.55**
Max. Cladding Temperature (C)	351.17	347.27	3.9**
Max. Fuel Enthalpy (J/kg)	2.11E+05	2.17E+05	2.76*
Min. DNBR	1.86	1.71	8.77*



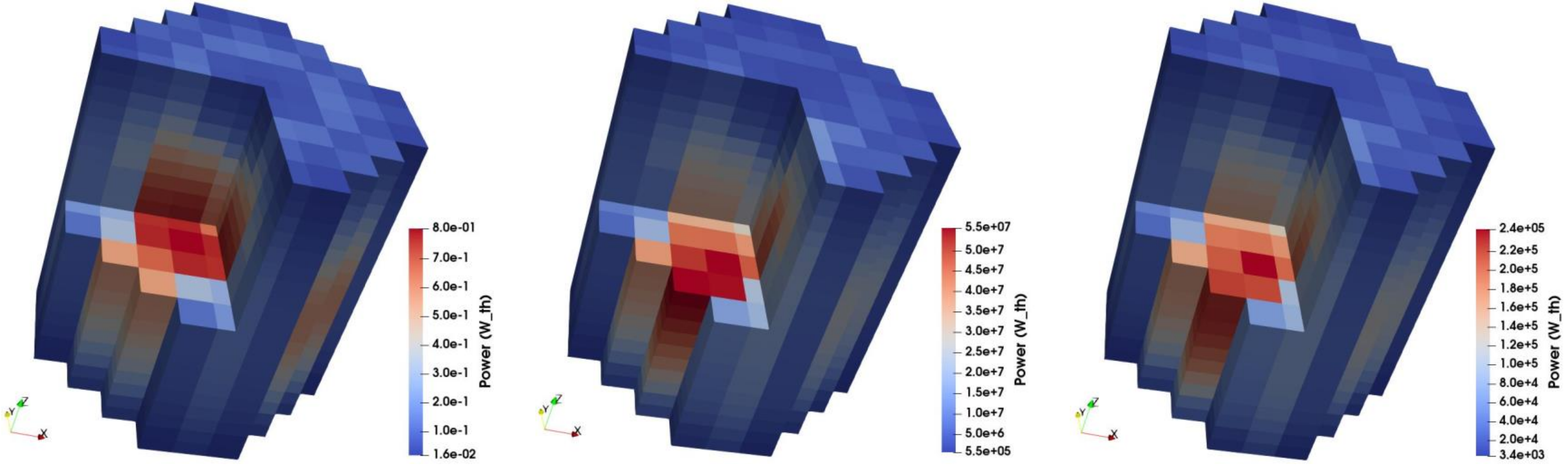


$$*\text{Error}=\frac{|\text{value}-\text{ref}|}{\text{ref}}\text{x}100$$

$$**\text{Error}=|\text{value}-\text{ref}|$$

KSMR: Selected Results

- Power evolution during the REA



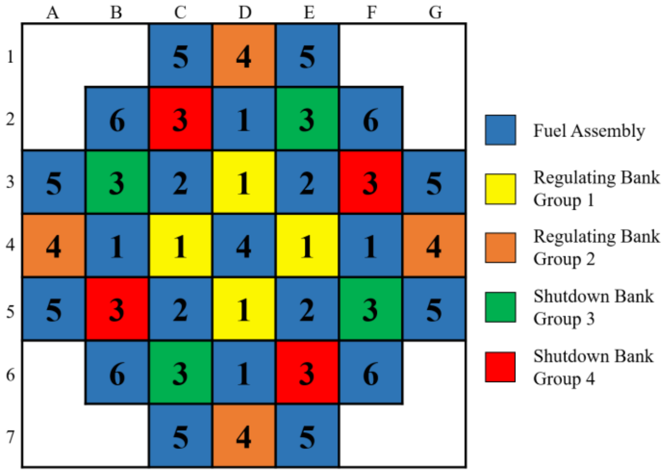
t = 0.0s

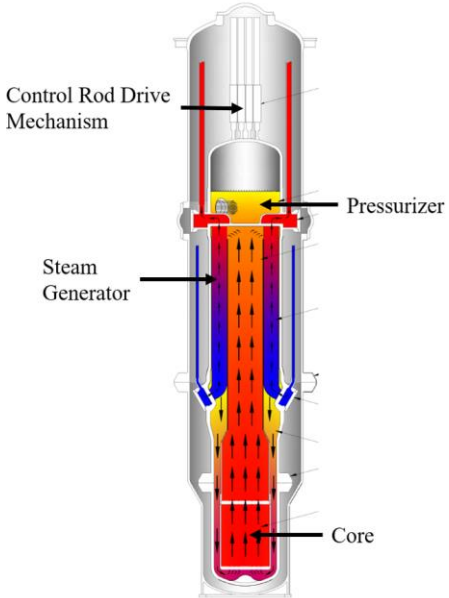
t = 0.16s

t = 3.0s

NuScale-like: Core Features

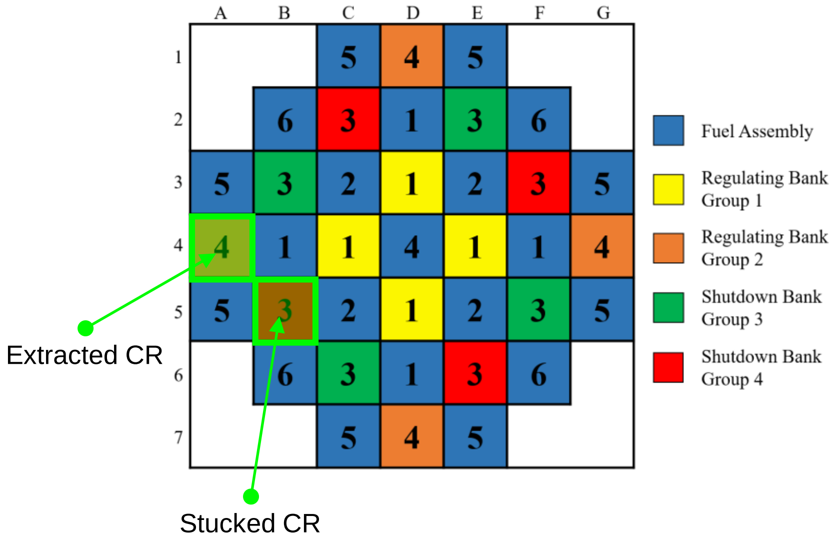
Parameter	Value
Total power	160 MW_{th}
System pressure	12.755 MPa
Core avg temperature	563.71 K
Core mass flow	496.17 kg/s





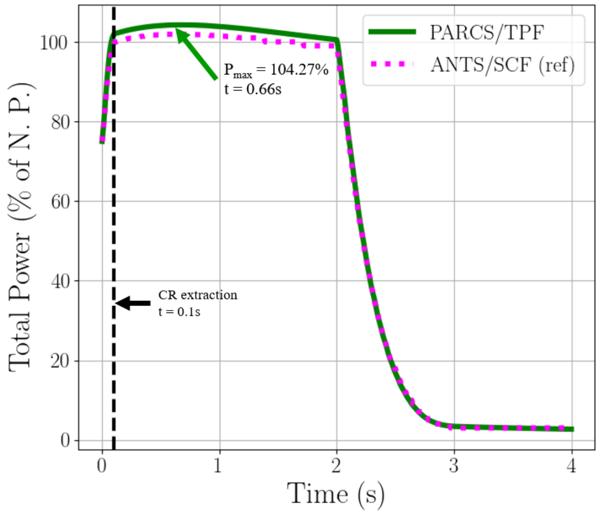
NuScale-like: Rod Ejection Transient Definition

Parameter	Value
Initial core power	75%
Highest CR worth	0.27 $
Ejection duration	0.1s
End of transient simulation	4.0s
Time step	0.001s
Scram start-end	2.0s - 3.0s



NuScale-like: Selected Results

NuScale	PARCS/TPF	ANTS/SCF (ref)	Error
Max. Power (%)	104.27	101.9	2.32*
Critical Boron Concentration (ppm)	1260.0	1228.0	2.60*
Max. Reactivity Insertion (pcm)	167.69	166	1.01*
Fuel Temperature Heat-up (C)	55.0	63.0	8.0**
Min. DNBR	6.23	5.9	5.59*

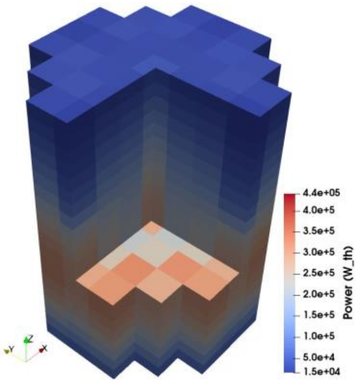


$$*\text{Error}=\frac{|\text{value} - \text{ref}|}{\text{ref}}\text{x}100$$

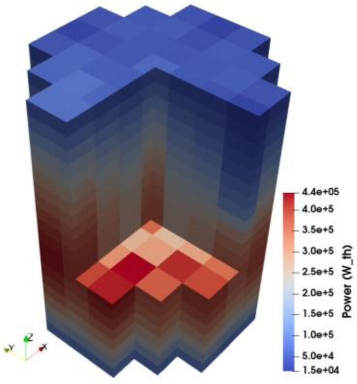
$$**\text{Error}=|\text{value} - \text{ref}|$$

NuScale-like: Selected Results

- Power evolution during the REA



t = 0.0s



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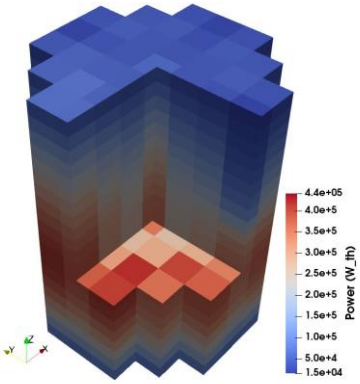
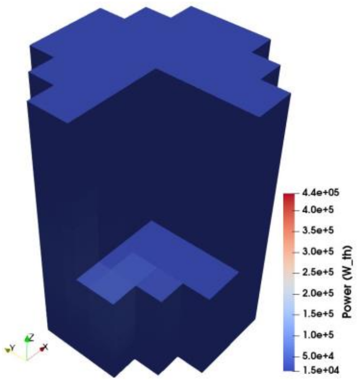


t = 2.0s



t = 3.0s

Summary and Outlook

- Successful coupling of PARCS and TWOPORFLOW based on ICoCo.
- Models for KSMR and NuScale-like SMRs were developed for PARCS and TWOPORFLOW codes.
- PARCS/TPF results were validated with PARCS/SCF for KSMR core.
- PARCS/TPF results were validated with ANTS/SCF for NuScalelike core.

- Future work:
  - Explore the possiblity of pin-by-pin calculations with PARCS/TPF.

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Extra Slides

Computacional Loads

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REA Case	Transient Duration	Time Step	Run Time	Memory Usage
PARCS/SCF KSMR	3 s	0.0005 s	37.6 min	1.5 Gb
PARCS/TPF KSMR	3 s	0.0005 s	34.5 min	1.5 Gb
PARCS/TPF NuScale-like	4 s	0.001 s	3.1 min	192 Mb

FAVOR Technique

- Fractional Area Volume Obstacle Representation

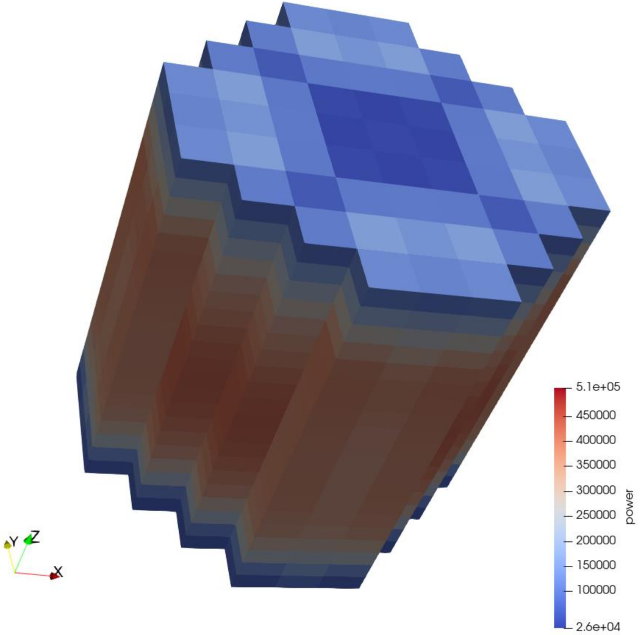
$$\vec{V}_k = \begin{pmatrix} \varphi_x & V_x \\ \varphi_y & V_y \\ \varphi_z & V_z \end{pmatrix}$$

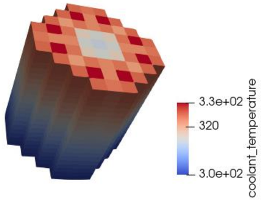
Where,φ is the flow area fraction, x, y, z represent the Cartesian coordinates, and k will become the fluid (l when liquid and v when vapor).

Methodology: PARCS/TPF Data Exchange

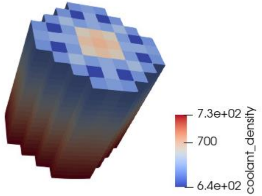
PARCS

TPF

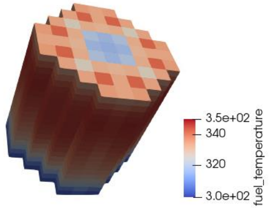




Power distribution

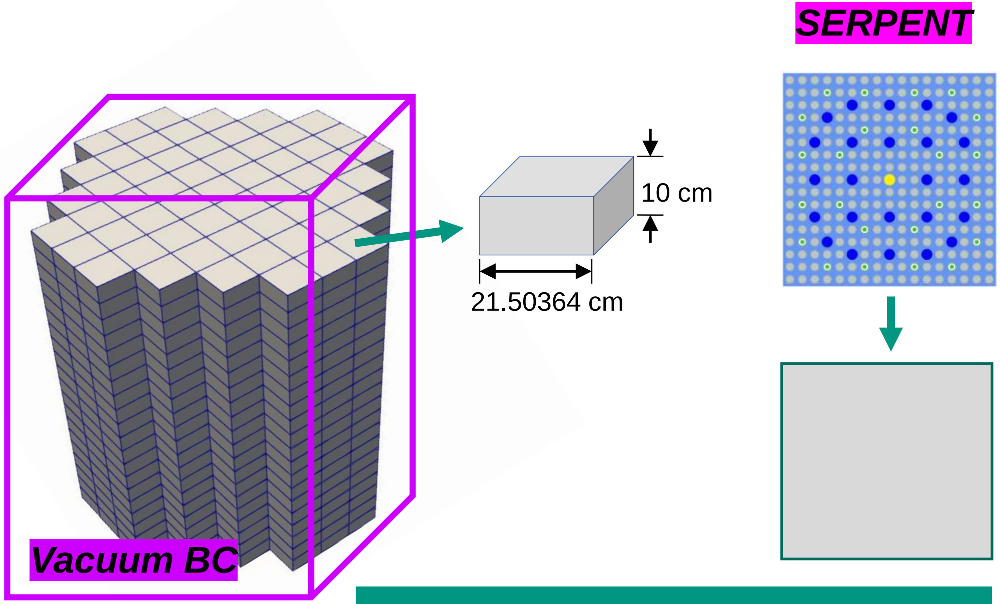


Coolant temp
Coolant density
Fuel temp



PARCS KSMR Core Model

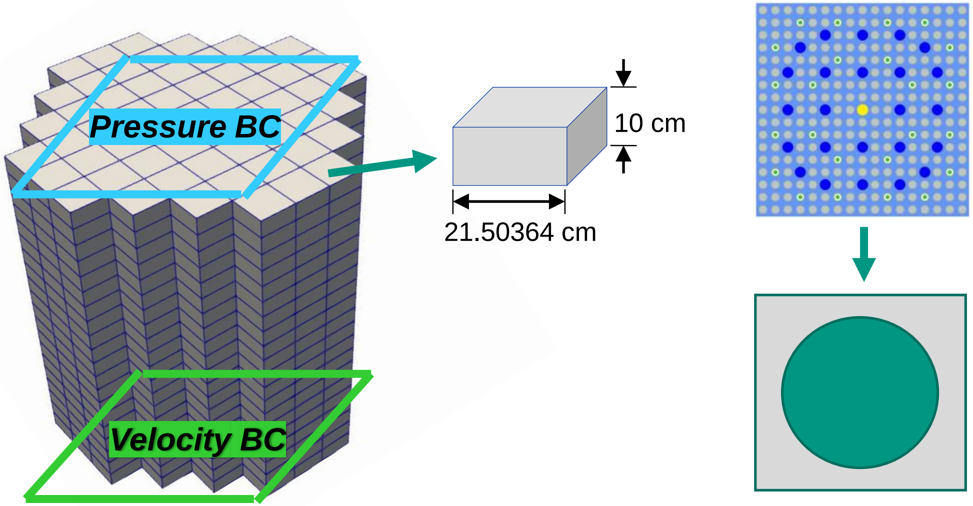
Parameter	Value
XS energy groups	2
PMAXS files • Fuel assemblies • Radial reflectors • Axial reflectors	32 20 10 2
Active length	2 m



- 9x9 radial nodalization (w/o reflector)
- 20 axial levels
- Assembly wise XS homogenization

TPF KSMR Core Model

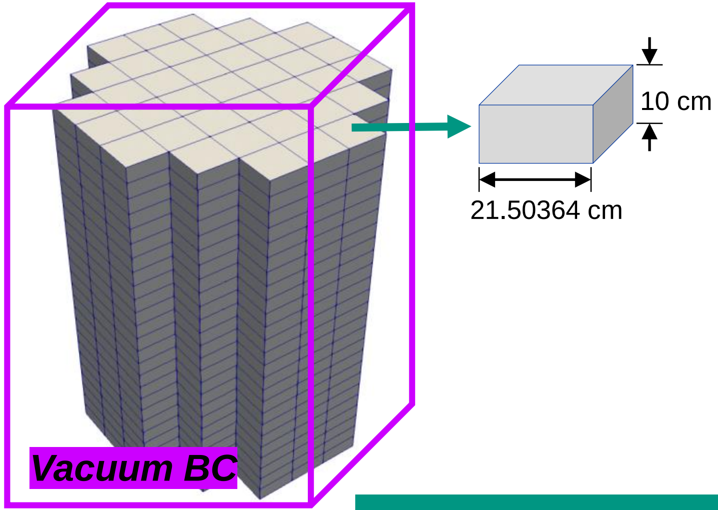
Parameter	Value
Fuel material	UO_2
Cladding material	Zircaloy
Fuel rod OD	9.1404e-3 m
Hydraulic diameter	1.2145e-2 m
X,Y porosities	0.28
Z porosities	0.56

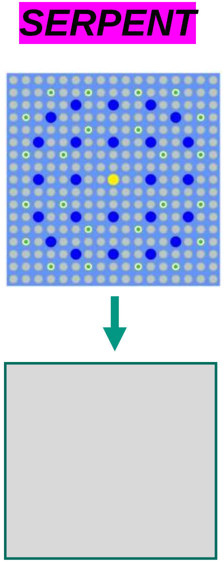


- 9x9 radial nodalization
- 20 axial levels
- Assembly wise rod discretization

PARCS NuScale-like Core Model

Parameter	Value
XS energy groups	2
PMAXS files • Fuel assemblies • Radial reflectors • Axial reflectors	14 6 6 2
Active length	2 m

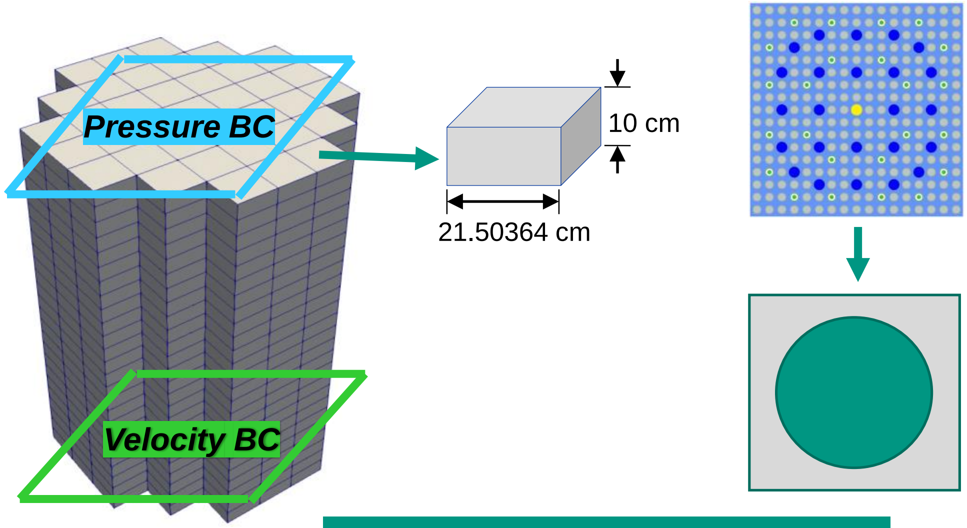




- 7x7 radial nodalization (w/o reflector)
- 20 axial levels
- Assembly wise XS homogenization

TPF NuScale-like Core Model

Parameter	Value
Fuel material	UO_2
Cladding material	M5
Fuel rod OD	9.4996e-3 m
Hydraulic diameter	1.112e-2 m
X,Y porosities	0.18
Z porosities	0.53



- 7x7 radial nodalization
- 25 axial levels
- Assembly wise rod discretization