Karlsruhe Institute of Technology

High-Performance Advanced Methods for Safety Evaluation of Generic Small Modular Reactors

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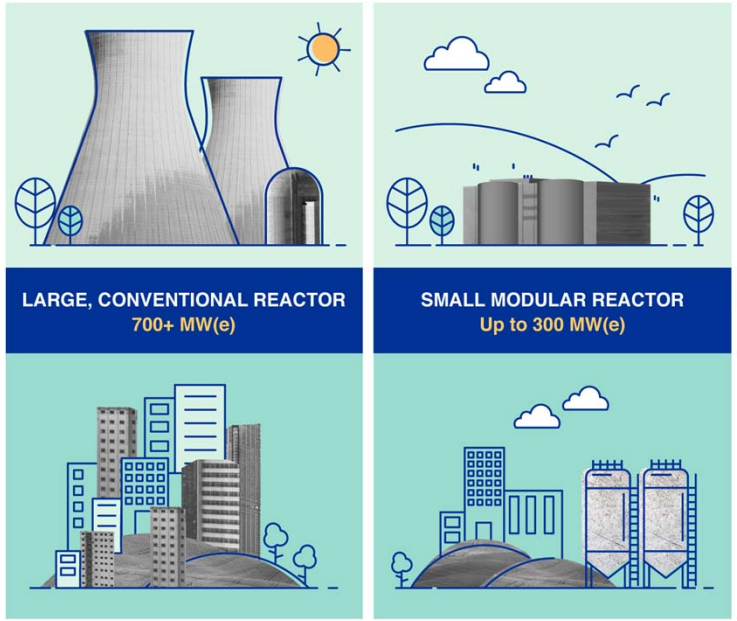
Small Modular Reactors (SMRs)

- **Small**: up to 300 MWe
- **Modular**: systems and components factory-assembled
- **Reactors**: harnessing nuclear fission

- Advantages:
  - Sited on locations not suitable for larger NPP
  - Savings in cost and construction time
  - Deployed incrementally
  - Safety relies more on passive systems and inherent safety characteristics
  - Less frequent refulling (3 – 7 years)



McSAFER technical goals

Technical goals:

- Advance the safety research for water cooled SMR
  - Perform key experiments relevant for SMR-safety (core, helical HX) at EU-facilities (COSMOS-H, MOTEL, HWAT)
  - Develop, improve, validate simulation tools for safety evaluations of SMRs
  - Demonstrate advantages of advanced (multiphysics /multiscale) tools compared to legacy ones
- Apply simulation tools to four SMR-designs (F-SMR, CAREM, NuScale, SMART)

McSAFER scientific approach

Scientific approach:

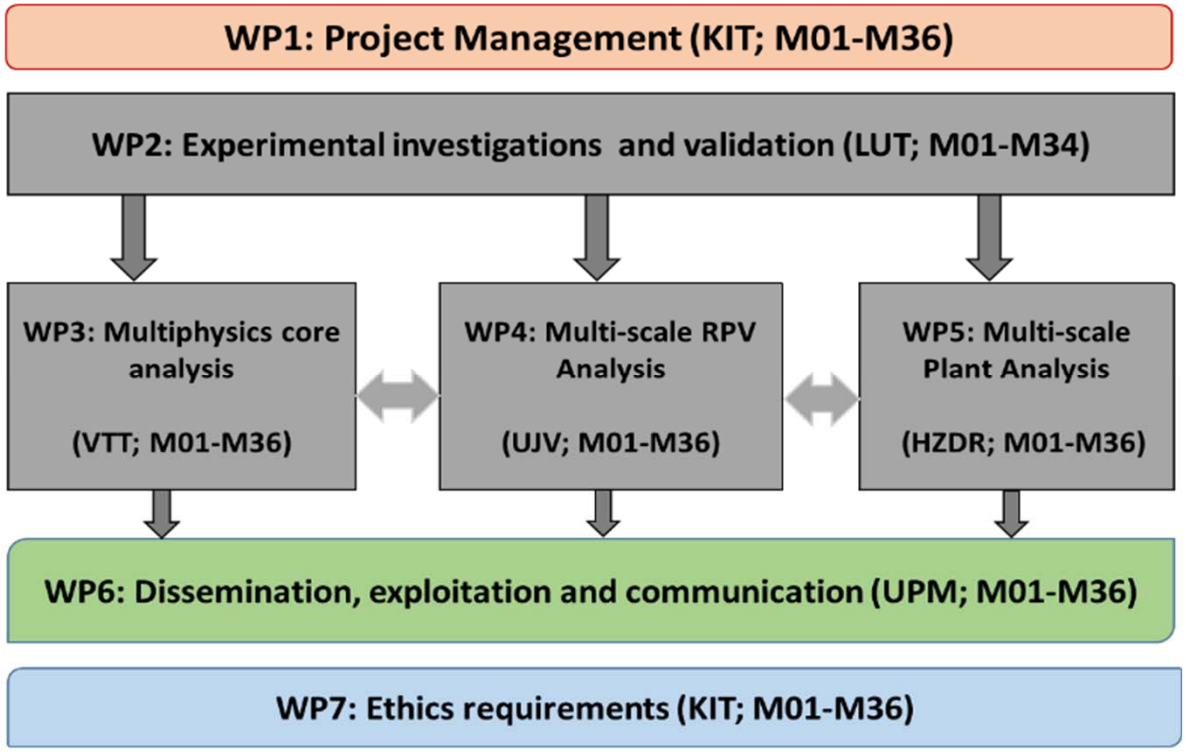
- Combine experimental investigations with numerical tools for safety
- Consider different SMR-designs:
  - Natural circulation: CAREM, NuScale
  - Forced convection: F-SMR, SMART
  - Core design: square (F-SMR, SMART, NuScale) and hexagonal (CAREM) fuel assemblies

McSAFER partners

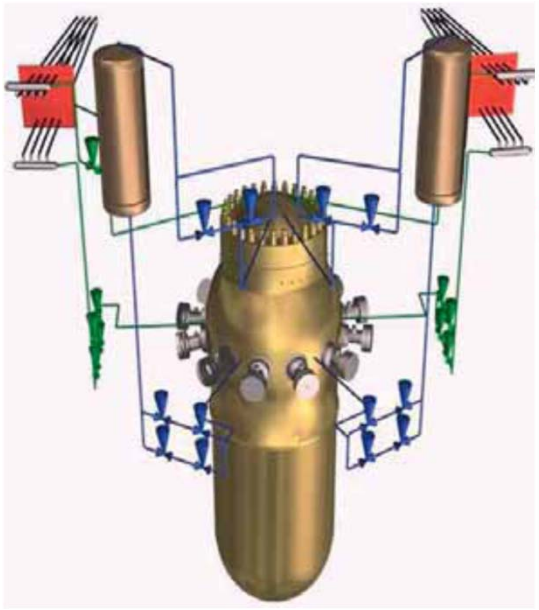
Partners: 13

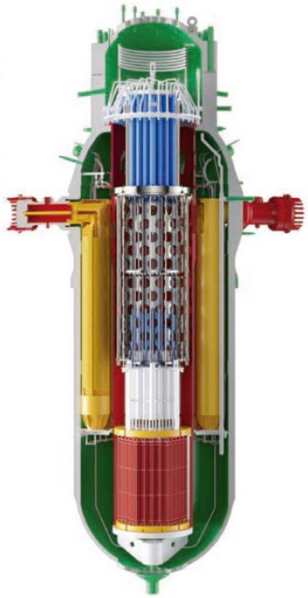
- **R&D:** CEA, VTT, HZDR, UJV, JRC KA, CNEA
- **Universities:** KIT, LUT, UPM, KTH
- **Industry:** Jacobs, TRACTEBEL, PEL

McSAFER work packages



SMR designs under investigation

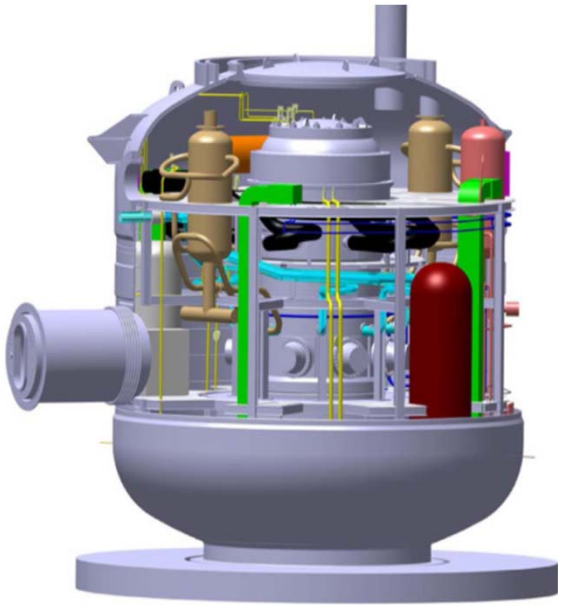


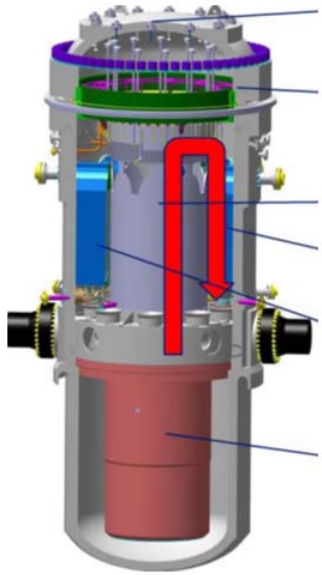


CAREM

Ch. Marcel; CAREM-25: A safetr innovative Small Nuclear Power Plant. Nuclear Revista Espanha 1, Enero 2017.

IAEA-2012: Status of Small and Medium sized Reactor Designs. A supplement to the IAEA Advanced Reactor Information System (ARIS)

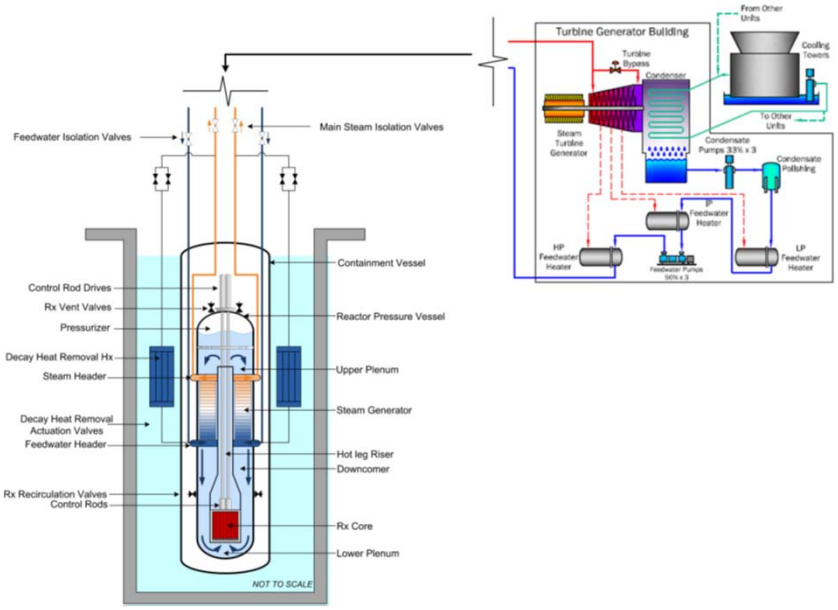




F-SMR

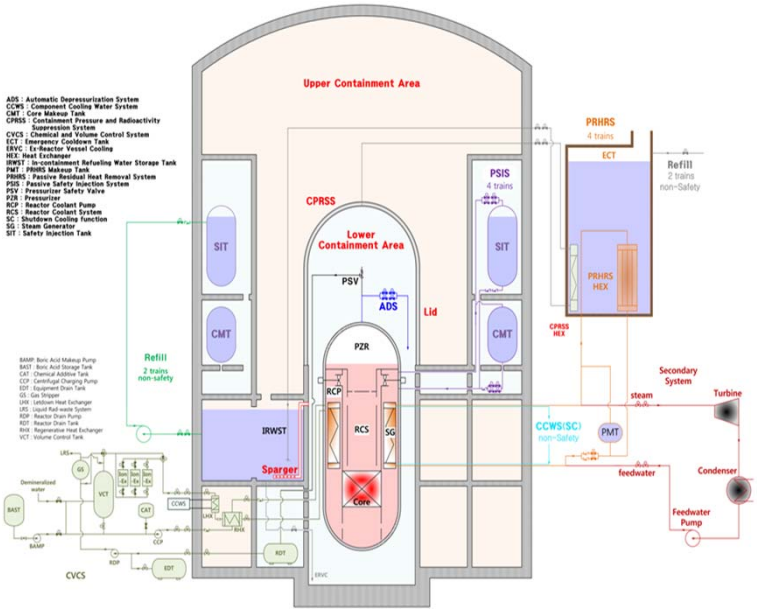
J. Chenais, M. Brun; SMR/The French Approach. IAE SMR Technical woreking group meeting. Vienna, July 8-11. 2019

SMR designs under investigation



NuSCALE

NuScale Plant Design Overview Revision 2. NP-ER-0000-1198-NP. September 16 2013. NuScale Power LLC.

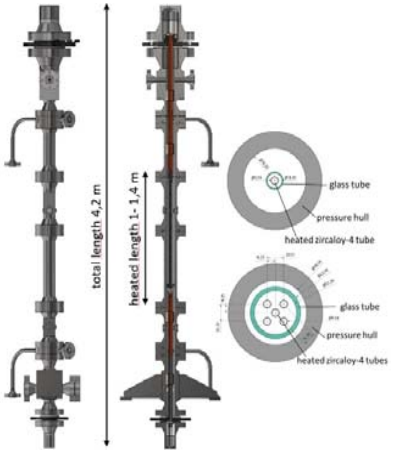


SMART

Source: BAE, KYOO HWAN "*Safety Analysis for the Major DBAs in Passive PWR SMART*", 28-29 June 2018

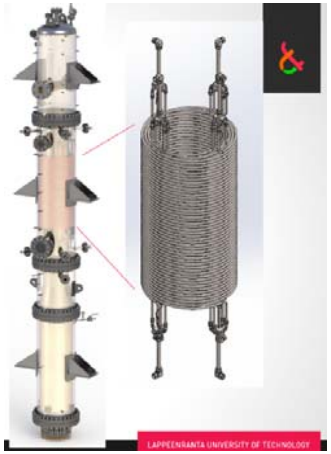
WP2 key experimental investigations & validation

- Validation matrix: CFD, subchannel, and system thermal hydraulics codes



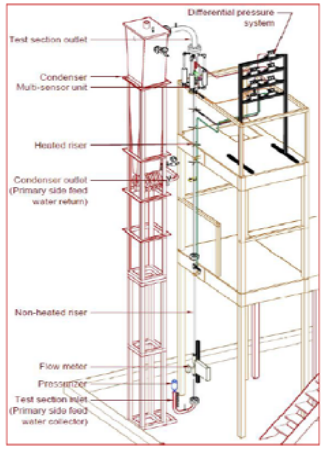
COSMOS-H (KIT)

Codes	COSMOS-H		
	KIT	LUT	UJV
CFD	CFX	OpenFOAM	CFX
SubCH	SCF		VIPRE
SysTH	TRACE		RELAP3D



MOTEL (LUT)

Codes	MOTEL				
	KIT	LUT	UJV	UPM	TBL
CFD	CFX		FLUENT		
SubCH			VIPRE		COBRA-TF
SysTH		APROS		TRACE	



HWAT (KTH)

Codes	HWAT	
	KTH	UPM
CFD	OpenFOAM	
SubCH		
SysTH	GOTHIC/TRACE	TRACE

WP3,-4,-5 McSAFER numerical tools

Core analysis (Static /transient)

- Traditional with system code and point kinetics
  - **RELAP5, ATHLET, TRACE**
- 1D system code + 3D nodal diffusion
  - **TRACE/PANTHER**
  - **TRACE/PARCS**
- Low order transport + subchannel codes
  - **PARCS-SP3/Subchanflow (SMART)**
  - **APOLLO3/FLICA (F-SMR)**
  - **WIMS/ARTHUR (NuScale)**
  - **DYN3D-SP3/Subchanflow (NuScale)**
- High-fidelity MC + subch + TM codes
  - **SERPENT2/Subchanflow/TU**

- 1D system TH code + PK
  - **TRACE**
  - **ATHLET**
  - **RELAP5-3D**
- 3D system TH-code + Subchannel code
  - **TRACE/Subchanflow**
  - **TRACE/ARTHUR**
- 3D system TH + CFD code
  - **TRACE/SCF/OpenFOAM**
  - **ATHLET/TrioCFD**
  - **ATHLET/FLUENT**

- 1D system TH code + 3D nodal diffusion
  - **TRACE/PARCS (KIT)**
  - **TRACE/PANTHER (TRACTEBEL)**
  - **TRACE/ANTS (VTT)**
  - **ATHLET/DYN3D (HZDR, UJV)**
- 3D system TH-code + Subchannel code + 3D nodal diffusion
  - **TRACE/PARCS/SCF (KIT)**
  - **TRACE/WIMS/ARTHUR (JACOBS)**
- 3D system TH code + 3D nodal diffusion + CFD code
  - **TRACE/PARCS/OpenFOAM (KIT)**
  - **ATHLET/DYN3D/TrioCFD (HZDR)**
  - **TRACE/ANTS/OpenFOAM (VTT)**
  - **ATHLET/FLUENT/DYN3D (UJV)**

WP3 Scenarios:

- **REA: NuSCALE / SMART**
- **Cold water insertion: CAREM / F-SMR**

WP4 Scenarios:

- **NuSCALE: Boron Dilution**
- **SMART: ATWS**

WP5 Scenarios:

- **NuSCALE: MSLB**
- **SMART: MSLB**

WP6 education & training, dissemination

- Training courses:
  - First training course on SMR Technologies: January 25-27.2021: UPM
    - Participants: 194
  - Second training course on neutronics / thermal hydraulics for SMR in March 22-24, 2022): LUT
    - Participants: 44
  - Upcoming: MOOC course on multiphysics simulations applied to SMR (March 2023): UPM
- All publications of the McSAFER project are published “open access”.
- Communication tools: https://mcsafer-h2020.eu/

INNOPOOL Project

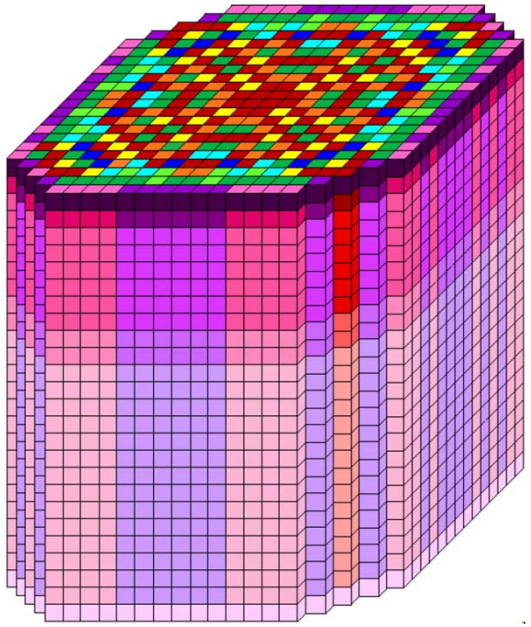
- **KIT: development and validation of two in-house codes**

PARAFISH

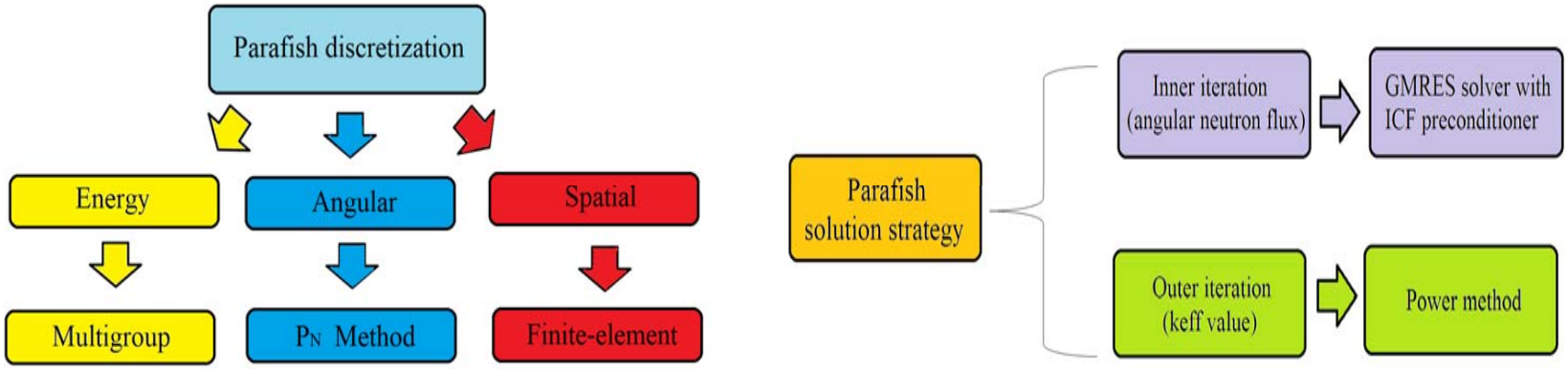
TWOPORFLOW

PARAFISH code

- **PARA**llel **FI**nite-element **S**pherical **H**armonics
- Neutron transport code
- Steady-state calculation
- 2D and 3D Cartesian geometry
- Parallel calculation

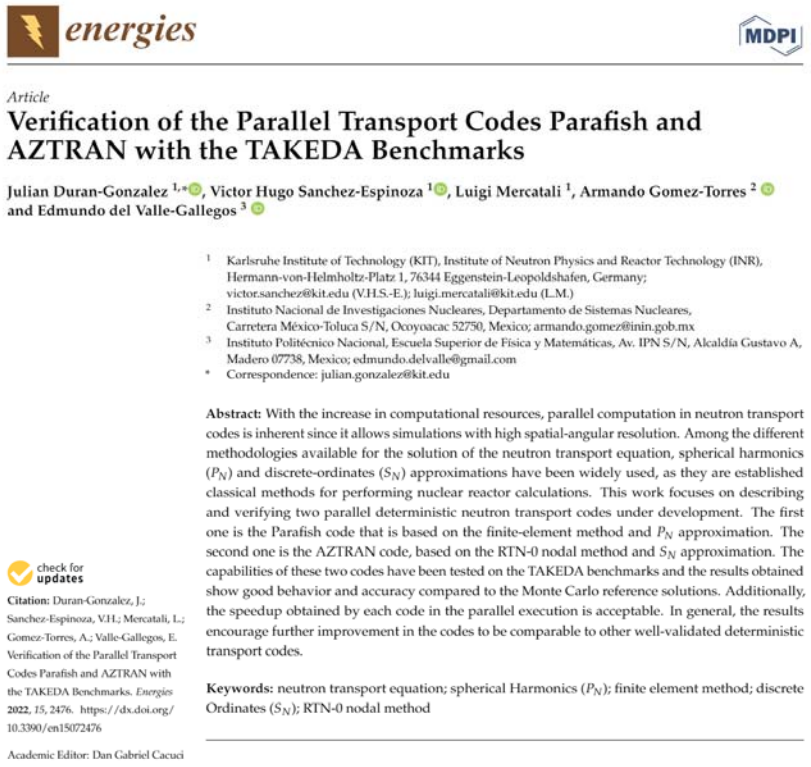


PARAFISH solution strategies



PARAFISH activities

- Maintainance and update of the source code.
- Enhance user interface.
- Verification with benchmarks.



energies

MDPI

Article

Verification of the Parallel Transport Codes Parafish and AZTRAN with the TAKEDA Benchmarks

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Abstract: With the increase in computational resources, parallel computation in neutron transport codes is inherent since it allows simulations with high spatial-angular resolution. Among the different methodologies available for the solution of the neutron transport equation, spherical harmonics (P_N) and discrete-ordinates (S_N) approximations have been widely used, as they are established classical methods for performing nuclear reactor calculations. This work focuses on describing and verifying two parallel deterministic neutron transport codes under development. The first one is the Parafish code that is based on the finite-element method and P_N approximation. The second one is the AZTRAN code, based on the RTN-0 nodal method and S_N approximation. The capabilities of these two codes have been tested on the TAKEDA benchmarks and the results obtained show good behavior and accuracy compared to the Monte Carlo reference solutions. Additionally, the speedup obtained by each code in the parallel execution is acceptable. In general, the results encourage further improvement in the codes to be comparable to other well-validated deterministic transport codes.

Keywords: neutron transport equation; spherical Harmonics (P_N); finite element method; discrete Ordinates (S_N); RTN-0 nodal method

check for updates

Citation: Duran-Gonzalez, J.; Sanchez-Espinoza, V.H.; Mercatali, L.; Gomez-Torres, A.; Valle-Gallegos, E. Verification of the Parallel Transport Codes Parafish and AZTRAN with the TAKEDA Benchmarks. *Energies* **2022**, *15*, 2476. https://dx.doi.org/10.3390/en15072476

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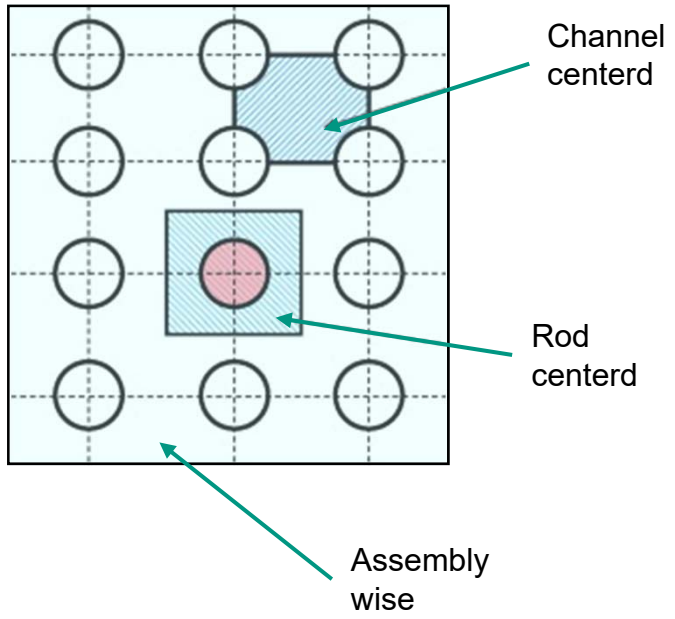
TwoPorFlow code

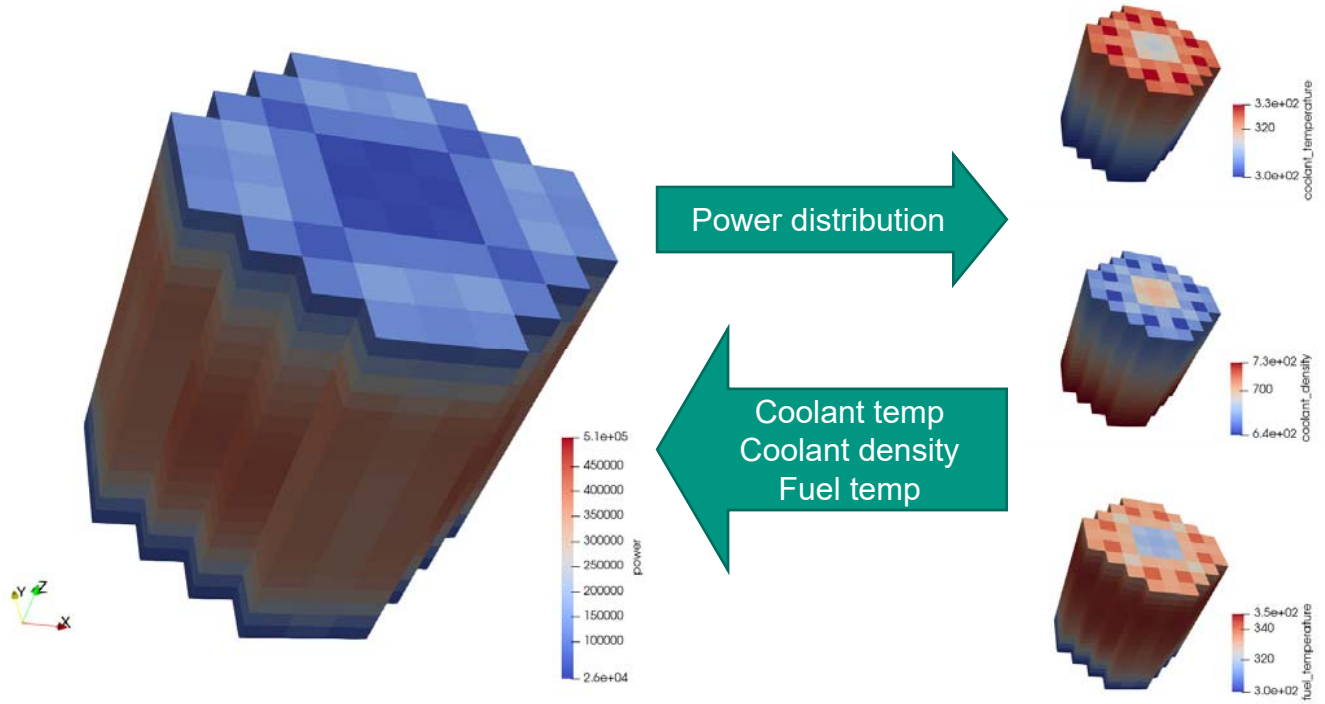
- Thermal-hydraulics code
- Porus-media forced convection
- Sub-channel fuel assembly simulations
- Steady-state and transient solution
- Two-phase flow (6 equations)
- 3D conservation equations
- 2D heat conduction model for fuel rods
- Coarse Cartesian grids
- ICoCo for coupling



NT/TH coupling

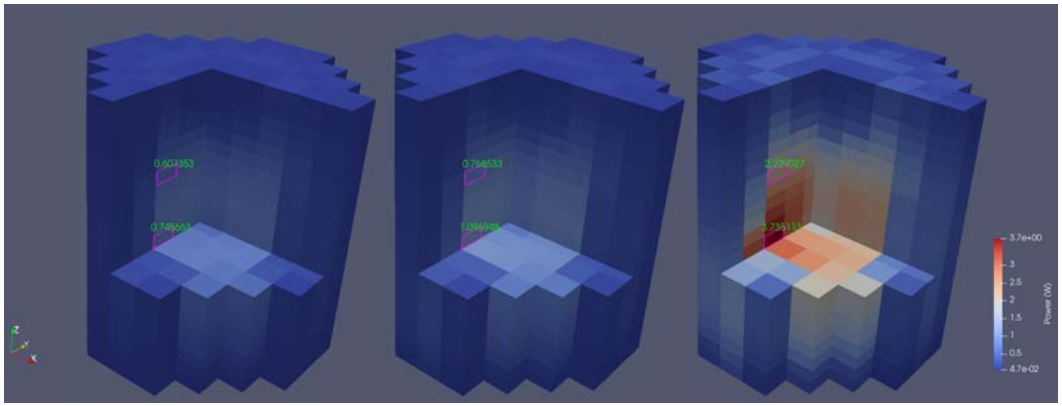
Neutronics (PARCS)

Thermal-hydraulics (TPF)

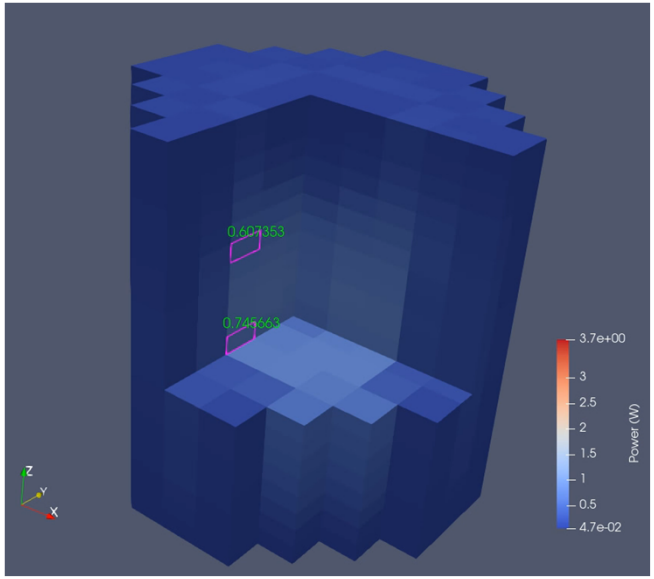


Results

Cell power evolution



0.0 s 0.05 s 1.0 s



Future work

- McSAFER Project:
  - Code to code comparisons
  - Verification and Validation with experimental data

- Innovation Pool Project:
  - Extend Parafish code to transient calculations
  - Implement NEMTAB XS's format to Parafish
  - Extend PARCS/TPF coupling with a system code (TRACE)
  - Extend TPF models to post-CHF conditions

  - Couple PARAFISH with TWOPORFLOW