# KIT Safety Research Activities for LWR, LW SMR and Research Reactors


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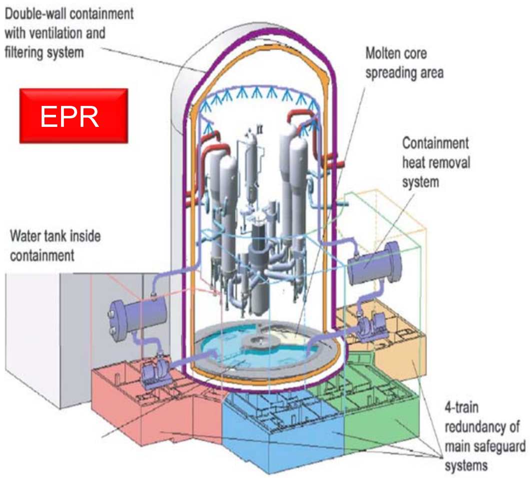
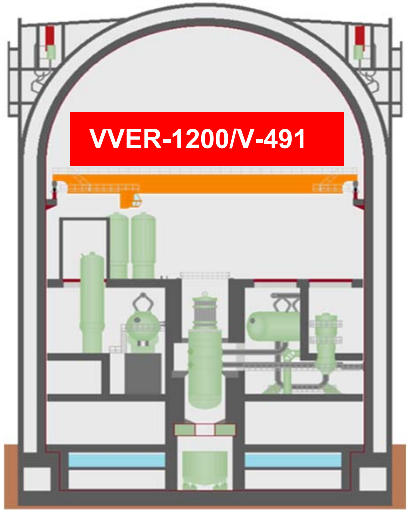
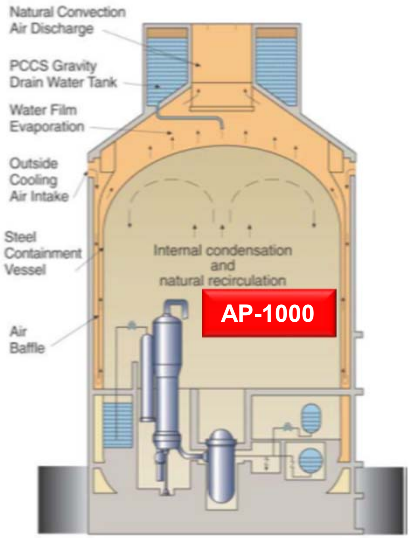
# Outline

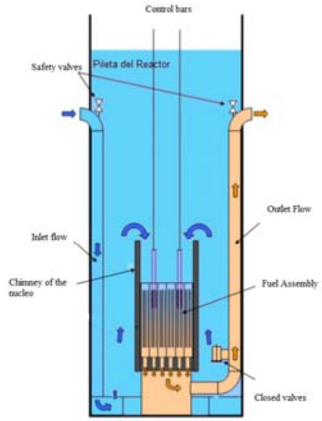
- Motivation
- Challenges for core and plant analysis
- KIT solution approach
- Selected results
- Final remarks

# Motivation: Nuclear Technology Developments

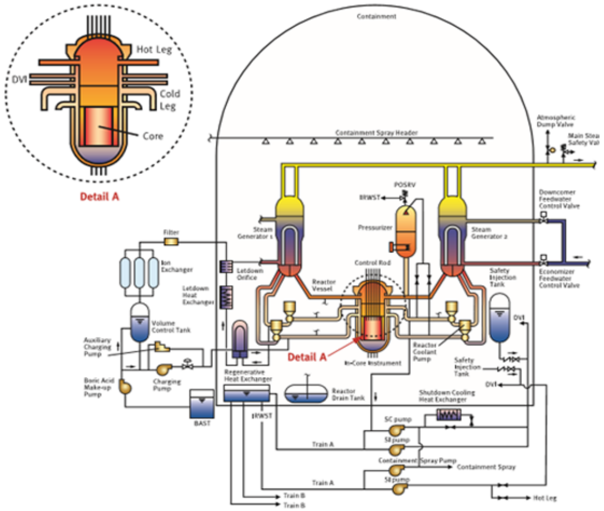


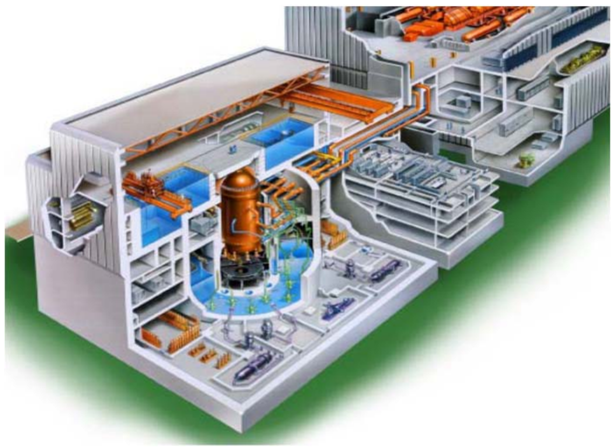



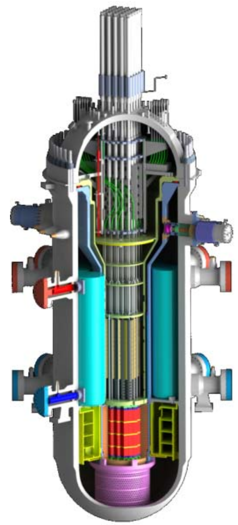

RR with MTR-Fuel




APR1400



GE ABWR

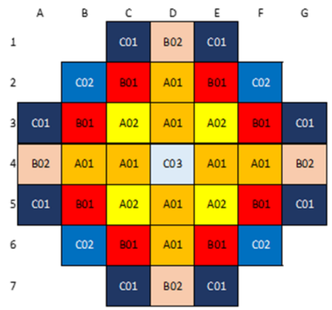


SMR SMART

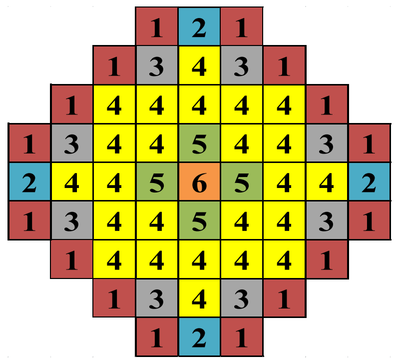
# Challenge I: Core Physics (Example SMR)

- Compactness
- Small size (H and D)
- Heterogeneity (radial, axial)
- High leakage
- Harder spectrum
- Complex control rod designs
  - Different types
  - Axial heterogeneity
- Increased role of reflector
- Boron free cores:
  - Need innovative control rod design
  - Optimized shutdown reactivity
  - Reduced reactivity swing over the cycle
  - Etc.

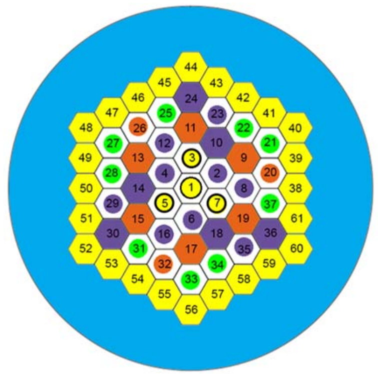
NuScale



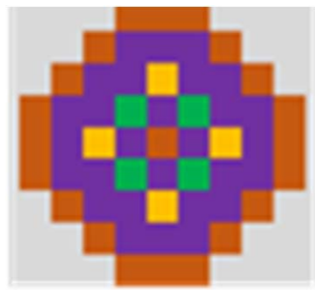

KIT KSMR-Core



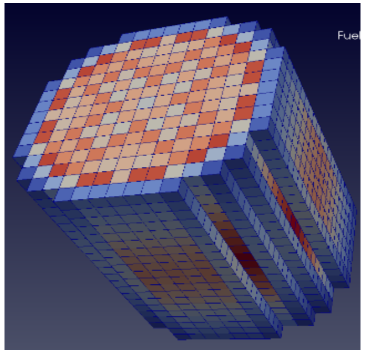

CAREM-Like core



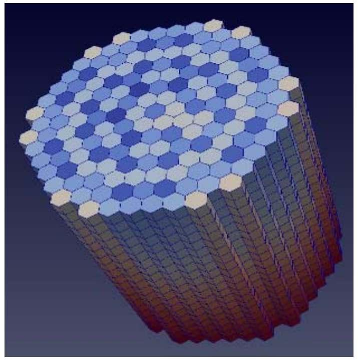
FSMR Core



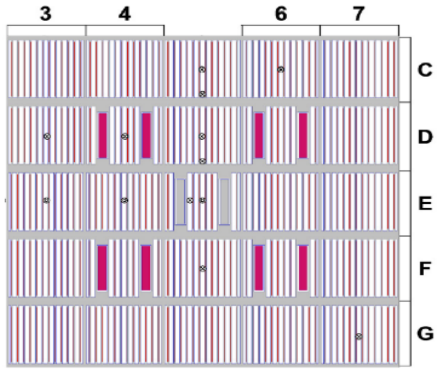
# Challenge II:
# Core Thermal Hydraulics (SMR, PWR, VVER, MTR)



**PWR Core**

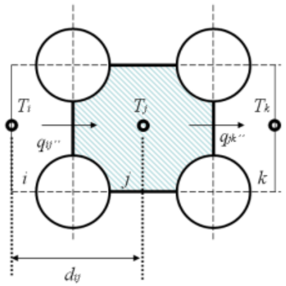


**VVER Core**




**Research Reactor Core: MTR**

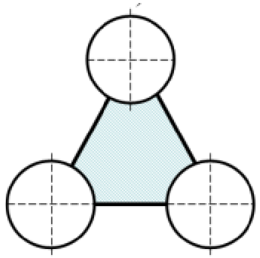
Thermal hydraulics:




**Square subchannel**

**Cross flow**

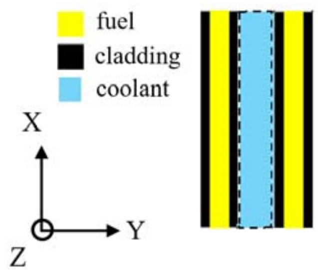
**Cylindrical fuel**



**Triangular subchannel**

**Cross flow**

**Cylindrical fuel**



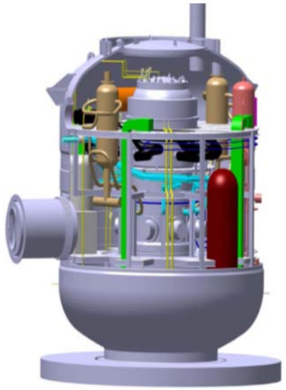

**Narrow rectangular subchannel**

**No cross flow**

**Plate fuel**

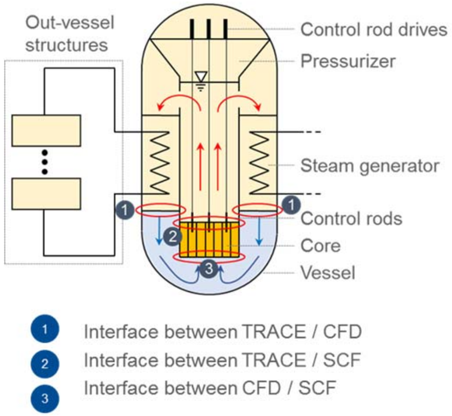
# Challenges III: Plant Thermal Hydraulics ( e.g. SMR)

- SMR with integrated RPV



**NUWARD Design**

**Multi-scale/-physics coupling**




**EU McSAFER approach**

## Challenges:

- Many components located inside the RPV
  - Pumps: e.g. SMART (8)
  - Helical HX e.g. SMART(8), CAREM (12)
  - Compact plate-type HX
  - PZR
- Structures enhance mixing
  - SMART, NUWARD, CAREM, etc.

## Consequences:

- Perturbed 3D flow patterns inside RPV
- Core TH: cross flow, CHF
- Natural circulation flow /forced convection transition

Remarks:

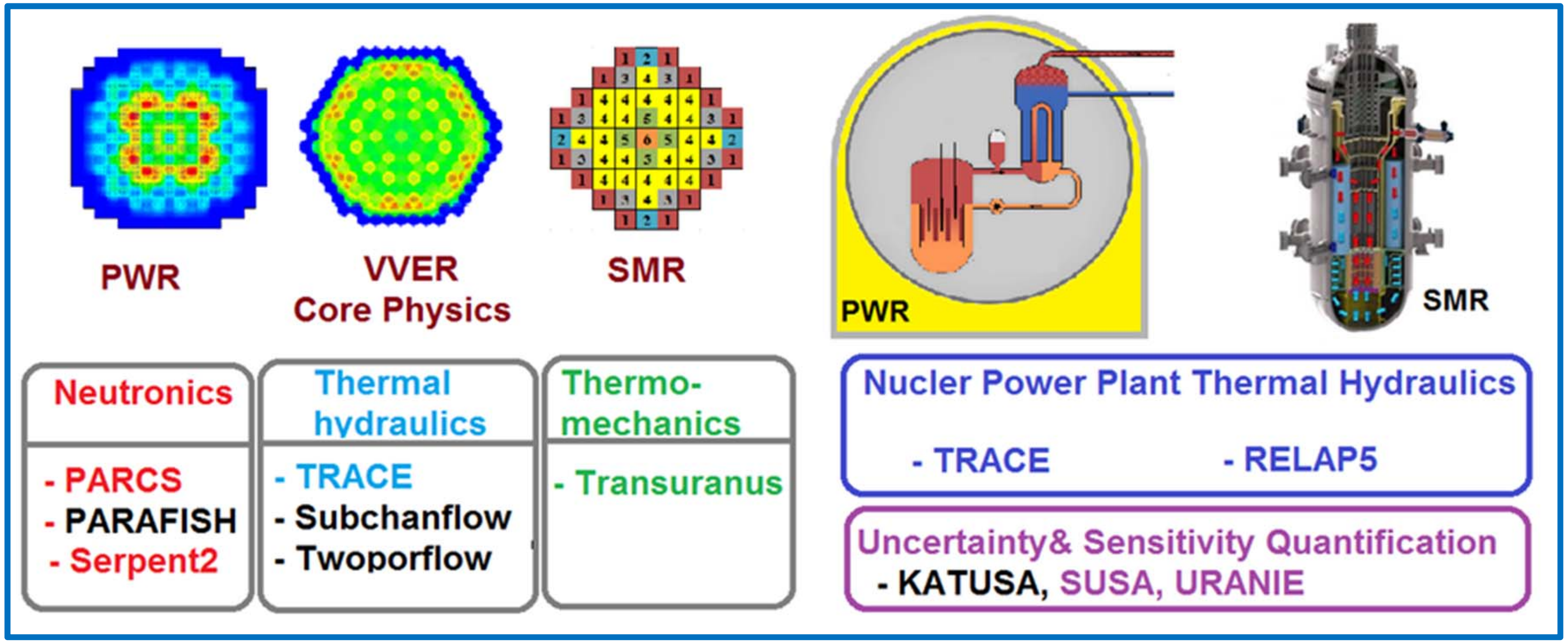
- 1D TH codes not appropriate
- Experimental data exist but proprietary (SMR developers)
- Public exp. Data for SMR scarce

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

# KIT Solution approach

- **Combination of in-house cores (SCF, TPF) with external codes like PARCS, Serpent, TRACE to improve core and plant analysis**

Multi-physics and multi-scale developments for core analysis and safety

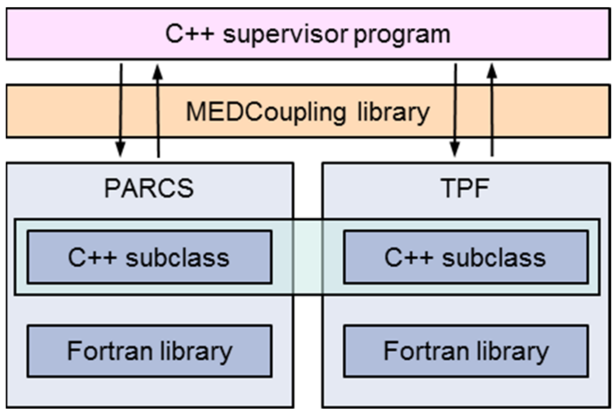



**In-house: PARAFISH, SUBCHANFLOW, TWOPORFLOW, KATUSA**

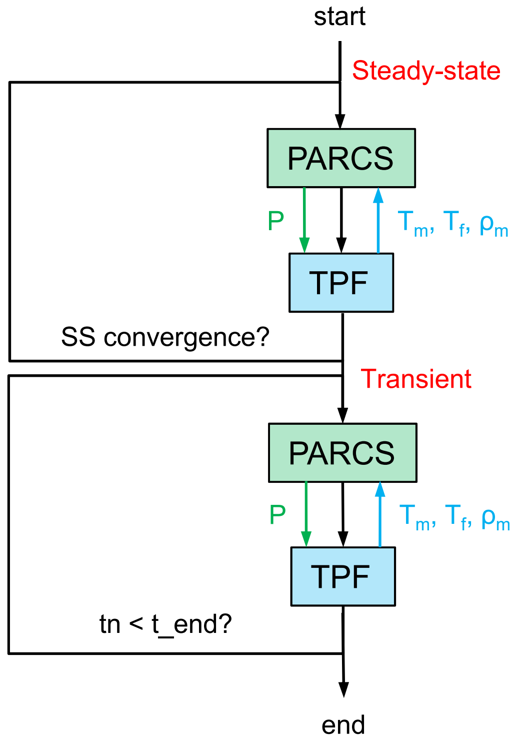
# KIT: Multi-physics Approach for Core Analysis

- Modular and flexible coupling (ICoCo):
  - SUBCHANFLOW/PARCS, TWOPORFLOW/PARCS
  - PARAFISH/TWOPORFLOW
  - SUBCHANFLOW/Serpent2 (dynamic capability)

- Multi-physics core analysis

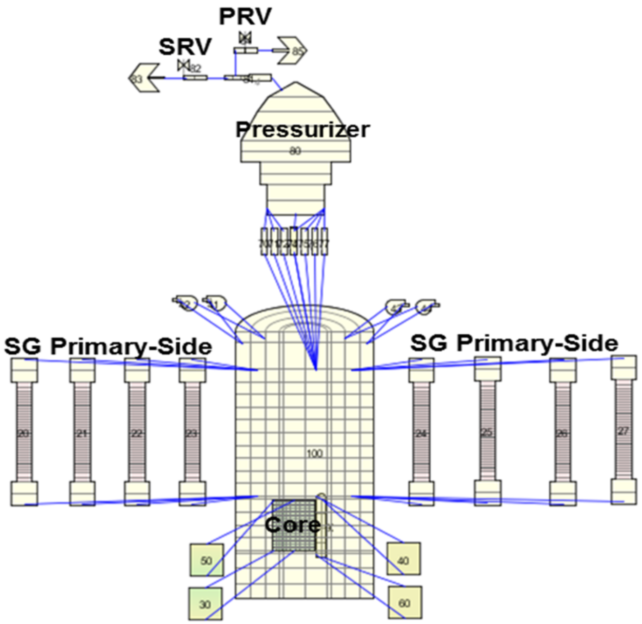



**ICoCo-Based Coupling**

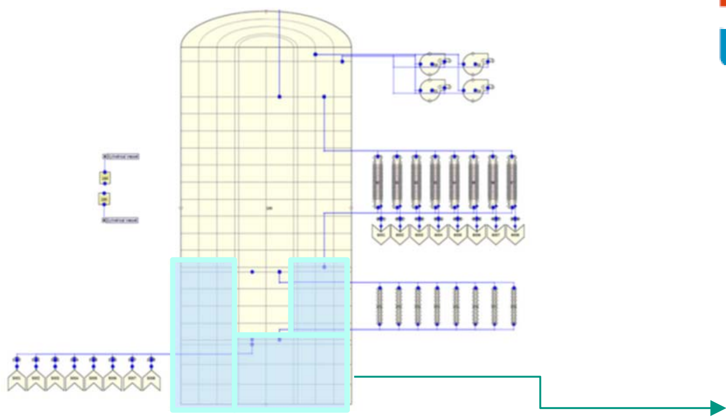



**Flowchart of PARCS/TPF Coupling (Explicit OS Picard Iteration)**

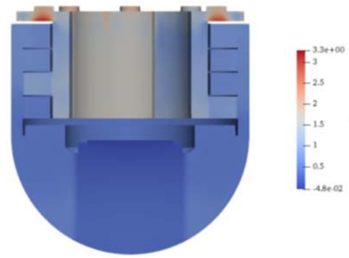
# Plant analysis:
# Multi-scale/-physics Coupling based on ICoCo:




TRACE Domain: Core + RPV + Plant



TRACE Domain: Core + RPV

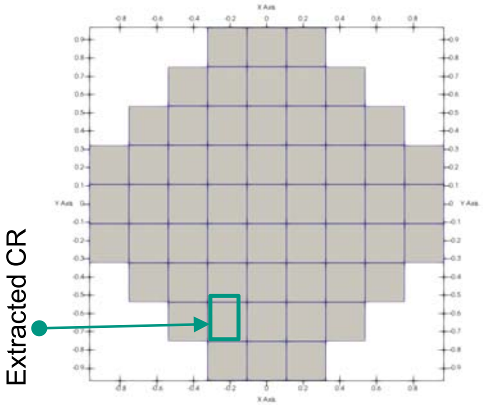


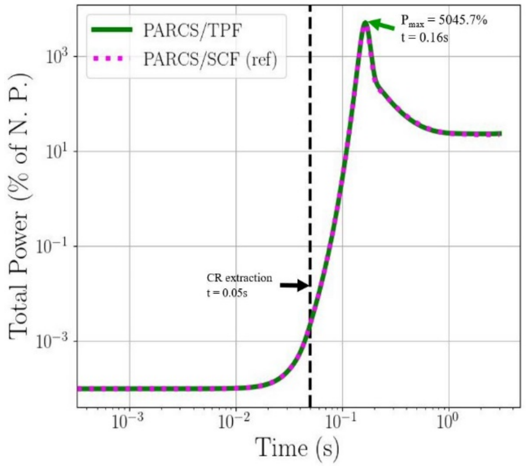
OpenFOAM Domain

- **McSAFER Solutions:**
  - KIT: TRACE-OpenFOAM/PARCS (ICoCo)
  - HZDR: ATHLET/TrioCFD/DYN3D (ICoCo)
  - UJV: ATHLET/FLEUNT/DYN3D (user defined functions)
  - VTT: TRACE/OpenFOAM/ANTS (Cerverus)

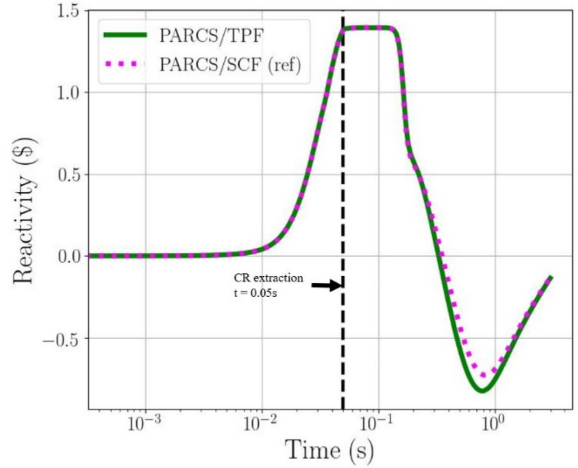
# KSMR: REA Analysis at HZP at Nodal Level

- REA at Hot zero power (HZP)
- CR worth of extracxted rod: 0.725 $



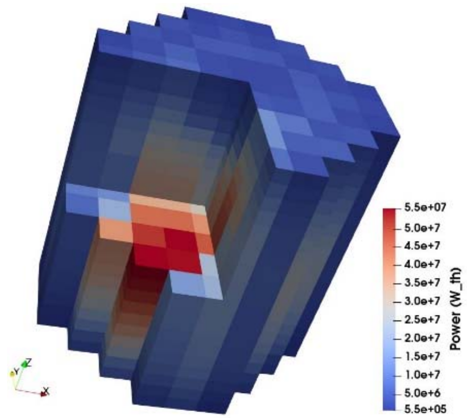




REA: Total power evolution




REA: Total reactivity

| Parameter | Value |
|---|---|
| Initial core power | 1.0E-4 % |
| Highest CR worth | 1.45 $ |
| Ejection duration | 0.05 s |
| End of transient simulation | 1.0 s |




REA: 3D power distribution

**Coupling of PARCS with in-house codes: SUBCHANFLOW (SCF) and TWOPORFLOW (TPF)**

# High Fidelity Transient Core Analysis: Pin Level

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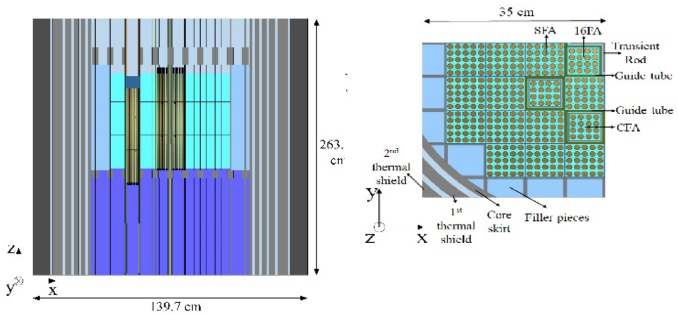
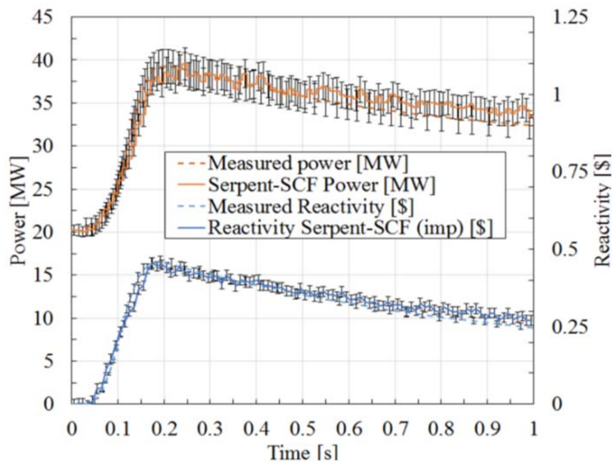
- **Validation of Serpent2/SCF dynamic capability:** SPERT-IV REA Tests 84

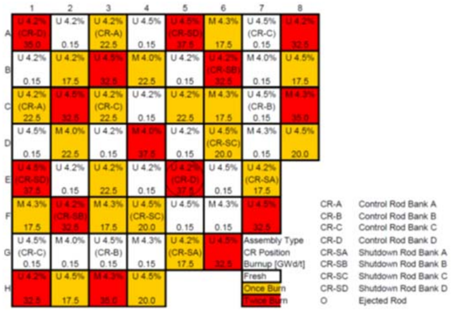



## SPERT/IV REA Test



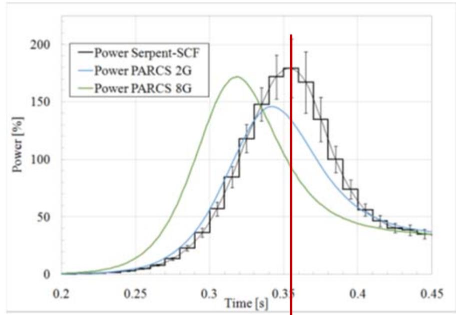

**REA Test 84: comparison Data/prediction**

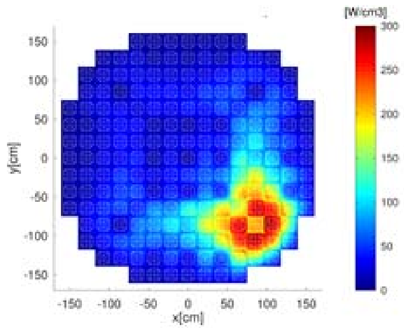
- PWR UOX/MOX REA HZP Analysis: **Serpent2/SCF**
  - o **Application: pin/subchannel level full core**




**WE PWR UOX/MOX core**

**SSS2/SCF: Power evolution**



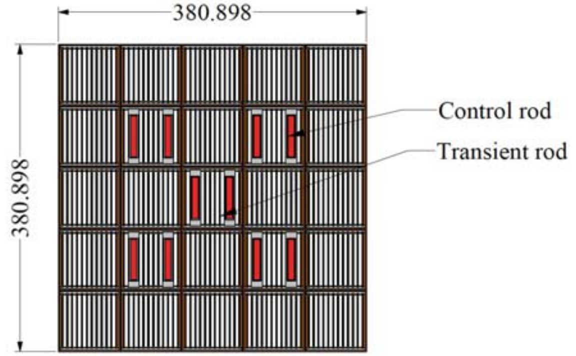




**SSS2/SCF: Power density pin-wise**

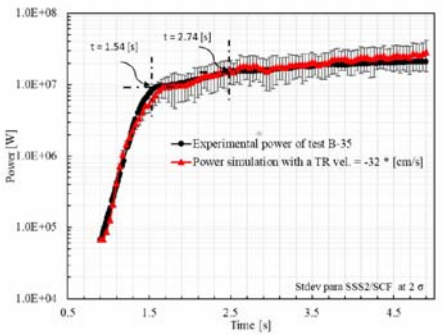
- **CPU time**: 122 h using 1280 processors

# High fidelity
# Analysis of MTR-Transients (Plate/subchannel level)

- **Validation of SSS2/SCF dynamic capability:** SPERT-IV D12-25 REA B-35




**MTR Core Configuration**
Model: 270 (N/TH)
- SSS2: plate-wise
- SCF: subchannel

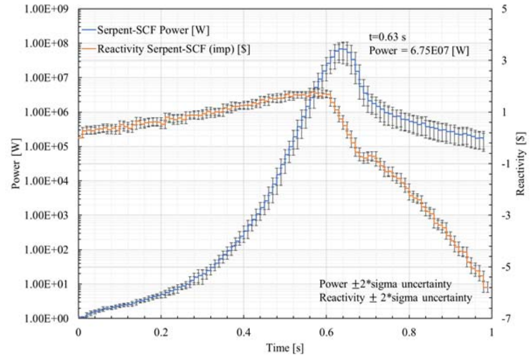



**SSS2/SCF: Data vs. Prediction Total power evolution after REA**
- **CPU time**: 60 h for 5 s using hybrid MPI/OpenMP (2x2) Cores

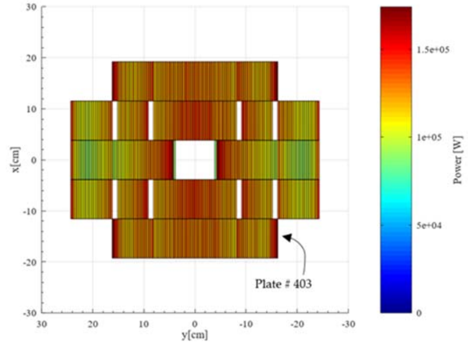
- **Analysis** of IAEA MTR RIA Benchmark with **SSS2/SCF**

| | A | B | C | D | E | F |
|---|---|---|---|---|---|---|
| 1 | Water | Graphite | Graphite | Graphite | Graphite | Water |
| 2 | Water | SFA BOL 5% | SFA BOL 25% | SFA BOL 25% | SFA BOL 5% | Water |
| 3 | SFA BOL 5% | CFA BOL 25% | SFA BOL 45% | SFA BOL 45% | CFA BOL 25% | SFA BOL 5% |
| 4 | SFA BOL 25% | SFA BOL 45% | SFA BOL 45% / H2O + Al | H2O + Al / SFA BOL 45% | SFA BOL 45% | SFA BOL 25% |
| 5 | SFA BOL 5% | CFA BOL 25% | SFA BOL 45% | SFA BOL 45% | CFA BOL 25% | SFA BOL 5% |
| 6 | Water | SFA BOL 5% | SFA BOL 25% | SFA BOL 25% | SFA BOL 5% | Water |
| 7 | Water | Graphite | Graphite | Graphite | Graphite | Water |

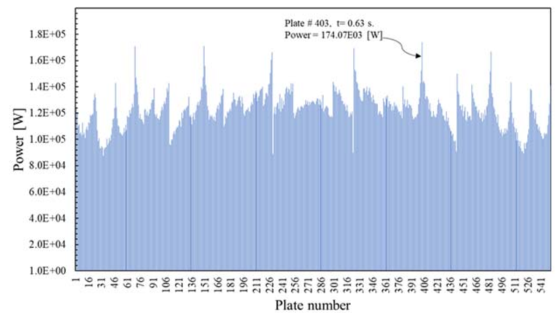
**Model: 552 N/ 552 NTH**
- SSS2: plate-wise
- SCF: subchannel




**SSS2/SCF: Power / Reactivity evolution for fast RIA (1.5$/0.5 s)**




**SSS2/SCF: Radial plate power**




**SSS2/SCF: identification of highest/lowest power of fuel plates**

- **CPU time**: 18 h for 5 s using 48 OpenMP cores

# Final remarks

Karlsruhe Institute of Technology

- High fidelity solutions (pin/subchannel and plate/subchannel) take profit of HPC-clusters of KIT
- Novel MC-based transient analysis applied to PWR, VVER, and MTR
- Multi-scale methods succesfully applied LWR-SMR (McSAFER)
- Strategic cooperations key for success!