The H2020 McSAFER: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors

Harmonise: Workshop on the Safety of Small Modular, Advanced and Fusion Reactors

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June 20-21, 2023, Celje, Slovenia

This project has received funding from the Euratom research and training programme 2019-2020 under grant agreement No 945063.

Content

- Goals and scientific approach
- Work packages, partners
- Challenges, solution approach, status
- Conclusions
- Dissemination

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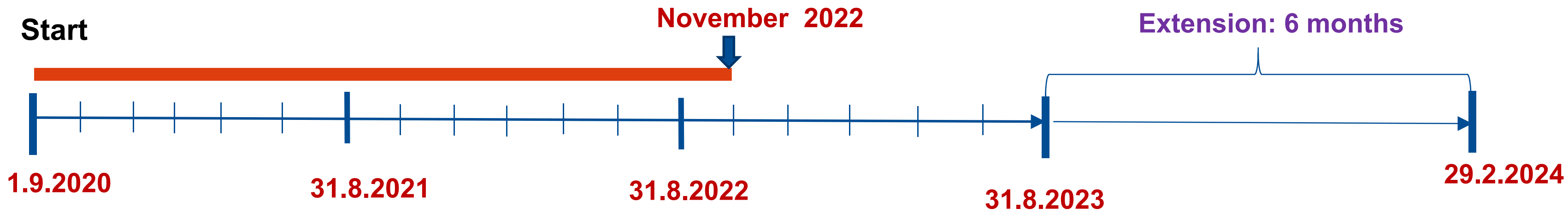
Technical Goals & Scientific approach

- Contribute to safety research for water cooled SMR
- Perform key thermal hydraulic experiments at three European facilities
- Develop and improve simulation tools for safety analysis of SMRs
- Validate thermal hydraulic tools using data generated in McSAFER
- Analyse the core and plant behaviour of selected SMR-designs under transient conditions
- Demonstrate advantages of multi-physics/-scale tools compared to industry-like tools

Scientific approach: Combine experimental investigations and numerical simulations

Project Timeline:



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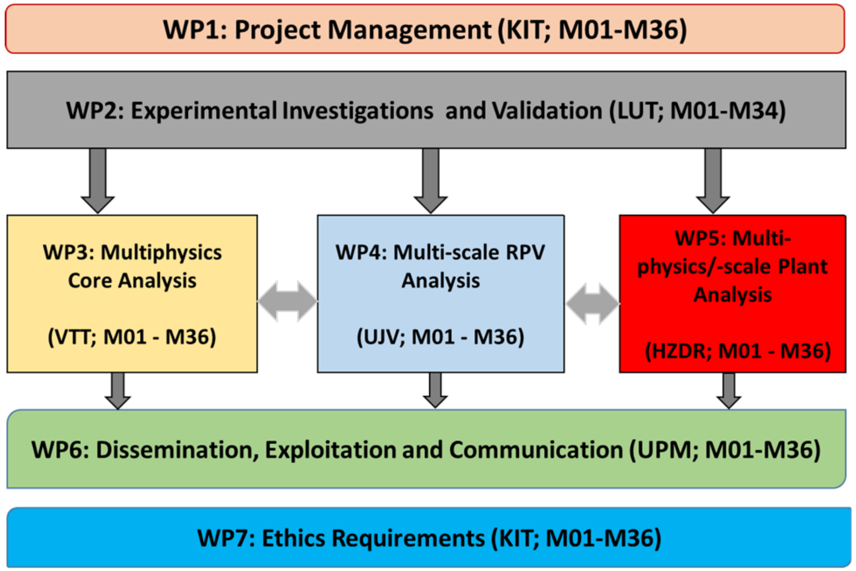
McSAFER: Work Packages, Partners



McSAFER: Work Package Structure

Universities

R&D, TSOs

Industry

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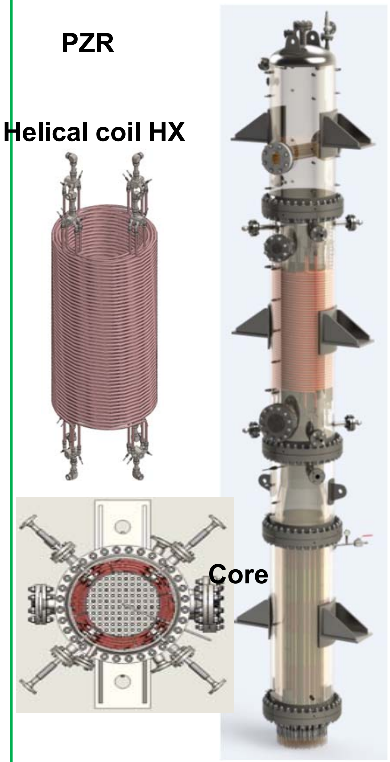
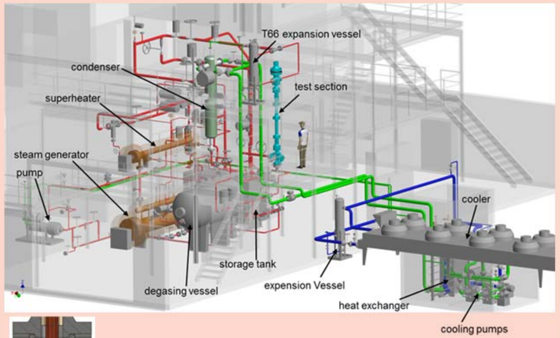
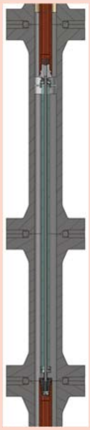
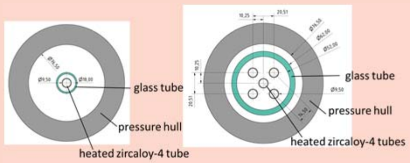
McSAFER Experimental Facilities: MOTEL, COSMOS-H, HWAT



MOTEL Nat. Circ. Loop

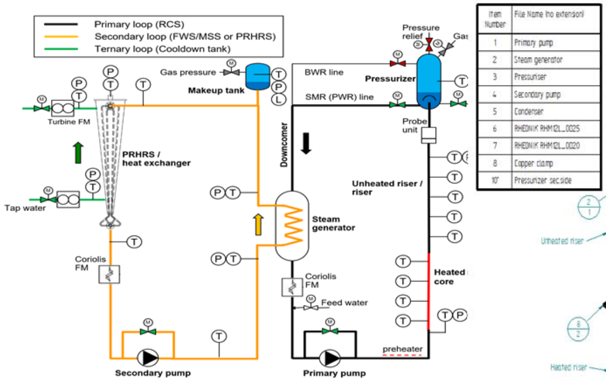




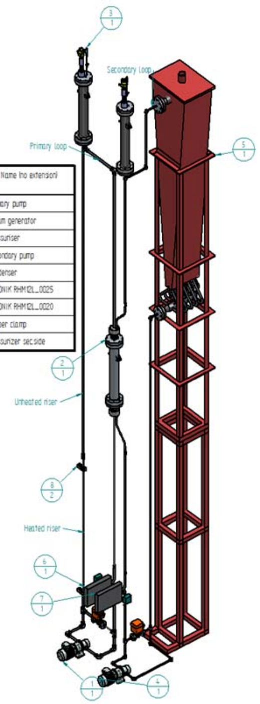


Serie-1 Serie-2

COSMOS-H: Test Section



HWAT Loop for forced and natural circulation (SS/TR)



HWAT Test Section

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McSAFER Experimental Facilities: Key Parameters and Features

Key-Parameters	COSMOS-H	MOTEL	HWAT
Focus	Fundametal HAT, Boiling, CHF	HX-performance, core crossflow	forced convection SS, transition to natural circulation, natural circulation
Power (MW)	2 (0.6)	0.99	1
Pressure (MPa)	5 to 17	4 MPa (PS) / 40 MPa (SS)	25
Max T_inlet (°C)	370	250 (PS) / 250 (SS)	350
Mass flow rate (kg/s)	0-1.4		1
Loop height (m)/D (m)	3.54 /0.08	7.4 / 0.711	8.8
Test section:			
Height (m)	1 to 2	1.830	3.7 (heated riser), 1.89 m diff between hot/cold sections
Heated rods /tubes	1 tube, 5 tubes	132 (heated) / 145 (dummy)	1
Instrumented rods	all	16	
Instrumentation:	Many TCs, p-sensors, high-speed cameras and LDA	340 TCs, 212 in the core, 5 p-sensors, 7 diff. pressure, Ultrasonic flowmeter	Multi-sensor probe at exit if heated riser to measure velocity, void and temperature, DP-transducers, Coriolis flow meter, TCs

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Status of the McSAFER Experimental Program

- Tests at MOTEL successfully done, data available for code validations

- Tests at HWAT facility: delays due to COVID (Delivery problems) and component failure
  - Test series 1: June 2023
  - Test series 2: October 2023

- Tests at COSMOS-H: delays due to COVID (Delivery problems) and leakage in SG at high pressure tests detected
  - Test series 1: June 2023
  - Test series 2: Mid-October/November 2023

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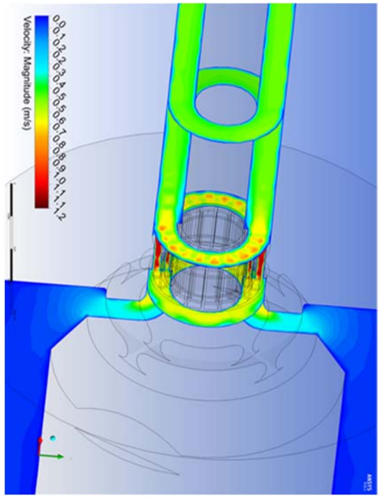
Validation of Thermal Hydraulic Codes using McSAFER-Data

Status:

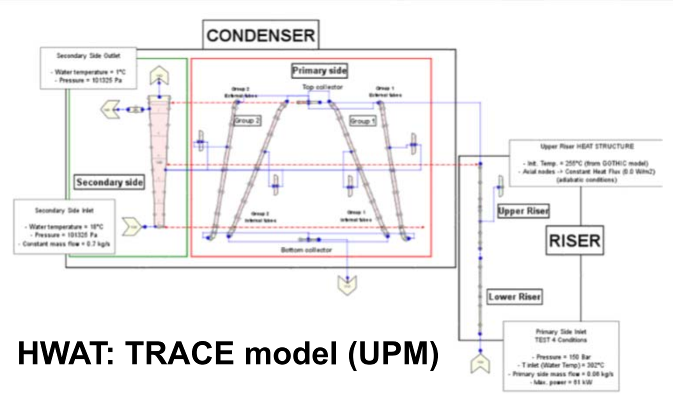
- COSMOS-H model under development
- HWAT pre-test calculations done
- First validation using MOTEL-data **done**

Tests	CFD	Subchannel	System TH
COSMOS-H	KIT LUT UJV	KIT UJV	KIT UJV
MOTEL	KIT UJV	TBL UJV	LUT UPM
HWAT	KTH		KTH UPM

Validation Matrix



COSMOS-H: FLUENT Model (KIT)



HWAT: TRACE model (UPM)

MOTEL CFX Core Model (KIT)

- Unstructured mesh
- Fully resolved geometry
- 150 millions cells

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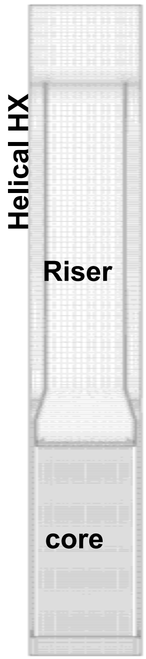
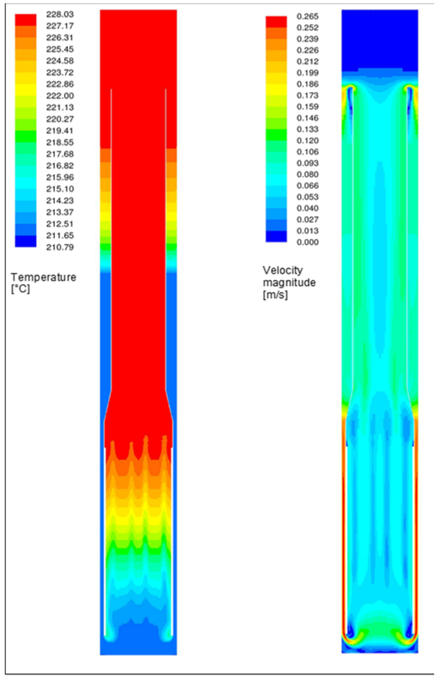
FLUENT Validation using MOTEL helical SG Data (UJV)

SG performance test:

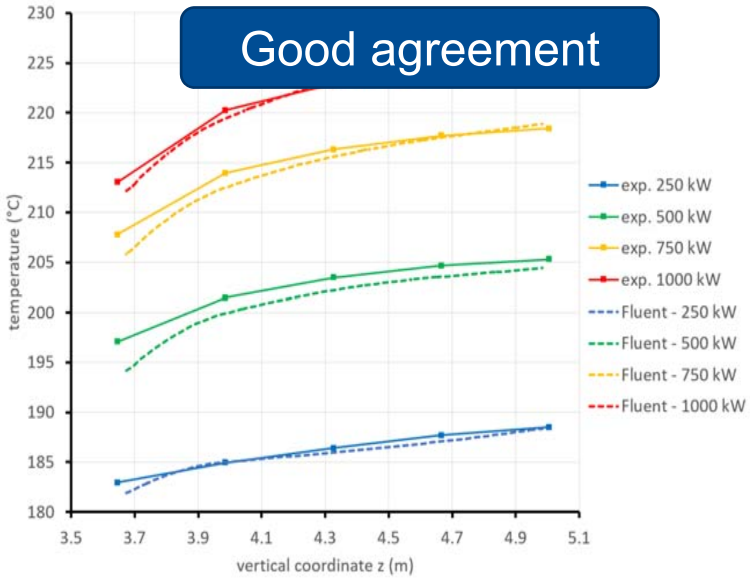
- Core: porous media with momentum losses and heat sources
- FA and probes as hexahedral block volumes
- SG as porous zone with momentum losses and heat sink
- Refined cells boundary layers to capture flow pressure losses



FLUENT: Motel mesh: 1.57 million cells



FLUENT: Temp. / velocity field in MOTEL facility (power 1000 kW)



Data-vs-Predictions: SG Primary axial temperature
(power 250, 500, 750 and 1000 kW
(Tests MS-SG01R, MS-SG01-A and MS-SG01-B)

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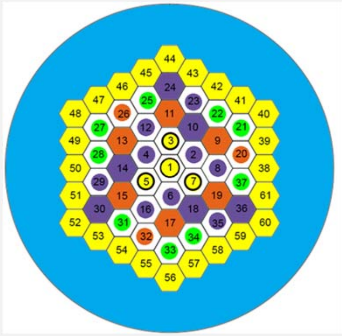
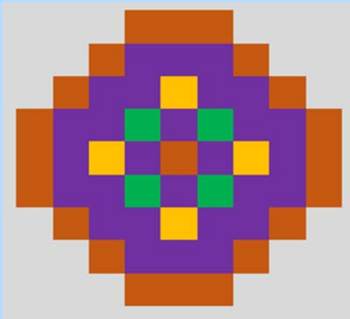
WP3: Multi-physics Core Analysis of different SMR-cores



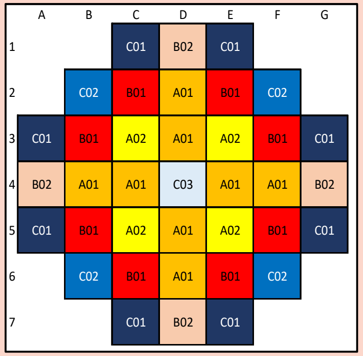
CAREM-Like core

- 61 HEX FA (1.4 m)
- Some FA with BP (6-12)
- 25 control FA
- U-235 enrichment: 1.8 to 3.1 %



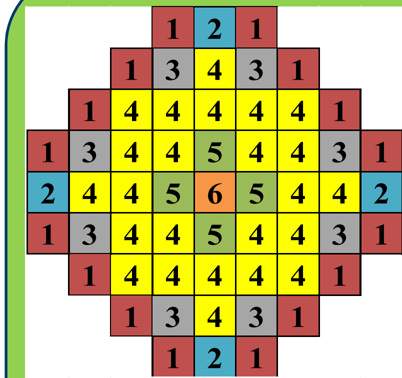
FSMR Core

- 57 FA 17x17-24-1 (1.6 m)
- All FA with AIC-rods
- Gd-rods (6-10 %)
- Heterogeneous FA-design
- Different enrich.3.5-4.95 %



NuSCALE-Like core

- 37 FA 17x17-24-1 (2m)
- GD-rods (16)
- U235 enrich: 1.5 -4.55 %
- Control rods design: Axial varying CR-materials: AIC, B4C



KSMR Core

- 57 FA 17x17-24-1 (2 m)
- 6 FA designs, each with CRs (AIC, B4C, SS)
- U235 enrich: radial/axial (2-4%)
- 20-24 BP rods (B4C, Al_2O_3)

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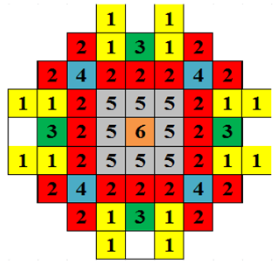
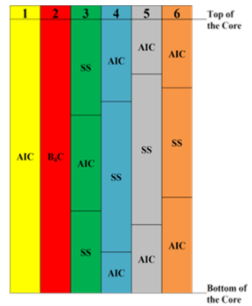
Challenges of Water-cooled SMRs for Core Physics

- 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.





McSAFER Approach

- Nodal diffusion /1D TH or Subchannel
- Pin-based transport / Subchannel
- Pin-based MC /Subchannel (SS, Transiet)

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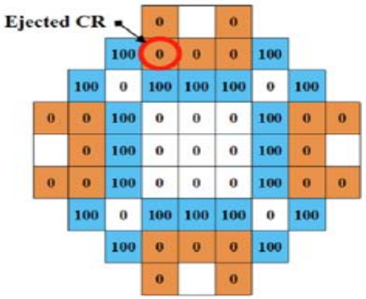
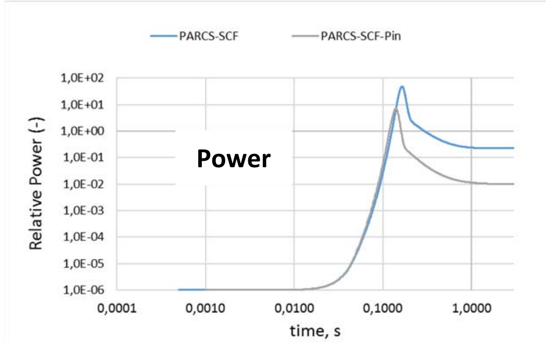
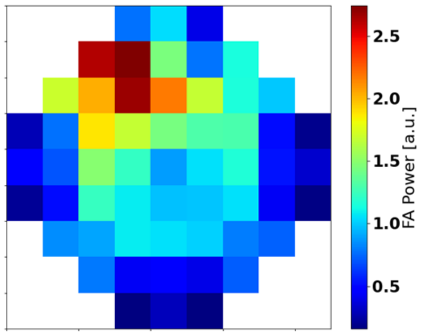
Karlsruhe Institute of Technology

KSMR-Core: REA Analysis with Nodal and Pin Level Simulations

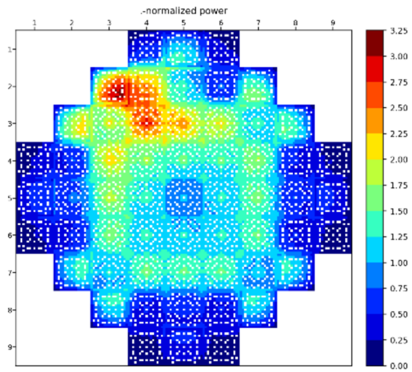


- Initial power: 1E-4 (HZP)
- Tcoolant: 296 °C, G: 2006 kg/s, CR-worth: 1.48 $
- Ejection time: 0.05 s, BOL

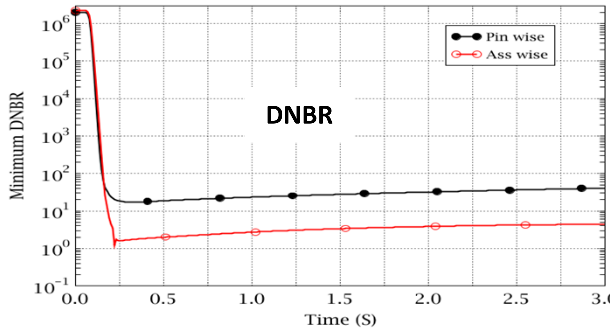




PARCS-SCF: Nodal /FA-level simulation: rel. rad. FA-power



PARCS-SCF: Pin/subchannel level simulation: rel. rad. Pin power



PARCS/SCF: Comparison of nodal and pin level solution

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Challenges for integrated SMR for Thermal Hydraulics & Safety

- Selected TH-challenges of water-cooled SMR
  - Cross flow in the core
  - Helical HX
  - Transition from
    - Forced to natural convection
    - Natural to forced convection
  - Safety parameters like
    - CHF
  - 3D flow inside the RPV
  - Stability of natural convection flow
  - Effectiveness of passive systems e.g. PRHRS

Experimental data exist but proprietary (SMR-designers)

McSAFER Approach

Extend data base for safety-relevant phenomena

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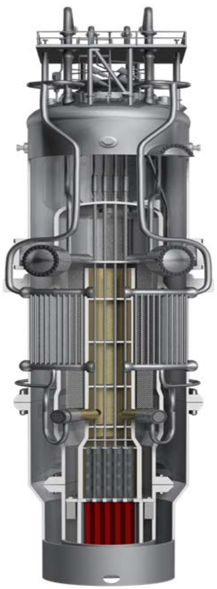
Karlsruhe Institute of Technology

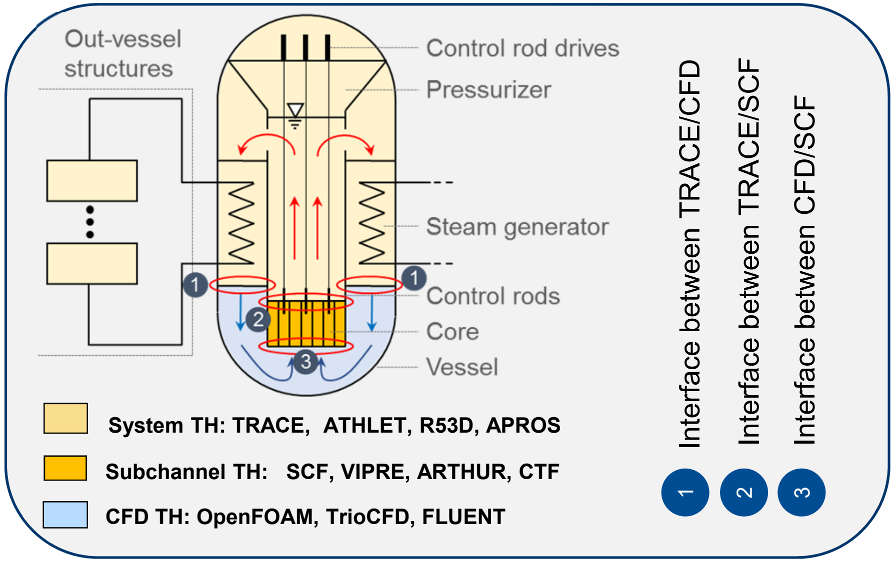
WP4 and WP5: Multiscale RPV Analysis Methodologies for SMR



NuScale (USA)

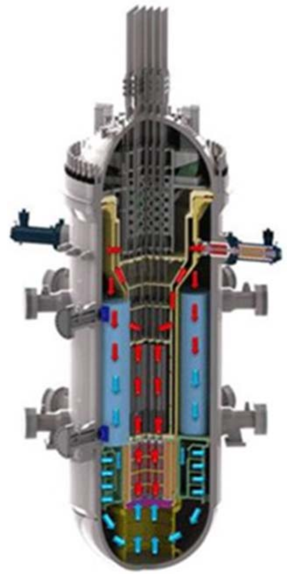
WP4: Boron dilution

WP5: SLB



WP4: Multiscale coupling
- System TH/ Suchannel TH
- System TH/ CFD

WP5: Multi-scale /-physics coupling
- System TH/ Suchannel TH/3D NK
- System TH/ CFD / 3D NK



SMART (KAERI)

WP4: ATWS

WP5: SLB

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WP4: Status of Multi-scale Analysis of the SMR RPV

SMART ATWS

Partners: KIT, TBL

- 1D/3D TH analysis: done

- System TH/Subchannel: done
  - TRACE/SCF/ICoCo (KIT)

- System TH/CFD: ongoing
  - TRACE/OpenFOAM/ICoCo (KIT)

NuScale Boron Dilution

Partners: HZDR, UJV, UPM, JACOBS, TBL, JRC

- 1D /3D TH analysis: done

- System TH/Subchannel: done
  - TRACE/SCF/ICoCo (UPM)
  - TRACE/ARTHUR (JACOBS)

- System TH/CFD: ongoing
  - ATHLET/FLUENT (UJV)
  - ATHLET/TrioCFD (HZDR)

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WP5: Status of Multi-physics/-scale Plant Analysis

SMART Steam Line Break (SLB)

Partners: KIT, TBL

- 1D TH /3D Neutronics (N): done
  - TRACE/**PANTHER** (TBL)
  - TRACE/**PARCS** (KIT)

- System TH/ SubCh/ **3D N**: done
  - TRACE/**PARCS**/SCF/ICoCo (KIT)

- System TH/ **3D N** /CFD: ongoing
  - TRACE / **PARCS** / OpenFOAM / ICoCo (KIT)

NuScale Steam Line Break (SLB)

Partners: HZDR, UJV, UPM, JACOBS, TBL

- 1D TH/ **3D Neutronics**: done
  - ATHLET/DYN3D (HZDR)
  - TRACE/PANTHER (TBL)
  - ATHLET/DYN3D (UJV)
  - TRACE/PARCS (UPM)

- **System TH/ 3D N/ SubCh: done**
  - TRACE/PARCS/SCF/ICoCo (UPM)
  - TRACE/WIMS/ARTHUR (JACOBS)
  - TRACE/PANTHER/CTF4 (TBL)

- **System TH/ 3D N/ CFD: ongoing**
  - ATHLET/DYN3D/FLUENT (UJV)
  - ATHLET/DYN3D/TrioCFD (HZDR)
  - TRACE/ANTS/OpenFOAM (VTT)

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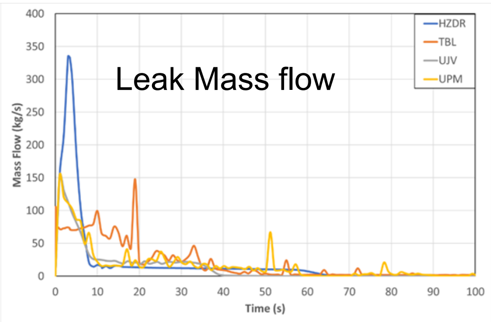
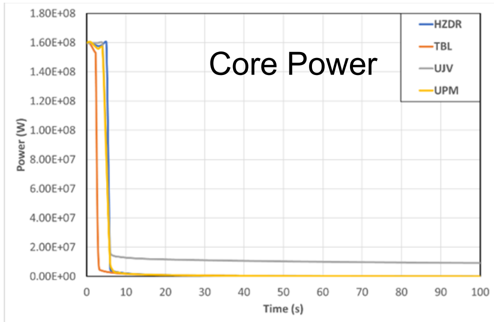
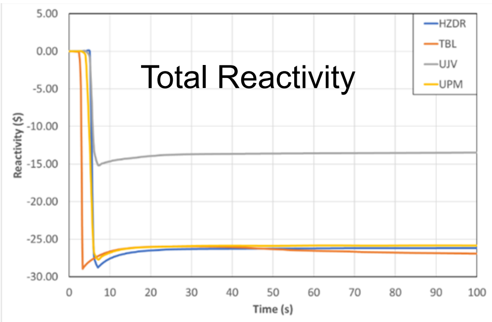
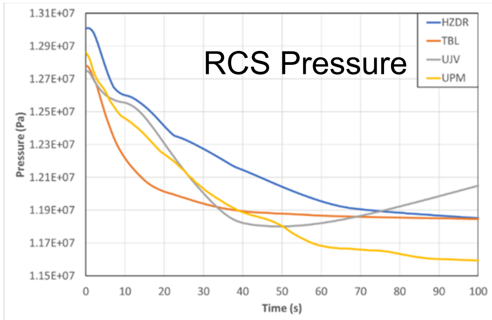
NuScale SLB: Preliminary Results with system TH /3D NK









Remarks:

- Similar trends of key parameters BUT
- Different timing
- NuScale models are under revision by the partners

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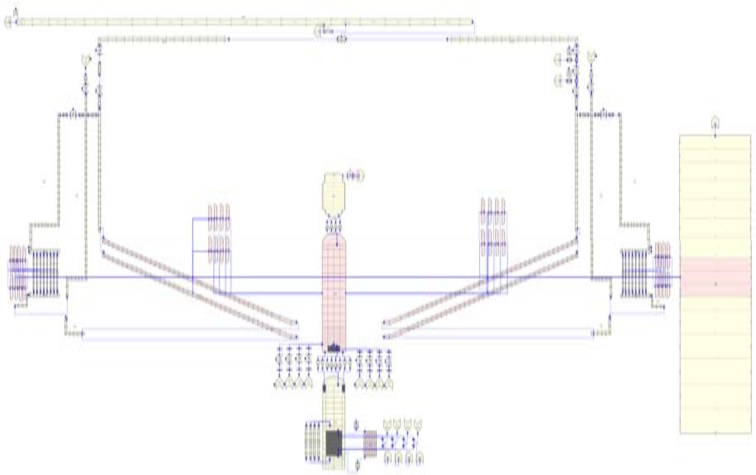
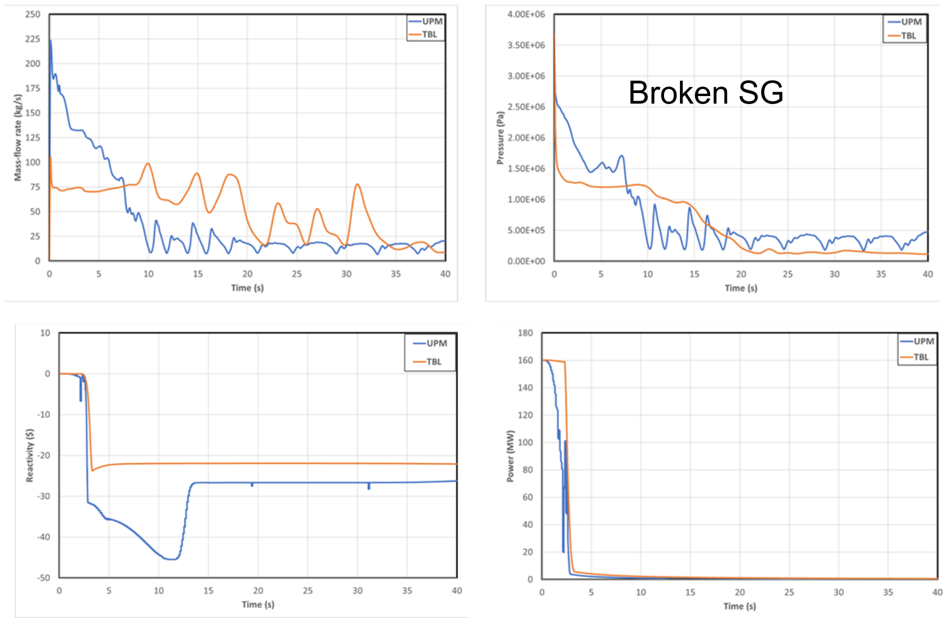
NuScale MSLB Analysis with different Approaches

- Codes:
  - UPM: TRACE/PARCS/SCF (3D TH)
  - TBL: TRACE/PANTHER (1D TH)

- NuScale: Multiscale model (UPM)



- NuScale: Steam Line Break
  - Initial event: at 0 s, SCRAM: Psl < 2.068 MPa, CR-insertion, Signal for MSIV, FWIV, MSIV (SG1 and SG2) close, DHRS start



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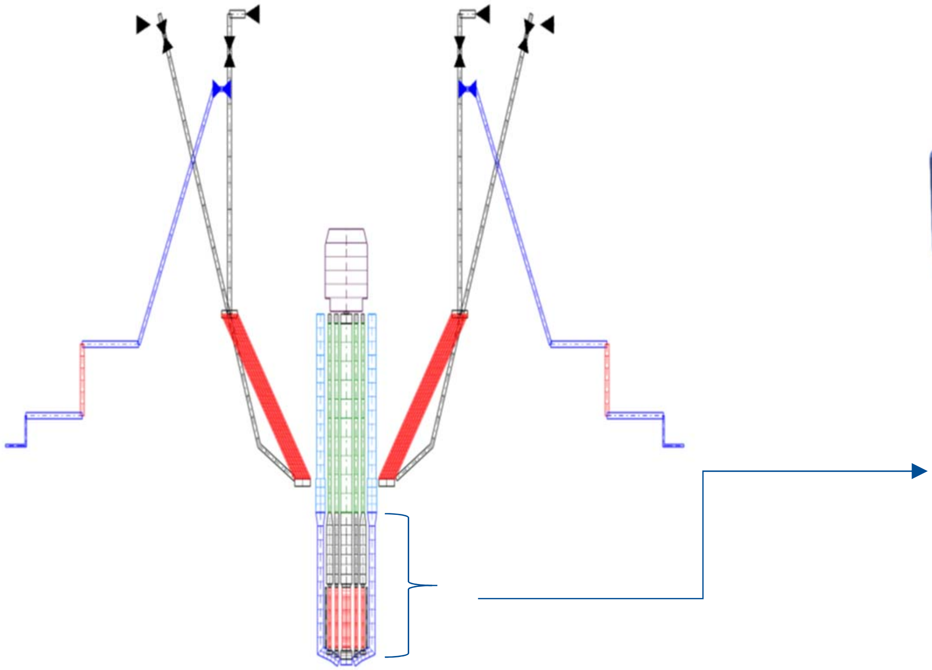
NuScale: Multiscale analysis using ATHLET/DYN3D/TrioCFD



NuScale 1D/3D Thermal Hydraulics Model (HZDR)

TrioCFD Model of Downcomer and lower plenum (HZDR)

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Conclusions

- Experimental program will provide key-data for code validation regarding
  - Behavior of helical coil HX
  - Cross flow in the core
  - DNB, transition from forced to natural circulation

- Multi-physics core analysis will allow to identify which kind of tools are needed to assess complex, small, heterogeneous SMR-cores

- Multiscale/-physics analysis of SMR-transients will demonstrate which numerical tools are most appropriate for safety evaluations of integrated SMRs
  - Reduce conservatism
  - Enhance operational flexibility
  - Improve economics

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McSAFER: Dissemination of Main results

McSAFER Zenodo Open Repository:

https://zenodo.org/communities/mcsafer/

User group members:
NRG, IRSN, ININ, BME, FRAMATOME GmbH

Contact:

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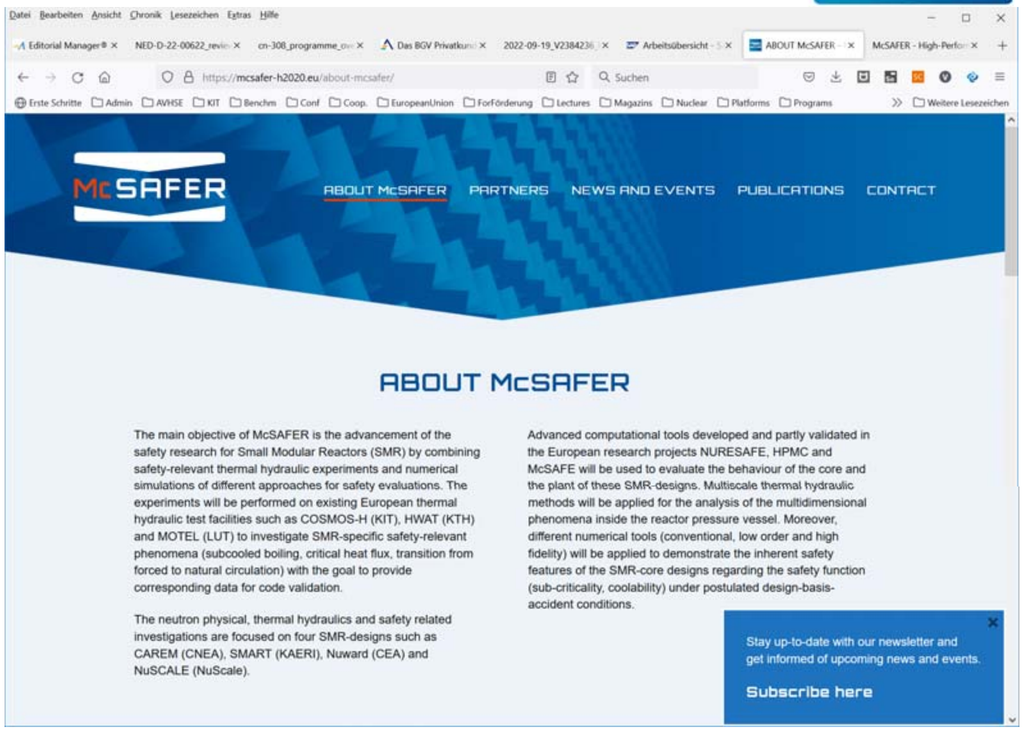
KIT CN Karlsruhe



Visit public website: www.mcsafer-h2020.eu

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