REDUCTION OF RADIOLOGICAL ACCIDENT CONSEQUENCES

UNIVERSIDAD POLITÉCNICA DE MADRID

Title	**The H2020 McSAFER: High-Performance Advanced Methods and Experimental Investigations for the Safety Evaluation of Generic Small Modular Reactors**
Speaker:	Cesar QUERAL
Affiliation:	Universidad Politécnica de Madrid
Event:	R2CA Summer School
When:	4-6 July 2023
Where:	ENEA Bologna

This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 847656.

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

R2CA Summer School

C. Queral

V. H. Sanchez-Espinoza, H. Suikkanen, V. Valtavirta, M. Bencik, S. Kliem, S. Chochet, P. Smith, P. Van Uffelen, M. Seidl, Ch. Schneidesch, D. Grishchenko, H. Lestani

July 4-6, 2023, Bologna, Italy

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

DEC-A sequences. Examples (PWR):

- **ATWS (McSafer)**
- **Boron dilution (McSafer)**
- **SLB with failures (McSafer)**
- TLFW + F&B
- SGTR, MSGTR, SGTR + SLB
- SBO w/wo seal LOCA
- SB/MBLOCA with failure of an active system
- LOCA during LPSD
- Loss of CCWS / SWS
- Loss of RHRS (RCS open/close)
- SFP loss of cooling

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Content

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

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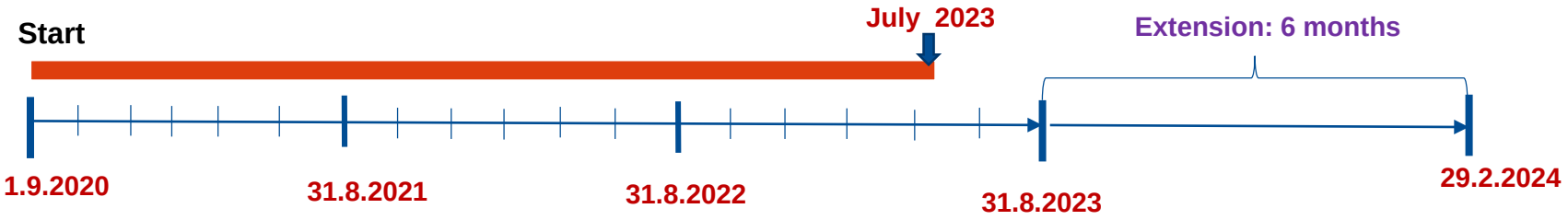
Technical Goals & Scientific approach

- 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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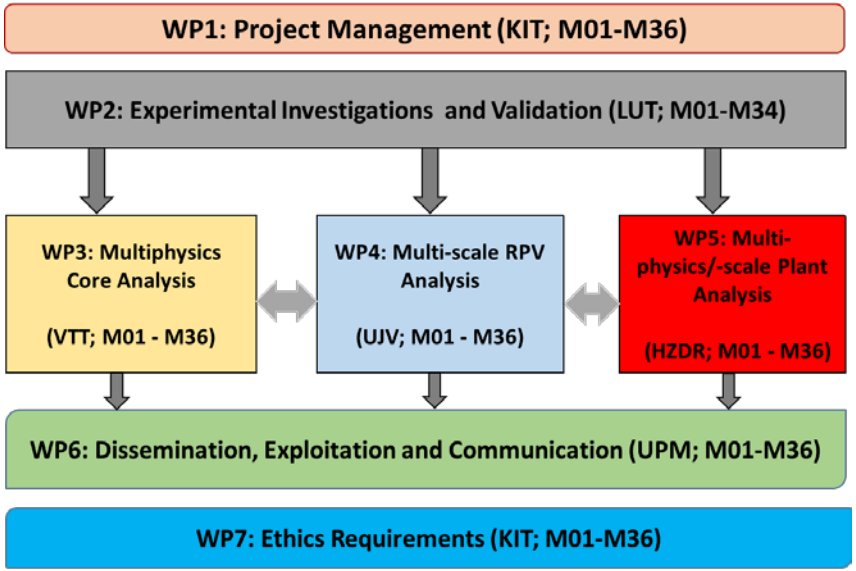
McSAFER: Work Packages, Partners



McSAFER: Work Package Structure

Universities

R&D, TSOs

Industry

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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)

Extend data base for safety-relevant phenomena

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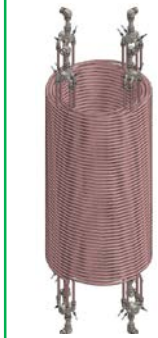
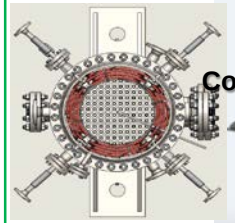
McSAFER Experimental Facilities: MOTEL, COSMOS-H, HWAT

PZR

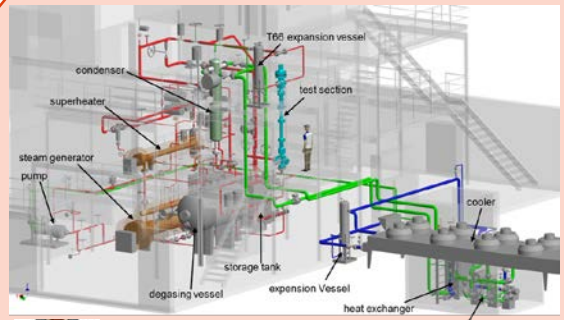
Helical coil HX

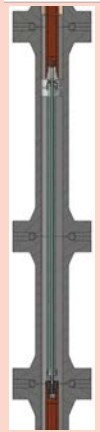


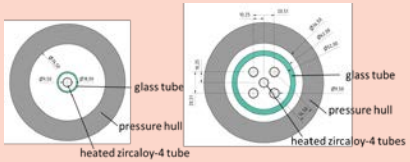


Core

MOTEL Nat. Circ. Loop

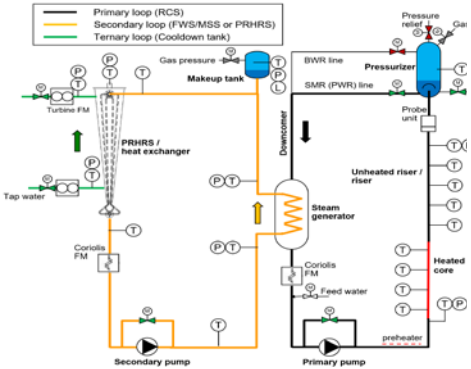




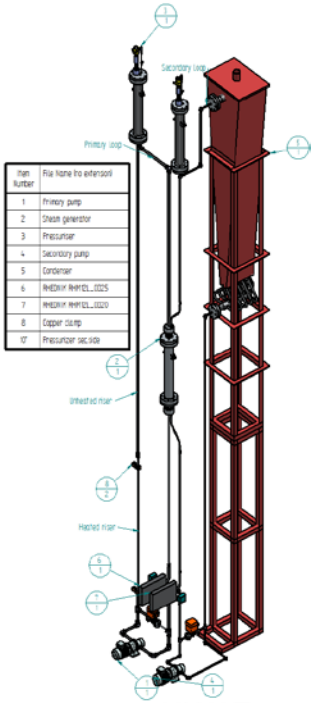


Serie-1 Serie-2

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	Fundamental HT, 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 and 2 will be done in July-August 2023

- Tests at COSMOS-H: delays due to COVID (Delivery problems) and leakage in SG at high pressure tests detected
  - Test series 1 and 2 will be done in July-August 2023

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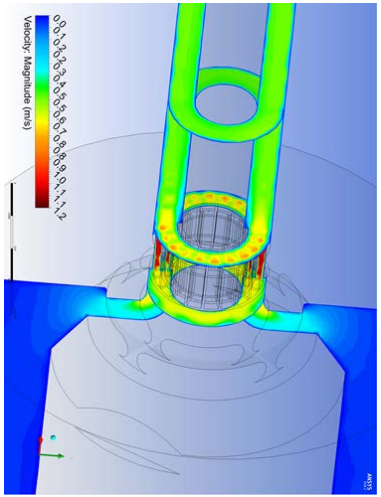
Validation of Thermal Hydraulic Codes using McSAFER-Data

Status:

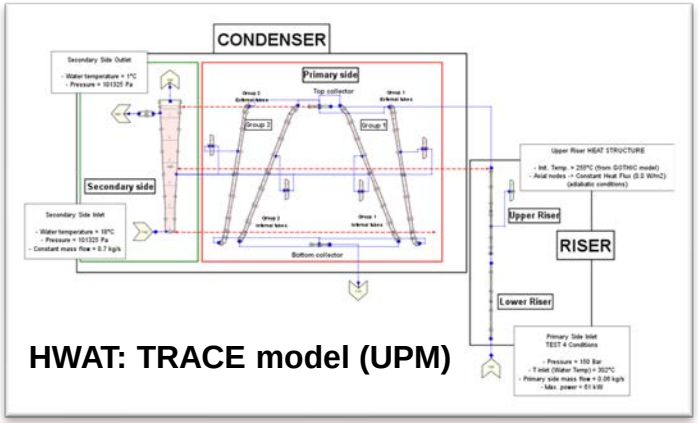
- COSMOS-H model under development
- HWAT pre-test calculations done
- First validation using MOTEL-data **done**



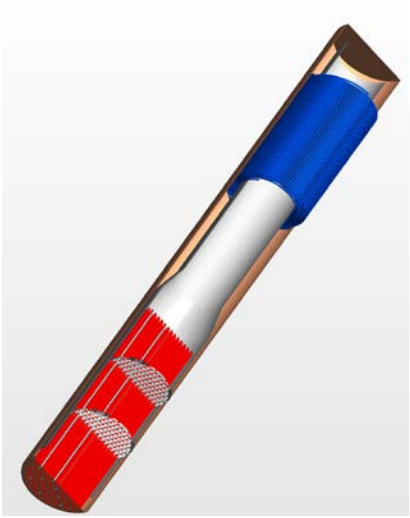
COSMOS-H: FLUENT Model (KIT)

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



HWAT: TRACE model (UPM)



MOTEL CFX Core Model (KIT)

- Unstructured mesh
- Fully resolved geometry
- 150 millions cells

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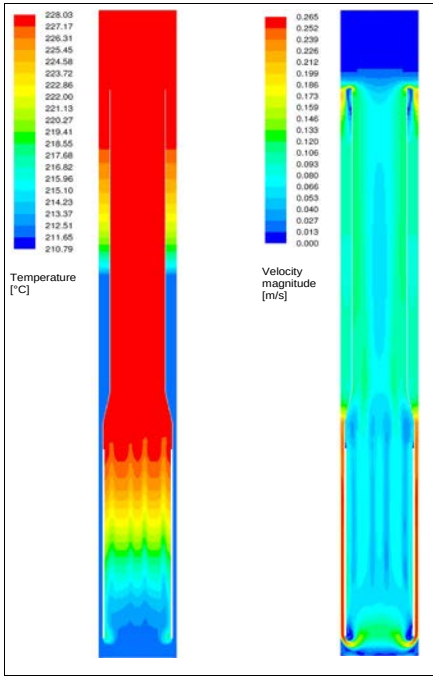
FLUENT Validation using MOTEL helical SG Data (UJV)

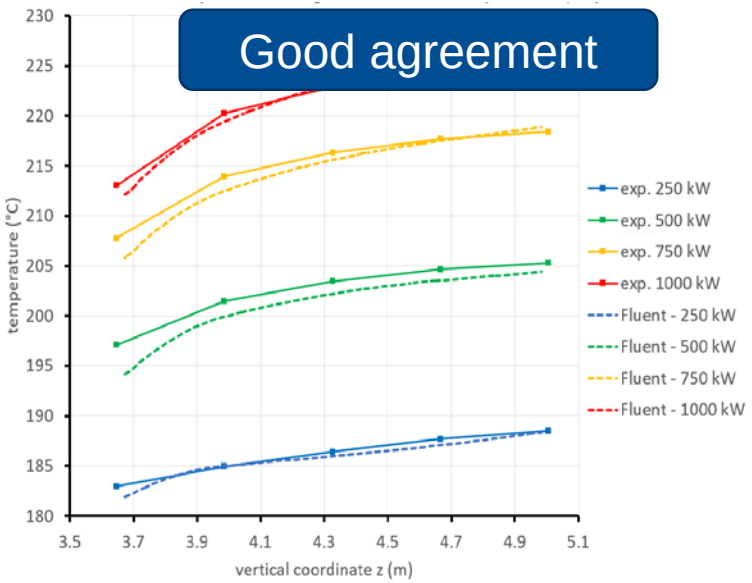
SG performance test:

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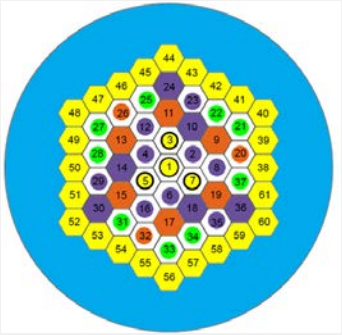
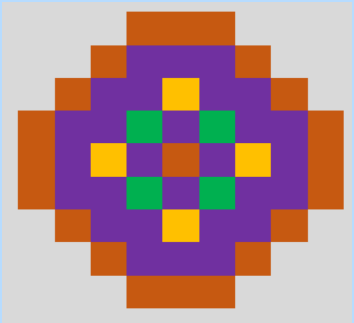
WP3: Multi-physics Core Analysis of different SMR-cores



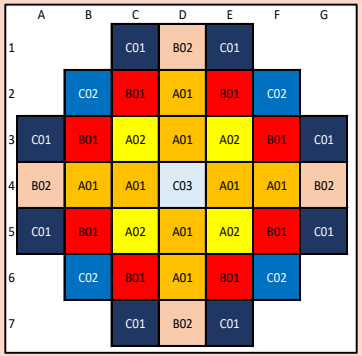
CAREM-Like core

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



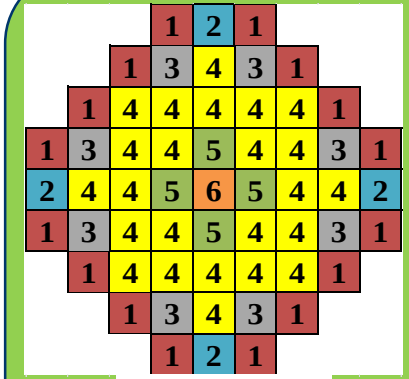
FSMR Core

- 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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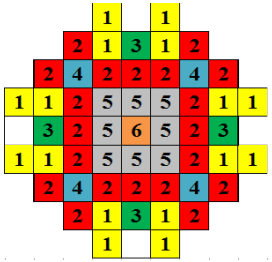
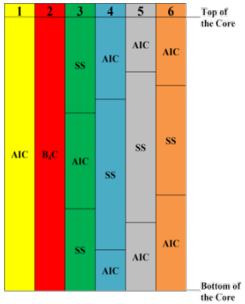
Challenges of Water-cooled SMRs for Core Physics

- Compact
- 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, Transient)

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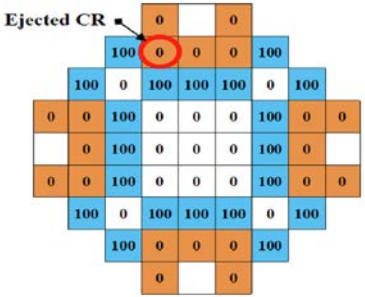
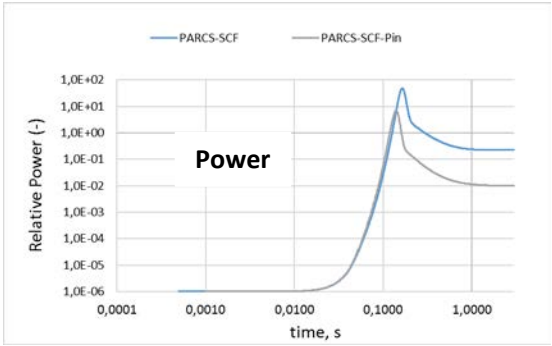
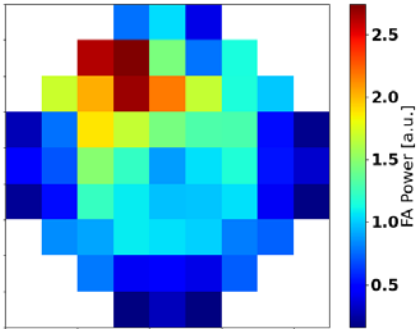
KSMR-Core: REA Analysis with Nodal and Pin Level Simulations

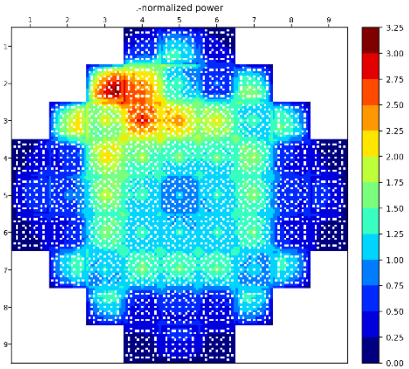


- Initial power: 1E-4 (HZP)
- Tcoolant: 296 °C, G: 2006 kg/s, CR-worth: 1.48 $
- Ejection time: 0.05 s, BOL

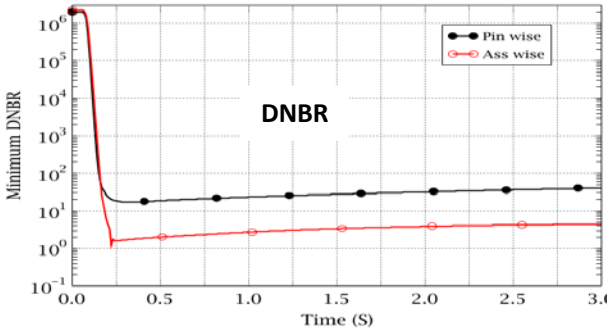




Nodal /FA-level simulation: rel. rad. FA-power



Pin/subchannel level simulation: rel. rad. Pin power



PARCS/SCF: Comparison of nodal and pin level solution

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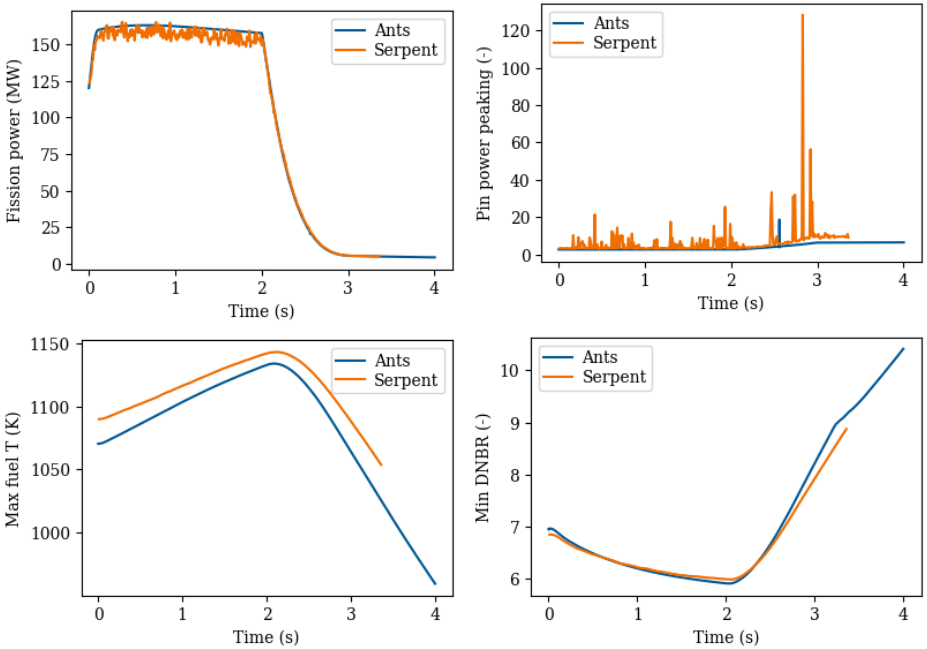
Serpent-Subchanflow-TRANSURANUS simulation of RIA in Nuscale-like core by VTT

- Simulation conducted within Kraken-framework:
  - Serpent
  - TRANSURANUS
  - SUBCHANFLOW
- First simulation of the transient conducted with the three codes (17 wall clock days with 128 cores).



Large stochastic uncertainties in power (top row),
But safety parameters (bottom row) better resolved.

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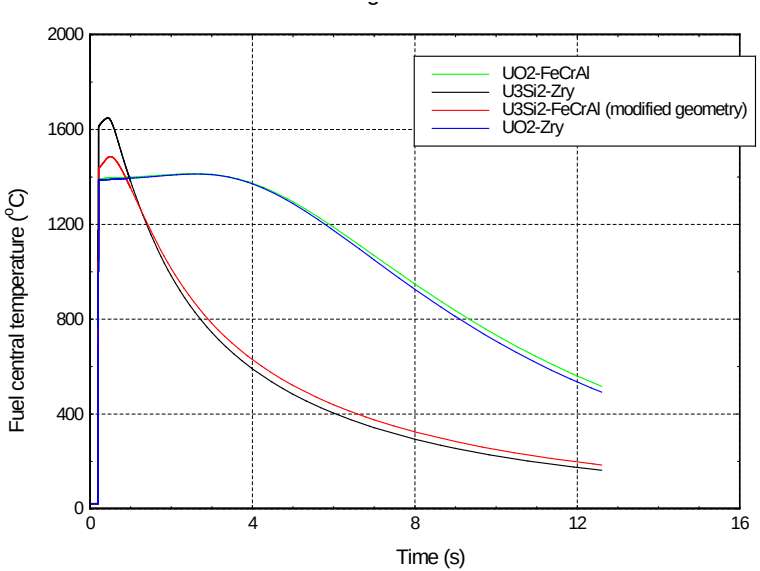
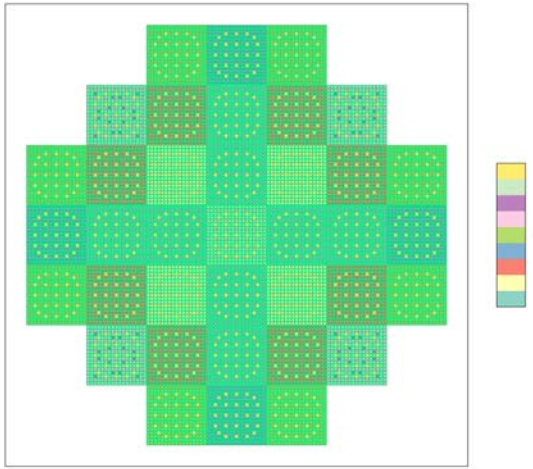
Serpent-Subchanflow-TRANSURANUS simulation of RIA in Nuscale-like core by JRC

Successful stand-alone TRANSURANUS simulation of FK1 rod during RIA with ATF



Pin-by-pin simulation of all rods during RIA in NuScale core underway



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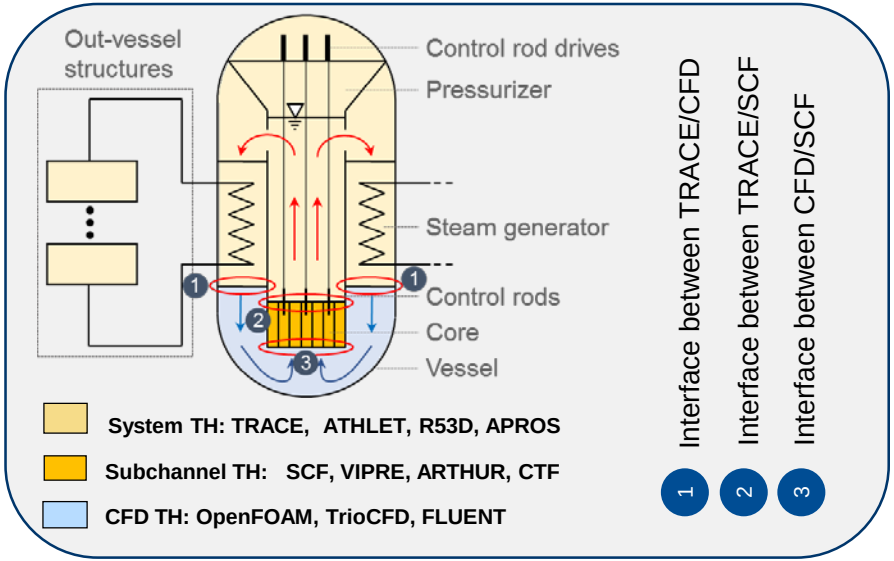
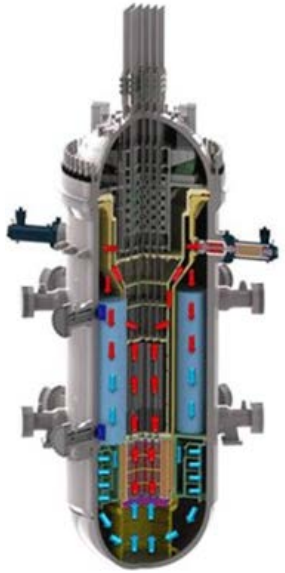
WP4 and WP5: Multiscale RPV Analysis Methodologies for SMR





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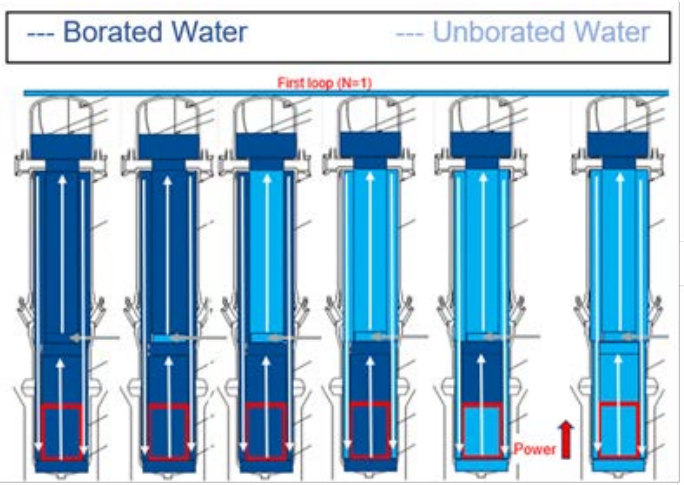
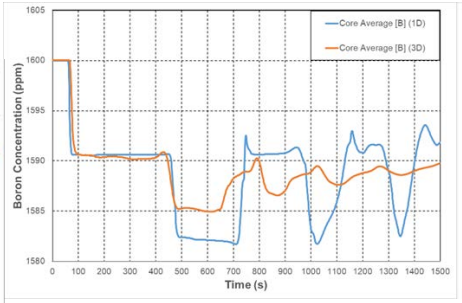
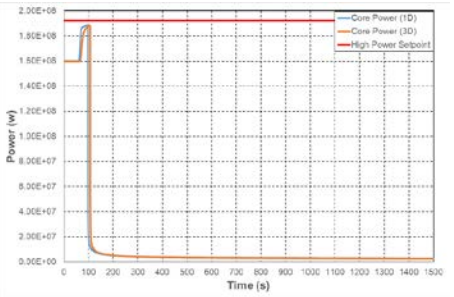
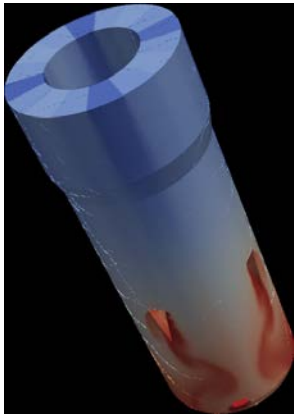
WP4: Status of Multi-scale Analysis of the SMR RPV

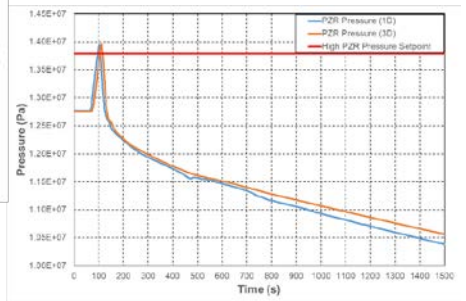
NuScale Boron Dilution

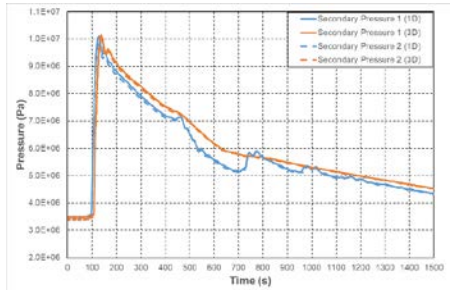


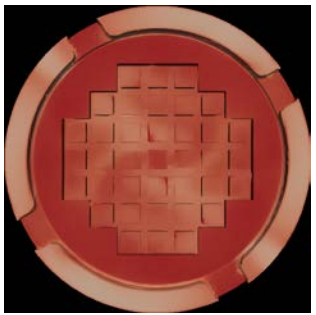












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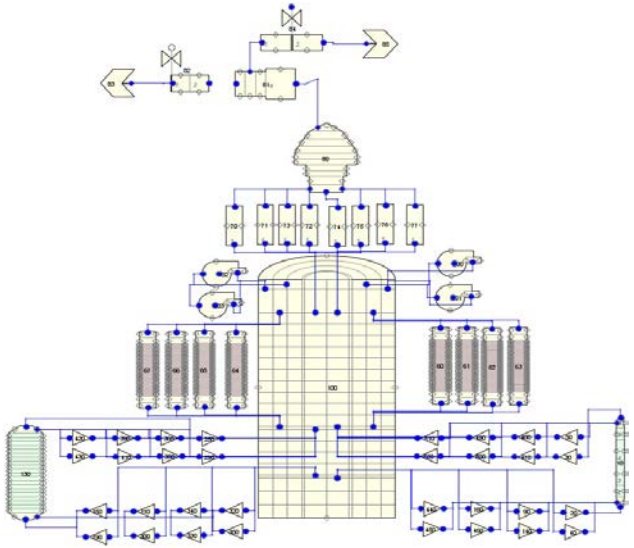
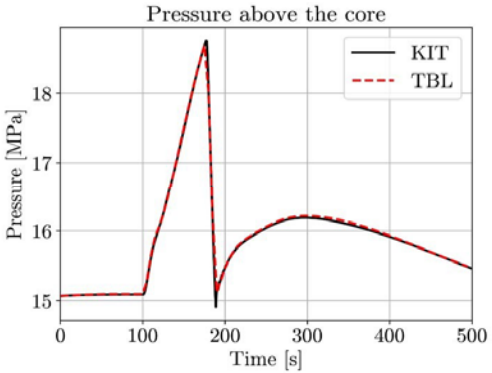
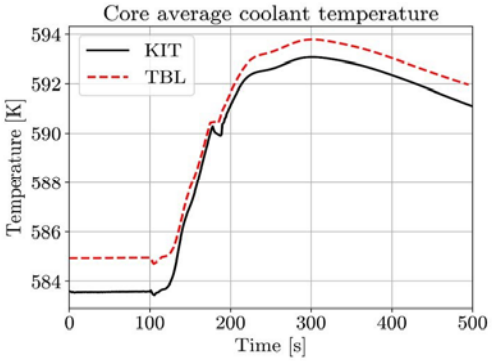
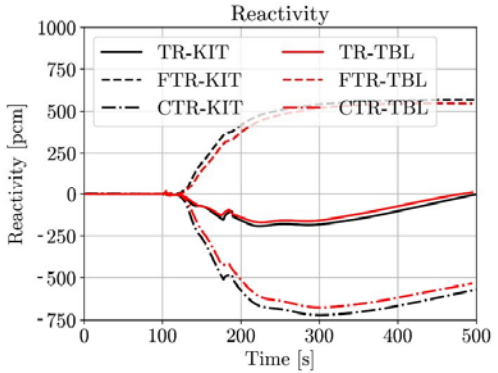
WP4: Status of Multi-scale Analysis of the SMR RPV

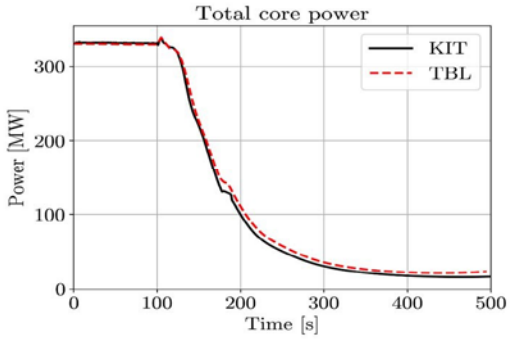
SMART ATWS











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

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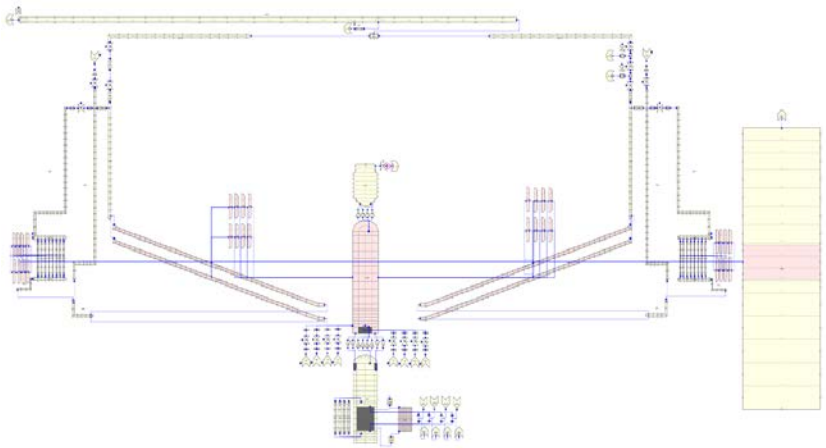
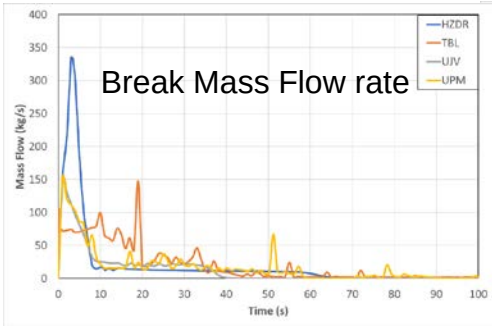
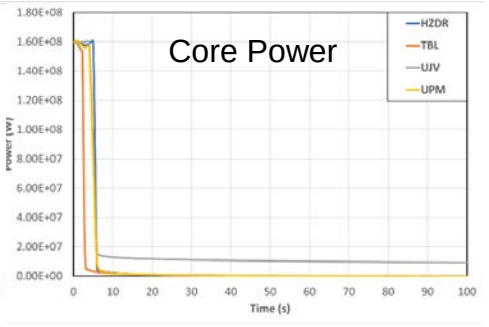
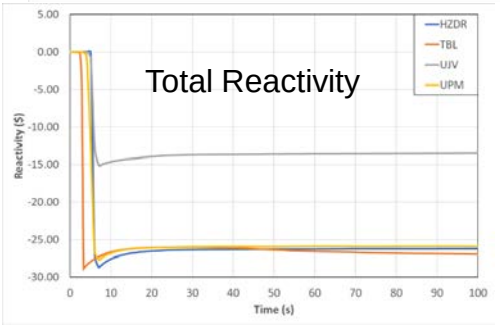
NuScale SLB: Preliminary Results with system TH /3D NK

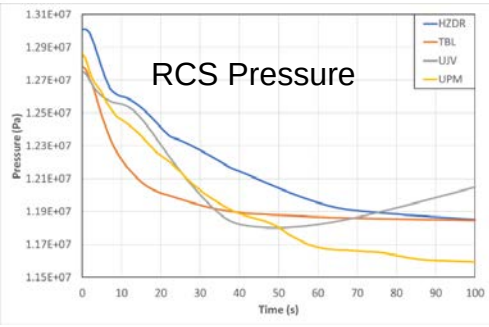
- Similar trends of key parameters BUT
- Different timing
- NuScale models are under revision











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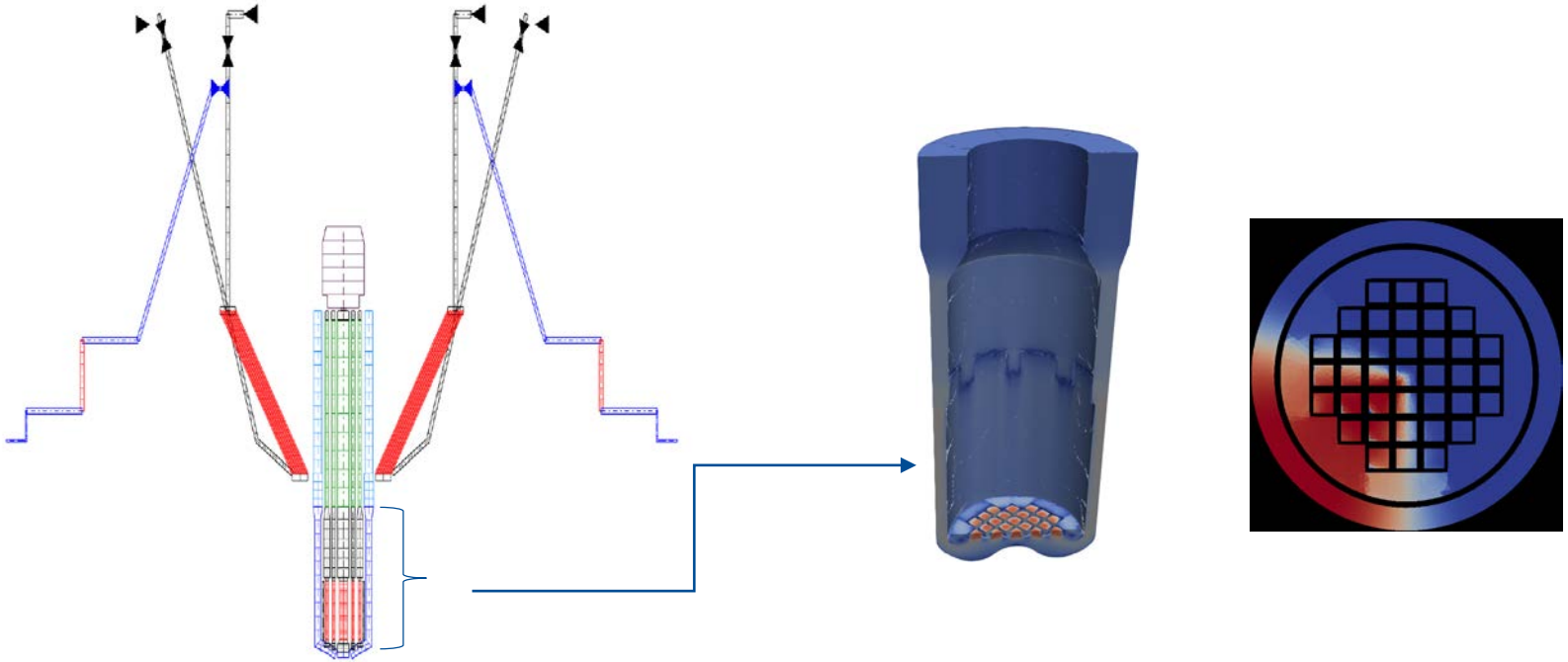
NuScale: Multiscale analysis using ATHLET/DYN3D/TrioCFD



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

TrioCFD Model of Downcomer and lower plenum (HZDR)

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

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

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

McSAFER: Dissemination of Main results

McSAFER Zenodo Open Repository:

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

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

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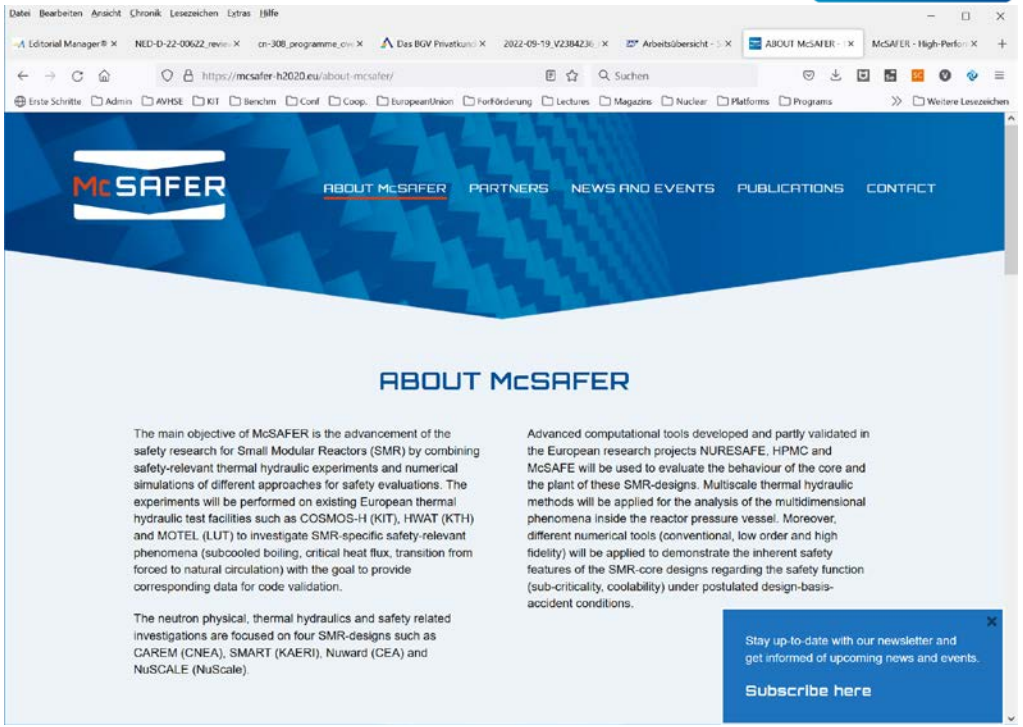

Visit public website: www.mcsafer-h2020.eu

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UNIVERSIDAD POLITÉCNICA DE MADRID

Thank you!

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