Karlsruher Institut für Technologie

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McSAFE – High Performance Monte Carlo Methods for SAFEty Demonstration

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From Proof of Concept to Industry-like Applications

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NUGENIA is mandated by SNETP to coordinate nuclear Generation II & III R&D

SNETP
Sustainable Nuclear Energy Technology Platform

www.snetp.eu

Content

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- McSAFE Tools

Scientific Gaps

- **Core analysis relies mainly on deterministic neutronic codes (daily work)**
  - Diffusion codes include multiple approximations (energy, angle, homogenized geometry)
  - Pin power approximately reconstructed from 2D lattice calculations
  - SP_3 and S_N solvers are still under development.
    - *Currently very time and memory expensive*
    - *Parallel versions under development*
- **Experimental data at pin level is scarce and not easy to be measured (pin power)**
- **Alternative option:**
  - Use of MC codes capable of simulating the neutron transport without approximations
  - Potential use taking advantage of HPC and parallelization

Innovative solutions needed to pave the way for industry-like applications

McSAFE: Technical Goals

- **McSAFE is based on innovative ideas developed within the EU 7. FP HPMC Project (High Performance Monte Carlo Core Analysis: 2011-2014)**
  - Optimal MC/TH coupling, stable MC-based depletion, **dynamic MC**
  - Many more ideas to simulate whole cores using HPC: UFS, Wieland Shift, Stochastic implicit Euler, …

(Proof of concept)

- **Goal: Move MC methods towards industrial applications**
  - **Generalize N/TH coupling to provided reference solutions**
  - Optimize depletion simulations (stability, CPU)
  - **Analysis of transients such as RIA and others (Safety)**
  - Solve whole cores making use of HPC (improve statistics, reduced CPU)
  - **Validate MC tools using experimental data**

(Industry-like applications➔ McSAFE)

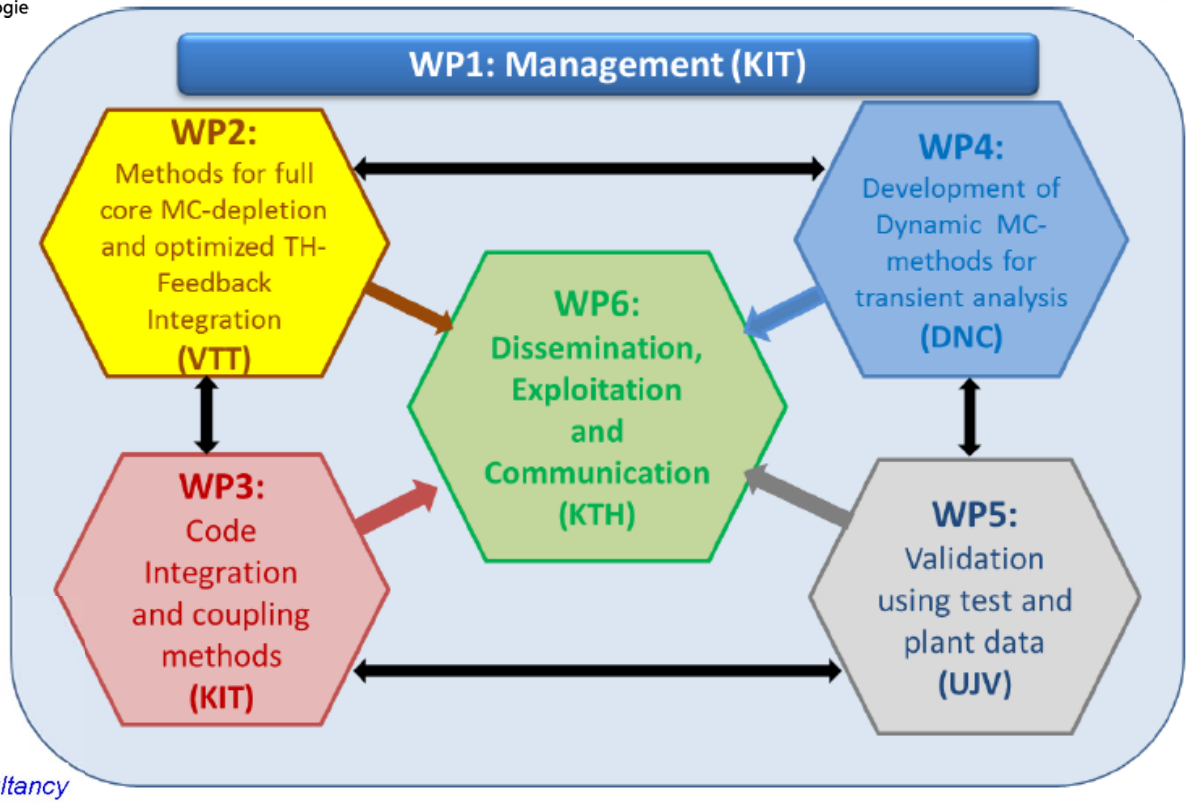
McSAFE: Time Frame

- **Phase 1: 2011 (10)-2014 (9), 7 FP EU HPMC project**

- **Phase 2: 2017 (9)-2020 (8) → McSAFE**
  - Consolidation of the methods for MC-TH coupling
  - Advance validation using exp. Data
  - Consolidate dynamic MC under HPC

- **Phase 3: 2020-2023 (9): McSAFE II NOIP**
  - Benchmarking of MC with high-fidelity deterministic core solvers for REFERENCE SOLUTIONS
  - Benchmarking of dynamic Monte Carlo solutions with transient deterministic codes for SAFETY CASES (pin level, steady-state and transient)
  - Uncertainty quantifications
  - Extension to Gen-IV reactors, research reactors

McSAFE: Work Packages



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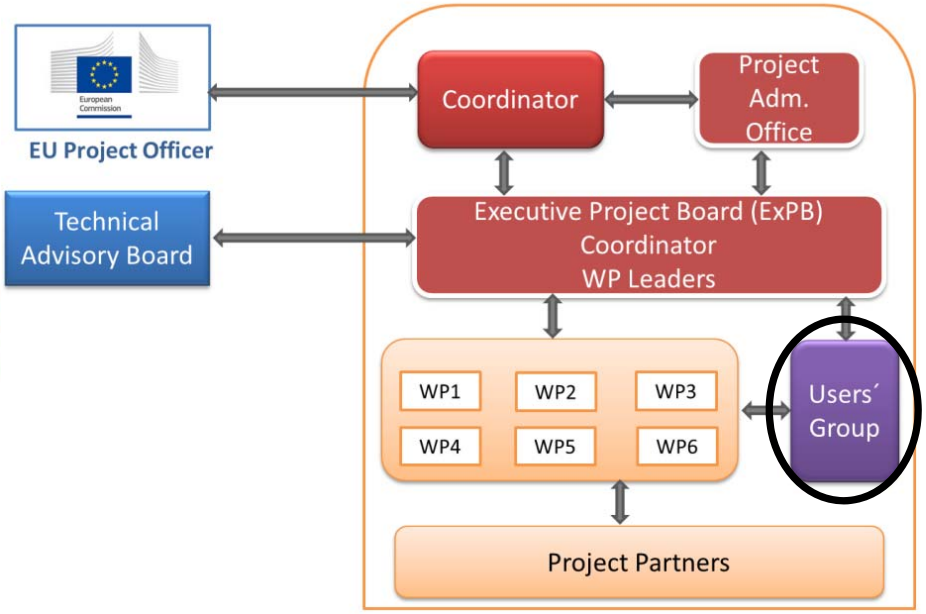
McSAFE: Management Structure and Partners



A Users Group will be created

Confirmed institutions:

- North Carolina State University (USA)
- National Institute for Nuclear Research (Mexico)
- University of Michigan, (USA)
- University of Illinois, (USA)
- Argonne National Laboratory (USA)
- Canadian Nuclear Laboratories, (Canada)
- Idaho National Laboratory (USA)
- Westinghouse Electric (Sweden)
- SCK-CEN (Belgium)
- IRSN (France)
- POLIMI (Italy)

RESEARCH

KIT Karlsruher Institut für Technologie
KTH ROYAL INSTITUTE OF TECHNOLOGY
VTT
cea
JRC EUROPEAN COMMISSION
HZDR
ÚJV
HELMHOLTZ ZENTRUM DRESDEN ROSSENDORF

INDUSTRY

N D C Delft Nuclear Consultanc
Preussen Elektra
EDF
amec
CEZ GROUP

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McSAFE: Main Concept (1)

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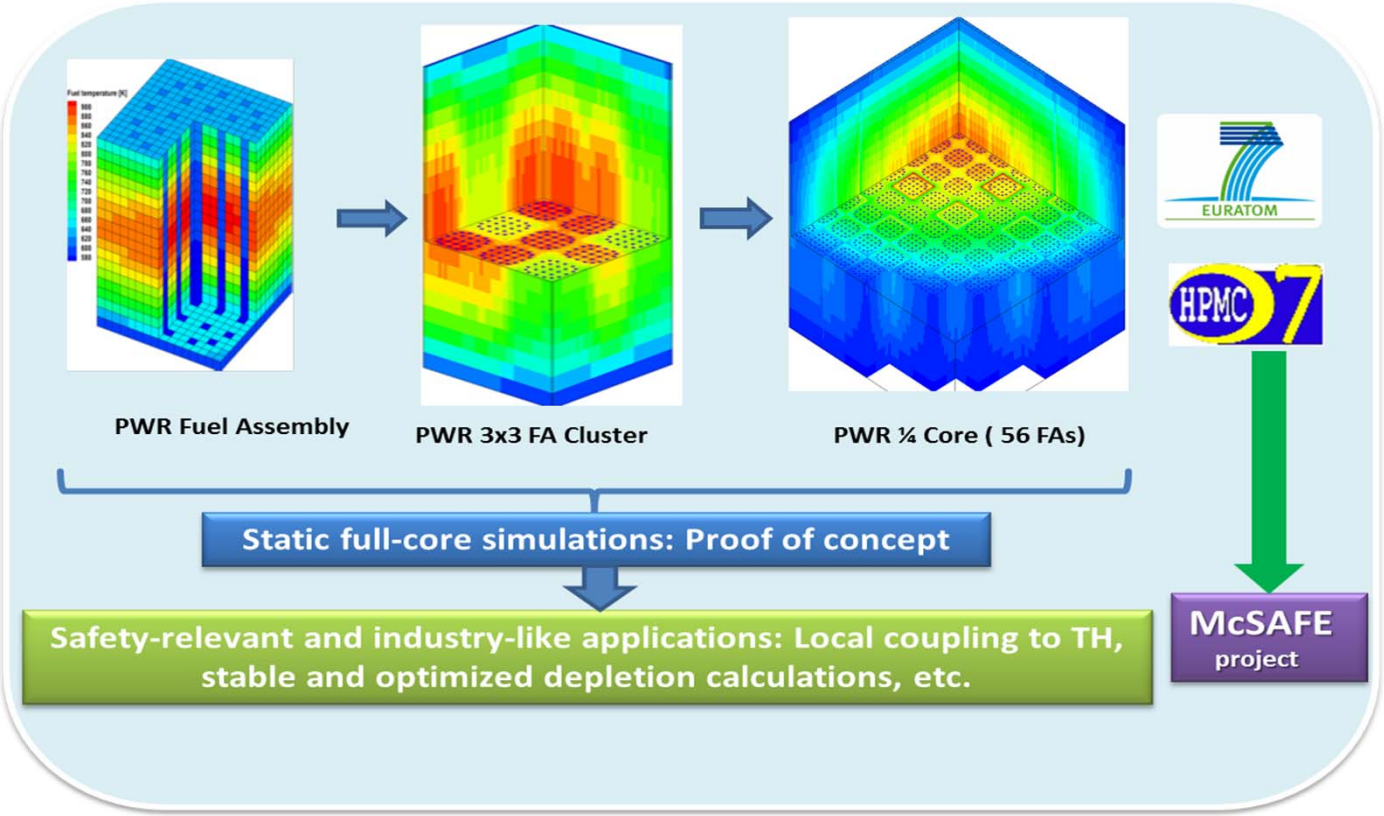
- **MCNP/SUBCHANFLOW Pin-wise Core Simulations**



PWR Core Problem

Size: 193x265x30 = 1 534 350 cells
MC/TH simulation: 1.3 E9 histories, **240 cores**, Data Storage: 2.5 GB
Input preparation: < 5 min
Convergence: 20 N/TH iterations, 5600 min **(3.88 days)**

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McSAFE: Main Concept (2)

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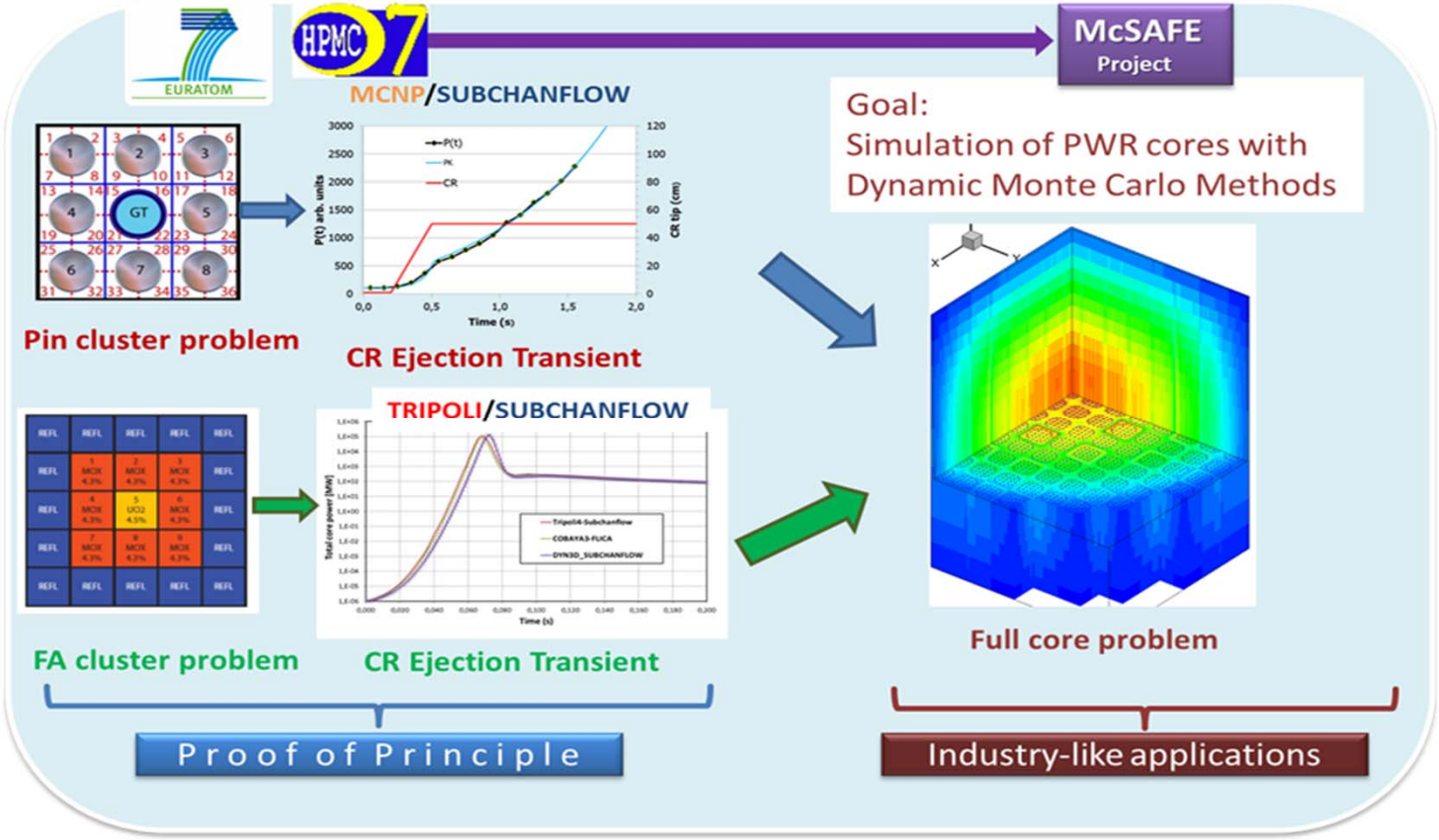
- **Transient analysis with MC/Sub-channel Codes**



DynMCNP: 3x3 Rod problem

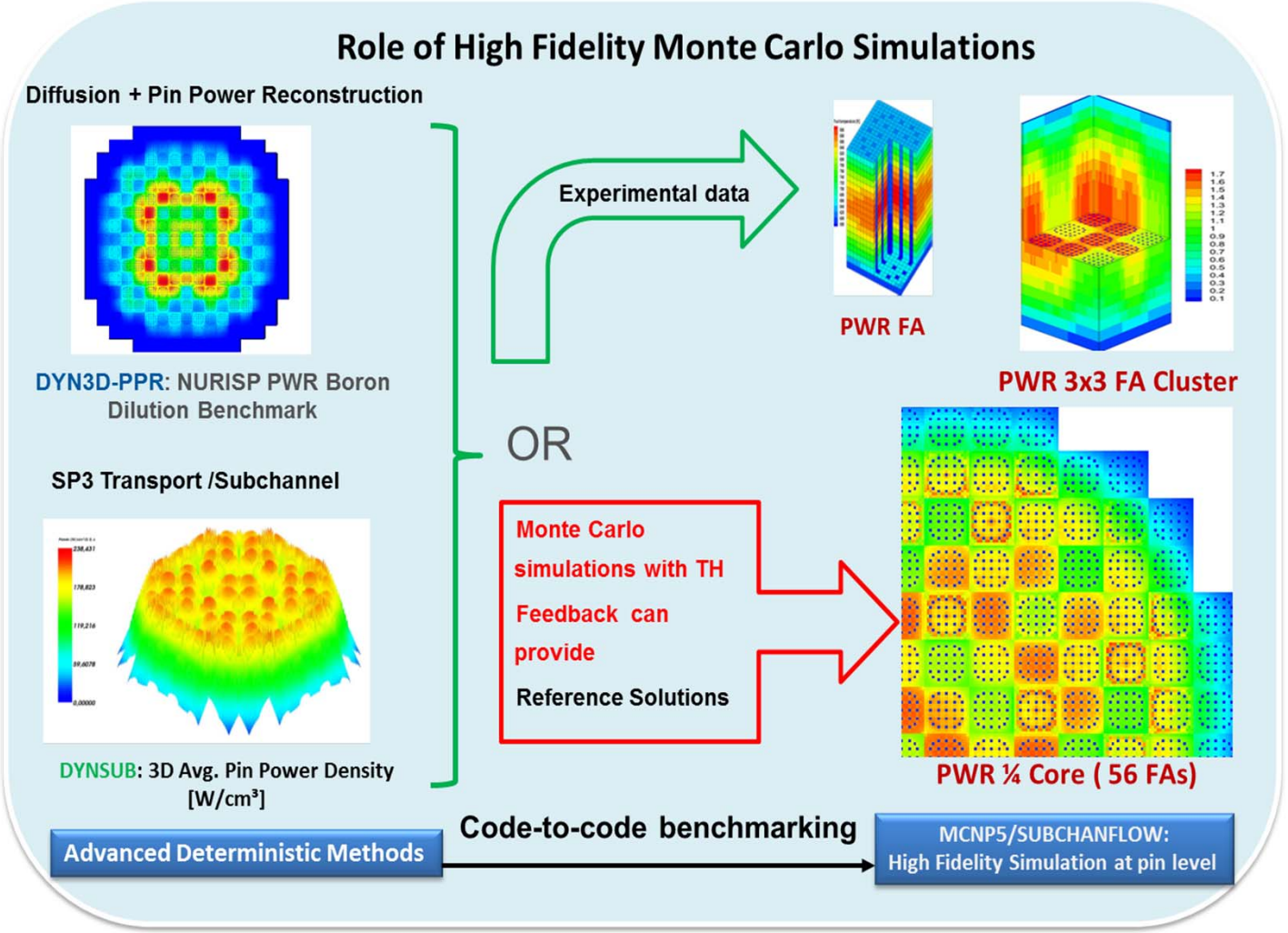
DynMCNP Simulation
1E06 particles
DynMCNP run
- 35 cores (MPI/openMP)
- 2.5 days

TRIPOLI/SCF : 3x3 Rod problem

Small cluster (28 cores): one week

McSAFE: Validation

- High-fidelity coupled MC-TH simulations as reference solutions



McSAFE: Numerical Tools and Coupling approaches

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- Focus on the **further development of European MC, TH and TM codes and on the coupled systems** already developed during the 7FP EU project HPMC to make possible **industry-like simulations of both fuel depletion with stable and accurate depletion methods and LWR transients** (safety-related) with the developed dynamic MC solutions

Methods	Monte Carlo (MC)	Thermal Hydraulic (TH)	Thermo Mechanics (TM)
Static MC-TH	TRIPOLI SERPENT MCNP MONK	SCF, FLICA, TRUST SCF, COSI SCF SCF	
Static MC-TH with depletion	TRIPOLI SERPENT MONK	SCF, FLICA, TRUST SCF, COSI SCF	TU TU, FINIX TU
Dynamic MC-TH	DynTRIPOLI Dyn SERPENT DynMCNP	SCF SCF, COSI SCF	
Dynamic MC-TH-TM	DynTRIPOLI DynSERPENT	SCF, FLICA, TRUST SCF, COSI	TU TU, FINIX

McSAFE: WP5 – Validation Matrix

- **Newly available plant data** in the frame of international benchmarks or in the single initiatives by utilities (e.g. PreussenElektra or CEZ) pave the way **for the validation of the improved capability of multi-physics tools based on Monte Carlo codes** regarding e.g. local safety parameters, depletion, and fuel behaviour

Plant Data	Static MC-TH Problem	Static MC-TH-TM Depletion Problem	Dynamic Problem
VVER-1000	TRIPOLI SERPENT/SCF MCNP/SCF	SERPENT/SCF/TU	
PWR Konvoi	TRIPOLI/SCF SERPENT/SCF MCNP/SCF	SERPENT/SCF/TU	
SPERT III E REA			DynTRIPOLI/SCF DynSERPENT/SCF DynMCNP/SCF

McSAFE: Expected Contribution

- The project will deliver **improved** and **validated high-fidelity numerical simulation tools** that can be used by different end-users (industry, regulators, research centres, etc.) to provide **reference solutions to deterministic codes for safety demonstration.**

- The McSAFE **tools** are **essential to design reactor systems with improved safety features keeping sufficient safety margins**. The project will **reinforce the European leadership's nuclear engineering methods** to better assess the safety of NPP and make NPP operation more flexible while keeping high safety standards

- The **McSAFE calculation schemes** are **applicable to any reactor type**, current or future, **provided the thermal-hydraulics codes are capable of dealing with the specific reactor type**. For future nuclear reactors verification of design calculation methods is even more important as reference data are not available

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Thank you for your attention!

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