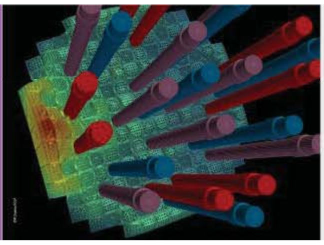

FISA 2022

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ADVANCED NUMERICAL SIMULATION AND MODELLING FOR REACTOR SAFETY – CONTRIBUTIONS FROM THE CORTEX, McSAFER AND METIS PROJECTS

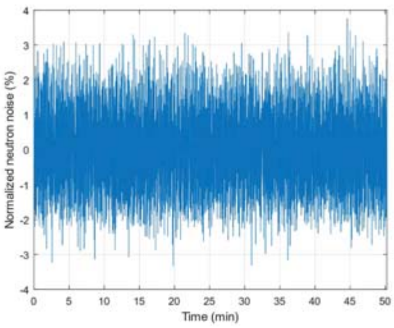
C. DEMAZIÈRE (Chalmers University of Technology, Sweden)
V.H. SANCHEZ-ESPINOZA (KIT, Germany)
I. ZENTNER (EDF R&D, France)

Introduction

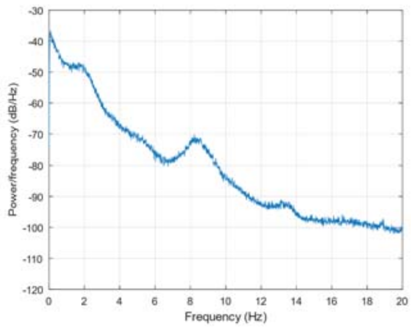
- Numerical simulations = one of the pillars of nuclear reactor safety
- New situations and/or new conditions require new modelling capabilities
- Any new modelling development also require:
  - Verification of the tools
  - Validation of the tools
- Presentation giving an overview of the CORTEX, McSAFER and METIS projects in this respect

Short description of the projects

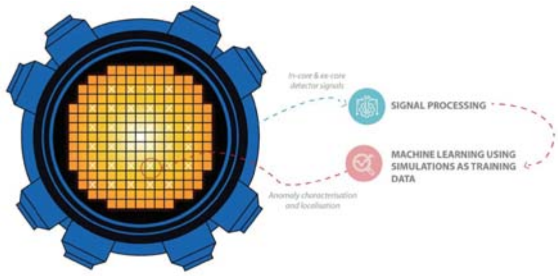
- CORTEX project overview:
  - Project running between September 1st, 2017, and August 31st, 2021
  - 18 European organizations and more than 70 researchers involved + Japan + USA
  - Main objective: develop a neutron noise-based core monitoring technique



Example of an in-core neutron detector time signal



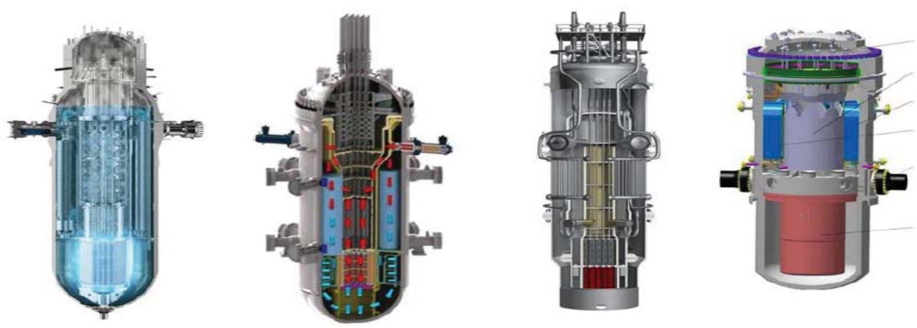
Corresponding power spectrum of the in-core neutron detector signal



More info at:
cortex-h2020.eu

Short description of the projects

- McSAFER project overview:
  - 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
- Consortium of 13 partners (6 R&D, 4 universities, 3 industry partners)
- Project running between September 1st, 2020, and August 31st, 2023
- Apply simulation tools to four SMR-designs (F-SMR, CAREM, NuScale, SMART)



CAREM (Argentina) SMART (Korea) NuScale (USA) F-SMR (France)

More info at:
mcsafer-h2020.eu

Short description of the projects

- METIS project overview:
  - Project running between September 1st, 2020, and August 31st, 2024
  - 12 European organizations + 1 Japan + 2 USA
  - Main objective: innovation in methodologies and tools for seismic risk assessment

METIS
Seismic Risk Assessment for Nuclear Safety

http://metis-h2020.eu

- METIS high level objectives:
  - Improve the predictability of (non-linear, best-estimate) beyond design analyses
  - Testing model performance by comparison to data and model updating
  - Uncertainty quantification and propagation
  - Develop, improve, disseminate open-source tools for seismic risk analysis

Key objectives in modelling needs

- In CORTEX, development of a set of complementary modelling tools:
  - Time-domain vs. frequency-domain
  - Deterministic methods vs. probabilistic methods (i.e., Monte Carlo)
  - Several levels of refinements/discretization:
    - For the angular variable, from coarse (i.e., diffusion) to fine (i.e., transport) discretization
    - For the spatial variable, from coarse (i.e., fuel assembly) to fine (i.e., fuel pin) discretization
    - For the energy variable, from coarse (i.e., two energy groups) to fine (i.e., several tens of energy groups)
    - ➢ Objective: determine the areas of validity of “low-order” approaches
  - Noise source specification via “expert opinion” or using more physical approaches (i.e., using structural mechanics models)

Key objectives in modelling needs

- McSAFER
  - Thermal hydraulics: Cross flow in the core, Helical HX, Transition from forced to natural convection, CHF, 3D flow inside the RPV, effectiveness of PRHRS, stability of natural convection flow
    - ➢ Key thermal hydraulic experiments at three EU facilities: COSMOS-H (KIT), HWAT (KTH), MOTEL (LUT)
  - Core physics: Small size (H, D), heterogeneity, harder spectrum, increased role of reflector design, increased leakage from core, etc.
    - ➢ Multiphysics deterministic and MC-based coupled codes for improve core analysis
  - 3D phenomena in integrated Reactor Pressure Vessel: Many components located inside the RPV, e.g., pumps, helical HX, PZR, structures to enhance mixing inside RPV, etc.
    - ➢ Multiscale/multiphysics safety analysis tools combining CFD, system TH and subchannel TH codes based on a modular and flexible coupling approach (ICoCo)
  - Improve safety analysis tools needed due to increase the prediction of complex phenomena in the core and inside the RPV (perturbed 3D TH phenomena) during accidents, e.g., ATWS, boron dilution, steam line break

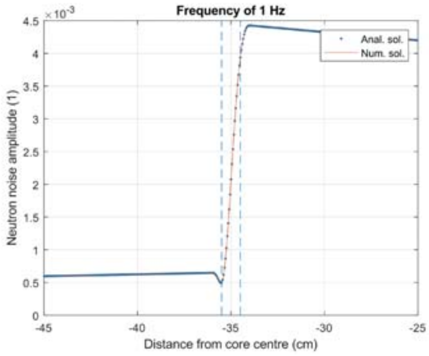
Key objectives in modelling needs

- METIS integrated approach from source to site:
  - For simulation of wave propagation from seismic source to the structure and equipment response to avoid conservatism at interface
  - For uncertainty propagation to avoid "double counting"
  - Open-source tools

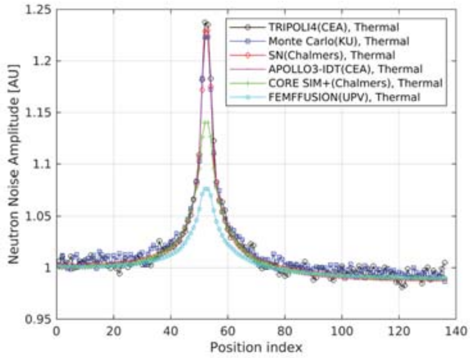
OPENQUAKE calculate share explore	code_aster	salome_meca EXPERIENCE OPEN SIMULATION	OpenSees	SCRAM
PSHA code	General purpose FEM code available with salome_meca platform	Simulation platform including pre and post processing (geometry, mesh, analyses, visualization)	FEM tool dedicated to earthquake engineering	PSA code

Key achievements

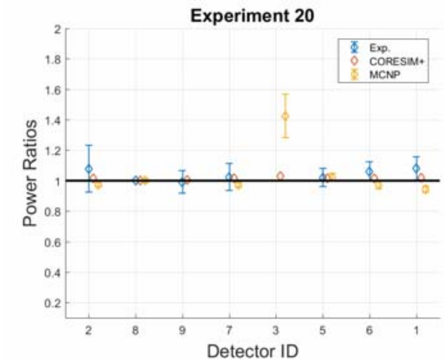
- In CORTEX, extensive program of verification and validation of the tools:



Comparison between CORE SIM and the analytical solution obtained for the case of a vibrating region



Benchmark of the various tools for a vibrating fuel pin in an infinite fuel assembly lattice

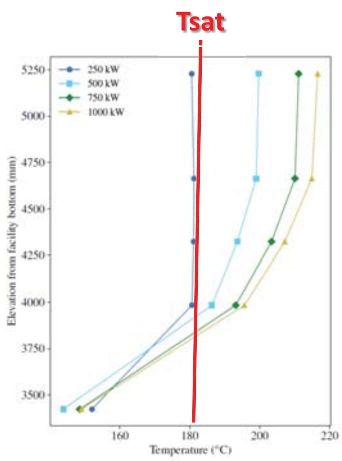


Comparisons between calculations and experiments at AKR-2, TU Dresden, Germany

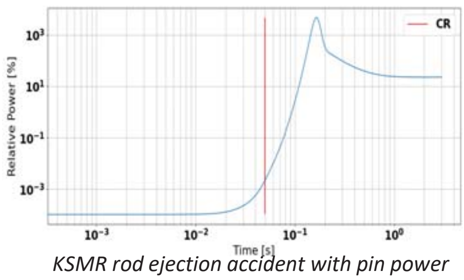
Key achievements

- McSAFER

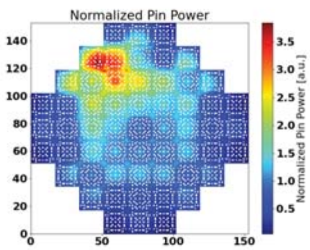
MOTEL test to study the TH of helical HX



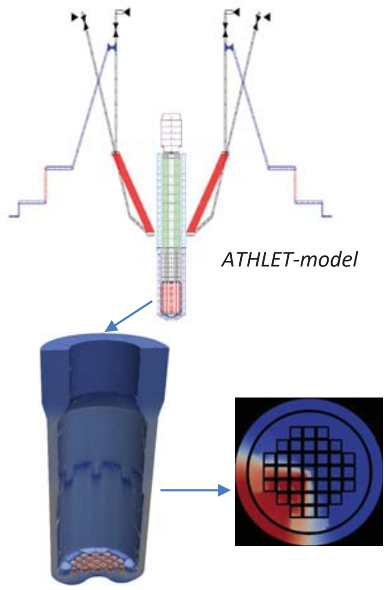
Averaged axial temperature profiles of all steam generator tubes with different core power levels



KSMR rod ejection accident with pin power reconstruction at power peak



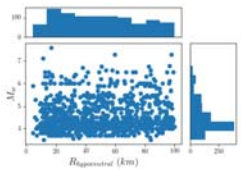
KSMR REA analysis: relative power [%] predicted by PARCS/SCF



Multiscale TH: NuScale analysis with ATHLET/TrioCFD

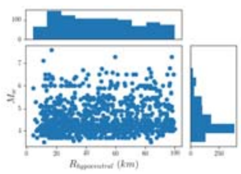
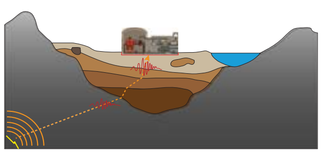
Key achievements

- METIS


Seismic source and ground motion
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Aftershock seismicity models • V&V procedure (« PSHA Testing »)

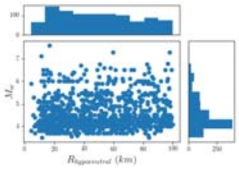
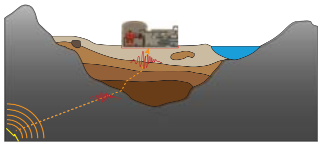
Key achievements

- METIS

	
Seismic source and ground motion	**Site response**
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Aftershock seismicity models • V&V procedure (« PSHA Testing »)	• Numerical simulation of wave propagation including geometry and spatial variability of soil properties

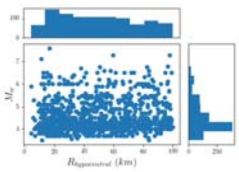
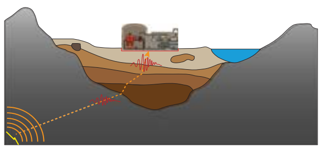
Key achievements

- METIS

		
Seismic source and ground motion	**Site response**	**SSCs response and fragility**
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Aftershock seismicity models • V&V procedure (« PSHA Testing »)	• Numerical simulation of wave propagation including geometry and spatial variability of soil properties	• V&V procedure including Bayesian model updating by comparison to observations

Key achievements

- METIS

			
Seismic source and ground motion	**Site response**	**SSCs response and fragility**	**Risk quantification**
• Efficient sampling plans for uncertainty propagation • Stochastic ground motion simulation model • Aftershock seismicity models • V&V procedure (« PSHA Testing »)	• Numerical simulation of wave propagation including geometry and spatial variability of soil properties	• V&V procedure including Bayesian model updating by comparison to observations	• New open-source tool for seismic risk assessment (SCRAM coupled to Andromeda) and data management tool to facilitate uncertainty propagation and parametric analysis

Training, education and dissemination activities

- All projects are based on:
  - The organization of short courses/workshops/summer schools
  - The organization of training sessions on tools/codes
  - The involvement of young scientists
  - The publication of many reports (deliverables), journal papers and conference proceedings – most of them being open access
  - The participation to and presentation at conferences and technical meetings
  - The use of various communication channels (website, social media channels, newsletters, popular science videos, posters, flyers)
  - The establishment of contacts with other projects and international organizations

Utilization and cross-fertilization

- Industrial applications and usefulness at the core of the projects
- Development of new modelling capabilities not (yet) part of the industrial tools

➢ Some of the tools are open source/freely available

- Cross-disciplinary projects involving many areas profiting from each other
- Projects having ramifications beyond Europe
- Heavy “end-user’s” involvement to always remain align with the needs of the industry

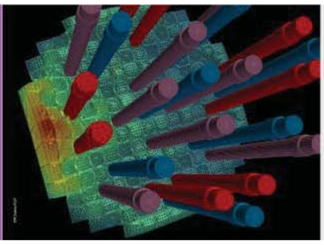
➢ Projects resulting in better understanding of the physics, safer plants, higher operational flexibility and enhanced economics

Conclusions and future recommendations

- CORTEX/METIS: Methods, if to be used by the industry, should be made:
  - Directly applicable to industrial contexts
  - Easier to use
  - More robust
  - More transparent
  - Available with validated software
- McSAFER:
  - New data from safety-related thermal hydraulic test under SMR-conditions will be available for code validation
  - Promising capabilities of multi-physics and scale methods for safety evaluations and their complementarity with industry-like tools
  - Potentials of modular and flexible ICoCo-approach for code coupling (multi-scale and physics)

Acknowledgements

- All contributors to the projects are deeply acknowledged for their efforts and dedication
- Financial support:
  - The CORTEX project was funded from the Euratom Research and Training Programme 2014-2018 under the grant agreement number 754316
  - The McSAFER project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement number 945063
  - The METIS project has received funding from the Horizon 2020 programme under grant agreement number 945121



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