

CORTEX

Core monitoring techniques and
experimental validation and demonstration

Status of the Horizon 2020 project on COre monitoring Techniques and EXperimental validation and demonstration (CORTEX)

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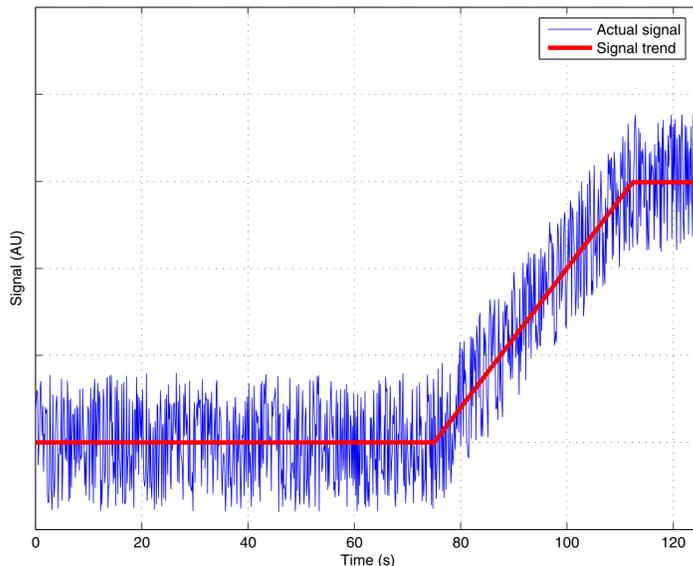
Introduction

- Ageing fleet of reactors and more frequent operational problems to be expected
- Of value to:
 - Monitor the instantaneous state of the reactor during operation
 - Detect possible anomalies early on
 - Pinpoint the reasons of the anomalies



Introduction

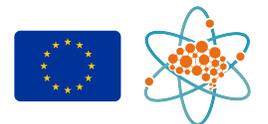
- Fluctuations always existing in reactors even at steady state-conditions (due to turbulence, vapour generation, mechanical vibrations, etc.)



Conceptual illustration of the possible time-dependence of a process signal from a nuclear reactor

$$X(\mathbf{r}, t) = X_0(\mathbf{r}, t) + \delta X(\mathbf{r}, t)$$

- Fluctuations carrying some valuable information about the system dynamics
- Fluctuations could be used for core diagnostics: “noise analysis”



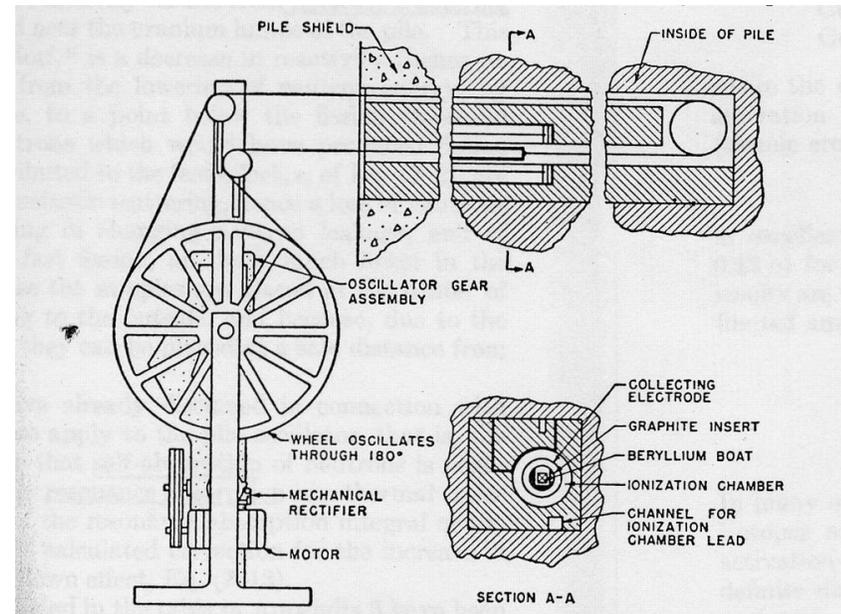
Introduction

- Presentation aimed at:
 - Giving an overview of the European project CORTEX (started on September 1st, 2017)
 - Quickly presenting some of the achievements so far



Early development in noise analysis

- Oscillator experiments in the Clinton Pile at ORNL, USA



- Response in neutron flux corresponding to a local (but stationary) excitation of the system deviating from point-kinetics: local component of the neutron noise (1949)

Early development in noise analysis

- Detection of excessive vibrations of control rods in the Oak Ridge Research Reactor and the High Flux Isotope Reactor (1971)
 - Noise analysis was born
- First applications in commercial reactors:
 - Core-barrel vibrations at the Palisades plant, USA (1975)
 - Estimation of in-core coolant velocity in German BWRs (1979)



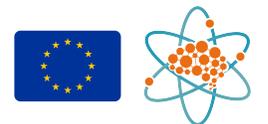
Some examples of core monitoring using noise analysis

- Location of excessively vibrating control rods
 - BWR stability monitoring
 - Detection of excessively vibrating and possibly impacting detector tubes in BWRs
 - Core barrel monitoring in PWRs
 - Location of excessively vibrating fuel assemblies
- In more general terms: detection and location of anomalies



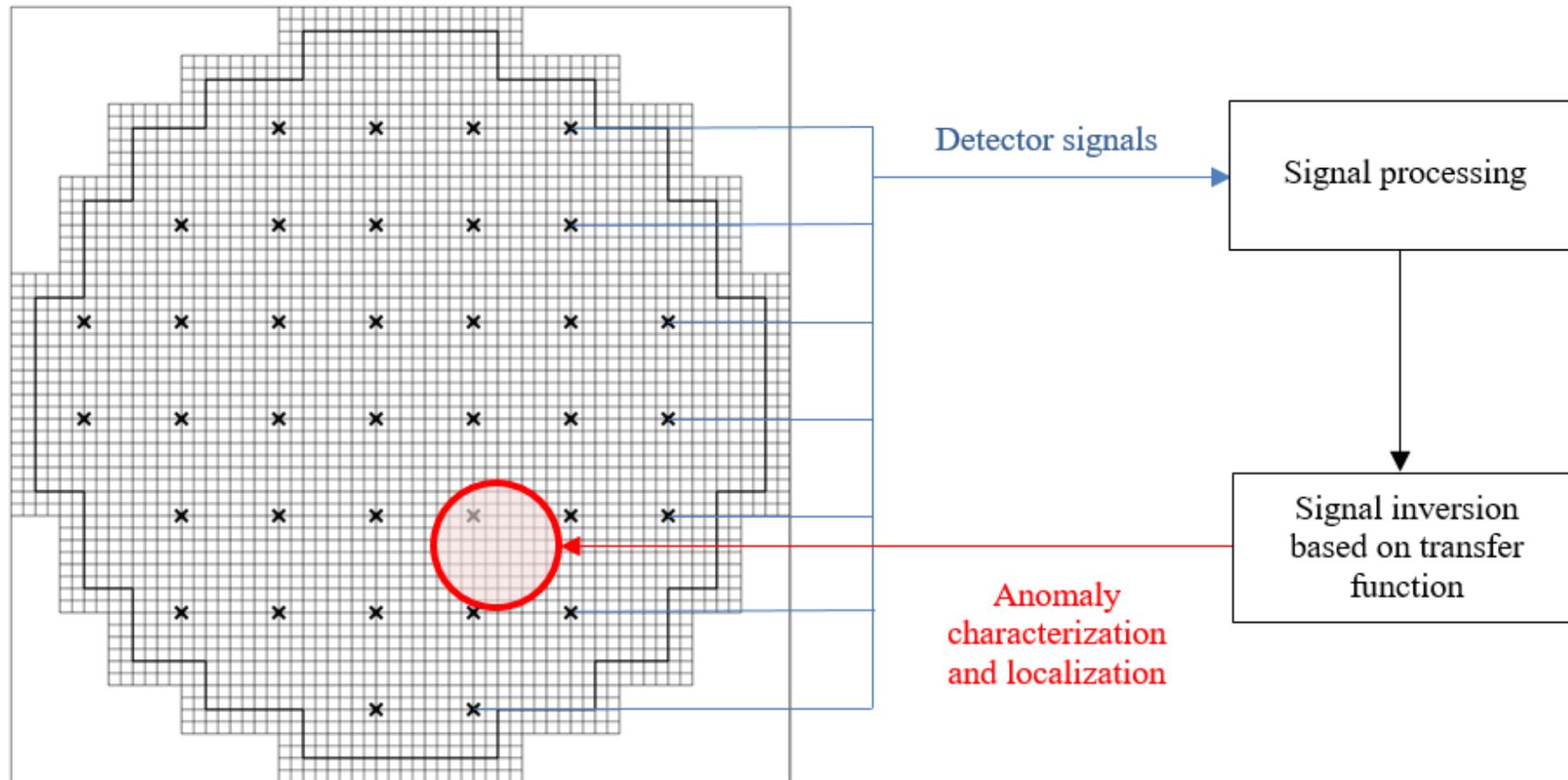
Overview of CORTEX

- Need for core monitoring techniques recently demonstrated by the increase in the neutron noise levels in some Spanish, German, and Swiss Pre-Konvoi PWRs
 - Need to develop the necessary tools before the problems occur
 - CORTEX project proposal submitted to the Euratom 2016-2017 work program (CORe monitoring Techniques and EXperimental validation and demonstration)
 - CORTEX obtained the NUGENIA label in August 2016
 - CORTEX project approved for funding by the European Commission in February 2017
 - CORTEX project started on September 1st, 2017



Overview of CORTEX

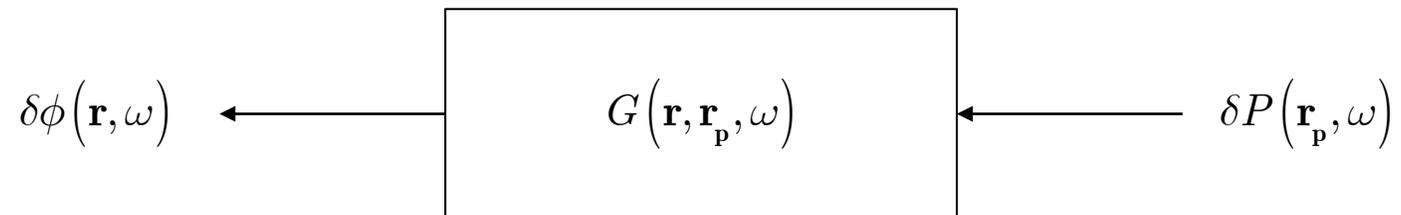
- Project concept:



Overview of CORTEX

- Signal analysis techniques of help...
but insufficient for backtracking the nature and spatial distribution of possible anomalies

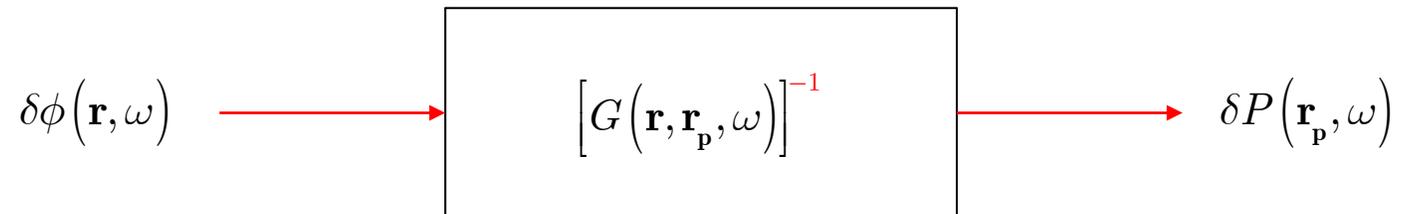
➤ Need to be able to invert the reactor transfer function $G(\mathbf{r}, \mathbf{r}_p, \omega)$



Overview of CORTEX

- Signal analysis techniques of help...
but insufficient for backtracking the nature and spatial distribution of possible anomalies

➤ Need to be able to invert the reactor transfer function $G(\mathbf{r}, \mathbf{r}_p, \omega)$



Overview of CORTEX

- Project aims:
 - WP1: Developing high fidelity tools for simulating stationary fluctuations
 - WP2: Validating those tools against experiments to be performed at research reactors
 - WP3: Developing advanced signal processing and machine learning techniques (to be combined with the simulation tools)
 - WP4: Demonstrating the proposed methods for both on-line and off-line core diagnostics and monitoring
 - WP5: Disseminating the knowledge gathered from within the project to stakeholders in the nuclear sector



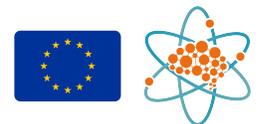
Overview of CORTEX

- Project participants:
 - Project led and coordinated by Chalmers University of Technology
 - 18 European organizations involved in the project:
 - CEA and LGI Consulting (France)
 - Centre for Energy Research, Hungarian Academy of Sciences – MTA EK (Hungary)
 - EPFL, KKG, PSI (Switzerland)
 - GRS, ISTec, TIS, PEL, TU Dresden and TU Munich (Germany)
 - Institute of Communication & Computer Systems - National Technical University of Athens (Greece)
 - UJV (Czech Republic)
 - University of Lincoln (UK)
 - UPM and UPV (Spain)



Overview of CORTEX

- Project participants:
 - 2 non-European organizations formally involved in the project:
 - KURRI (Japan)
 - AMS Corp (USA)
 - + 1 organization informally involved in the project: Nagoya University (Japan)
- 7 additional organizations involved in the Advisory End-User Group:
 - IRSN (France)
 - KKG (Switzerland)
 - PEL (Germany)
 - Ringhals (Sweden)
 - Tractebel (Belgium)
 - CNAT (Spain)
 - AREVA (Germany)
 - Westinghouse Electric Sweden AB (Sweden)
 - NRG (the Netherlands)



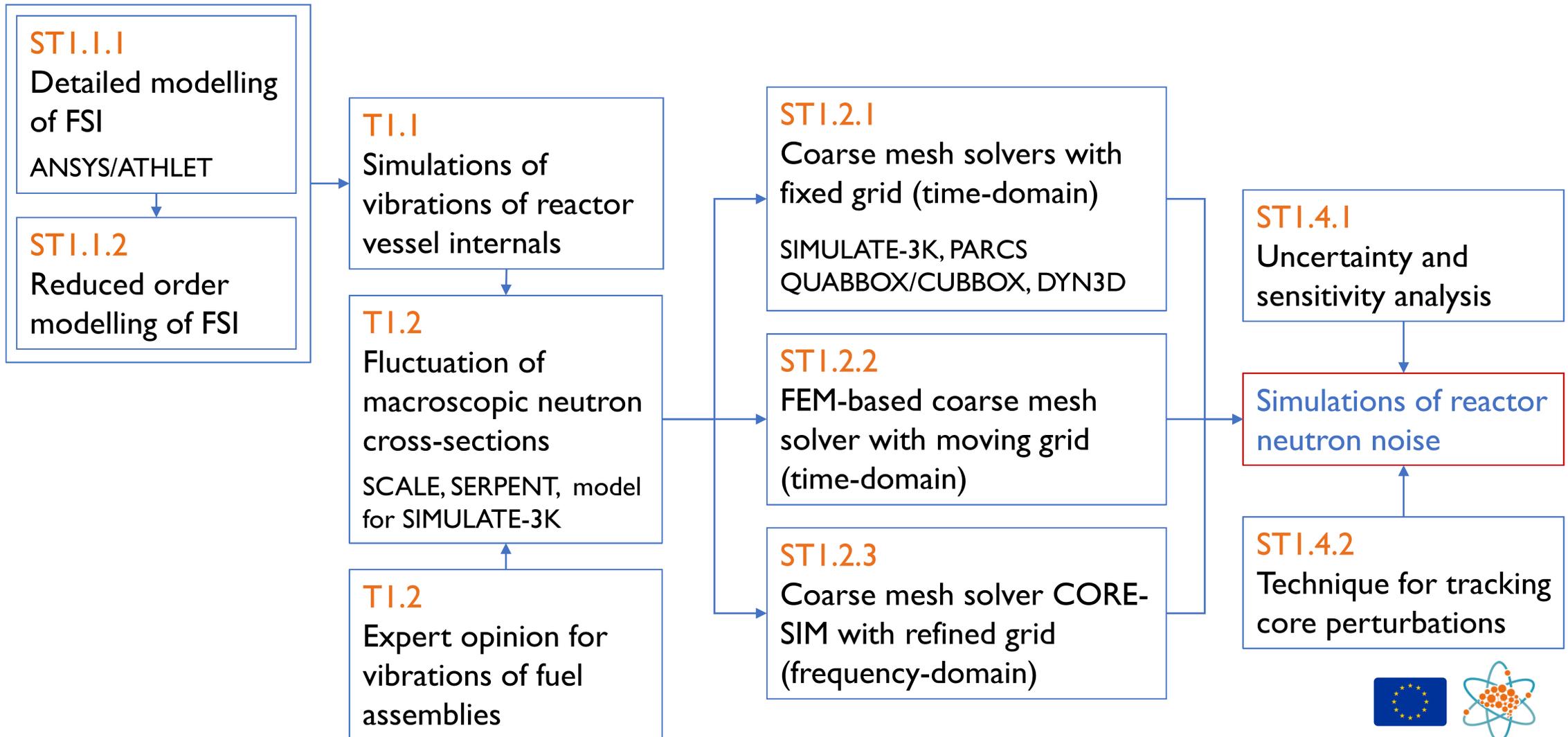
WPI: Development of modelling capabilities for reactor noise analysis

Objectives:

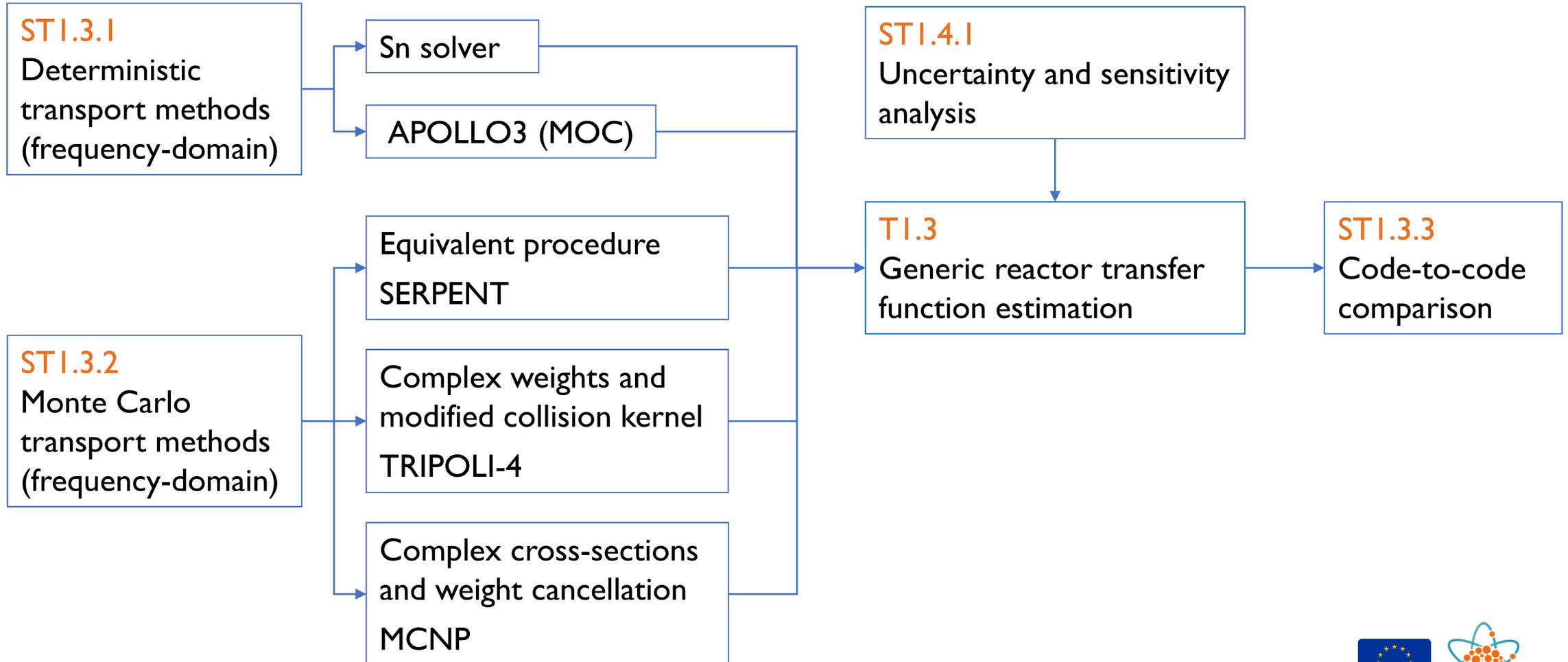
- To develop modelling capabilities allowing the determination, for any reactor core, of the fluctuations in neutron flux resulting from known perturbations applied to the system
- To express such perturbations as either fluctuations of macroscopic cross-sections based on expert opinion, or in more physical terms, such as vibrations of components (FSI)
- To evaluate the uncertainties associated to the estimation of the reactor transfer function and to perform sensitivity analysis in reactor dynamic calculations



WPI: Development of modelling capabilities for reactor noise analysis

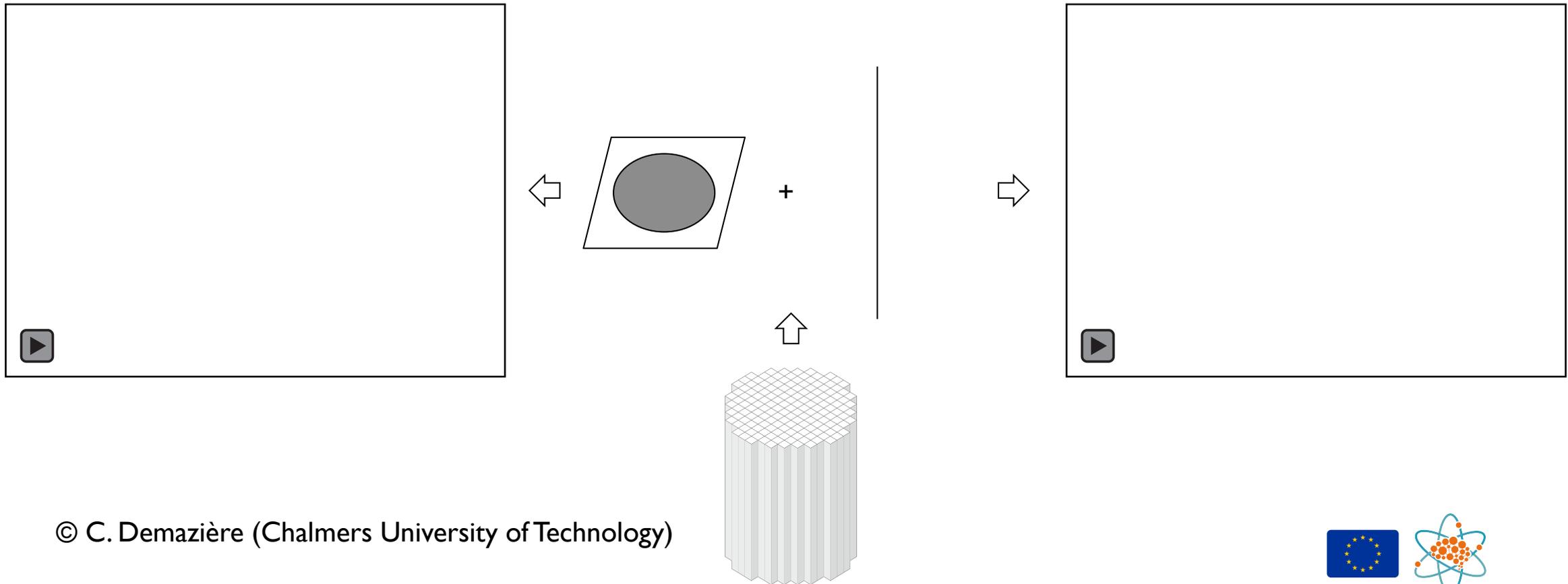


WPI: Development of modelling capabilities for reactor noise analysis



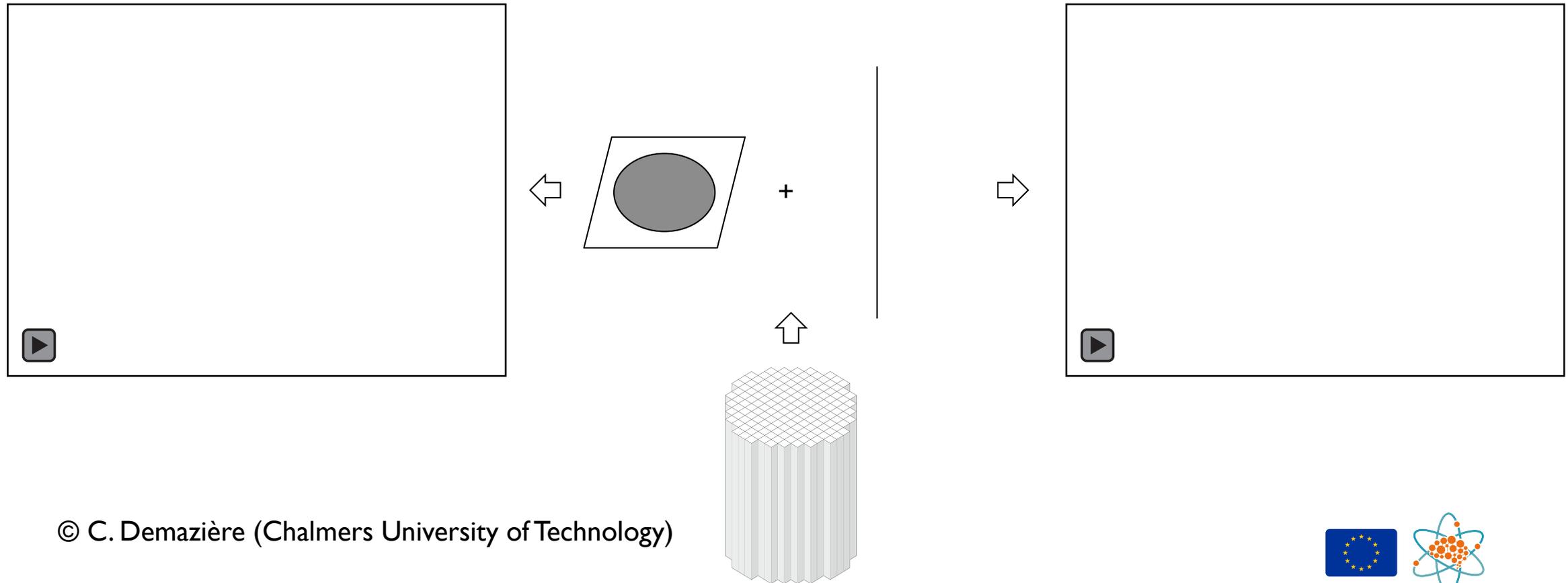
WPI: Development of modelling capabilities for reactor noise analysis

Example of a localized “absorber of variable strength” @ 1kHz



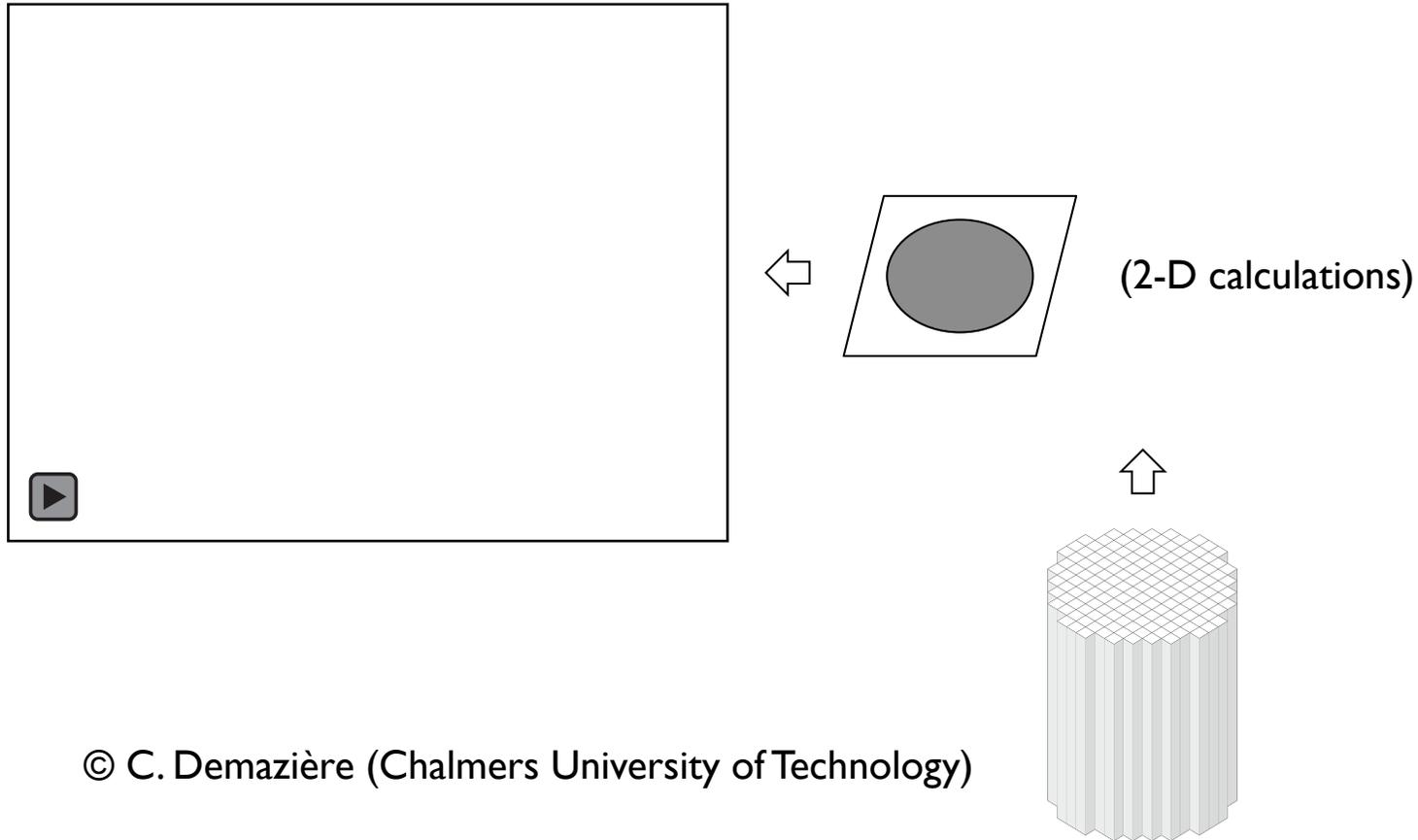
WPI: Development of modelling capabilities for reactor noise analysis

Example of a travelling perturbation @ 1 Hz



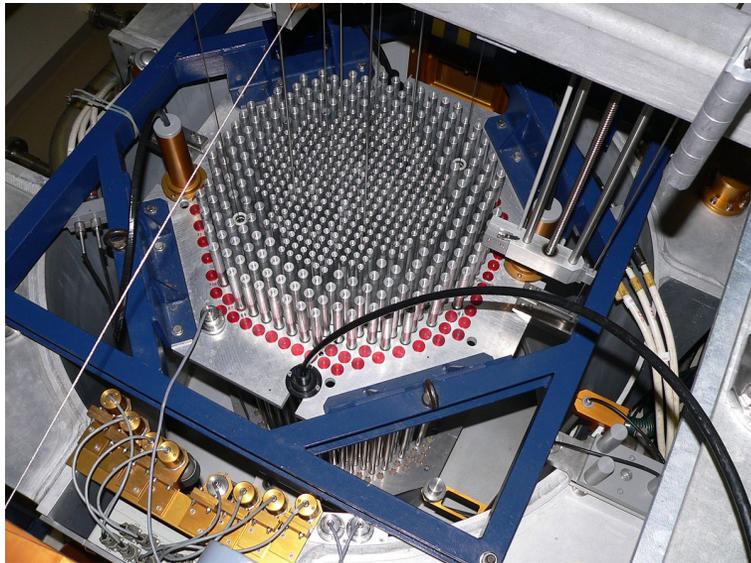
WPI: Development of modelling capabilities for reactor noise analysis

Example of a vibrating control rod @ 0.2 Hz



WP2: Validation of the modelling tools against experiments in research reactors

Use of the AKR-2 (TU Dresden) and CROCUS (EPFL) research reactors for reactor transfer function validation



CROCUS reactor @EPFL, Switzerland

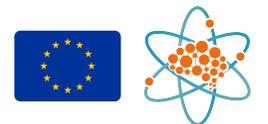


AKR-2 reactor @TU Dresden, Germany

WP2: Validation of the modelling tools against experiments in research reactors

Objectives:

- Validation of the modelling tools produced in WP1 against experimental measurements: localized absorber of variable strength + moving absorber
- Development of new detectors
- First measurements at AKR-2 just completed



WP3: Development of advanced signal processing and machine learning methodologies for analysis of plant data

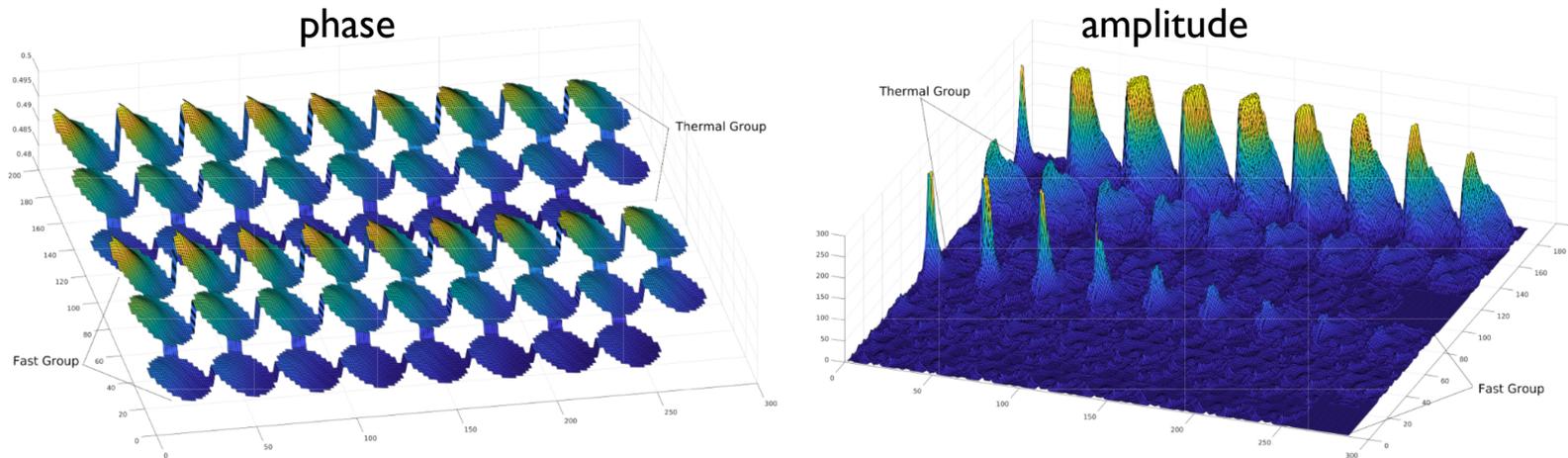
Objectives:

- Detection of abnormal fluctuations and their classification
- Inversion of the reactor transfer function
- Handling of the scarcity of in-core instrumentation
- Handling of intermittences



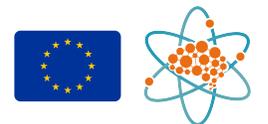
WP3: Development of advanced signal processing and machine learning methodologies for analysis of plant data

- First machine learning tests performed by University of Lincoln, UK:
 - Absorber of variable strength
 - 3-D induced neutron noise unrolled as 2-D images:



© F. Calivà, F. De Sousa Ribeiro, G. Leontidis, S. Kollias (University of Lincoln)

- Use of a Deep Convolution Neural-Network (Inception V3 CNN) leading to excellent unfolding



WP4: Application and demonstration of the developed modelling tools and signal processing techniques against plant data

Objectives:

- Demonstration of the applicability and usefulness of the tools on many reactors (PWRs and VVERs)
- Detection of abnormal fluctuations, understanding of their origin and classification according to their safety impact
- Recommendations about in-core/out-of-core instrumentation

WP just started with neutron noise measurements at KKG



Conclusions

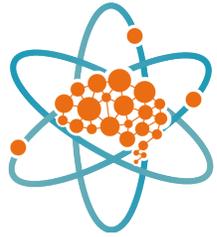
- Core monitoring becoming increasingly important
- Need to develop the necessary tools and expertise before the problems occur
- CORTEX gathering a cross-disciplinary team of experts for developing core monitoring techniques for industrial applications
- Short course “Fundamentals of reactor kinetics and theory of small space-time dependent fluctuations in nuclear reactors”, June 18-21, Chalmers University of Technology, Gothenburg, Sweden



Conclusions

- Follow the project on LinkedIn, Twitter and Facebook and at <http://cortex-h2020.eu/>





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