CORTEX

Core monitoring techniques and experimental validation and demonstration

Overview of the CORTEX project

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This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754316.

Introduction

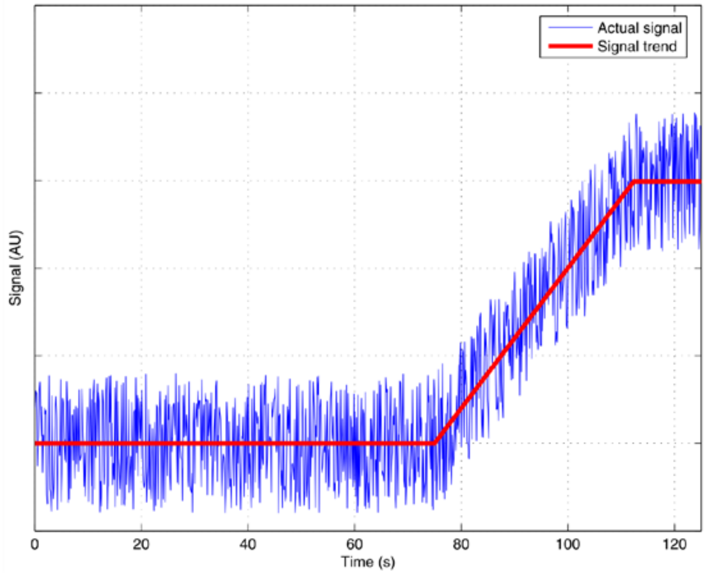
- Ageing fleet of reactors and more frequent operational problems to be expected

➢ 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

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

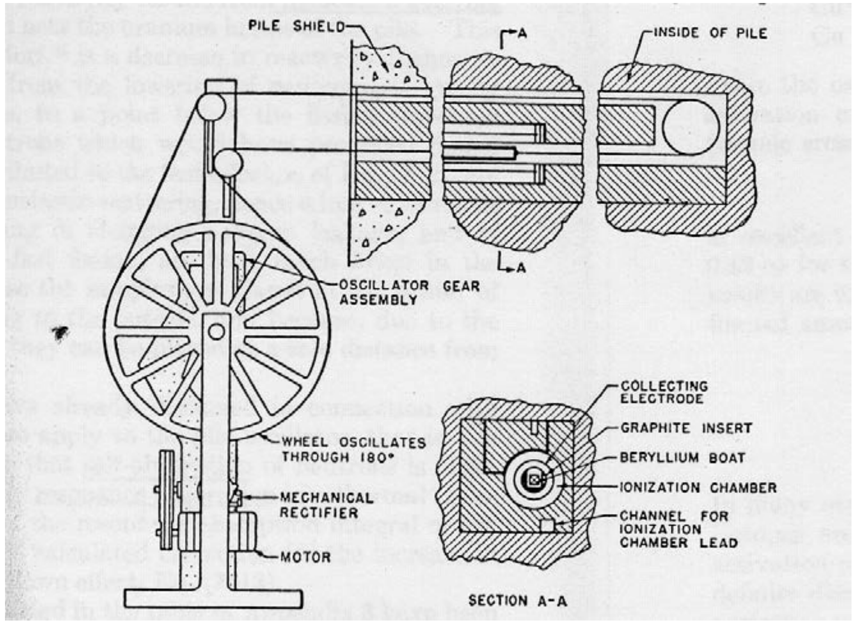
- ➢ Fluctuations carrying some valuable information about the system dynamics
- ➢ Fluctuations could be used for core diagnostics: "noise analysis"

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)

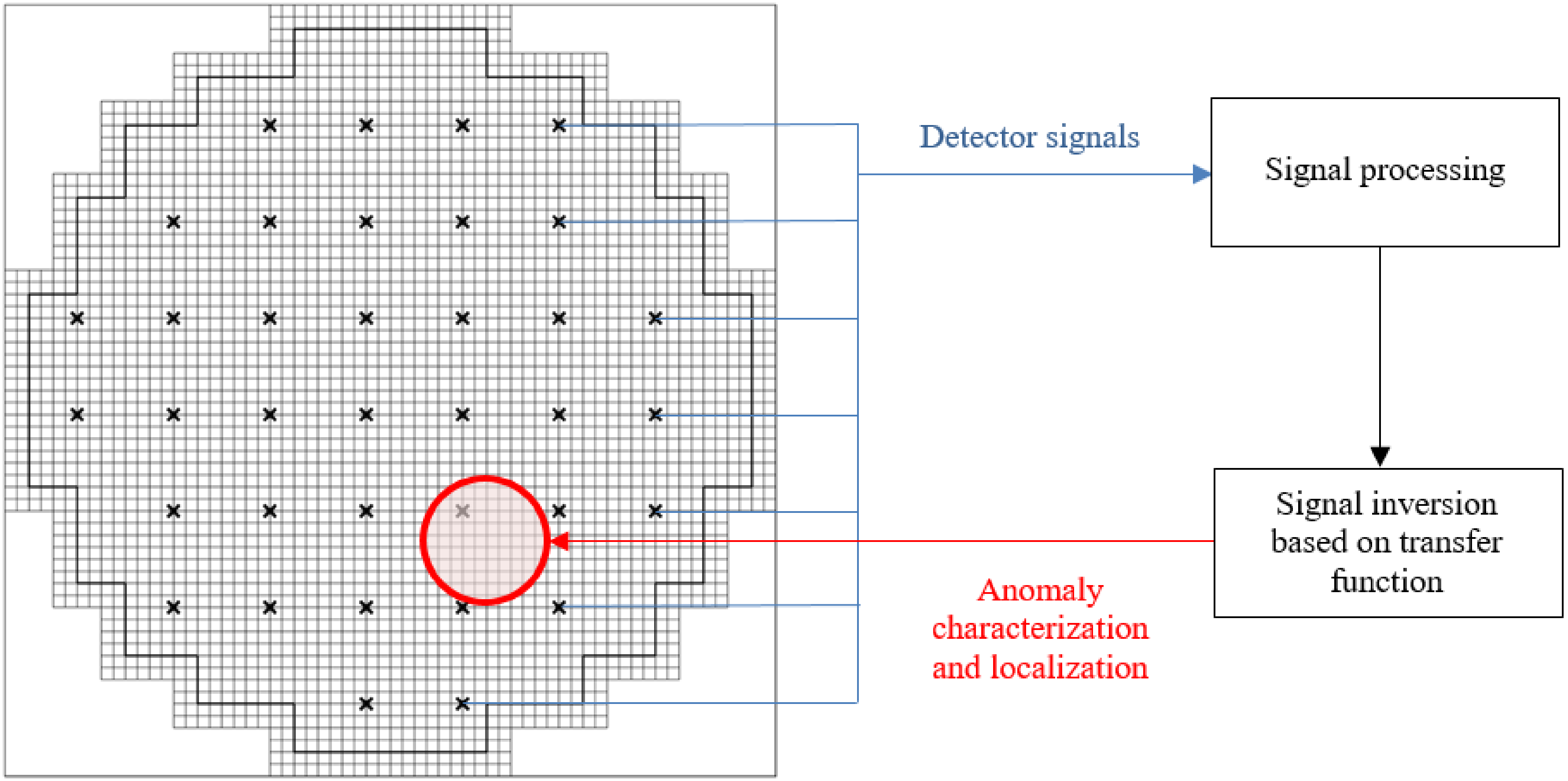
➢ CORTEX obtained the NUGENIA label in August 2016

➢ CORTEX project approved for funding by the European Commission in February 2017

➢ CORTEX project started on September 1st, 2017

Overview of CORTEX

- Project concept:

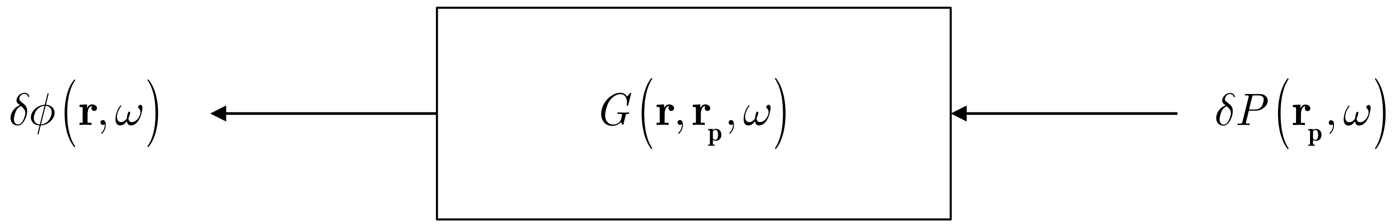


Overview of CORTEX

- 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 $G(\mathbf{r}, \mathbf{r}_{\mathrm{p}}, \omega)$



Overview of CORTEX

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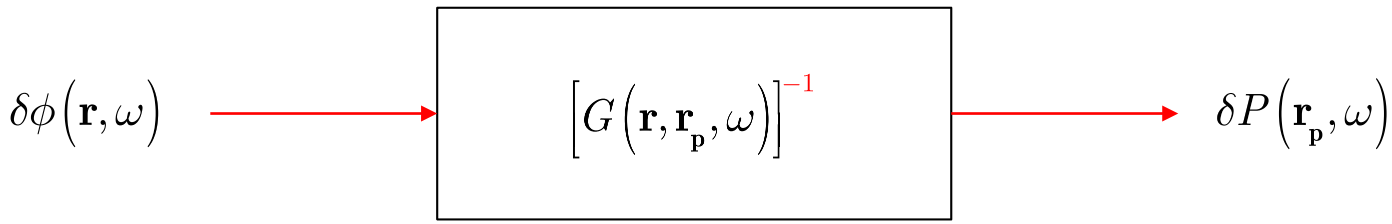


Overview of CORTEX

- 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
  - WP4: 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)

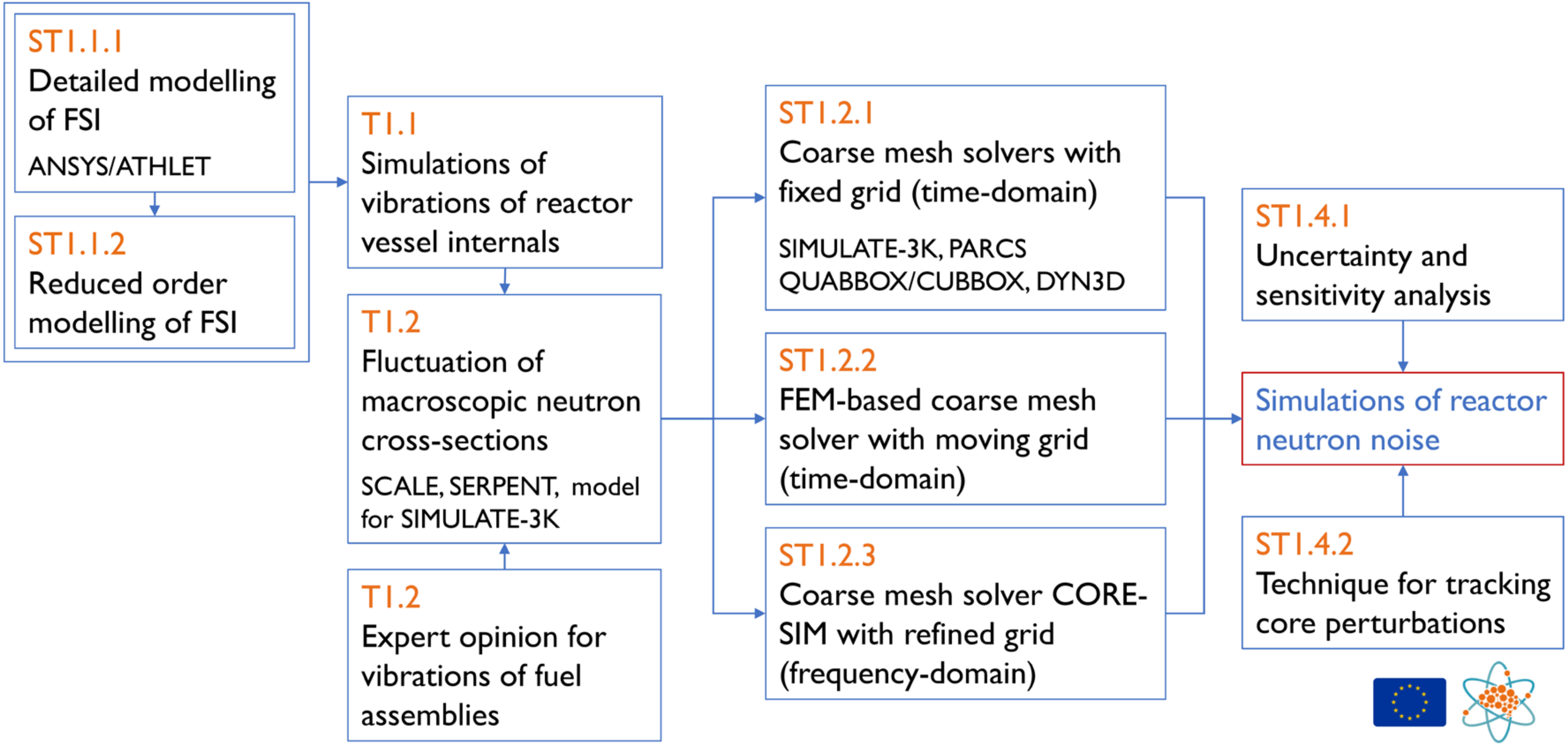
  - 7 additional organizations involved in the Advisory End-User Group:
    - IRSN (France)
    - KKG (Switzerland)
    - PEL (Germany)
    - Ringhals (Sweden)
    - Tractebel (Belgium)
    - CNAT (Spain)
    - AREVA (Germany)
    - Westinghouse Electric Sweden AB (Sweden)
    - NRG (the Netherlands)

WP1: Development of modelling capabilities for reactor noise analysis

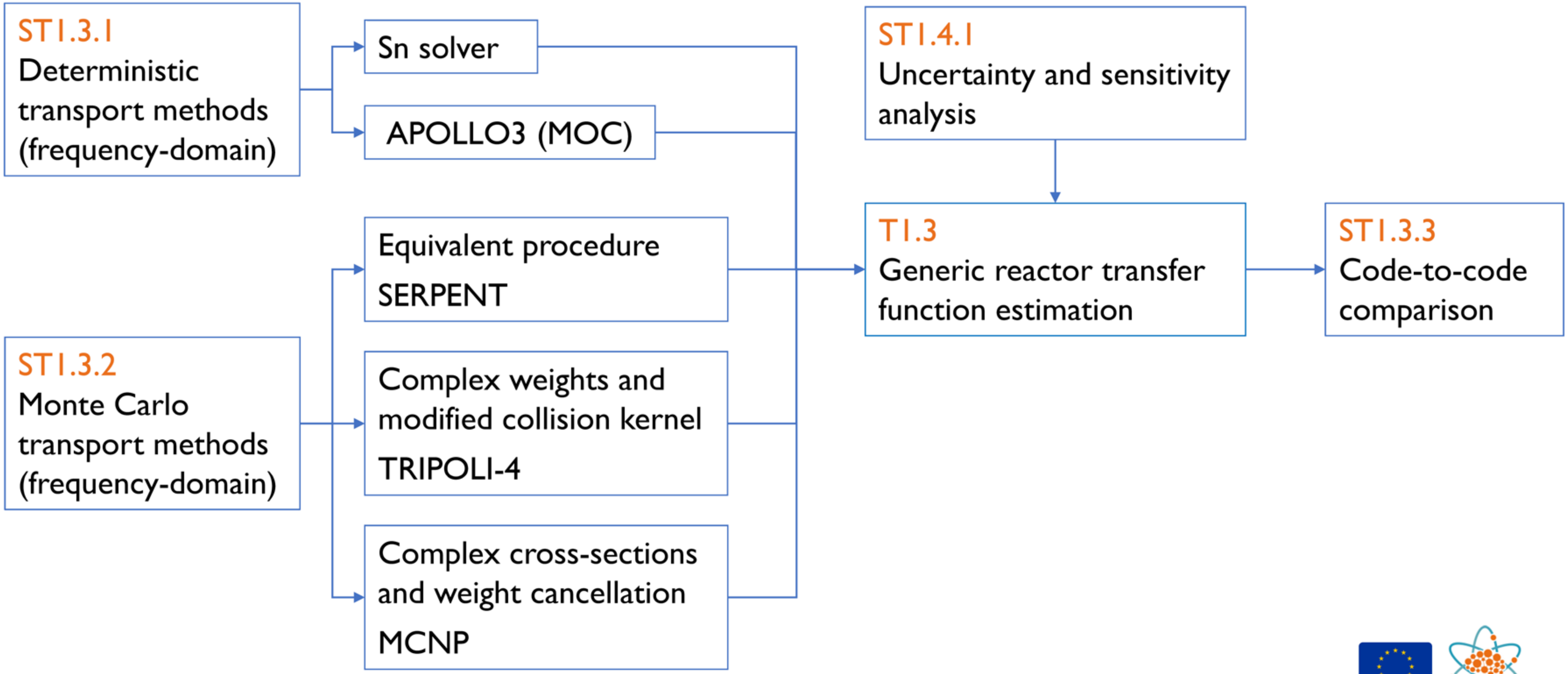
Objectives:

- 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

WP1: Development of modelling capabilities for reactor noise analysis

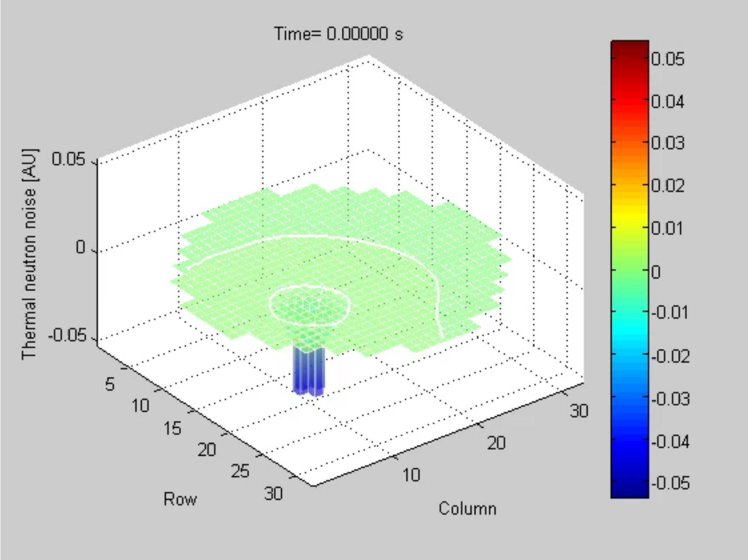


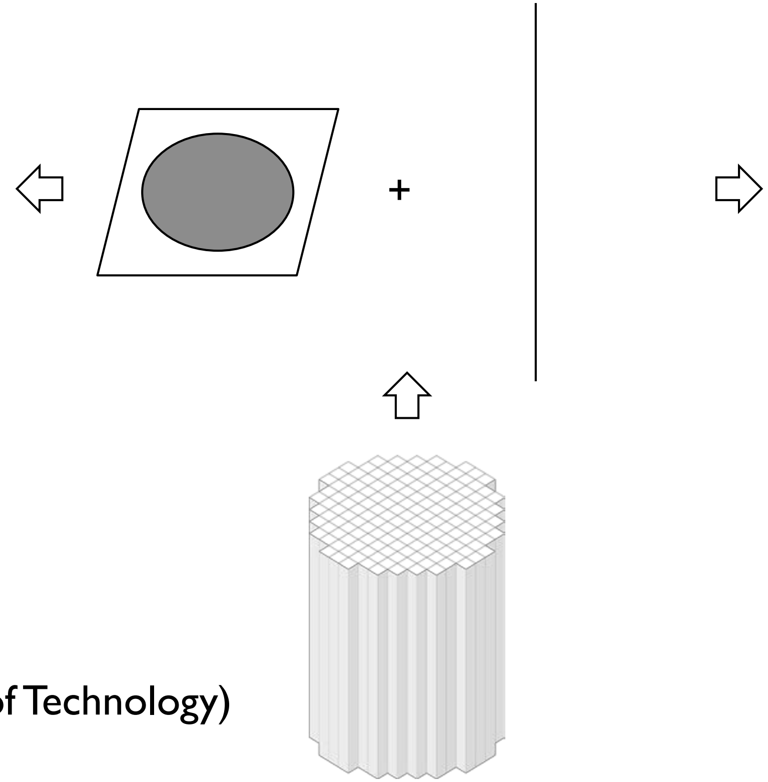
WP1: Development of modelling capabilities for reactor noise analysis

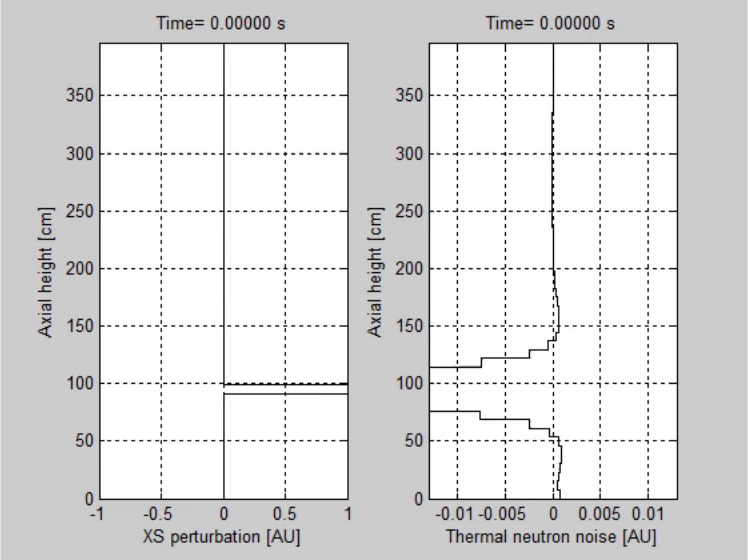


WP1: Development of modelling capabilities for reactor noise analysis

Example of a localized "absorber of variable strength" @ 1kHz







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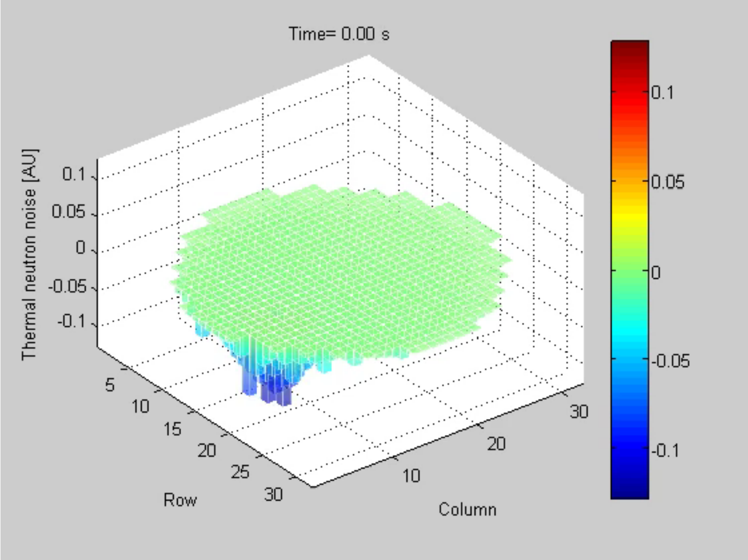
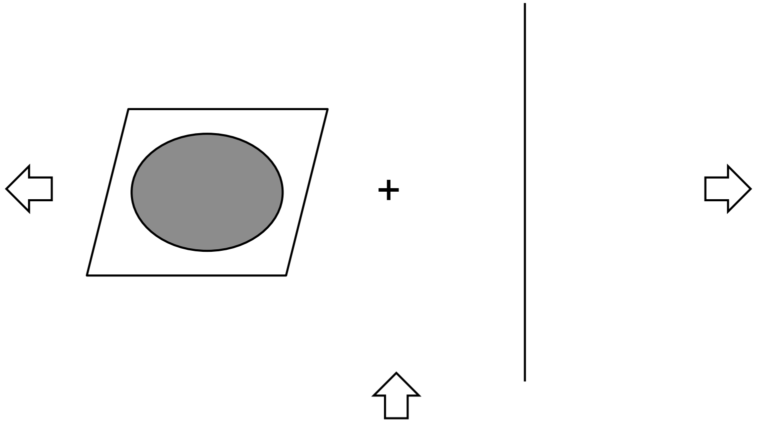
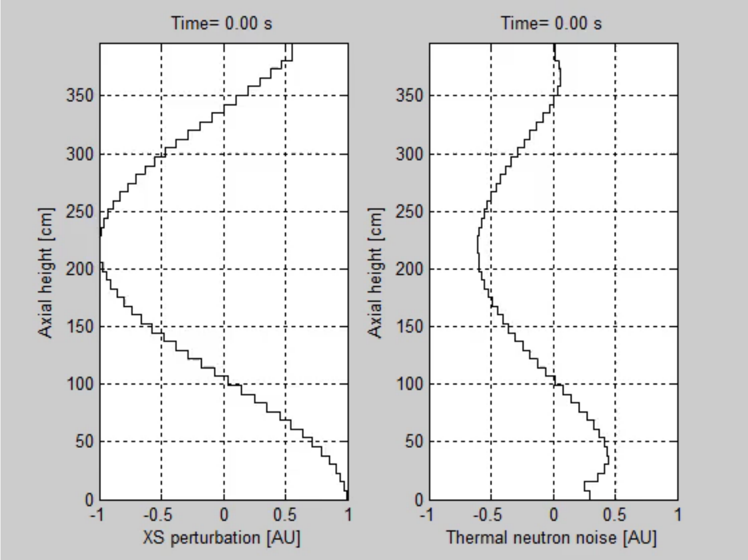
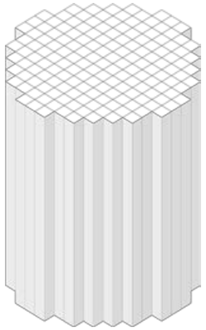
WP1: Development of modelling capabilities for reactor noise analysis

Example of a travelling perturbation @ 1Hz



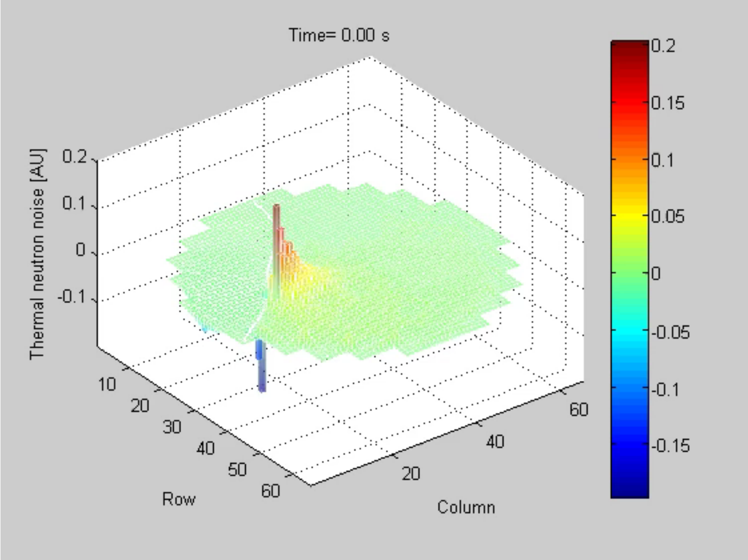


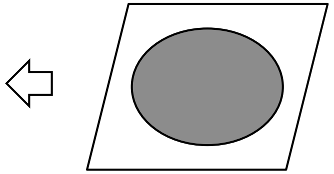




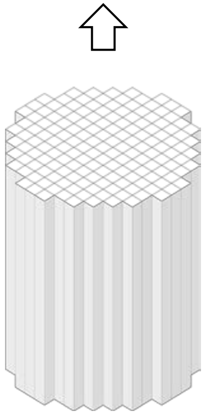
WP1: Development of modelling capabilities for reactor noise analysis

Example of a vibrating control rod @ 0.2 Hz



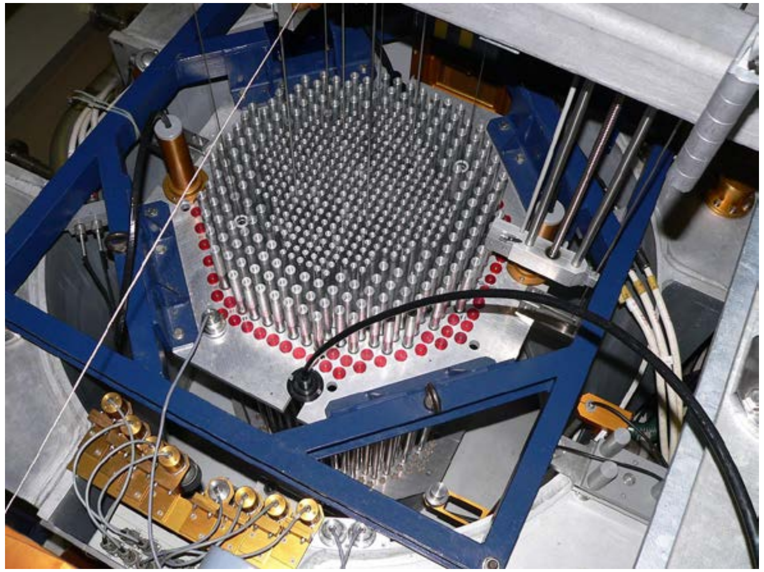


(2-D calculations)



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

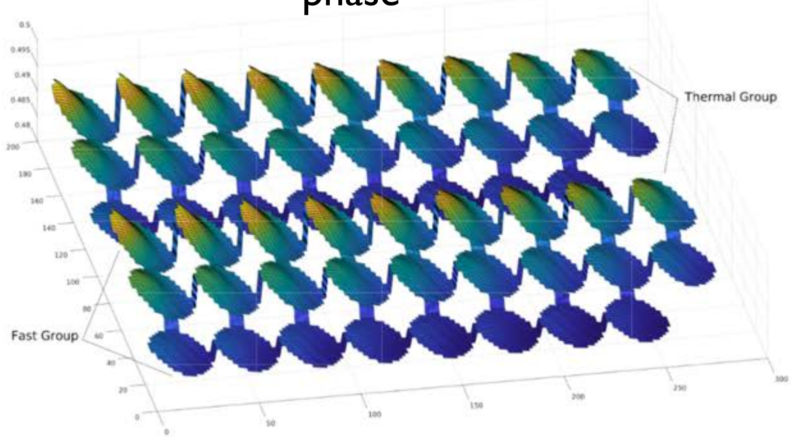
Objectives:

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

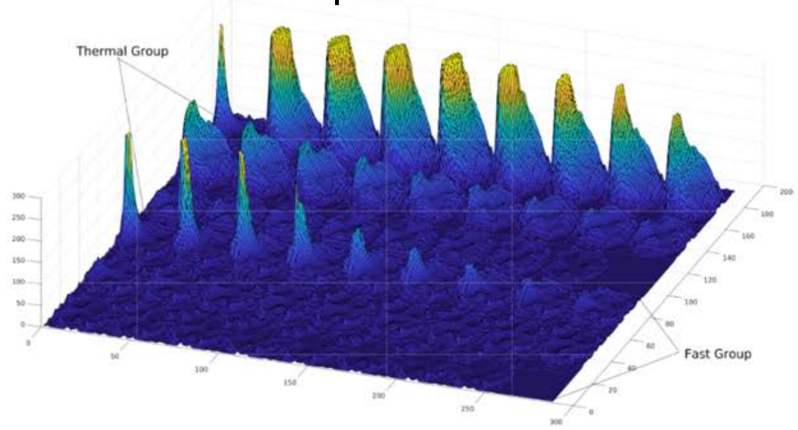
WP3: Development of advanced signal processing and machine learning methodologies for analysis of plant data

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

phase



amplitude



➢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 (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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