CORTEX

Core monitoring techniques and experimental validation and demonstration

Recommendations for Core Monitoring to Enhance the Detection and Discrimination of Anomalies by Neutron Noise Measurements

2022-06-21

Kerntechnik 2022, Leipzig

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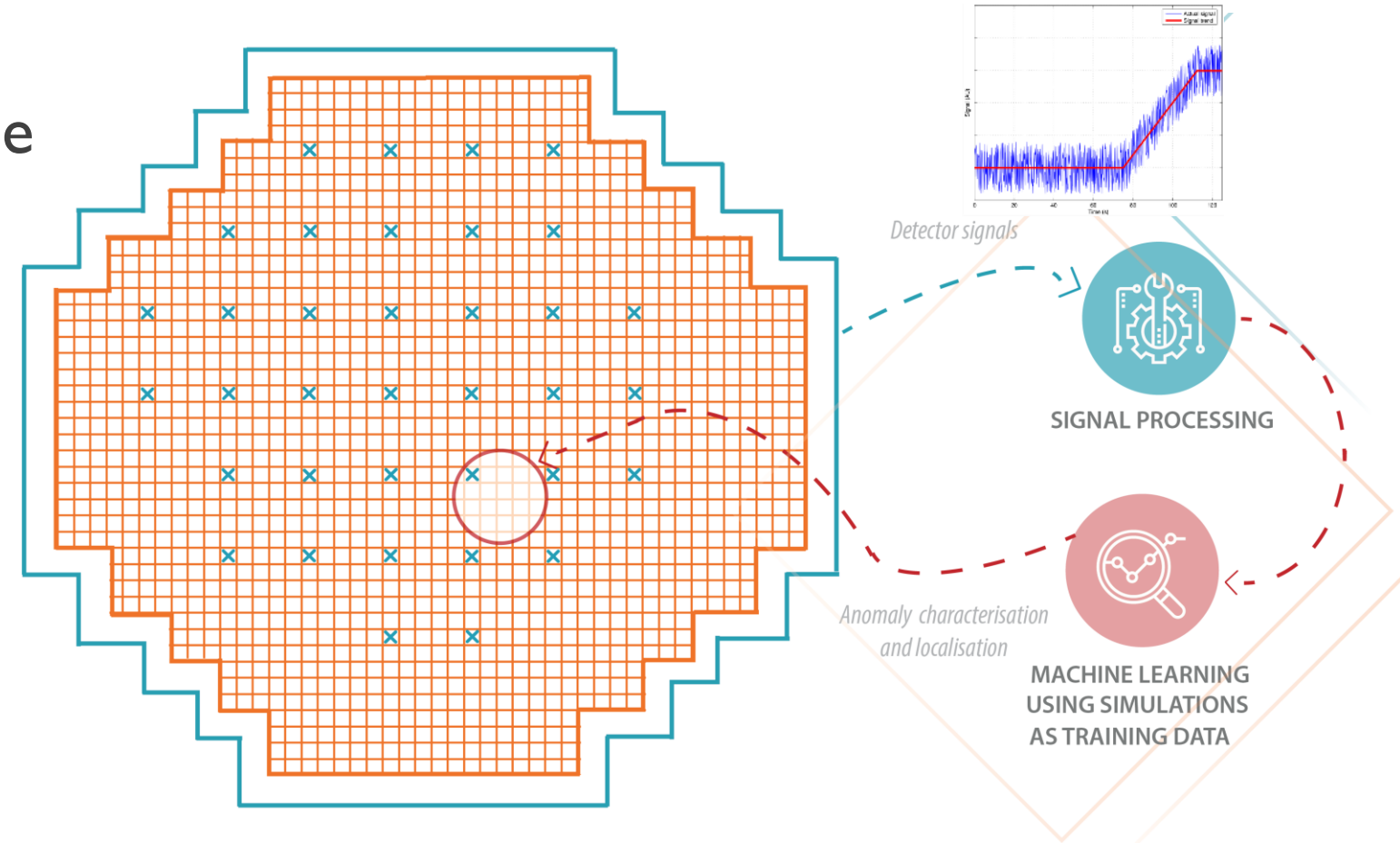
This project has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 754316.

Background and Objective

Background: Overall principle of the Horizon 2020 CORTEX project

- Different **techniques** and **tools** to monitor the **reactor core** using measurements of the neutron flux noise
- To **detect** and **identify anomalies**



More info at:
cortex-h2020.eu

Objective

- Use results of **simulations, sensitivity analyses, operational experience** to derive

⇒ **Recommendations, how to improve the applicability and accuracy of the techniques/tools,**
based on

- FSI simulations
- Machine learning-based unfolding
- Results of data processing and reconstruction

Based on FSI analysis

FSI Analysis

- **Interaction** between **fluid flow** and **mechanical behavior** of core internals
- Result in **perturbation** of neutron flux
- Are based on assumptions about **fluid flow** which **cannot be measure directly**

Recommendations based on FSI analyses (existing detectors)

- *Investigate the correlation of the measured neutron noise with other measurements, like **primary pressure gauges, displacement transducers, thermocouples, accelerometers** mounted to the RPV head, **acoustic instrumentation**, or **main coolant pump supply current***
- *Measure the neutron flux and other quantities under special operating conditions, like **commissioning tests, start-up, shutdown, partial load**, or the **unavailability of one main coolant pump***
- *Use information from **operational experience**, because **defects** or **wear** can be a sign for increased motion in the affected area*

Recommendations based on FSI analyses (additional detectors)

- *Include **in-core accelerometers** in the fuel elements and at the core barrel*
- *Develop and **add in-core detectors** capable to measure the **coolant velocity** in axial and radial direction*

Recommendations based on FSI analyses (additional experiments)

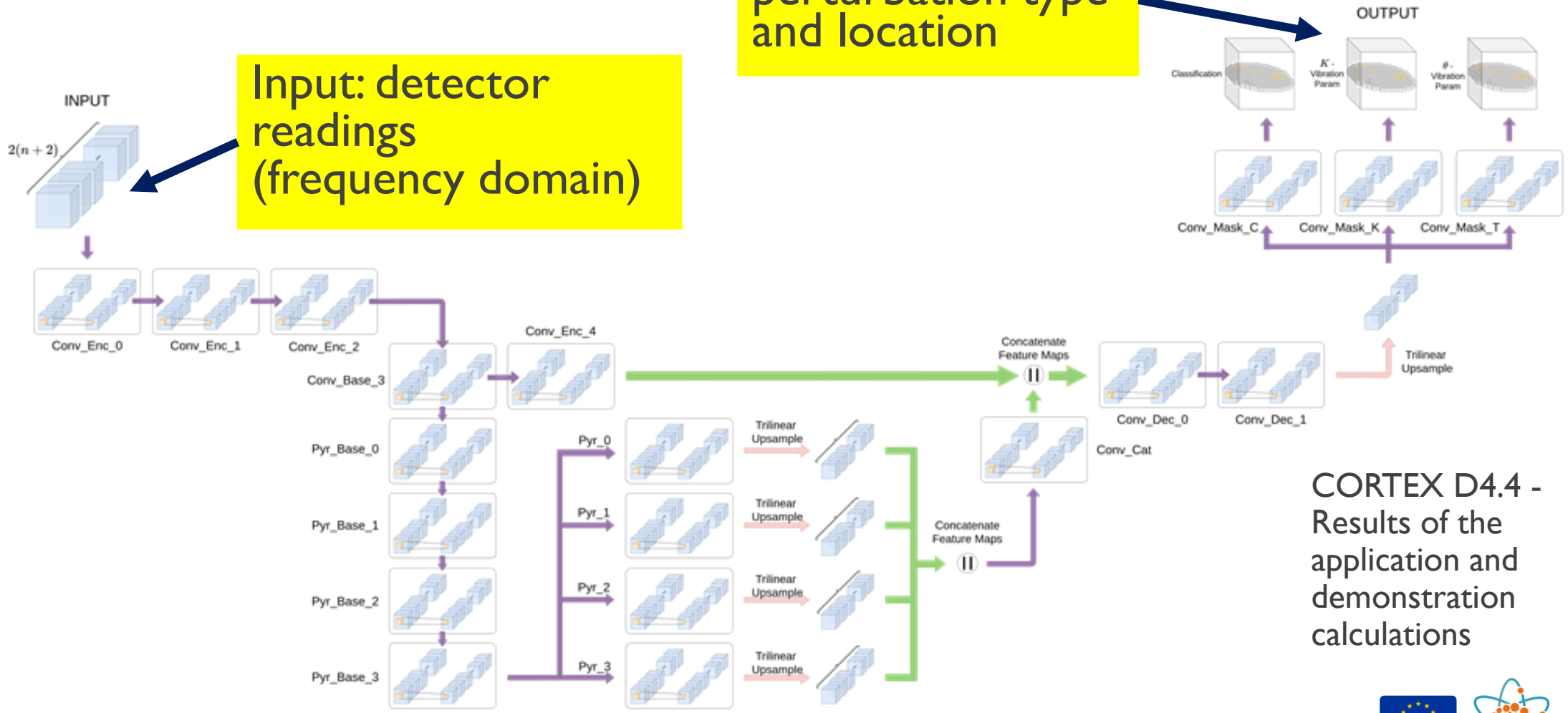
- *Implement **scaled mock-up experiments** to investigate FSI phenomena in detail and without nuclear safety requirements*

Based on Machine Learning-Based Unfolding

Anomaly prediction and analysis of plant measurements

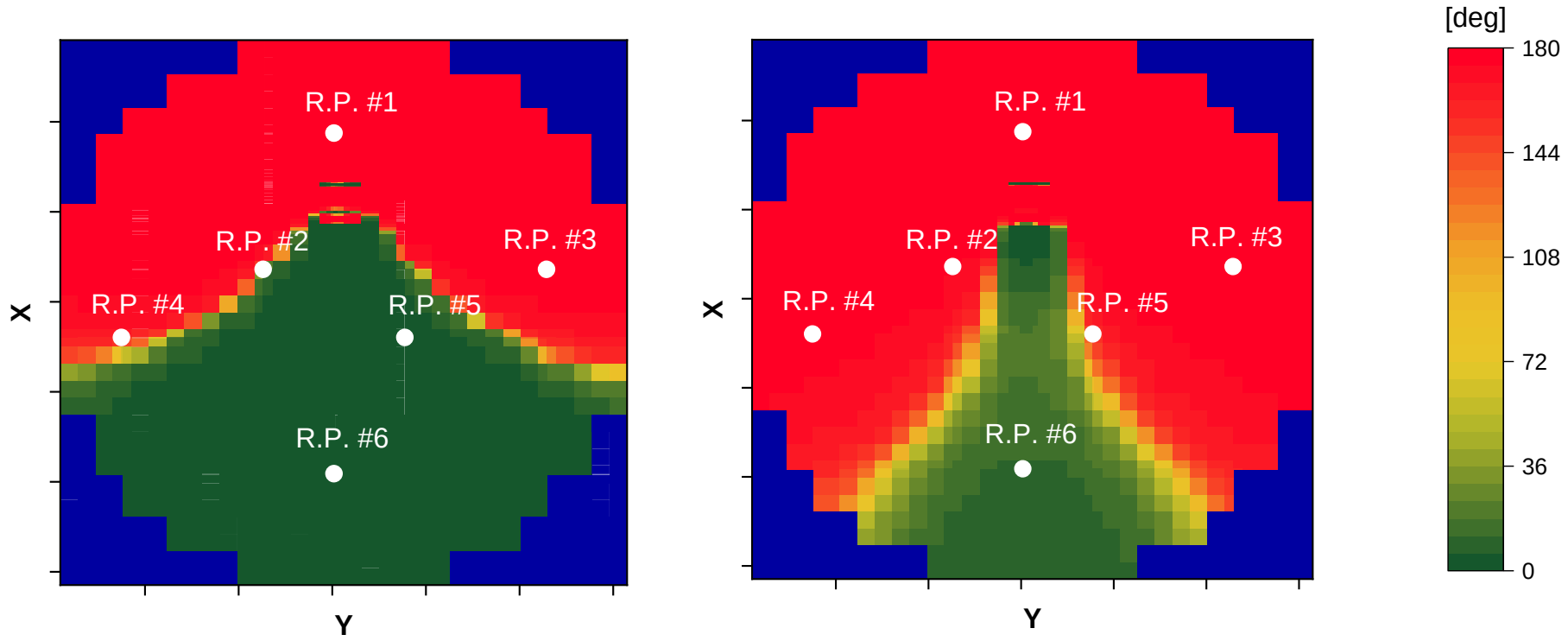
Output: perturbation type and location

Input: detector readings (frequency domain)



CORTEX D4.4 - Results of the application and demonstration calculations

Training by simulation data



CORTEX D4.6 - Recommendations for modifications, improvements, additional detectors

The **phase** of the thermal neutron flux noise of a vibrating fuel element with slightly changed x-positions of the vibrating fuel assembly (left 4.3 mm upwards, right 4.3 mm downwards)

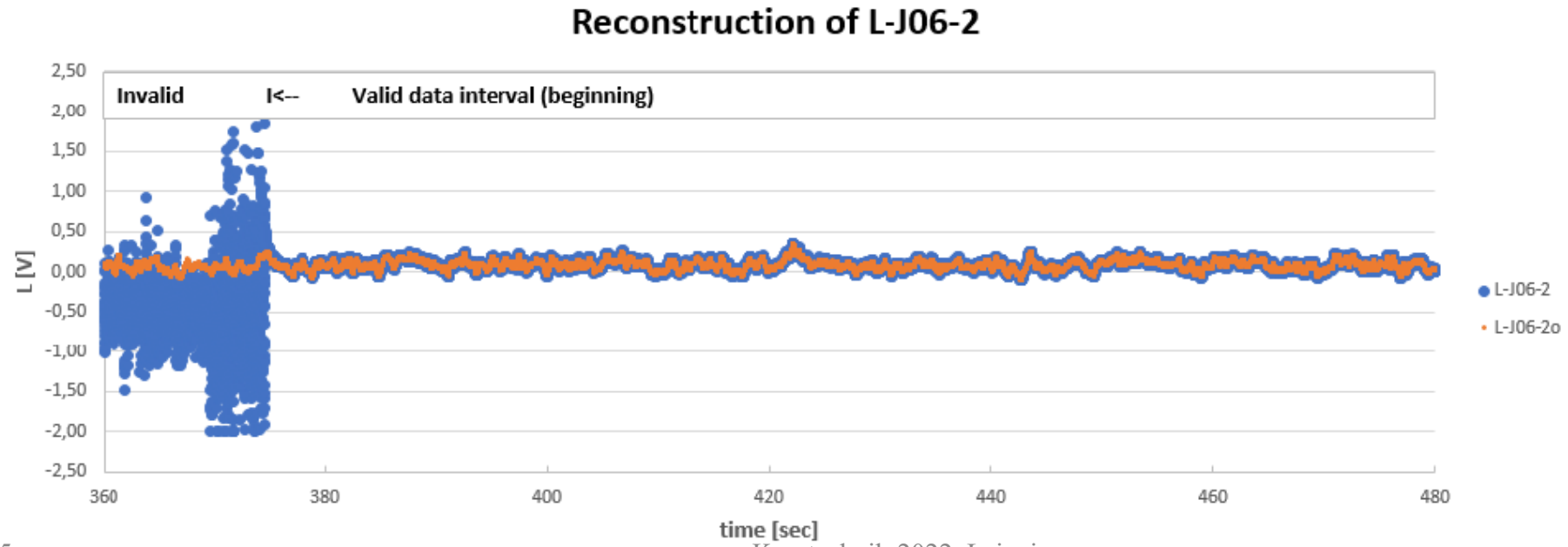
Recommendations based on machine-learning

- *Detectors should be **homogeneously distributed across** the reactor core*
- *Have a **high in-core detector coverage***

Results of Data Processing and Reconstruction

Example for signal reconstruction

- Reconstruction by using the **correlation** between different detectors
- Comparing reconstructed and actual detector signals
  - to determine faults of the detector signals
  - to estimate the signal-to-noise ratio



CORTEX D3.3 - Development of advanced signal processing techniques and evaluation results

Recommenations for SPNDs

- *Have a **high detector density***
- ***Uniform distribution** throughout the reactor core*
- *Know the **transfer function** of **each SPND***
- ***Normalize** the signal of **each SPND** against its concurrent steady state component*
- ***Correct** the **burnout rate** of **each SPND individually***

Recommentations for ionization chambers

- *Place them in the upper and lower positions* ***against the reactor head accelerometers***

for the detection and determination of core barrel movements

Recommendations for additional measurements/signal processing

- *Record the signals of the **accelerometers** as well as of **pressure fluctuations** simultaneously with the reactor instrumentation*
- *Use a **uniform time base** for all measurements of the whole plant*

Recommendations for analysis

- *Use the **same parameters** for the measurements and their analysis for different plants, like*
  - *sampling frequency*
  - *spectral resolution*
  - *normalization*
  - *frequency range*
- ***Use reconstructed signals** instead of the raw signals as **inputs** for the **machine learning-based tools and techniques***

Conclusions

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- **Recommendations reported** were **specifically** derived to improve **applicability** and **accuracy** of **CORTEX** techniques/tools
- But they can **improve neutron noise analysis in general**
- Two groups of recommendations were given
  - **Using existing detectors**
  - **Add new detectors**
- **Commissioning of new reactors** in Europe is a **unique opportunity** to increase knowledge about causes of neutron noise
- Look at recordings of **commissioning** of **second generation reactor**