CORTEX
Core monitoring techniques and
experimental validation and demonstration

UJV activity in the NPP noise diagnostics

CORTEX Workshop

Advanced signal processing methods and learning methodologies applied to the monitoring of NPP reactor conditions

20 February 2019, Řež

Petr Stulik

Petr.Stulik@ujv.cz

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

CONTENT

NPP Dukovany

NPP Temelín

Plant data acquiring, processing and evaluating

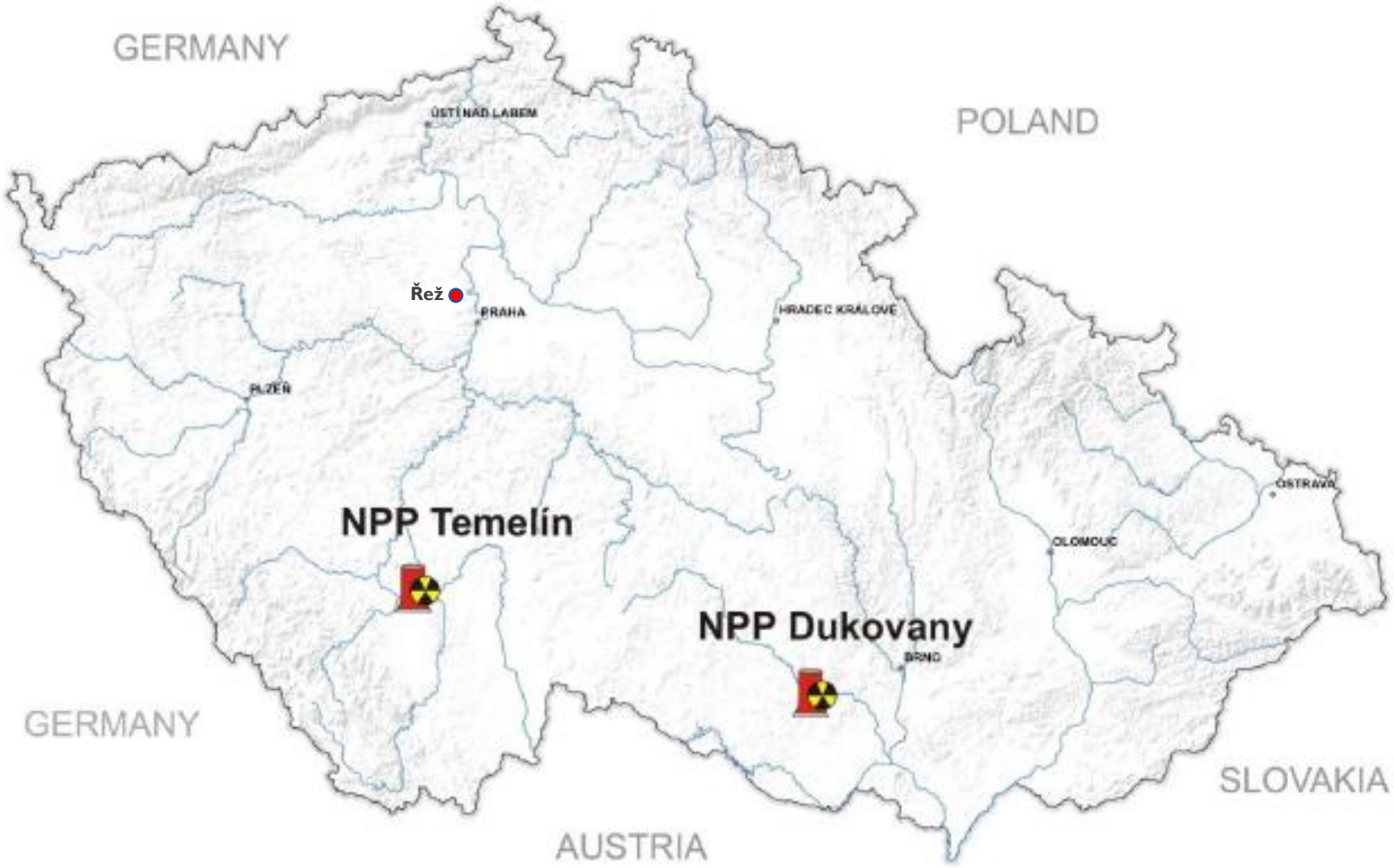
Diagnostic systems

Conclusion

MOTTO

No data, no analyses

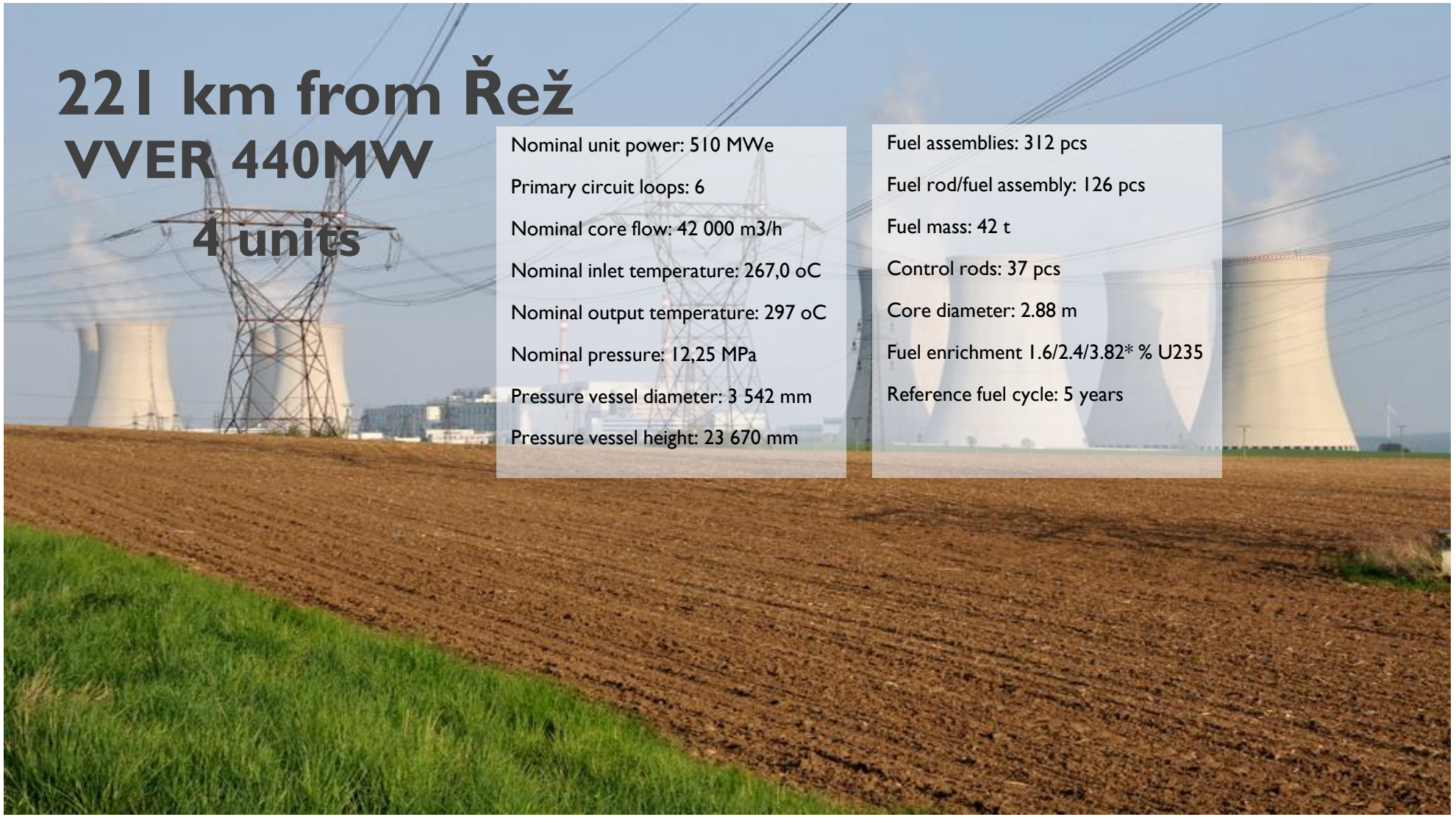
Czech NPP


GERMANY
POLAND
ÚSTÍ NAD LABEM
Řež
PRAHA
HRADEC KRÁLOVÉ
PLZEŇ
OSTRAVA
OLOMOUC
NPP Temelín
NPP Dukovany
BRNO
GERMANY
SLOVAKIA
AUSTRIA

NPP Dukovany

NPP Dukovany

NPP Dukovany



221 km from Řež

VVER 440MW

4 units

- Nominal unit power: 510 MWe
- Primary circuit loops: 6
- Nominal core flow: 42 000 m3/h
- Nominal inlet temperature: 267,0 oC
- Nominal output temperature: 297 oC
- Nominal pressure: 12,25 MPa
- Pressure vessel diameter: 3 542 mm
- Pressure vessel height: 23 670 mm

- Fuel assemblies: 312 pcs
- Fuel rod/fuel assembly: 126 pcs
- Fuel mass: 42 t
- Control rods: 37 pcs
- Core diameter: 2.88 m
- Fuel enrichment 1.6/2.4/3.82* % U235
- Reference fuel cycle: 5 years

NPP Temelín

NPP Temelín

NPP Temelín


158 km from Řež
VVER 1000MW
2 units
Nominal unit power: 1 055 MWe
Primary circuit loops: 4
Nominal core flow: 82 000 m3/h
Nominal inlet temperature: 293,8 oC
Nominal output temperature: 320 oC
Nominal pressure: 15,7 MPa
Pressure vessel diameter: 4 500 mm
Pressure vessel height: 10 900 mm
Fuel mass: 92 t
Fuel assemblies: 163 pcs
Fuel column height: 3 680 mm
Fuel rod/fuel assembly: 312 pcs
Fuel rod outer diameter: 9,1 mm
Fuel rod pitch: 12,75 mm
Fuel rod average linear loading: 156,3 W/cm
Fuel rod max burnup: 72 MWday/kgU
Control rods: 61 pcs in 10 groups
Reference fuel cycle: 5 years

Plant data acquiring, processing and evaluating

NPP Dukovany

- **Operational measurements of WWER440 units (4 Dukovany units, 2004 – 2018)**
  - **Signals**
    - **Reactor head displacement (OA) – 4**
    - **Excore-re ionisation chambers signals (VIK) – 6 (Outer mid reactor plane)**
    - **Steam generator relative displacement (RY) – 12**
    - **Acceleration of SG, RPV, MCP – 16**
  - **Diagnostic systems**
    - **In-plant : SPD (all sensors without ex-core VIK)**
    - **Special UJV : MVI (ex-core VIK)**
    - **Special Siemens: Mobile SÜS ´95**
    - **Mobile UJV : NNCS (2000-), DMTS (2004-)**
    - **On-line, remote access diagnostic terminal UJV : RVDT (tested 2017, installation through 2018-2019)**
- **Operation analysis**
  - **Vibration identification by means of reactor head absolute displacement sensors and supplemental measurement chains of excore ionisation chambers**
- **Vibration models** (in cooperation with West Bohemian University)
  - **Mathematical models were realized for identification of reactor vibrations**

Plant data acquiring, processing and evaluating

NPP Temelin

- **Operational measurements of WWER1000 units (2 Temelin units, 2004 – 2017)**
  - **Signals**
    - **Pressure fluctuation (TP) – 5 (4 Re input, 1 output)**
    - **Reactor head vibration (ACC) – 4**
    - **Ex-core ionisation chambers signals (XNN) – 12 (3 planes x 4)**
    - **Self-powered neutron detectors signals (INN) – 256 (16 groups x 16)**
  - **Diagnostic systems**
    - **In-plant WEC : RVMS, RECOP (2000 –)**
    - **Mobile distributed UJV : DMTS (2004 –)**
    - **On-line, remote access diagnostic terminals UJV : RVDT (tested 2017, installation through 2018-2019)**
- **Operation vibration analysis**
  - **Vibration identification by means of reactor head accelerometers**
  - **Exciting acoustic pressure fluctuations of coolant : computation and measurement**
  - **Step-by-step analysis of in-core neutron detector signals to obtain more information about fuel asemblies and rods dynamic behaviour**
- **Vibration models** (in cooperation with West Bohemian University and Skoda JS)
  - **The model development was finalized in 3D mathematical reactor model with 137 DOF**
  - **Influence of the reactor vibrations on the core barrel stability was investigated under the condition of full and incomplete MCPs operation with slightly different revolving and confirmed by measurement results**

Diagnostic systems
The first attemps

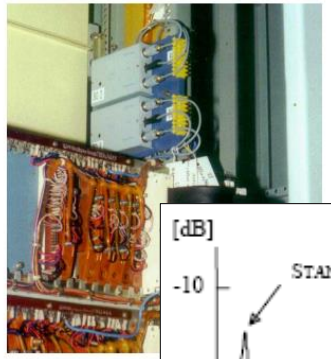
1985-1987

NPP Dukovany 4 units commissioning

- analog and digital oscilloscopes
- developed CAMAC systems
- data recording on magtape systems

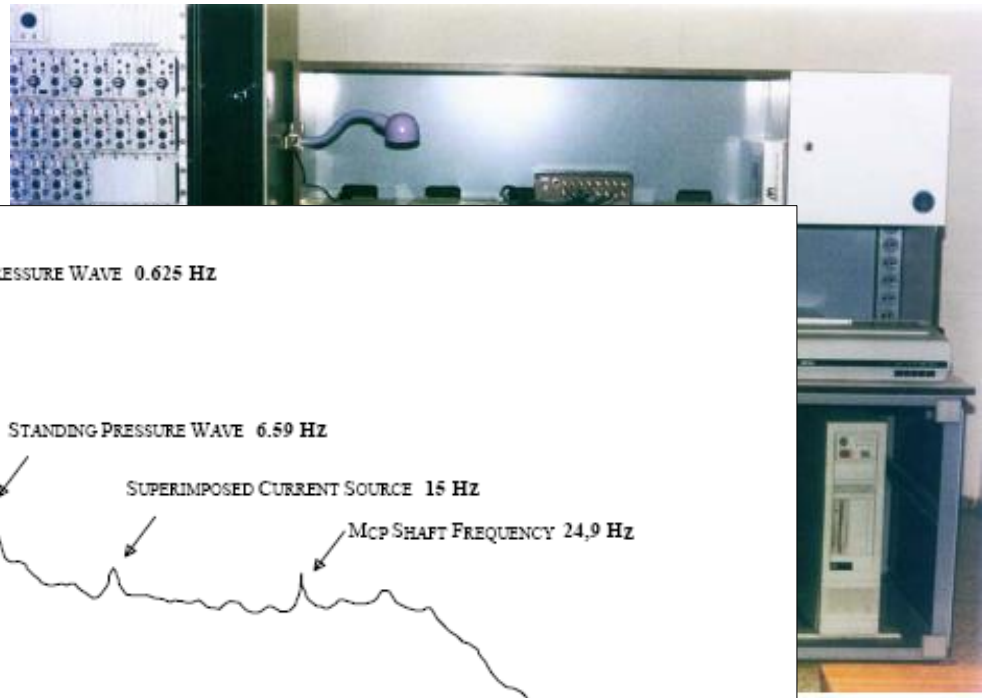
Diagnostic systems

MVI



Optical isolation units BO location in

Detail of optical isol



Sensitivity of noise neutron channel (Dukovany unit 4, 100% N_{nom} , 1990)

1991

- galvanic opto separation of up-to 8 standard excore ionisation chambers
- processing input pulse train from ionisation chambers in two output components : mean and noise (0.1-32.5 Hz)
- 16 inputs with 12 bit resolution
- the utilisation of Piety statistical descriptor algorithm for monitoring of the signal changes in the frequency domain
- automated data storing in the case of anomal events i.e. when Piety descriptors are going over settled limits
- the system workstation compact and ergonomic design suitable not only for plant personnel work routine but also for development activity
- the resolution expressed as signal/noise ratio can achieve values in the range **1,54 - 6,5*10^{-6}** for the detected peak height of 1dB in the shown APSD
- evaluation of deflection and detection of core barrel movement within corresponding frequency band
- equivalent rms core barrel deviation can be conservatively determined in about 1μm range

Diagnostic systems
NNCS

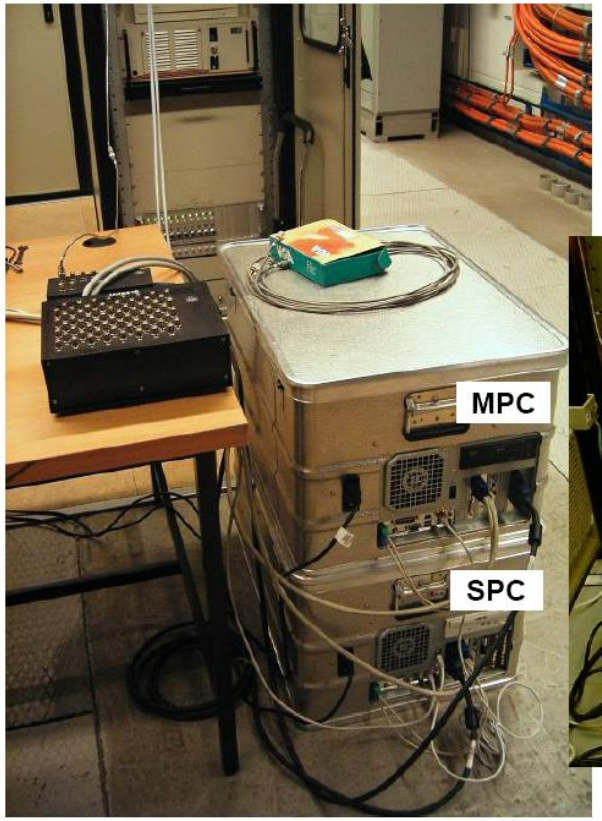
Input panel

Panel with calibration results

2000

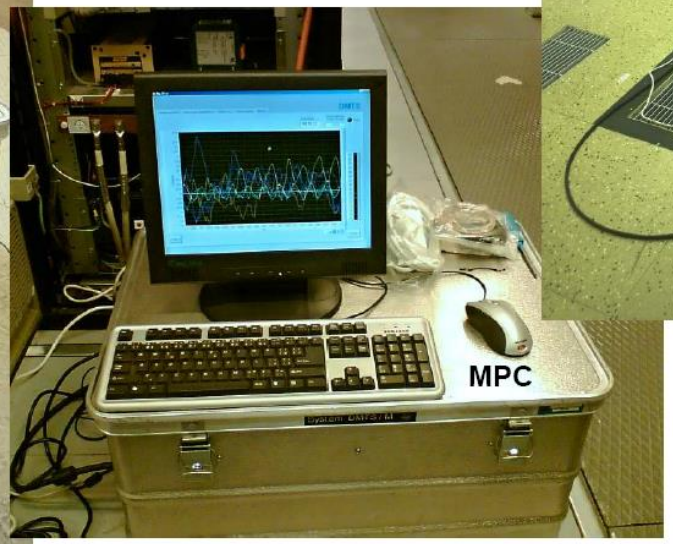
- system NNCS for the calibration of neutron noise channels was developed in the frame of Phare Project with Siemens AG
- development was initiated by the NPP Dukovany user who demanded calibrated neutron noise channels for reactor internals diagnostics.
- it performs defined calibration procedure in the frequency domain with minimised staff involvement either during reactor outages or on-line under the normal reactor operation
- system design is open, based on the utilisation of virtual instrumentation
- portable two-processor system
- main input panel is used for the specification of operation data, system connection and calibration set-up
- final panel contains the result graphic and tabular calibration data

Diagnostic systems
DMTS



Overal **DMTS** view

RVMS



Subsystem **MPC** connected to **RVMS**

RECOP

Subsystem **SPC** connected to **RECOP**

2004

Multiprocesor system for distributed measurement, diagnostics and testing in NPP technology environment

- common prophylaxis of measuring chains
- NPP Temelin and Dukovany operational diagnostic system **enhancement**
- **concurrent** measurement and processing of all RVMS and RECOP channels NPP Temelín
- **testing** of neutron instrumentation, PAMS thermocouples, RVMS accelerometers and reactor loop RTD‘s
- HW and SW **modularity**
- **robust** transportable mechanical construction
- 16 measurement channels with 24 bit resolution at 1 - 102,4kHz sampling frequency interval
- 2 voltage output for generating of test sequencies

Diagnostic systems
RVDT

2017 – 2020

- two RVDT Diagnostic Terminal Systems have been proposed to both units of the NPP Temelin for monitoring dynamic responses of reactor core influenced by pressure fluctuations generated by main circulating pumps
- each system consists two subsystems connected as diagnostic terminals to standard plant daignostic systems RVMS (Reactor Vibration Monitoring System) and RECOP (Main Circulation Pump Diagnostic)
- synchronized measurements of subsystems at sampling frequency 1 ms with 18 bit resolution
- remote access via UJV network
- data acquiring on demand with following processing and evaluating in time, frequency and joint frequency time domains at the UJV site
- acquired data parametrized by unit technological data
- prototype testing and NPP Dukovany and Temelin operational measurements from 2016
- under development with anticipated outlook of installation in 2019-2020

CONCLUSION

- NPP Dukovany and Temelin commisioning
- Development of diagnostic systems
- Operational vibration analysis with the cooperation of West Bohemian University and Škoda JS from Plzeň
- Several cycles database of frequency domain data from standard plant diagnostic systems regularly gathered
- Time series of plant data acquired on the unregular basis
- Frequency domain data and time series of plant data can be parametrized by technological data in various regimes of reactor operation
- Gathered datasets were used for investigation of power tilt causes, fuel assembly and internal parts vibration, incompatible rod insertion, beat effects, parametric flow oscillation, control rod behaviour, pressure vessel orbits etc.
- Diagnostic Terminal System RVDT for evaluation of core behaviour influenced by MCP pressure fluctuations under development

Thank you for attention!