MEASUREMENT AND EVALUATION SYSTEMS FOR NPP COMMISSIONING

Marek Elko, VUJE, Inc.

ABSTRACT

Standard core monitoring and information systems are designed with an emphasis on normal operation of nuclear power plant. Their purpose is to provide necessary support for reactor operators and other operating personnel during the fuel cycle. After each fuel reloading, and to the larger extent during the plant commissioning, a variety of start-up tests need to be carried out and evaluated. Sampling periods, accuracy and communication delays of standard systems are not always suitable for test performance and evaluation. For technical and safety reasons, the access to standard monitoring and information systems is very limited. Non-Standard Measurement and Evaluation Systems are highly specialized devices designed with an emphasis on start-up tests performance and evaluation. They are capable of high frequency sampling, processing and communication of hundreds of technological signals with required accuracy and low communication delay. All technological signals needed for the test performance and evaluation are collected from various systems, concentrated in one system and fully accessible to a test leader, a reactor physicist or other users. In addition, Non-Standard Measurement and Evaluation Systems can perform other tasks like data storing and presentation, data distribution to other systems or external computers via network, reactivity calculations, etc. Structure of such systems can vary, but generally it is a mixture of two basic concepts: a mobile system and a stationary system. A basic description of hardware structure and software equipment of Non-Standard Measurement and Evaluation Systems is given in the paper.

MOBILE SYSTEMS

Typical representative of a mobile Non-Standard Measurement and Evaluation System is iNMS (Innovative Non-Standard Measurement System) system used at the 1st and the 2nd Unit of Bohunice NPP (Slovak Republic). Basic wiring diagram of iNMS system is shown in Figure 1. Despite it is a mobile system; it contains a small stationary box (grey rectangle) with connectors and a module for optical isolation of source range chambers signals. The rest of the system is mobile. It consists of one or more laptops, a portable printer and other optional devices. Laptops are equipped with A/D converters and specialized software modules. Not time-critical data like temperatures of coolant loops, water levels or boron concentrations are transmitted from the plant's technological information system (TIS) via the local area network (LAN). Time-critical data, such as source range ionization chamber signals are directly sampled with a required frequency by A/D converter. It must be assured that the system cannot affect functioning of other systems like a standard core monitoring system or safety systems. The signals important for safety can be accessed only via converters with optical isolation.

Compared to stationary system, the mobile system requires much lower initial investment and can easily be transported from one NPP unit to another. On the other hand, it requires some installation time and, as it is uninstalled after the start-up, it cannot be used for any analysis of unexpected events, which can occur during the operation. Compared to the stationary systems, a number of processed signals is much lower.

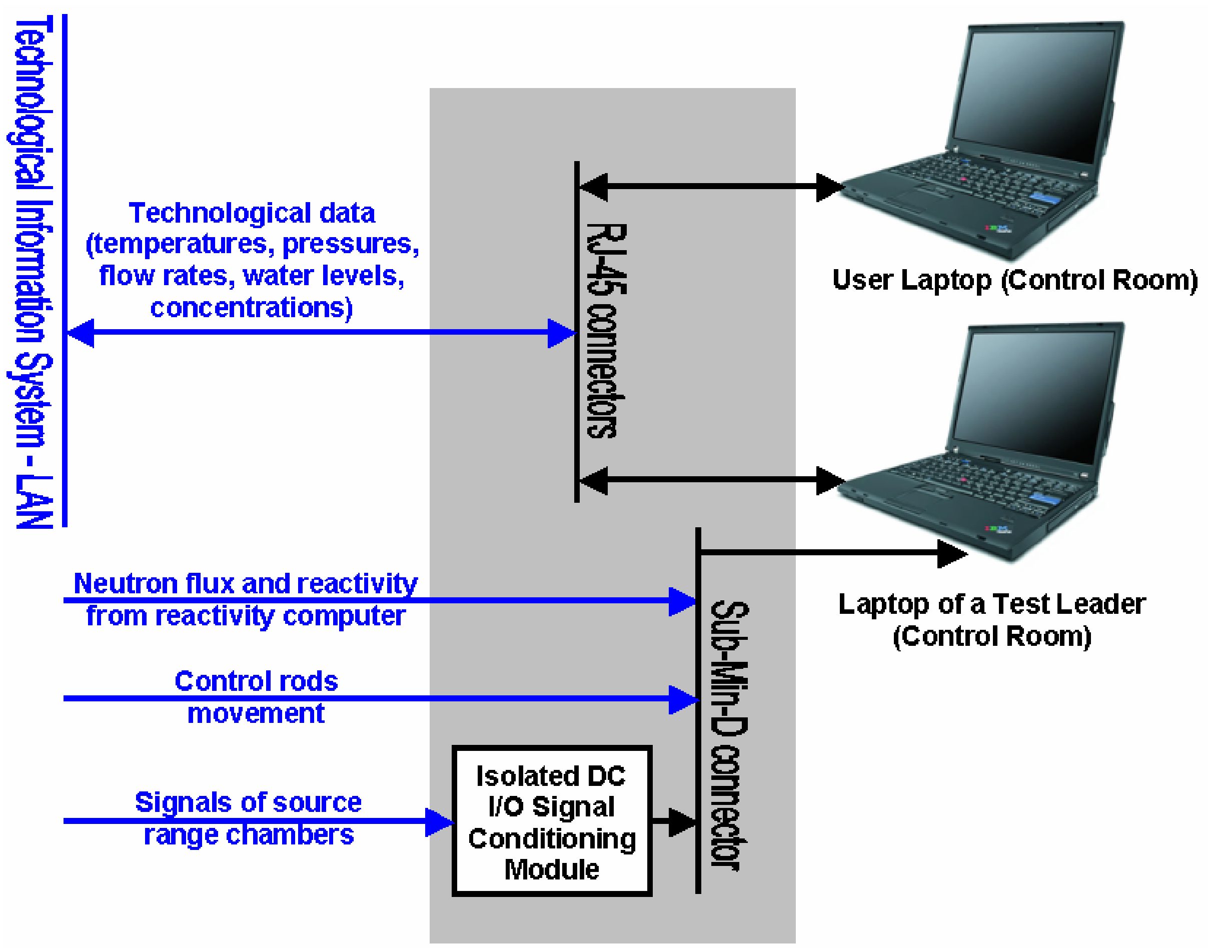

Figure 1: Basic wiring diagram of mobile Innovated Non-Standard Measurement System iNMS for Bohunice NPP (Slovak Republic).

STATIONARY SYSTEMS

Physics Start-Up Panel (PFS) measurement and evaluation system at Temelin NPP (Czech Republic) is an example of a stationary system. Its basic wiring diagram is shown in Figure 2. It consists of a variety of stationary devices installed at each unit. Three independent neutron flux measurement chains consist of a compensated ionization chamber; a measurement and power supply unit, and an industrial computer responsible for reactivity calculation and data storage. Central server is responsible for communication with external systems, industrial PCs and user computers. The server also performs a backup of measured data. A special external device for reactor noise measurements can also be connected to the system. Two connectors with an access to all system data are located in the control room. Computer of a test leader and other user computers or laptops equipped with communication software can easily be connected to the system and receive required data in real time. The system is in operation during the whole fuel cycle. In case of an unexpected event, required data can be retrieved from the archives and analysed in detail. Despite it is a stationary system, it can contain mobile parts, too. For instance, user laptops connected to the system during the measurement can be disconnected and transported after the measurement has finished and used for post analysis of measured data.

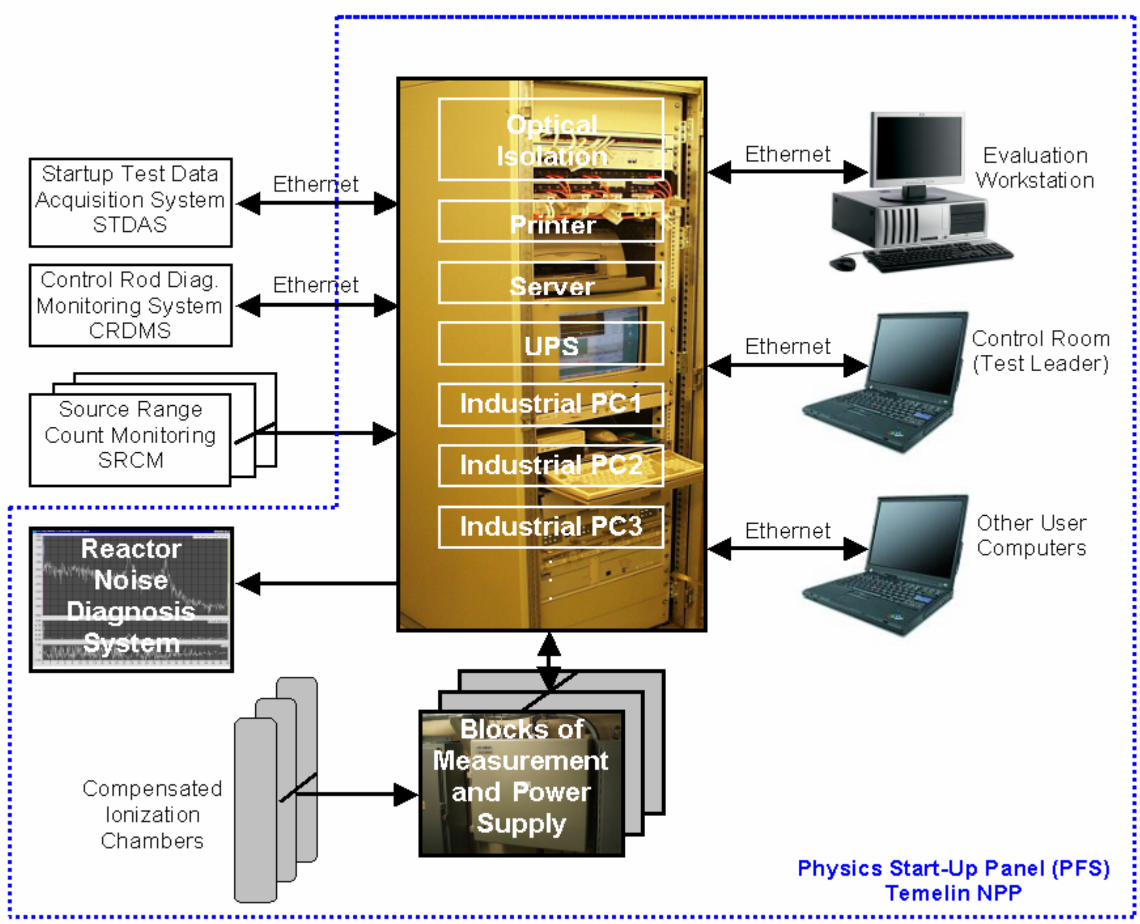

Figure 2: Basic wiring diagram of stationary measurement and evaluation system Physics Start-Up Panel at Temelin NPP (Czech Republic).

Stationary Non-Standard Measurement and Evaluation System usually requires higher initial investment than a mobile system, but it is able to process hundreds of signals, it does not need an installation before each start-up, it allows a backward analysis of unexpected events, which can occur during the fuel cycle and it can provide some additional functionality to a standard core monitoring system.

SOFTWARE

Bundled software is a crucial part of delivered Non-Standard Measurement and Evaluation System. It consists of independent software modules responsible for specialized tasks. System modules are responsible for basic functionality of the system. Specialized modules designed according to user requirements are focused on performance and evaluation of specific test. The purpose of system modules is to assure reliable operation and integrity of the system. They are responsible for control of A/D and D/A converters, data acquisition, processing, communication, storage of technological data in cyclic archives and their retrieval on user demand, basic data presentation in a numerical or graphical form and export of the data into a text file. Other system modules perform a system calibration and configuration, time synchronisation, reactivity calculation, average values calculations, etc.

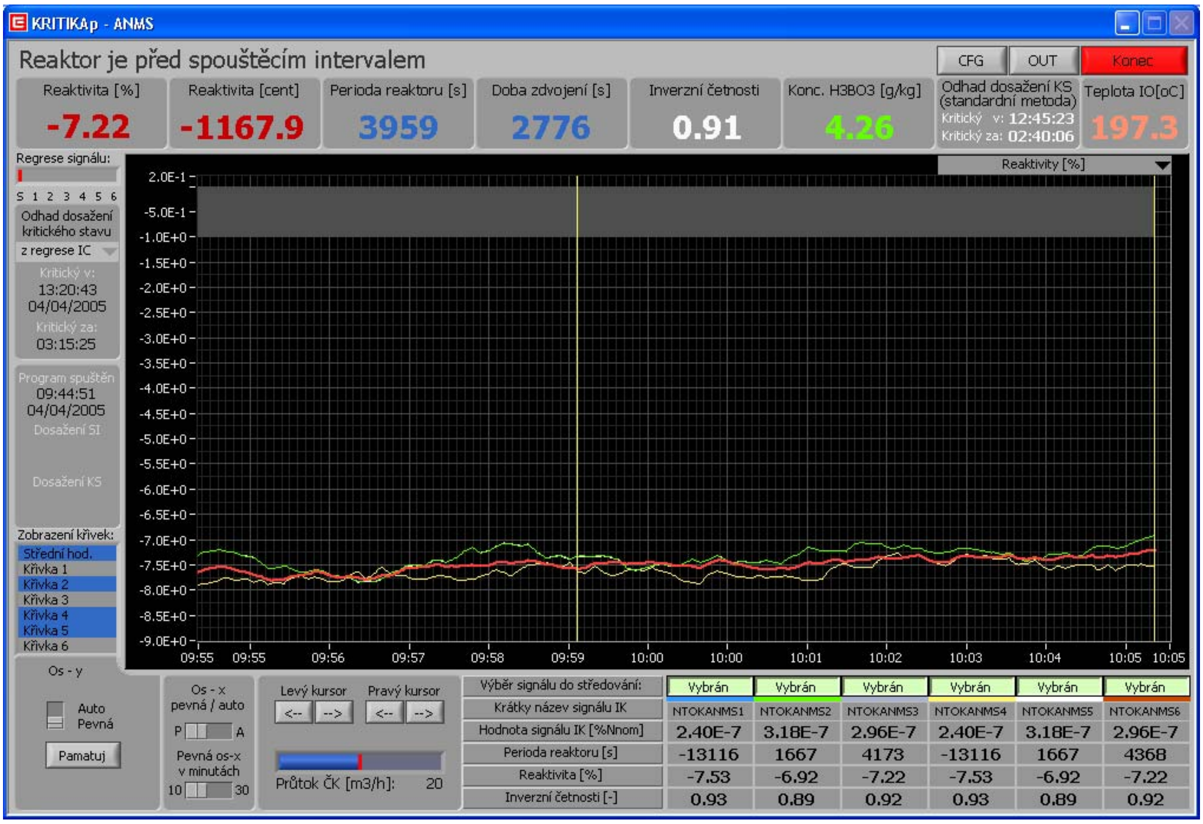

Figure 3: Module for monitoring of approaching to reactor critical state (Dukovany NPP).

Specialized software modules are designed according to user requirements. Their purpose is to process specific test related data and provide online support for a test leader during the test performance and evaluation. These modules periodically receive the data from various sources, store them on a local hard drive, present the data on the screen, calculate additional not measured values, allow post processing of the data, test evaluation, comparison of obtained results with expected theoretical values, printing the protocol, etc. From a huge variety of yet developed modules we can mention: module for monitoring of approaching to critical state, module for measurement of temperature reactivity coefficient, modules for measurement of power and pressure reactivity coefficient, module for boron worth measurement, module for measurement of differential and integral worth of control rods, module for measurement of total worth of control rods after the reactor trip, module for measurement of reactor core symmetry, module for check of reactivity computer precision, module for check of control rods connection with the drives, etc. Some screenshots of the modules are presented in Figures 3, 4 and 5.

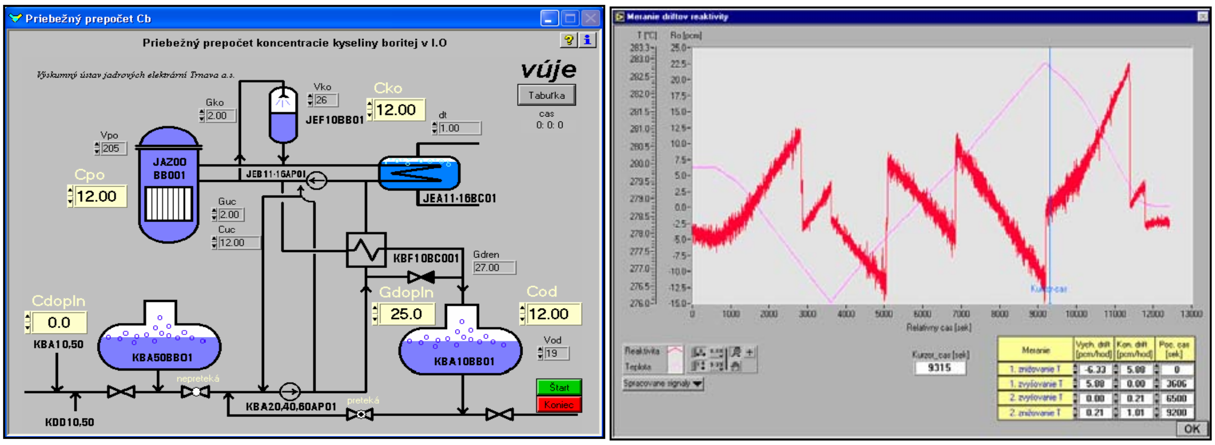

Figure 4: Module for simulation of boric acid concentration changes in primary circuit (left) and module for evaluation of temperature coefficient (right).

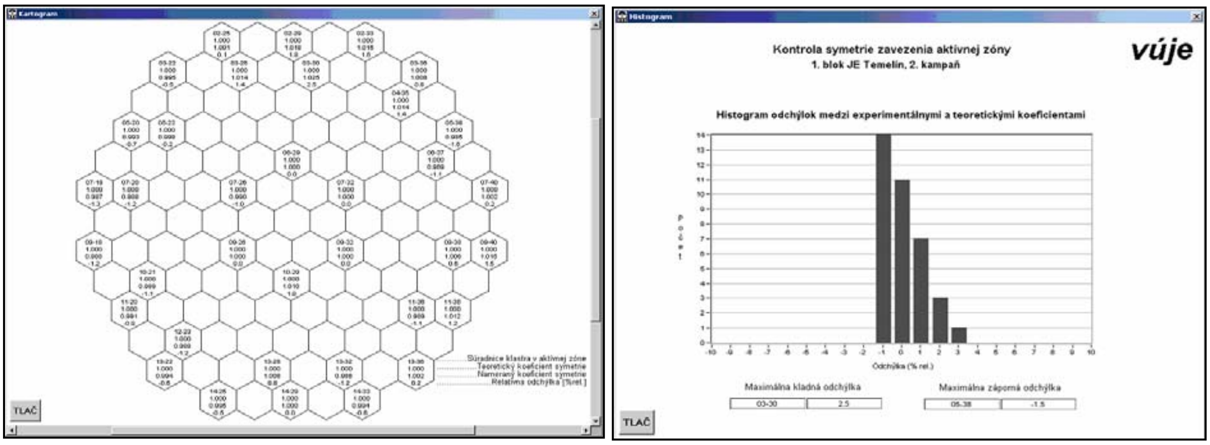

Figure 5: Screenshots of the module for measurement of reactor core symmetry.

PRACTICAL APPLICATIONS

Refuelling causes a change in configuration of reactor core. Specific tests must be carried out to verify if important physical parameters of “new” core are in conformity with theoretical calculations and safety limits. Naturally, number of tests is much larger if a newly built NPP Unit is started-up for the first time. Normal reactor operation can start only if the tests are successful. Three examples of low-power tests are shown below.

First critical state of WWER type reactor is usually achieved by withdrawing the control rods to initial position and decreasing the concentration of boron in primary circuit coolant by filters and dilution. During the dilution, flow rate of pure condensate fed into primary circuit is high while reactor is far from critical state, but it must be decreased after reaching the beginning of so-called start-up interval. Information about current concentration of boron in primary circuit is delayed as no accurate online measurement of concentration is installed and a chemist must evaluate it from manually collected samples of coolant. The only immediate information provided by standard monitoring system is power and reactor period. To monitor the state of reactor during the process of approaching to critical state Non-Standard Measurement and Evaluation System is used. Software module called KRITEX (Figure 3) provides reactor operator with additional information like: current reactivity value, inverse counts, doubling time, prediction of time needed to achieve critical state and so on. Visual and acoustic alarms indicate achievement of start-up interval, critical state or dangerous sate.

Measurement of total worth of control rods is another quite common low-power test. During the test, reactor trip switch is pressed manually and all rods are dropped into the core. Due to fast change of neutron flux, source range ionisation chambers signals need to be sampled quite accurately and with higher frequency (at least 10 Hz). This is usually not possible with standard core monitoring system. Non-Standard Measurement and Evaluation System allows sampling of source range ionisation chambers signals with required frequency and precision and bundled software modules allow evaluation of the measurement immediately after the sampling of the data is finished. To eliminate dynamic space-time effects, caused by the fall of control rods, necessary corrections are applied to the sampled data and point kinetic equations are used to calculate reactivity. Finally total worth of control rods is calculated from average reactivity curve and compared with theoretical value. The time of fall of individual control rods is usually measured during the test too. Dynamic measurement of worth of separate groups of control rods or measurement of total worth of control rods with one or two rods stuck in upper limit position can also be performed and evaluated.

Measurement of temperature reactivity coefficient is usually carried out during primary circuit coolant heating up while other parameters, which have an influence on reactivity, are kept constant during the measurement. Continuous increase of temperature introduces negative reactivity into the system. To keep reactor critical, negative reactivity must be compensated by withdrawing the control rods continuously from reactor core. During the measurement, Non-Standard Measurement and Evaluation System allows collecting, storing and presenting important data (reactivity, trends of temperature rise, position of control rods, etc.) live on a computer screen. After the measurement, TEPKO software module is used for evaluation. It allows eliminating subtle changes of boron concentration, reactor power and pressure during the test and evaluating temperature dependency of temperature reactivity coefficient. Finally, measured values are compared with calculated theoretical values and fulfilment of acceptance criterion is checked.

DEVELOPMENT OF NON-STANDARD MEASUREMENT AND EVALUATION SYSTEMS

VUJE, Inc. has a 25-year experience in NPP commissioning and development of mobile and stationary Non-Standard Measurement and Evaluation Systems for NPP Commissioning. The list of systems developed since 1992 is shown in Table 1. Hardware and software equipment is always designed according to specific user requirements and can easily be expanded in future upgrades, if required.

Table 1: List of Measurement and Evaluation Systems developed by VUJE since 1992

System / Type	***Year of Delivery***	***NPP / Country***	***Reactor Type***	***Number of Units***
ANMS (Mobile)	1992	Dukovany NPP (Czech Republic)	WWER 440	4
NMS (Mobile)	1993	Bohunice NPP (Slovak Republic)	WWER 440	4
AMS (Stationary)	1998 1999	Mochovce NPP (Slovak Republic)	WWER 440	2
PS Panel (Stationary)	2000 2002	Temelin NPP (Czech Republic)	WWER 1000	2
iNMS (Mobile)	2003	Bohunice NPP (Slovak Republic)	WWER 440	2
iANMS (Mobile)	2003 2005	Dukovany NPP (Czech Republic)	WWER 440	4

CONCLUSION

Non-Standard Measurement and Evaluation Systems for NPP Commissioning are highly specialized devices, which provide the users with a centralized access to all data needed for performance and evaluation of start-up tests. Small mobile systems require lower initial investment and can easily be transported from one NPP unit to another. However, the number of processed signals is lower and they cannot be used during the whole operation. Stationary systems are able to process a much higher number of technological signals and remain in operation during the whole fuel cycle. Stored data can be used for backward analysis of unexpected events, which can occur during the fuel cycle. Bundled software is a crucial part of delivered system. System modules are responsible for basic functionality of the system. Specialized modules designed according to user requirements are focused on performance and evaluation of a specific test. VUJE, Inc. has a long-term experience in NPP commissioning and development of mobile and stationary Non-Standard Measurement and Evaluation Systems for NPP Commissioning.