Developing a New Neutron and Reactivity Monitoring System for Paks NPP

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ABSTRACT

The Reactivity Monitoring System and the Refuelling Neutron Monitoring System of Paks NPP are aged and need to be reconstructed. Since both systems are based on neutron flux measurements, the new system is to be served by the same detectors and measurement instrumentation. In order to provide data during refuelling, start-up and at full power, a full-range system is required, i.e. the detectors and the associated instrumentation should cover the full range of neutron flux measurements from 0% to 100% of reactor power. Additionally, the new system is required to operate continuously, to maintain a measurement archive, and to provide data for the Process Computer and the VERONA core monitoring system. In order to cover the full neutron flux range, Photonis CFUL08 type fission chamber was chosen. The interface module will serve all three operation modes of the detector: pulse, Campbell (AC) and current (DC) modes. In order to obtain high reliability and dependability, the system will be built from independent and redundant components.

1 INTRODUCTION

Reactivity measurement systems assist in the phase of reactor physics testing during the start-up of power reactor units with determining reactivity, displaying parameters, archiving and evaluating measurements.

The first generation of reactivity measurement systems at the Paks NPP was called RPM (Reactivity Parameter Monitoring) system and served properly for twenty years. The system was based on the originally installed Russian made KNK-4 gamma compensated ionisation chambers filled with $^3$He + $^4$He (since these chambers are intermediate range detectors, they are not fixed, but they are pulled into the measurement channels located around the core only for
the measurements). Maintenance of the system become harder and harder with the years passing and replacement of its main components become virtually impossible. Additionally installation and setup of the system before each reactor start-up was rather complicated and time consuming and connecting its hardware to the measurement system of the reactor required the assistance of a high skilled professional. Finally, the replacement of the original system has become necessary [1].

The accuracy of the second generation system (called RMS – Reactivity Monitoring System) based on the same detectors and installed in 2003 considerably surpassed its predecessor: the detector signals were measured by stable, high precision picoammeters, the output signals of which were handled and digitalised by a portable signal processing unit [2]. The on-line reactivity calculation algorithm of the signal processing unit also surpassed its predecessor: it was based on a point-kinetic model with six delayed neutron groups. The system was equipped with a user friendly, up-to-date man-machine interface, as well. The values of the process variables required for the evaluation were transferred from the unit process computer and the measured and calculated signals were transferred to the process computer, as well, for archiving. In order to make the off-line evaluation of the reactivity more accurate, a direct connection was established with the “fine” (i.e. accurate) control rod position meter.

The refuelling Neutron Monitoring System (RNMS) provides neutron flux monitoring during reactor refuelling. For safety reasons it consists of two independent subsystems installed in separate rooms.

The RNMS-I subsystem is based on three removable proportional ex-core neutron detectors located equidistantly (at 120 degrees) around the core. These measurement channels can be used only in a rather low neutron flux range, and in order to avoid detector burnup, the detectors have to be removed after refuelling.

The RNMS-II subsystem is also based on three equidistantly placed ex-core neutron detectors, which are fission chambers operated in pulse mode and their sensitivity is about one tenth of the detectors of the RNMS-I subsystem. RNMS-II is a redundant subsystem of RNMS-I supplying it with independent measurements, however its signal level is a little lower.

The main components of these two monitoring systems are the same age as the reactor units of the plant. A partial reconstruction of RNMS in 1996 [3] and the reconstruction of RMS system in 2003 did not concern the detectors, but the measurement and evaluation system. Experts of the plant have concluded that the rate of the degradation of the internal components of the ex-core neutron measurement system requires repairing or replacing in the near future. Informal price quotations showed that simple replacement of the main components by appropriate technical means is not possible or economically not feasible. Additionally there is no guarantee that the parameters of the replica detectors agree with the parameters of the existing detectors and their cost is so high, that installing fixed wide range detectors – serving both systems – became a viable option. Therefore Reactor Physics Department of Paks NPP, Centre for Energy Research and Regtron Ltd. decided to develop a multi-purpose monitoring system based on a detector type already used in the Paks NPP Reactor Protection Systems (RPS) since the nineties. It has been proved that this detector type (i.e. CFUL08) can be used in continuous operation and it is still reliable after two decades of utilization.
2 DESIGN CONCEPTS OF THE COMBINED SYSTEM

Advantages of the planned new system are as follows:

• The same detectors serve both the Reactivity Monitoring System and the Refuelling Neutron Monitoring System
• The detectors handle the full neutron flux range
• 6 detectors are sufficient without any loss of functionality instead of the 3 + 6 detectors of the present systems
• Fixed detectors resulting in simpler operation and lower probability of failures
• Additional functionality can be provided compared to the old systems

3 DEVELOPMENT AND TESTING OF THE MEASUREMENT CHAIN

![Figure 1: Scheme of CFUL08 fission chamber](image1)

The following steps were needed in order to substantiate the development of the new system:

• Development of a new signal processing module that can handle all three operation modes of CFUL08 (note that the DC operation mode handling the power range is not realized in the Reactor Protection System)

![Figure 2: Prototype of the signal processing module for CFUL08 fission chambers](image2)

• Developing a software system handling and processing the detector signals (with regard to the server mode operation of the planned system)
• Measurement and testing of the prototype system (detector, signal processing module and software) at the Training Reactor of the Budapest University of Technology and Economics. Testing was performed at different steady state power levels and during power level changing; the main goals were setting the optimal value of the discrimination level and the high voltage supply to the detector, verifying the linearity of the measurement system and the transitions between the different amplification levels. (The core of the pool-type university training reactor is constructed of fuel assemblies with 10% enrichment. The maximum thermal power is 100 kW, the maximum thermal neutron flux is $2.7 \cdot 10^{12}$ n/cm$^2$/s.) Data acquisition was performed with a mobile system based on a Lenovo ThinkPad T530 notebook and a National Instruments NI USB-6341 module (Fig. 3).

![Image](image1.png)

Figure 3: Mobile data acquisition and processing system for BUTE Training Reactor measurements

4 MEASUREMENTS AT THE PAKS NPP

In order to investigate the system under industrial conditions, it was tested in pilot operation at Unit 2 and later at Unit 3 of the Paks NPP. Here the data acquisition was performed by a PCIe analogue-to-digital converter card installed in a Dell server computer (Fig. 4).

![Image](image2.png)

Figure 4: Server configuration for the power reactor measurements

Main goals of the measurements with the pilot system were as follows:

• Investigation of the gamma sensitivity of the detector
• Investigation of the noise sensitivity of the system according to the long signal cables and electrical grounding in the reactor
• In order to test the system in permanent operation (stability, heat dissipation) it was operated during several months continuously
• In order to verify the operation in the whole neutron flux range, a continuous measurement covering a reactor shut down, a refuelling, a start-up and measurement at 100% power level was performed.

• The goal of the measurement at Unit 3 was to verify the developments carried out in the system based on the experiences obtained at Unit 2.

• Finally an additional measurement was performed in order to verify the suitability of the built-in signal cables for digital communication.

After the validation of the detector, the next step of the development was establishing digital communication (according to the RS422 protocol) between the preamplifier and the remote signal processing system. This provided the following advantages:

• Due to the decreasing need of signal cables the originally installed cables will be enough for the whole final system, there is no need to install new cables.

• Decreased noise and noise sensitivity.

• Simpler and more robust construction.

• Less complicated maintenance.

5 EVALUATION OF THE MEASUREMENTS, INVESTIGATION OF THE SUITABILITY OF THE DETECTOR

The measurement in the training reactor aimed at adjusting and tuning up the two operation modes of the amplifier module (i.e. pulse and current modes). In the measurement the reactor power was gradually changed and the detector signal was measured in pulse and current mode. Fig. 5 shows the trend of the reactor power during the measurement, while in Fig. 6 the count rate of the pulses and the detector current is plotted against the reactor power. Readings in steady states (large markers with border in the figures) were the main results of the measurement. However, data measured when the reactor power was changing are also plotted in the figures, but they have slightly bigger deviation due to the uncertainty of the power measurement of the training reactor.

A small overlapping of pulse and current operation modes can be seen in Fig. 6.

![Figure 5: Reactor power during the measurement in the Training Reactor](image-url)
Based on the measurements on the training reactor, the prototype system was improved and extended with handling AC operation mode, and then it was installed in pilot operation at Unit 2 of Paks NPP close to the end of a fuel cycle and it was used to measure the reactor shutdown, the refuelling period and the start-up of the reactor. This timing allowed us to measure the whole power range and thus start-up measurements could also be compared with the measurements made by using the old RMS system.

Fig. 7 presents measurements of a control rod drop test in all three operation modes of the detector. The figure also contains count rates measured with the Reactor Protection System instrumentation and with the old RMS system for comparison (the numbers shown in the legend of the figure denote the detector position corresponding to the 24 equidistantly located measurement channels around the core).
This comparison aims to investigate the different operation modes, how they follow the fast decreasing neutron flux. It can be seen that the AC and the pulse modes are satisfactory from this point of view, but the plot of current mode converges to \(3 \cdot 10^3\) cps, which is larger than the initial value of the DC mode. (Note that the negative peak in the Pilot-DC graph is caused by the still not-tuned measurement level transition of the device.)

Fig. 8 presents pulse operation mode count rates measured with the Reactor Protection System (RPS) and with the new pilot system. This magnification uncovers that the pulse mode signal of the new system has better resolution and smaller deviation than the RPS signal.

Figure 8: Control rod drop test (pulse mode)

In order to validate the DC mode and to compare it to the old system, the measurement of the moderator temperature coefficient of the reactivity (MTC) was used. One of the compensation steps during MTC measurement is presented with high zoom in Fig 9. Fluctuation of the raw signal measured with the new system is three times larger than that could be explained with the underlying Poisson distribution (note that the output of the old system contains filtered signal only). The signal of the new system is shown after filtering with a 20-point-wide moving average in Fig. 10. The signals of the two systems well agree with this filtering.
Figure 9: A compensation step during MTC measurement (current mode)

Figure 10: A compensation step during MTC measurement (current mode); (signal of the Pilot system is filtered with a 20-point-wide moving average)

6 STRUCTURE OF THE PLANNED SYSTEM

Based on the prototype and the pilot measurements it was concluded that the CFUL08 fission chambers with the newly developed signal processing devices are suitable to provide signals for a new system replacing the two old neutron monitoring systems. The scheme of the planned new system is presented in Fig. 11.
The six fission chambers to be installed in the measurement channels placed equidistantly in the biological shield around the reactor core are shown in the bottom of Fig. 11. The devices (RNL-04.04D) processing the detector signals in all three operation modes simultaneously and digitizing the signals of the three modes are placed in a room near to the biological shield. The digitized signals are transferred via industrial serial communication (RS422) to the interface units (NFL-04.04D) placed in a rack (containing the servers, as well) in a room next to the Main Control Room (MCR). Serial signals are duplicated and transferred to the redundant servers of the Neutron Monitoring System (NMS) by the interface units through separated connections. All six detector signals are transferred into both servers. The NMS servers provide information to all other systems through redundant network switches. Neutron signal levels and alarm signals are provided for the MCR, the Emergency Control Room (ECR) and the Refuelling Machine. The measured signals are archived by the NER servers; these archives can be reached through thin clients placed in the MCR. Neutron flux signals are also provided for the RMS gateway performing reactivity calculations. Accurate control rod positions required for the reactivity calculations are provided through the so called SOK gateways, all other information and signals needed (properties of the actual core loading, boric acid concentration, primary loop
temperatures etc.) are coming from the Process Computer and the Verona core monitoring system [4]. The latter is supplied with the calculated reactivity values, as well.

Installation of the new system will be performed in two steps. Only one of the Refuelling neutron monitoring subsystems (RNMS-II) will be replaced by the new system built using three detectors only. The old and the new reactivity monitoring system will operate simultaneously. In this way two redundant RNMS subsystems will be in operation and the new RMS system will be validated with the old system. In the second step the remaining part of the system (marked with a yellow cloud in Fig. 11) will also be installed and will replace RNMS-I.

7 CONCLUSIONS

Measurements with RMS-Pilot system proved that the whole neutron flux range can be covered with CFUL08 fission chambers using the newly developed signal processing devices and data acquisition system:

- The pulse mode is applicable up to about $10^6$ nv and so it can provide signals for both the refuelling monitoring system and the start-up measurements.
- The current (DC) mode provides appropriate reactivity values even at relatively low signal levels after filtering with moving average (to remove undesirable noises) and subtracting the constant parasitic signal component; so it can be used even for start-up measurements.
- The pulse and DC modes together cover the whole desired neutron flux range.
- The AC mode – due to its operation principle – contains so high noise that can be filtered out only with a relatively wide moving average; therefore it cannot be used for transient measurements. However, it is applicable to measure slowly changing neutron fluxes.

Pilot measurements performed under industrial conditions prove that the measurement chain is suitable to serve both reactivity monitoring and refuelling neutron monitoring purposes. The planned new, combined system with redundant implementation and six detectors provides the measurement of the reactor core with better coverage for both systems.

REFERENCES


