NON-STANDARD PHYSICS TESTS OF AKNT-17R SYSTEM COMMISSIONING AT BOHUNICE NPP

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ABSTRACT

New system for neutron power measurement AKNT-17R was commissioned at Bohunice NPP, in Unit 3 in 2007 and in Unit 4 in 2008. The supplier of AKNT-17R system was SNIIP Moscow. VUJE prepared, carried out and evaluated commissioning tests of the system. The AKNT-17R commissioning tests during physics start-up were also called as non-standard physics tests, and the paper deals with them. Some of the non-standard physics tests were carried out in parallel with the standard tests. In this case, e.g. during the reactor criticality achievement or during the rod-drop measurement, the response of AKNT-17R system was also tested. The other non-standard tests were carried out as extra tests and they slightly prolonged the physics start-up duration. During these extra non-standard tests the overlapping and switching of neutron power ranges were checked-out, the accuracy of reactor period and reactivity was verified and also the response of AKNT-17R system to step, impulse and harmonic changes of reactivity was tested.

In the first part of the paper, the AKNT-17R system is briefly introduced. Then scope, objectives and acceptance criteria of the non-standard tests are described. At the end, some results of the selected non-standard physics tests of AKNT-17R system are presented and discussed.

1. INTRODUCTION

During the period from 2001 to 2008 the Bohunice Units 3&4 were modernized. In the frame of the modernization, the original system of neutron flux measurement AKNT-2 was replaced by the new AKNT-17R system. The supplier of AKNT-17R system was SNIIP Moscow. VUJE prepared, carried out and evaluated commissioning tests of the system. The AKNT-17R commissioning tests during physics start-up were also called as non-standard physics tests, and the paper deals with them.

2. BRIEF DESCRIPTION OF AKNT-17R SYSTEM

The AKNT-17R system consists of three independent identical redundancies. The each redundancy measures neutron power by three ranges: Source Range (SR), Intermediate Range (IR) and Power Range (PR), see Table 1.

Table 1. Measured ranges of AKNT-17R system

Name of Range	**Power Range [% N_{nom}]**
Source Range (SR)	From $5\cdot10^{-10}$ to $2{,}0.10^{-5}$
Intermediate Range (IR)	From 5.10^{-7} to $5{,}0.10^{-2}$
Power Range (PR1)	From 1.10^{-3} to 200
Power Range (PR2)	From 1 to 125

For each redundancy and each power range there are three measurement channels with ionization chambers, so altogether there are 9 SR, 9 IR and 9 PR ionization chambers. Three ionization chambers of the same redundancy and of the same power range are located symmetrically around the reactor core. The SR ionization chambers are located in their own channels and the pairs of IR and PR ionization chambers are together in common channels - the PR ionization chambers are located horizontally at the level of the reactor core middle and the IR ionization chambers are under their PR ionization chambers.

The AKNT-17R system measures reactor period and reactivity, too. Reactor period is measured for each ionization chamber, so there are 27 reactor power and 27 reactor period signals in the system. Reactivity is measured only for each redundancy and each measurement channel, so there are 9 reactivity signals. The reactivity measurement range is from $-25\ \beta_{ef}$ to $1\ \beta_{ef}$ for power range from $5\cdot10^{-10}$ % N_{nom} to 125 % N_{nom}.

3. TWO STAGES OF AKNT-17R SYSTEM INSTALATION AND COMMISSIONING

The new AKNT-17R system was installed and commissioned at Bohunice Units 3&4 in two stages. The activities in Unit 3 were performed approximately one year prior to the activities in Unit 4.

In the first stage, only the third redundancy of AKNT-17R system was installed and operated in so called the “open-loop” regime. This redundancy was tested during fuel reloading, physics start-up and power start-up. In Unit 3 it was tested from August to October 2006 and in Unit 4 it was from July to September 2007. During the testing it was possible to compare the third AKNT-17R redundancy behaviour to the old AKNT-2 system behaviour. On base of the comparison and evaluation of the “open-loop” regime testing, the third redundancy could be tuned and justified.

In the second stage, the remaining two redundancies of AKNT-17R system were installed and afterwards the whole AKNT-17R system was tested during fuel loading, physics start-up and power start-up. In Unit 3, the whole AKNT-17R system was tested from September to November 2007 and in Unit 4 it was from July to September 2008.

4. NON-STANDARD TESTS SCOPE, PURPOSE, OBJECTIVES AND ACCEPTANCE CRITERIA

The non-standard physics tests of the new AKNT-17R system were performed in Units 3&4 twice after the both installation stages. It means that altogether the testing was performed four times. The scope of each testing was in principle the same and it consisted of following non-standard physics tests:

- Test F2 “Checkout of neutron power and reactor period during physics start-up”:
  - Subtest F2/1 “Checkout of neutron power and reactor period during reactor criticality achievement by boron concentration decreasing”
  - Subtest F2/2 “Checkout of neutron power and reactor period during rod-drop measurement”
  - Subtest F2/3 “Checkout of neutron power and reactor period during reactor criticality achievement by control rods withdrawal”
- Test F3 “Checkout of neutron power and reactor period by asymptotic period method”
- Test F4 “Checkout of automatic switching and overlapping of neutron power ranges”
- Test F5 “Checkout of reactivity calculation”
- Test F6 “Verification of AKNT-17R system dynamical characteristics during step, impulse and harmonic changes of reactivity”.

The scope of AKNT-17R testing during physics start-up was planned in such a way to minimize start-up stage prolongation. It means that standard physics tests as “Reactor criticality achievement” or “Rod-drop measurement” was also used for AKNT-17R testing. This testing was called as the non-standard test F2 with three subtests F2/1, F2/2 and F2/3. The other non-standard tests F3, F4, F5 and F6 were carried out as extra tests and they slightly prolonged the usual physics start-up duration.

The general purpose of the non-standard tests was the new AKNT-17R system verification and validation. Some data from the non-standard tests evaluations were also used for AKNT-17R system setting.

The general objectives of the non-standard tests were as follows:

- To measure and archive neutron power, reactor period and reactivity time charts during the non-standard tests performance

- To find out whether there is an anomaly on measured neutron power, reactor period and reactivity time charts
- To checkout automatic switching and overlapping of neutron power ranges SR, IR and PR1 during reactor power increasing and decreasing
- To determine accuracy of reactor period and reactivity measurement
- To determine reactor period time delay in case of positive reactivity step changes.

The general criteria of the non-standard tests were as follows:

- Comparison of the third AKNT-17R redundancy behaviour to the old AKNT-2 system behaviour (applied only after the first stage of AKNT-17R installation)
- Comparison of the first and the second AKNT-17R redundancy behaviour to the third redundancy behaviour (applied only after the second stage of AKNT-17R installation)
- Comparison of the AKNT-17R system behaviour to the system design after the both stages of AKNT-17R installation

Besides the general criteria there were typical test criteria as follows:

- Difference between common logarithm of neutron power measured by corresponding channels of all three redundancies were less than 0,3 of decade
- Overlapping of neutron power ranges SR, IR and PR1 was more than 0,5 of decade
- Difference between measured and theoretical reactivity was less than ±5% rel.
- Measured reactivity noise was less than ±0,005 β_{ef}
- Difference between measured and theoretical asymptotic reactor period was less than ±30% rel.
- Difference between measured and calculated worth of control rod system was less than ±21% rel.

5. NON-STANDARD TESTS EVALUATION

Non-standard tests evaluation was characterized by processing of huge amount of measured data. During the non-standard tests performance there were collected approximately 100 signals with sampling period 1s. The data were gathered from the standard Technological Computer System and also from the Non-standard Measurement System (NMS), which has been used for management and evaluation of standard Physics tests.

Each non-standard physics test was preliminary evaluated within two hours after the test completion. On the base of the preliminary results the AKNT-17R could be brought into harmony with the AKNT-2 system or with the AKNT-17R design.

The final evaluation of the non-standard physics tests was elaborated in one month after physics start-up stage completion. Selected results of some non-standard tests from final evaluation are presented in this chapter.

After the first stage of AKNT-17R installation the third redundancy was tested. During the testing, the non-standard tests F2÷F6, which are described in Chap. 4, were performed. For brief information, reactor period testing is shown in Fig. 1 and 2.

In Fig. 1 and 2 there are comparisons of the original AKNT-2 reactor period and the AKNT-17R 3-rd redundancy reactor period in the case of reactivity step changes. From Fig. 1 it can be seen that in the intermediate range the AKNT-17R reactor period is more sensitive to reactivity changes (less dumped) than the AKNT-2 reactor period. From Fig. 2 it is seen that in the beginning of the power range, the AKNT-17R reactor period is more delayed than AKNT-02 reactor period. The time delay of reactor period measured in the beginning of the power range (while reactor power was less than 10^{-2} % N_{nom}) was 15-20 s. Later it was shown that the reactor period increased noise in the intermediate range and the increased time delay in the power range are features of the new AKNT-17R system.

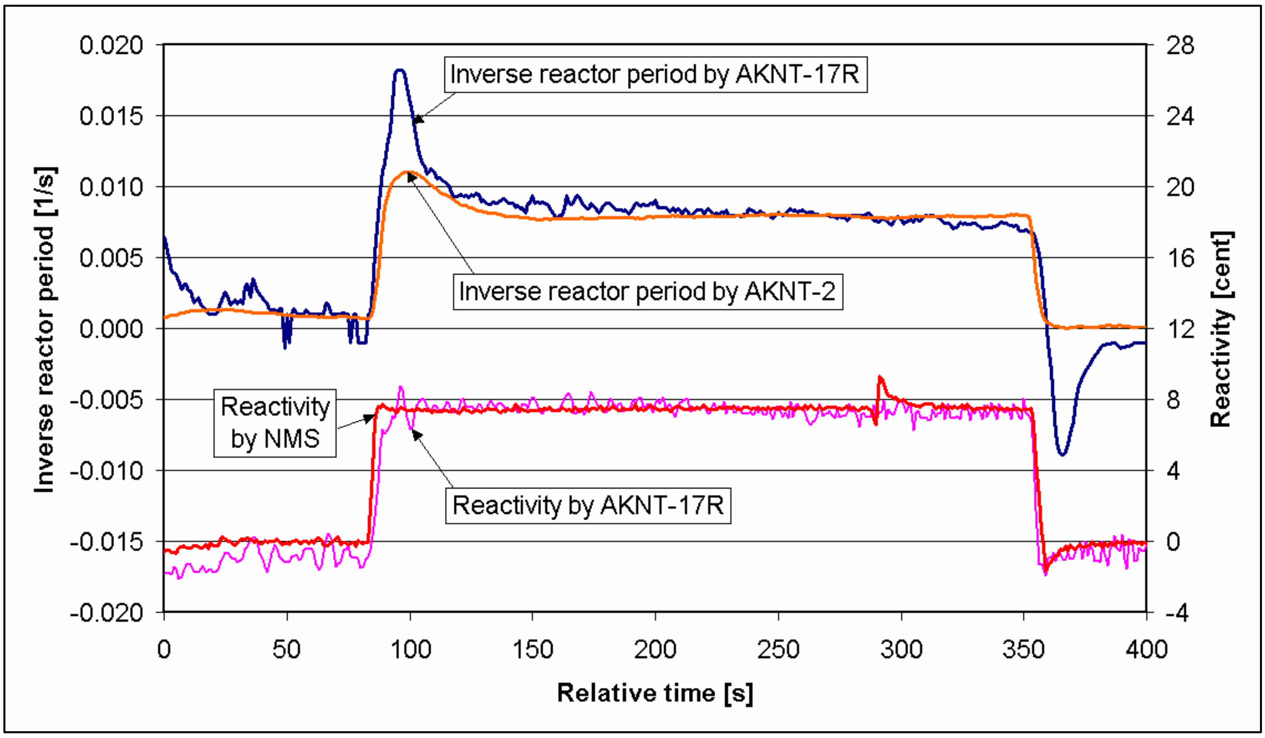

Figure 1. Comparison of reactor period measured by the AKNT-2 and by the AKNT-17R, the third redundancy in intermediate range in case of reactivity step change at reactor power $4,0.10^{-3} \div 8,0.10^{-3}$ [% N_{nom}]

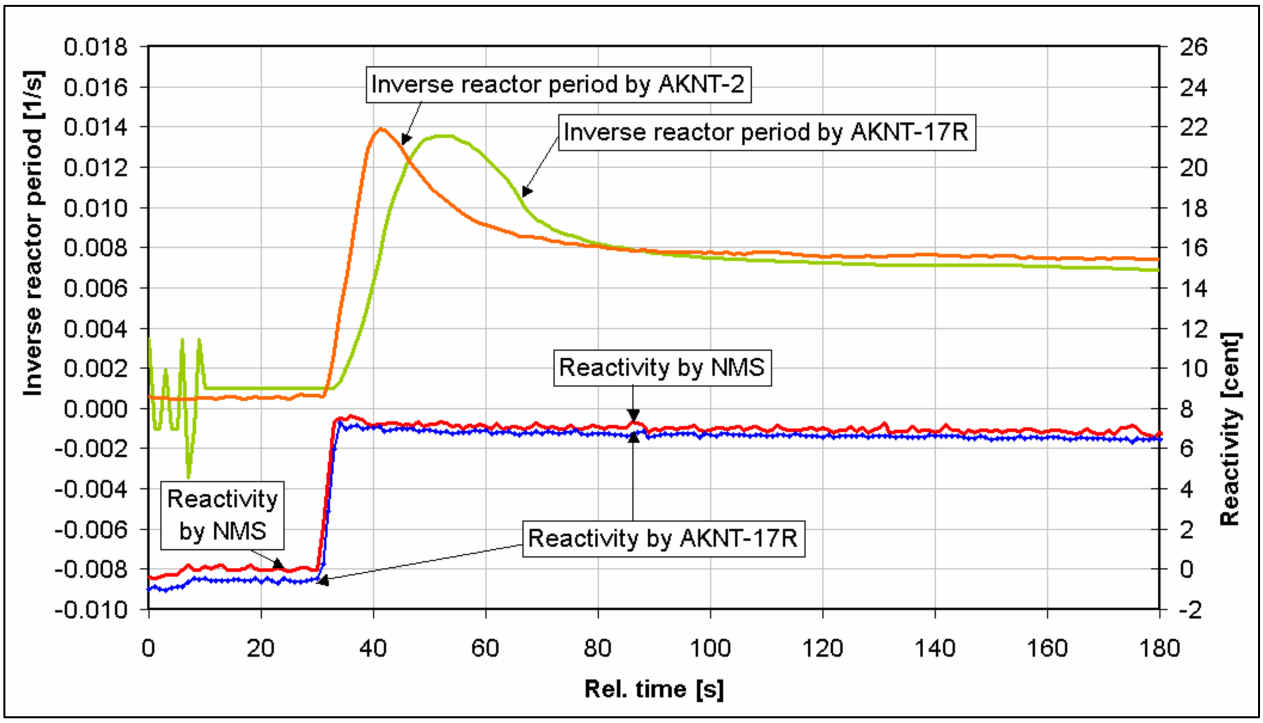

Figure 2. Comparison of reactor period measured by the AKNT-2 and by the AKNT-17R, the third redundancy in power range in case of reactivity step change at reactor power $2,0.10^{-2} \div 4,0.10^{-2}$ [% N_{nom}]

In the second stage of AKNT-17R installation, when the original AKNT-2 system was fully replaced by the new AKNT-17R system, the same non-standard tests F2÷F6 as in the first stage (in the "open-loop" regime) were performed. Some examples of the tests F2÷F6 evaluation are shown in the paper.

In Fig. 3 there are AKNT-17R reactivity time charts during the reactor first criticality achievement after reloading. At this time the AKNT-17R system had not been yet justified. It is seen that in the beginning of the start-up interval there were steps in reactivity caused by reactivity calculation switching from the source range to the intermediate range. After this test evaluation, the AKNT-17R system was justified. Later, after rod-drop measurement, when the reactor second criticality was achieved, unwanted reactivity steps were not present, see Fig. 4

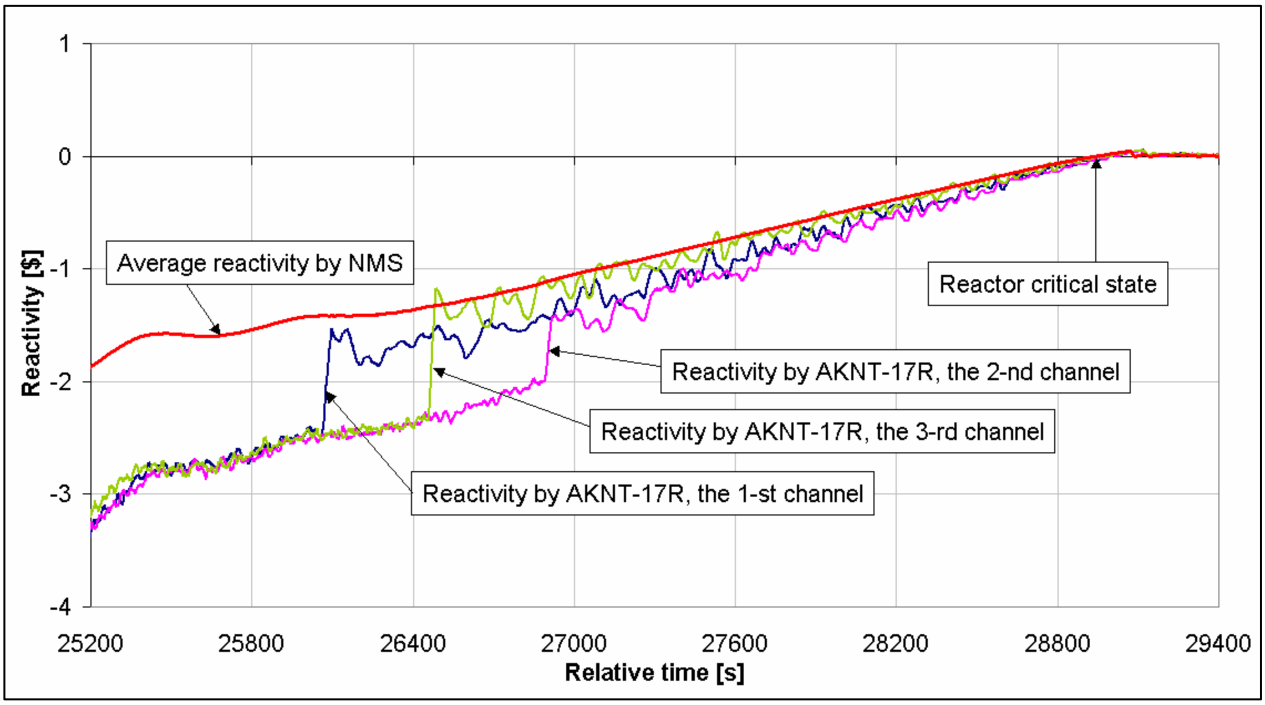

Figure 3. Reactivity time charts of the first redundancy of AKNT-17R during the first criticality achievement, when the AKNT-17R was not justified

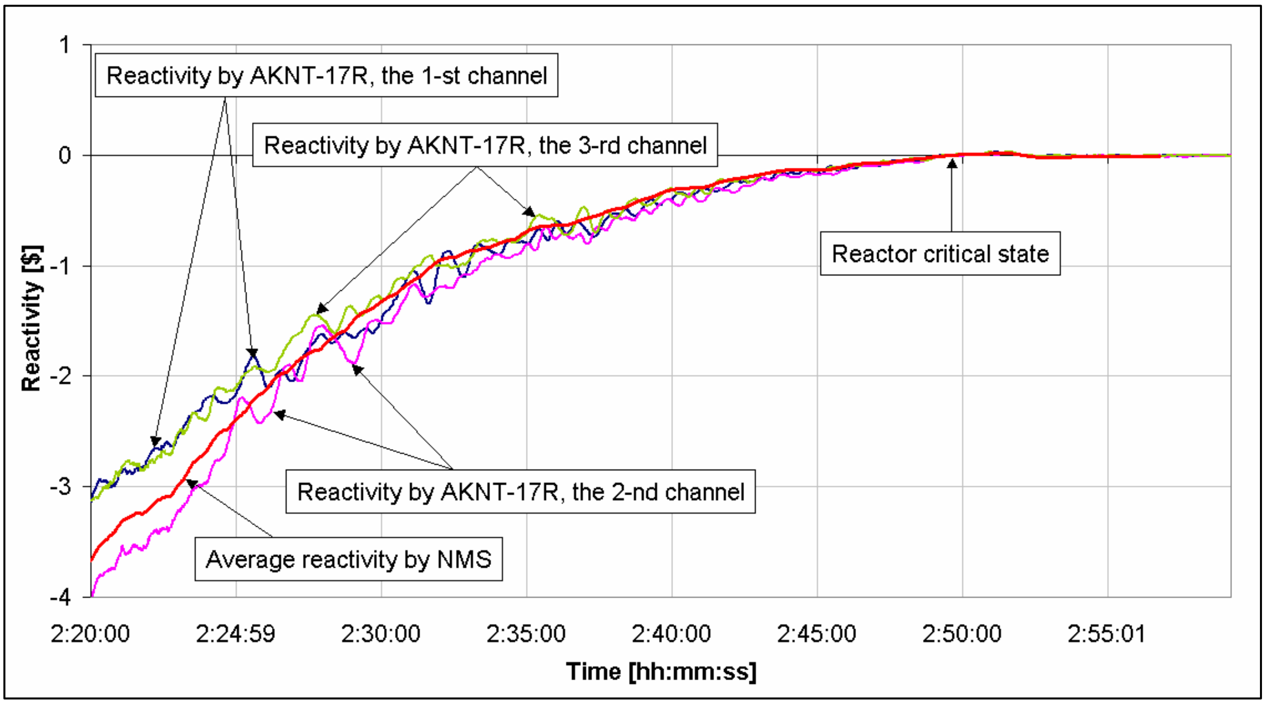

Figure 4. Reactivity time charts of the first redundancy of AKNT-17R during the second criticality achievement, after the AKNT-17R justification

The asymptotic period method was applied for AKNT-17R reactor period and reactivity checkout. Reactor period and reactivity checkout were carried out parallel, at one measurement, see Fig. 5 and 6. After positive step change of reactivity cca 0,055β_{ef}, reactor power was increased from the intermediate range to the power range. Reactor period and reactivity checkout were evaluated for the both ranges. Reactor power, reactivity and reactor period time charts measured by the first redundancy of AKNT-17R are plotted in Fig.5 and 6. Numerical results of this reactivity checkout are shown in Table 2. The accuracy of reactivity measured by the first redundancy was from -0,4 % rel. to +1,1 % rel., what met the acceptance criterion ±5% rel.

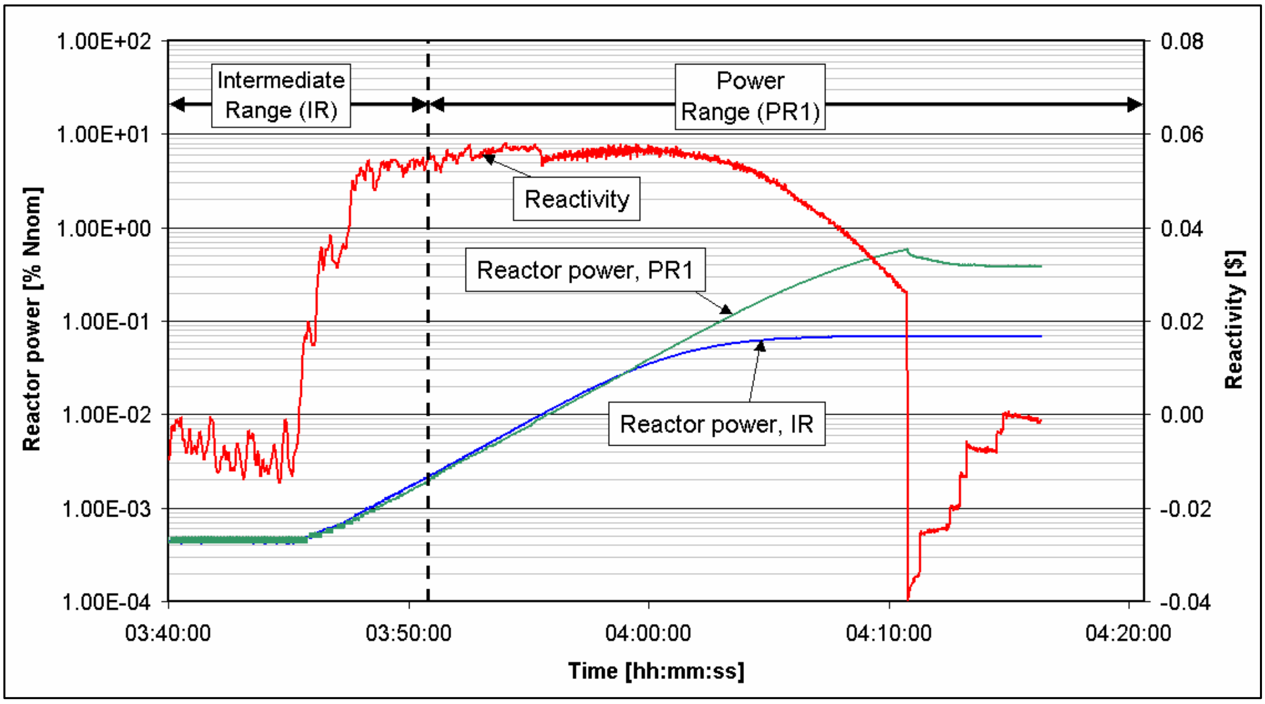

Figure 5. Reactor power and reactivity time charts measured by the 1-st redundancy of AKNT-17R during reactivity checkout

Table 2. Checkout of reactivity measured by the 1-st redundancy of AKNT-17R in intermediate and power ranges

Range	Channel	Reactivity [cent]		ε [% rel.] *)
		Measured	Calculated	
IR	1	5,52	5,54	-0,4
	2	5,41	5,43	-0,4
	3	5,49	5,49	0,0
PR1	1	5,62	5,59	0,5
	2	5,62	5,56	1,1
	3	5,61	5,56	0,9

*)
$$\varepsilon = \frac{Measured - Calculated}{Calculated} \, .100\,\%$$

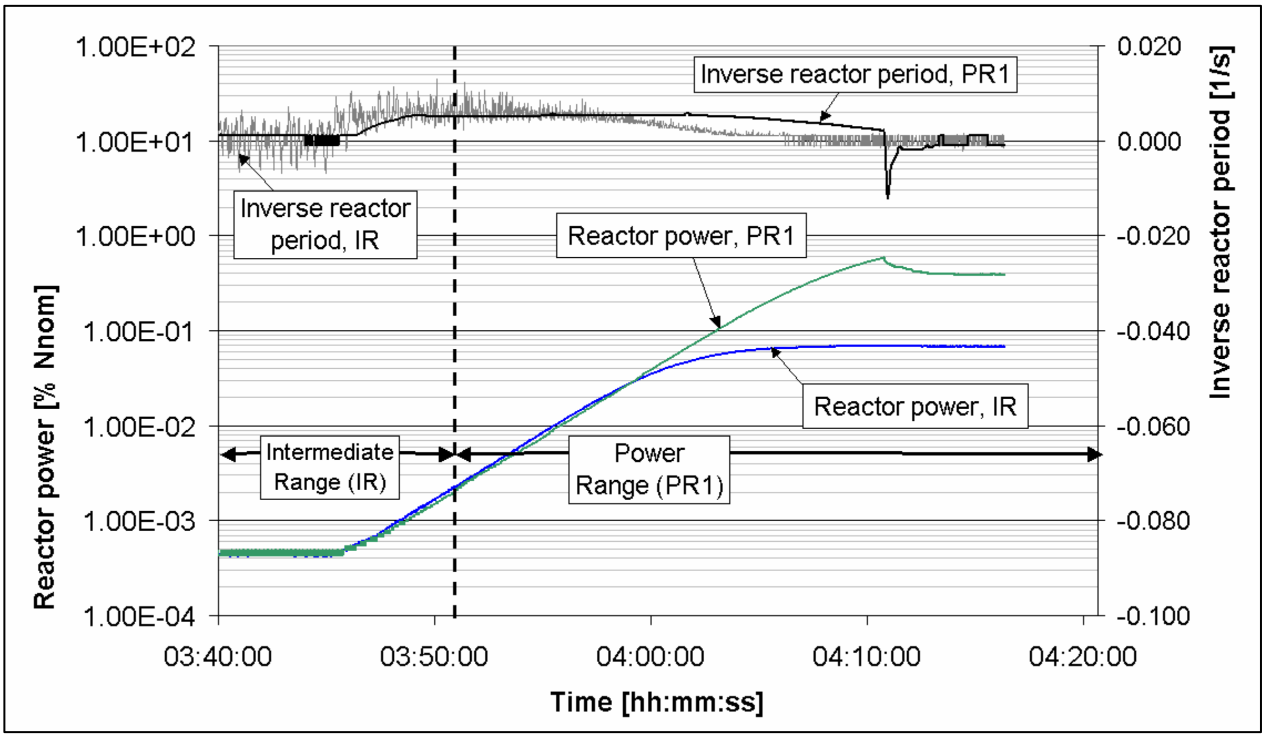

Figure 6. Reactor power and reactor period time charts measured by the 1-st redundancy of AKNT-17R during reactor period checkout

Table 3. Checkout of reactor period measured by the 1-st redundancy of AKNT-17R in intermediate and power ranges

Range	Channel	Reactor Period [s]		ε [% rel.] *)
		Measured	Calculated	
IR	1	178,4	186,2	-4,2
	2	184,6	190,5	-3,1
	3	183,6	188,0	-2,3
PR1	1	187,6	184,4	1,7
	2	187,6	185,5	1,1
	3	187,4	185,3	1,1

In Table 3 there are numerical results of reactor period checkout. The accuracy of reactor period measured by the first redundancy was from -4,2 % rel. to +1,7 % rel., what was less than acceptance criterion ±30 % rel.

In Fig.7 there are time charts of inverse reactor period measured by AKNT-17R in case of reactivity impulse changes. The reactivity impulse changes were introduced by the group 6 control rods. It is seen, that the AKNT-17R system responded adequately.

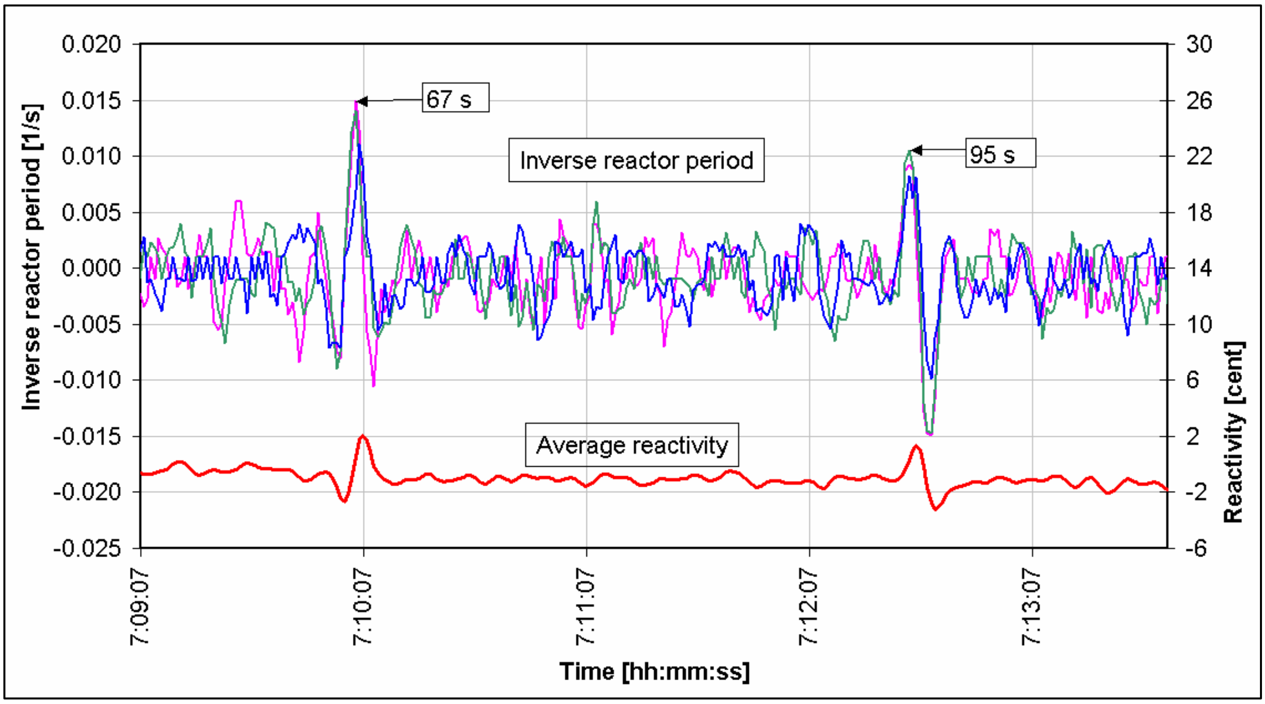

Figure 7. AKNT-17R response to reactivity impulse changes in the intermediate range

6. CONCLUSION

VUJE prepared, carried out and evaluated the non-standard tests of AKNT-17R commissioning at Bohunice Units 3&4 in the years 2006÷2008. The new AKNT-17R system was tested during the standard physics tests as reactor criticality achievement or the rod-drop measurement. In addition, the extra non-standard tests were carried out in order to verify overlapping and switching of neutron power ranges and to verify the accuracy of reactor period and reactivity. The AKNT-17R system dynamical characteristics were also tested for step, impulse and harmonic changes of reactivity. During the non-standard tests performance, some AKNT-17R parameters were justified.

On the base of the non-standard tests results, it can be said that the AKNT-17R system of Bohunice Units 3&4 met all conditions for safe operation. The Bohunice Units 3&4 are now in process of reactor power up-rating to 107 % Nnom, and the new AKNT-17R system is helpful in this process.