STARTUP PHYSICS TESTS AT TEMELÍN NPP, UNIT 1

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ABSTRACT

The objective, scope and proceedings of the physics tests of Temelín NPP, Unit 1 physical commissioning are given in this paper. Furthermore, some results of selected physics tests are presented: reactor initial criticality test, determination of reactor power range for physics testing, measurement of control rod cluster assembly group no. 10 reactivity worth in case of limitation system LS(a) actuation, control rod cluster assembly system reactivity worth measurement with single control rod cluster assembly of greatest reactivity worth stuck in fully withdrawn position, measurement of differential reactivity worth of control rod cluster assembly group no. 9, boron "endpoint" determination and measurement of power reactivity coefficient.

1. INTRODUCTION

VÚJE Trnava, Inc. participated in the commissioning of Temelín NPP Unit 1 in the area of physics tests preparation, performance and evaluation. VÚJE Trnava Inc. specialists developed the test procedures, which include test objective, initial and final conditions of NPP instrumentation and systems before and after the test performance, test sequence, evaluation methods, test criteria etc. Specialized data acquisition, treatment, archiving and evaluation software applications developed by VÚJE Trnava were used in course of the test performance and evaluation.

This paper gives an overview of objective, scope, process and some results of selected startup physics tests of Temelín NPP Unit 1 commissioning.

2. OBJECTIVE, SCOPE AND PROCESS OF STARTUP PHYSICS TESTS

The objective of Unit 1 startup physics tests was to verify the reactor core neutron characteristics, which are important to nuclear safety.

The scope of physics tests was determined according to commissioning programs of WWER-1000 plants in Russia and Ukraine and guidelines of Westinghouse Electric Corporation, USA. This scope was extended with the tests that conform to the latest nuclear safety practice, namely ejection of control rod cluster assembly and limitation system actuation with the control rod cluster assembly of greatest reactivity worth stuck in fully withdrawn position. The final test program consisted of following tests and subtests, in chronological order:

F003/A	Reactor initial criticality test,
F003C/1,2	Determination of the neutron source used in point kinetics equations,
F004	Check for coupling of control rod assemblies with their drives,
F003B	Determination of reactor power range for physics testing,
F003D	Reactivity computer checkout,
F006/1	Efficiency of limitation system (reactivity worth of all control rod cluster assemblies dropped into reactor core),
F005/1	Verification of control rod cluster assembly group no. 10 reactivity worth in case of limitation system LS(a) actuation,
F007/1	Isothermal Temperature Coefficient in the range within 268÷285 °C and pressure reactivity coefficient measurement,
F016/1	Reactor noise measurement with all control rod cluster assemblies in working positions at HZP,
F006/2	Verification of selected control rod cluster assembly group reactivity worth after limitation system LS(c) actuation,
F005/2	Integral reactivity worth of control rod cluster assembly groups measured using group swap method and boron "endpoint" determination,
F005/3	Determination of differential and integral reactivity worth of control rod cluster assembly groups by changing the boron concentration in moderator and measurement of differential boron worth (boron reactivity coefficient),
F007/2,3,4	Measurement of temperature and pressure reactivity coefficient on 8^{th}, 9^{th} and 10^{th} group of control rod cluster assemblies,
F006/5	Efficiency of limitation system (reactivity worth of all control rod cluster assemblies dropped into reactor core from RIL position estimated after 1000 Mwd/tU),
F016/2	Reactor noise measurement with control rod cluster assemblies in RIL position at HZP,
F006/6	Efficiency of limitation system (reactivity worth of (N-1) control rod cluster assemblies dropped into reactor core from RIL position estimated after 1000 Mwd/tU with single control rod cluster assembly of greatest reactivity worth stuck in fully withdrawn position),
F005/4	Reactivity worth of single control rod cluster assembly ejected from the reactor core,

F006/3	Efficiency of limitation system (reactivity worth of (N-1) control rod cluster assemblies dropped into reactor core with single control rod cluster assembly of greatest reactivity worth stuck in fully withdrawn position),
F014	Measurement of reactor core symmetry,
F009	Measurement of power coefficient of reactivity at 1 % of full power.
Note:	There were several subtests performed as a part of the whole test. The number of subtest is listed after the slash behind the test procedure number.

The physics tests at Unit 1 of Temelín NPP were performed from October 9, 2000 to October 24, 2000. The net time needed for all tests performance (not considering non-physics tests and idle-time) was 260 hours. First reactor criticality was achieved on October 11, 2000 at 6:19 AM. All physics tests were carried out in power range $3 * 10^{-3} \div 1.9$ % of full power.

VÚJE Trnava specialists worked as test leaders/coordinators and were responsible for data acquisition from systems PFS and STDAS and their further processing. They were supported by ČEZ-ETE reactor physicists. Technological systems were controlled exclusively by ČEZ-ETE operating staff.

3. RESULTS OF SELECTED STARTUP PHYSICS TESTS

Preliminary evaluations of individual tests were produced immediately after the test completion. The test leader submitted the preliminary evaluation results to ČEZ-ETE in form of Test Report [1]. Temelín NPP Unit 1 Startup Physics Tests Final Evaluation Report [2] was delivered to ČEZ-ETE in two months after completion of startup physics test program.

Overview of selected test results is summarized in following paragraphs.

REACTOR INITIAL CRITICALITY TEST (F003A)

Control of reactor criticality achievement was improved by neutron sources used for the first time in this type of reactor in order to increase initial neutron flux. Neutron sources were placed in fuel assemblies 02-31 and 12-37. Criticality approach was controlled with source range neutron detectors (ionization chambers - IK) no. 5, 15, 25 and neutron detectors (IK) of PFS system no. 4, 14, 24. After withdrawal of all 10 groups of control rod cluster assemblies the critical state was achieved with decrease of boron concentration in primary coolant/moderator. Time scale graph of source range detectors' inverse count rates during boron dilution is shown in Fig. 1. The shown time interval represents filter saturation followed by boron concentration equalization among primary circuit (PO), pressurizer (KO) and deaerator of make-up system (OD), boron dilution in high flow and low flow regime until the first reactor critical state achievement at 6:19 AM, October 11, 2000.

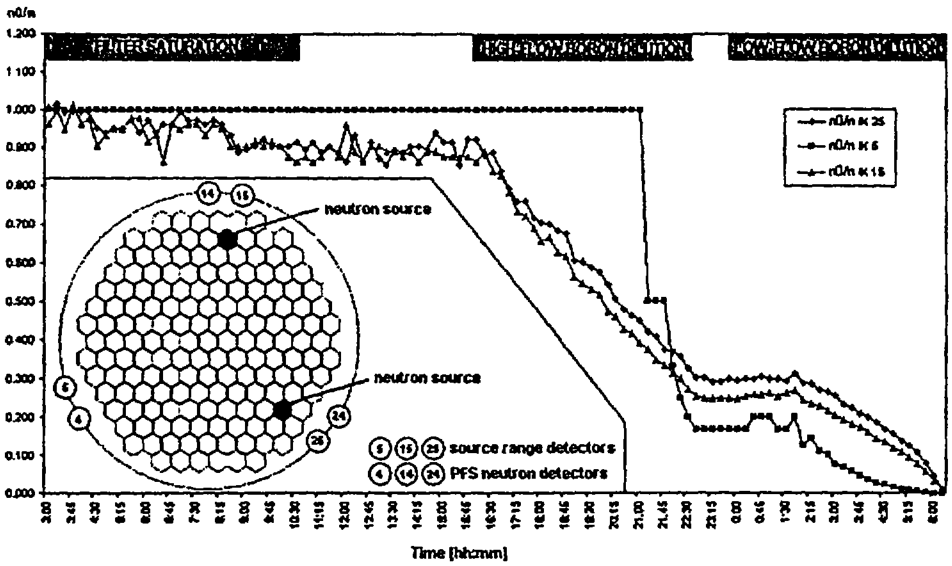

Fig. 1 Time scale graph of source range detectors' inverse count rates during boron dilution.

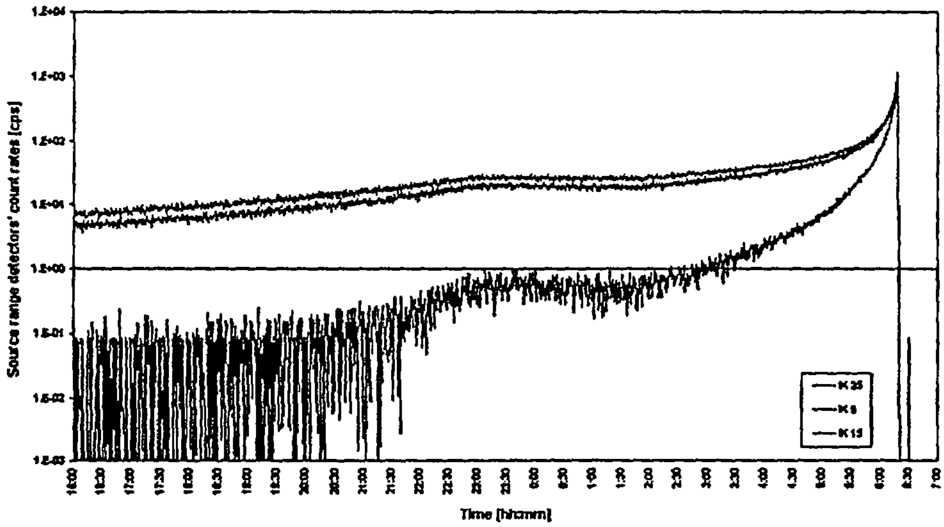

Fig. 2 Signal of source range neutron detectors recorded during first criticality approach at Unit 1 Temelín NPP.

From Fig. 1 it's evident that source range detector no. 5 (IK 5) which was the farthest placed from neutron sources staid under its sensitivity threshold until high flow boron dilution stage was finished. Time to criticality during approach was assumed from extrapolation of inverse count rate curves to zero value. Taking into account that shape of these curves depends on mutual position of source and detector (for detector placed near the neutron source the curve is of concave shape and for detector placed far from the neutron source the curve is of convex shape) the predicted time of criticality differed for each IK. As the control of criticality approach followed the conservative strategy the time to criticality was predicted according to values obtained from IK 5, which in comparison with other ionization chambers had shown the shortest time to criticality.

VERIFICATION OF CONTROL ROD CLUSTER ASSEMBLY GROUP NO. 10 REACTIVITY WORTH IN CASE OF LIMITATION SYSTEM LS(A) ACTUATION (F005/1)

The test was divided into four parts. Reactivity worth measurement of control rod assembly group 10 between positions given in Table 1 after LS(a) actuation was performed in each part of the test. Individual measurements consisted of stepwise control rod group insertion into the core followed by stepwise group withdrawal to initial position (final position).

Comparison of measured and calculated values is listed in Table 1. Experimental reactivity worth of measured interval is represented as an average of measured worth values determined during rod group insertion and withdrawal. Measured reactivity worth of the measured interval is determined using the calculated integral worth of control rod group no. 10. Relative deviations between measured and calculated values are within range -6.6 ÷ -5.9 % rel. and conform to test criterion which allows for ±20 % rel. deviation.

Table 1 Reactivity worth of control rod group no. 10 for measured intervals at primary coolant temperature of 279.6 °C.

Position of control rod group no. 10	ρ_{meas}	ρ_{calc}	$\frac{meas - calc}{calc}.100$
step (1 step = 2 cm)	pcm	pcm	% rel.
103,6 ÷ 127,1	58,9	62,75	-6,1
88,3 ÷ 126,8	111,3	119,19	-6,6
73,3 ÷ 130,0	173,0	185,24	-6.6
153,5 ÷ 122,3	40,2	42,71	-5,9

DETERMINATION OF DIFFERENTIAL AND INTEGRAL REACTIVITY WORTH OF CONTROL ROD CLUSTER ASSEMBLY GROUPS BY CHANGING THE BORON CONCENTRATION IN MODERATOR AND MEASUREMENT OF DIFFERENTIAL BORON WORTH (BORON REACTIVITY COEFFICIENT) (F005/3)

Determination of integral and differential reactivity worth (using boron exchange) of control rod cluster group 9 ran simultaneously with reactivity worth measurement of groups 8 and 10. Overlap of these groups is set to 50% (see Fig. 3). Worth of group 9 was measured throughout its whole length, from fully inserted to fully withdrawn position (0 ÷ 175 steps). The measurement used boron exchange method. Small reactivity changes caused by boron concentration change were compensated by periodical insertion/withdrawal of groups 8, 9 and 10 in such way, that the reactivity was kept within ±30 pcm. Value of reactivity introduced by insertion/withdrawal regarding to shift in control rod cluster group position represents the differential worth for respective group position. Measured points of differential worth form the measured differential worth curve – see Fig. 3.

Numerical integration of individual differential worth in measured position range results in measured integral worth characteristic curve for control rod groups 8, 9 and 10. Calculated values are taken from neutron-physics calculations for Unit 1. Relative deviation between measured and calculated integral reactivity worth of control rod cluster groups 8, 9 and 10 in measured range was -7.2 % rel. and the result meets the test criterion.

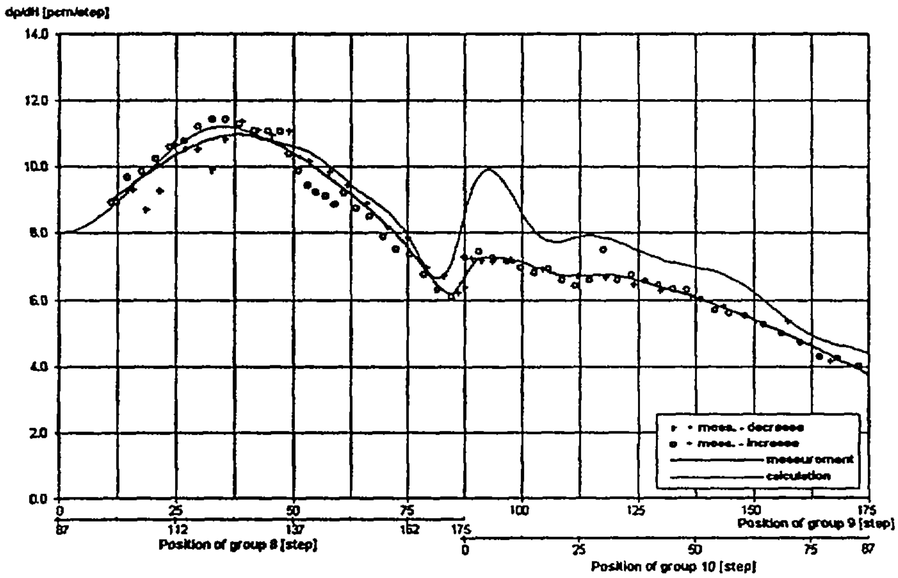

Fig. 3 Differential reactivity worth of control rod cluster group 9 measured with boron exchange method, T_{PO} = 279.0 °C, p_{PO} = 15.60 MPa, N_R = 0.003 % N_{nom}.

BORON "ENDPOINT" DETERMINATION (F005/2)

The purpose of this test is to determine so called "endpoint" boron concentrations for these control rod group positions:

- ARO, all control rod cluster assemblies are fully withdrawn from reactor core, or
- ARI x, all control rod cluster assemblies of group x are in individual mode fully inserted into the core, where x is the number of measured group (x = 1, 2, 3 ... 10), other groups are fully withdrawn from the core.

It's impossible to bring the reactor into steady state exactly in these positions therefore the reactor is stabilized in positions near to ARO or ARI x. The remaining reactivity worth of respective group has to be estimated. This is done by inserting of respective group (in case of ARO by withdrawal) into the end position and from the reactivity change the addition to measured boron concentration is assessed. This corrected value of boron concentration is called "endpoint" concentration. Measured values of "endpoint" concentrations are listed in Table 2.

Table 2 "Endpoint" concentrations for control rod group positions.

Group position	$(C_B)_{meas}$	$(\Delta C_B)_{END}$	$(C_B)_{END}$	$(C_B)_{calc}$	meas–calc
	g/kg	g/kg	g/kg	g/kg	g/kg
ARI 1	6,3250	-0,0047	6,3203	6,5826	-0,26
ARI 2	6,3250	-0,0050	6,3200	6,5826	-0,26
ARI 3	6,1750	-0,0215	6,1535	6,4276	-0,27
ARI 4	6,1750	-0,0117	6,1633	6,4276	-0,26
ARI 5	6,3500	-0,0103	6,3397	6,5820	-0,24
ARI 6	6,4500	-0,0183	6,4317	6,7061	-0,27
ARI 7	6,3250	-0,0175	6,3075	6,5643	-0,26
ARI 8	6,3250	-0,0185	6,3065	6,5637	-0,26
ARI 9	6,2000	-0,0110	6,1890	6,4384	-0,25
ARI 10	6,3500	-0,0107	6,3393	6,5957	-0,26
ARO	6,5500	0,0184	6,5684	6,8337	-0,27

$$(C_B)_{END} = (C_B)_{meas} + (\Delta C_B)_{END}$$

$(C_B)_{meas}$ - measured value of boron concentration near to ARI x/ARO
$(\Delta C_B)_{END}$ - boron concentration assessed from insertion/withdrawal to ARI x/ARO
$(C_B)_{END}$ - measured value of "endpoint" boron concentration
$(C_B)_{calc}$ - calculated value of "endpoint" boron concentration

EFFICIENCY OF LIMITATION SYSTEM (REACTIVITY WORTH OF (N-1) CONTROL ROD CLUSTER ASSEMBLIES DROPPED INTO REACTOR CORE WITH SINGLE CONTROL ROD CLUSTER ASSEMBLY WITH GREATEST REACTIVITY WORTH STUCK IN FULLY WITHDRAWN POSITION (F006/3)

Test process was monitored with IK 14 and IK 24 which are shifted by 120° around the reactor center.

Control rod cluster assemblies were dropped into the core from above critical state with ρ = +24 pcm (+3.4 cent) and power of 0.4 % N_{nom}. Control rod cluster assembly 02-33 which is the nearest assembly of group no. 4 to IK 14 was stuck in fully withdrawn position. The reactivity computed from IK 14 and IK 24 signals exhibited different behavior. Detector IK 14 registered the stuck control rod cluster and from steady reactivity value it's possible to assess influence of the stuck cluster on total worth of all control rod groups. According to evaluation methodology the test criterion is based on the difference between reactivity determined from the signal of the detector nearest to stuck control rod cluster and calculated reactivity. IK 24 didn't register the stuck control rod cluster and recorded just the reactivity corresponding to total reactivity worth of all control rod cluster assemblies without the stuck cluster.

The stuck control rod assembly 02-33 was released and dropped into the core 76 seconds after limitation system actuation. Reactivity of IK 14 stabilized at approximately the same value as of IK 24, i. e. at the value corresponding to total reactivity worth of control rod system without the stuck cluster.

Reactivity worth of the system with one control rod cluster stuck in withdrawn position and also the total worth of all control rod clusters are summarized in Table 3.

Table 3 Reactivity worth of control rod cluster system (total and with one stuck cluster).

Measurement	IK no.	ρ_{meas}	ρ_{calc}	$\frac{meas - calc}{calc} 100$
		pcm	pcm	% rel.
60 clusters dropped into core with cluster 02-33 stuck	4	---	4994,2	---
	14	4355,9		-12,8
	24	---		---
after stuck cluster 02-33 was dropped into core	4	---	6649,4	---
	14	5638,1		-15,2
	24	5555,9		-16,4
	14+ 24	5597,0	6649,4	-15,8

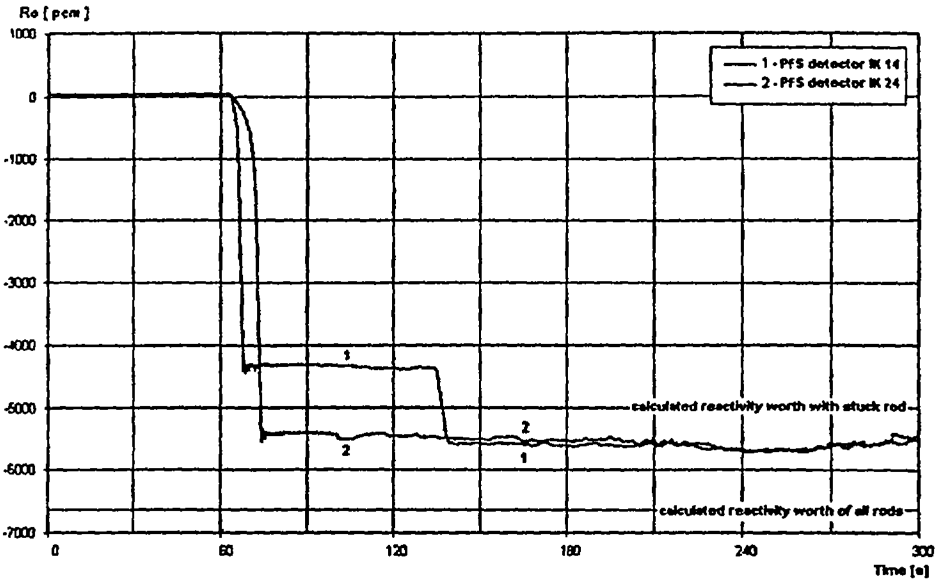

Fig. 4 Behavior of reactivity determined from signals of IK 14 and IK 24. (N-1) control rod clusters were dropped into the core with delayed drop of single control rod cluster.

MEASUREMENT OF POWER COEFFICIENT OF REACTIVITY (F009)

Power coefficient of reactivity measurement was the last physics test of physics commissioning. It was performed by raising and lowering the reactor power – two power increases and two decreases were carried out. The test evaluation is based on processing of reactivity, IK current signals, values obtained from wide range neutron detectors, average temperature and average pressure of primary circuit coolant. Reactor thermal power was determined with use of thermal power calibration curve for IK 24 current signal. Temperature, pressure and reactivity drift changes occurred during the measurement whose influence on reactivity had to be compensated. Measured power coefficients of reactivity and their comparison with calculated value are listed in Table 4 together with changes of primary circuit main parameters during measurement.

Relative deviation between mean measured and calculated value of power coefficient of reactivity is -0.8 % rel. and meets the test criterion of ±30 % rel.

Table 4 Comparison of measured and calculated values of power coefficient of reactivity.

Meas.	Initial and final values			$\left(\frac{\partial\rho}{\partial N}\right)_{meas}$	$\left(\frac{\partial\rho}{\partial N}\right)_{calc}$	Rel. dev.*
	N_R	T_{PO}	group 10			
	% N_{nom}	°C	step	pcm/%N_{nom}	pcm/%N_{nom}	% rel.
1. power increase	0,009÷1,263	279,1÷279,0	102÷110	-14,02±0,57	-14,30	-2,0
1. power decrease	1,035÷0,007	278,9÷278,6	108÷99	-14,65±1,31		2,4
2. power increase	0,010÷1,121	278,5÷278,6	103÷109	-14,48±0,59		1,3
2. power decrease	0,980÷0,006	278,7÷278,3	109÷102	-13,56±1,13		-5,2
mean value	0,006÷1,263	278,7	105	-14,18±0,90		-0,8

* Rel. dev. = $\frac{meas - calc}{calc} \cdot 100$

4. CONCLUSION

The startup physics test program for low power tests of Temelín NPP Unit 1 was performed according to Stage program [3] and all measured values of neutron-physics parameters compared with calculated values [4] met the requirements of test criteria.

Due to limitations of this paper it wasn't possible to present complete information about methods of test performance and evaluation and all test results. More detailed information is provided in [1], [2], [5].

LIST OF NOMENCLATURE

ARO	- All Rods Out, all control rod clusters are fully withdrawn from core
ARI x	- All Rods In, all rods of control rod cluster group x are fully inserted into core
calc	- calculated value
ČEZ-ETE	- Czech Power Board – Temelín NPP
HZP	- Hot Zero Power
ITC	- Isothermal Temperature Coefficient
IK	- ionization chamber
KO	- pressurizer
LS	- Limitation System
meas	- measured value
NPP	- Nuclear Power Plant
N_{nom}	- reactor nominal power output
OD	- deaerator of make-up system
pcm	- percent milli-rho, unit of reactivity (1/1000 of % reactivity)
PFS	- reactivity computer and data acquisition system for physics tests
PO	- primary circuit
p_{PO}	- primary system pressure
rel.	- relative
RIL	- Rod Insertion Limit
step	- unit of cluster motion; 1 step = 2 cm
STDAS	- plant data acquisition system
T_{PO}	- Reactor Coolant System temperature
ρ_{meas}	- measured reactivity
ρ_{calc}	- calculated reactivity

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