COMMENT ON THE IN-CORE MEASUREMENT
IN THE WWER NUCLEAR POWER PLANT

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ABSTRACT

The activity of the Nuclear Research Institute (NRI) Řež in the field of in-core measurement sensors is described in the paper. The results of comparison and calibration experiments realized on the WWR-S research reactor at the NRI are presented. Measurements with fission calorimeters and SPN detectors carried out in the framework of diagnostic fuel assembly program of WWER NPP reactors are described. Noise measurements with detectors of in-core instrumentation of diagnostic fuel assemblies are also mentioned. Comparison experiments on the WWER-440 NPP reactor are described and the method of function verification of neutron sensors of the in-core control system of these reactors is given.

1. INTRODUCTION

In the Nuclear Research Institute the research of in-core measurements sensors of WWER reactors is concentrated in several fields. On the research reactor WWR-S are carried out works aimed at sensors metrology, reliability analysis, and reproducibility of measured signals of sensors. Experimental works on WWER reactors are realized in the framework of diagnostic fuel assembly program; standard in-core control system of WWER-440 reactors are also used for these experiments.

2. EXPERIMENTAL WORKS ON THE WWR-S RESEARCH REACTOR

The WWR-S research reactor at the NRI [1] with its maximum output of 10 MW and the mean neutron flux density of $\approx 10^{18}$ n/m^2 s, which has multilateral use, is also used for the research in the field of in-core measurements. As to the character of experiments, calibration and comparison experiments are carried out mostly.

2.1. Calibration experiments

In a selected irradiation channel of the WWR-S reactor core, radiation field parameters are determined by an activation method and monitored during the experiment with a measuring probe installed in the adjoining channel. In the measured and monitored channel, distribution of radiation parameters along the height of the reactor core is measured with measuring probes containing vanadium, rhodium, cobalt and platinum SPN detectors. The interpretation of measured values is based on the determination of particular components forming composite signals of detectors

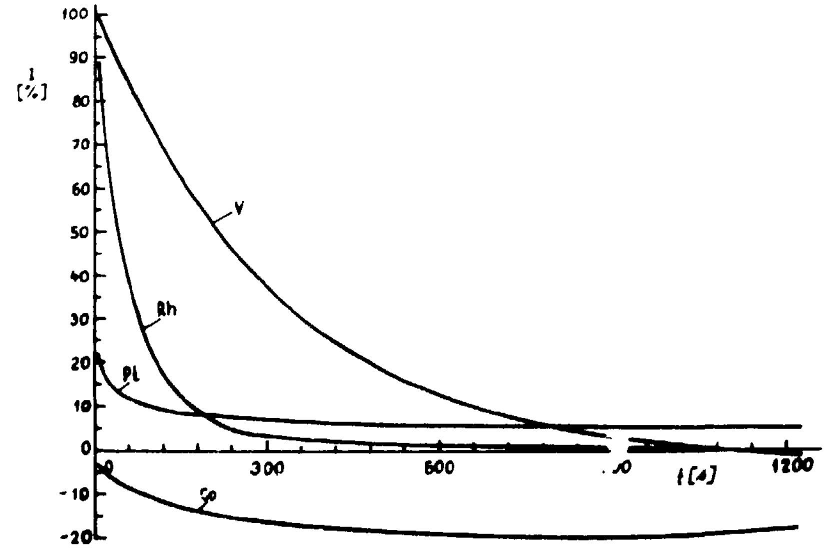

Fig. 1 Relative signals of vanadium, rhodium, cobalt and platinum SPN detectors after the reactor scram

by means of the analysis of detector signals, measured either after the reactor scram or after the fast pulling-out of the detector from the reactor core [2], and on their following comparison. Typical relative signals of vanadium, rhodium, cobalt and platinum SPN detectors after the reactor scram are presented in Fig. 1.

2.2. Comparison measurements

Properties of sensors, their reliability and the reproducibility of measured signals are studied in long-term experiments. In the course of several weeks, sensor signals are measured in regular intervals, and their transient characteristics after the reactor scrams are recorded.

As an example, an experiment can be mentioned in which signals of the measuring probe consisting of five fission calorimeters with absorption elements made of 3.6 % enriched ^{235}U and one calorimeter with a tungsten element for the determination of radiation heating, located along the height of the reactor core, are compared with those of ten vanadium SPN detectors placed five by five in two measuring probes in the fission calorimeters planes and those of ten rhodium SPN detectors placed analogically in two probes. The scheme of the experiment arrangement is given in Fig. 2.

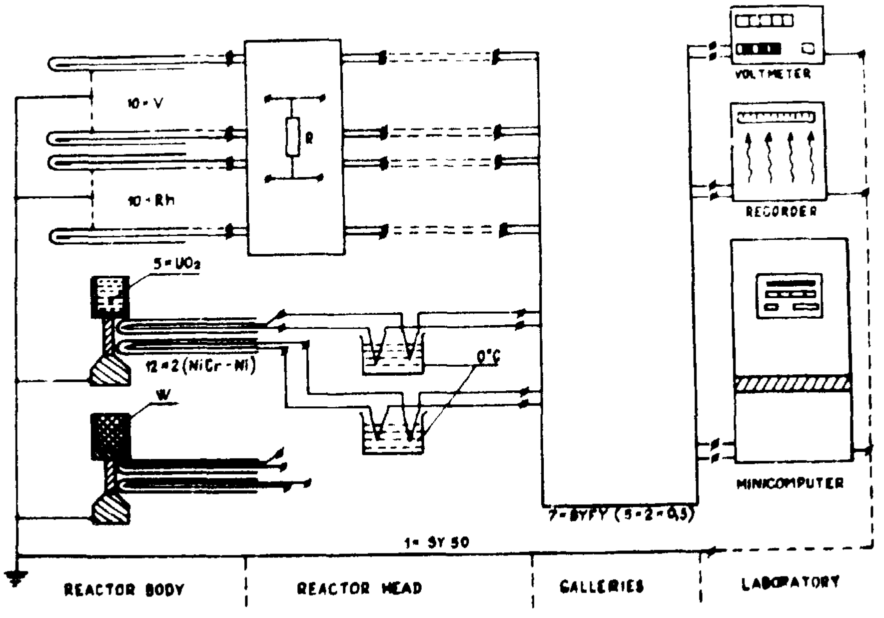

Fig. 2 Scheme of the arrangement of a comparison experiment

In the following analysis, neutron components of the sensors, i.e. H_f - a specific fission output of calorimeters, I_V, ev. I_R - activation components of vanadium, ev. rhodium SPN detectors signals, are determined and compared with one another. In Table 1, mean values of the ratios of signals of sensors located in the central plane along the height of the reactor core, obtained from measurements carried out during ten irradiation weeks, are presented. In Table 2, standard deviations of component ratios from the mean value for the given irradiation weeks are given.

Table 1 Mean values of the ratios of the neutron components of signals of calorimeters, vanadium and rhodium SPN detectors located in the central plane along the height of the WWR-S reactor core

Irradiation week	I_V/I_R [-]	I_V/H_f [μA/W/g]	I_R/H_f [μA/W/g]
1	0.0716	0.505	7.06
2	0.0716	0.507	7.09
3	0.0716	0.511	7.13
4	0.0710	0.511	7.20
5	0.0713	0.516	7.24
6	0.0724	0.521	7.20
7	0.0723	0.525	7.26
8	0.0729	0.528	7.25
9	0.0739	0.536	7.25
10	0.0731	0.537	7.35

Table 2 Standard deviations of component ratios from the mean value for the given irradiation week (see Table 1)

Irradiation week	Standard deviations [%]		
	I_V/I_R	I_V/H_f	I_R/H_f
1	0.0265	0.094	0.0311
2	0.0131	1.201	0.0614
3	0.0184	0.415	0.102
4	0.0372	0.426	0.170
5	0.0694	0.177	0.202
6	0.0501	0.067	0.282
7	0.0389	0.096	0.131
8	0.0336	0.103	0.0476
9	0.0486	0.132	0.145
10	0.0537	0.261	0.0890

3. MEASUREMENTS ON DIAGNOSTIC FUEL ASSEMBLIES

An intensive research in the field of in-core measurements is concentrated on the diagnostic fuel assembly program of WWER (NPP) reactors which is realized in the cooperation with the Soviet Union, the German Democratic Republic, Hungary and Czechoslovakia [3]. Experimental works are carried out on the WWER-2 (NPP) reactor in the German Democratic Republic.

3.1. Measurements with fission calorimeters

A great many results comparable with one another were obtained from measurements with fission calorimeters and SPN detectors [4]. A calorimetric probe with the diameter of 7 mm was inserted into a dry channel of the diagnostic fuel assembly. The probe consisted of five sensors with fissile elements of 3.6 % enriched ^{235}U and of one compensating sensor with a tungsten element. The constant ratio of fissile and non-fissile elements of heat generation along the height of the assembly was assumed. In the centre of the assembly, another dry channel was placed with a probe containing five SPNdetectors with rhodium emitters. In Fig. 3, distributions measured with both the types of probes are compared. The distributions are normalized to signals of the detectors placed approximately in the middle of the core height. Relative distributions obtained from both

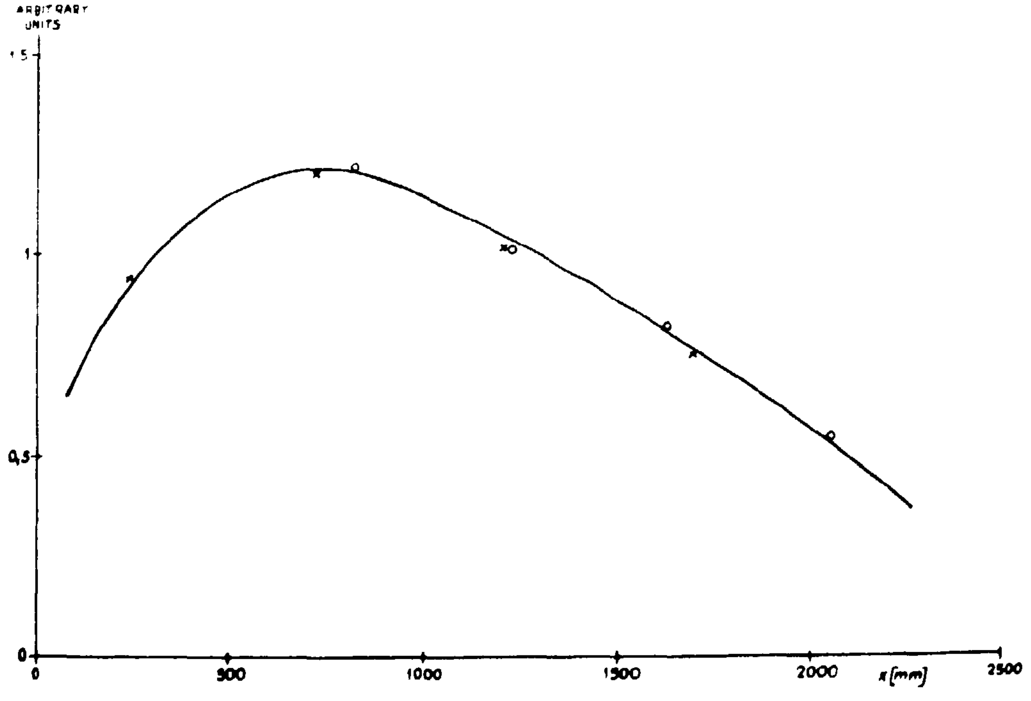

Fig. 3 Relative incomparison of SPN detectors and calorimeters signals (x - data of calorimeters, o - data of SPN detectors)

the types of probes are practically identical. This identity makes it possible to combine signals from both the probes inorder that the distribution may be more precise or the signals of failed detectors of one probe may be replaced by those of the second one. This case is shown in Fig. 4 where the calorimeter at the height of 2178 mm and the SPN detector at the height of 420 mm were out of operation.

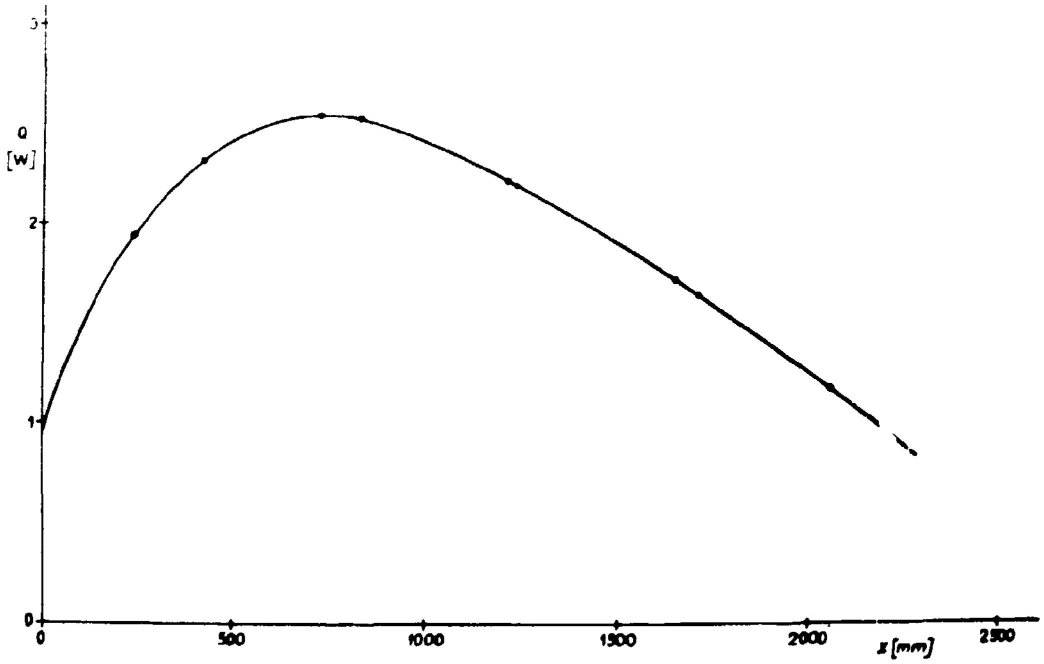

Fig. 4 Distribution of fission power obtained from SPN detectors and calorimeters signals

3.2. Measurements with SPN detectors

In the field of use of SPN detectors and of interpretation of their signals, the attention is paid among other problems to the determination of neutron flux density distribution along the assembly height, the determination and the monitoring of local energy output [5].

In Fig. 5, the distribution of thermal neutron flux density along the assembly height are presented for particular reactor outputs during reactor start-up.

In Fig. 6, thermal neutron flux density distributions along the assembly height are presented for nominal and minimum coolant flow through the assembly.

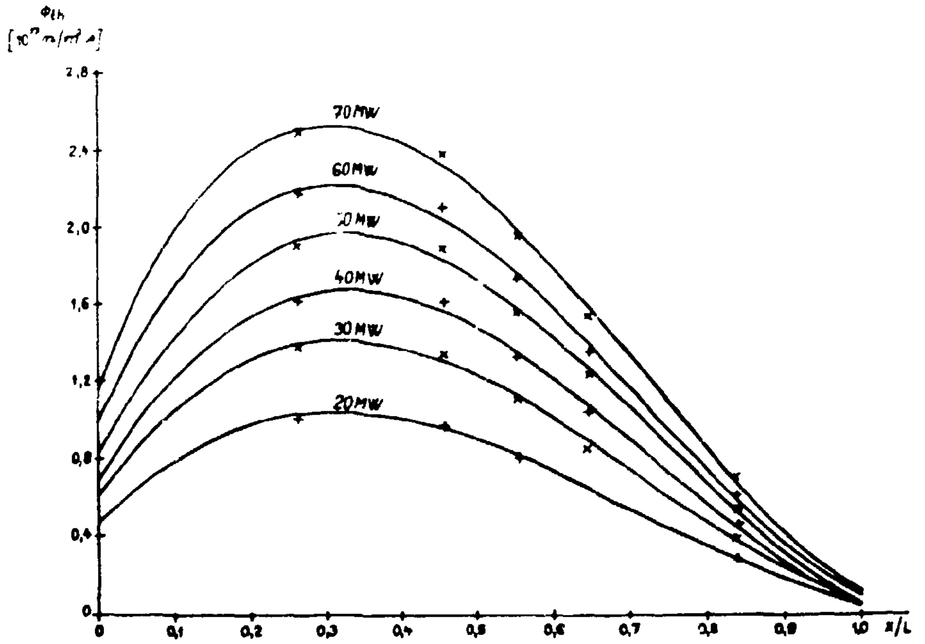

Fig. 5 Distribution of thermal neutron flux density along the assembly height for particular reactor outputs during reactor start-up

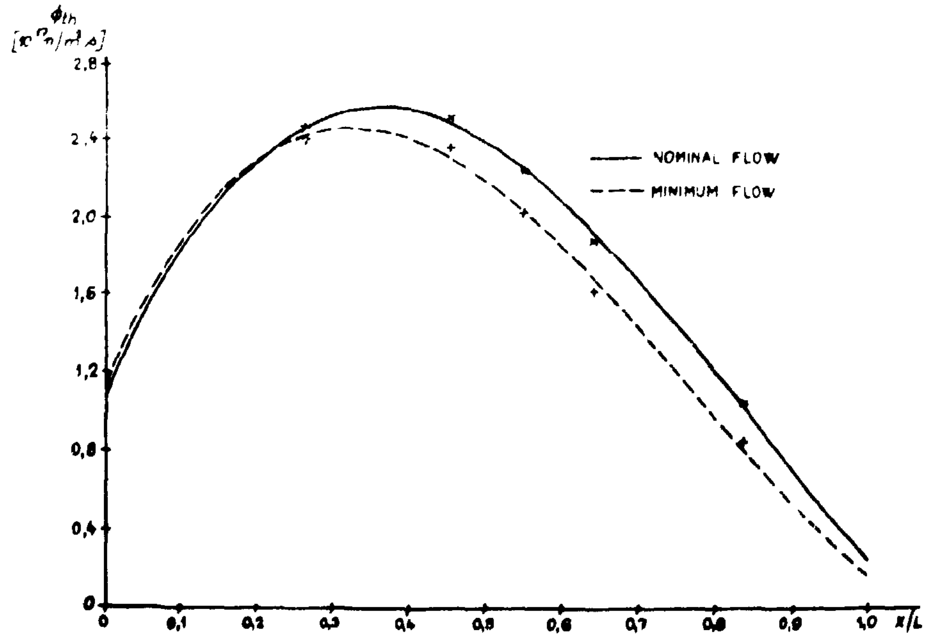

Fig. 6 Distribution of thermal neutron flux density along the assembly heigh for nominal and minimum coolant flow through the assembly

In Table 3, is given the comparison of the mean value of NV and NS outputs of fuel elements surrounding the measuring probe with SPN detectors normalized to one fuel element divided into 10 sections along the element height for these measurements. NV outputs are determined from the total heat power of the assembly by means of the computer code VE-VERKA-F [3,6]. NS outputs are determined from the measured values of SPNdetectors signals with calculation of reaction rates in emitter material and on the fuel of surrounding fuel elements by means of the computer codes THESEUS and REMUR and by using the method of interpretation presented in [7,8].

Table 3 Comparison of values of NV and NS outputs

Number of a section	Nominal flow			Minimum flow		
	NV [kW]	NS [kW]	$\frac{NV}{NS}$	NV [kW]	NS [kW]	$\frac{NV}{NS}$
1	1.368	1.322	1.035	1.405	1.389	1.012
2	2.042	1.954	1.045	2.058	1.995	1.032
3	2.452	2.336	1.049	2.393	2.313	1.035
4	2.625	2.495	1.052	2.482	2.389	1.039
5	2.590	2.556	1.053	2.365	2.272	1.041
6	2.377	2.259	1.052	2.118	2.006	1.056
7	2.018	1.930	1.045	1.778	1.637	1.086
8	1.555	1.510	1.030	1.307	1.213	1.077
9	1.063	1.036	1.026	0.831	0.779	1.067
10	0.565	0.550	1.027	0.398	0.382	1.043
the whole fuel element	18.67	17.95	1.041	17.13	16.37	1.049

3.3. Noise measurements

A great number of noise experiments with SPN detectors and microcalorimeters has been carried out inorder to verify usefulness of noise experiments for diagnostic purposes.

In Fig. 7, the comparison between APS detectors of neutron noise of ex-core ionization chambers (I01, I02, I03) and in-core SPN detectors (E07, E11) positioned in the diagnostic fuel assembly and the SPN detector which was placed in the core out of the diagnostic assembly (E02) is given. Distinct sharp peaks in a frequency of about 1.7 Hz and peaks of double frequencies are observed in the spectra of the detectors E07, E11 and I01, I02. These peaks are more marked than those observed in the spectra of the ionization chamber I03 placed on the opposite side of the detectors I01 and I02. In the spectrum of the detector E02, which is placed out of the diagnostic assembly, these resonances are indistinct. The analysis of experimental data was made by an autoregressive method [9].

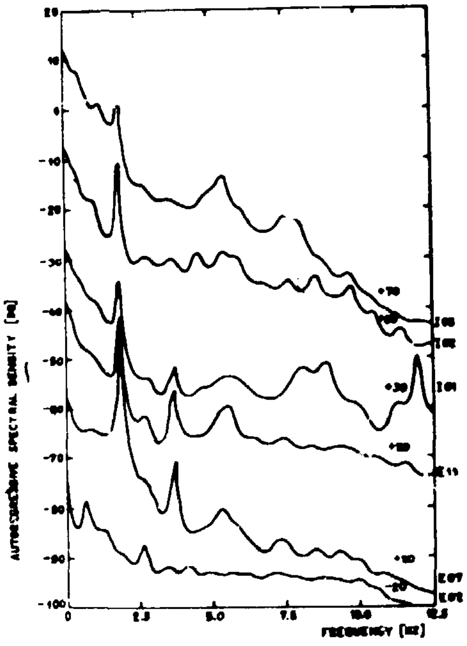

Fig. 7 The autoregressive spectral density of different ex-core and in-core detectors in the diagnostic assembly and out of the diagnostic assembly

The interpretation of observed resonances was presented in SMORN IV [10].

Preliminary results of noise analysis of microcalorimeters signals lead to conclusions that fission microcalorimeters could be useful not only for determination of fission heat removal and neutron flux density but also for evaluation of feedback effects which occur in the low frequency range [11].

4. MEASUREMENTS ON WWER-440 NPP REACTORS

4.1. Comparison measurement

In Fig. 8, results of comparison measurement carried out during the start-up of the third unit of the nuclear power plant NORD in GDR are presented. Calorimeters were adapted to enable their insertion into a dry experimental channel of the diameter of 6.4 mm, running through the centre of the selected fuel assembly. The diameter of the calorimeter was 5.5 mm. The calorimeter signal was recorded with 60 mm step movement. Vertical distribution of released fission heat indicates high sensibility of this sensor to local disturbances of neutron flux distribution due to distance pieces in the fuel assembly. Fig. 8 shows very good correspondence of relative neutron flux distribution measured with fission calorimeters and SPN detectors. The latter were positioned in the same channel as the former, in a probe with five Rh-SPN detectors [12].

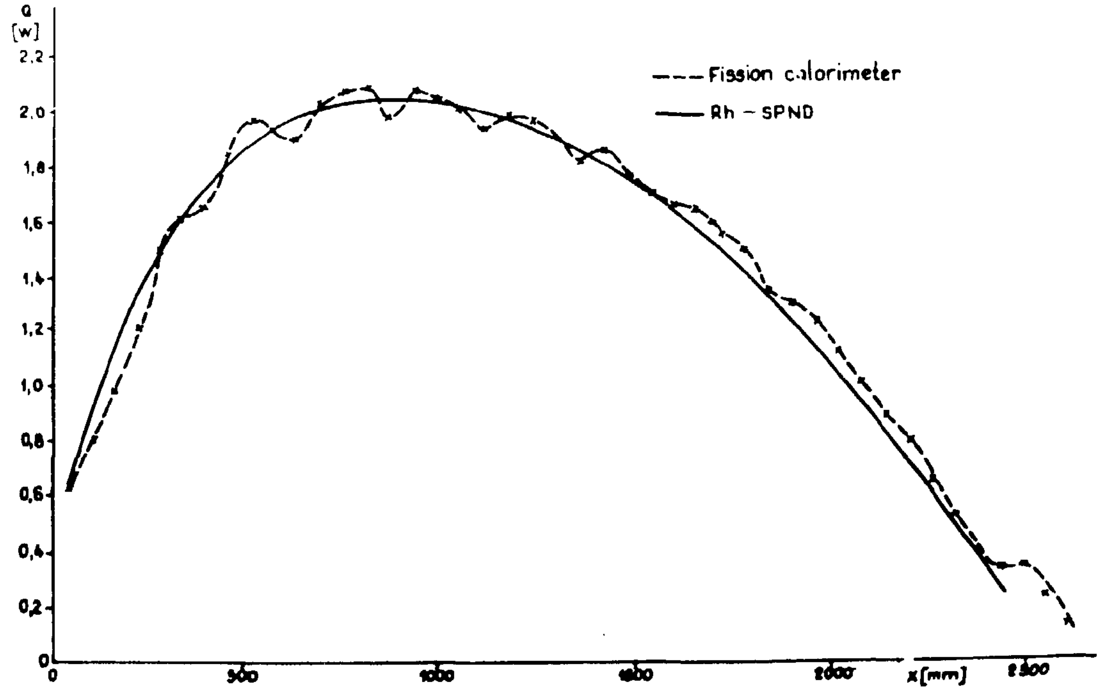

Fig. 8 Axial power distribution measured with the fission calorimeter and the Rh-SPN detector

4.2. Function verification of neutron sensors of the in-core control system

Neutron sensors of the in-core control system of the V-213 reactor of WWER-440 consist of 252 rhodium SPN detectors and 36 background cables located in 36 measuring probes. One of the tests verifying the function of the sensors during the power plant start-up is based on the measurement and record of the sensors signals after the reactor scram and on the following analysis of the signals. In Fig. 9, relative signals of the SPN detector located in the fourth layer of the measuring probe and those of the background cable are presented.

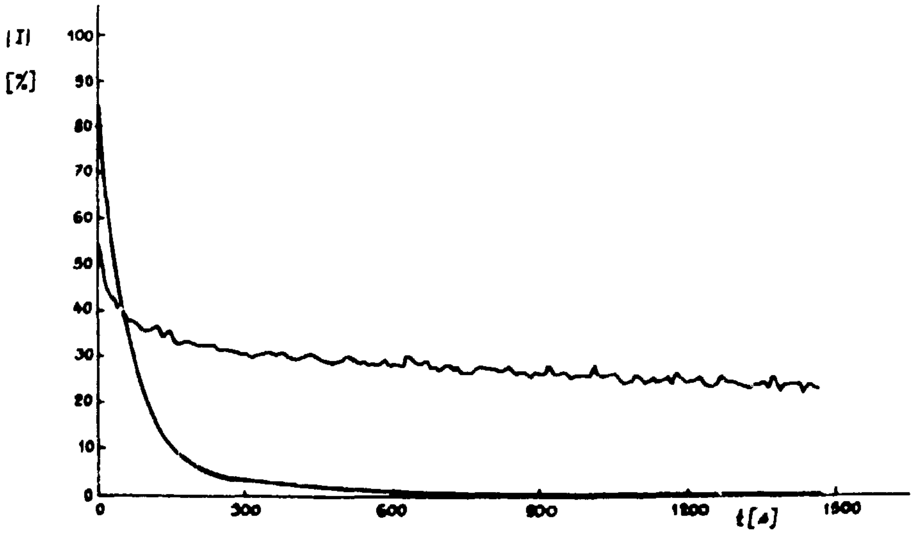

Fig. 9 Relative signals of SPN detector located in the fourth layer and of the background cable after the reactor scram

5. CONCLUSIONS

In the above chapters, a review on the works carried out at the Nuclear Research Institute Řež in the research of sensors for in-core measurements on WWER NPP reactors is given. The research on the WWR-S research reactor will continue. The number of sensors for calibration experiments will be increased above all in calorimeters with absorption elements made of different materials. The works on WWER NPP reactors will be concentrated on the increase of the accuracy of measured values interpretation, on hardware and software works aimed at increasing reliability and operative processing of measured data. A great effort will be given to the measurement, analysis and interpretation of noise signals of in-core sensors.

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