EQUIPMENT FOR SUBCRITICALITY MONITORING BY PULSE METHOD

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ABSTRACT

At the present time methods and means of determining, evaluating, and monitoring the effective neutron multiplication factor or the subcriticality are becoming very important for validating and monitoring nuclear safety in connection with the accumulation of a large number of spent fuel assemblies and the transition to a more tight mode of their storage arrangement in the spent-fuel pools of NPP. Pulse method is an effective subcriticality monitoring tool for subcritical reactors and spent nuclear fuel storages. This method is based on the use neutron generator, fission chambers and instrumentation for data acquisition and processing. The measurement and control equipment was designed. It allows: neutron pulses generation with specified parameters; neutron flux response monitoring by measuring the count rate at predetermined set of sequential time intervals; data transmitting to the personal computer; data processing and subcriticality calculation; self diagnostics and health monitoring; data recording, archiving and storage. The special device is proposed to check the electronic equipment. This device simulates a signal of a neutron detector counting rate after neutron generator pulses appear. The paper presents hardware structure and composition, specification and software of the control unit, which provides neutron generator operation, data acquisition and processing.

Key Words: subcriticality, spent nuclear fuel storages, pulse method, neutron generator.

1 INTRODUCTION

This work extends to subcritical reactor facilities and spent nuclear fuel storages. There are several different methods of definition and assessing the effective multiplication factor (Keff), or subcriticality (1 - Keff), which can be used for substantiation and monitoring of nuclear safety of these facilities [1].

In assessing of subcriticality in subcritical systems by pulse method, the assumption is used that some time after injection into subcritical system a short pulses of neutrons from neutron generator, the decline in the flow of prompt neutrons acquires exponential dependence on time. The quantity of delayed neutrons is a complex function of time and ceases to change after a certain number of neutron generator pulses. Thus, by registering neutron detector count rate during the small successive time intervals (Δt) after the pulse of neutron generator, it is possible, for some defined period of time, to interpret the measured detector signal in the shape of dependence

$$N(t)=A\times e^{\alpha t}+B(t), \qquad (1)$$

where A is a constant;
α – prompt neutrons decay constant ($\alpha<0$);
$t=k\Delta t$, $1\leq k\leq n_k$, n_k – full number of used time intervals;
$B(t) \approx const$ – detector signal background component.

Fundamental characteristics of subcritical system in the point kinetics model are described by the following relations:

$$k_{eff}=1/(1-\beta_{eff}-\Lambda\cdot\alpha), \quad (2)$$

$$\rho/\beta_{eff}=1+\alpha(\Lambda/\beta_{eff}), \quad (3)$$

where βeff is the effective fraction of delayed neutrons, Λ is the generation time of prompt neutrons.

When measured by the pulse method it is necessary to provide:
- neutron pulses generation with specified parameters;
- registering of neutron flux response by signals of detector count rate at successive small time intervals;
- measurement data processing in accordance with predetermined algorithms and calculation of effective multiplication factor and subcriticality.

2 DESCRIPTION OF MEASURING EQUIPMENT

The measuring equipment has been developed on the basis of program-technical complex "PARUS" [2]. A block diagram is shown in Fig.1. The equipment includes: suspension of fission chamber SFC, pulse neutron generator PNG, control unit CU, personal computer PC, set of communication lines.

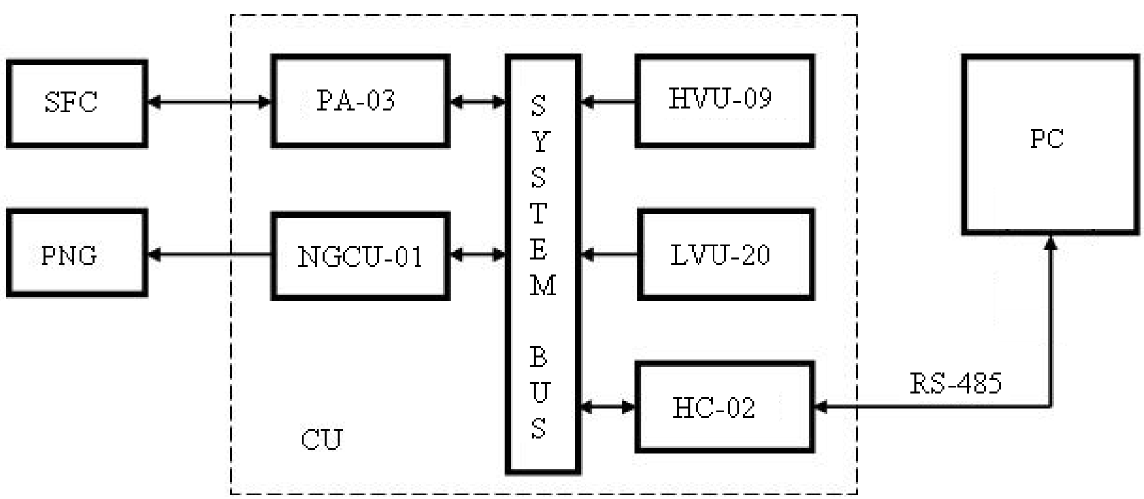

Figure 1. Measuring system block diagram

Suspension of fission chamber contains chamber with pulse sensitivity of at least (0,25 ±0.05) count·cm^2·s·n^{-1}.

Pulse neutron generator allows the neutron pulses generation with the required parameters. Pulse neutron generator includes neutron emitter and block of power supply and control. PNG characteristics:
- oscillation frequency range is 1-20 Hz;
- neutrons emission at 20 Hz at least 10^8 n·s^{-1};
- continuous operation time of the generator at 20 Hz at least 15 min.;
- break time of the generator – less than 30 min.;
- neutron pulse duration - less than 1 µs;
- supply voltage is +150 V;

- power consumption is less than 30 W;
- maximum operating temperature is +120 ^{0}C;
- the control signal (start) is a positive polarity rectangular pulse with the following parameters:
- amplitude is 15 V;
- duration - from 10 to 100 μs.

Suspension of fission chamber and the neutron pulse generator are placed in a sealed tube with welded bottom. The design includes a special system to measure the coordinates of the pulse neutron generator and the detector, when they are moved along the tube axis.

The control unit operates under PC control and provides:
- amplification of fission chamber signals;
- measurement of the pulses counting rate at successive time intervals, that can be set from 0.5 μs to 1000 μs (the number of time intervals can be set – up to 8000);
- formation a fission chamber high-voltage supply in the-range from 0 to +500 V;
- formation the PNG supply voltage (150 V at load current 300 mA) and a control signal (start) with 15 V amplitude.

Pulse-current signal and the fission chamber supply are transferred to the inputs of the control unit by “twisted pairs” cables with isolated shield. Control signal (start) and neutron generator power supply are transmitted from control unit to pulse neutron generator by two "twisted pairs" with joint isolated shield. The length of the line is up to 50 m.

Control unit to PC connection is provided through serial RS-485 interface. Length of the communication line (shielded twisted pair) is up to 1000 m.

The control unit has a modular design "Euromechanics". It is a crate with installed 3U modules. The units are electrically connected via the power distribution board. Dimensions plug-in units allowed to perform the control unit in the form of a portable device with a size of 275×135×315 mm and a mass not exceeding 7 kg. Control unit operates from 12 V DC source. The power consumed by this device at a nominal voltage is not exceeding 80 W.

Control unit includes the following plug-in blocks:
- pulse analyzer PA-03;
- neutron generator control unit NGCU-01;
- host controller HC-02;
- power supply low-voltage unit LVU-20;
- power supply high-voltage unit HVU-09.

Host controller HC-02 provides control of pulse analyzer BPA-03 and neutron generator control unit NGCU-01; data processing in accordance with predetermined algorithms; storage of archival data in the operational storage device and the various parameters in the flash memory; exchanging digital data with a PC via serial communication in accordance with accepted protocols.

Neutron generator control unit NGCU-01 generates signal start of pulse neutron generator and provides its power supply.

Pulse analyzer BPA-03 is the core of the measuring system. It provides fission chamber signals receiving; detector count rate measuring; measurements arrays accumulation for a specified time; accumulated measurement data preprocessing; measurement data transfer through the system bus. Block diagram of the pulse analyzer is shown in Fig. 2. BPA-03 includes: an input pulse current amplifier PA, amplitude selector AS, the pulse shaper PS, digital signal processor DSP, static RAM, synchronous dynamic RAM, programmable logic integrated circuits FPGA, electrically programmable read only memory EEPROM.

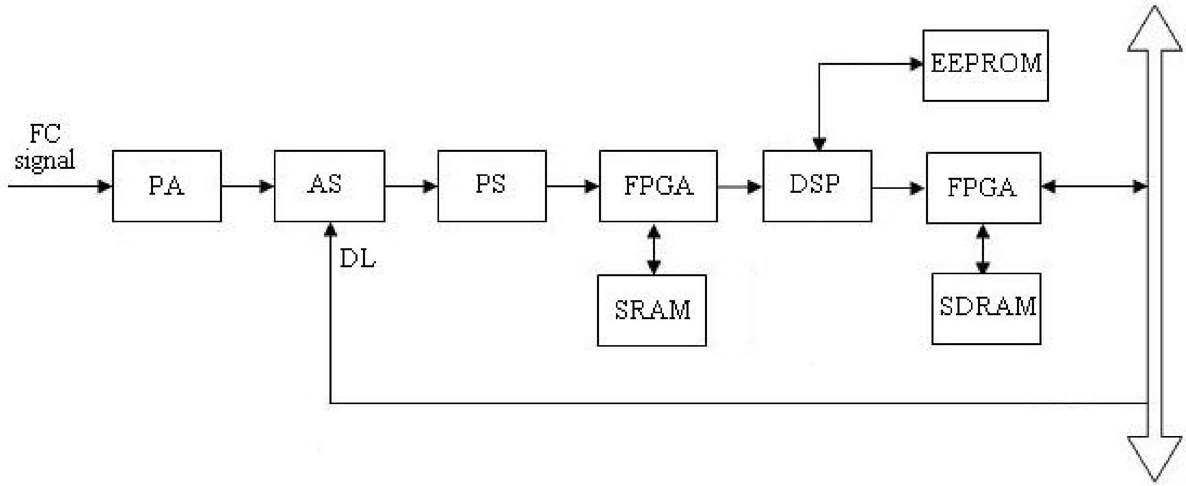

Figure 2. Pulse analyzer block diagram

Current pulses from the fission chamber are fed to the input of pulse amplifier, the output of which is compared with the discrimination level DL in the amplitude selector. The value of the discrimination level can be set from Host controller. The pulse shaper generates a pulse signal of a TTL voltage level. The normalized pulses from the output of the PS are fed in the FPGA, which implements the algorithm of measurement of the count rates of pulses at successive time intervals. The values of the count rates for the one sequence of measurements are stored in SRAM (up to 8000 consecutive time intervals). The accumulation of arrays of measurements is performed in the SDRAM. Settings of the measuring path (width and number of time channels of the analyzer, etc.) are stored in EEPROM. The processes of measurement, accumulation of arrays of measurement information are completely controlled by a digital signal processor.

Power supply low-voltage unit LVU-20 is designed to convert power line DC 12 V into constant regulated voltage required to supply the control unit. The output voltage of LVU-20: +15 VDC with load current 1 A; -15 V with load current 1 A; +5 V with load current of 5 A.

Power supply high-voltage unit HVU-09 is designed to convert power line DC 12V into adjustable voltage 0...+500 VDC required to supply the fission chamber.

Control of the entire measuring system is provided by PC with specialized software package. The software module provides setting of instrument parameters and characteristics of the process of gathering information, starting the measurement process, the monitoring process of gathering information in the on-line mode with the ability to stop the measurements.

The software includes drivers for control units and software for data processing in accordance with predetermined algorithms.

It should be noted that the equipment that implements the pulse method of measurement is always accompanied by a calculation on the program STEPAN [1], designed for the assessment of neutron-physical characteristics in the spent fuel pools. Neutron-physical calculation in this program includes the definition of neutron field of the spent fuel pool, as well as the simulation of the pulse experiment at the specified location of the pool with the determination the constant of recession of the neutron flow. The calculated neutron field distribution allows to evaluate the possible hazardous area of the fuel pool with the relatively high multiplying properties and the place of maximum neutron flux in the pool. These data are used in the planning of measuring experiment. Before the experiment the calculation is done on the basis of which the optimal coordinates of installation of fission chamber and pulse neutron generator are determined, as well as the distance between them.

Before the beginning of measurements the following parameters are set: time channels amount (n), time channels width (Δt), PNG start frequency (f), PNG launches amount, run delay time (n_3), fission chamber supply voltage, discrimination level. The itself measurement process consists in a multiple periodic repetition of the pulses of neutron generator, measurements and summation of the detector signal after each pulse on each successive time intervals till to obtain an acceptable statistical count in the measurement channels and random error of result of data processing.

During the measurements, which can take quite a long period of time, the operator can monitor the process of data set in the online mode, having a visual picture of the response of the neutron flux from the impact of the pulse neutron generator (fig. 3) and, if necessary, can intervene in the process of measurement. The data, measured in each measurement, are stored in a separate named file on the PC disk and contain the main characteristics of the experiment. These files can later be used for detailed processing.

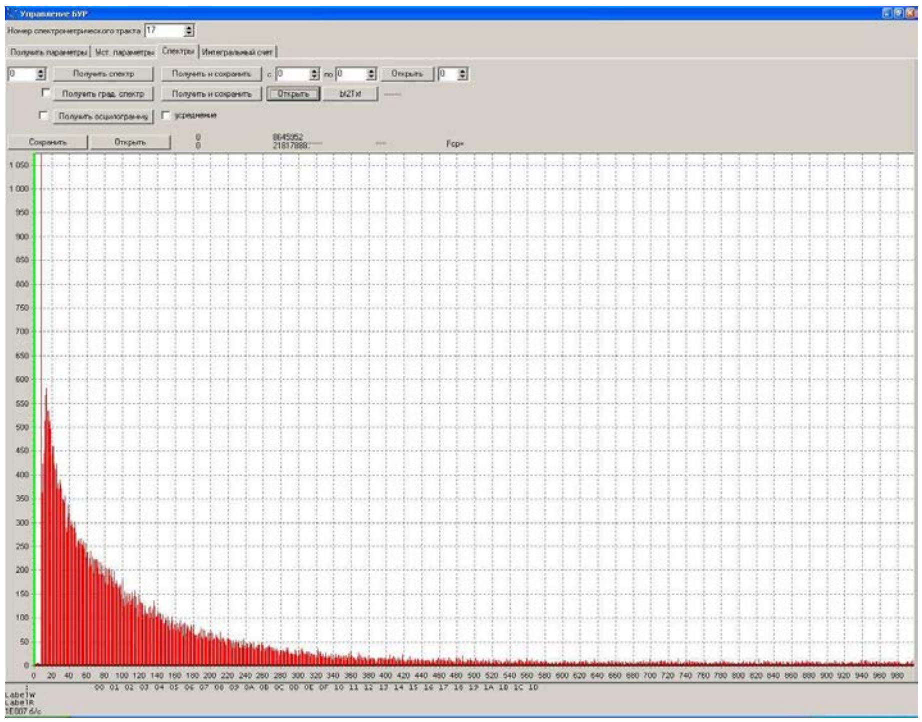

Figure 3. Software screenshot for online monitoring of the measurement process

The software also includes pre-processing the measured data and their presentation in graphic and digital form. Processing of the obtained experimental information is carried out by the method of least squares with the subsequent calculation of the values of the recession constants and the statistical error of the measurements. The processing results are presented in graphical format - in the form of dependence $\alpha(t)$ and $\Delta\alpha(t)$, where $t=n\times\Delta t$. Further, using the calculated recession constants and pre-entered calculated data (βeff, Λ, etc.), keff is evaluated. Screen software module for pre-processing is shown in Fig.4. The upper window displays the resulting spectrum of measured data. In this window, regions for processing of main signals and background signals can be specified using the special rulers. The bottom window is a graph of calculated values of recession constant.

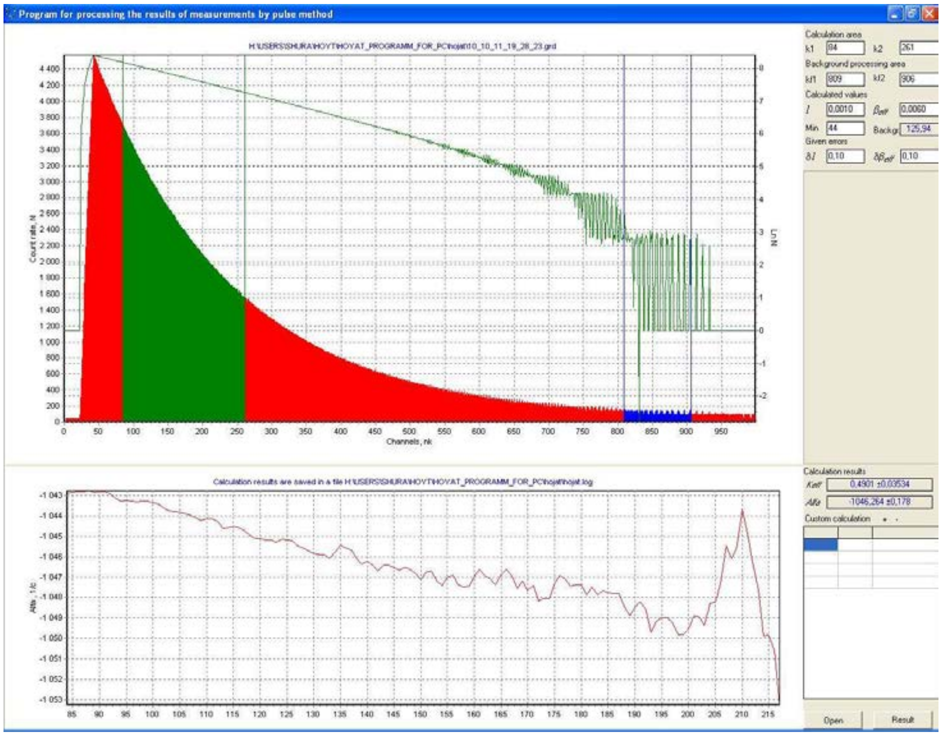

Figure 4. Software screenshot for pre-processing the measured data

A special device was developed for system measurement channels calibration and verification. This device provides:

- electrical signals reproduction, simulating the fission chambers signals and the pulse neutron generator control;
- test signals parameters control from a local remote panel;
- receiving of measurement information from control unit and display it on a local remote panel.

The device includes:

- I/O signals controller KVVS-02.06;
- laptop based local remote panel;
- local remote panel software for data acquisition, processing and visualization.

I/O signals controller performs the functions of test influences forming. It has a channel of frequency signal formation, simulating the fission chamber signal after a neutron generator pulse. I/O signals controller can operate both in autonomous mode and by the local remote panel control, allowing to check operation closed circuit of the measuring channel under different conditions. The device provides the playback of voltage and current frequency signals pulses in the range from 1 to 1×10^{6} Hz. The parameters of the pulse signals are set in accordance with the table:

Table I. The parameters of the pulse signals

Parameter, dimension	Range	The limit of permissible relative error, %
Voltage and current pulse duration, μs	0,05…12,5	$\pm[0,1+0,1\times(12,5/\tau_x-1)]$
Voltage pulses amplitude, V	0…10	$\pm[5+(10/A_x-1)]$
Current pulse charge, C	$0,5\times10^{-13}\ldots4\times10^{-12}$	±1
Decay time constant, ms	0,5…500	±5

Timing diagram of the signals that simulate the fission chamber response on the neutron generator pulses shown in Fig. 3. In this figure the following notation:

$F_{out}(t)$ - the output frequency at time t, Hz;

F_o – the initial value of the frequency at time T_{start}, Hz;

F_b – the value of the background frequency, Hz;

T_a – constant of recession, s;

T_{start} – the time of arrival of the trigger pulse is generated, s;

t – current time, s.

The values of the parameters F_0, F_b, T_a can be set from the local control panel to verify operation of equipment under different conditions of measurement.

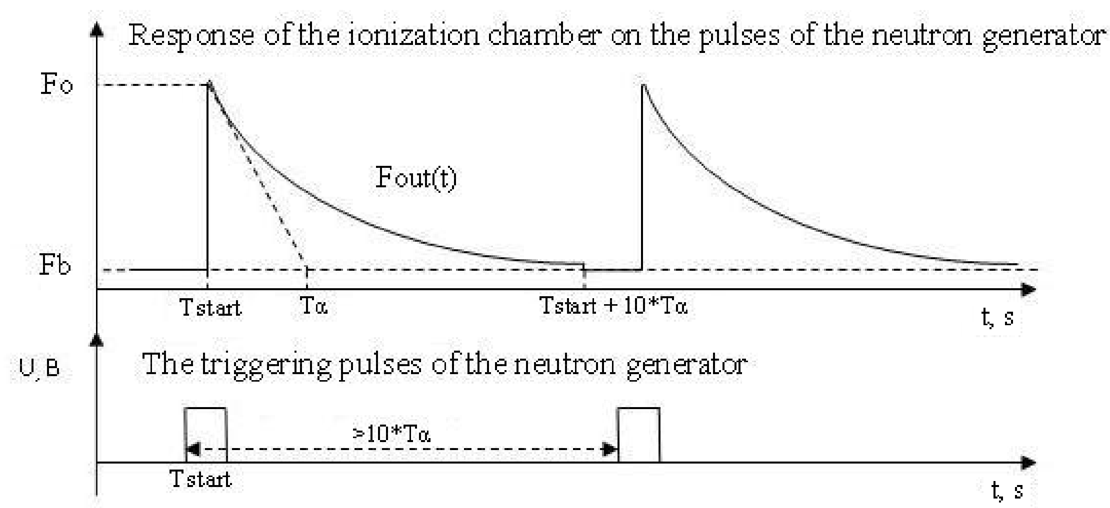

Figure 3. Timing diagram of the signals, simulating the fission chamber response

Block diagram for calibration and validation is shown in Fig. 4.

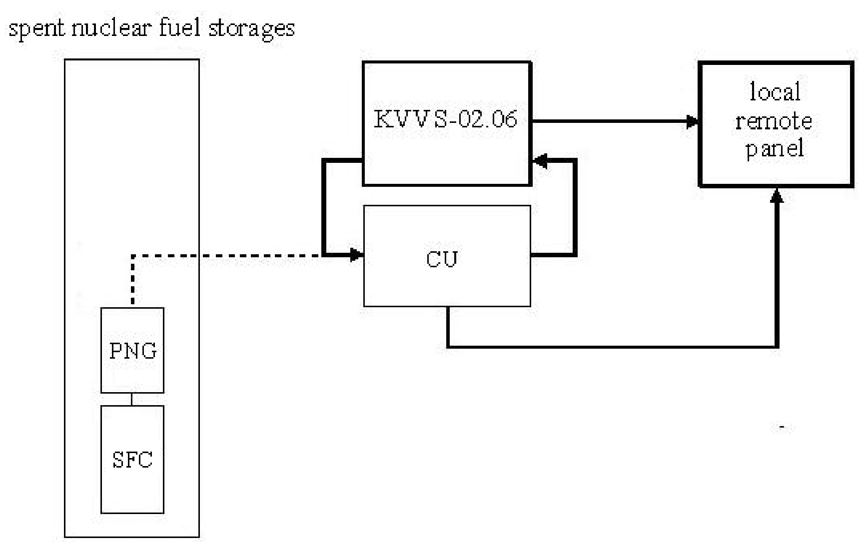

Figure 4. Block diagram for calibration and verification

As can be seen from this figure, to perform calibration and verification, you must connect the signals simulating the operation of fission chamber and neutron generator from the controller KVVS-02.06 to respective inputs of the control unit CU using a special connecting cables. Next, you need to make settings of the simulator to generate the desired timing diagram of the signal response of the neutron flux. Then you can work with measuring equipment as usual and consistently test all possible operation modes of equipment.

3 CONCLUSIONS

Software and hardware were developed for measuring decay constant of prompt neutrons to determine subcriticality by pulse method. The device was proposed for calibration and verification of measurement channels of the equipment.

The equipment was tested in the storage of spent nuclear fuel at Smolensk nuclear power plant [1], where its metrological characteristics and reliability in the process of trial operation were confirmed.

4 ACKNOWLEDGMENTS

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5 REFERENCES

1. I.N. Geraskin, V.E. Zhitarev, V.M. Kachanov, etc. "Method and Means for Monitoring the Spent-fuel Pool Subcriticality at the Smolensk NPP", *Atomic Energy,* **Vol. 2(120)**, pp.79-85 (2016).
2. Alferov V.P., Kudryavtsev A.V., Mokhononozhkin B.E., Rakhmatulin A.B., Selyaev N.A., Fedorov V.A., "Software and Hardware suite "PARUS", *Nuclear measurement and information technologies*, **Vol. 2(30)**, pp.88-95 (2009).