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# Investigation of dependence of BN-600 reactor sector fuel cladding leak detection system responses on the operation parameters

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**Abstract**

The purpose of the present study was to investigate the dependence of readings of the sector fuel cladding leak detection system (SFCLDS) of the BN-600 nuclear power reactor on the operational parameters and the development of regression model for forecasting the SFCLDS background parameters.

List of parameters of regression model for determination of the background level for the SFCLDS measurement channel was developed. Calculated value of temperature outside the detection unit (DU) which is proportional to the value of temperature increment in the DU was included in the composition of the model along with parameters of reactor power level, temperature in the DU and time from the start of time interval between reactor refueling operations.

Coefficients of the regression model were determined using the least squares method (LSM) with application of stepwise regression with sequential addition of parameters to the model. The criterion for inclusion of the parameter in the composition of the model was the reduction of the value of average error of approximation $e$ and normalization of distribution of model residues. Data processing was performed using MS Excel, MS Access and VBA.

Results of construction of the model demonstrated that all parameters are statistically significant. Uncertainty of the developed model for forecasting the SFCLDS background parameters for all sections of the data for one BN-600 cycle between refueling operations does not exceed 1% which satisfies the original requirements.

Implemented studies of dependence of background on the reactor operational parameters are of practical importance and are original scientifically - similar types of research have not been done previously. Upon completion of testing and validation of the developed model using extended volume of reactor operation data the issue will be addressed of the implementation of the methodology within the composition of the SFCLDS of BN-600 and BN-800 reactors.


*Keywords:* BN-600; Sector fuel cladding leak detection system; Background readings; Delayed neutrons; Power; Detection unit; Regression model; Average error of approximation; Histogram.

## Introduction

Delayed neutron based SFCLDS of BN-600 reactor [1] allows conducting continuous monitoring of fuel cladding integrity in the process of reactor power operation, as well as tentatively determining locations of leaking fuel pins over the arrangement of fuel inside fuel assemblies (FAs) [2]. The main task addressed using the leak detection system is to trigger emergency alarm signaling the power plant operating personnel the need either to reduce the reactor power level, or to initiate reactor emergency shutdown after reaching the operational limit and reactor safety limit caused by the loss of fuel cladding integrity.

Method of control of fuel cladding integrity is based on the registration of delayed neutrons emitted by fission products – precursors of delayed neutrons – penetrating the coolant through the defects in the fuel pin cladding. Fission ionization chambers positioned in the detection units (DU) in the reactor cavity opposite to the windows of six intermediate heat exchangers (IHE) are used as detectors of delayed neutrons (DDN) of BN-6000 reactor (Fig. 1).

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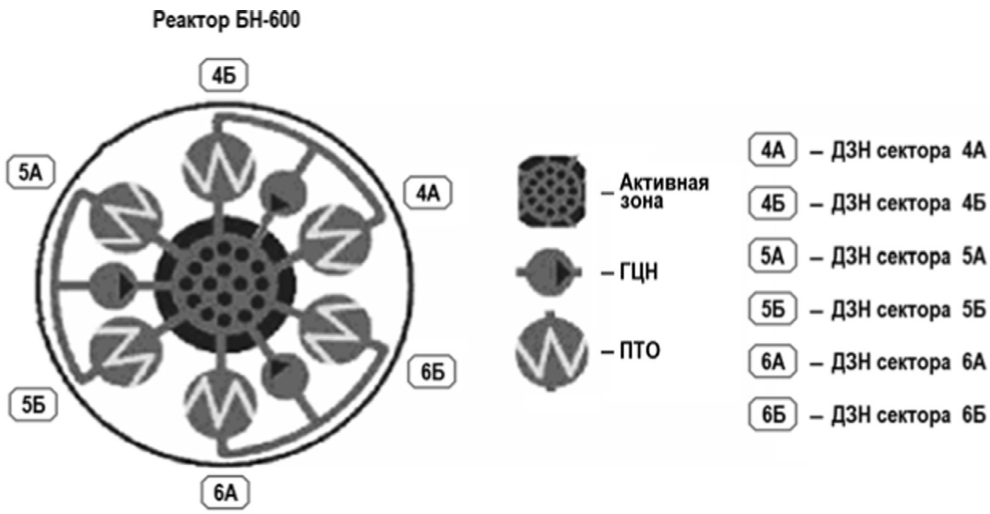


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|---|---|
| Реактор БН-600 | BN-600 reactor |
| Активная зона | Reactor core |
| ДЗН сектора 4А | Delayed neutron sensing element, Sector 4A |
| ГЦН | Main circulation pump |
| ПТО | Intermediate heat exchanger |

Fig. 1. Arrangement of detection units of the BN-600 reactor SFCLDS system.

## Determination of background parameters of the SFCLDS

In the absence of damaged fuel pins in the reactor core readings of measurement channels (MC) of the LFCLDS are composed of several components of neutron flux at the place where the DU is positioned associated with presence of surface contamination of fuel and photoneutrons. However, the most significant contribution is made by neutrons from the reactor core penetrating reactor cavity through non-uniformities in the shielding and entering the detection area after multiple scattering [3,4]. The value of background readings of measurement channels of the LFCLDS is non-uniform and significantly depends not only on the reactor power level but, as well, on the arrangement of detection units inside the reactor cavity [5]. When reactor is operated on nominal reactor power level background readings differ between the detection units by up to two orders of magnitude.

Variation of detection efficiency of neutron detectors with changing temperatures inside the DU also affects the readings of measurement channels (MC) of the LFCLDS. Beside that slow effect is observed of dependence of readings of measurement channels in the process of cycle between reactor refueling operations with burned up fuel as the result of changing power density field [6]. Excess of MU readings over the background means generation of signal from delayed neutrons, thus characterizing appearance in the reactor core of fuel pins damaged to the extent of development of direct contact between fuel and coolant. Therefore, the task of correct determination of background readings of the LFCLDS measurement channels is extremely important. At present background readings of MC are manually input by the NPP personnel on as needed basis using the data collected in the course of LFCLDS operation. Calculation determination of background parameters will allow escaping errors during inputting the data, more correctly singling out the component of the signal from delayed neutrons, ensuring more reliable forecasting of the time moment when emergency shutdown trip setpoints of the LFCLDS will be reached and enhancing the precision of localization of damaged fuel assemblies [7].

## Development of regression model

Let us present the results of modeling obtained for one LFCLDS measurement channel with the highest value of background component [5].

Dependence of background readings of the LFCLDS on the reactor power level is the most significant and is close to linear dependence [2]. Taking into consideration that at zero reactor power level background readings of the LFCLDS are also zero, it is logical to assume the dependence:

$$N_{MC}(t_i) = k \cdot W(t_i), \qquad (1)$$

where $N_{MC}(t_i)$ are the readings of the measurement channel; $W(t_i)$ is the reactor neutron power; $t_i$ is the reactor operational time between reactor refueling operations, and $k$ is the factor linking the measurement channel readings with reactor power.

However, as it was demonstrated by the results of processing and analysis of reactor data, the value of factor $k$ is not constant and is described by the function dependent on the following reactor operation parameters: fuel burnup (depending on operational time $t$) and temperature in the detection unit $T_i$. Beside that delay of temperature evolution as compared with variation of readings of LFCLDS measurement channels was observed in the process of studies conducted at non-stationary temperature regimes. Assumption