NUCLEAR TECHNOLOGY
EXPERIMENT

ACTIVATION TYPE PULSED NEUTRON RADIATION DETECTOR WITH CONTINUOUS RECORDING OF RECORDED SECONDARY ELECTRON PULSES IN REAL TIME

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Received June 11, 2024

Revised September 03, 2024

Accepted September 23, 2024

Abstract. A pulsed neutron radiation detector of the activation type with continuous recording of registered secondary electron pulses in real time is described. Silver foil with a thickness of 0.3 mm is used as an activation material. A gas-discharge Geiger-Muller counter of the industrial brand SBM-19, sensitive to hard beta and gamma radiation, is used to register secondary electrons. The recording interval of the accumulated number of registered secondary electron pulses is 10 s. The volume of the cyclic memory buffer used to record the registered secondary electron pulses is 16 MB, which ensures continuous recording for 2.5 years. A modern galvanic element LiSOCl2 with a voltage of 3.6 V and a capacity of 2.1 A is used as a power source for the pulsed neutron radiation detector.·h. The estimated operating time without replacing the battery is 5 years.

DOI: 10.31857/S00328162250111e9

1. INTRODUCTION

The simplest method for recording pulsed neutron radiation is to estimate its flux based on the induced radioactivity in Rh, Ag, In, and Au foils [1, 2]. This paper presents a detector whose operating principle is based on slowing down fast neutrons in a paraffin moderator and activating silver foil with them. When silver is activated by neutrons, two isotopes are known to form: silver-110 (110Ag) with a half-life of 24.2 s and silver-108 (108Ag) with a half-life of 2.42 min. The main contribution to the secondary electron emission is made by the decay of silver-110, since the cross section for the interaction of the initial slowed neutron radiation for silver-110 is significantly higher than for silver-108. In addition, the half-life for silver-110 is significantly shorter than for silver-108, which allows experiments with pulsed neutron sources to be carried out much more frequently.

A pulsed neutron radiation detector is presented, which is based on the activation method with a delayed registration: first, fast neutrons are slowed down in a paraffin block, then the slowed neutrons interact with a 0.3 mm thick silver foil. Registration of secondary electrons is carried out using a Geiger-Muller counter SBM-19.

2. DETECTOR STRUCTURE

Structurally, the neutron moderator block is made of two coaxial polyethylene tubes, which are connected to each other using two polycarbonate flanges. The outer diameter of the external tube is 160 mm, and the inner diameter of the smaller tube is 35 mm. The length of the cylindrical moderator housing is 180 mm. The volume between the inner and outer tubes is filled with paraffin. A 0.3 mm thick silver foil is wound without gaps on the Geiger-Müller counter SBM-19. A 0.5 m long RK50-4 coaxial cable with a SR-50 coaxial connector at the end is soldered to the electrodes of the Geiger-Müller counter SBM-19. A heat-shrink tube is placed over the Geiger-Müller counter SBM-19 with the wound silver foil and soldered cable to fix the foil and cable, which additionally protects the maintenance personnel from accidental contact with the electrodes of the Geiger-Müller counter SBM-19, which develop dangerous voltage during operation. The Geiger-Müller counter SBM-19 prepared in this way is placed inside the moderator block. Figure 1 shows the basic electrical circuit of the electronic part of the neutron detector.

Fig. 1. Basic electrical circuit of the neutron radiation detector.

The modern microcontroller EFM32G222, designated in Fig.1 as DD_1, is used to control the neutron radiation detector. The main feature of this microcontroller is that it can operate in sleep mode, waking up only by interrupts from signals from external or internal devices, consuming a current of no more than 1 μA.

Functionally, the neutron radiation detector consists of the following units:

1. Power supply for the Geiger-Müller counter SBM-19 with an output voltage of 350 V.
2. Detector of pulses coming from the Geiger-Müller counter SBM-19.
3. Real-time clock with a set time interval for counting pulses and storing the current time.
4. Non-volatile memory, which is used for continuous storage of the number of accumulated pulses from the Geiger-Müller counter SBM-19.

5. Autonomous power source with a voltage of 3.6V.
6. Communication unit with a personal computer and an external monitor for controlling the current value of accumulated pulses from the Geiger-Müller counter SBM-19.

3. PRINCIPLE OF OPERATION AND MEASUREMENT RECORDING

The power supply of the Geiger-Müller counter SBM-19 with an output voltage of 350V consists of a controlled step-up DC-DC converter, a pump generator, and an 18-fold voltage multiplier with a storage capacitor. The step-up converter *DC-DC* consists of a control transistor T_2, an inductance L_1, a diode D_6 and a storage capacitor C_{12}. The control of the step-up converter *DC-DC* is carried out directly by the microcontroller. The voltage level from the storage capacitor is checked by a detector consisting of a protective diode D_7, a fixing diode D_8 and a resistor R_{11}. The signal from the detector goes to the input of the microcontroller's comparator. Every 60 μs, the microcontroller checks the signal level from the detector; if it is less than a certain predetermined value, the microcontroller turns on the transistor T_2 for 10 μs, the current in the inductance begins to rise and after 10 μs reaches a value of 1.2 A. Then the transistor turns off and the accumulated energy in the inductance flows through the diode D_6 to the storage capacitor C_{12}, the voltage on which begins to rise. If the voltage of the detector is higher than this predetermined value, the microcontroller does not turn on the transistor T_2. Thus, the voltage of the storage capacitor is stabilized. The voltage level of the storage capacitor is 20 V. The voltage from the storage capacitor of the *DC-DC* converter goes to the pump generator.

The pump generator converts the DC voltage of the storage capacitor into a pulse-periodic signal of alternating polarity with an amplitude of 20 V. The pump generator consists of a transistor assembly DD_4, transistors $T_3 - T_5$, diode D_9, capacitor C_{13} and resistors R_{12}, R_{13}. The operating principle of the pump generator is as follows: the microcontroller every 60 μs alternately turns on/off transistors T_3, T_4 with a small delay between turning on/off. When transistor T_4 turns on, the transistor assembly R_{12}, R_{13}. Transistor DD_4 is simultaneously activated through resistors T_3 is in the off state during this time. The voltage of the storage capacitor C_{12} flows through the transistor assembly DD_4 to the output of the pump generator and to charge capacitor C_{13}. Diode D_9 and the switched-on transistor T_4 ensure the passage of charging current for capacitor C_{13} in this cycle. When transistor T_3 is turned on and transistor T_4 is turned off, the transistor assembly DD_4 is simultaneously turned off. The reverse polarity voltage of capacitor C_{13} flows through transistor T_5 to the output of the pump generator. Thus, in two cycles, voltage pulses of different polarities with an amplitude of 20 V are formed at the output of the pump generator. The resulting pulse-periodic signal of alternating polarity passes through capacitor C_{14} to an 18-fold standard voltage multiplier. The multiplied voltage is then used to charge the capacitive storage C_{33}. The charging current of the capacitive storage is measured using resistor R_{16}, shunted by protective diodes D_{28}, D_{29}. The voltage from the measuring resistor R_{16} is fed to the input of the ADC built into the microcontroller, and in each cycle of the pump generator's operation, it is compared with a specified threshold. When the voltage drops below the specified threshold, it is assumed that the voltage on the storage capacitor has reached its set value of 350 V. The pump generator then stops its operation, and the microcontroller enters sleep mode. At the same time, the converter *DC-DC* is also switched off. In this operating mode, the microcontroller only counts pulses coming from the pulse detector of the Geiger-Müller counter SBM-19, waits for commands from the personal computer, and waits for a signal from the real-time clock chip about the end of the pulse counting period.

The pulse detector from the Geiger-Müller counter SBM-19 consists of a decoupling capacitor C_{34}, protective diodes D_{30}, D_{31}, pull-up resistor R_{19} and protective resistor R_{18}. Voltage pulses from the Geiger-Müller counter SBM-19 are negative relative to the supply voltage pulses with a duration of 300 μs and an amplitude of 30-100 V. Capacitor C_{34} removes the DC component of the Geiger-Müller counter SBM-19 power supply and transmits the pulse itself to the diode limiter on diodes D_{30}, D_{31}. The diode limiter reduces the pulse voltage swing to the supply voltage of the neutron radiation detector. The pulse voltage limited in this way passes through the protective resistor R_{18} to the input of the comparator built into the microcontroller. The microcontroller wakes up after the comparator triggers and increases by one the accumulated value of the number of incoming pulses, stores the new value in its memory and goes back to sleep. Upon receiving a signal about the end of the pulse counting period from the real-time clock chip DD_2, the microcontroller also wakes up.

Then it records in non-volatile memory DD_3 the value of impulses received from the Geiger-Müller counter SBM-19 accumulated over a specified period of time, transmits this value via fiber optic transmitter on LED D_1 using the USART protocol to an external monitor, then resets the value of accumulated impulses in its memory and goes back to sleep. The fiber optic LED D_1 is adapted for use with a 2 mm diameter plastic optical fiber. Using plastic optical fiber to transmit information about the value of accumulated impulses to an external monitor simplifies the task of installation and galvanic isolation between the neutron radiation detector and the monitor located in the control room. Plastic optical fibers are easily cut to length without special equipment and do not require special connectors, unlike quartz optical fibers. Fiber optic plastic LEDs already contain a collet clamp for mounting. Additionally, in sleep mode, the microcontroller can receive control commands from a personal computer using an external USB to COM converter, which connects to the neutron radiation detector via the audio connector XS2. By command from the control computer, synchronization of the current computer time and the real-time clock of the neutron radiation detector can be performed. Information about the values of accumulated impulses from non-volatile memory for the entire observation period can also be retrieved.

The period of pulse accumulation from the Geiger-Müller counter SBM-19 is 10 seconds, this value is set when programming the real-time clock chip. The non-volatile memory capacity is 16 MB, which is sufficient for continuous recording of pulses accumulated over 10 seconds from the Geiger-Müller counter SBM-19 for more than 2.5 years. When the entire memory is filled, the recording process continues in a cycle, destroying the earliest information about accumulated pulse values from the Geiger-Müller counter SBM-19. The data block structure of accumulated pulses also includes information about the exact time of recording this data block. In effect, the neutron radiation counter stores complete information about neutron radiation with precise time reference (similar to a black box). A modern $LiSOCl_2$ galvanic cell with a voltage of 3.6 V, capacity of 2.1 A · h, and a very low self-discharge rate of about 1% per year is used as the power source for the neutron radiation detector.

To increase reliability, the microcontroller periodically restarts its control program every four seconds using the built-in Watchdog timer. This mode returns the microcontroller to proper operation after any program failure due to interference. The measured current consumption when operating with the connected Geiger-Müller counter SBM-19 in background radiation mode does not exceed 40 μA. With such current consumption, the calculated continuous operation time without replacing the galvanic cell is more than 5 years.

Structurally, the electronic part of the neutron radiation detector is located on a printed circuit board, which is placed inside a steel tube with an external diameter of 40 mm and a length of 170 mm. The tube ends have external threads onto which two flanges are screwed. One flange has an SR-50 connector for connecting the Geiger-Müller counter SBM-19, and the second flange has a center hole for a plastic light guide, through which information is transmitted to an external monitor. The external view of the neutron detector is shown in Fig. 2.

Fig. 2. External view of the neutron detector: *1* – neutron moderator block with SBM-19, *2* – pulsed neutron radiation detector.

4. RESULTS OF EXPERIMENTAL VERIFICATION OF THE DEVICE

The operation of the device was tested on a pulsed plasma accelerator (PPA) installation, developed at the Shatura branch of JIHT RAS. The description of the accelerator is presented in work [3]. The main elements of the coaxial PPA are two coaxial electrodes: the central one is the cathode, the outer one is the anode. A diagnostic section follows the electrodes. The PPA also includes a system of solenoids to create an external quasi-stationary magnetic field. In the gap between the electrodes, a dosed amount of working gas is injected through a system of holes in the central electrode using a fast-acting electrodynamic valve. When high voltage is applied to the electrodes, breakdown and ionization of the working gas occurs, closing the load circuit of the accelerator. Then, the formation and acceleration of the plasma bunch takes place under the action of the Ampere force, which arises due to the interaction of the radial component of the electric current in the plasma between the PPA electrodes and the self-magnetic field in the current circuit. At the end of the acceleration path, a solid target is installed in the diagnostic section. The target serves to decelerate the plasma flow in order to convert the kinetic energy of the plasma jet into radiation energy. From the flash of radiation that occurs during the deceleration of the flow, in case of achieving thermonuclear reaction conditions, a neutron flux is generated, which is registered by the neutron radiation detector described above. The results of the detector operation in the form of a time diagram of secondary electron pulses during experiments on the PPA within one working day are presented in Fig. 3.

Fig. 3. Time diagram of secondary electron pulses registered by the neutron detector during experiments on the pulsed accelerator within one working day.

5. CONCLUSION

The application of the described neutron radiation detector is relevant in hydrogen and thermonuclear energy tasks, where neutron output is used to evaluate the effectiveness of various plasma processes in real time. Experimental testing of the device on the operating IPU installation demonstrated the device's functionality and its advantages, such as:

- reliable registration and time recording of all cases when neutron radiation output is present in experiments;
- technological efficiency in assembly, unlike analogues, the assembly does not contain any winding products;
- composed entirely of commercially available serial products;
- ease of use, as no preliminary adjustment is required throughout the entire cycle of experiments.

FUNDING

The work was carried out within the research program conducted by JIHT RAS on the topic "Investigation of physical processes providing an increase in the energy content of plasma flow in a pulsed accelerator" (FFUE-2022-0012).

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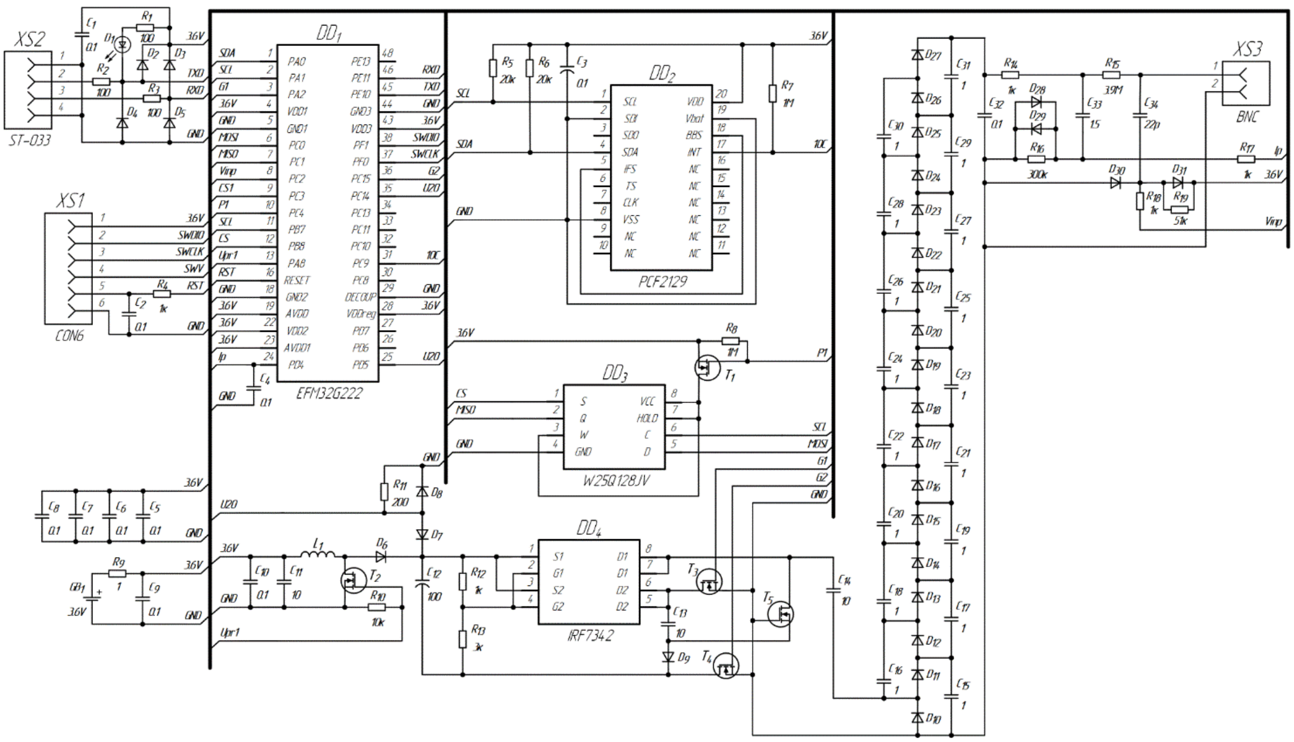
FIGURE CAPTIONS

Fig. 1. Electrical schematic diagram of the neutron radiation detector.

Fig. 2. External view of the neutron detector: *1* – neutron moderator unit with SBM-19, *2* – pulsed neutron radiation detector.

Fig. 3. Time diagram of secondary electron pulses registered by the neutron detector during experiments on a pulsed accelerator throughout one working day.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XS1
CON6
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XS3
BNC

Fig. 1.

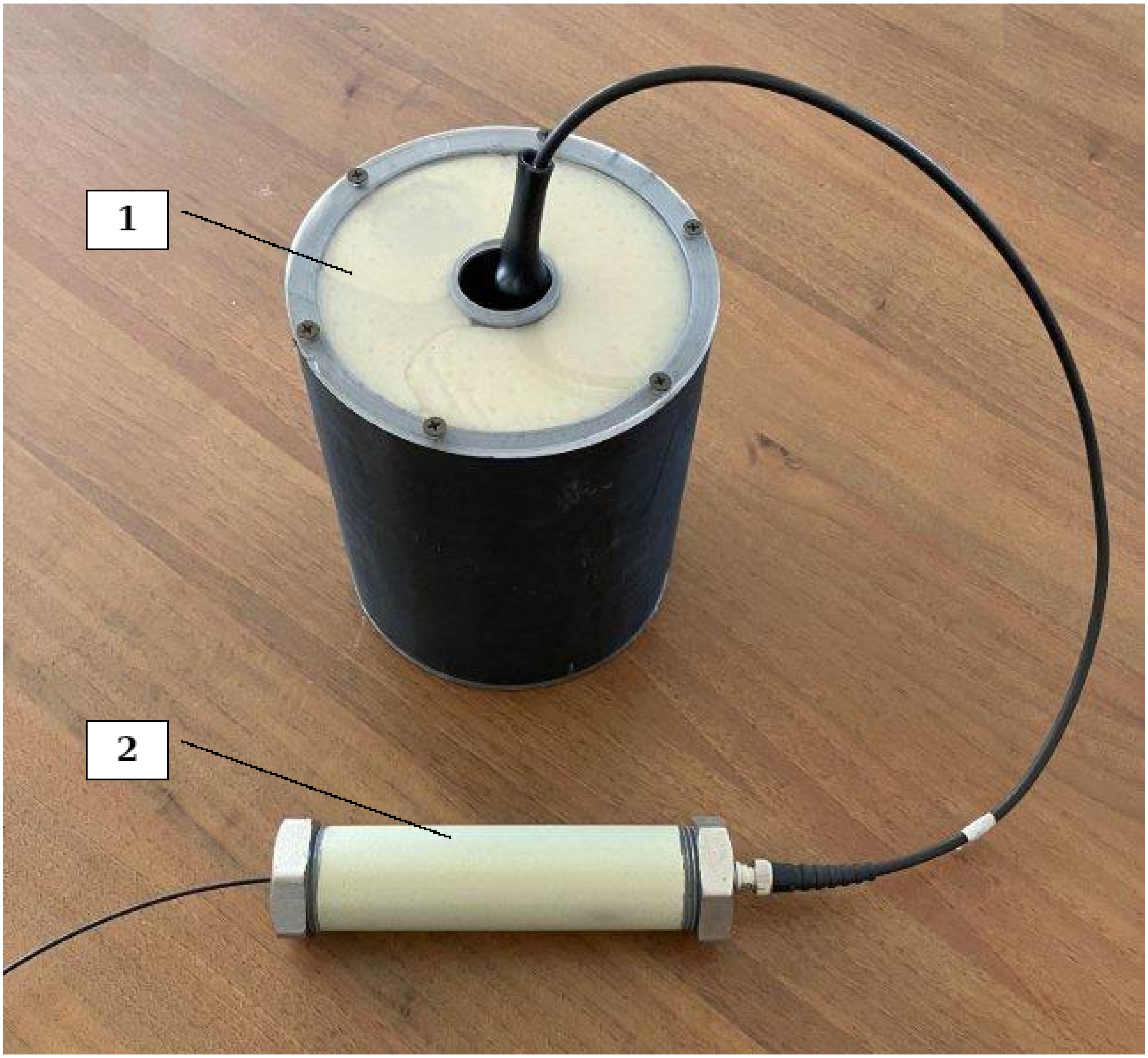
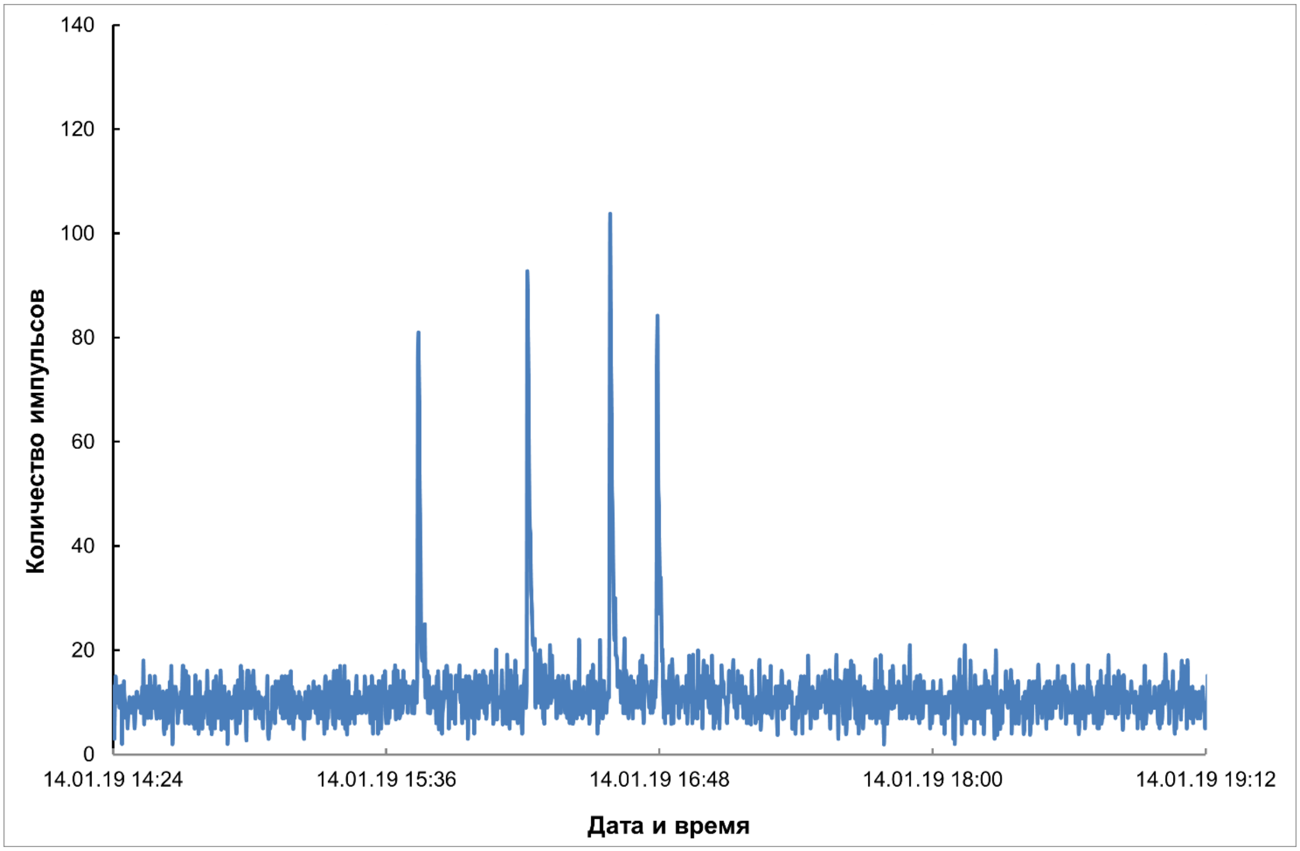


Fig. 2.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Дата и время

Fig. 3.