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GAS-FILLED IONIZATION CHAMBER AND SECONDARY-EMISSION DETECTOR FOR MEASURING γ-RAY DOSE RATE

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The design of a KGK-2 γ-ray dose rate detector is described. The basic characteristics of the detector are presented. The readings of a KGK-2 gas-filled ionization chamber detector and VED-2 secondary-electron emission detector during power startup of BR-K1 and BR-1M reactors are compared. It is shown that by using KGK-2 and VED-2 detectors in combination the γ-ray dose rate can be measured in the interval 1 μGy/sec to 10 GGy/sec with the linear sections of the regulation curves overlapping to at least four decimal orders.

Electronuclear plant development entails measurement of the γ-ray dose rate in the interval 1 μGy/sec–10 GGy/sec [1]. Compared with an evacuated detector, the sensitivity of a gas-filled detector with the same design is a factor of several thousand higher as a result of the formation of electric charge carriers in the sensitive volume. The successful use of VED-2 detectors in the process of generating reactor fission pulses on prompt neutrons in stationary or slowly varying power regimes (seconds, minutes) on the one hand and the need to reduce the controlled dose rate level on the other foreordained the use of a KGK-2 detector within the overall dimensions of a VED-2 detector [2].

A KGK-2 detector contains a system of three electrodes which are fabricated from austenitic-class stainless steel and placed in a hermetic cylindrical vessel, made from the same material, with outer diameter 50 mm and wall thickness 0.8 mm [3]. The signal electrode is assembled from 10 disks and the two other electrodes from five and six disks, 44 mm in diameter and approximately 0.36 mm thick. The disks of each electrode are secured by three metal rails. Supporting insulators made from high-alumina ceramic separate the rails from the body. Each disk of one electrode, which is the signal electrode, is arranged between the disks of the two other electrodes, forming with it two sections. The distance between the neighboring disks of unlike electrodes is equal to 1.6 mm. The rods of unlike electrodes are connected by current-carrying conductors with separate power points consisting of a corundum ceramic junction with Kovar and welded into the housing cover.

After firing in a vacuum furnace at 750 K, the detector was filled with a mixture of helium, nitrogen, and argon to pressure 0.45 MPa. The partial pressure of helium and nitrogen is the same and equal to 0.9 kPa.

The electrode system and the appearance of the gas-filled ionization chamber KGK-2 are displayed in Fig. 1. The basic characteristics of the chamber are as follows:

Working electric voltage, V	50–1000
Sensitivity to γ-radiation, 10^{-5} C/Gy	1 ± 0.1
Slope of saturation curve at supply voltage 360 V, 10^{-5} V^{-1}	≤5
Sensitivity to fast neutrons, 10^{-19} C·cm^2	<5
Background current in the absence of irradiation, 10^{-12} A	<1
Insulation resistance of power points, 10^{12} Ω	≥1
Electric strength, kV	≥1.8

The maximum height of the chamber is equal to 240 mm; the mass does not exceed 400 g. The guaranteed operating time at temperature 650 K is equal to 25000 h, The assigned service life is equal to 25 years.

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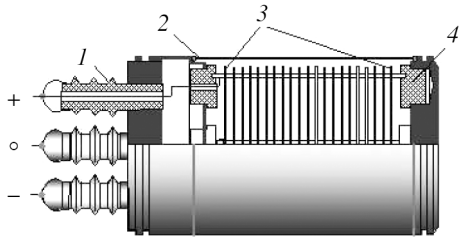

Fig. 1. Design of the detector: *1*) power point; *2*) housing; *3*) electrode system; *4*) insulator.

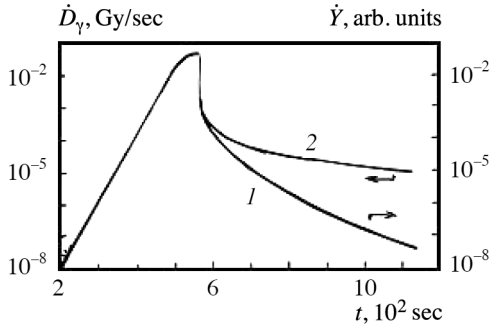

Fig. 2. Time dependence of the power of a BR-K1 reactor on delayed neutrons (*1*) and the γ-ray dose rate (*2*) measured using KGK-1 in the reactor room at a distance ~9 m from the center of the core.

When the Bragg–Grey relations are satisfied and all charge carriers are collected the electric currents in the evacuated $I_{\gamma v}$ and gas-filled $I_{\gamma g}$ electrode system are related with the γ-ray dose rate absorbed in evacuated $\dot{D}_{\gamma v}$ and gas-filled $\dot{D}_{\gamma g}$ electrode system by the relations [4]

$$I_{\gamma v} = eK_{\text{ems}}S\dot{D}_\gamma; \quad I_{\gamma g} = e(\rho V/w_i f)\dot{D}_{\gamma g},$$

where e is the electron charge; K_{ems} and S are, respectively, the emissivity of the material and the area of the electrode-emitter; f is the ratio of the mass stopping power of the electrode system material and the gas in the gas-filled structure; w_i, ρ, and V are, respectively, the average formation energy of the ions, the density, and the sensitive volume in the gas-filled structure (1 Gy = 1 J/kg; 1 eV = $1.6 \cdot 10^{-19}$ J).

In the process of developing the detectors, working together with the metrological service, a specialized gamma-source (SGS) was created and qualified and a procedure for calibrating the indicated type of detectors in SGS BR-K1 was formalized [5]. A γ-rate dose rate from 0.1 μGy/sec to 10 Gy/sec was obtained in the 10 × 10 × 5 cm working volume of the SGS. An integral component of the methodological instrumentation is a computer program for calculating the change of the γ-ray dose rate in the SGS during the calibration power startups of a reactor. A model for calculating the time dependences of the yield of delayed γ-rays according to a formula recommended in [6] was chosen as the main computational model.

The methodological recommendations developed for calibrating VED-2 were extended to the procedure for calibrating KGK-2.

A calibration power start is a separate power start of a reactor for the purpose of calibrating the means and methods of measurement when using KGK-2 and VED-2 chambers in the radiation field of SGS shows that there is no difference between the responses of the detectors. The obtained result attests that in the radiation fields of reactors with different neutron to γ-ray flux ratio (prompt and delayed γ-rays) the indications of the KGK-2 detector are similar to the indications of the VED-2 detector. We note that the results obtained by sampling and using the KGK-2 and VED-2 simultaneously in the radiation field of the reactors BR-1M, BR-K1, and GIR-2 did not show any discrepancies in the compatible interval of linearity of the load characteristics – the interval where the linear sections of the regulation curves of the devices are covered within the limits of the methodologically established measurement errors [7].

Figure 2 shows the time dependence of the γ-ray dose rate in a pulse of the BR-K1 reactor on delayed neutrons at a distance of about 9 m from the center of the core and illustrates the possibility and features of γ-diagnostics of the radiation

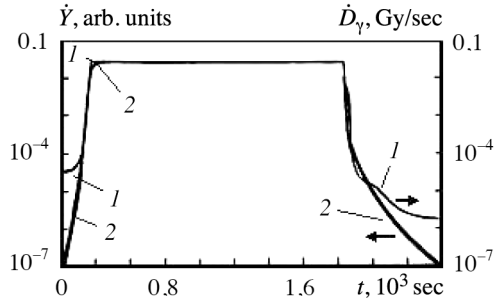

Fig. 3. Time dependence of the γ-ray dose rate (*1*) in the pulse of BR-1M reactor (*2*) on delayed neutrons with KGK-2 placed in a container of the vertical load of the core.

fields of reactor facilities. At the completion of power startup bounded by the thermal expansion of the fissile material of the core, a difference appears in the readings of γ-ray detectors and the reactor power. The difference is associated with the appearance of delayed γ-rays.

Figure 3 shows the change in the γ-ray dose rate in comparison with the reactor power in power startup of BR-1M, performed on delayed neutrons with asymptotic runaway time 21.8 sec and the maximum attained power ~0.5 MW with nuclide fission rate in the core $\sim 1.77 \cdot 10^{16}$ sec^{-1}. The KGK-2 detector was placed in a 14 m long, 10.4 m wide, and 8 m high reactor room at a distance of ~9 m from the core center at the same height above the floor as the center. For clarity, the reactor power $\dot{Y}$ is represented in relative units.

The significant distance from the core – source of γ-radiation and the low level of the natural background current of the detection system with the KGK-2 chamber ($\sim 1 \cdot 10^{-13}$ A) made it possible to perform reliable measurements of the electric current with γ-ray dose rate from 0.1 μGy/sec at reactor power ~1 W. On the entire active section of power startup, in the time interval $(2.4–16.4) \cdot 10^2$ sec, the change in the dose rate is similar to the change in the reactor power. The change in the dose rate within the controlled limits is equal to a factor of $\sim 4.5 \cdot 10^5$.

The character of the change in the γ-ray dose rate after completion of the reactor pulse generating procedure by extraction of all reactivity control rods into the initial position is due to the extraction of the vertical load container from the core after the reactivity control rods are put into the initial state and the container is removed from the core to a distance ~2 m.

The post-pulse diagnostics, called to provide reliable measurement of the γ-ray dose rate after a powerful fission pulse on prompt neutrons, has a special place in the practice of diagnostics of the γ-ray fields of pulsed reactors. The possibilities of VED-2 detectors are almost exhausted at $\sim 1 \cdot 10^{-3}$ Gy/sec.

The possibilities of using VED-2 and KGK-2 in γ-diagnostics are shown in Fig. 4. The measurement results were obtained by irradiating a KGK-2 chamber and six VED-2-03 chambers connected in parallel. To increase the γ-ray flux, the detectors are surrounded by a shell made of a pressed mixture of polypropylene with cadmium oxide in the ratio 9:1 by weight. Measurement was conducted in the BR-1M reactor when generating a pulse on prompt neutrons. The BR-1M power at pulse maximum was equal to ~60 GW. The width of the pulse at half of the maximum power was ~86 μsec. Thanks to the procedure of minimizing the power level of the reactor prior to generation of a fission pulse the background currents are recorded at the level $\sim 10^{-12}$ A.

The previous data, obtained in pulsed measurements, on the peak current of a VED-2-03 battery recalculated in terms of the peak power of the reactor $\sim 2 \cdot 10^{21}$ fissions/sec make it possible to evaluate the current of six VED-2-03 in the peak of the studied pulse $\sim 1.2 \cdot 10^{-4}$ A with admissible working current of a single VED-2-03 equal to 10 A. This makes it possible to prevent overloading of the detectors in terms of current and to attribute the character of the change in the dose response, shown in Fig. 4, exclusively to the response of the measuring module of the current chamber to the pulsed current spike at its input.

Coincidence of the current responses of VED-2 and KGK-2 was established approximately 0.7 sec after the pulse in calibration power startup of the BR-1M reactor with power yield to $2.7 \cdot 10^{17}$ fissions in the core. This experimentally determined fact makes it possible to assert that no later than 1 sec after the fission power pulse the system equipped with the KNK-2 chamber and the measurement module of the current chamber operates on the linear section of the regulation curve.

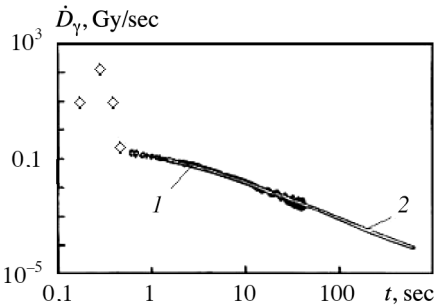

Fig. 4. Time dependence of the γ-ray dose rate recorded by VED-2-03 (*1*) and KGK-2 (*2*) at a distance of ~3 m from the center of the core of the BR-1M reactor: ◇) VED-2-03 signal on overloading of the measurement module of the current chamber.

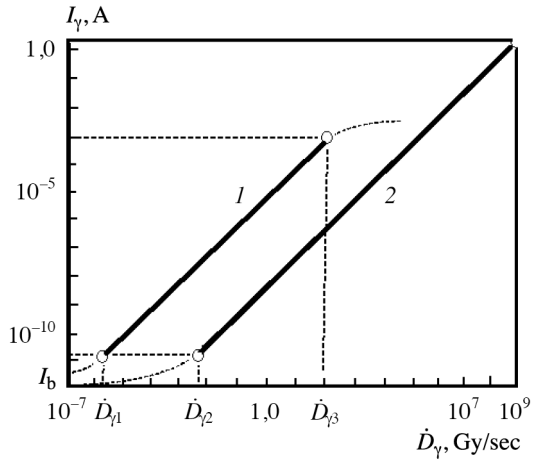

Fig. 5. Regulation curves of gas-filled ionization chamber KGK-2 (*1*) and the secondary-emission detector VED-2 (*2*).

The top boundary of the linear section of the regulation curve of KGK-2 is determined by analyzing the characteristics of industrial gas-filled ionization chambers with a similar design [7]. The fact that a KGK-2 detector has two identical sections, as a result of which the upper limit of the working current of the detector with parallel connection of the section is twice that for an individual section, was taken into account. The maximum linear current of a KGK-2 chamber is equal to 1.5 mA with electric power voltage up to 1 kV.

The regulation curves of vacuum and gas-filled structures are shown in Fig. 5. The linear section of the regulation curve at low γ-ray dose rate is limited by the intrinsic background current. In the absence of radionuclides and contamination in the chambers, $I_{bg} = I_{bv} = I_b \le 1 \cdot 10^{-12}$ A. The minimum dose rate $\dot{D}_{\gamma 1}$, $\dot{D}_{\gamma 2}$ at which the relative deviation of the electric currents in the gas-filled and vacuum structures from linear curves does not exceed δ is determined by the relations

$$\dot{D}_{\gamma 1} = I_b/\delta K_{\gamma g}; \quad \dot{D}_{\gamma 2} = I_b/\delta K_{\gamma v}.$$

The maximum linear current in the gas-filled structure is limited by the volume charge created by gas ions in the interelectrode gap [4]. The maximum dose rate $\dot{D}_{\gamma 3}$ at which the relative deviation of the electric current in the gas-filled structure from a linear curve does not exceed δ; the values of $\dot{D}_{\gamma 1}$ and $\dot{D}_{\gamma 2}$ are shown in Fig. 5 for $\delta = 0.05$.

On intersection of the linear sections of the load characteristics of the gas-filled and vacuum structures we can write the relations

$$\dot{D}_{\gamma 1} \le \dot{D}_{\gamma 2} \le \dot{D}_{\gamma 3},$$

from which follow

$$\dot{D}_{\gamma 1}\dot{D}_{\gamma 3} = 1/D \le \dot{D}_{\gamma 2}/\dot{D}_{\gamma 3} \le 1/\chi; \quad 1 \le \dot{D}_{\gamma 2}/\dot{D}_{\gamma 1} \le D/\chi,$$

where $D = \dot{D}_{\gamma 3}/\dot{D}_{\gamma 1}$ is the relative linear range of the regulation curve of a gas-filled electron system; $1 < \chi < D$ is the overlap

factor of the linear sections of the regulation curves of the vacuum and gas-filled electrode systems. Taking into account the relations between the minimum values of the γ-ray dose rate, we can write

$$K_{\gamma v} \le K_{\gamma g} \le (D/\chi)K_{\gamma v}.$$

For the same attenuation of the γ-ray flux by the vessel wall of the vacuum and gas-filled structures of the detector $\dot{D}_{\gamma v} = \dot{D}_{\gamma g}$, the ratio $I_{\gamma v}/I_{\gamma g} \sim f$. The ratio f of the mass stopping power of steel and argon is almost independent of the energy of the γ-rays [8]. Therefore the dependence of the sensitivity on the γ-ray energy of the vacuum and gas-filled ionization chambers VED-2 and KNK-2 is similar.

The KGK-2 and VED-2 chambers make it possible to measure the γ-ray dose rate in reactors, critical assemblies, and radiation facilities with isotopic sources, charged-particle accelerators, and electron nuclear facilities in the interval 1 μGy/sec–10 GGy/sec with the linear sections of the regulation curves overlapping to least four decimal orders [9].

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