Automation of the monitoring system for surface contamination with α-active radionuclides

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Abstract. The paper presents research on radiation control at nuclear enterprises working with α-active radionuclides. The focus of the research is on the registration of ^{239}Pu radionuclides on hands surface. The experimental results show the possibility to create a turnstile for automatic monitoring the presence of α-active radionuclides on hands. Such a device can be used with a minimum helium consumption of 66 liters per hour in a measuring chamber with an open bottom of 5.4 liters.

1. Introduction

The radiation safety maintenance and monitoring personnel in terms of radionuclides contamination are integral parts of the nuclear fuel cycle enterprise. The radiometric control systems of the RZB, RZA, RZBA series are currently manufactured in Russia. They are made as a frame with built-in detection units and a measurement processing unit. Some of these devices are equipped with a turnstile. Existing devices, as a rule, have β-particles detection units, fixed at various points of the turnstile and external α-particles detection units. Monitoring β- and γ-emitting radionuclides is carried out on existing devices with a turnstile in automatic mode. Such contamination is also possible with the disposal of radioactive waste [1, 2].

It is known that the α-particle path in the air does not exceed 2–3 cm [3]. Therefore, it is difficult to create a device for automatic control of the radiating nuclide presence, for example, 239Pu, at stationary positioning of a detector. This is due to the fact that stationary α-particles detection units may not register the radionuclides out-of-the-way places for the detector flat surface, for example, in the recesses between fingers or under nails. Therefore, the remote detection units are used in a manual mode for more accurate measurement. In this case, a human factor appears in the process of monitoring radioactive contamination, the detector damage risk, for example a scintillator film, increases, and the detection unit may fall.

The work of stationary radiometric control devices becomes ineffective with the nuclear industry development and the creation of new industries using radionuclides emitted mainly α-particles [4, 5].

Therefore, the development of stationary automated devices for monitoring α-active contamination of personnel in nuclear fuel cycle enterprises are topical.

2. Gas Mixture Search For α-Particles Recording

The device in which the source and detector of α-particles is in a single hermetic chamber is assembled to substantiate the possibility of creating an automated monitoring system of surface contamination with α-emitting radionuclides (Figure 1). This allows controlling a gas mixture composition in which α-particles are distributed. The α-particles source is installed thereby an external magnetic manipulator can change the distance from the detecting unit to an α-particles source. The source installation on the rail runner allows experimental determination of the α-particles path length.

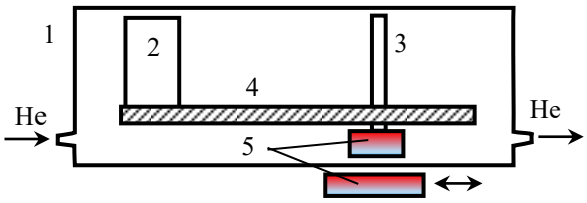

Figure 1. Experimental facility: 1 – chamber, 2 – sensor α-particles, 3 – source α-particles, 4 – rail, 5 – permanent magnet.

The counting unit is located outside the hermetic chamber. The chamber is equipped with two fittings for changing the gas mixture. An MKS-AT1117M radiometer with a remote BDPA-01 detection unit was used. An α-particles source is performed in the tablet form with a diameter of 30 mm and a thickness of 4 mm. ^{239}Pu (activity 3.4 kBq) was chosen as a α-particles source, because this isotope makes the main contribution to the surface contamination of personnel [6, 7].

The ^{239}Pu activity is associated with α decay with the probability close to 100% [8]. In this case, α-particles are emitted with energy: 5105.5 keV – 11.94%; 5144.3 keV – 17.11%; 5156.59 keV – 70.77%. Spontaneous fission with the probability not exceeding 3.2 10^{-10} % is also possible. The particle energy is about 5.1 MeV at the α-decay of ^{239}Pu. The path of the α-particles in the air at 760 torr and at 15°C depends on the energy of α-particles, respectively, on the initial velocity, and is determined as:

$$L = K \times E_a^{1,5}.$$

The K-value depends on the units of measurement and the propagation medium [9]. If the energy of α-particles (E_a) is in MeV, at a temperature of 15°C in air, the α-particle path can be determined by the equation:

$$L_0 = 0.316\ E_a^{1,5}.$$

For example, the mean path of α-particles with an energy of 5.1 MeV in air is L_v = 3.63 cm. The α-particles path in a given medium can be determined from the known path in the air with an accuracy of ±15% using the equation:

$$L = L_0\ (\rho_0 : \rho)\sqrt{A : A_0}\ ,$$

where L is a path of α-particle in substance; L_0 is path of α-particle in air; ρ_0 and A_0 are air density and atomic mass (ρ_0 = 1.29 g/l, atomic mass is 14.4); ρ, A are density and atomic mass of substance.

It can be seen that the α-particle path will be maximal in gases which have a minimum density and maximum atomic mass. Therefore, to increase the α-particle path and the number of pulses, it is necessary to create a helium atmosphere in the space between the detector and the controlled surface. In the helium atmosphere, the path of α-particles has a maximum value.

The α-particles flux at different distances from the detector and the maximum path of α-particle in the air and a mixture of helium with air are experimentally determined. Experimental results are

shown in Figure 2. It can be seen that the minimum distance at which it is possible to register of α-particles in air is 2.5 cm. In the helium, the path of α-particles does not exceed 12 cm. The obtained path of the α-particles allows the measuring unit formation for an automated complex for the radioactive contamination control.

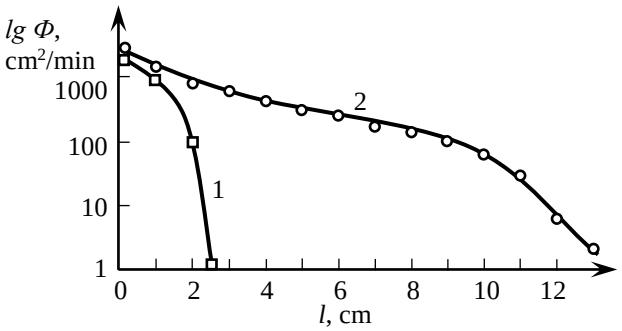

Figure 2. α-intensity at various distances from the source:1 – Air, 2 – Helium.

The source was installed at a distance of 6 cm from the detector, and helium was introduced into the chamber for additional verification of the obtained results. The flux density was 250 α-particles. After an air blow of the chamber, the detector stopped detecting α-particles.

3. Development of Measuring Chamber for a Turnstile

It is necessary to place two detectors of α-particles, designed to monitor contamination of the inner and outer sides of a palm into the chamber. The requirements for the measuring chamber of the automated device are the following: the chamber should provide free and unobstructed movement of a hand during the measurement, maintain constant measurement conditions - keep the gas mixture with helium content above a certain specified value. Helium is lighter than air, therefore the hermetic chamber window for hand insertion should be located in its lower part (Figure 3).

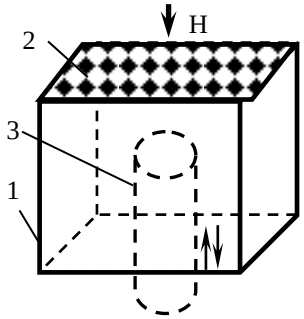

Figure 3. Measuring chamber scheme: 1 – chamber, 2 – perforation, 3 – mobile cylinder.

When a hand is put into the chamber, the working gas mixture is forced out, and when the hand is removed, air is drawn into the counting volume. As a result of a hand movement in the chamber, turbulence is created, which also draws air into the counting volume, reducing He concentration. Also, to maintain He concentration above a predetermined value, a continuous supply of helium is necessary in the upper part of the box. This is due to the fact that the attenuation of the α-radiation flux in helium is much less than in air.

The gas volume in the chamber and the He feed rate are the main parameters providing, under a given people flow through the turnstile, required helium content in the gas mixture of the measuring chamber. To estimate these parameters, we calculated the gas flows in a helium-air mixture with periodical hand moving inside the chamber.

In the simulation, the chamber has a parallelepiped shape ($18 \times 25 \times 50$ cm) oriented vertically

with the open part down. An 8 cm diameter cylinder with a rounded upper end is inserted every 10 seconds for a time of 2 seconds into the chamber along the longitudinal axis of symmetry. The cylinder stops at a distance of 5 cm from the chamber top. Helium is fed into the rectangular chamber from the upper end over the entire area uniformly. The simulation results of the gas flows inside the chamber obtained using the Comsol are shown in Figure 4.

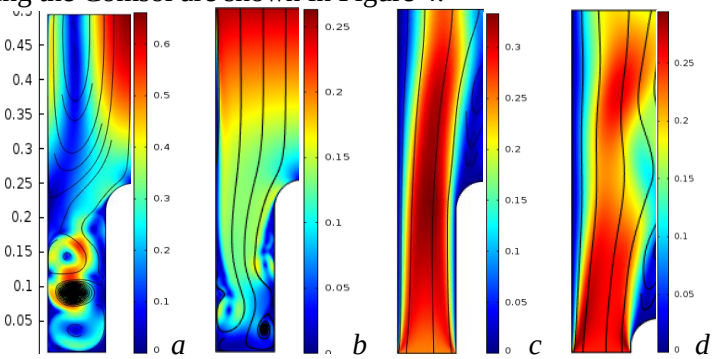

Figure 4. Gas flow diagrams in the chamber at the cylinder moving: *a*, *b* – up; *c*, *d* – down.

The calculated values given in Figure 4 allow us to state the following: the cylinder movement up through the chamber leads to the intensive formation of a turbulent flow in the space between the cylinder and the body. A laminar flow is maintained in the volume of the chamber above the cylinder. Therefore, the mixing of helium with air is insignificant. The cylinder moving downward, gas vortices are formed mainly when it leaves the chamber cavity.

Therefore, each time the cylinder exit from the chamber forms a turbulent flow, the vortex of which replaces the gas mixture with clean air at the chamber bottom. Thus, two processes contribute to the helium dilution in the chamber: displacing a helium with a cylinder followed by replacing this volume with air and replacing helium with air as a result of cylinder removing from the chamber, which triggers the vortex gas movement. The scale near to each Figure 4 shows the linear velocity in m/s.

4. Experimental Tests of the Turnstile Chamber Model

For experimental studies, a 5.4-liter parallelepiped chamber ($18 \times 25 \times 50$ cm), a rotameter RM-06 with a maximum air flow of 83 *l*/h, and a MS-200 mass-spectrometer were used. Helium was supplied from a balloon through a rotameter. The mass spectrometer MS-200 is designed for analysis with constant pumping at a sample flow rate of 110 m*l* / min through a 5 m long capillary. Therefore, sampling on mass-spectrometer was carried out for less than 2 minutes at regular intervals. For periodic introduction of the capillary into the chamber on its side wall, a tube was installed vertically, ending at a distance of 5 cm from the upper end.

First, the helium natural leakage rate from the chamber was evaluated. For this purpose, the mass-spectrometer capillary was installed at the 5 cm height from the lower section of the chamber. Then the helium balloon was opened. After the helium steady state at the chamber cut, the mass-spectrometer sampling capillary was transferred to the upper part of the chamber through a tube, and the supply of helium was stopped. Sampling S was carried out periodically. The measurement results are shown in Figure 5.

It can be seen from Figure 6 that the helium concentration is about 2 times greater than in the section at the initial moment in the center of the chamber. It is caused by the constant dilution of the working mixture due to the mutual diffusion of air and helium. The comparison of the first two peaks shows that the helium concentration decreased 1.55 times in 6 minutes. The estimated helium leakage rate is 0.5 *l* / min. Therefore, to maintain a constant composition gas mixture in the chamber, it is necessary to continuously feed He into the chamber.

Then, the He concentration change was experimentally determined with periodic cylinder (5 cm diameter) bringing into and out the chamber at different helium consumption values. First, He was fed

into the chamber until the stationary concentration establishing (the first 1.5 minutes) and then the feed was blocked. The cylinder was stopped at a distance of 5 cm from its upper end. Manipulation with the cylinder in the chamber was repeated 4 times with an interval of 20 seconds. The He content change graph at a distance of 5 cm from the upper end of the chamber is shown in Figure 5.

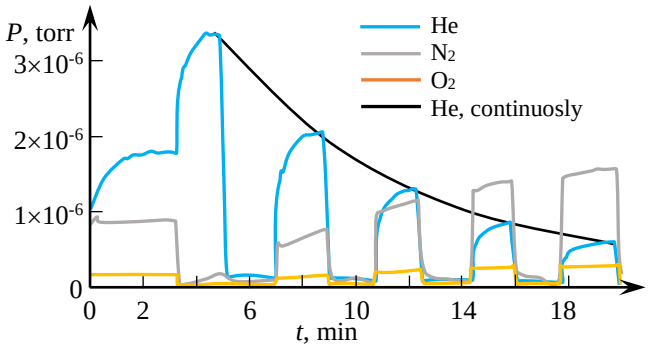

Figure 5. Time dependence of the gas mixture components.

The graphs in Figure 6 show four small peaks associated with the cylinder insertion into the chamber. At the beginning of the cylinder movement, the partial pressure of helium increases, and when the cylinder is removed, air is sucked into the released volume, so the He concentration decreases. The downward shift of the curve is seen by about 5% after each peak. The estimate of this helium loss is 0.27 liters. This time period on Figure 6 is highlighted with a circle. However, a more significant decrease in He concentration is observed due to leakage.

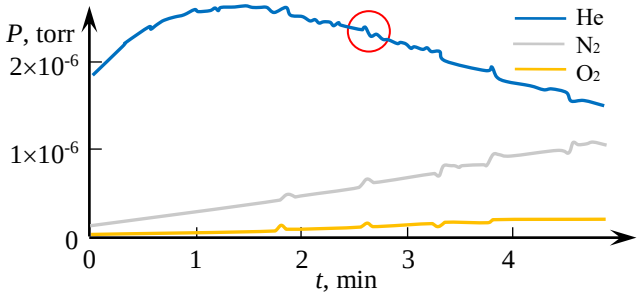

Figure 6. Gas mixture composition changes in the chamber lower part.

To design a turnstile, it is necessary to estimate the minimum helium flow rate at which its concentration fluctuations will be negligible. Figure 7 shows helium concentration changes at a consumption of 33 *l*/h, 50 *l*/h, 66 *l*/h and 83 *l*/h supplied from the upper end of the chamber.

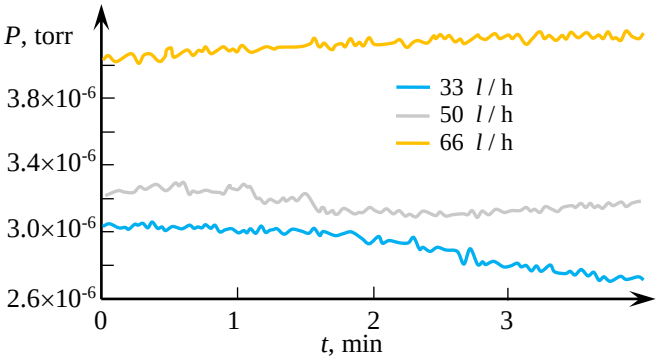

Figure 7. Helium concentration changes.

Figure 7 shows that the steady state of helium with the concentration of 84% of the maximum possible is achieved at a flow rate of 33 liters per hour. The helium concentration decreases with several manipulations with a moving cylinder inside the chamber. The steady state of helium is achieved at 90% of the maximum concentration at a flow rate of 50 liters per hour. The helium concentration decreases slightly with cylinder multipassing re-insertion into the chamber. The helium concentration in the chamber is maintained at the maximum level at a flow rate of 66 and 83 liters per hour. The concentration of helium does not change, and concentration fluctuations are not noticeable during several manipulations with the cylinder in the chamber.

5. Summary

The experiments showed that it is possible to implement an automated system for monitoring hand surface contamination with α-active radionuclides. For this purpose a rectangular chamber blown with helium is used in which the α-particles sensor is installed. It is necessary to maintain a helium consumption of at least 66 liters per hour when using a 5.4 liter-chamber with an open bottom.

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