Measurement of Radon concentration by Xenon gamma-ray spectrometer for seismic monitoring of the Earth

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Abstract. A method for earthquake precursors search based on variations of $^{222}$Rn concentration determined via intensity measurement of $^{222}$Rn daughter nuclei gamma ray emission lines by means of xenon gamma-ray spectrometer is discussed. The equipment description as well as the first experimental data are presented.

1. Introduction
Prediction of earthquakes today is a very important topic of interest of the modern science. One of the most promising methods for earthquake prediction today is based on measurement of concentration of radon-222 ($^{222}$Rn), emitted from the rock. Preliminary research shows that a certain increase in $^{222}$Rn concentration can act as a precursor of a possible earthquake (several days in advance) [1].

One of the most perspective methods for the task is the registration of gamma-ray emission lines of $^{222}$Rn daughter nuclei, in particular $^{214}$Bi and $^{214}$Pb.

Notably, there have already been attempts to employ scintillation detectors for this purpose [2]. However, this kind of equipment has a number of disadvantages. First of all, insufficient energy resolution that, for example, does not allow to resolve the 609 keV energy line of $^{214}$Bi and the 583 keV line of $^{208}$Tl. Secondly, this type of detector is sensitive to temperature variations, which greatly limits the options for installation locations.

Therefore, for reliable isolation of gamma-ray emission lines of $^{222}$Rn daughter nuclei a gamma-ray spectrometer with good energy resolution capable of stable operation in various environments is required. These requirements can be satisfied by detectors based on high-pressure xenon [3].

2. Equipment description
In this study a gamma-spectrometer based on a two-liter cylindrical xenon gamma-ray detector (XGD) was used. Its main physical and technical characteristics are given in table 1.

In March 2015 this equipment was installed in a seismic research laboratory of the North-Osetian branch of the Russian Academy of Sciences Geophysical Survey (Vladikavkaz). This room did not have a ventilation system and the temperature and the humidity were kept at a constant level, which eliminated influence of external factors on the radon concentration. The continuous seismic monitoring by means of the equipment described above at the seismic station in Vladikavkaz was organized in such a way that all of the information was in the on-line mode transmitted to the Radiation laboratory at NRNU MEPhI, where it was processed, and where the operation of the measurement equipment was controlled.
Table 1. XGD main physical and technical characteristics.

| Characteristics                  |       |
|----------------------------------|-------|
| Mass, kg                         | 6.0   |
| Working medium mass, g           | 580   |
| Working volume, cm$^3$           | 2000  |
| Gas density, g/cm$^3$            | 0.29  |
| Dimensions, cm                   |       |
| (Diameter)                       | 14.0  |
| (Length)                         | 38.5  |
| Power consumption, W             | < 10  |
| Registered $\gamma$-rays energy range, MeV | 0.5 – 3 |
| Energy resolution at 662 keV, %  | 2.1±0.5 |
| Operating temperature range, °C  | 0 ÷ 100 |

3. Experimental results

The measurement of Rn activity was carried out from 19.03.2015 to 13.05.2015 and spectra were registered each hour. In figure 1 a total energy spectrum for 24 hours is presented. In this spectrum gamma-ray lines of $^{40}$K, daughter nuclei of radon $^{222}$Rn ($^{214}$Bi and $^{214}$Pb), and also $^{232}$Th (one of the products of decay of which is $^{220}$Rn) are present. For seismic monitoring it is necessary to distinguish between gamma-ray lines of daughter nuclei of radon and thoron, in particular 583 keV and 609 keV, which is enabled by the high energy resolution of XGD.

![Figure 1. Total energy spectrum for 24 hours.](image)

As an example, the time variation of the intensity of the 609 keV ($^{214}$Bi) gamma-ray line is shown in figure 2.
In the course of the experiment daily variations of gamma-ray lines intensities for daughter nuclei of $^{222}$Rn were observed. To account for them time dependences of the intensities during night-time were plotted. To do that the collected energy spectra were averaged over the period of 10 hours (22:00 – 07:00). The obtained plots could be used for qualitative analysis of intensity variations for the gamma-ray lines in question and therefore for seismic monitoring.

In accordance with the data presented at the web-site of The European-Mediterranean Seismological Centre an analysis of earthquakes with regard to their epicenter and magnitude was carried out. Two areas were chosen, 200 km and 700 km away from the measurement equipment. The first area was used to account for earthquakes with magnitude $\geq 3.5$, and the second one for more powerful earthquakes with magnitude $\geq 4$.

During two months of measurements in the studied region of seismic activity six earthquakes marked in figure 3 were registered. The “star” symbol on the map corresponds to the location of the equipment. Table 2 contains information on each of the events.

**Table 2.** Information on the earthquakes that took place in the chosen region during measurement period.

| №   | Magnitude | Date     | Time, UTC | Coordinates | Distance, km | Depth, km |
|-----|-----------|----------|-----------|-------------|--------------|-----------|
| 1   | ML 3.6    | 21.03.15 | 17:15:30  | 42.53       | 131          | 2         |
| 2   | Mw 5.0    | 22.03.15 | 22:45:24  | 40.32       | 690          | 30        |
| 3   | ML 4.2    | 30.03.15 | 9:54:01   | 40.90       | 399          | 6         |
| 4   | mb 4.1    | 06.04.15 | 1:26:32   | 40.22       | 316          | 2         |
| 5   | mb 3.5    | 14.04.15 | 0:34:08   | 43.66       | 105          | 5         |
| 6   | ML 4.0    | 28.04.15 | 14:01:02  | 38.91       | 468          | 15        |
Figure 3. Locations of the earthquakes and measurement equipment.

Figure 4 presents the time dependence of the night-time intensity of the 609 keV gamma-ray line. The time of the beginning of each earthquake is marked with an arrow. According to the plot, before each earthquake a growth of intensity of a $^{222}\text{Rn}$ daughter nuclei line is observed, however to confirm these results more long-term measurements in areas with higher seismic activity are necessary.

Figure 4. Time variation of the night-time intensity of the 609 keV ($^{214}\text{Bi}$) gamma-ray line.

4. Conclusion
A method for search of possible earthquake precursors based of measurement of $^{222}\text{Rn}$ concentration by means of intensity measurements of gamma-ray lines of its daughter nuclei using high-pressure xenon gamma-ray spectrometer is shown. First experiments employing such method that have been carried out show the possibility of its utilization.

For more reliable distinction of the possible precursors detailed statistics and placement of equipment in locations with high variation of $^{222}\text{Rn}$ concentration and high seismic activity are needed. For more detailed information on the expected time and location of the earthquake a large number of gamma-spectrometric devices in various locations connected into a wide network is necessary.

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References
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