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Effect of Pressure and Ventilation in the Experimental Hall on the Count Rate of Background Events in the LVD Detector

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Abstract—A study is performed of variations in the count rate of detector background pulses in the LVD experiment (Gran Sasso, Italy). Such variations are caused by the injection of radon from the rock into the experimental hall. Dependences are presented for variations in the air pressure on the Earth's surface and in the experimental hall of the LVD, along with others in the count rate of LVD events associated with changes in the concentration of radon.

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INTRODUCTION

The main task of the LVD experiment [1] at Italy's INFN Gran Sasso National Laboratory (LNGS) to search for neutrinos from supernova explosions in our Galaxy [2, 3]. Variations in the count rate of detector background pulses associated with the injection of radon from the naturally radioactive rock in the experimental hall are also studied [4]. The lower threshold of the variations in the LVD count rate is associated with changes in the concentration of radon near the detector [5]. The LVD records gamma quanta from the decays of the radon daughter nuclei. Radon's half-life is 3.8 days. Gamma radiation is mainly generated by ^{214}Bi nuclei (the energy of gamma quanta can be as high as 3 MeV) [6, 7].

The aim of this work was to study the long-term behavior of radon fields and their relationship to the air pressure and ventilation in the underground experimental hall, and to the air pressure on the surface.

LVD EXPERIMENTAL HALL

The INFN LNGS is located in the Gran Sasso mountain range in central Italy. It lies under a layer of rock around 1 km thick and roughly at the same altitude above sea level. The experimental underground halls of the laboratory are located nearby, 50–100 m away from two parallel transport tunnels (both around 10 km long) for traveling from central Italy. The underground hall where the LVD experiment is located has a volume of 24000 m^3. Equipment is delivered and removed through two gates. When the gates are closed and the ventilation turned off, the hall is virtually sealed. Fresh air is supplied through an inlet ventilation system with a capacity of 8000 m^3/h in order to create a slight overpressure in the hall. The air is taken from the valley, and its content of radon is negligible. In accordance with safety requirements, the ventilation is constantly operating. It is regularly turned off to change the supply pumps or, in rare cases, for technical reasons. The concentration of radon starts to grow is kept constant at a level of $+(19 \pm 1)$°C [8].

RESULTS AND DISCUSSION

A thermohygrometer was placed inside the LVD to perform a detailed study of the behavior of temperature T_{hall}, humidity H_{hall}, and pressure P_{hall} inside the experimental hall. It operated from May 5, 2019, to March 3, 2020. After measuring the parameters at different levels of the detector [8], the thermohygrometer was fixed in one position at the center of the detector for several months. The average pressure in the detector hall was $\langle P_{\text{hall}} \rangle = 680 \pm 5$ mmHg.

A comparative analysis was performed of the behavior of atmospheric pressure P_{atm} and pressure P_{hall} in the underground experimental hall. Pressure P_{atm} was taken from the ECMWF (European Centre for Medium-Range Weather Forecasts) database for a point on the surface near the laboratory (50 km away from the entrance) that was equivalent to sea level [9].

The P_{atm} and P_{hall} time series from May 2019 to April 2020 repeated each other and correlated strongly ($r = 0.95$). The difference between the pressures was

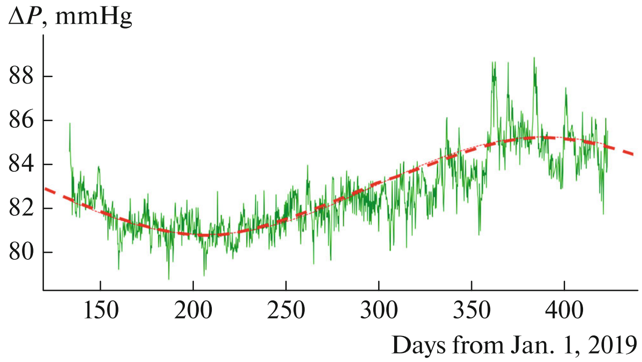

Fig. 1. Seasonal variation in the difference between air pressure on the surface and in the LVD hall. The dashed curve corresponds to approximation $f(t) = 2.2\cos(2\pi(t - 390)/365) + 83$.

almost constant $\langle P_{atm} - P_{hall}\rangle = 82.1 \pm 1.6$ mmHg. We found a seasonal variation of around 2% in the pressure difference with a minimum in late July and a maximum in late January. Figure 1 shows the change in the difference between the pressure on the surface and in the hall: $\Delta P = P_{atm} - P_{hall}$. The same amplitude and phase of variations in difference $P_{atm} - P_{hall}$ were obtained for three other nearby ECMWF points.

In light of the high correlation between the atmospheric pressure and the pressure in the experimental hall, we decided to use the ECMWF database for the long-term analysis of the pressure dependence of the count rate of LVD background events according to the lower threshold (CR_{LVD}). The procedure for recording and selecting LVD background radon events was described in [6, 7].

Figure 2 shows variations in P_{atm} and CR_{LVD} from 2016 to 2020. The curves show an anti-correlation in their behavior, and a strong anti-correlation is seen in the region of the ellipse. These curves do not depend on the season. We assume that a change in the atmospheric pressure affects the smooth trend in the radon release and plan to find better characteristics of this dependence. Sharp outliers in the LVD data associated with anomalous behavior of radon fields (shaded regions in Fig. 2) will be a subject of further research.

CONCLUSIONS

Experiments to search for rare events are performed at the LNGS underground laboratory. The unique LVD detector was designed for studying variations in background conditions in the underground hall and events associated with changes in the concentration of radon underground.

A comparison between the air pressures on the surface and in the underground hall measured with a thermohygrometer in the LVD showed they correlate strongly ($r = 0.95$).

Pressure difference $P_{atm} - P_{hall}$ varies by 2% with the season (with a minimum in late July and a maximum in late January). This variation is associated with the underground hall's ventilation, which can alter the mode of operation with the weather conditions and the load on the network.

An anticorrelation between the time series of LVD background events and the surface air pressure was obtained on the basis of 4 years of observations. Our results [8] showed no correlation between the LVD data (CR_{LVD}) and the atmospheric pressure (P_{atm}) and temperature on smaller scales (on the order of days and weeks) ($r_{Pearson} < 0.2$). Individual cases of a correlation between changes in P_{atm} and CR_{LVD} require further study. They could be due to the barometric pumping effect for underground gases [10].

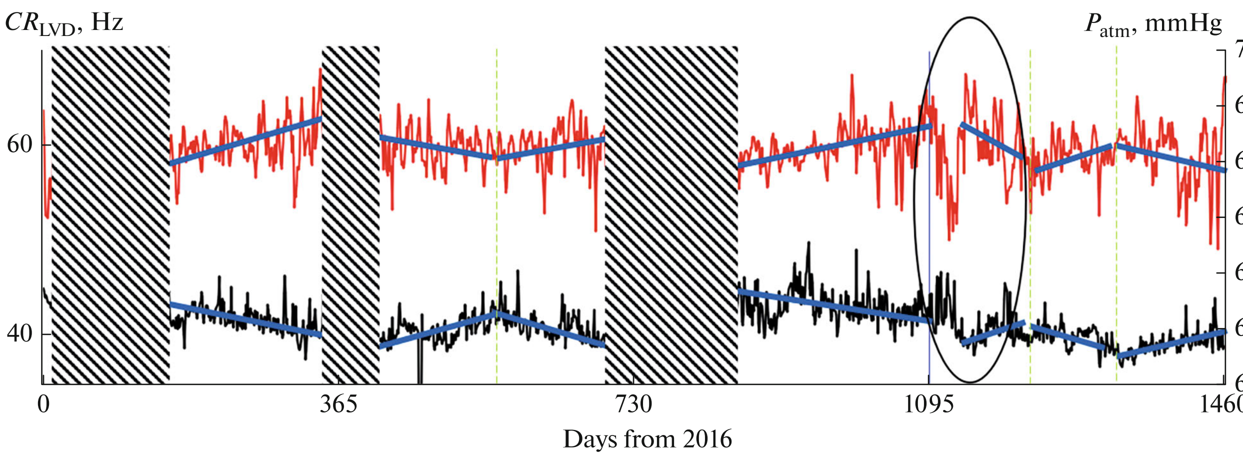

Fig. 2. Time series of atmospheric pressure P_{atm} on the surface (upper curve, right scale) and the LVD count rate CR_{LVD} (lower curve, left scale) over 4 years of observations. The shaded areas correspond to the periods of outliers in the LVD data, which are probably associated with tectonic activity in the region.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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