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Development of a high sensitivity radon detector for purified gases

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Abstract. For underground particle physics experiments, noble gas radon from U-chain decay series could be a source of serious background events. We have developed a high sensitivity detector for radon using electrostatic collection and PIN photodiode. Recently, we have developed a new type of radon detector. We report basic performance of the new 80L radon detector.

1. Introduction

In underground laboratories around the world, like Kamioka in Japan, LNGS in Italy, SNOLAB in Canada etc, many particle physics experiments are ongoing. Neutrino experiment Super-Kamiokande[1] and dark matter search experiment XMASS[2] are underway at Kamioka. Dark matter search experiment XENON100[3] continues at LNGS. Neutrino experiment SNO+[4] is ongoing at SNOLAB.

All of these experiments need very low background environments, and they are conducted in underground to achieve low background. Especially for underground experiments, noble gas radon from U-chain decay series could be a source of serious background events. Radon gas is generated from decay series of ^{238}U continuously. Because it is contained in the air and has half-life 3.824 days, it exists in large quantities underground. It potentially will dissolve into the xenon and water of XMASS, and in the water of Super-Kamiokande etc. Even if only a little, detector materials contain ^{238}U. The radon concentration has to be reduced in these experiments, and it is necessary accurately know the remaining concentration.

2. High sensitivity radon detector for purified gases

We developed a high sensitivity detector for radon using electrostatic collection and PIN photodiode for underground experiments (70L radon detector)[6]. Radon detectors give the concentration of radon in purified gases or water. In order to detect radon, the radon detector observes alpha ray signals from ^{214}Po decay. The principle of radon detection used

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in this detector is the electrostatic collection of the daughter nuclei of ^{222}Rn, and the energy measurement of the alpha decay with a PIN photodiode.

2.1. 80L radon radon detector

Figure 1. shows a schematic view of the high sensitivity new 80L radon detector for purified gases. It consists of a stainless steel vessel, a HAMAMATSU-S3204 series 18 mm × 18 mm PIN photodiode, a high voltage divider, amplifier circuit and a feed through. Negative high voltage is supplied to the p-layer of the PIN photodiode, and the vessel is grounded.

Viton O-rings for gaskets and acrylic plates for flanges are used in previous 70L radon detector. They were not airtight. In order to achieve a lower background level, we developed an experimental model of a new detector equipped with airtight parts, copper seal for gaskets and ICF flange. After exchanging the parts, the limit of vacuum level in the detector vessel became 1.0×10^{-5}Pa from 10kPa.

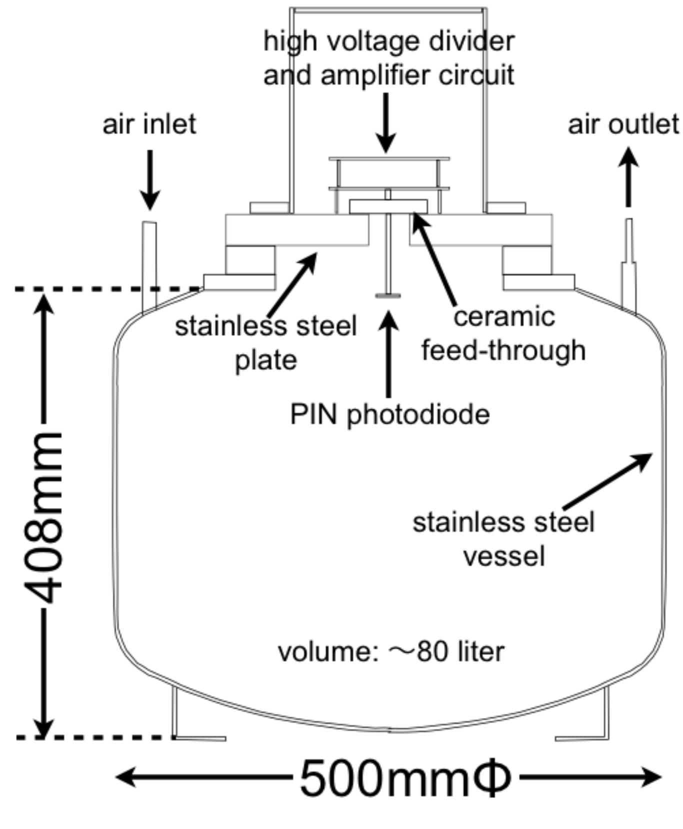

Figure 1. Schematic view of the 80L radon detector

3. Performance evaluation of new 80L radon detector

3.1. Energy spectrum

A typical pulse height spectrum of ^{222}Rn daughter signal is shown in Figure 2.. The ^{214}Po peak signal is used to measure radon concentration, because there are fewer interferering noise events, and no alpha ray peak overlapped its energy region, and it has a higher collection efficiency than ^{218}Po. The signal region of ^{214}Po alpha decay is from 169 to 179 ADC channel for this case. Peak position depends on the supplied voltage value and the settings of the amplifier.

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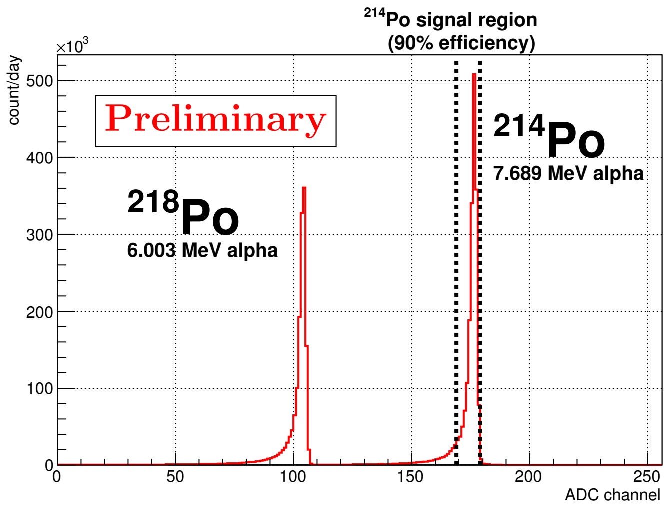

Figure 2. Typical energy spectrum from α decay of ^{222}Rn daughter nucleus

3.2. Calibration factor

To calculate radon concentration in mBq/m^3 from the ^{214}Po count rate in count/day, calibration factor (counts/day)/(mBq/m^3) needs to be obtained. A calibration system was constructed. Using the system, the high voltage dependence and purified gas humidity dependence of the calibration factor were obtained.

3.3. Calibration system

Figure 3. shows a schematic diagram of calibration system for the new 80L radon detector. The detector was connected to a refrigerator to control the dew point temperature, i.e. absolute humidity, a circulation pump, dew point meter, mass flow controller and a ^{222}Rn source. PYLON RNC ^{226}Ra with $0.0783kBq \pm 4\%$ activity was used as ^{222}Rn source. Calibration data was taken with atmospheric pressure purified Ar gas, purified Xe gas or purified air circulation.

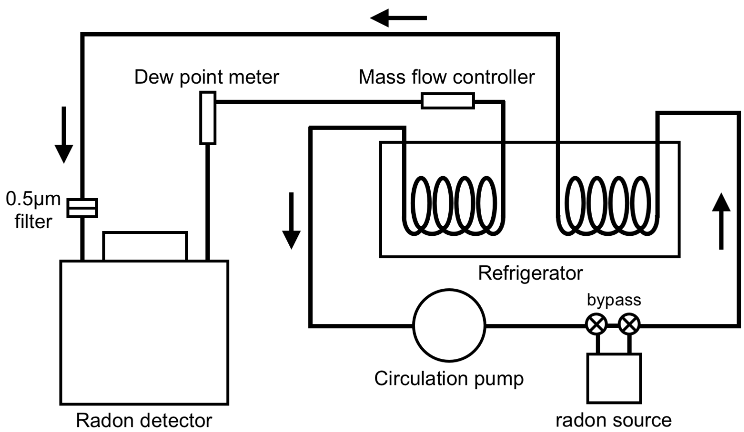

Figure 3. A schematic diagram of calibration system for the new 80L radon detector

3.4. High voltage and humidity dependence of calibration factor

In figure 4., left figure shows calibration factor as a function of high voltage. We can see that the calibration factor of the radon detector rises with higher voltage. The calibration factor became almost settled around -2.0kV.

The right figure shows calibration factor as a function of absolute humidity. Using a refrigerator, we controlled the humidity in order to study the humidity dependence of the calibration factor using the calibration system. Black circle shows old 70L detector′s calibration factor with pure air. Colored markers show new 80L detector′s calibration factors with pure air, Ar and Xe. New 80L detector with -2.0kV high voltage achieved higher calibration factor than 70L detector. Dotted black line shows 30% detection efficiency in the 80L radon detector. Considering direction of alpha-ray from Po at diode surface, i.e. half of them direct to diode, and signal region covers 90% of ^{214}Po signals, about 70% Po ions are collected by electric field to PIN photo diode surface over dotted line.

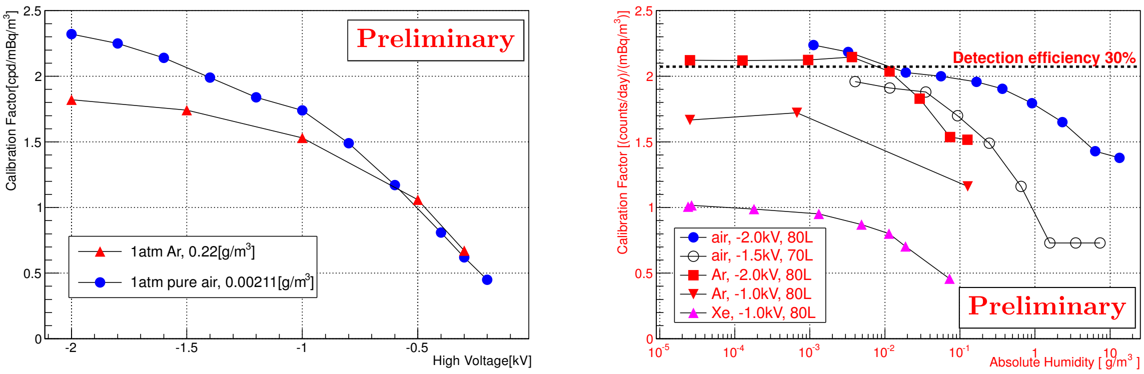

Figure 4. Calibration factor as a function of high voltage(left) and absolute humidity(right)

4. Conclusion

Experimental model of a high sensitivity radon detector was developed and its performance was investigated. Calibration data to calculate its calibration factor were taken. In Kamioka observatory, the radon detectors are used for radon measurement, material screening etc in various underground experiments.

Acknowledgement

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