

# Radon monitoring in the Kamioka mine

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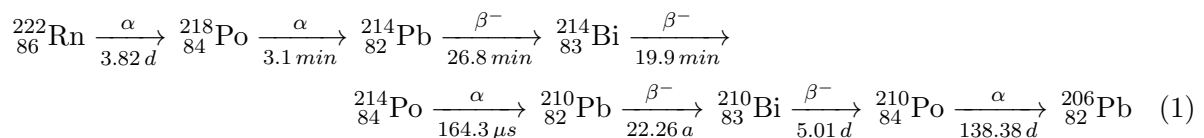
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**Abstract.** Radioactivity from radon is one of the main backgrounds for low energy experiments, like Super-Kamiokande and the other experiments hosted in Kamioka Observatory. In addition, it is an issue for the safety of the researchers and technicians working in underground laboratories. In the Kamioka Observatory, a total of 29 1-L radon detectors are deployed in different areas in order to monitor the radon concentration and ensure it stays below a certain limit. Here we briefly describe the 1-L radon detector system and their Raspberry Pi-based data acquisition system. The evolution of the tunnel's radon concentration over the last 3 years is then shown and discussed.

## 1. Introduction

Radon-222 (noted “radon” thereafter) is a radioactive gas which tends to accumulate underground, like in the Kamioka Mine. Its decay chain, described in Eq. 1, includes the production of  $\alpha$  and  $\beta^-$  particles over a long period, hence it is a serious background for low-energy physics and experiments, like the ones on-going in Kamioka Observatory. In addition, since radon tends to accumulate underground, it is a major health issue for technicians and researchers working in Kamioka Observatory. For these reasons, we needed to develop and deploy a radon monitoring system inside the Kamioka mine.



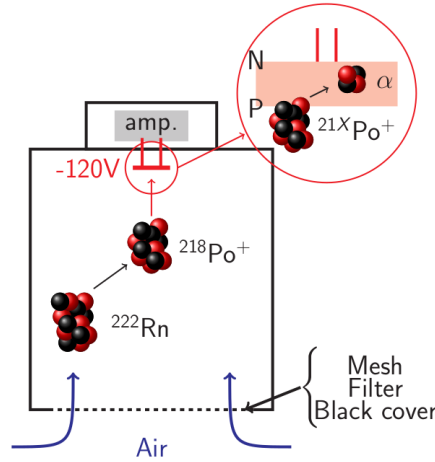
## 2. Radon detectors

In order to monitor the radon concentration, we developed a small 1-L radon detector based on the well known electrostatic collection method [1]. This method takes advantage of the fact that more than 90% of the radon daughter nuclei are positive ions. Therefore, applying a negative high voltage (HV) on a PIN photodiode allows collection of these daughter nuclei. The  $\alpha$  decays occurring later on the PIN photodiode then produce a signal which can be recorded. Figure 1 shows the conceptual design of the detector we are using.

The detector is a free-air detector, using natural ventilation to monitor the variation of the radon concentration in the environment. Its ventilation rate was determined to be  $\sim 7$  per hour, fixing its default measurement rate to one measurement per 10 minutes.



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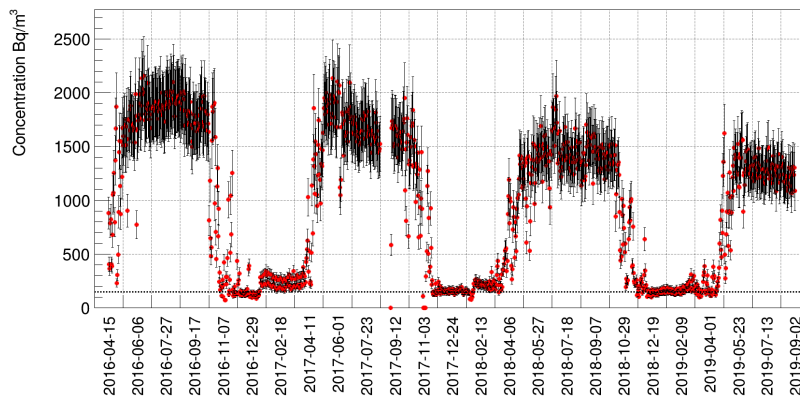
**Figure 1.** Conceptual design of the 1-L radon detector

The data taking is performed with a Raspberry Pi-based electronics. These electronics are able to handle input rate  $> 20$  kHz, which corresponds to a radon concentration above  $250 \text{ MBq/m}^3$ . The background of the detector has been estimated with the Currie's method [2] to be  $0.4 \text{ Bq/m}^3$ . Thanks to this radon concentration measurable range, we can use our 1-L radon detector anywhere in the Kamioka Observatory.

Technical details about the detector, its electronics, and its calibration are available in [3].

### 3. Radon monitoring in the Kamioka mine

For the purpose of radon monitoring, since April 2016, we have deployed 29 1-L detectors in the Kamioka Mine, 26 of them using the Raspberry Pi electronics. In this section we focus on the radon concentration in the “Atotsu” tunnel of the Kamioka Mine and discuss its variations.

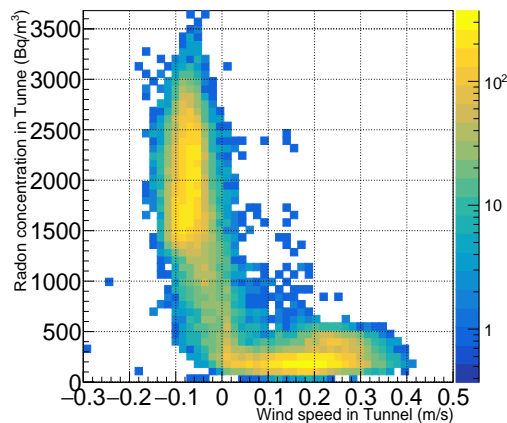


**Figure 2.** Daily-averaged radon concentration in the Atotsu tunnel from April 2016 to September 2019. The dotted line represents the  $148 \text{ Bq/m}^3$  limit for workplace in the US legislation, which is used as reference.

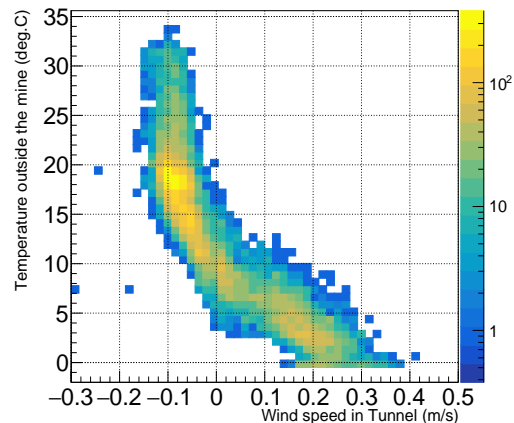
Figure 2 shows the radon concentration in the tunnels of the Kamioka Mine from April 2016 to September 2019. We will discuss in the following sections about the two main variations of

the radon concentration which can be observed in these data: a seasonal variation and a daily variation.

### 3.1. Seasonal variation of the radon concentration



**Figure 3.** Hourly-averaged radon concentration in Atotsu tunnel as function of the wind speed and direction in Atotsu tunnel. Positive (negative) wind speed indicates wind coming from outside (inside) the mine.



**Figure 4.** Temperature at the entrance of the Kamioka Mine as function of the wind speed and direction in Atotsu tunnel. Positive (negative) wind speed indicates wind coming from outside (inside) the mine.

As seen in Figure 2, we observed a seasonal variation, with high radon concentration ( $> 2000$  Bq/m<sup>3</sup>) during spring and summer, and low radon concentration ( $\sim 200$  Bq/m<sup>3</sup>) during fall and winter. This pattern has been repeated every year since April 2016.

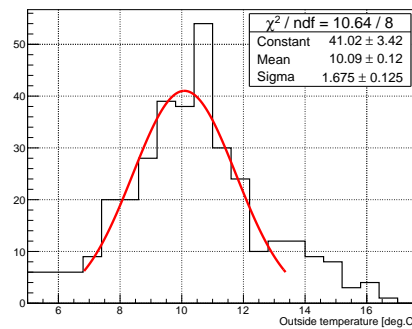
Using an anemometer we measured the direction and the speed of the wind of the tunnel. In Figure 3 we observe a clear correlation between the radon concentration and the direction of the wind in the tunnel: when the wind comes from outside the mine, the radon concentration in the tunnel is lower, whereas it is higher when the wind comes from the inside of the mine. Our interpretation is that during fall and winter, fresh air is being pushed into the tunnel from outside, significantly reducing the radon concentration in tunnel. On the contrary, during spring and summer, radon-rich air coming from the deep tunnels of the Kamioka mine is expected to be pushed into the Atotsu tunnel by the wind.

In Figure 4, we observed the correlation between the direction of wind in the tunnel and the temperature at the entrance of the tunnel. Figure 5 shows the projection of the temperature for a speed of the wind within  $[-0.01, 0.01]$  m/sec. From this data, we were able to determine that, on average, the direction of the wind changes for a temperature around  $10.1 \pm 1.7$  °C.

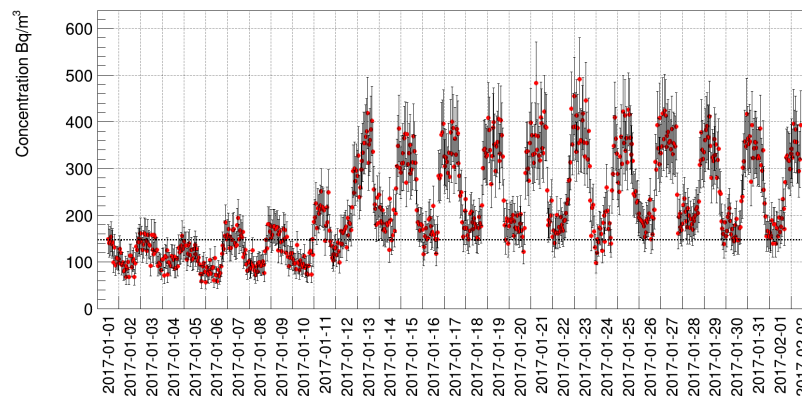
### 3.2. Daily variation of the radon concentration

On Figure 2, we can also notice a large day-by-day variation from January 2017 to July 2017. During this period the radon concentration goes from  $\sim 150$  Bq/m<sup>3</sup> to  $\sim 400$  Bq/m<sup>3</sup> every other day. This variation happens actually during the whole year, but was specially visible from January to July 2017 due to a temporary modification of the mine water flow.

We believe the reason behind this daily fluctuation is due to the location of the radon detector. Indeed, this radon detector is located near a water ditch. Two pumps extract water from this



**Figure 5.** Outside temperature for a wind speed within  $[-0.01, 0.01]$  m/sec



**Figure 6.** Hourly-averaged radon concentration in the Atotsu tunnel during January 2017. The dotted line represents the  $148 \text{ Bq/m}^3$  limit for workplace in the US legislation, which is used as reference.

ditch alternately every other day. The radon concentration increases by several  $10\text{s Bq/m}^3$  when the nearest pump is active, and decreases when the farthest pump is running. From January to July 2017, the water ditch was supplied with a radon-rich water coming from deep underground. This led to an increase in radon detected. Figure 6 shows the daily fluctuation of the radon concentration before and after the change in the water flow. The radon-rich water was supplied in the water ditch from January 11th.

#### 4. Conclusions

In the Kamioka Observatory we developed a small 1-L radon detector and Raspberry Pi-based electronics in order to monitor the radon concentration in the Kamioka Mine. Since April 2016 we deployed 29 of these detectors in the different areas of the Kamioka Mine. In this document, we focused on the radon monitoring in the Atotsu tunnel of the Kamioka Mine. We observed seasonal and daily fluctuations during the 3 years of data taking. The results of the radon monitoring in other areas of the Kamioka Mine are available in [3].

#### References

- [1] Kotrappa P *et al.* 1981 *Health Phys.* **46** 35
- [2] Currie L A 1968 *Analytical Chemistry* **40** (3) pp 586-593
- [3] Pronost G *et al.* 2018 *PTEP* **2018** no.9 093H01