Radon background study in Super-Kamiokande

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Abstract. Super-Kamiokande (SK), a 50 kton water Cherenkov detector in Japan, observes $^8$B solar neutrinos with neutrino-electron elastic scattering. SK searches for distortions of the solar neutrino energy spectrum caused by the edge of the MSW resonance in the core of the Sun. The installation of new front-end electronics in 2008 marks the beginning of the 4th phase of SK (SK-IV). With the improvement of the water circulation system, calibration methods, reduction cuts, this phase achieved the lowest energy threshold thus far (3.5 MeV kinetic energy). To improve the sensitivity to the MSW effect, it is required to achieve lower energy threshold. For this purpose, understanding the origin of background events and reducing them are important. Currently, the main background is known as a beta decay of $^{214}$Bi in a Radon decay chain. So far, SK collaboration has developed several techniques for studying Radon contamination in the SK water. In this proceedings, a measurement system which can measure Radon concentration in the SK water with the accuracy of $0.1 \text{ mBq/m}^3$ level is presented. In addition, an evaluation of Radon background events in SK injecting Radon rich water into the SK tank, as well as future prospects are also presented.

1. Introduction
Super-Kamiokande (SK) detector is a ring imaging water Cherenkov detector with ultra-pure water [1]. SK is located 1000 m underground at Ikenoyama, Kamioka, Gifu, Japan.

A main physics target of the SK detector is to measure the energy spectrum of the recoil electrons scattered by $^8$B and hep solar neutrinos. Currently, precise energy spectrum measurement is required to approach the expected MSW resonance curve [2, 3]. In order to improve the sensitivity to the MSW resonance, the analysis threshold should be lowered as much as possible. However, this threshold is limited by the background contamination due to the radioactive daughter nuclei of $^{222}$Rn dissolving in the SK pure water [4]. One possibility of the main background source is emitted electrons from the $\beta$ decay of $^{214}$Bi which is the daughter nuclei of $^{222}$Rn. Since the $Q$-value of $\beta$ decay of $^{214}$Bi is $\sim 3.27$ MeV, the emitted electron’s energy is overlapped with the energy range of solar neutrino.

In order to understand origins of the background events in the solar neutrino analysis in SK, following studies were perfomed:

- Development of a Radon measurement system to measure the Radon concentration at $\sim 0.1 \text{ mBq/m}^3$ in the purified water.
- Radon injection study to estimate the Radon concentration in the SK water tank.
2. Radon measurement system

Since the Radon concentration in the SK pure water is low, which is estimated less than 1.0 mBq/m³, it is difficult to measure its Radon concentration precisely using commercially available techniques such as liquid scintillator method. Therefore, it is required to develop a Radon measurement system which is designed to measure ~ 0.1 mBq/m³ level of the Radon concentration in pure water.

We newly developed a Radon measurement system to measure Radon concentration in the SK pure water by mixing with pure air as shown in Figure 1. The main components of this system are a Radon extraction mixer, cooled Cu wool traps, a cooled activated charcoal trap and a 80 L Radon detector [5]. The detail of this measurement system can be found in the reference [6].

![Figure 1. The schematic view of the Rn measurement system [6].](image)

Figure 2 shows the measurement results by sampling the SK pure water from the several positions. The Radon concentration in the bottom region is higher than that of the supply water. This situation implies that some of the SK structures (PMT, FRP and so on) supply Radon into the water in the SK tank. On the other hand, we achieve 0.34 ± 0.06 mBq/m³ of the Radon concentration in the center region.

3. Radon injection study

An easy way to evaluate the background events caused by Radon daughters is to inject Rn rich water into SK water tank directly [7, 6]. For this purpose, about 11 L of Radon rich water was produced on May 7th 2016. Radon rich water was produced by dissolving Radon rich gas from a $^{222}$Ra source into the SK pure water by a bubbling technique [7]. Then its Radon concentration was measured by a liquid scintillation counter. In consequence, its concentration is $0.88 \pm 0.11$ Bq/L. 5 L of the Radon rich water in total was injected into the SK water tank at $(x, y, z) = (+35.3, -350.0, 0.0)$ cm on May 18th 2016.

To evaluate the background events caused by Radon daughters in the SK solar analysis, all reduction cut [8] is applied to sample the observed events. The top panel of Figure 3 shows the typical $z$ vertex distribution in $3.5 - 5.0$ MeV$_{\text{kin}}$ before and after the Radon injection. For the comparison, a background vertex distribution is prepared by applying the same reduction cut to the 1 week SK data just before the Radon injection. It is clear that an excess can be found after the Radon injection. The bottom panel of Figure 3 shows the vertex distribution of the excess events after subtracting the event distribution of the usual data taking. This result
indicates that Radon contamination in the SK pure water result in producing the background events in the low energy region. Figure 4 shows the number of the excess events as a function of the time. It decreases along with the time constant of the Radon.

**Figure 3.** Top: Typical vertex distribution before (black) and after (red) the Rn injection. Bottom: Vertex distribution of the excess events after subtracting the vertex distribution under the usual data taking.

Comparing the excess of the events with the injected Radon radioactivity, a conversion factor can be obtained. It is 10 event/day/kton = 0.138±0.026 mBq/m³ in the energy region of 3.5–5.0 MeV_{kin}. A current event rate for 3.5–5.0 MeV_{kin} in the analysis fiducial volume (8.85 kton [8]) is 9.53 ± 0.06 event/day/kton. Using the conversion factor, the Radon concentration in the center region can be estimated to be 0.13 ± 0.04 mBq/m³ assuming all the remaining events are originated from the Radon daughters.

### 4. Summary and Conclusion

Rn study in the Super-Kamiokande was carried out to understand the origin of the low energy background events in the solar neutrino analysis. For this purpose, the Rn measurement system was developed. It can measure the Rn concentration at ~0.1 mBq/m³ level. Using this system, the Rn concentration in the SK center region is 0.34 ± 0.06 mBq/m³.

In addition, Rn injection study was also performed. The conversion factor is obtained as 10 event/day/kton = 0.138 ± 0.026 mBq/m³ (3.5–5.0 MeV_{kin}). Using this factor, the estimated Radon concentration in the center region is 0.13±0.04 mBq/m³. According to both approaches, SK achieves sub-mBq/m³ level of Radon concentration in the center region. However, it is required to investigate systematic uncertainties for the discrepancy (factor 2 ~ 3) between the measurement result and the estimated value.

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