Reduction of radioactive impurities from the liquid scintillator by using a Metal scavenger

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Abstract.
The KamLAND2-Zen experiment is a future plan to perform the search for neutrinoless double-beta decay ($0\nu\beta\beta$) by using a large liquid-scintillator (LS) based detector, i.e., KamLAND2. The KamLAND detector will be upgraded by increasing the light yield of scintillation. One of the upgrade plans consists of using a new linear alkylbenzene (LAB) based LS. We have developed the LAB-LS radio-puriﬁcation method by using a metal scavenger. The scavenging process resulted in a Pb-removal efﬁciency of 90.1$\pm$1.0% at most, and LS performance parametrics, such as light yield, light transparency, amount of radioactive impurities remaining, and the concentration of components were observed to be stable after scavenging. Therefore, it can be asserted that scavenging is a useful method for LS puriﬁcation.

1. Introduction
The KamLAND detector is a large, ultrapure liquid scintillator (LS) detector located approximately 1000 m under the peak of Mount Ikenoyama, Japan. It is used to detect the scintillation light emitted by radioactive decay. To perform the KamLAND-Zen experiment, we installed a LS container loaded with Xe into KamLAND for $0\nu\beta\beta$ of $^{136}$Xe search. The $0\nu\beta\beta$ denotes the key interaction to test the Majorana nature of neutrinos [1].

The KamLAND2-Zen experiment is the future upgrade plan of KamLAND-Zen. A new LS will be used in the KamLAND2-Zen experiment. The new LS consists mainly of linear alkylbenzene (LAB) and 2 g/L fluor PPO (2,5-diphenyloxazole). Moreover, the $0\nu\beta\beta$ exploration requires the development of low-background techniques. $^{214}$Bi event on the container of Xe-loaded LS is one of the dominant backgrounds in KamLAND-Zen [2]. To introduce $^{214}$Pb-$^{214}$Bi delayed coincidence method, the main accidental background source of $^{210}$Pb should be removed by more than 90%. Therefore, we suggest a new LS puriﬁcation method for LAB-LS by using a metal scavenger (MS).

2. Metal Scavenger
The MS is an adsorbent that is used to remove metallic elements [3, 4]. We used the R-Cat-Sil AP(silica powder with a functional group) product as the MS in our test experiment. The MS was ﬁlled into a column, and the LS was puriﬁed by ﬂowing through the column. The puriﬁcation column was designed for KamLAND-scale puriﬁcation (ﬁgure 1). The weight of the MS used was only 160 g.
3. Requirements for purification method
During the LS purification using the MS, it was required not to lose the high scintillation-light transparency, high scintillation-light yield, and the components of the LS. There were no problems in the performance of LS after LS purification.

First, the light transparency and the light yield of the LS were measured after circulating the LS at a flow distance equivalent to a flow of 30 m$^3$ through the column. In the worst case, the 9 cm light transparency ratio before and after the scavenging was 0.997 ± 0.004 at a wavelength of 350 nm. The scintillation-light yield ratio was 0.99 ± 0.02.

Second, radioactive impurities in the LS after circulating through the column were measured using inductively coupled plasma mass spectrometry (Agilent Technologies 7500) for $^{238}$U and $^{232}$Th and frame-spectrophotometry (Varian SpectrAA-55B) for $^{nat}$K. The overall contamination of $^{238}$U, $^{232}$Th, and $^{nat}$K in the LS will be less than $10^{-15}$ in 30 m$^3$ LS considering concentration by self-circulation of the LS.

Finally, the concentration of PPO after scavenging was measured by gas chromatography. If the PPO in the LS is adsorbed by the MS, the light yield of the LS decreases. We found the PPO adsorption reaches saturation after circulating the LS by $\sim$170 mL per 1 g MS. The concentration of PPO was stable within 1% after the saturation.

4. Pb reduction
$^{220}$Rn was dissolved into the LS and decayed to $^{212}$Pb. Subsequently, the LS was repeatedly purified using the column process. Finally, the Pb-removal efficiency was calculated to be 90.1±1.0%. The result of the Pb removal is depicted in figure 2.

![Purification system](image)

**Figure 1.** Purification system. The MS column was designed for the KamLAND-scale MS column. The final Pb reduction using column was designed for the KamLAND-scale MS column. The final Pb-removal efficiency reached was 90.1±1.0%.

**Figure 2.** Result of the $^{214}$Pb reduction using column was designed for the KamLAND-scale MS column. The final Pb-removal efficiency reached was 90.1±1.0%.

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