Inner balloon production for KamLAND-Zen 800

A Gando[1], Y Gando[1], T Hachiya[1], S Hayashida[1], K Hosokawa[1], H Ikeda[1], S Obara[2], H Ozaki[1], K Ueshima[1] and H Watanabe[1] for the KamLAND-Zen Collaboration

[1] Research Center for Neutrino Science, Tohoku University, Sendai 980-8578, Japan
[2] Department of Physics, Kyoto University, Kyoto 606-8502, Japan

E-mail: `azusa@awa.tohoku.ac.jp`

Abstract. KamLAND-Zen searches for neutrinoless double-beta decay with ^{136}Xe loaded liquid scintillator (LS). The LS container, a 25-μm-thick clean nylon inner balloon is a key of the experiment since one of the main backgrounds in the ROI is ^{214}Bi from the inner balloon. In KamLAND-Zen 400 (operated from 2011 to 2015), dust contamination of the inner balloon from the environment limited the sensitivity, although the inner balloon was fabricated at a class-1 super clean room. We improved the production method of the inner balloon for KamLAND-Zen 800 (started DAQ in January, 2019) and successfully reduced the ^{214}Bi background level to one fifteenth as compared to the 2nd phase of KamLAND-Zen 400. The inner balloon film material and requirements, improved fabrication scheme, including establishment of clean environment and dust control, will be described.

1. Introduction

Neutrinoless double-beta ($0\nu\beta\beta$) decay requires two characteristic neutrino properties: the neutrinos must have mass and must be a Majorana type lepton [1]. The decaying nucleus emits only two electrons and no neutrinos, the process thus violates lepton number conservation. This phenomenon is forbidden in the standard model. It was predicted theoretically 80 years ago, but has not yet been observed. Different experiments are searching for it using different technologies and isotopes.

KamLAND-Zen is a ^{136}Xe double-beta decay search experiment with xenon loaded liquid scintillator (Fig. 1, left). The detector is part of KamLAND which was primarily designed to observe few MeV neutrinos. It has a large and clean environment such as highly purified 1,000 ton of liquid scintillator contained in a 6.5-m-radius 135-μm-thick EVOH/nylon balloon. The concentration of ^{238}U and ^{232}Th in the liquid scintillator is 5.0×10^{-18} g/g and 1.3×10^{-17} g/g, respectively [2]. This liquid scintillator acts as an active shield for double-beta decay search. Scintillation light produced by signal/background is detected by 1,325 of 17-inch and 554 of 20-inch photo-multiplier tubes (PMTs) mounted on the inner surface of the 9-m-radius stainless steel tank. The outer detector (19-m-diameter and 20-m-height cylindrical rock cavity) is filled with 3,000 tons of pure water and surrounds the inner detector. It vetoes/shields muons, muon-induced fast neutrons, and external gamma rays from surrounding rock using 225 PMTs of 20-inch diameters. The double-beta decay isotope ^{136}Xe has a Q value of 2.458 MeV and is dissolved into liquid scintillator with approximately 3% by weight. KamLAND-Zen 800 uses 91% enriched 745 kg of xenon and contained in a 1.90-m-radius 25-μm-thick nylon inner balloon. Physics DAQ has started in January 2019.

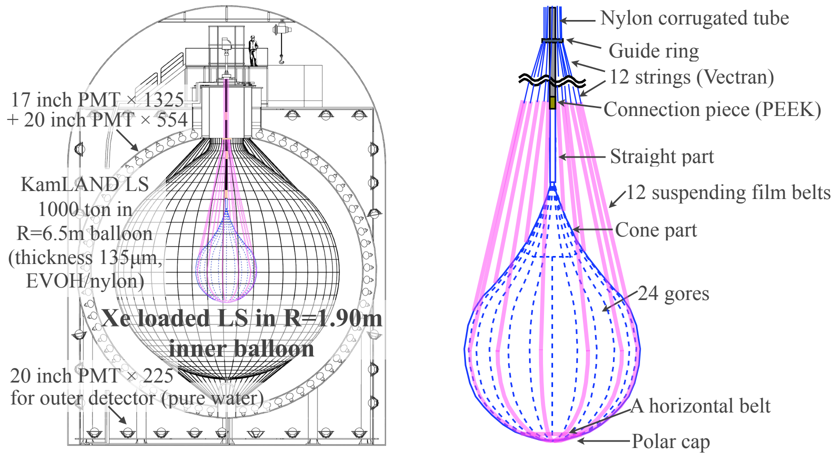

Figure 1. Schematic diagram of KamLAND-Zen detector (left) and inner balloon (right).

Based on the experience gained from KamLAND-Zen 400, a cleaner inner balloon was required, because ^{214}Bi originated from ^{238}U contamination in/on the inner balloon, limited the $0\nu\beta\beta$ sensitive volume. Delayed coincidence tagging of ^{214}Bi and ^{214}Po ($\beta + \gamma$'s, then α-decay, $\tau = 237$ μs) eliminates more than 99.9% of ^{214}Bi events in the liquid scintillator [3], however, in the inner balloon, the tagging efficiency is only about 50% due to α-particle absorption in the 25-μm-thick film.

2. Inner balloon production

Figure 1 (right) shows a diagram of the inner balloon and its supporting structure. The inner balloon consists of a main sphere with 24 gores, polar cap, a 1.5-m straight tube and cone. All of them are made of heat-welded 25-μm-thick clean nylon film. Twelve suspending belts are also made of the same material with the same method. The inner balloon is connected to the top flange of the detector with approximately 7 m of nylon corrugated tube and suspended by 12 belts connected to 12 Vectran strings. Vectran is one of the super fibers. It is hard to cut and has chemical stability.

The inner balloon was fabricated at a super clean room, classified as class 1 cleanliness. Ordinary 1 means the number of dust particles in 1 ft^3 with size of more than 0.5 μm. However, in this clean room, the counted dust size is more than 0.1 μm. The procedure of the inner balloon fabrication was as follows: (1) film washing by supersonic cleaning with ultra pure water, (2) searching for scratches on film to avoid them, (3) clipping films with patterns, (4) heat welding, (5) leak search with helium gas and helium detector and patching, (6) assembly with supporting structure, (7) wrapping and sending to the experimental site and (8) installation to the KamLAND detector. The process started in May 2017 and the inner balloon was installed successfully into the detector in May 2018. Regarding (4) and (5), heat welding sometimes makes hole(s) due to crease on the film(s), remaining air between the films, the boiling of water contained in the film, local heat concentration or partial lack of heat. We searched for leak points by filling the inner balloon with He and detecting it from the outside with a helium detector. Small leaks, such as pin holes, were repaired with glue and small film patches, while some of large ones were repaired by re-welding.

The film for the inner balloon is specially made not to contain inorganic lubricant “filler”. Usually a filler is used for commercial film to avoid films sticking to each. However it has a high radioactive contamination. Avoiding the use of filler, contamination of ^{238}U is reduced from $O(10^{-9})$ g/g to $O(10^{-12})$ g/g. According to ICP-MS measurements, the amount of ^{238}U and ^{232}Th in the film after washing were 2×10^{-12} g/g and 6×10^{-12} g/g, respectively. For comparison, the inner balloon in KamLAND-Zen 400 2nd phase contained 4.6×10^{-11} and 3.4×10^{-10} g/g of those isotopes. One of the reasons of increased background in the latter case was due to fabrication and installation procedures. The main contamination comes from dust brought in by the working people.

To reduce background from the environment and handling for the production, we introduced various improvements compared to KamLAND-Zen 400's: The first one was clean suits control. At KamLAND-Zen 400, we wore clean suits at class 1000 changing room used by all of clean room users. For KamLAND-Zen 800 inner balloon production, we firstly changed from normal cloths to low dust generated clean inner wear at another changing room, and then wore 1st clean suits at same place as KamLAND-Zen 400's. We built a small changing room in class 1 clean room, and we again changed newly washed clean suits there. Face was fully covered by mask and goggles and gloves were double folded. We washed our hands with ultra pure water if we touched something before touching the inner balloon. The second improvement was static electricity control. We introduced static eliminators when we touched films. Humidity control in the clean room was also introduced. The ideal humidity is higher than 60% in all seasons, however, between autumn and early summer, it is lower than expected. Especially in the winter, it is less than 20%. Low humidity easily causes static electricity on the film, which collects dust from the air. In addition, low humidity removes moisture from the film which then has a brittle texture and must be handled with great care. Therefore we installed a mist generation system upstream of the ULPA filter unit in the ceiling of the clean room. To prevent the contamination from the mist, it is generated from ultra pure water. The third improvement was particle flow check. We checked the flow by visualization with a green laser near/on the work desk and also confirmed what kind of action caused dust. For example, the dust is made by rubbing gloves, flicking fingers even just after washing gloves with ultra pure water. The fourth one was film cover setting. The film for the inner balloon was sandwiched with the same clean nylon cover film to prevent dust accumulation. During clipping the films, we cut 3 layers simultaneously. When welding, we stripped the edge of the film cover and after welding, restored it. All covers inside of the inner balloon were removed before the last welding line was welded. The outside covers were removed after leak check and repair of welding lines. The final one was a semi automatic heat welding machine. For the KamLAND-Zen 400 inner balloon production, a professional company person welded all lines with a hand-pushing heat welding machine. It required experience to press films from right above with stable strong forces for a few seconds. It was not easy to keep the quality constant even if performed by a professional. Therefore we introduced a semi automatic welding machine. This machine enables to speed up the process and also prevents particle drop from humans. We can modify the welding parameters such as heating and cooling temperature, pressure and heat welding time. We optimized the parameters to achieve the required rapture strength of more than 10 N/cm and to minimize the number of holes. The mean value for the actual strength is 35.2 N/cm.

3. Summary and future prospects

We successfully produced cleaner inner balloon for the KamLAND-Zen 800 experiment. The amount of ^{238}U and ^{232}Th is 3×10^{-12} and 4.0×10^{-11} g/g, respectively. Compared to KamLAND-Zen 400 2nd phase, it is reduced by 1/15 and 1/9. The ^{238}U level is almost the same just after washing film. In other words, no further improvement can be expected for a cleaner inner balloon production. One solution for a future experiment, such as KamLAND2-Zen, is a scintillating balloon. If the inner balloon itself scintillates with α-particles from ^{214}Po, the tagging efficiency of ^{214}Bi in the inner balloon will be increased. R&D is ongoing and the estimated background removing efficiency is about 99.7% [4].

References

[1] Schechter J and Valle J W F 1982 *Phys. Rev.* D **25**, 2951.
[2] Gando A *et al.* (KamLAND Collaboration) 2015 *Phys. Rev.* C **92** 055808.
[3] Gando A *et al.* (KamLAND-Zen Collaboration) 2016 *Phys. Rev. Lett.* **117** 082503.
[4] Obara S, Gando Y, Ishidoshiro K 2019 *PTEP* **2019** 073H01.