Status of balloon production for KamLAND-Zen 800 kg phase

S.Obara^a

For the KamLAND-Zen Collaboration

^a *Research Center for Neutrino Science, Tohoku University, Sendai 980-8578, Japan*

Abstract

KamLAND-Zen is an experiment for neutrinoless double beta decay ($0\nu2\beta$) search with ^{136}Xe , based on the large liquid scintillator detector KamLAND. KamLAND-Zen includes 16.5 m³ xenon loaded liquid scintillator in a 3.16 m diameter nylon balloon (inner-balloon) with 25 μm wall thickness.

KamLAND-Zen 400 (383 kg ^{136}Xe used) released a lower limit on the $0\nu2\beta$ half-life of ^{136}Xe . However, the sensitivity is limited by the contamination of radioactive backgrounds from the inner-balloon. Then, we planned KamLAND-Zen 800, upgrading the detector with a new inner-balloon of 3.84 m diameter with 800 kg ^{136}Xe and 31.4 m³ liquid scintillator.

We present the current status of KamLAND-Zen, the new mini-balloon construction and methods to avoid background contaminations. In addition, the development of a scintillating balloon for future upgrades in order to remove the radioactive decay chain daughter nuclei bismuth is also introduced.

Keywords: Double beta decay; Majorana neutrino; PolyEthylene Napthalate

1. INTRODUCTION

Neutrinoless double beta decay ($0\nu2\beta$) is a rare event with $10^{25} \sim 10^{26}$ years or longer lifetime, and requires lepton number violation beyond the standard model by the Majorana neutrino mass term. Majorana neutrinos give a simple

Email address: obara@awa.tohoku.ac.jp (S.Obara)

5 answer for the reason why the neutrinos have a much lighter mass than other
6 fermions, through the see-saw mechanism introduced by Yanagida and Gellmann
7 [1][2]. The $0\nu2\beta$ observation would demonstrate the existence of Majorana
8 neutrinos and give some information about neutrino mass scale as $\langle m_{\beta\beta} \rangle \equiv$
9 $|\sum_i U_{ei}^2 m_{\nu_i}|$.

10 The KamLAND-Zen experiment searched for $0\nu2\beta$ with ^{136}Xe ($Q = 2.46$ MeV)
11 as double beta nucleus, shown in Fig.1, and obtained a lower limit on the $0\nu2\beta$
12 half life, $T_{1/2}^{0\nu2\beta} > 2.6 \times 10^{25}$ yr, and an upper limit on neutrino effective mass,
13 $\langle m_{\beta\beta} \rangle < 140 - 280$ meV (90% C.L.) [3]. In the energy region of interest (ROI),
14 the dominant backgrounds are from $^{110\text{m}}\text{Ag}$, the ^{238}U series, the ^{232}Th series,
15 and ^{40}K which contaminate the inner-balloon surface. $^{110\text{m}}\text{Ag}$ is suspected to
16 originate from xenon spallation during air transportation or Fukushima fall out,
17 but its rate is reduced to $\sim 1/10$ in a purification campaign [3]. Since the xenon
18 gas is stored for two years in the mine with low cosmic backgrounds, the $^{110\text{m}}\text{Ag}$
19 contamination will be not serious, but the ^{238}U , ^{232}Th , and ^{40}K contaminations
20 during inner-balloon production remain. Then we planned the next-phase up-
21 grade “KamLAND-Zen 800”, with the installation of a new cleaner and larger
22 inner-balloon and the use of 800 kg ^{136}Xe .

23 In the next phase, the new inner-balloon is designed to have a diameter of
24 3.84 m as shown in Tab.1 for loading twice as much xenon as in the current
25 phase (KamLAND-Zen 400).

26 The requirements of environmental radioactive contamination in the inner-
27 balloon are ^{238}U , $^{232}\text{Th} < \mathcal{O}(10^{-12})$ [g/g], and $^{40}\text{K} < \mathcal{O}(10^{-10})$ [g/g] to limit
28 their decay rate in the ROI. To satisfy these requirements, we need a class-1¹
29 clean production room.

30 In this paper, we report the new inner-balloon production and scheme to
31 make and keep clean production environment. In addition, at the end of this

¹The clean room class is defined by how many order $0.5 \mu\text{m}$ size particles exist in 1 ft^3 .
For example, operation room in a hospital: class-10,000 $\sim$ 100,000; semiconductor factory:
class-10 $\sim$ 100.

Figure 1: The schematic of KamLAND-Zen. Located at 1,000 km underground from the top of Mt. Ikenoyama, Gifu Prefecture in Japan. Nylon-based 3.08 m ϕ inner-balloon is suspended at the center of KamLAND, filled with 383 kg xenon loaded liquid scintillator.

proceeding, one of the future upgrade proposals is introduced.

2. CLEAN ENVIRONMENT TECHNIQUES

The inner-balloon production room has downwards air flow, grated floor, ultra pure water, ultra pure nitrogen gas, a particle counter, and a neutralization apparatus. All tools such as desks, cutting mat, cutter, and others are washed by detergent or ethanol. Handheld digital devices should be fan-less to avoid swirling up dirt or dust, and must be wiped with isopropyl alcohol.

For checking the actual cleanroom condition, we operate a fine particle visualization with SHIN NIPPON AIR TECHNOLOGIES Co., Ltd., using a green laser and monitoring the scattered light. Figure 2 shows significant dust from human body, even if wearing new clean suits. Of course, clean suits becomes dirty after use. Thus we send the clean suits to the laundry after every work shift

Table 1: The comparison of inner-balloon design between current phase and next phase of KamLAND-Zen.

	KamLAND-Zen 400 (current-phase)	KamLAND-Zen 800 (next-phase)
Xenon amount	383 kg	~ 800 kg
Inner-balloon diameter	3.08 m	3.84 m
Design	24 gores	
Material	Custom made clean nylon	
Thickness	25 μm	
Fabrication	heat-welding, full manual product	heat-welding, by manual and custom made machine
Clean room	class 1	class 1, with carefully dust control

44 and wear fresh clean suits every time. Moreover, we wear the clean innerwear
45 because dust might penetrate through the clean suit seam lines.

46 We also found dust on our gloves, but it can be removed by washing hands
47 with pure water. It is difficult to prevent the dust dispersal from the wrist slit,
48 or the face zone during working. Therefore we layer clean items as shown in
49 Fig.3. Clean gloves are worn in two layers for covering the wrist. Goggle and
50 mask are for covering the face. Clean innerwear is worn under the clean suit.

51 In this way we achieve and keep the class-1 clean environment.

52 3. INNER-BALLOON PRODUCTION

53 First, the inner-balloon material nylon is washed in an ultrasonic bath with
54 ultra pure water as shown in Fig.4, and dried with pure nitrogen gas. This
55 results in a cleaner nylon surface as shown in Tab.2.

56 After that, we choose the cleaner part which has no scratches or contamina-
57 tions by optical inspection. The cleaner part is packed double-side with other
58 nylon films which are also washed, in order to prevent any dust contamination
59 during handling, such as cutting or heat-welding.

Figure 2: Fine particle visualized with the scattering light.

60 Next, we cut the nylon into 24 gores while covered by nylon film. The 24
 61 nylon gores are welded by a custom ordered welding machine, and the pole part
 62 is welded by hand as shown in Fig.5. We have already finished to weld the nylon
 63 gores as shown in Fig.6 but there is no leakage test yet, since nylon will easily
 64 tear with low humidity in the winter. Now the inner-balloon is kept packed in
 65 nitrogen gas in the clean room waiting for the leakage check and repair in this
 66 spring. The new inner-balloon installation is scheduled for this summer, and we
 67 will start the next step of $0\nu 2\beta$ search experiment as “KamLAND-Zen 800”.

68 4. SUMMARY

69 We are very nervous about dust contamination from humans, thus we have
 70 made our clean room class-1 and established a particular work scheme for the
 71 clean room. We smoothly fabricated the new larger and cleaner inner-balloon

Figure 3: Our clothing in clean room.

Table 2: The comparison of nylon radioactive impurities between before and after the washed. ^{238}U and ^{232}Th are measured by ICP-MS, K is by the Frame photometry and ^{40}K is estimated natural abundance ; 0.0117%.

	^{238}U [g/g]	^{232}Th [g/g]	^{40}K [g/g]
before washed	4×10^{-12}	7×10^{-12}	$< 1 \times 10^{-11}$
after washed	2×10^{-12}	6×10^{-12}	$< 1 \times 10^{-11}$

for the KamLAND-Zen next phase, which is waiting now for installation.

5. SCINTILLATING BALLOON

In this section, I introduce the “scintillating balloon” proposal, which is planed after the “KamLAND-Zen 800” phase, in order to remove the most dominant radioactive background from ^{214}Bi which is a daughter nuclei of ^{238}U .

^{214}Bi -Po consecutive events in the KamLAND liquid scintillator,

can be tagged with 99.97%, with the inefficiency coming from event pile-up.

On the other hand, at or near the balloon surface, the tagging efficiency is

Figure 4: Washing nylon film with ultrasonic bath.

79 reduced to about 50% since the delayed signal ^{214}Po alpha-ray has a short
 80 mean free path and stops in the inner-balloon material without scintillation-
 81 light emission as shown in Fig.7. I propose the use of a scintillator as the inner-
 82 balloon material (scintillating balloon) for effective observation of all delayed
 83 signals from ^{214}Po . The requirements for the scintillating balloon material are
 84 (i) scintillation ability over the KamLAND detector threshold (about 300 keV),
 85 (ii) establishment of the balloon fabrication procedure (easy processable organic
 86 plastic material), and (iii) chemical compatibility. Actually, chemical resistance
 87 is the most critical and important requirement. We already know some large
 88 light intensity scintillators, but most commercial plastic scintillators dissolve in
 89 a liquid scintillator, particularly, pseudocumene (C_9H_{12}) is a strong solvent.

90 PolyEthylene-Napthalate has scintillation ability [4], can be produced in
 91 films and has strong chemical resistance. The feasibility study shows it is a
 92 good candidate for the scintillating balloon material, and has about 99.7% of
 93 ^{214}Bi removing efficiency.

Figure 5: Heat welding of nylon.

Figure 6: Finished inner-balloon production.

Figure 7: ^{214}Bi - ^{214}Po events on the inner-balloon surface without delayed signal observation. A beta-ray from ^{214}Bi goes through the inner-balloon film and emits scintillation light in liquid scintillator, but an alpha-ray from ^{214}Po stops in the film. We cannot identify the beta-ray as a background signal.

94 Currently, the fiducial volume (FV) of KamLAND-Zen is restricted by the
 95 ^{214}Bi event rate near the inner-balloon surface, and it amounts to about 25%
 96 with 1 m FV-selected [3]. However, if 99.7% of ^{214}Bi backgrounds can be sup-
 97 pressed, the full volume can be used and the exposure will be dramatically
 98 increased in proportion to the FV increase, without additional xenon.

99 In the future KamLAND-Zen with a scintillating balloon if it will be in-
 100 stalled, $0\nu 2\beta$ effective mass sensitivity reaches $\langle m_{\beta\beta} \rangle = 50$ meV (QRPA [5])
 101 with 800 kg ^{136}Xe and 2.5 years operation, owing to the decrease of the domi-
 102 nant background and the increase of exposure with full FV.

103 The important points in this study are a thin film-shaped scintillator and
 104 the chemical compatibility. The former means ease of use, the latter allows

105 use with the liquid scintillator. For low background liquid scintillator type
 106 detectors, radioactive contamination in the detector or its container introduces
 107 serious backgrounds. We cannot suppress many backgrounds at the edge of
 108 detector without FV cut. However if a detector container will be a detector,
 109 such as a scintillating balloon, we will be free from detector edge backgrounds
 110 and FV requirements.

111 6. ACKNOWLEDGEMENT

112 The KamLAND-Zen experiment is supported by the Grant-in-Aid for Spe-
 113 cially Promoted Research under grant 21000001 of the Japanese Ministry of
 114 Education, Culture, Sports, Science and Technology; the World Premier Inter-
 115 national Research Center Initiative (WPI Initiative), MEXT, Japan; Stichting
 116 FOM in the Netherlands; and under the US Department of Energy, Office of
 117 Science, Office of Nuclear Physics under contract No. DE-AC02-05CH11231, as
 118 well as other DOE awards to individual institutions. The Kamioka Mining and
 119 Smelting Company has provided service for activities in the mine. Nishizawa
 120 Junichi Memorial Research Center has provided the super clean room.

121 The scintillating balloon study is supported by Grant-in-Aid for Japan Soci-
 122 ety for the Promotion of Science Fellows Grant Number 15J02193, and TEIJIN
 123 Co., Ltd. which provides poly ethylene naphtalate film samples.

124 I would like to thank the organizers of VCI 2016 for the very interesting
 125 conference and the allowance to merging two topics.

126 [1] T.Yanagida, in: Proceedings of the workshop on Unified Theory and Baryon
 127 Number of the Universe, eds. O.Sawada and A.Sugamoto (KEK), 1979, p.
 128 95.

129 [2] P. M.Gell-Mann, R.Slansky, in Supergravity, eds. P.van Nieuwen-huizen and
 130 D.Freedman (North holland, Amsterdam).

131 [3] K. Asakura, A. Gando, Y. Gando, T. Hachiya, S. Hayashida, H. Ikeda, K.
 132 Inoue, K. Ishidoshiro, T. Ishikawa, S. Ishio, M. Koga, R. Matsuda, S. Mat-

- 133 suda, T. Mitsui, D. Motoki, K. Nakamura, S. Obara, Y. Oki, M. Otani,
134 T. Oura, I. Shimizu, Y. Shirahata, J. Shirai, A. Suzuki, H. Tachibana, K.
135 Tamae, K. Ueshima, H. Watanabe, B. D. Xu, Y. Yamauchi, H. Yoshida, A.
136 Kozlov, Y. Takemoto, S. Yoshida, K. Fushimi, T. I. Banks, S. J. Freedman,
137 B. K. Fujikawa, T. O'Donnell, L. A. Winslow, B. E. Berger, Y. Efremenko, H.
138 J. Karwowski, D. M. Markoff, W. Tornow, J. A. Detwiler, S. Enomoto, M.
139 P. Decowski, Results from KamLAND-Zen, in: XXVI INTERNATIONAL
140 CONFERENCE ON NEUTRINO PHYSICS AND ASTROPHYSICS: Neu-
141 trino 2014, Vol. 1666, AIP Publishing, 2015, p. 170003.
- 142 [4] H. Nakamura, Y. Shirakawa, S. Takahashi, H. Shimizu, Evidence of deep-
143 blue photon emission at high efficiency by common plastic, EPL (Euro-
144 physics Letters) 95 (2) (2011) 22001.
- 145 [5] V. Rodin, A. Faessler, F. Aïme, P. Vogel, Assessment of uncertainties
146 in $q\bar{q}$ -decay nuclear matrix elements, Nuclear Physics A 766 (2006) 107 -
147 131.