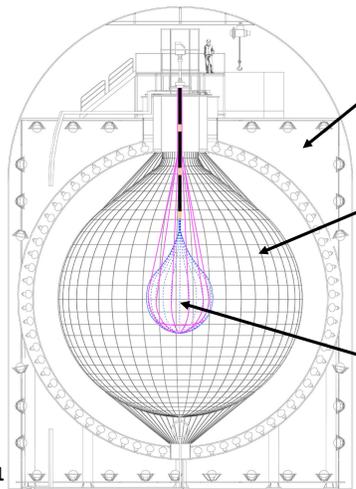


KamLAND-Zen experiment ^[1]

Neutrino-less double-beta decay ($0\nu 2\beta$) search with ^{136}Xe



- Outer detector**
 - Water cerenkov detector for muon veto
 - 20" PMT × 140
- Inner detector**
 - 1000 ton of ultra pure liquid scintillator (LS) in $\Phi 13\text{m}$ outer-balloon
 - 17" PMT × 1325 + 20" PMT × 554
- Mini-balloon (inner balloon: IB)**
 - ^{136}Xe loaded LS in $\Phi 3.84\text{m}$ balloon
 - Made of Nylon film (25 μm thickness)

Fig. 1

Motivation of Scintillation Balloon

- ^{214}Bi , daughter nuclei of ^{238}U series:
 - will be one of the largest backgrounds.
 - can be rejected by delayed coincidence tagging with ^{214}Po .

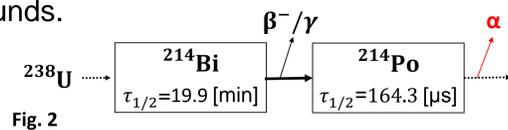


Fig. 2

- The tagging efficiency in a KamLAND-LS is 99.97%.
- But the efficiency decrease to 52.5% near the IB due to the α -ray absorption in nylon film, IB material.
- This limits the IB fiducial volume to almost half.

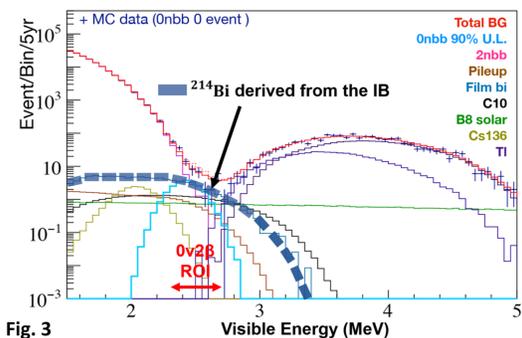


Fig. 3

- MC simulation of KamLAND-Zen 800 background
- ^{214}Bi derived from the IB makes a spectrum on $0\nu 2\beta$ ROI

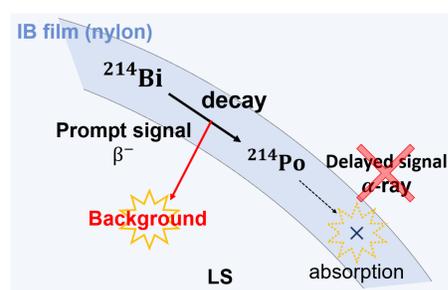


Fig. 4

Since nylon film is not a scintillator, the α -ray can not be detected if the IB made of scintillator...?

The α -ray CAN BE detected and ^{214}Bi tagging efficiency will be improved to 99.97%
 ⇒ We get an ultra-low background IB !

- IB fiducial volume will increase to almost 100%.
- Almost all ^{136}Xe will be effectively used.

PolyEthylene Naphthalate (PEN)

- Candidate of scintillation balloon materials
- Blue photon emission
- High chemical resistance, flexibility, and transparency

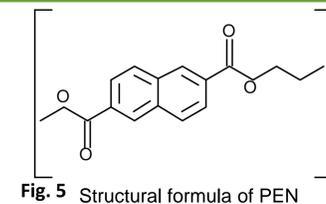


Fig. 5 Structural formula of PEN



Fig. 6 Light emission of PEN with black light

Evaluation and Feasibility of Scintillation Balloon

Radioactive Impurities in PEN film ^[2]

	^{238}U [g/g]	^{232}Th [g/g]	^{40}K [g/g]
Requirement	$\mathcal{O}(10^{-12})$	$\mathcal{O}(10^{-12})$	$\mathcal{O}(10^{-11})$
PEN film	3.6×10^{-11}	$< 5.0 \times 10^{-12}$	$< 2.3 \times 10^{-14}$
	NO?	OK	OK

- Requirement values is for nylon-IB.
- ^{238}U , ^{232}Th are measured by ICP-MS, ^{40}K is measured by frame-spectrophotometry.

- Although ^{238}U value is higher than the requirement, PEN-IB can suppress it by delayed coincidence tagging.
- Since the contamination level reaches the detection limits, we are planning to develop the measurement method.

Fabrication ^[2]

- IB material film is required to have a strength of 40 MPa.
- Measurement with force gauge, strength of on film and on welded line are satisfied with the requirement.

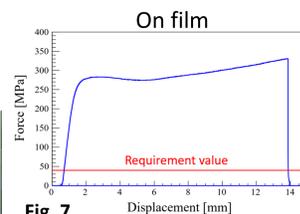


Fig. 7

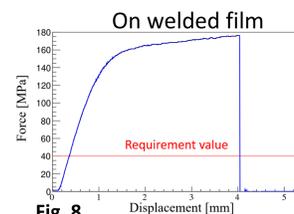


Fig. 8



Fig. 9

We establish methods to make a balloon with PEN.

- Test-size PEN-balloon is made by heat-welding with these parameters:
 - max temperature : 237 [degC]
 - heating time : 3.5 [sec]
 - Cooling temperature : 80 [degC]

Scintillation Property

Light Yield ^[2]

- In order to detect ^{214}Po α -ray, light yield of PEN for α -ray should be larger than KamLAND threshold $\sim 300\text{keV}_{\text{vis}}$.
- The energy spectrum of ^{214}Po event has a peak of $442.9 \pm 0.7 \text{ keV}_{\text{vis}}$.

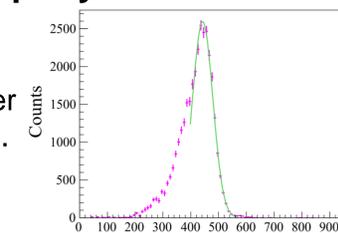


Fig. 10 Visible Energy [keV]

Ongoing Study

Potential for a Pulse Shape Discrimination (PSD)

- Since the scintillation balloon can detect a α -ray, ^{212}Bi - ^{212}Po pile-up become a new background.
- ^{212}Po has a too-short half-life for KamLAND event time window.
- There is a possibility that ^{212}Bi - ^{212}Po pile-up can be rejected by pulse shape discrimination.

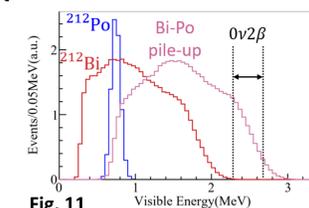


Fig. 11

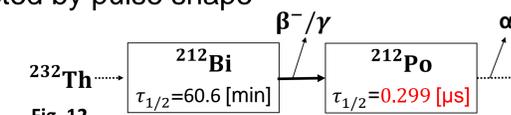


Fig. 12

- In a vial size measurement, there is an obvious difference in pulse shape between PEN and KamLAND-LS.

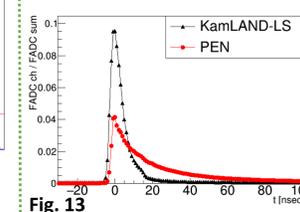


Fig. 13

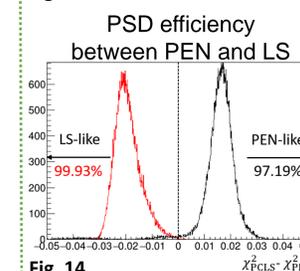


Fig. 14

- PSD between PEN and LS is possible in high efficiency in vial.
- In order to reject ^{212}Bi - ^{212}Po in KamLAND, PSD method between LS and LS-PEN pile-up is under developing.

Summary

- Scintillation balloon can reduce ^{214}Bi background in KamLAND-Zen experiment.
- PolyEthylene Naphthalate is candidate of scintillation balloon material.
- Feasibility study of scintillation balloon is ongoing.
- PSD method is under developing toward ^{212}Bi - ^{212}Po background rejection.

Reference

- [1] A. Gando *et al.* (KamLAND-Zen Collaboration), Phys. Rev. Lett. **117**, 082503
- [2] S Obara, Y Gando, K Ishidoshiro, PTEP 2019, 7, 073H01 (2019)