

Balloons for a Future Detector

Physics Opportunities of Large Liquid Scintillator Detectors (II)

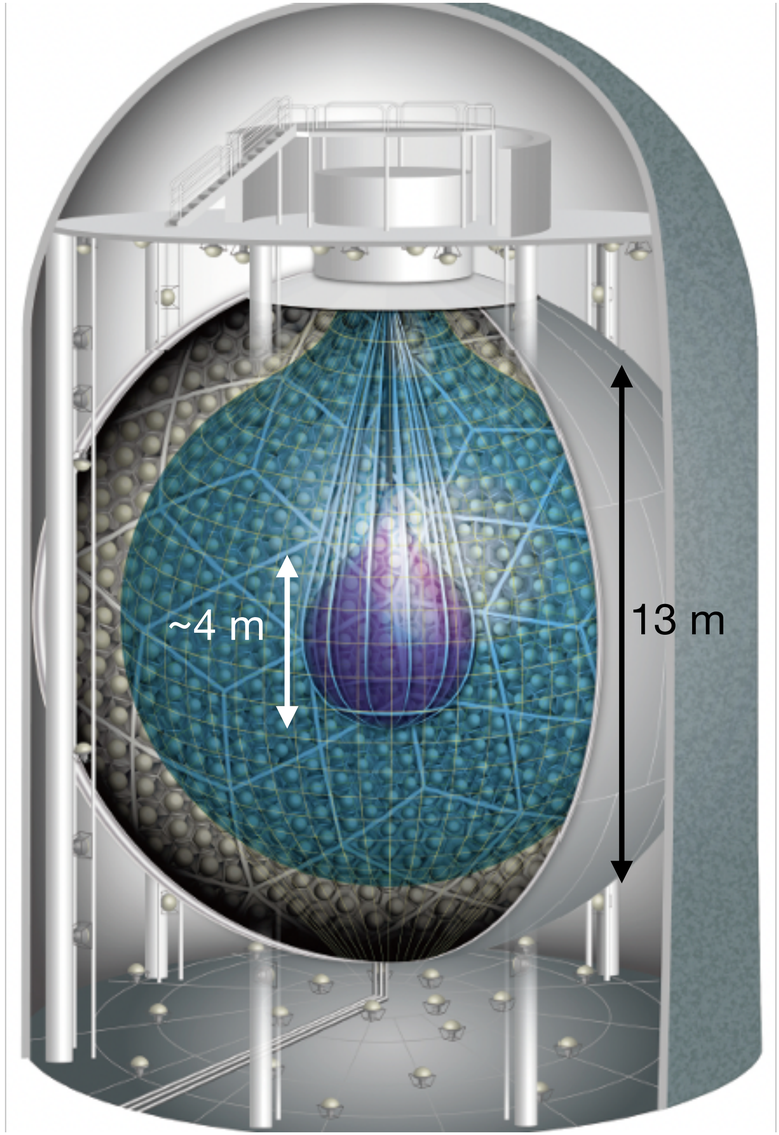
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Helmholtz Institute Mainz, Oct 13 – 15, 2026

BOSTON UNIVERSITY

KamLAND2-Zen

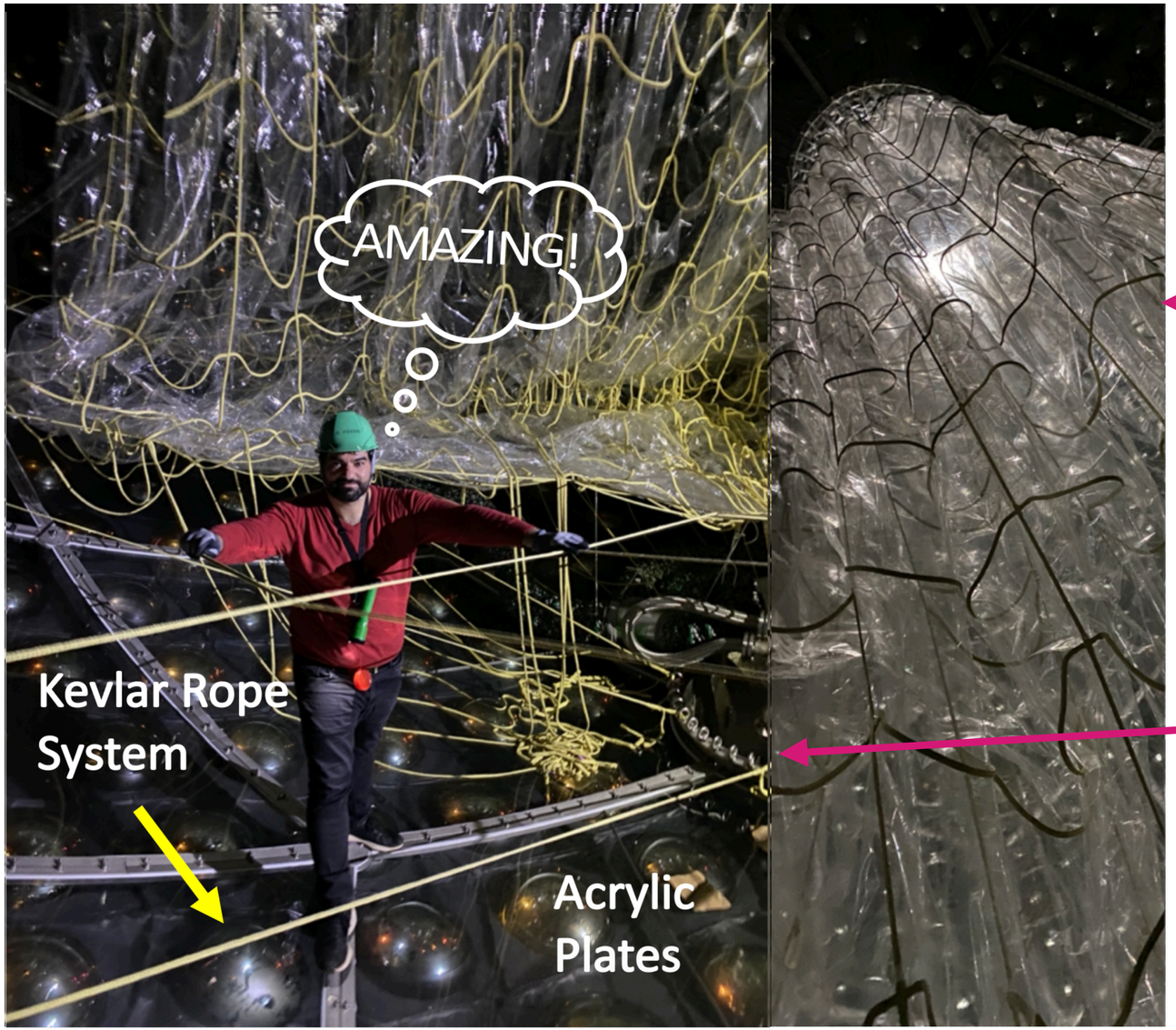
Contain the target, preserve the physics!

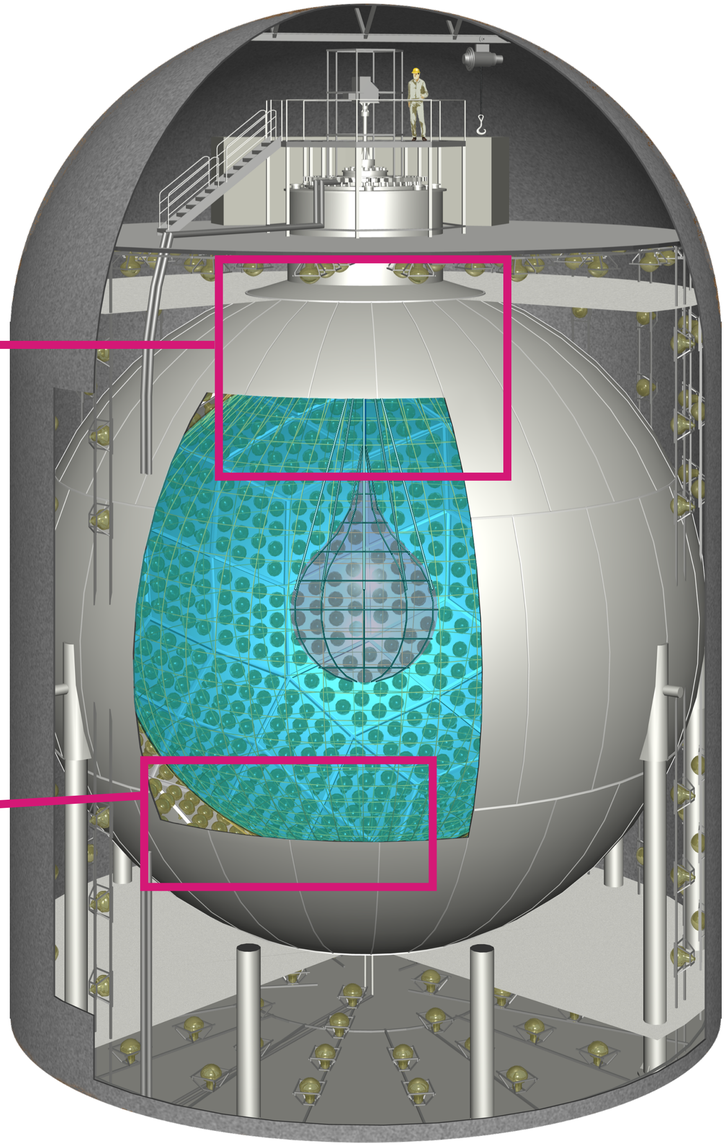


Goals

- **Keep the target clean:** minimize radioactive impurities in the film, seams and supports, and contamination introduced during construction.
- **Let scintillation light through:** maintain high transmission across the detector's useful wavelength range.
- **Contain the liquid reliably:** control leakage and permeation, and maintain compatibility with the scintillator over years.
- **Survive construction and operation:** withstand handling, filling, density differences and pressure changes with reliable seams and distributed support.

Out with the Old, In with the New

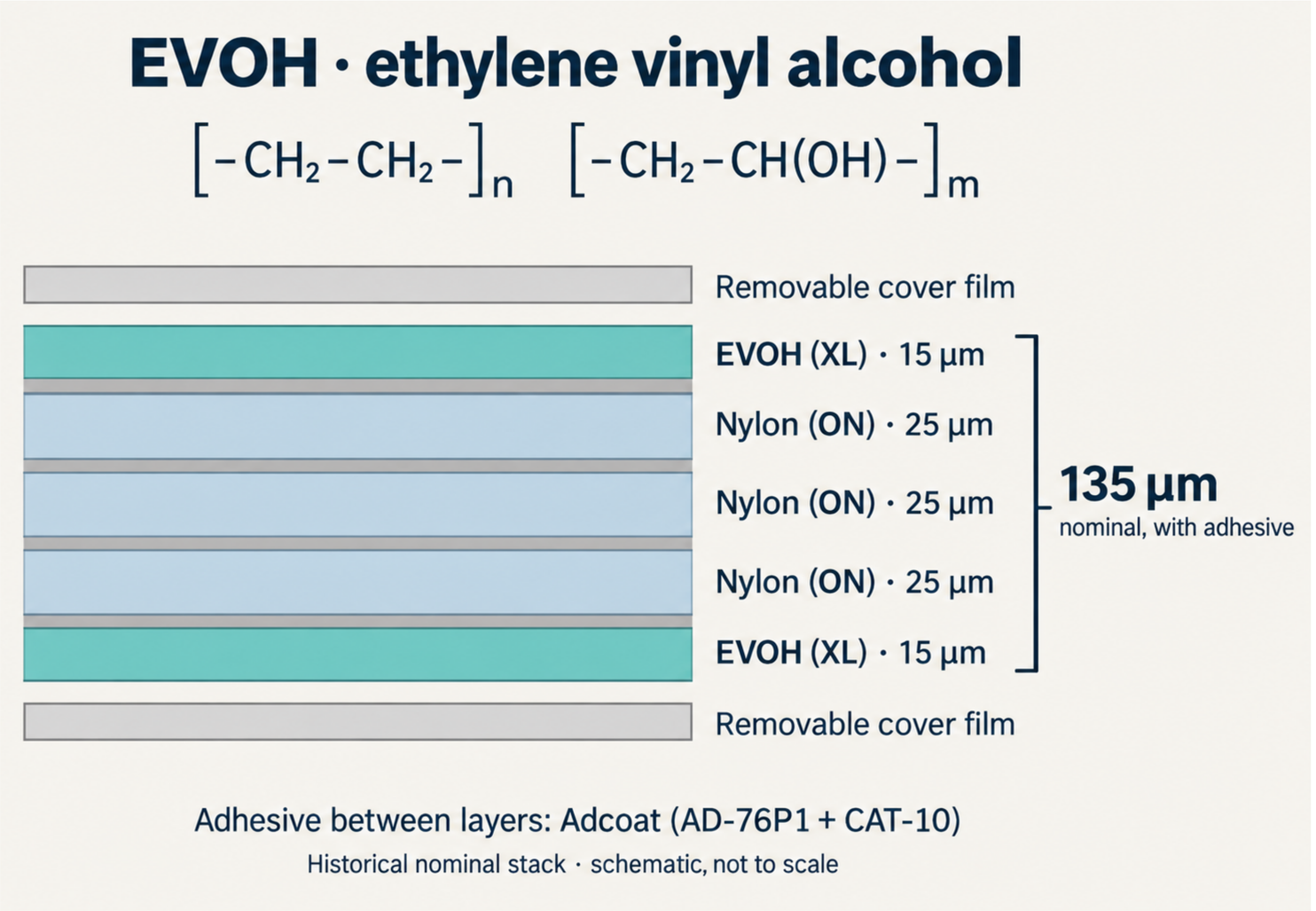






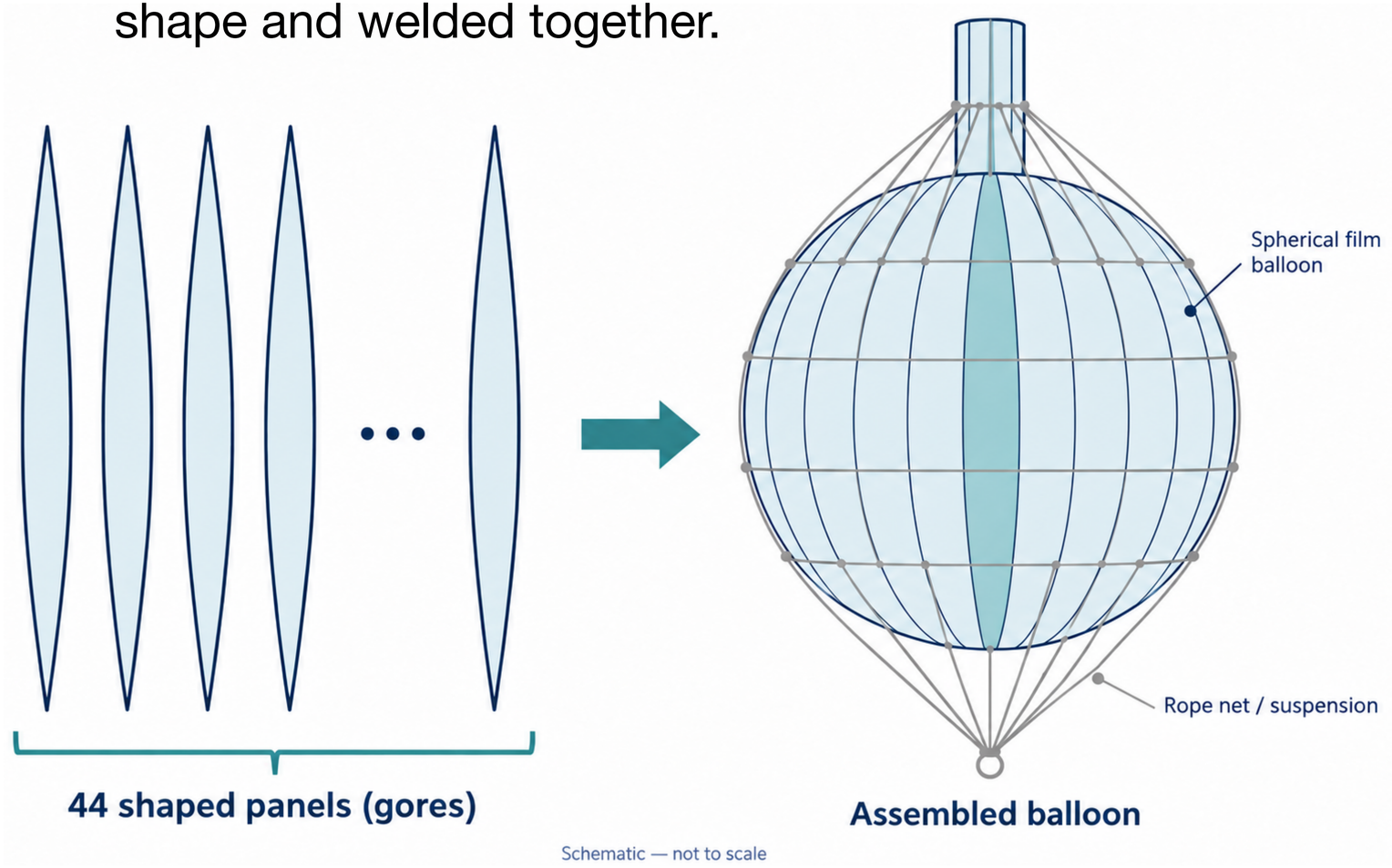
Large Balloon Materials

- Three Nylon layers provide strength needed to carry the mechanical load
- Two EVOH layers limit Radon permeation into the inner volume and are weldable using Radio-Frequency
- Adhesive application on 5 layers requires some ‘finesse’ to end up optically clear
- Important: need to glue the layers together before final quality testing



Forming the Balloon

Tapered panels (gores) are cut to shape and welded together.



Two gores joined together for testing at the factory in Japan.



Mirai Techno Co., Ltd., Isawa Factory (未来テクノ・胆沢工場)

Welding the Balloon

RF Welding: *a manufacturing process that fuses polar thermoplastic materials together using high-frequency EM waves rather than external heat sources.*

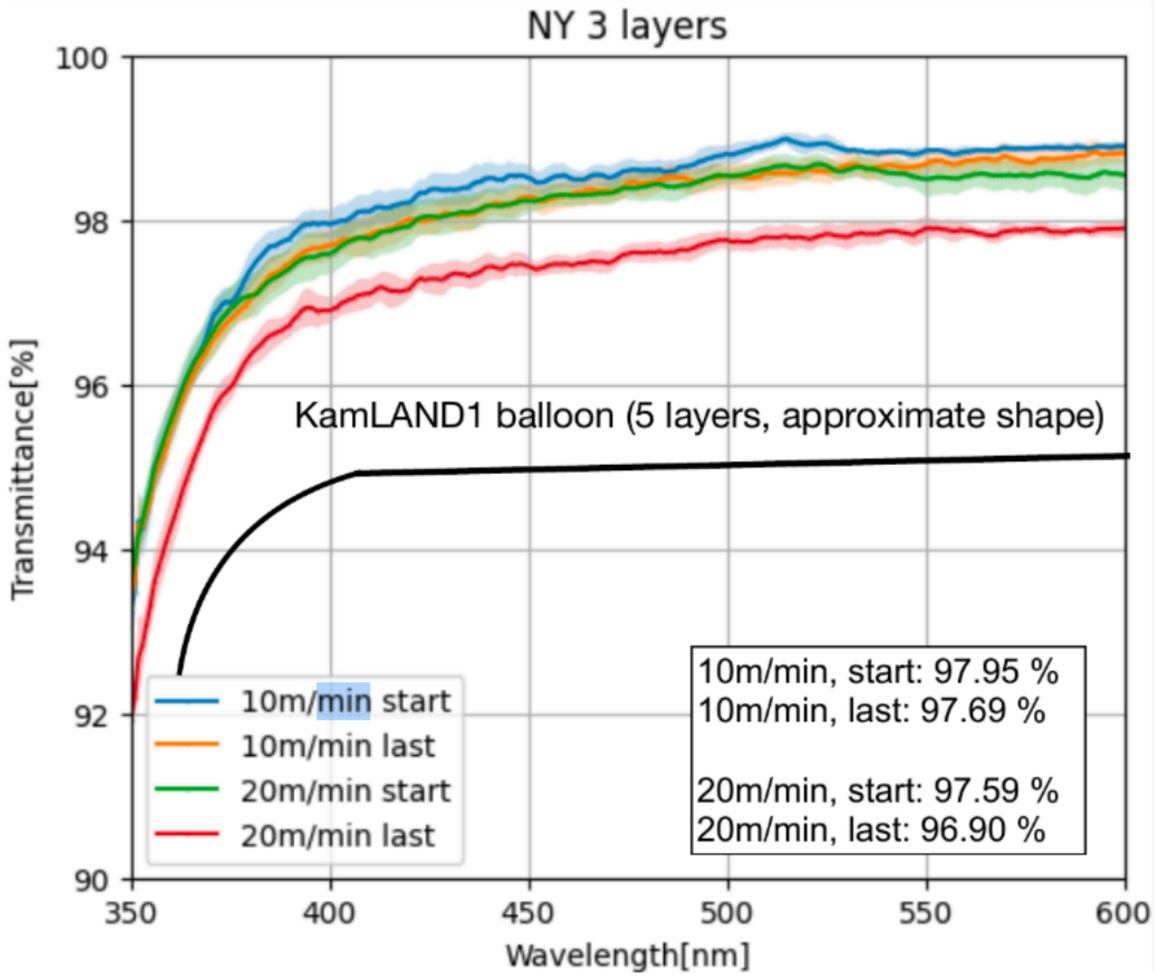
- **RF heats the EVOH.** Allows it to weld together with neighboring panel.
- **Transparent seams make defects visible.** Can inspect melting, bubbles and uneven joining. Mechanical and leak tests provide additional checks.



June 2026 rehearsal of the welding process at the industrial factory using the old KamLAND balloon.

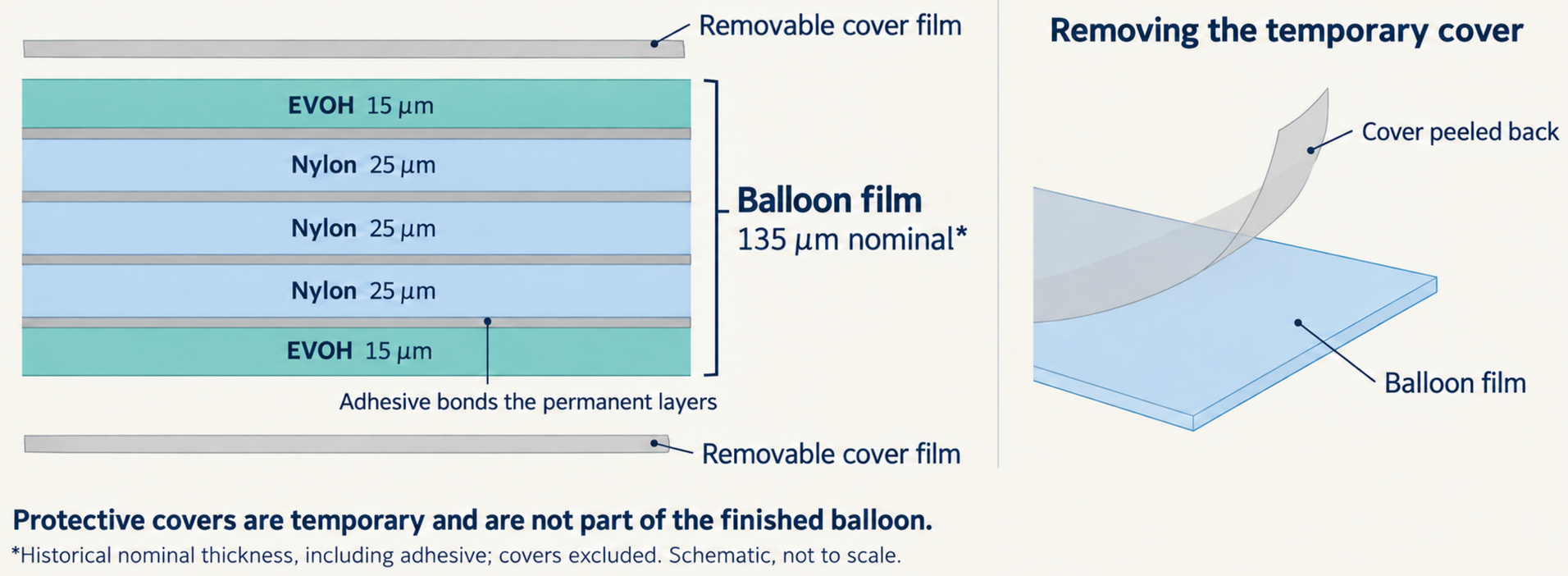
Improving Transparency

- First, the lamination process was improved during testing. Thinner adhesive and revised curing reduced optical losses.
- We also noticed the newly supplied nylon (from same manufacturer as old KamLAND balloon) had worse transparency than original KamLAND nylon.
- Within the last couple of weeks we found a new manufacturer, Toyobo.
- Toyobo three-layer nylon showed approximately 97% transmission. Full five-layer film still needs to be tested.



Transmittance of 3-layer nylon in buffer oil

Protecting the Balloon Film



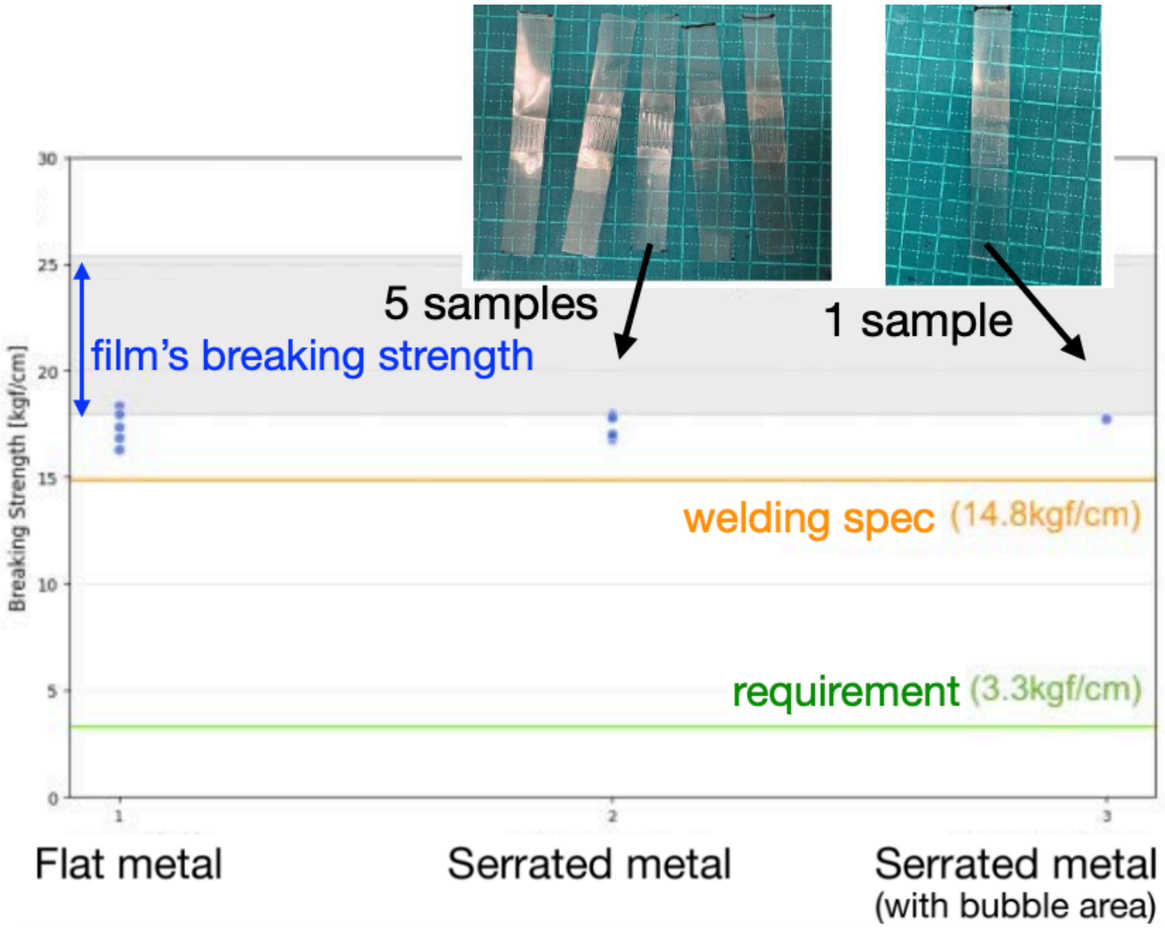
- Covers protect the surfaces from dust and scratches during cutting and handling, and provide a surface for marking.
- During welding, the joining surfaces need to be exposed while the remaining film stays protected.
- Static electricity attracts dust, so we control humidity (> 65%) and ionizers alongside the covers.

Strength Testing the Film

- Pull on the film on either side of the weld and measure the load it can carry before breaking (**tensile test**). See if joint can withstand forces pulling the neighboring panels apart.

- Deliberately pull the two overlapping sheets away from each other (**peel test**). This reveals how uniformly they have joined across the weld.

- These tests helped develop the fabrication process. They still need to be repeated for the final production film and its welding conditions.



(different welding tool surfaces were tested)

Rehearsing the Closing of the Balloon

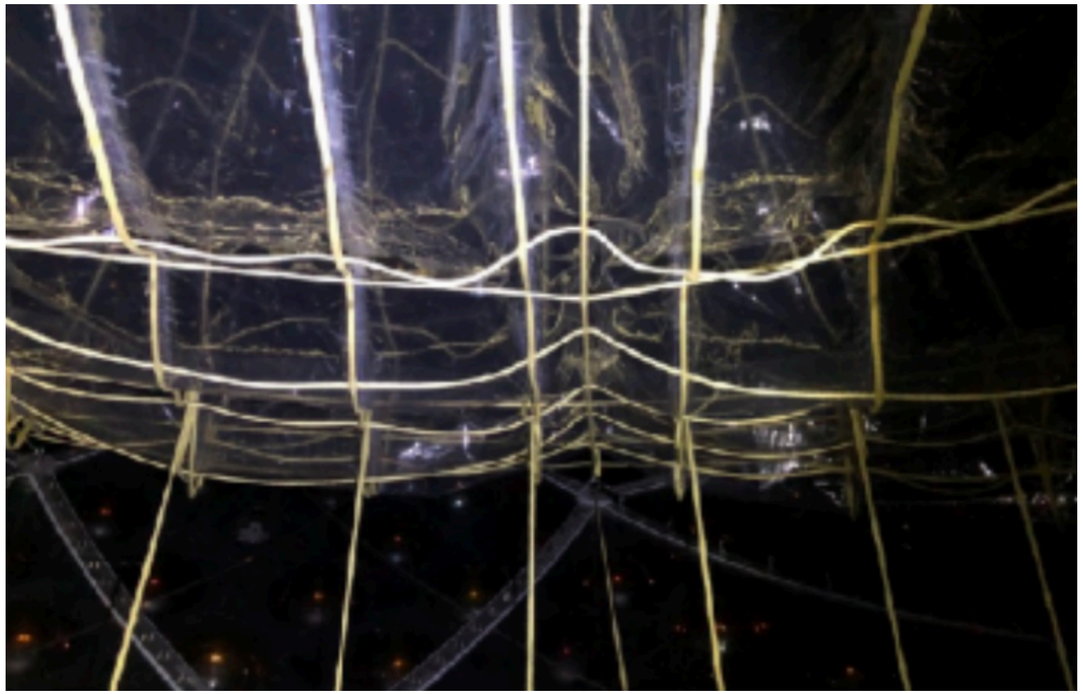


- As the last long seam closes, access to the joint and welding equipment becomes restricted. We rehearsed operation at full scale, using new film sections attached to the old KamLAND balloon.

- June 2026 rehearsal tested whether the material could be aligned and handled in practice. Also examined when to install the bottom flange.

Rope-Net System

- Rope support system must be strong and radio pure.
- Kevlar 29 had the lowest measured potassium among tested fibers.
- Recovered ropes from original KamLAND net system gave us an ‘aging allowance' and allowed for a lower-mass design:
  - **KamLAND1:** rope rated at **9,000 lbf** breaking strength (about 40 kN)
  - **KamLAND2:** selected **4,000 lbf**-class rope (nominally 17.8 kN)



- **Cleaning can weaken it.** Tests showed strength loss with ultrasonic cleaning, so that step was dropped.

Folding and Packaging Rehearsal





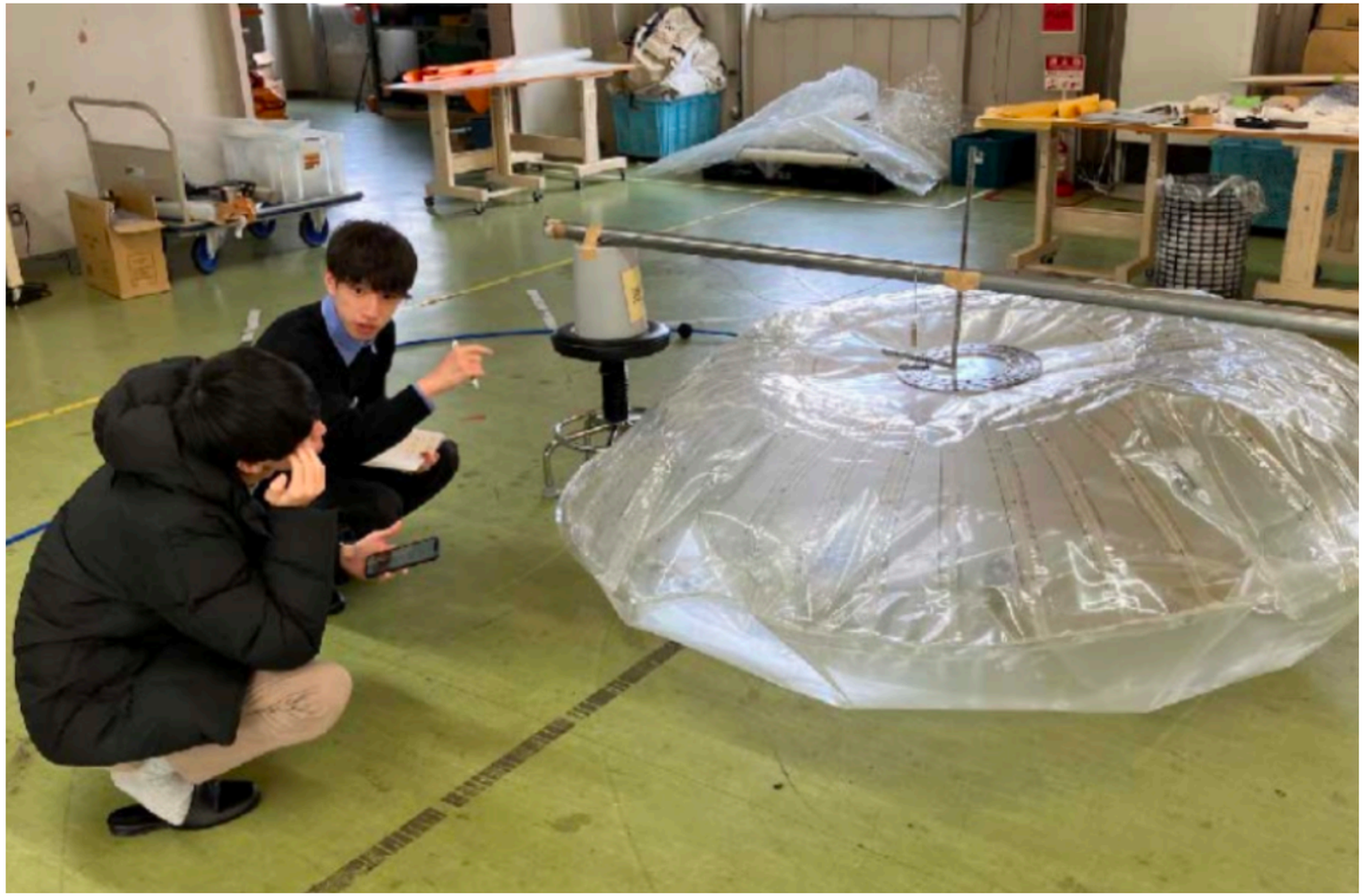


Practiced folding, rolling, and packaging with the old KamLAND balloon

Testing Complicated Parts

- Bottom of balloon is one such region, particularly where the film joins metal flange.

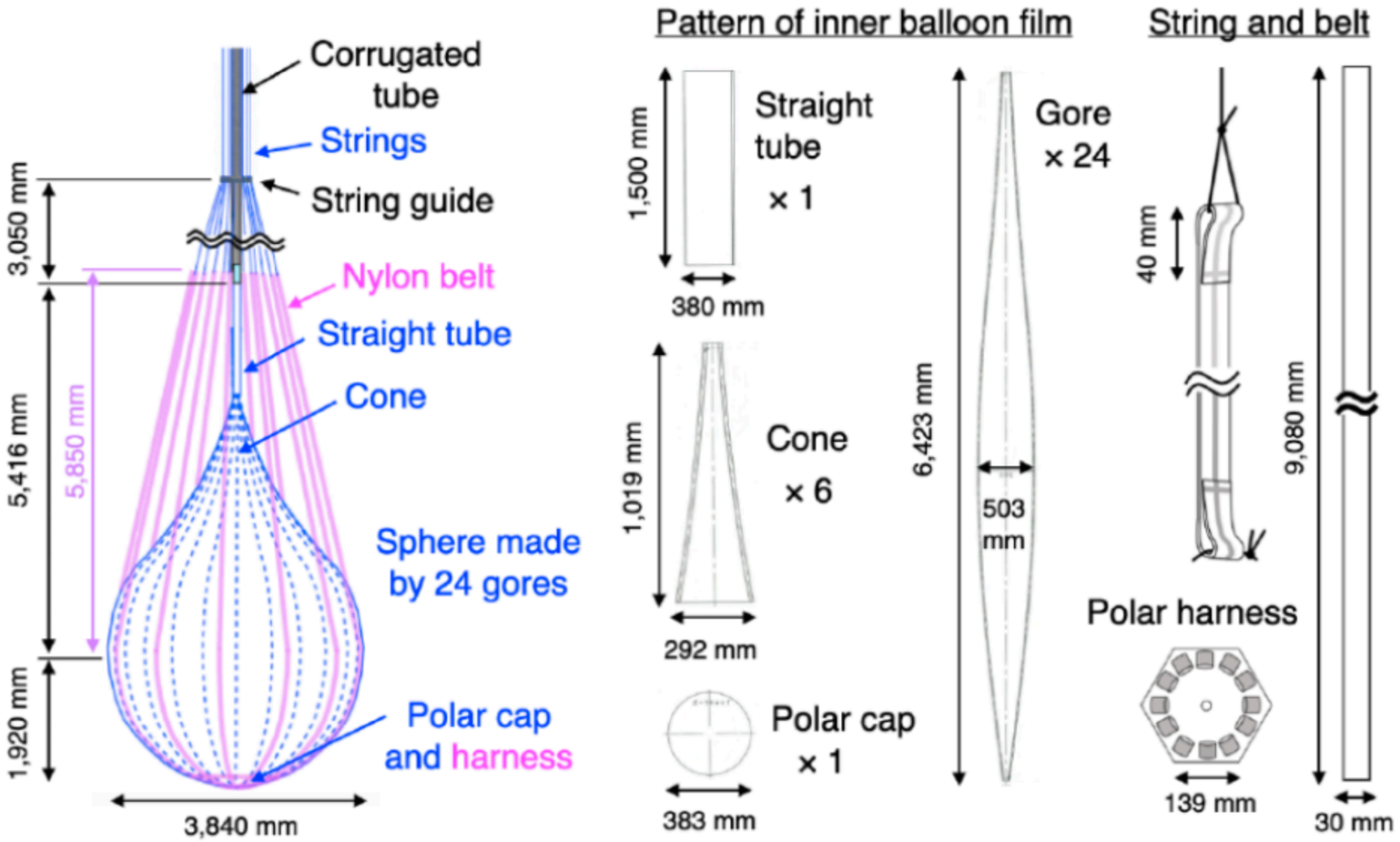
- Built representative bottom-section prototypes, with and without that fitting, and tested their leakage. Leakage estimates are well below the allowable level.



Current Standing of Big Balloon

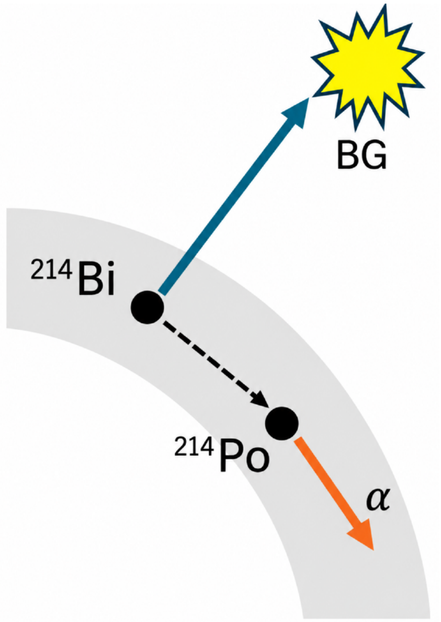
- Methods for welding, rope and bottom-section tests, and handling rehearsals were demonstrated.
- Now testing final material mesh (Toyobo nylon with high transparency + EVOH)
- Production capability established with skilled fabrication, equipment and a clean facility at Mirai Techno Co. Ltd.
- Total cost ~$1.9M and about one year start to finish for final product (coming in June 2027)

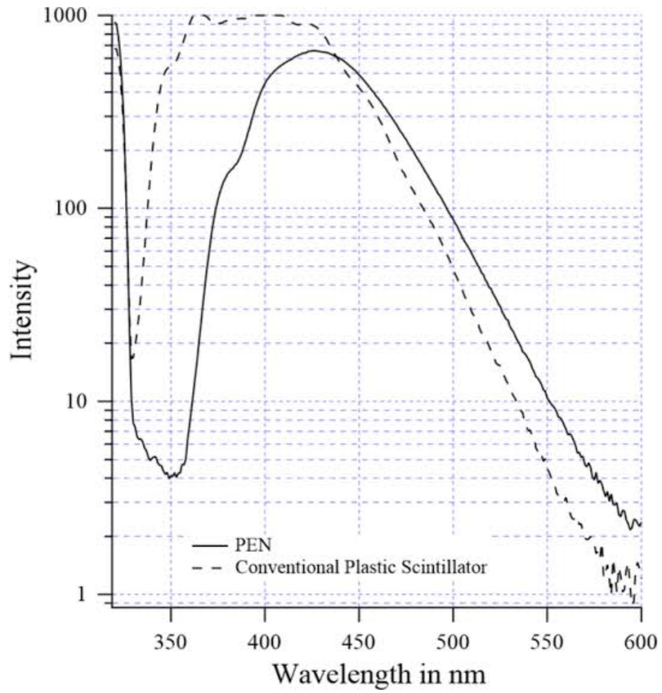
KamLAND-Zen Mini-Balloon



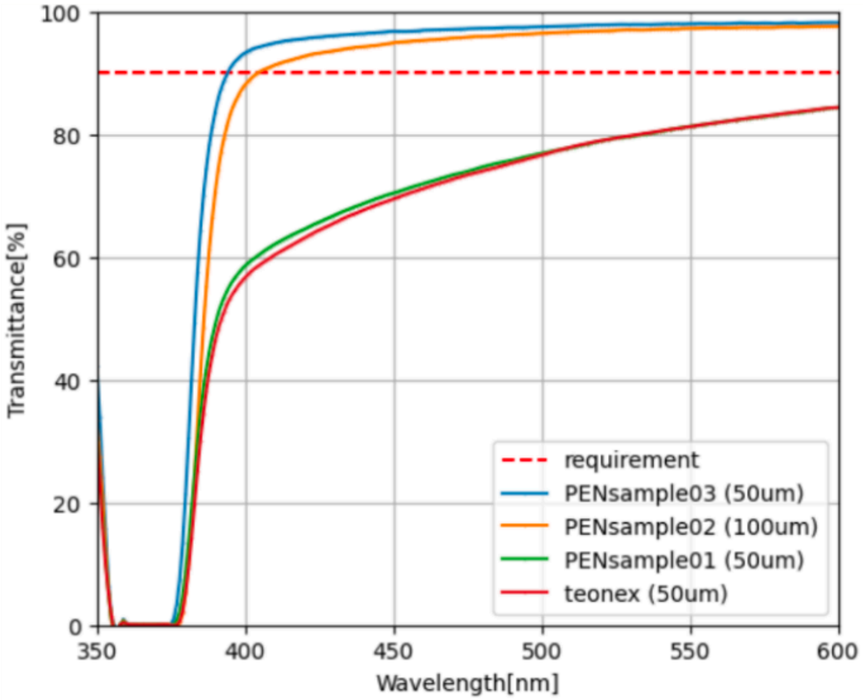
- Original mini-balloon, holding the xenon-loaded LS, was 25 μm thick
- Heat welded and manufactured inside a Class 1 cleanroom facility

KamLAND2-Zen Mini-Balloon





Polyethylene Naphthalate (PEN)



Found sample with sufficient transparency just one week ago

- ^{214}BiPo background rejection with coincidence tagging

- α particles decaying in non-scintillating material are invisible and escape detection - make the balloon scintillate!

Conclusions and Discussion

- KamLAND2-Zen will have finish construction of large balloon in June 2027, followed by mini-balloon (PEN) in early 2028.

- Techniques, materials, and lessons learned will be documented and will be transferrable should a future detector desire a large-scale, ultra-low-background balloon vessel.

- Ideally, one would use PEN to make a large balloon for 0νββ decay in Theia to sufficiently reduce ^{214}BiPo decays in balloon film.

