Construction Record of Liquid Argon Tank (Prismatic Membrane Tank)

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IHI was awarded a contract to perform EP+SV works from Fermi National Accelerator Laboratory (Fermilab) in USA for a prismatic liquid argon storage tank (–189°C), which is to be used as prototype for the LBNE Project. Fermilab decided this contract due to IHI's membrane cryostat technologies from its EPC (Engineering, Procurement and Construction) experience in in-ground LNG storage tanks. The structure for the prismatic liquid argon storage tanks, however, differs to that of in-ground membrane LNG storage tanks due to the shape of the argon storage tank being prismatic and the difference in the secondary barrier system used to maintain ambient temperature of the outer concrete tank in case of leakage from the membrane inner tank.

1. Introduction

The Long-Baseline Neutrino Facility (LBNF) envisions using a membrane tank technology for a large liquid argon detector (four tanks of not more than 14 000 m^3 of volume each) to measure the properties of neutrinos and other high energy physics phenomena. LBNF is an international project recently created expanding upon the former Long-Baseline Neutrino Experiment (LBNE) with the addition of significant national and international participation.

Under the former LBNE project, IHI was awarded a contract from Fermi National Accelerator Laboratory (Fermilab, **Fig. 1**), operated by Fermi Research Alliance, LLC under Contract with the United States Department of Energy, to perform EP+SV work for a liquid argon tank to be used as prototype for the LBNE Project, the LBNE 35 ton prototype.

The goals of this project are:

(1) to demonstrate the membrane cryostat technology in terms of thermal performance, feasibility for liquid argon, leak tightness.

(2) to demonstrate that it is possible to achieve and maintain the purity requirements in a membrane cryostat without evacuation; for LBNE the requirements are less than 200 parts per trillion (200×10^{-12}) oxygen equivalent contamination.

(3) to test Time Projection Chambers (TPCs) inside the tank by drifting electrons in high purity liquid argon.

(Note) ★ : Construction site in Batavia IL

Fig. 1 Construction site

The temperature of liquid argon is –189°C (Centigrade). On the basis of the well-developed LNG (–162°C) in-ground membrane tank technology, we developed a new shape for the liquid argon membrane cryostat for the LBNE project: the prism.

In the following sections we introduce the prismatic membrane argon tank.

2. Specification of liquid argon tank

Type of tank	Prismatic membrane tank
Contents	Liquid argon
Capacity	28 m^3
Dimensions	Width 2.7 m, Height 2.7 m, Length 4.0 m
Design temperature	–189°C (Centigrade)
Design pressure	20.7 kPaG
Density of liquid argon	1 393 kg/m^3
Main materials	
Membrane	SS304, Thickness 2 mm
Insulation	Polyurethane foam (PUF) Thickness 200 mm × 2 layers
Secondary barrier	Two layered barrier in the insulation
Vapor barrier	Carbon steel, Thickness 1.2 mm

Figure 2 shows the configuration of liquid argon tank.

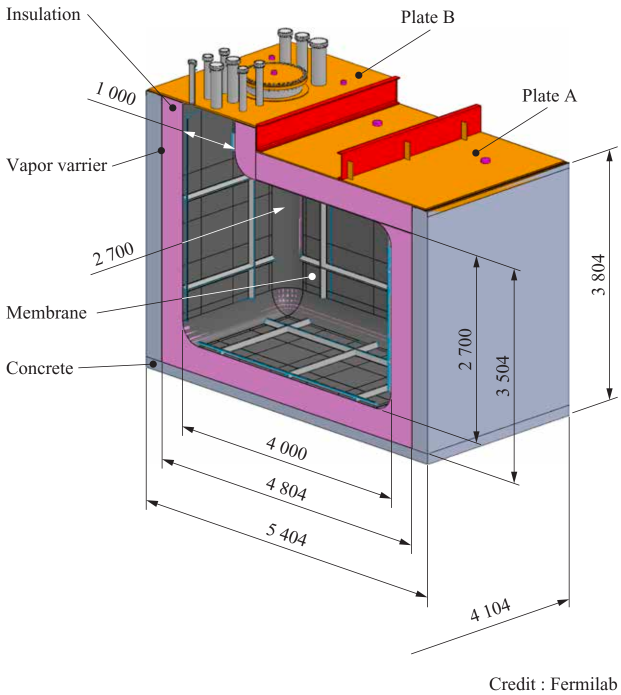


Fig. 2 Liquid argon tank configuration (unit:mm)

3. Characteristics of liquid argon tank

3.1 Membrane

The primary barrier of the liquid argon tank is a SS304 membrane. It contains the liquid argon and it is required to be leak tight. IHI has experience with in-ground membrane tanks of cylindrical shape for LNG storage, while this liquid argon tank requires prismatic shape. The membrane pieces of the corner of a prismatic shape tank are made from a 1/8 cut of spherical material.

A membrane anchor in the center fixes the corner element and is the center of thermal shrinkage (**Fig. 3**). The membrane anchor is fixed to the outer concrete through the PUF insulation.

The roof is made from two parts, one is Plate A and the other one is Plate B as shown in **Fig. 2**. There is a step between Plate A and Plate B, therefore a membrane element of a new shape was necessary to connect Plate A and Plate B. We made this new membrane element of a new shape and it was composed of elbow of piping and rolled plate butt welded together. The butt welds of this part were examined by radiographic test and penetration test (**Fig. 4**).

3.2 PUF insulation with secondary barrier

There are two layers of PUF insulation panels, each one 200 mm thick. Upper and lower panels are arranged in such a way that their joints do not overlap (**Figs. 5** and **6**). In order to prevent a potential spill of liquid argon from the inner membrane to reach the concrete structure (which cannot handle the liquid argon temperature), a secondary barrier system is inserted in the insulation region. This system is composed of two layers: one over the first layer of insulation (between the two layers of insulation), and one over the second layer of insulation (between the insulation and the membrane). See **Figs. 5** and **6**. The joints between two adjacent PUF panels were filled with liquid PUF to leave no empty space between the panels. Furthermore, glass cloths were epoxied over the surface of the joints to form a continuous secondary barrier system and contain potential spills of liquid argon from the primary barrier. Typical execution work is shown in **Fig. 6**. The secondary barrier system was inspected by vacuum box testing (**Fig. 7**).

This secondary barrier system is usually applied to the IHI above-ground PC membrane tank without the dike specified in EN14620.

3.3 Vapor barrier

The outer concrete vessel is porous and it contains moisture. To prevent the moisture from reaching the insulation and keep the insulation region air tight, a vapor barrier (1.2 mm carbon steel) was installed on the inner concrete surface. The air tightness of the vapor barrier was confirmed by helium leak test (**Fig. 8**).

4. Project Schedule

Starting was the inquiry from Fermilab about whether membrane technology for LNG tank can apply to the liquid argon tank or not on April 2011. And then from August of

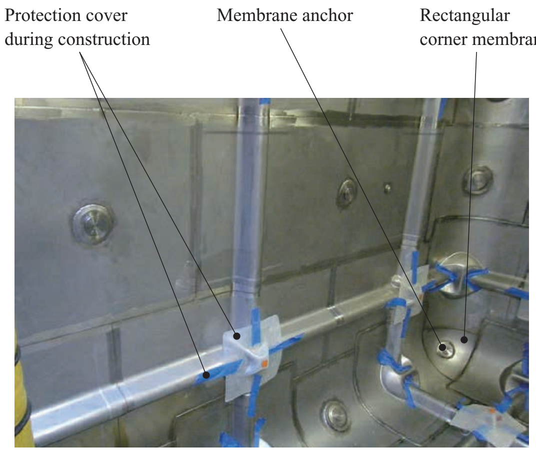
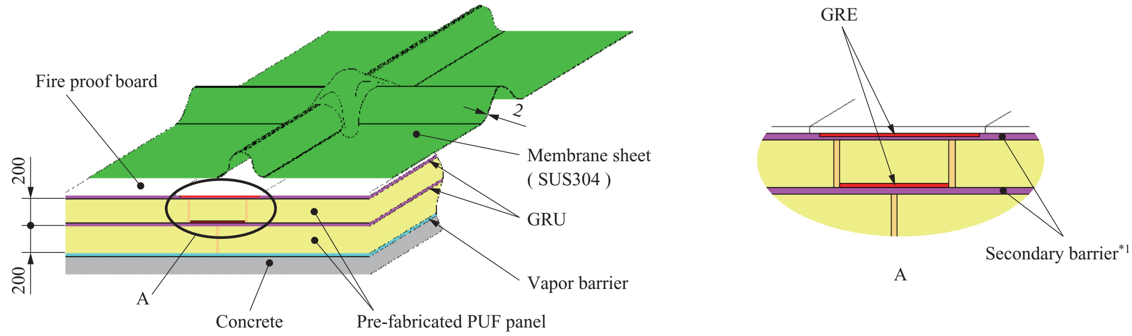


Fig. 3 Rectangular corner membrane

Fig. 4 Corner membrane of roof part



(Notes) GRE : Glass cloth reinforced epoxy
GRU : Glass cloth reinforced urethane
*1 : GRU+GRE component, surface and intermediate, 2 layer system

Fig. 5 Concept of secondary barrier system (unit:mm)

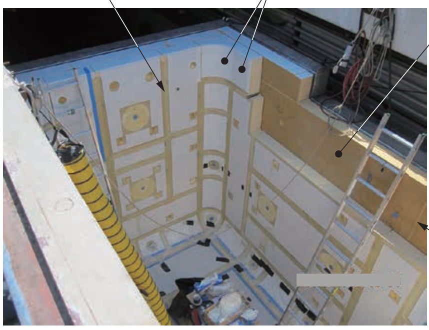


Fig. 6 Insulation panels and secondary barrier work

Fig. 7 Vacuum box test applied to the secondary barrier system

Fig. 8 Helium gas leak test of vapor barrier

2011, basic design of membrane type liquid argon tank was started and mechanical completion was finished on October 2012. Project schedule will be shown in **Fig. 9**.

5. Commissioning and operation by Fermilab

On 20_{th} Dec. 2013, Fermilab commissioning team carried out the cool-down of this liquid argon cryostat and finished it to have reached −183 Celsius (−298 F) after 28-hours.

And then liquid argon of 19 m^3 (5 000 gallons) maintained

Item		Year / Month	2011					2012									
			8	9	10	11	12	1	2	3	4	5	6	7	8	9	10
1	Engineering	- Mock up tests for Vapor barrier, roof corner membrane and bottom corner insulation															
		- Drawings and calculation sheets															
		- Construction documents															
		- Inspection documents															
2	Procurements	- Membrane															
		- Insulation materials															
3	Packing & shipping																
4	Site construction	- RC outer concrete tank by Fermilab															
		- Welders training															
		- Vapor barrier															
		- Insulation															
		- Membrane															

Fig. 9 Project schedule

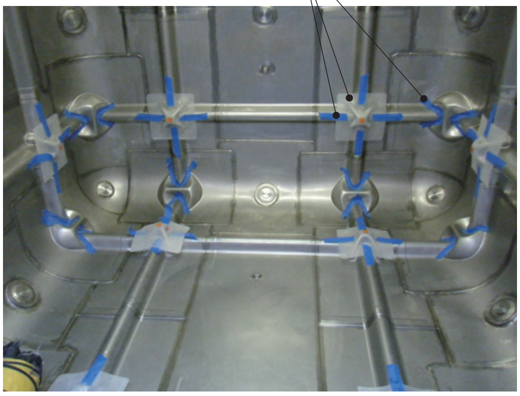


Fig. 10 Internal view of tank after welding of membrane

−184 degrees Celsius (−299 F) was injected to the tank. Team confirmed that the systems for purifying, recirculating and re-condensing the argon were properly operated and the purity tests were begun. The test results of purity of liquid argon were 100 to 120 parts per trillion (120×10^{-12}) oxygen equivalent contamination which was approximately half of requirements (less than 200 ppt (200×10^{-12}) and electron lifetimes between 2.5 and 3 milliseconds were recorded, nearly twice of the goal of 1.5 milliseconds. IHI had received e-mail of "SUCCESS" from Fermilab. Plans for phase 2 testing program, which focuses on installing TPC (Time Projection Chamber) inside the tank, is scheduled to start in May 2015. The aforementioned TPC will detect cosmic rays, and shall act as prototypes for neutrinos detectors.

6. Summary and conclusion

The volume of this tank is much smaller than the LNG storage tanks usually built by IHI, 28 m^3 compared to hundreds of thousands of cubic meters. Since the work space inside the tank was very small, and much smaller than IHI typical constructions, we built a mock up test in Japan using actual materials before beginning the construction at the work site to confirm the construction procedures (**Fig. 10**).

In the near future, Fermilab or one of the international partners member of LBNF, might award contracts for the design and construction of four (4) cryostats of not more than 14 000 m^3 of volume each built with the same membrane cryostat technology.

IHI continues to work to develop this technology and anticipate providing a proposal for the contract for the future argon tank.

— Acknowledgements —

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