C1PoJ-01

Development of Membrane Cryostats for Large Liquid Argon Detectors

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DESCRIPTION

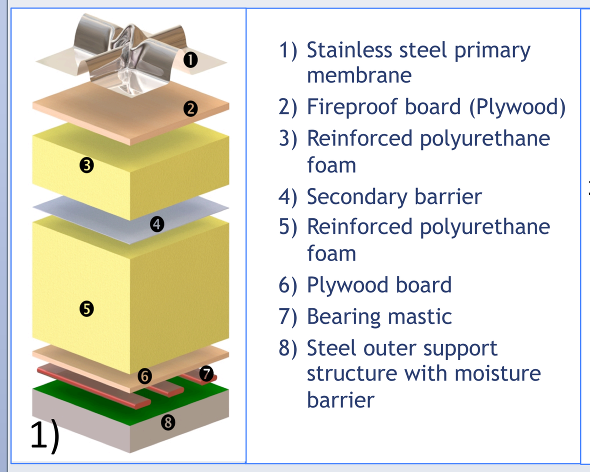
The prototyping involves the following membrane cryostats:

- **WA105 1x1x3:** containing about 19 m³ of liquid argon to be constructed at CERN.
- **Short-Baseline Near Detector** (SBND): containing about 189 m³ of liquid argon. It will serve as near detector for the Short-Baseline Neutrino Program at Fermilab.
- **DUNE Single Phase:** containing about 485 m³ of liquid argon. It will be located on the H4 beam line extension in the CERN EHN1 area.
- **WA105 6x6x6:** containing about 485 m³ of liquid argon (with a different configuration detector than the previous one). It will be located on the H2 beam line extension in the CERN EHN1 area.

Membrane cryostat technology is widely used for Liquefied Natural Gas (LNG) transportation and storage, with over 100 operating vessels that could now be as large as 250,000 m³ of volume. The structural part of a membrane cryostat is the surrounding outer support structure, steel in the case of these prototypes, but it can also be concrete as in the 35 ton prototype at Fermilab. The corrugated membrane contains the liquid argon. The pressure is transferred through the insulation to the support structure.

A membrane cryostat is built from the outside in (Figure 1). First the support structure with its vapor barrier. The two layers of insulation are then installed, with a secondary barrier in between to protect the insulation from potential spills of liquid Argon. Last, the membrane is installed.

Membrane cryostats are not rated for internal vacuum. The Liquid Argon Purity Demonstrator (LAPD) at Fermilab proved that a slow gaseous argon purge can remove impurities down to parts per million from a large cylindrical vessel without evacuation. With a liquid argon filtration system composed by a molecular sieve and copper filters, it then reached over 14.0 ms electron lifetime, far exceeding the level of purity for the liquid argon required by these detectors, which is 3.0 ms (equivalent to 100 ppt oxygen equivalent contamination). With the same liquid argon filtration system, the 35 ton prototype at Fermilab (Figure 2) exceeded 3.0 ms electron lifetime, (measure limited by the available instrumentation), in a cubic membrane cryostat using the same piston purge technique. During phase 1 it demonstrated the feasibility of the membrane cryostat technology for liquid argon, exceeding the purity requirement of 1.4 ms lifetime. It is now being outfitted with TPCs for a phase 2 (Figure 3).



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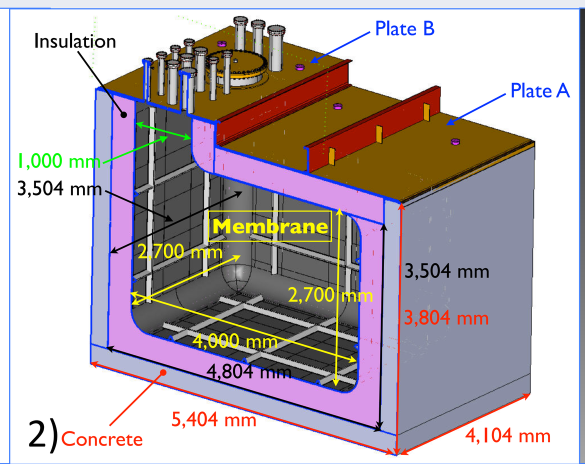

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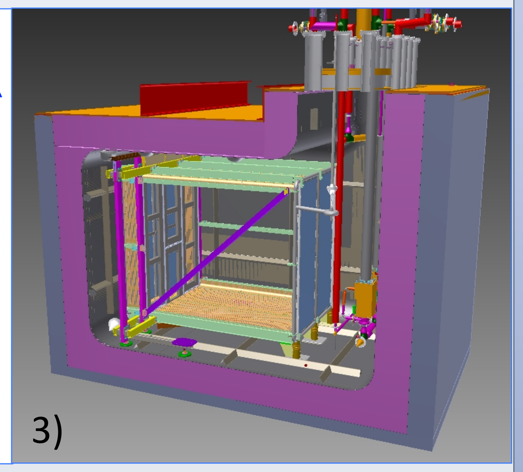
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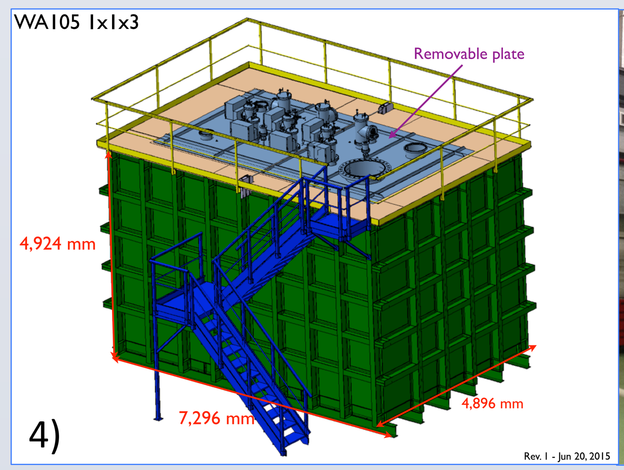
We started with the design of a modular steel support structure for the LBNF cryostats (Fig. 15, 16) and adapted it to the smaller cryostats. The design (that uses standard commercial elements) employs large beams to bear the load of the liquid and gaseous argon (~20,000,000 kg on the floor of the LBNF cryostat) and web interlinks made with smaller beams (with a pitch of 0.8 m for LBNF and 0.6 m for all the others) to uniformly distribute the load. The design also allows air to flow underneath the cryostat to maintain the temperature of the bottom part of the steel structure within the allowable limits. The roof (subject to over 3,000,000 kg in the LBNF cryostat) is an integral part of the support structure and is developed in a similar way. Large openings for installation of the detectors are available as modular units (blocks of web interlinks with or without the large support beams). Penetrations are located in the available space between the smaller beams.



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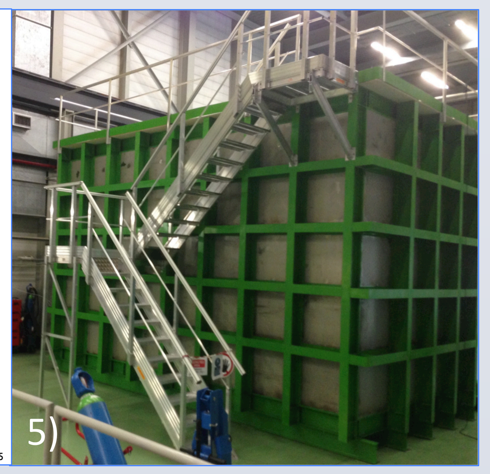
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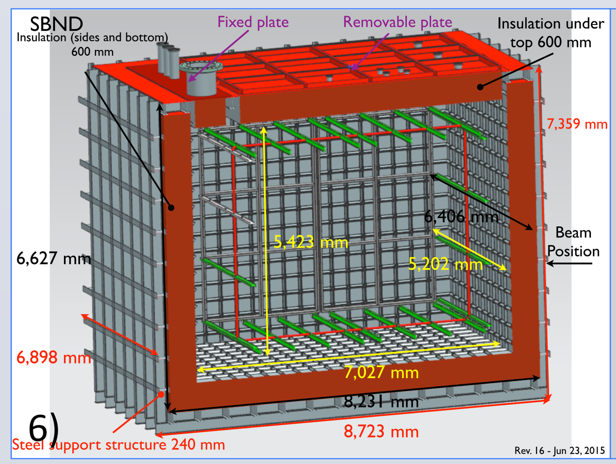

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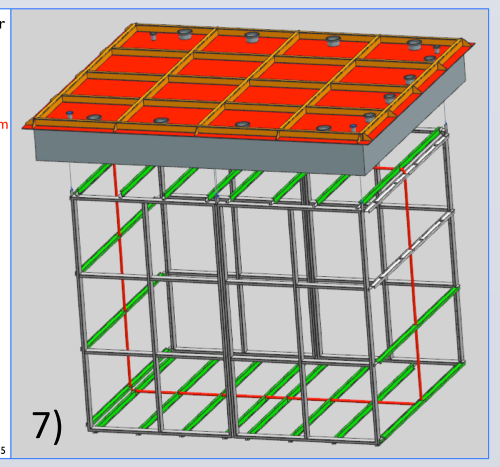
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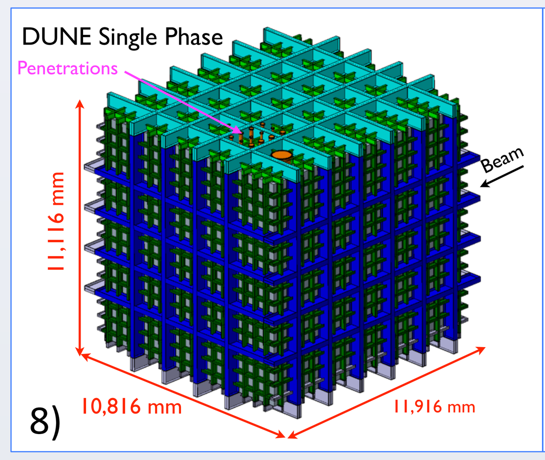
INTRODUCTION

The Deep Underground Neutrino Experiment (DUNE) – Long-Baseline Neutrino Facility (LBNF) project envisions using a membrane tank technology for a large liquid argon detector with the start of construction in the 2020 time frame and operations in 2024. The current detector configuration has a total fiducial mass of 40,000 tons of ultra pure liquid argon (less than 100 parts per trillion of oxygen equivalent contamination) to be located at the 4850L of the Sanford Underground Research Facility (SURF), in Lead, SD, USA, about 1.5 km (4850 ft) underground. The experiments are being developed in a phased approach, which is to total four identical cryostats of about 12,100 m³ of total liquid argon each, each one instrumented with Time Projection Chambers (TPCs). The initial phase is to include two cryostats, with the corresponding required cryogenic system. The remaining cryostats will come at a later time.

To qualify the membrane technology for future very large-scale and underground implementations, a strong prototyping effort is ongoing: several smaller detectors of growing size with associated cryostats and cryogenic systems will be designed and built in the next 2-3 years. A 35 ton prototype is already operational at Fermilab and will take data with single-phase detector in early 2016. A similar size prototype with a dual-phase detector is being constructed at CERN and will be operational next year. In the coming years three more membrane cryostats will be constructed: a 260 ton cryostat with single-phase detector at Fermilab and in parallel two 670 ton prototypes at CERN, with single-phase and dual-phase detectors. After the prototyping phase, the multi-kton detector will start.

After commissioning, the DUNE TPC will detect and study neutrinos from a new improved beam line from Fermilab. These cryostats will be engineered, constructed, commissioned, and qualified by an international engineering team.



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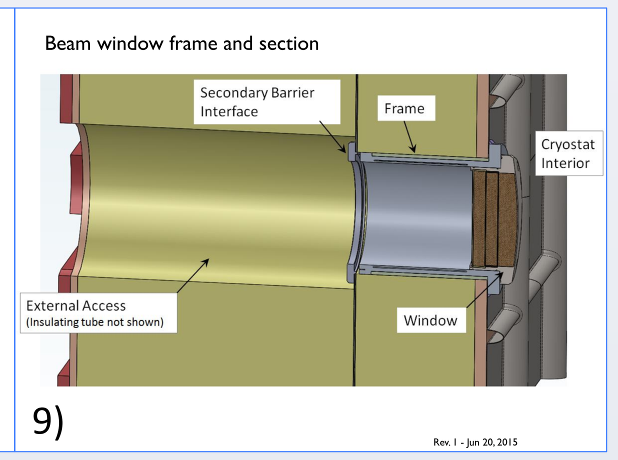

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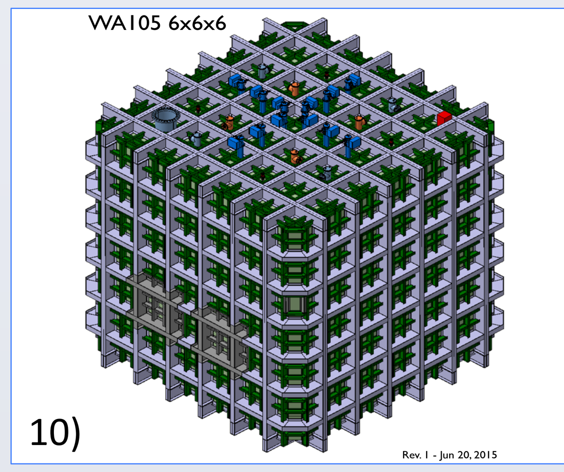

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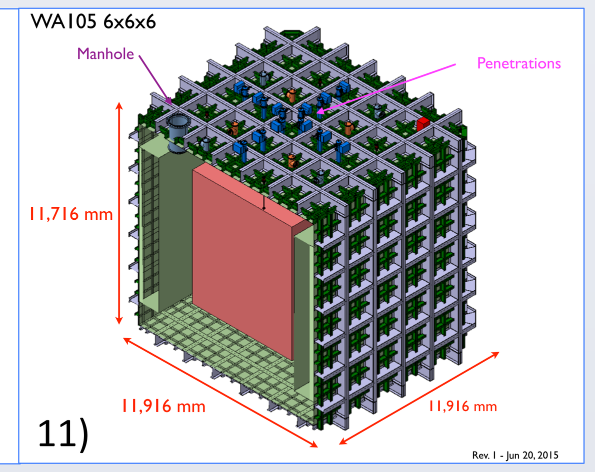

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Design Parameter	WA105 1x1x3	SBND	DUNE Single Phase Proto	WA105 6x6x6	LBNF
Cryostat Volume	23 m³	200 m³	562 m³	558 m³	13,100 m³
LAr Total Mass	25,600 kg	263,000 kg	676,000 kg	676,000 kg	17,100,000 kg
Inner Dimensions of the Cryostat	4.8 m (L) x 2.4 m (W) x 2.0 m (H)	7.1 m (L) x 5.2 m (W) x 5.4 m (H)	8.9 m (L) x 7.8 m (W) x 8.1 m (H)	8.3 m (L) x 8.3 m (W) x 8.1 m (H)	62.0 m (L) x 15.1 m (W) x 14.0 m (H)
Depth of LAr	1.6 m	5.2 m	7.3 m	7.0 m	13.2 m
Insulation (Polyurethane foam)	1.0 m 1.2 m (top)	0.6 m	0.9 m	1.2 m	0.9 m
Primary Membrane	1.2 mm SS 304L corrugated				
Secondary Barrier	Triplex (< 0.1 mm): a thin sheet of aluminum between glass cloth and resin				
Vapor Barrier	6 mm SS304L	6 mm SS304L	6 mm SS304L	6 mm SS304L	10 mm SS304L
Steel Support Structure	Web interlink I-beams 0.24 m	Web interlink I-beams 0.24 m	Web interlink I-beams 0.24 m	Web interlink I-beams 0.24 m	Web interlink I-beams 0.3-0.4 m
Additional Steel Reinforcement	Not needed	May be needed	I-beams 0.6 m	I-beams 0.6 m	I-beams 1.1 m
LAr Temperature	87 K ± 1 K	88 K ± 1 K	88 K ± 1 K	87 K ± 1 K	88 K ± 1 K
Operating Gas Pressure	± 50 mbarg	70 mbarg	70 mbarg	± 50 mbarg	130 mbarg
Vacuum	No Vacuum, we will perform a SLOW GAr purge (See contribution to ICEC 24 – ICMC 25 – 2014)				
Design Pressure	160 mbarg	350 mbarg	350 mbarg	160 mbarg	350 mbarg
Leak Tightness	1E-06 mbar*l/sec	1E-06 mbar*l/sec	1E-06 mbar*l/sec	1E-06 mbar*l/sec	1E-06 mbar*l/sec
Heat Leak	<5 W/m²	<15 W/m² (sides) <20 W/m² (top)	<10 W/m² (sides) <15 W/m² (top)	<5 W/m²	<10 W/m² (sides) <15 W/m² (top)

NOTE

We are here presenting the current status of the design of these cryostats. The design is progressing as we speak and it may now look different. New ideas may have been incorporated and/or have altered the design.

SUMMARY

The DUNE-LBNF project requires the construction of four very large membrane cryostats at SURF, in Lead, SD, USA, about 1.5 km underground. Each cryostat contains 12,100 m³ of liquid argon, equivalent to 17.1 kton. To qualify design choices and installation procedures for these very large underground applications, and familiarize with the technology, we are developing smaller prototypes ranging from 19 to 485 m³ of liquid argon (25.6 to 676 ton), which will be constructed at CERN and Fermilab in the next 2-3 years by an international engineering team.

These designs will test the membrane cryostat technology, the outer support structure and all the interfaces, in particular the one with the TPCs. All cryostats will be instrumented with detectors that will take physics data and validate the performance of the detectors, cryostats and associated cryogenic systems, to ensure that the required purity of 100 ppt oxygen equivalent, corresponding to 3.0 ms electron lifetime, is achieved.

The 35 ton prototype at Fermilab was already operated cryogenically without a detector and it is now being equipped with single phase TPCs for a second run in early 2016. The WA105 1x1x3 is being constructed this summer at CERN and will be operational with a dual phase TPC at the end of 2016.

The preliminary design of the support structures of all other cryostats is almost completed. A feasibility study for each membrane cryostat will be awarded to a membrane cryostat vendor in the next months. It will feed back eventual modifications to the design, if needed. At that point, the final engineering of the support structure and the engineering of the membrane cryostat by the manufacturer start.


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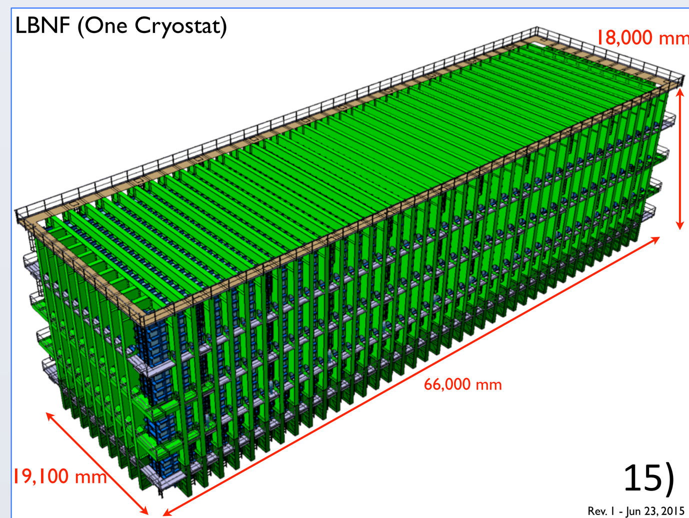

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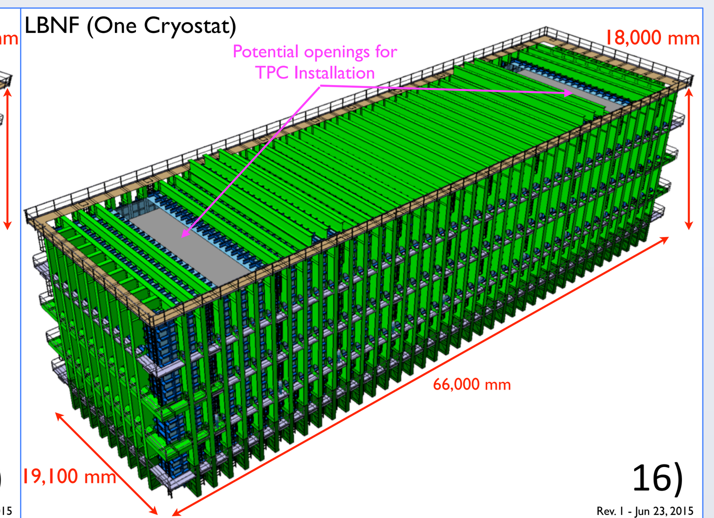

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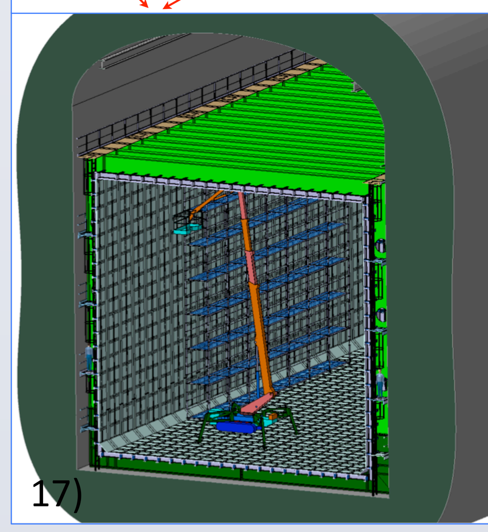
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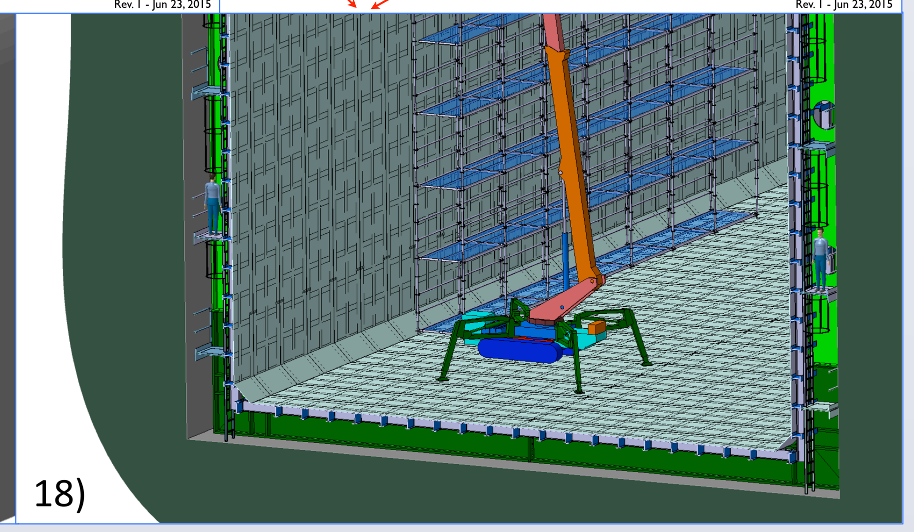
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CAPTIONS

1) Membrane cryostat technology – 2) 35 ton prototype – 3) 35 ton prototype – 4) WA105 1x1x3 – 5) WA105 1x1x3 – 6) SBND – 7) SBND – 8) DUNE Single Phase – 9) DUNE Single Phase – 10) WA105 6x6x6 – 11) WA105 6x6x6 – 12) Cage at SURF – 13) Underground tunnel at SURF – 14) Underground unloading area at SURF – 15) LBNF support structure – 16) LBNF support structure – 17) LBNF: installation of membrane– 18) LBNF: detail of the installation of the membrane.

REFERENCES

- Montanari D et al, 2014 First Scientific Application of the Membrane Cryostat Technology, *AIP Conf. Proc.* **1573** 1664-71.
- Noble P G, 2009 A short history of LNG shipping 1959-2009, Texas Section, SNAME.
- Adamowski M et al, 2014 The Liquid Argon Purity Demonstrator, *JINST* **9** P07005.
- Bromberg C et al, 2015 Design and operation of LongBo: a 2 m long drift liquid argon TPC, *ArXiv*: 1504.00398.
- Montanari D et al, 2014 Performance and results of the LBNE 35 ton membrane cryostat prototype, ICEC 25–ICMC 2014 *Phys. Proc:* in publication.

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