LBNF Cryostat Conceptual Design Review

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Reviewers:

Tom Page - FNAL

David Taylor - SURF

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Introduction

A conceptual design review of the Long- Baseline Neutrino Facility (LBNF) cryostat, which will support the operation of the far detector of the Deep Underground Neutrino Experiment (DUNE) was held at CERN on 27 and 28 May 2015. This review is a prerequisite for a planned CD-1 Refresh DOE Independent Project Review/Independent Cost Review (IPR/ICR) scheduled for July 2015.

The LBNF Project will enable a world-class program in neutrino physics for DUNE focused on precision measurements of neutrino mixing via νe appearance and νμ disappearance with goals of determining the sign of the mass hierarchy and searching for CP violation in the lepton sector, searches for nucleon decay, and measurement of astrophysical neutrinos. LBNF consists of a high-power, broad-band neutrino beam at Fermilab that will illuminate the DUNE liquid argon TPC far detector at the Sanford Underground Research Facility in Lead, South Dakota and the DUNE near detector on the Fermilab site, the cryogenic infrastructure to support the far detector, and all the necessary conventional facilities.

CERN has developed a conceptual design for four cryostats to be utilized as part of the DUNE far detector. The cryostats will each contain approximately 17.5 kt of liquid Argon. The cryostats will utilize membrane cryostat technology developed for transport and storage of liquefied natural gas. The mechanical structure supporting the thermal insulation system and membrane is a free-standing steel-frame rectangular parallelepiped with dimensions on the order of 60 m x 15 m x 15 m.

Design documents comprised of design LBNF's Conceptual Design Report, design drawings, specifications, and analysis results were provided in advance of the review. Multiple design presentations were made in support of the conceptual design during the review. Reviewers David

Taylor from SURF and Tom Page from Fermilab evaluated the presentations against six charge questions that follow:

- Key requirements/specification: Are the driving requirements adequately defined and do the key design parameters follow from them?
    - **Yes, but Requirements should be documented and agreed upon.**
- Does the conceptual design meet the requirements?
    - **Yes.**
- Have risks related to the cryostat design been identified?
    - **Yes.**
- Are engineering analyses adequate to support conceptual design?
    - **Yes, with the exception of the thermal analysis.**
- Are major system interface points identified to the LBNF conventional facilities, cryogenic system and the DUNE detector?
    - **Yes, but Interfaces should be documented and agreed upon.**
- Are safety issues identified and adequately addressed at the conceptual design level?
    - **Yes.**

Summary

The committee was impressed with the level of analysis presented. We think CERN has done a good job in the short amount of time they have been working on this design and the amount of resources assigned to the cryostat design seems adequate at this stage of the project. The planned prototypes will help CERN gain experience with the construction and assembly of membrane cryostats. There are a few outstanding items that need to be addressed as described in the recommendations but overall the conceptual design looks feasible.

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Findings

- Schedule for Cryogenics installation is ~30 months per detector; installation of the warm cryostat is estimated at 18-weeks; there is slight schedule reduction for modules 3 & 4 indicating some learning curve
- CERN warm cryostat approach involves the use of a structural steel frame to alleviate risks of geological movements in rock walls while allowing visual inspection of the cryostat exterior after beginning of operations.
- Nitrogen or argon injected into the cold cryostat insulation will keep the insulation dry from possible moisture incursion.
- Cryostat exterior and interior dimensions were presented.
- Structural analysis showed tremendous diversity of methods that show good agreement for maximum deflection, stress, and resistance to buckling. Analytical methods using textbook equations show consistency with the finite element (FEA) method. Checks have been done using both European and USA (ASME) analysis methods.
- The warm cryostat design uses catalog EU beam sizes that have USA equivalent shapes in the structural design. Per manufacturer documentation, the selected steel is ductile to -50^{o} C while expected operating temperature is 20-30^{o} C. Equivalent ASTM material designations are identified.
- Stresses resulting from pressure are based on the relief valve pressure being the maximum operating pressure. Credit was not taken for internal pressure on the roof for buckling analysis. These assumptions are both reasonable and conservative.
- Warm cryostat stresses have been initially modeled in FEA using 1D beam elements. As the beam elements are modeled to the centroid, the resultant FEA structure corners are larger than internal dimensions. That combined with joint effects of the beam ends likely result in higher deflections than will actually be incurred. This is both reasonable and conservative.
- The design team has assumed a design factor of 4 for buckling although only a factor 2 is required. This is both reasonable and conservative.
- A shared schedule requirement is that cryostat1 can't be filled with liquid Argon until the cryostat 2 is done with assembly and commissioning in the event that cryostat 1 needs to be emptied. The cyclic loading due to filling should be a maximum of a couple cycles so cyclic fatigue analysis isn't required.
- CERN is building multiple prototypes of membrane cryostats. This will provide hands on experience with the construction of these types of cryostats as well as experience working with the membrane cryostat installation vendor(s).
- A risk assessment of the conceptual design including technical, safety and financial risks was provided.

Comments

- Due to elevated humidity in the underground ventilation, moisture in the cavern could condense on the warm cryostat exterior if the exterior is below the cavern dew point. As the experiment is responsible for supplemental ventilation in the cavern, an early assessment of the thermal conditions would be useful for setting the cost expectations for ventilation.

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- How design codes and standards are interpreted may have a significant impact on the warm cryostat total mass and construction cost. The project should work to reconcile the interpretation difference for the possible benefit to project cryostat cost and reduction of mass of the largest components.
- The development of multiple analysis methods for cross-checking both reduce design risk provide opportunity for investigation of design optimization options. Existing analysis of pinned versus fixed connections is already providing insights for design optimization.
- A thermal analysis of the insulation system was not presented. The plan is to contract GTT to perform a design study including the thermal analysis in the near future. This analysis will help determine the temperature of the support structure and contribute to the evaluation of the condensation risk as described in the risk assessment. The outcome of the analysis may impact the interfaces with Conventional Facilities should heating of the outside structure be required.

Recommendations

- Various requirements for cryostat size, configuration, and structural integrity were presented although there wasn't formal requirements documentation shared. As assumptions of engineers on the cryostat team can potentially vary from engineers on teams for interfacing equipment, there should be more rigor applied to documenting requirements even if the final value of the requirement is not yet settled. Requirements for detector size, configuration (e.g. required ports, feedthroughs), and applicable codes and standards for design and construction should be discussed and documented well in advance of CD-3a preliminary reviews.
- A few shapes shown in the design create a risk that they could exceed SURF capabilities for maximum size or weight. The list of proposed loads should be reviewed with SURF to verify that options exist for the load transport and logistics. This review should also consider the logistics impact to other construction activities.
- Seismic design information from a DUSEL design report from Golder Associates shows that Lead, SD is fairly inactive. There is evidence that at the depth of 1.6 km, possible seismic activity will be further damped. Details of projected seismic behavior at 4850 should be investigated to provide a more firm seismic design requirement for the warm cryostat.
- Multiple physical interfaces were presented with particular focus on size and mass of structural components. There are additional interfaces to be addressed including the following: location of liquid pumps, cryogenic system, DUNE experiment (TPC detector) and Conventional Facilities capabilities including safety systems to facilitate construction and operation. A detailed list of interfaces should be created and maintained prior to preliminary reviews that will occur before the CD-3a review. This list should identify which parties need to agree to each side of the interface.
- Complete the thermal analysis of the insulation system and cryostat support structure well in advance of CD-3a preliminary reviews.
- Presentations focused on the structural integrity of the design and that is an important starting point. For future efforts, increase the focus on systems engineering aspects related to requirements, interfaces, and logistics to assure that the product both functions as designed and can be built to a known cost and schedule.

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