LONG BASELINE NEUTRINO FACILITY (LBNF) CRYOGENIC SYSTEM TECHNICAL REVIEW REPORT

Jonathan Creel, creel@jlab.org
Cryogenics Engineering and Operations Department Head and Senior Electrical Engineer,
Thomas Jefferson National Accelerator Facility

Nandhini Dhanaraj, dhanaraj@fnal.gov
Mechanical-Cryogenics Engineer, Fermi National Accelerator Laboratory

Ali Hemmati (Committee Chair-person), hemmati@fnal.gov
Mechanical-Cryogenics Engineer, Fermi National Accelerator Laboratory

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EXECUTIVE SUMMARY

An independent conceptual review of the Long Baseline Neutrino Facility (LBNF) cryogenic system has been completed by the following committee members:

- Jonathan Creel, creel@jlab.org
- Nandhini Dhanaraj, dhanaraj@fnal.gov
- Ali Hemmati (Committee Chair-person), hemmati@fnal.gov

The review was based on documents provided to the review panel and the presentations given to the panel by the project engineers. The Review Committee has focused on major changes since the last review in 2012. The following are a summary of the comments and recommendations that the committee would like the design team to consider. Recommendations need to be completed before CD-2 review.

COMMMENTS

1. Consider the feasibility of placing the major cryogenic plant components on the surface to improve safety, improve maintainability and reliability, and reduce costs.
2. Research reliability of the pumps that will be used in the experiment, specifically the cryogenic pumps. If the process could be redesigned to utilize the available head pressure, even with the small temperature deltas, the need for pumps might be eliminated.
3. Study the use of plate heat exchangers instead of the tube and shell design that is presented in the current conceptual design.
4. Study the effect on the experiment of vibration due to placing rotating machinery inside the mine.

RECOMMENDATIONS

1. Include the amount of refrigerants present in the experiment hall to the overall ODH analysis
2. Provide technical specification and cost estimates for implementation of process controls and instrumentation
3. Provide technical, cost, and feasibility study of delivering large amounts of argon for the experiment.
4. Ensure that flanges are rated and selected per ANSI B16.5 and ensure that the maximum temperature and pressure rating of the each flange does exceed ANSI B16.5 ratings.
5. All documentation must be reviewed by independent reviewers

6. Provide documentation on contingencies used to determine heat loads to the cryogenic system
7. Provide specific documentation regarding the FEA analysis mentioned during the review as support for the engineering analysis to support the conceptual design

The Technical Design Review Committee believes that the reference design presented to the committee on May 14, 2015 is technically sound and the committee believes the reference design is ready to proceed to CD-1. The committee has provided recommendations that need to be addressed before CD-2.

INTRODUCTION

The Long Baseline Neutrino Facility (LBNF) project director has asked an independent review panel to perform a design review of the LBNF Cryogenic System. The LBNF project has gone through several reviews and the project has been through several design iterations. The reference design in this document will be referred to as the design presented to the Review Committee as of May 14, 2015 and includes the latest changes and the latest design considerations, which this committee has been tasked to review.

The committee has reviewed the conceptual design of the cryogenic system, excluding the design and safety of the cryostat, which is not within the scope of this review. The goal of the review is to verify that the design of the LBNF cryogenic system is at conceptual level or greater.

The following factors were provided by the LBNF project director to assess the LBNF cryogenic system design:

- Major design alternatives considered, the relative risk for each and the justification for the selection, including any value management activities.
- Key requirements/specifications: Specification spreadsheets have been completed and have been reviewed by the appropriate Project Engineer for Conceptual Design readiness. All of the specification terms have been identified and the driving requirements are defined.
- Risk has been assessed on specifications that are to be resolved (TBR) or to be determined (TBD), or with other issues.
- Risk Registry completed (including mitigation of technical, cost & schedule risk).
- Conceptual design that meets the requirements.
- Engineering analyses to support conceptual design
- Major system interface points identified, both organizational and technical, including control systems implementation plan and draft interface
- Consideration for quality control and reliability
- Completed Hazard List. Identify planned hazard reports

All documentation and relevant information including any engineering analysis, quotes, drawings, and P&ID were placed under the following link:

https://web.fnal.gov/project/LBNF/ReviewsAndAssessments/Cryogenic%20System%20Review%20May%202015/SitePages/Home.aspx

SYSTEM DESIGN REVIEW CHARGES AND COMMITTEE'S REMARKS

1. MAJOR DESIGN ALTERNATIVES CONSIDERED, THE RELATIVE RISK FOR EACH AND THE JUSTIFICATION FOR THE SELECTION, INCLUDING ANY VALUE MANAGEMENT ACTIVITIES

The committee requested that the cryogenic system design team provide information regarding the previous designs that had been considered throughout the design iteration process of the LBNF cryogenic system. The engineering design team presented a case where the majority of the cryogenic system had been proposed to be placed on ground level at the surface of the mine with liquid argon transferring down, through vacuum jacketed transfer lines, to the cryostats. According to the LBNF engineering design team, this design has been re-configured due to many factors such as: hazards due to geysering effects, ODH considerations, additional costs and other technical challenges associated with vacuum insulation and long transfer lines. The design team presented the successful experience of CERN's design and operation of the ATLAS experiment which helped formulate the basis for the reference design.

The committee believes placing cryogenic equipment on the surface may help improve safety, improve maintainability and reliability, and reduce costs.

2. KEY REQUIREMENTS/SPECIFICATION: SPECIFICATION SPREADSHEETS HAVE BEEN COMPLETED AND HAVE BEEN REVIEWED BY THE APPROPRIATE PROJECT ENGINEER FOR CONCEPTUAL DESIGN READINESS. ALL OF THE SPECIFICATION TERMS HAVE BEEN IDENTIFIED AND THE DRIVING REQUIREMENTS ARE DEFINED

Key requirements, specifications, and documentation were presented adequately by the design team for the components presented in the design, such as LN2 refrigeration, Ross shaft piping, condensers, filters, etc. The committee's concern is that not all documentation might have been independently reviewed, specifically the calculations and P&ID. The committee asks the design team to have all documentation reviewed by independent reviewers.

3. RISK HAS BEEN ACCESSED ON SPECIFICATIONS THAT ARE TO BE RESOLVED (TBR) OR TO BE DETERMINED (TBD), OR WITH OTHER ISSUES.

The Review Committee requested that the engineering design team investigate the risk associated with placing rotating machinery in the mine, specifically studying the reliability of the cryogenic pumps, and possibility of vibration interfering with the experiment. The LBNF design team indicated that due to a large working area available for operation in the mine, placing rotating machinery in the mine's working area is no different than placement of such machinery at Fermilab' s site for other similar experiments. The Review Committee asks that the effect of vibration on the experiment be further studied.

The Review Committee has asked the LBNF design team to include the effect of all refrigerants that are part of the chillers to the ODH analysis. These chillers, which are part of the water cooling system, are placed in the mine and contain refrigerants that can affect the ODH analysis when spilled.

4. RISK REGISTRY COMPLETED (INCLUDING MITIGATION OF TECHNICAL, COST & SCHEDULE RISK)

The committee has identified that supply of such large amount of argon for this experiment could prove to be challenging, and will have the potential to impact schedule and cost if not enough resources are allocated to study and secure the argon required for the experiment.

The committee identified the need for spare equipment such as spare pumps in case of failure. The LBNF design team indicated that during the experiment at least one extra pump will not be in use and can be used as a spare.

Moreover, the LBNF design team has indicted that the supply of power to the mine is provided by access to three main grids and a backup diesel generator. The risk associated with supplying electricity to the mine has been considered and minimized.

The committee requests that the design team provide documentation on contingencies used to determine heat loads to the cryogenic system. The committee believes that these contingencies might create technical, cost, and schedule risk.

5. CONCEPTUAL DESIGN THAT MEETS THE REQUIREMENTS

The Review Committee believes that the conceptual design meets the requirement set forth by the LBNF project. For the reference design, the LBNF design team will be using LN2 plants that can be used in both modes of refrigeration and liquefaction to meet

design requirements. The flange selection for purification system should be revisited to ensure all flanges are rated appropriately according to ANSI B16.5.

6. ENGINEERING ANALYSES TO SUPPORT CONCEPTUAL DESIGN

Some engineering documentation and analysis were provided to the Review Committee to support the conceptual design of the reference design. The use of some FEA analysis was mentioned during the review. Due to lack of sufficient specific documentation on FEA analysis, the committee is unable to provide full assessment of the engineering analysis.

7. MAJOR SYSTEM INTERFACE POINTS IDENTIFIED, BOTH ORGANIZATIONAL AND TECHNICAL, INCLUDING CONTROL SYSTEMS IMPLEMENTATION PLAN AND DRAFT INTERFACE

The committee believes that the LBNF engineering design team has identified many of the major technical points and has acquired sufficient information regarding the implementation of the cryogenic system presented in the reference design. The Review Committee believes that the LBNF team needs to study and implement a design for the controls system and arrive at a plan for implementation of such system. The controls system and instrumentations are a large portion of this project and they make up part of the full implementation of the cryogenic system.

8. CONSIDERATION FOR QUALITY CONTROL, RELIABILITY

The Review Committee believes, as previously mentioned, that the reliability of cryogenic pumps needs to be studied based on past and current experiences. The Review Committee indicated that NASA has used LN2 pumps in the past and had issues with their reliability. The LBNF design team indicated that CERN's use of such pumps has not proven to be problematic. An investigation into understanding the difference between the pumps and the reason for their failure in NASA's case and the pumps' high reliability in CERN's case should be done to ensure that the pumps selected for the reference design will not cause any operational issues.

The LBNF design team has used standard equipment used in the LNG industry throughout the design process. The proven track record, established reliability, and safety factors for these equipment increase the reliability of the reference design.

9. COMPLETED HAZARD LIST. IDENTIFY PLANNED HAZARD REPORTS

The committee believes that the LBNF design team has identified many of the potential hazards related to ODH that can result from failure of the cryogenic system. The following hazards were identified by the design team:

- Oxygen deficiency hazard: The design team has provided a detailed analysis of the ODH analysis. As mentioned previously, the Review Committee asks the design team to add the refrigerants from the chillers present in the mine to the ODH analysis
- Emergency evacuation due to ODH event: the design team has identified that there is sufficient time for anyone in the mine to walk through the experiment hall and enter “safe zones,” before oxygen level reaches 18%.