Report of the Cost and Schedule Review of the
ND-LAr 2x2 Demonstrator Installation
August 2-4, 2021

A Cost and Schedule Review of the ND-LAr 2x2 Demonstrator Installation was held August 2-4, 2021. A charge was issued by Stephen Brice, Fermilab Neutrino Division Head. The purpose of this review was to evaluate not only if the cost and schedule estimates currently in place were appropriate, but also if the level of project management and associated project planning tools were appropriate given the size and scope of the installation effort.

The LAr-ND 2x2 Demonstration Installation plan is to install the ND LAr 2x2 Demonstrator above ground at LArTF for initial checkout and commissioning, and then to install it to take neutrino data underground in the on axis NuMI beamline, surrounded by segmented scintillator planes formerly used by MINERvA.

The review committee consisted of Deborah Harris (Fermilab/York, chair), Pat Lukens (Fermilab), Dave Pushka (Fermilab), Paul Rubinov (Fermilab), and Terry Tope (Fermilab). Ting Miao (Fermilab) organized the presentations and gave two of them. Other presentations were given by Min Kim (Fermilab), Mike Zuckerbrot (Fermilab), Linda Bagby (Fermilab) and Michele Weber (University of Bern). Brian Beckford from the Department Of Energy attended as an observer.

The review committee thanks the presenters and the entire Installation team for their efforts during this review, and for providing detailed presentations and documentation. The committee asked several questions at the end of the first day and the team was able to respond to all questions by the end of the morning of the second day of the review.

The text of this review includes a summary followed by sections that were covered by each of the presentations. There are also sections on cost and schedule issues separately. Each section includes findings, comments, and recommendations. The answers to the charge questions are provided at the end of this document.

Web site with Presentations: https://indico.fnal.gov/event/49143/

Executive Summary:

The project has a lean but effective management team and the level of detail in the project planning documentation seems appropriate for a project of this size. There are a few tasks identified that need more labor assigned, as detailed in the full report below. The largest concern

the committee identified is that this project suffers from not getting the required labor on the necessary time scale to complete tasks on the desired schedule. The schedule presented was largely driven by projected resource availability and was significantly delayed from what a technically driven schedule might be. As a result, this 2x2 demonstrator is currently scheduled to start data taking underground at MINOS in the NuMI beamline on March 3, 2023, 8 months after the last module is scheduled to arrive at Femilab (July 9, 2022), and five months after the time scale desired by the DUNE Consortia (after the end of the summer 2022 shutdown). The project management is clearly aware of the labor resource limitations.

This was not a technical review, so the technical justification for installing the 2x2 Demonstrator at LArTF before installation underground was not described. However, given the ultimate goal of running the Demonstrator underground and the resource limitations, the committee recommends that the Installation team and Consortium perform a cost benefit analysis of the LArTF installation to ensure that the risk mitigation expected by that step warrants the cost and schedule impact.

Responses to Presentations:

1) Layout and Installation Support

    a) Findings:
        i) 3D Solid Models are actively being used for planning the layout and assembly sequences of the cryostat and related electronics and equipment for both areas (LArTF and MINOS).
        ii) FNAL provides a walking working surface for use in MINOS hall (WBS 1.3.1). Design of the platform is in WBS 1.2.3.1.
        iii) A new lifting fixture is needed for lifting the TPC modules underground in MINOS. The design is a work in progress, and the current design has a lift angle of 35 degrees to accommodate the maximum hook height of the MINOS underground crane.
        iv) A heat load analysis has not yet been done to ensure that the cooling capacity of the existing system can handle the modified heat load (the addition of up to 6 cryocoolers and the new compressors but the removal of the MINOS Coil and power supply).

    b) Comments:
        i) The use of 3D solid models for planning is a best practice.
        ii) Schedule includes ample time for preparing safety review documentation for the rigging efforts.

iii) Plans for performing the needed electrical work in the MINOS hall under the "do-it-all-fixed-price-contract" rules are understood.

c) Recommendations:
   i) Prepare the engineering design for the walking working surface in the MINOS hall, include safety professional review of the design, and document in an engineering note per FESHM 5100.
   ii) Perform a heat load analysis in the cavern to verify that the ambient temperature in the cavern will remain at an acceptable level.
   iii) Develop the cryostat lifting fixture design so that the lift angle is not less than 45 degrees.
   iv) Communicate with the stock room prior to starting the cryostat argon fill to give the stockroom and the vendor notice of the relatively large argon needs.

2) Cryogenics and Related Instrumentation

a) Findings:
   i) Cryogenic estimates are based on the lead engineer's past experience on similar systems.
   ii) Overall schedule for LArTF was presented:
      (1) Cryogenic design extends from 5-7-21 to 12-15-21
      (2) Cryogenic procurement extends from 5-7-21 to 2-4-22
      (3) Cryogenic installation extends from 8-31-21 to 2-22-22
   iii) The BERN-provided cryostat has passed a 4X proof pressure test.
   iv) The plan is that BERN delivers the cryostat and its associated internal cryogenics. FNAL delivers the external cryogenics including cryocoolers, filter vessels, interconnect piping, and other support infrastructure such as ODH mitigation.
   v) The cryocooler system is nominally sized for 3 cold heads but can be expanded to 5 cold heads such that a significant cooling margin is available.
   vi) Fermilab will provide the water chiller system for the cryocoolers.
   vii) The Condenser is likely to be procured from cryocooler vendor Cryomech.
   viii) Filters to be a procurement managed by Fermilab based on an existing BERN design.
      (1) Cryostat valves and filter vessel procurement dates are listed as extending from 7-2-21 to 12-27-21
      (2) Filter vessel engineering note and safety review listed as extending from 9-16-21 to 10-15-21.

(3) M&S is listed as $30k

ix) Preliminary calculations suggest that the existing MINOS vent header will work for the 2x2 primary relief. The vent header integrity has been verified by pressure testing.

x) It is noted that for the LArTF test 480 VAC power is required.

xi) At MINOS the fill will be performed using 60-70 160 liter LAr dewars.

xii) The major cryogenic components are modeled in CAD at both LArTF and MINOS to aid in understanding the physical interfaces.

xiii) An ODH analysis for MINOS for a similar proposed liquid argon effort already exists.

xiv) FNAL contributed a controls system for the BERN tests which gives the controls group a head start for the FNAL effort.

xv) The heat rejection into the MINOS HVAC has not been documented.

b) Comments:

i) Historically one task code has been used for a wide range of cryogenic activities and it is difficult to obtain actuals for specific subsystem tasks.

ii) The 4X pressure test of the cryostat at Bern should greatly aid FESHM compliance and ORC.

iii) The cryogenic system has a mature design informed by previous systems and is led by an engineer with significant experience.

iv) How FESHM applies to the Cryomech standard condenser product is not fully understood. Ensure a path to FESHM compliance for the Cryomech condenser, since it is likely that this vendor does not follow ASME codes.

v) Ensure that the proposed chiller complies with FESHM 5035: this has been difficult for several recent chiller procurements to comply with and may lead to commissioning delays.

vi) The duration of the filter vessel procurement (7-12-21 to 1-4-22) may be too short. Recently it has been taking 2-3 months from submittal of a requisition to work through the RFP process and place a Purchase Order. Also the cryogenic industry is very busy at the moment and it may be difficult to find a vendor that can complete these filters in the time currently specified. The $30k M&S listed for two filter vessels may be low as material prices have increased significantly and vendors are increasing prices due to their high workload.

vii) It was discussed in the Electronics and Readout Integrations talk this fact has relevance here as well: fixed price electrical distribution contracts have greatly impacted cryogenic installations over the past year due to the slow procurement cycle. Thus the committee suggests getting

cryogenic-related electrical requisitions submitted as soon as possible. There may be schedule value in splitting the electrical tasks into multiple Purchase Orders if some electrical tasks are well defined before other tasks are, as electrician availability and fitting within the lab's operational priorities are another variable.

viii) Cryocoolers do not appear to have a specific safety documentation task.

ix) The fill process using 60-70 stock room size dewars may take more time than in the schedule due to the logistics of handling so many dewars. Handling this many dewars also increases the risk of gross contamination. Consider contacting the vendor to see if 500 liter or larger dewars are an option. It may be possible to crane down larger dewars if they don't fit in the elevator and move by fork truck underground.

x) In general the cryogenic schedule seems very aggressive with respect to the ongoing shortage of cryogenic resources at the lab. Historically cryogenic engineering estimates based on experience significantly underestimate the required effort.

c) Recommendations:

i) Revisit the labor estimates for the cryogenic work based on a more thorough assessment of as-realized costs for other projects.

ii) Revisit the duration and cost estimates for the large cryo procurements that have yet to begin.

3) Electronics and Readout Integration

a) Findings:

i) There is a clear plan for AC distribution, rack preparation and installation, networking and cabling.

ii) The AC power distribution for the final installation in the MINOS hall is divided into 4 systems:
Building, Quiet, Low Noise Grounding, Generator backup

iii) The installation in LArTF will have the same except for "quiet" which is unique to Minerva modules.

b) Comments:

i) Overall, this part of the project is in excellent shape. The team is very experienced, they know exactly what needs to be done and they know how to do it.

ii) The milestones are clear, the work list is clear and complete, the schedule seems reasonable.

iii) All tasks have labor estimates at the appropriate level of detail, including estimates for the required physicist labor

iv) It might be helpful to add an explicit link in the schedule that is tied to accelerator down times to improve the planning of the electrical work.
v) Adding the new fans for the ODH mitigation and other AC modifications are going to require substantial electrical effort. The prohibition on performing electrical work on a Time and Materials basis likely increases the overall cost for performing such work and clearly substantially increases the cost of managing the work.

c) Recommendations:
i) A risk should be added to account for potential problems with the refurbishment of the Wiener DC power supplies.

4) TPC and Consortium Deliverables
a) Findings:
i) The cryostat was delivered from Bern last week
ii) The first module ("Module-0") has been tested at Bern and is going to be shipped at the end of August 2021 with an expected arrival time in September 2021.
iii) The schedule for the production and delivery of the next three modules was presented.
b) Comments:
i) The schedule for the associated charge and light readout delivery was not as clearly described as that of the module delivery.
ii) There is some flexibility with the LArTF testing schedule: the statement was that the LArTF test should include at least one or two modules, but testing all 4 modules at LArTF was not critical before bringing the modules underground.
iii) The delivery schedule for components other than the modules and the cryostat was not outlined in detail, there is still some flexibility in what gets shipped to Fermilab and what stays at Bern.
iv) Although there are several tasks in the schedule that have physicist labor as a resource, the fraction of that physicist labor that comes from the consortium was not clearly specified
c) Recommendations:
i) Take credit for the consortium labor contributions in the schedule to facilitate planning (see below)

5) Cost and Schedule Estimates (General comments here, specific electronics or cryo issues will be in the other sections)
a) Findings:

i) The committee was not provided with basis-of-estimate explanations or documents.
ii) The total cost of the installation and test program was not provided.
iii) Risks were shown but the cost and schedule impact was not quantified.
iv) Labor resource requirements for FY2022 are projected to increase significantly from FY 2021.
v) There are periods where the schedule duration is less than or equal to the effort for particular labor types (for example, tasks labeled 1.2.5.1 – 1.2.5.3 all begin on the same day, and the longest is 60 days duration. The sum of the Cryo Engineer resource for these three tasks is 80 days. This assumes that there will be at least two Cryo Engineers available for this work during that time.)
vi) One milestone remains in 2021 and there are five in 2022.
vii) Effort profiles for each resource type were shown after inquiry.

b) Comments:
i) The installation group needs to determine the availability of the additional resources that will be needed in FY2022.
ii) The potential cost and schedule impact of the risks needs to be quantified.
iii) A greater number of milestones is needed to allow project tracking. Approximately one per month is suggested.

c) Recommendations:
i) Calculate the total cost of the project.
ii) Determine the resource profile required to meet the schedule requirement of DUNE.

6) Management:

a) Findings:
i) No organization of the installation group was shown.
ii) The position of the 2x2 project within the DUNE organization was shown.
iii) A schedule problem with the installation was shown. We were told that data from the 2x2 run at Minos was mission-critical to DUNE with a deadline before the end of 2022. However, the installation plan shown provides a date of March, 2023 for the beginning of commissioning.
iv) The installation and test at the Liquid Argon Test Facility is scheduled to require 8.5 months. Design work for the MINOS cryogenic system appears to follow the completion of these tests.

b) Comments:
i) The plan shown does not appear to meet the requirements of the DUNE collaboration.

ii) The purpose of the Liquid Argon Test Facility installation was not obvious or thoroughly explained.

c) Recommendations:

i) A complete cost/benefits analysis should be performed for the installation and test program at the Liquid Argon Test Facility.

ii) A reevaluation of the plan should be performed in an attempt to satisfy the schedule requirements of DUNE. If this schedule requirement cannot be met, the plan should be reconciled within the experiment.

Charge Questions:

1. Does the installation have an appropriate level of project management for its scale?

   The committee's concern is less with the number of managers, but more with the number of people available to address each specific task. Management level is appropriate, but management is struggling to get enough of the identified resources. The team has an appropriate set of management tools to characterize labor resource needs and M&S needs as a function of time. Although there were some risks identified, they were not quantified as much as would be helpful from a management perspective. One example: there's a schedule risk associated with the ODH analysis, and one could mitigate that by starting this task earlier.

2. Is there a resource loaded schedule and is it thorough? Is it developed to the appropriate level of detail so that it can serve as a useful tool for managing cost and schedule performance?

   Yes, and it is serving for tracking cost and schedule. (see response to question 1).

3. Have a complete set of milestones been defined that enable adequate tracking of progress?

   More milestones are needed, we suggest roughly one per month for adequate tracking.

4. Are all required M&S and labor resources included at the appropriate level of detail and are the associated costs and schedule durations realistic?

   The project that was presented was adequate from a detail point of view of the list of tasks, but the committee considers some of the labor resource efforts needed optimistic. One example was inserting the modules in the cryostat at LArTPC: the task was listed 10 technician days but during the discussion it was agreed that the effort will "probably take 1-2 weeks of a 3-person crew", this should be listed at 15-30 technician days instead of 10. The

prohibition on performing electrical work on a Time and Materials basis likely increases the overall cost for performing such work and clearly substantially increases the cost of managing the work.

5. Are major procurements, interfaces between the subsystems, and integration of the installation being adequately identified, planned for, and managed?

The interfaces are in the process of being documented: The interface document we were presented had many interfaces listed but not all the interfaces had supporting documentation referenced. This is an experienced team that understands the importance of interfaces, and they are in the process of planning and managing these interfaces.

6. Are the dependencies on non-Fermilab resources understood and integrated into the planning?

The dependencies are understood reasonably well for the delivery of the modules and electronics. The dependencies on non-Fermilab labor resources are not as well-documented. The committee is happy to see that a new person has been added to the planning effort, Jay Hyun Jo (from Yale University) and we encourage the team to document the expected non-Fermilab scientific effort to the specific tasks where it is needed. This way the Consortium can plan long stays at Fermilab as needed.