Fermilab

Final Report – Issued June 10, 2015

Director's CD-1 Refresh Review of LBNF/DUNE

June 2-4, 2015

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Executive Summary

A Fermilab Director's review of the Long Baseline Neutrino Facility and Deep Underground Neutrino Experiment (LBNF/DUNE) project was conducted on June 2-4, 2015 at Fermi National Accelerator Laboratory (FNAL). The review was to look at the *refresh* of Critical Decision 1 (CD-1) Preliminary Design in advance of an external review by the Department of Energy Office of Science. The review was conducted by the Office of the Chief Project Officer, and chaired by Kem Edward Robinson on behalf of Michael Lindgren, the FNAL Chief Project Officer, at the request of Nigel Lockyer, Director of FNAL.

The committee determined that the project is developing well and has strong, capable project teams in place to develop and execute the project. All of the charge questions were answered positively. The consolidated and reconfigured project has developed rapidly and is progressing well. The committee feels that the LBNF/DUNE project will be prepared for the DOE CD-1 refresh review.

Environment, Safety and Health (ES&H)

The committee found that the project's ES&H hazards and controls are addressed in the Preliminary Hazards Analysis Report, the Integrated Safety Management, and Environmental Assessment and that these documents are well written and comprehensive. ES&H risks and issues are being properly identified and tracked in risk registries. Lessons learned are being appropriately incorporated from a variety of sources. The flowdown of ES&H requirements to DOE-leased spaces is addressed in the Project Execution Plan and should be further reinforced by highlighting the crosswalk that SURF performed (10 CFR 851 vs. OSHA). The commitment to ALARA, for industrial safety as well as radiation protection, is noteworthy.

Detectors

The detector team has done an excellent job in pulling together a CDR and presentations in very short order. The presentations were very good, although some refinement and tightening of them need to be completed before CD-1 refresh review. Some of the remaining issues are related to the newness and the complexity of establishing an international collaboration and dealing with many international partners. The management needs to pay close attention to the off-project areas that may have significant impact on the construction project. Although the detailed collaborator responsibilities cannot be crisply defined at this time, the assumptions of the division between DOE and non-DOE scope used for cost and schedule presentations should be clearly specified. The detector team will be in good shape for the CD-1 refresh review once the recommendations and some of the comments are addressed.

Beamline

In the beamline area there has not been significant changes to the design that was presented at the previous CD-1 review. The few changes to the baseline in this area were summarized in the plenary talk. The committee was very pleased to see that a Beamline Technical Design Review was conducted on May 27-28, 2015. We were presented with the review report, and concur with its recommendations. The design is beyond what is needed for CD-1. This committee has two general concerns. The first is the two-year gap in funding, beginning essentially now and going through FY17. The second issue is how the project will handle non-DOE funded portions of the scope in the beamline area.

Cryogenic Infrastructure

The Cryogenics Infrastructure subcommittee is satisfied with the technical progress at this stage of the project. The design appears to meet the requirements of the entire project. The reviewers were presented with descriptions of the cryostat, cryogenic cooling, ES&H – with an emphasis on oxygen deficiency hazards (ODH), argon procurement plans, refrigeration cost estimates and schedule. Requirements are for the most part well understood, independent reviews have been conducted; ES&H concerns have been well addressed, and in many areas the design is well beyond CD-1 requirements. The cryogenic cooling and ODH safety concepts are well developed for this stage of the project. A conceptual design of the cryostats was presented. The risk assessment has appropriately addressed argon procurement and the team is developing plans to reduce this risk.

Conventional Facilities

The conventional facilities team has put together a comprehensive CDR that meets science requirements and supports realistic cost and schedule estimates for this level of design. Many of the design elements have carried over from previous concepts. The conventional facilities team is well balanced, with good experience from previous LBNE work and newer members with key skills needed moving forward. The subcommittee recommends that the conventional facilities team continues to communicate with the cryogenic infrastructure group to develop the interface between the cryostat design and cavern dimensions as the project proceeds toward CD-3a. This may require an increase in the horizontal dimensions of the cryostat caverns to accommodate construction of the cryostat itself.

Cost and Schedule

The committee found that the scope, schedule, and cost were credible, realistic, and appropriate for a CD-1 review. The schedule was well developed and the cost details were well documented. A clear and coherent picture of how the LBNF/DUNE DOE project fits into the comprehensive international effort should be developed to facilitate the reviewers' understanding of the relationship. All project staff should understand this relationship as well, and be able to describe how their area of responsibility is impacted by, and fits within, the comprehensive international effort. The subcommittee believes these issues can be worked through and presented in a way to ensure a successful DOE CD-1 Refresh Review.

Project Management

Overall, a credible organizational, oversight, and project management structure was presented for developing the international partnership to execute the Fermilab/US-hosted world-class long-baseline neutrino program. The formation of LBNF and DUNE, the reconfiguration of the long-baseline neutrino program to a four cavern underground concept based on liquid argon time projection chamber (TPC) technology to meet the P5 requirements has been a remarkable accomplishment over the past 6 months. The key positions within the LBNF and DUNE projects are defined and for the most part staffed at a level sufficient for the CD-1R. The DUNE collaboration leadership is established along with a governance structure. Several management positions are not yet filled and should be filled as soon as possible after CD-1R. The CD tailoring strategy appears reasonable and justified. The project documentation for the required project management systems, with some minor cleanup, is suitable for CD-1 approval. Additional work is needed in refining the risk analysis and associated proposed contingency levels, as well as re-examining the requirements for systems engineering type functions, including associated staffing levels. Some benchmarking with other Laboratories could result

in refinement in the acquisition planning. With the resolution of Review Team recommendations, the project is ready to proceed with CD-1.

1.0 Introduction

A Director's CD-1 Refresh review of the Long Baseline Neutrino Facility/Deep Underground Neutrino Experiment (LBNF/DUNE) was held on June 2-4, 2015. The focus of this review was to assess whether LBNF/DUNE meets the requirements of DOE Critical Decision (CD-1) "Approve Alternative Selection and Cost Range" in preparation for the DOE Office of Science "CD-1 Refresh Review". The review was conducted by the Office of the Chief Project Officer, and chaired by Kem Edward Robinson on behalf of Michael Lindgren, the FNAL Chief Project Officer, at the request of Nigel Lockyer, Director of FNAL.

The charge for the review may be found in Appendix A of this report. The three-day review consisted of technical, managerial and programmatic discussions. The agenda is included with this report in Appendix B. The review committee consisted of external independent subject matter experts with relevant experience and knowledge. The list of the review committee members and their subcommittee assignments may be found in Appendix C.

This report reflects the general findings, comments and recommendations of the committee as a whole. An initial draft version of this report comprised the basis for the closeout briefing provided at the conclusion of the review.

The following provides context of this review and is quoted from the background section of the review charge:

> *Since the approval of CD-1 for the Long Baseline Neutrino Experiment (LBNE) in December 2012, the LBNE project has been recast as the Long Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE) in order to allow for enhanced capability through increased international participation. As a result, LBNF and DUNE have developed updated conceptual designs, cost and schedule estimates, management plans, and a Critical Decision tailoring strategy. ...*
>
> *DUNE will yield an experimental program in neutrino physics, nucleon decay, and astroparticle physics at LBNF using a deep underground liquid argon detector time-projection chamber (LAr-TPC) with an ultimate fiducial mass of 40 kilotons, to be built in increments of 10 kilotons at the Sanford Underground Research Facility (SURF) in South Dakota. The goal of the international team is for the first 10 kiloton fiducial mass detector to be deployed as soon as possible, followed by expansion to 40 kilotons as soon as possible thereafter.*
>
> *The project strategy has been developed to meet the requirements set out in the P5 report and taking into account the recommendations of the European ESPP strategy, adopting a model where the DOE and international funding agencies share costs on the DUNE detectors, and CERN provides large in-kind contributions to the supporting infrastructure.*
>
> *LBNF will provide:*
>
> - *Excavation in a single subcontract of four underground caverns at SURF, each capable of hosting a cryostat with a 10 kt fiducial mass LAr-TPCs.*
> - *Surface, shaft, and underground infrastructure to support the outfitting of the caverns, four free-standing steel-supported cryostats, and the cryogenic systems. The installation of the first*

two cryostats allows for a rapid deployment of the first two 10 kt far detector modules. The intention is to install third and fourth cryostats as rapidly as funding will allow.

- *The conventional facilities for the near detector systems at Fermilab.*
- *The conventional and technical facilities for a 1.2 MW neutrino beam for utilizing the PIP-II upgrade of the Fermilab accelerator complex, upgradable to 2.4 MW with the proposed PIP-III upgrade.*

DUNE will provide:

- *Four LAr-TPCs, each with a fiducial mass of at least 10 kt. The division of the far detector (FD) into four equal mass detectors allows the project flexibility in the installation and funding (DOE vs non-DOE) in the case of new resources being identified, mitigates risks, and allows for an early and graded science return.*
- *The near detector systems, consisting of a highly-capable neutrino near detector and the muon monitoring system to reach the precision requirements needed to fully exploit the statistical power of the very massive FD coupled to the powerful MW-class neutrino beam.*

Based on the reference design described the LBNF-DUNE conceptual design report, the project plan will first see the first two 10 kt far detector modules operational, with the beam shortly afterward. At this time the cavern space for all four 10 kt far detector modules will be available, allowing for an accelerated installation schedule if sufficient resources (likely international) for the experiment can be established. The project strategy described above meets the goals of reaching an exposure of 120 kt x MW x yr by 2032, and potentially earlier if additional resources are identified. The P5 recommendation of sensitivity to CP-violation of 3σ for 75% of δ_{CP} values can be reached with an exposure of 850 kt x MW x yr with an optimized beam.

This report is organized around the review technical subcommittees: Detectors, Beamline, Cryogenic Infrastructure, and Conventional Facilities. Additional subcommittees examined the Environment, Safety and Health (ES&H), Cost and Schedule, and Project Management. The specific charge questions associated with each area and the attendant findings, comments and recommendations are contained in the subsequent sections of this report.

2.0 Environment, Safety & Health (ES&H)

Charge Questions:

- Are the required environmental approvals and permits on track to meet the project schedule?

  — *Yes*

- Have the required ESH documents been updated for the CD-1 refresh?

  — *Yes*

- Is ESH being appropriately addressed given the projects' stages?

  — *Yes*

Findings

- ES&H hazards and controls are addressed in the Preliminary Hazards Analysis Report, Integrated ES&H Plan and the Environmental Assessment.

- ES&H risks and issues are being identified and tracked in the risk registries.

- The Project Execution Plan (PEP) draft contains a strategy for assuring the required environmental approvals and permits will meet the project schedule.

- Radiation Physics simulations are being benchmarked against NUMI and NOVA for validation.

Comments

- The DOE decision to pursue an EA rather than an Environmental Impact Statement (PEP page 31) is beneficial to the project.

- There is only one ESH risk being tracked on the Project Level Risk Registry and this regards the unknowns associated with tritium production. The mitigation action to complete simulations in time to iterate on CFNS design appears to be a manageable action.

- The Preliminary Hazards Analysis Report is very well written and is comprehensive.

- The LBNE/DUNE project is actively incorporating lessons learned from other neutrino experiments and DOE operating experience (e.g. WIPP, NuMI,MINOS) yielding safety, cost and schedule benefits. Also, workshops and reviews include subject matter experts from other neutrino facilities. These are best management practices.

- There is a clear delineation of ESH requirements at the SURF between DOE leased areas and non-DOE areas (e.g. 10CFR851 vs OSHA). The flowdown of DOE requirements to DOE leased spaces at SURF is addressed in the Project Execution Plan. However, the apparent plurality of requirements could be confusing to reviewers. This confusion may be alleviated early in the presentations, perhaps even in the Plenary presentations, by explaining (1) that SURF did a crosswalk between OSHA and

10CFR851 requirements which illustrated that the requirements are not significantly different and (2) the SURF ES&H Manual is derived from the FermiLab ES&H Manual.

- Fermi Lab's ES&H organization is actively engaged with the Project (e.g. the ES&H Director is visiting SURF).
- The hazard analysis for oxygen deficiency is thorough, detailed, and advanced at this stage of the project.
- The commitment to design for safety and ALARA is impressive. Examples include:
  - Argon and nitrogen gas transport system
  - Utility corridor to support the four cryostat chambers
  - Severe restrictions on proton beam losses to minimize activation
  - Above ground beam/target construction to minimize impact on groundwater
  - Designing shielding for 2.4 MW and gaining five years of operating experience at 1.2 MW to validate the design.
  - Radiotolerance and design life of 50 years for the geosynthetic membrane.

Recommendations

1. The crosswalk comparison of the 10CFR851 and OSHA requirements illustrated that the only significant difference is the reporting requirements. Although the 10CFR851 reporting requirements only apply to the DOE leased areas at SURF it is recommended that SURF continue to maintain the current reporting protocols for the SURF non-leased areas with Fermilab which have been utilized between LBNL and SURF management, which are working well, after the operations the transition from LBNL to Fermilab in 2017 (post CD-1).

2. The selection of a Construction Management (CM) contractor is key. As part of the construction management plan it is recommended that the project consider (post CD-1):
   - Flowing down the safety performance selection criteria to subcontractors
   - In addition to the safety selection criteria of OSHA recordable rates and Experience Modification Rates, require bidders to submit their safety and health plan
   - Provide safety incentives in the contract
   - Use a unified insurance plan
   - CM should provide a nurse on-site during the construction phase

3.0 Detector

Charge Questions:

- Have the performance requirements been defined and are they consistent with the Particle Physics Project Prioritization Panel (P5) recommendations and the DOE mission need?

  — Yes. The performance requirements have been defined and include and are consistent with the P5 recommendations, although some of the alternatives discussed could provide more robust P5 recommendation performance. Given that DOE mission need (CD-0) was developed before the recent changes, we have limited our response to the P5 recommendations only.

- Have independent design reviews been conducted?

  — Yes. The independent design reviews have been conducted, but only concluded very recently. As a result, the committee was not able to carefully study these review reports, but the project appears to have successfully passed the reviews.

- Based on the design reviews, are the conceptual designs sound and likely to meet the physics requirements?

  — Yes.

- Are the conceptual designs described in the Conceptual Design Report representative of the entire scope and adequately defined to support the associated cost and schedule ranges?

  — Yes. The reference design together with possible alternatives described in the CDR were presented to the committee and we find them representative of the scope required to meet P5 recommendations. Given the complexity of the international contributions, it is important to state clearly what the assumptions on the non-DOE scope are in order to support the transition from the CDR to the cost and schedule ranges presented.

Findings

- The conversion of LBNE/LBNO to LBNF and DUNE has brought significant changes and new opportunities for the detectors. International collaborators will now make major contributions to the near detector and the far detector.

- The DUNE detector consists of two major elements – a Far Detector (FD) and a Near Detector (ND)

- The FD consists of four 10 kt (fiducial volume) liquid argon detectors located at the SURF facility in South Dakota at the 4850 ft level. The DOE is planning to commit to ~50% of the first two detectors.

- The DUNE collaboration is a newly formed international collaboration with major partnerships being developed with Italy, CERN and India to date. Agreements have not yet been finalized.

- The DUNE physics requirements were updated to be consistent with the P5 recommendations and include nucleon decay and astrophysical neutrinos (atmospheric, supernovae) compared to the last

CD-1. The ND has been designed for beam-neutrino physics. The FD can meet the physics requirements. A low-cost alternative design to improve timing performance and electron energy resolution for low-energy supernova neutrino events was presented.

- The committee heard seven talks on the FD and eight talks on ND over two days.
- The FD uses single-phase technology as the reference design for at least the first 10kt detector. The expected better performing dual phase technology is being considered as a potential upgrade for the remaining 10kt detectors.
- Conceptual designs and conceptual schemes for detector production were presented. Also a preliminary conceptual scheme for detector assembly was presented.
- The staging plan for the FD was presented.
- The ND, located on the Fermilab site, is based on proven technology (straw tubes for tracking, lead-scintillator for calorimetry and RPC for muon detector) with a total channel count similar to existing detectors.
- A crisp definition of "preliminary US vs. non-US" contributions for the ND was presented.
- A conceptual scheme for detector assembly in the ND experimental hall was presented.
- The collaboration indicated that a ND task force charged with performing an end-to-end physics simulation to help to define the appropriate requirements for the near detector system is planned.
- In the ND, a gaseous argon target is planned to study nuclear effects for the FD. The stated goal is to acquire 10 times the un-oscillated events compared to the far-site.
- The near detector system seems (on paper) to be able to measure fluxes independently of poorly known nuclear cross sections by using various leptonic processes, which are theoretically clean and thanks to the fine grained tracker can be identified with good efficiency and reasonable purity. The relevant nuclear cross sections can be determined by a combination of better beam predictions, largely derived from data from US NA61, and the measured fluxes. If necessary, the specifications and design of the near detector will be adapted.

Comments

- Overall the committee was impressed by the significant amount of work that has gone into the preparation of this review. The presenters are to be commended and the committee appreciated their openness in discussions. However, given the short time available for preparation it is not surprising that there are some rough edges that need to be polished before the upcoming CD-1 refresh review.
- The international nature of the DUNE project and the early stage of the collaboration make it difficult to crisply specify DOE and non-DOE scope. It is true that the collaboration needs to retain flexibility in assigning responsibilities at this stage. That said the split seems well defined for the ND, and less well defined for the FD. It would be useful to, as best as possible, state the assumptions used to define the DOE and non-DOE scope.

- The formation of the end-to-end physics simulation task force is commendable. However, it is unclear whether there is sufficient manpower available and whether the reconstruction software development will be concluded in time for the finalization of the DUNE detector for the TDR. The collaboration should be prepared to articulate a plan on how they will find the required manpower.

- The near detector plan presented appears to be well organized and advanced. The DOE contributions appear to be understood.

- The far detector plan is less certain. Following two major paths (single phase and double phase) may prove a challenge to manage resources.

- While all conceptual schemes for detector design, assembly and installation have been presented, neither design, nor production scheme, nor assembly procedures can be considered much more advanced than "conceptual" and definitely not ready for "baseline". So DUNE is meeting CD-1 requirements, but still a lot of work to do before CD-2.

- There has been little time for the DUNE collaboration to react/respond to the external review recommendations.

- The choice of the single phase LAr detector is a good choice for the conceptual design. However the conceptual photon detection design is marginal at best for low energy neutrino physics.

- Detector interfaces are always a potential area of confusion, so continue to play close attention to interfaces.

- Given the difficulties that other experiments have had with small passive nuclear targets, it would be worthwhile to explain why the planned gaseous argon target in the ND will not be a problem in this case. The concerns are reinforced by the proposed use of a calcium target, for which the justification apparently is that it has the same atomic mass as argon. The potential mitigation strategy for the risk associated with the gaseous internal argon target is an external active argon detector. This is a valid strategy for a CD-1 review but the "belt and suspenders" approach needs to be carefully presented.

- The testing of the cold electronics front end ASIC and ADC with a detector in August of 2015 and the testing of the same electronics with a full scaled prototype at CERN in 2018 are excellent opportunities to evaluate the cold electronics and LAr detector system. It is unfortunate that the COLD DATA chip will not be available for testing even in 2018. The reason is that an engineer is not available for this job.

- The dual phase LAr approach is an exciting and promising approach for the 2nd, 3rd and 4th 10 kt detectors. However this raises the question of whether or not to purchase the cold ASICs for all of the detectors at once. If the cold ASIC technologies are expected to be available for the foreseeable future, it may be worth considering staging the purchases with multi-project runs.

- If the 2 phase LAr detector is adopted, it is likely that none of the cold electronics may be used. The experiment should discuss who and how the production electronics would be built for the two-phase LAr detector.

- ITAR may not be an issue for the electronics, but given the international nature of DUNE and the potential of possibly shipping restricted items it might be prudent to verify that ITAR is not an issue, or if it is, specify how it will be dealt with.

- Fast MC choices and parameters are not documented in the CDR. Based on the information provided by Elisabeth Worcester: A.3 of the science book and the Table on page 12 of doc-DB 7806 is a good description of the process. Merge and update the table to use *actual* values and make it part of the CDR, maybe annex 4C.

- Supernova pointing in Ref. 163 is quite old (2003), despite this being an important part of the supernova physics program.

- A larger ND hall appears like a very good investment.

- Since a specific charge was to assess that the performance requirements have been defined and that they are consistent with P5 recommendations, and assuming this same charge will be given to the CD-1 committee, then it would help future reviewers to have a way of clearly identifying the "P5 related" items in the requirements document.

- The agenda of the review was less than optimal. Having two large blocks of talks on far detector and near detector without time for drill downs on day 1 and no mechanism to reply to questions on day 2 did not work very well. One overview talk each for the near and far detector and how they work together on day 1 would have been preferable, also the dual phase alternate detector presentation should be given on day 1. Overall, 7+ talks on each of the two detectors seems excessive.

- The handling of non-DOE risk as explained in reply to a question by the committee should be summarized in one of the introductory high-level management talks.

- The drill down preparation needs to be practiced – it was confusing and presenters stumbled when asked to follow a specific drill-down path for DOE items. They need to practice this drill-down to make it defendable.

- The mechanics of some of the presentations need to be checked beforehand – some pdf and mac-pc "translation" problems are avoidable problems. Be sure to check that they work before giving the talks.

- Some presentations failed to properly label cost numbers. Be sure to specify AY$, FY15$, etc. for clarity

Recommendations

3. Refine the detector commissioning activities that will be included in CD4. This should be done for the CD-1 refresh review.

4. Work with DOE (and other partners if appropriate) to assure adequate off-project software/computing support is available in order to minimize risk to the project [post CD-1].

5. Clearly identify the "P5 recommendation" items in the requirements document as it flows down from the science requirements to the performance requirements. This should be done for the CD-1 refresh review.

6. Seriously consider inclusion in the "reference design" of the photon detector scheme presently considered as "alternative" to allow a better reach in supernova neutrino physics (low energy ~10 MeV). This should be done as quickly as possible.

7. Hire an ASIC engineer with appropriate experience as soon as possible for the cold electronics [post CD-1].

8. Address as much as possible all the technical review recommendations before the CD-1 refresh review

9. Clearly state the assumptions used to define the DOE and non-DOE scope in the detector presentations. This should be done for the CD-1 refresh review.

4.0 Beamline

The beamlines scope of work was presented and showed there have not been significant changes to the design that was presented at the earlier CD-1 review. The few changes to the baseline in this area were summarized in the plenary talk and are: helium in the decay pipe, a replaceable upstream decay pipe window that separates the air-filled Target Chase from the helium-filled Decay Pipe, and component readiness for 1.2 MW on day one instead of 700 kW.

The committee was very pleased to see that a Beamline Design Review was conducted on May 27-28, 2015. We were presented with the review report, and concur with the recommendations made.

This committee has two general concerns included in what is noted below. The first is the two-year gap in funding, beginning essentially now and going through FY17. The second is the issue of how the project is going to handle non-DOE funded portions of the scope in this area.

Charge Questions:

- Have the performance requirements been defined and are they consistent with the Particle Physics Project Prioritization Panel recommendations and the DOE mission need?

  — Yes, the performance requirements are well defined, consistent with the P5 recommendations and DOE mission need.

- Have independent design reviews been conducted?

  — Yes, there have been a number of design reviews appropriate for this stage of the project. In particular a technical review of the beamlines systems was conducted one week before this review, and the report was made available. This review had talks on critical level 4 systems that we were not able to accommodate in our review schedule. There have also been important reviews on issues such as "Air releases". While not explicitly "reviews", we note that many lessons learned from existing Fermilab neutrino beamlines and projects have been incorporated to further validate the conceptual design choices.

- Based on the design reviews, are the conceptual designs sound and likely to meet the physics requirements?

  — Yes

- Are the conceptual designs described in the Conceptual Design Report representative of the entire scope and adequately defined to support the associated cost and schedule ranges?

  — Yes

Beamline General

Findings

- There is a ~2 year funding gap for the beamline WBS elements. That gap begins now and runs through FY17.
- About 25% of the beamline cost is expected to come from non-DOE sources.

Comments

- The committee is concerned that the 2-year funding gap will have significant impacts on the state of the beamline design. We have several suggestions, leading to recommendations, to minimize this impact. Firstly we are concerned that staff with unique skills could choose to leave the laboratory during this period. To this end we encourage the lab to document the state of the design as well the underlying reasons for the design choices as soon as possible with remaining funds. Secondly, there are several critical areas of design work that should be brought to a good stopping point before going into the funding gap. It would be unfortunate to need to start over and duplicate work.

- Since the beamline design is well advanced, even at the component level, any non-DOE contributions will need to build-to-design. This may make attracting contributors more challenging as contributors often desire intellectual ownership.

Recommendations

10. Document the designs and, bases of design, of beamline systems before going into the funding gap period [post CD-1].

11. Ensure that ongoing design work is brought to a good stopping point before turning off beamline work due to the funding gap [post CD-1].

12. Proceed to CD-1

Primary Beamline

Findings

- The primary beamline delivers protons from a new extraction point at MI-10 in the Main Injector to the LBNF target hall, pointed at the Far Detector. An artificial hill is constructed to allow the correct down bend without requiring deep underground construction. The beamline transport is tunable over the full design range of 60-120 GeV. A separately tunable final focus section allows for the independent tuning of the beam spot size at the target, with a maximum design spot size of 4 mm, which will permit operation at 2.4 MW.

- The construction of the artificial hill will take place early in the project, with an anticipated CD-3b in May 2018. This allows the settling of the earth to be largely complete before the beamline is installed.

- Much of the installation work in the primary beamline is sequential. This is driven by safety considerations associated with installing heavy equipment (magnets etc.) on a hill.

- A design review was completed on 27-28 May 2015. There have also been detailed reviews of particular subsystems, for example a design review for the new-build corrector magnet, and a radiation shielding review of the primary beamline.

Comments

- The design of the primary beamline has advanced well past the conceptual stage in all areas, and in most parts is complete to a preliminary level.

- The LBNF project team has successfully incorporated lessons learned from NuMI and from other recent accelerator construction into the planning for the project.

- The requirement for beam transport losses of less than 10^{-6} is achievable based on experience with NuMI. The LBNF optics design supports this requirement.

- The primary beamline is of standard design and construction, and poses no unusual risks to cost or schedule. The installation on a slope presents challenges that are not present in a horizontal installation; the issues involved appear well thought out, and Fermilab has experience with the construction and maintenance of the NuMI beamline on a similar grade, which lends confidence to these estimates.

- The planned early installation of the hydrostatic level system to monitor the settling of the beamline enclosure will validate geotechnical calculations.

- The main bend and focusing elements are of existing design, with which there is substantial operational experience. The dipole correctors are a sensible modification of an existing design; the design has been reviewed and a prototype will be constructed.

- The instrumentation scheduled for installation (button BPMs, toroids, multiwires, beam loss monitors and total beam loss monitors) are of existing design or have been successfully prototyped.

- The project should consider installing at least one resistive wall current monitor along with the other instrumentation.

Recommendations

- None.

Neutrino Beamline

Findings

- The performance of the Neutrino beamline has been thoroughly studied over the past years and documented in the physics section of the CDR. A baseline design of the Neutrino beamline has been presented to produce a beam with the desired characteristics.

- A major scope change has occurred since the 2012 CD-1 review, namely the requirement to be ready on day one for 1.2 MW operation vs. 700 kW of the previous design, to take into account the possible availability of the PIP II linac around 2024. This required the revision of the design of all the elements of the neutrino line (target, horns, horn power supply etc…). In addition, the project has been asked to study the 2.4 MW option to identify items that have to be inserted already in the present baseline

because it would be too costly or impossible from an ALARA point of view to realize after a period of operation at 1.2 MW

- Presently the facility is designed to cope with 5 years of operation at 1.2 MW, and 15 years at 2.4 MW. Taking into account shutdowns and inefficiencies of the injectors, the real lifetime of the facility is estimated at 30 years. All infrastructure (tunnel, water containment by geomembranes etc. have been designed to last at least 50 years. Radiation damage to the infrastructure has been taken into account for lifetime estimation.

- The design of all the beam elements is based on the experience from NuMI and therefore presents very few unknowns – provided the experience of people working today on this equipment is captured and transferred to those who will have to build and run the components of LBNF. A succession plan for those people has not been presented and represents a major concern for this committee, even though this does not fall under the scope of the CD-1 review.

- Possible improvements to the physics performance are discussed in the EFIG working group between the LBNF beamline team and the DUNE collaboration to insure full mutual understanding of the performance reach of possible alternatives. Recently, the two teams have come to a consensus for a modification of the design of the focusing system that increases the neutrino flux and reduce background in the 2nd oscillation region.

- The new design involves a major modification of the target chase, since it requires an enlargement by 10 meters in length and 60 cm in width, implying an increase in budget of about $14M. The beamline team has investigated also other possibilities, namely the enlargement of the Decay pipe or increasing its length to 250m. Those options are by far more expensive (up to $55M) and much less efficient (neutrino flux lower by at least 10%). Convincing plots of neutrino flux enhancement have been produced.

- Radioprotection studies have been conducted and shielding designed accordingly. A design review for air releases has been conducted with positive results.

Comments

- The Neutrino beamline design has already been reviewed for CD-1 and approved by the DOE in 2012. Since then the following changes occurred:
  - Decision to have He in the decay pipe, introducing the need for an upstream window to separate the decay pipe from the target chase atmosphere
  - Decision to enlarge the target chase to be able to accommodate an optimized horn type focusing system.
  - Revision of the horn and target design to cope with 1.2 MW proton beam on day1.
  - Decision to design certain elements to be compatible with a possible upgrade of the facility at 2.4 MW.

- All the previous changes have been presented to technical reviews and accepted by the project management. Their level of development is well beyond what needed for CD-1 approval and we believe the project team should be commended.

- The main concern for this committee is the suspension of the budget available to the beamline team to carry on activities across FY 2016 and 2017. The project team shall make plans on how to keep the know-how acquired and restart at full speed in FY 2018 when funds will become available again to prepare the CD-2 – CD-3c review presently planned in December 2019.

- The project team should be maintained at least for the time needed to properly document all design choices, and to start the analysis of the impact of modifying the target chase and the horns.

Radiation Safety

Findings

- Radiological safety concerns address both off-site and on-site conditions, and address ground and surface water, prompt radiation, residual radiation, and activated air emissions.

- The LBNF radiological design goal is to contribute to less than 30% of the limits of the environmental radiological quantities specified by the Fermilab policies and implement ALARA in all aspects of the design

- The parameters used in the design are a 2.4 MW beam; 5 years at 1.2MW and 15 years at 2.4 MW.

- Simulation work is ongoing in these areas.

Comments

- Robust designs have been developed to deal with the radiation issues noted above.

- The specific design reviews which have begun in this area are very helpful, (i.e., “Air Releases” and “LBNE Primary Beam Radiation Shielding Review”). We anticipate and encourage other reviews related to radiation safety as the project proceeds.

- The simulation work has been benchmarked with data from NuMI. This should continue as power levels at NuMI increase.

- It is important that the expertise gained in this area (particularly related to simulations) is not lost during the two years in which this WBS area receives little funding.

Recommendations

13. Use every opportunity to gather data from NuMI that can help validate design choices or benchmark simulation codes, even during the two-year funding stop [post CD-1] .

Risk

Findings

- At the 2012 CD-1 review there were 34 Beamline risks and 1 opportunity
- Three risk workshops have been held since the 2012 CD-1 review where each Beamline risk was re-evaluated and either retained/ revised, archived, retired or deleted.
- As of now there are 38 risks and 1 opportunity

Comments

- Risk analysis is thorough and well advanced, particularly for this stage of a project
- Beamline risks are not related to unknown scientific or engineering challenges, rather a choice has been made for a less expensive solution, and the risk is associated with falling back to the more expensive solution. Contingency has been allocated.
- A number of risks await the conclusion of the Corrosion Working Group's studies and analysis.

Recommendations

- None

Scope Enhancement

Findings

- Optimization of simulated horn shapes indicate a significant enhancement of the sensitivity to the mass hierarchy and δ_{CP} could be achieved with a redesigned focusing system.
- To accommodate the larger horns required for this, the target chase will be made longer by 10 m and wider by .6 m. ($14M and will be in base cost at CD-1).

Comments

- The committee concurs that this is a good, cost effective way to increase the physics reach.
- The CDR should be updated to reflect this change before the CD-1 review

Recommendations

- None.

Installation:

Findings

- We were shown the installation schedule for all beamline activities, and took a close look at magnet installation, including a drill down into installation effort and costs.

- Installation has been planned with a high level of detail, particularly for a design at the conceptual level.

- Much of the installation planning and costs is based on recent experience at Fermilab on ANU, and the LBNF planning is being done by the same people.

Comments

- The planning for installation is thorough. We did not observe any missing pieces in the installation planning. The estimates appear credible, and the allotted contingency is healthy. We understand the contingency may be revised downward as the design is firmed.

- We acknowledge that the installation of LBNF is many years in the future. The installation planning thus far has been done without consideration of other activities at Fermilab. As the installation nears we would expect FNAL to look into efficiencies of shutdown planning and resource allocation to minimize impact to the ongoing physics programs.

Recommendations

- None.

5.0 Cryogenic Infrastructure

Charge Questions:

- Have the performance requirements been defined and are they consistent with the Particle Physics Project Prioritization Panel recommendations and the DOE mission need?

  — *Yes*

- Have independent design reviews been conducted?

  — *Yes*

- Based on the design reviews, are the conceptual designs sound and likely to meet the physics requirements?

  — *Yes*

- Are the conceptual designs described in the Conceptual Design Report representative of the entire scope and adequately defined to support the associated cost and schedule ranges?

  — *Yes*

Findings

- Cryogenic Infrastructure falls under the "far site" portion of the LBNF Project.

- The far detector consists of QTY4 10 kt fiducial mass (17.1 kt total mass) LAr TPC modules which are implemented in a staged approach in four independent 19 m x 17 m x 68 m caverns.

- LAr market risk (CR-103) is the highest ranked risk for both the LBNF and DUNE projects with a 50% probability of occurrence, $36M cost impact, and 12-month critical-path delay. LAr procurement may be funded via the Common Fund.

- ES&H methodology follows the Fermilab ESH Manual (FESHM) and satisfies the requirements of all project and facility partners.

- Since the original CD-1, the following major changes to the cryogenic infrastructure and LAr cryostat have been implemented:
  - LAr cryostat uses free-standing steel support structure
  - Larger LAr filters housed in vacuum jacketed vessels, quantity of 4 each gas & liquid filters per module
  - LAr condensers have the LN_2 moved to the tube side and are sized for GAr filling (85 kW each)
  - LN_2 cryoplant locates the coldbox in the utility cavern and the compressors on the surface.

- LN_2 storage dewars in the utility cavern provide enough refrigeration to last ~2 days in the event of a power outage.

- Boost compressors are located in the utility cavern to push GN_2 back to the surface compressors.
- Equipment installation is staged such that there will be quantity of 3 systems available to cool the first two modules.
- DUNE LAr requirement equals 3% of annual US capacity, which is running around 90% utilization.
- Conservative oxygen deficiency hazard (ODH) analysis indicates ODH Class 0 for the Ross shaft and ODH Class 1 for the detector module and utility caverns.

Comments

- Communication with other systems (particularly Conventional Facilities [CF]) regarding interfaces has been excellent so far and should be maintained.
- Although a decision strategy has been developed, the dividing of scope between DOE and non-DOE partners may carry both cost and schedule risk which should be captured by the project.
- The project has an extensive list of Cryo Level-2 Science and engineering objectives. Some objectives are clearly defined and others should be quantified. For example, the team has adopted a self-imposed target for LAr fill duration of 6-12 months but guidance from a defined objective would be beneficial.
- Risk analysis seemed to focus correctly on the liquid argon supply. The project has a good plan to develop alternative supplies and reduce this risk.
- The motivations for moving to a free-standing steel cryostat support structure are reasonable and appear to be acceptable to the non-DOE candidate contributors.
- Cost data are quite mature for this stage of the project. The cost management strategy is well developed and well implemented. During drill down the BOE estimates we saw regarding the RFP design and cold box installation underground seemed reasonable and well documented. A 20% contingency on labor may be low, but the estimates themselves seemed to be adequate. These are split between surface and underground installations. The project should also include estimates for vendor oversight.
- ODH preliminary analysis and ventilation plan is well developed for this stage of the project.
- Purification and condensing plan seems well developed for this stage of the project.
- The project has clear plans to purge, cool down and fill the cryostats. Provisions to empty the cryostats at the end of the project should be considered during the design phase. It is recognized that this responsibility is outside the LBNF project scope and must be addressed by SURF/DUNE/DOE as part of the decommissioning plan.
- The inclusion of cryogenics-related long lead procurements in CD-3a is uncertain at this point. The LN_2 cryoplants at $5.6M per unit would be an appropriate candidate for long lead procurements (LLP).

Completing the pre-CD-3a tasks by November 2015 will be a challenge. Tasks related to the design of the membrane cryostats (in particular the CF interfaces) must be finished before CD-3a.

- We note that there are still open recommendations from previous reviews, some of which are not scheduled to close until the end of CY2016.

Recommendations

14. Develop an end-of-life disposition concept for the LAr prior to CD-1.

6.0 Conventional Facilities

Conventional facilities are divided into near site and far site. The project and review team evaluated progress at both sites. Due to the schedule, science prioritization, and complexities of far site facilities and design over the next two years, many of the comments and recommendations focus on the far site. The committee believes that both near site and far site are prepared for the upcoming CD-1 refresh.

Charge Questions:

- Have the performance requirements been defined and are they consistent with the Particle Physics Project Prioritization Panel recommendations and the DOE mission need?

  — Yes, the performance requirements for conventional facilities have been defined based on LBNF/DUNE experimental needs and meet P5 recommendations regarding schedule (before 2035), detector fiducial volume (40kt Lar) and beam energy (upper bound of 2.4 MW > 1.2MW).

- Have independent design reviews been conducted?

  — Yes. Hatch Mott MacDonald has completed an independent design review for the far site, Burns and McDonnell has completed an independent design review for the near site. In addition, an independent advisory board (NCAB) has been engaged to provide guidance on design issues specific to the cryostat caverns. The conventional facilities project team has responded well to suggestions from the independent reviewers and advisory board.

- Based on the design reviews, are the conceptual designs sound and likely to meet the physics requirements?

  — Yes, the conceptual design appears appropriate to enable beam energy and detector fiducial volumes identified by P5.

- Are the conceptual designs described in the Conceptual Design Report representative of the entire scope and adequately defined to support the associated cost and schedule ranges?

  — Yes, the CDR conventional scope appears comprehensive and supports the cost and schedule estimates.

Findings

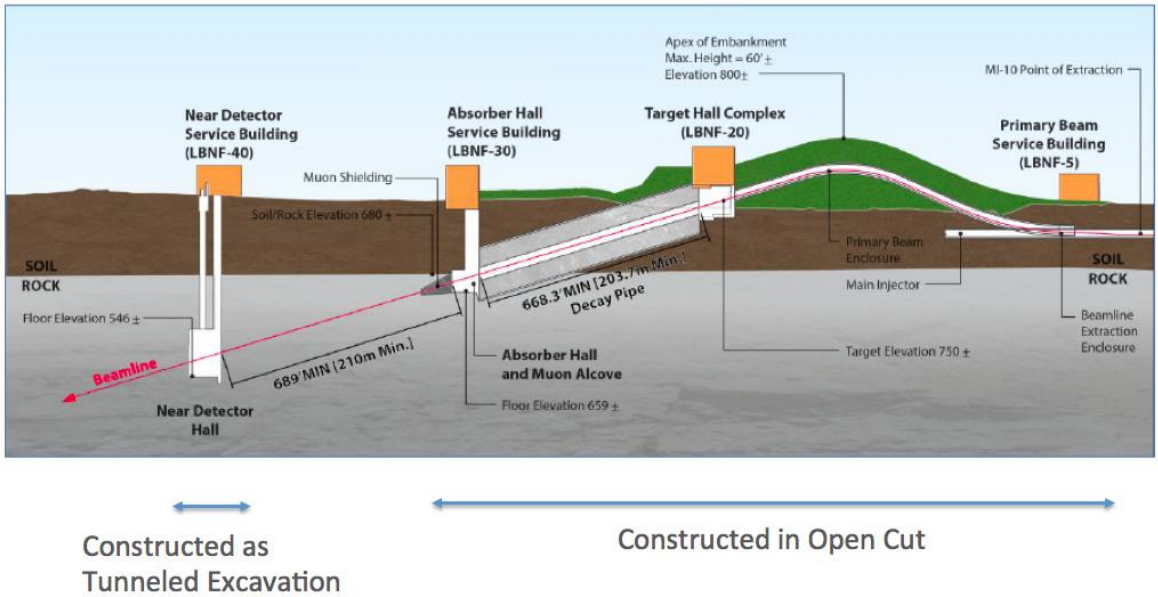
- The conventional facilities scope is divided into near site (at Fermilab) and far site (at SURF).

- Conventional facilities are the responsibility of LBNF with DOE funding.

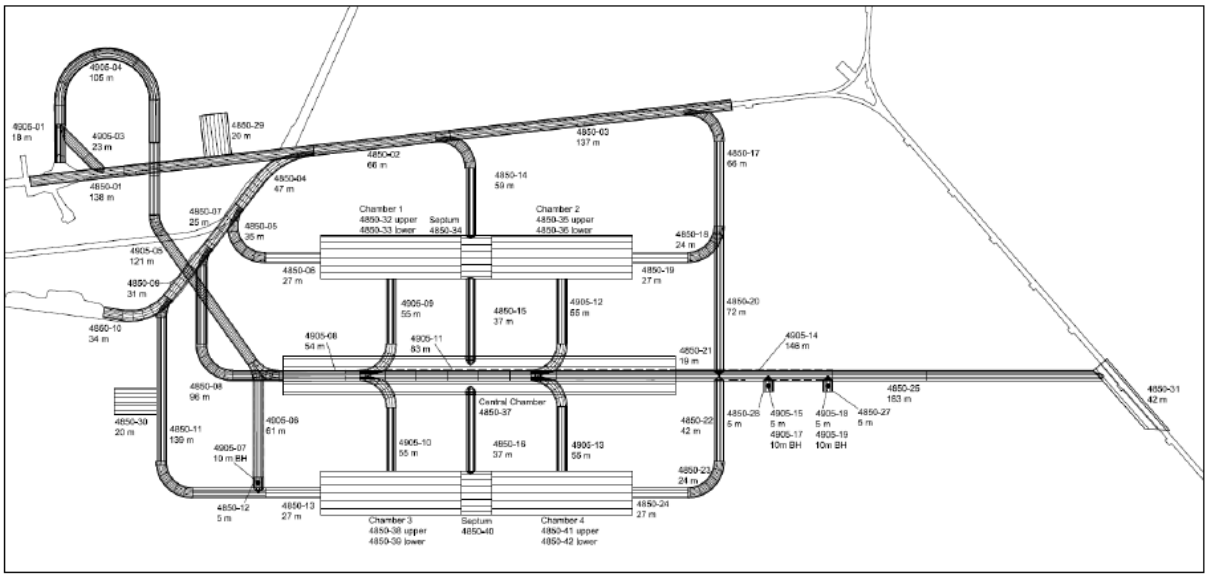
- Design requirements, specifications and assumptions have been documented and flow down from high-level science requirements such as the P5 guidance of 40 kt LAr detector and 1.2 MW beam power upgradable to 2.4 MW capacity.

- A conceptual design exists for both sites and has an estimated average maturity of 20%.

- Near site conceptual design consists of a near surface, primarily cut-and-cover solution that includes a near detector hall, absorber hall, target hall and primary beam (connection to Main Injector) outfitted with mechanical, electrical, plumbing, fire protection systems and finishes required to support 2.4 MW beam power. Limited drill-and-blast excavation will be required for the portions of the Near Detector Hall to be placed in bedrock. Most recently a decision has been made to utilize a helium filled decay pipe to improve beam quality. See image below:



- The scope at the far site includes rock excavated drifts and caverns on the 4850 Level at SURF that are sized to house a 40kt fiducial volume LAr detector and related heat rejection, mechanical, electrical and life safety systems. Scope and cost for cryogenic systems contained in the central utility cavern are outside of the Conventional Facilities scope and contained in another project WBS. One surface building and portions of other surface infrastructure are also included in the Conventional Facilities The image below shows the excavations at the 4850 Level associated with LBNF/DUNE:



- Requirements for dimensions of each of the four far site caverns shown on the conceptual design drawings can be traced back to external dimensions of the planned DUNE cryostats (DocDB #3383). Current dimensions for cryostat and cavern are shown in the table below:

	Cryostat Outside Dimension (m)	**Cavern Inside Dimension (m)**	**Clearance (m)**
Width	18.72	19.3	0.29
Length	65.62	66.2	0.29
Height	16.62	16.9 (to springline)	0.28

- Waste rock disposal will be skipped up the Ross Shaft, transported by conveyor to a location on Kirk Road, then trucked to the former Gilt Edge mine, which is now a federal Superfund site. Gilt Edge has more capacity than needed to accept the volume of waste rock anticipated from the LBNF/DUNE excavations. Appropriate agreements are being pursued to facilitate this option.

- Independent design reviews of the current conceptual design of the far and near site have recently been completed by Hatch Mott MacDonald (HMM) and Burns & McDonnell respectively.

- An independent advisory board (Neutrino Cavity Advisory Board, NCAB) has been engaged.

- Cost estimates have been developed and compared with independent cost estimates based on work done on previous iterations related to LBNE. Estimated costs based on this work are as follows:

L2 Project	Estimated Costs through FY15	Base Cost beyond FY15	Est Uncertainty Contingency	Actual + Base + EU Cont.
130.06.01 CF Project Management	**$3,780 K**	**$13,536 K**	**$2,707 K**	**$20,023 K**
130.06.02 Near Site Conventional Facilities (NSCF)	**$6,122 K**	**$264,839 K**	**$65,515 K**	**$336,476 K**
130.06.02.01 NSCF Project Mgmt & Concept thru CD-1	$3,966 K	$3,380 K	$676 K	$8,022 K
130.06.02.02 NSCF Conceptual Design beyond CD-1	$1,498 K			$1,498 K
130.06.02.03 NSCF Preliminary Design	$658 K	$7,453 K	$1,491 K	$9,602 K
130.06.02.04 NSCF Final Design		$12,276 K	$2,526 K	$14,802 K
130.06.02.05 NSCF Construction		$241,730 K	$60,822 K	$302,552 K
130.06.03 Far Site Conventional Facilities (FSCF)	**$13,384 K**	**$287,443 K**	**$87,680 K**	**$388,507 K**
130.06.03.01 FSCF Project Mgmt & Concept thru CD-1	$5,066 K	$3,023 K	$231 K	$8,320 K
130.06.03.02 FSCF Conceptual Design beyond CD-1	$1,435 K			$1,435 K
130.06.03.03 FSCF Preliminary Design	$6,644 K	$1,377 K	$249 K	$8,270 K
130.06.03.04 FSCF Final Design	$239 K	$14,469 K	$2,832 K	$17,541 K
130.06.03.05 FSCF Construction		$249,126 K	$82,444 K	$331,570 K
130.06.03.06 SURF Operations		$19,447 K	$1,924 K	$21,371 K
	$23,286 K	**$565,818 K**	**$155,902 K**	**$745,006 K**

- Updated cost and schedule estimates, reconciled with the HMM independent estimate and based on current LBNF/DUNE conceptual designs, have recently been received from the A/E consultants for the far site. The project team reports that the updated cost/schedule will be incorporated into the CD-1 review in July 2015.

- The far site construction is considered highest priority with construction beginning in FY17 and completing in FY23. A CD3a is scheduled for Fall 2015 to support the FY17 start at the far site.

- The near site funding for construction will be delayed. Near site activities are expected to begin in FY18 and complete in FY25.

- The project and sub project risk registers contain a total of 29 conventional facility related risks, 5 of which are at a high or medium high level and include some level of mitigation planning.

- Construction Manager / General Contractor (CM/GC) delivery method is planned for both sites. An advanced procurement plan has been developed for the far site. A draft RFP for CM/GC services has been prepared and is being socialized through Laboratory and DOE channels to expedite award later this year in time for CD-3a and completion of the preliminary design.

- A preliminary Fire Hazard Analysis is complete for both sites documenting compliance with local requirements for life safety and fire protection.

Comments

- Design maturity of conventional facilities is sufficient for CD-1.

- The Conventional Facilities team for both the near site and far site has a good blend of experience from LBNE and newer members with key skills. The team has done a very good job of integrating past designs and evaluations with new work to quickly react to evolving requirements and facility configurations. Good integration and open communication between LBNF and SURF personnel is

evident. The current A/E consultants are working well with the project team and also respond well to changing project needs.

- Strategizing the approach to preparing for the far site CD-3a is critical. Working with the DOE site and program offices on expectations of design completion and cost risk mitigation are key to focus efforts to meet this aggressive CD-3a milestone.

- The project would benefit if the far site CM/GC could be in place prior to the CD-3a review. Having CM/GC input to preliminary and final design, and potential EH&S procedures during construction would streamline design and reduce uncertainties.

- Evaluation of constructability of the far site underground facilities is under continuous review by the LBNF/CF and SURF team. Optimization of details like shift schedules, on-cycle vs. off-cycle ground support installation, slicklines vs. cage transport of materials, underground surge capacity for mucking, etc. prior to CD-3a could provide opportunities for schedule and cost improvement.

- Current design dimensions of the cryostats and caverns indicate very tight (0.29 m) clearance between excavation wall and cryostat frame. The committee is concerned that this may cause constructability and access issues. Evaluation and reconciliation of cavern and cryostat dimensions is advisable prior to the CD-3a review.

- Addressing the Independent Design Review recommendations in the conceptual design and estimates before the July CD-1 refresh IPR is important and will be a challenge given the short timeframe.

- Permitting is on track at both sites. The biggest remaining hurdle at the near site is the 401/404 permit. The project has engaged with state and federal agencies to keep this effort moving forward. A COE permit is not expected to be required for the far site.

- The committee found the costs and related assumptions to be reasonable and traceable. Some commodity unit costs (excavation, concrete and building area) were reviewed and deemed to be reasonable for the conceptual level. Control account managers exhibit good knowledge of the cost book, requirements, and basis of estimates.

- The change from liquid to gaseous delivery of cryogens to the 4850’ Level provides for simpler operation, reduced power loads at the 4850’ Level, and reduces project risk. This is a beneficial change from previous concepts and illustrates the advantages to the project of good communications with LBNF/DUNE scientific teams.

- Identifying scope enhancement opportunities at conceptual design is a best practice. Considering the relative priority of these enhancements and their ability to contribute to the objective KPPs would be advisable prior to the IPR.

- The Conventional Facilities team has identified critical interfaces and potential requirements to limit impacts to existing experiments on the 4850’ Level at the far site, particularly CASPAR. Blast designs that limit vibration and air overpressure effects could affect overall excavation productivity and thus the excavation schedule. Refinement of these requirements and understanding of potential schedule impacts are anticipated as the project moves toward the CD-3a review.

- Costs to the project of Conventional Facilities adherence to the funding profile should be understood as the project moves toward CD-3a. This may help identify opportunities to increase overall value or reduce cost related to schedule and escalation.

Recommendations

15. Address the Independent Design Review recommendations related to the conceptual design and cost prior to the July 2015 IPR [pre CD-1R].

16. Incorporate the reconciled cost estimate from the A/E consultants prior to the July 2015 IPR and ensure the control account managers are familiar with the revised estimate [pre CD-1R].

17. DUNE and LBNF/CF should continue to engage in interface discussions moving toward the CD-3a review. If cryostat dimensions remain as currently configured, the Conventional Facilities team should consider increasing the horizontal dimensions of the cryostat caverns to accommodate assembly of the cryostat. Continued refinement of designs for the DUNE far site detector(s), particularly cryostat dimensions, loads, and construction sequence would be beneficial to the CF team by reducing uncertainties and potentially opening value engineering opportunities in the CF design [post CD-1R].

18. The excavation schedule presented by the A/E consultants is aggressive. Schedule contingency for work moving toward beneficial occupancy of the first cryostat cavern should be incorporated into the estimate prior to the CD-3a review [post CD-1R].

7.0 Cost and Schedule

Charge Questions:

- Are the cost and schedule estimates, including life-cycle costs, credible and realistic for this stage of the projects?

  — *Yes, for the DOE portion of the Project.*

- Is adequate scope, cost, and schedule contingency included?

  — *Yes, for the DOE portion of the Project.*

- Is the proposed funding profile supported by DOE and is it adequate to support the cost and schedule ranges?

  — *Yes, but there are concerns around the FY2016 funding level.*

- Has the project identified all scope for which DOE will be responsible?

  — *Yes, at a high level there is an understanding of the scope that DOE is responsible for but there is some confusion among the Project CAMs regarding the allocation of scope details to DOE funds.*

- Has a common accounting method been developed to allow for discussions between international funding agencies and for tracking progress of in-kind non-DOE deliverables?

  — *Yes, the CORE accounting method has been identified for estimating and milestones will be used for tracking status.*

Findings

- The DOE Total Project Cost (TPC) point estimate for the LBNF/Dune Projects is $1,456,617K including a contingency of $383,998K. The details by WBS element are shown below.

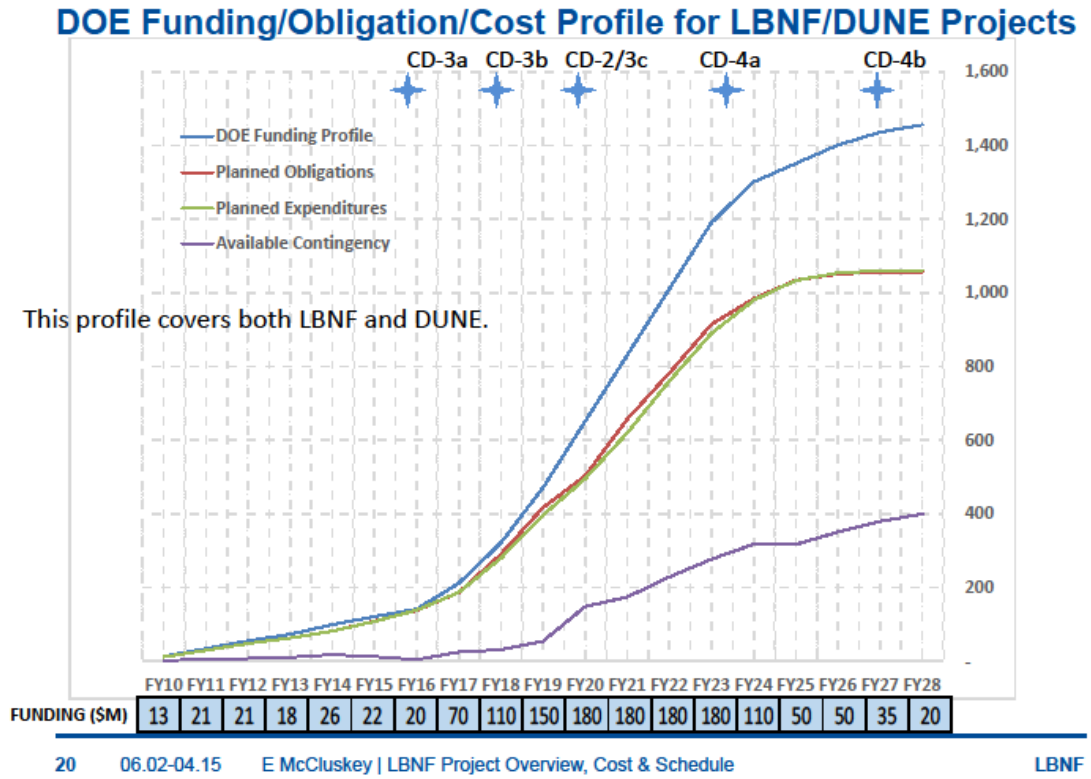
Level 0	WBS#	LBNF/DUNE WBS NAME	DOE Total $K**
Level 1	**LBNF**	**LBNF Project**	
Level 2	**LBNF.01**	**Project Office**	**117,720**
	LBNF.02	**Far Site Facilities**	**391,204**
Level 3	LBNF.02.01	Far Site Facilities Management	14,718
	LBNF.02.02	Far Site Conventional Facilities	299,694
	LBNF.02.03	Cryogenic Infrastructure	76,792
Level 2	**LBNF.03**	**Near Site Facilities**	**414,845**
Level 3	LBNF.03.01	Near Site Facilities Management	27,129
	LBNF.03.02	Near Site Conventional Facilities	261,699
	LBNF.03.03	Beamline	126,017
		LBNF Subtotal	**923,768**
Level 1	**DUNE**	**DUNE Project**	

Level 2	**DUNE.01**	**Project Office**	**29,481**
	DUNE.02	**Near Detector Systems**	**20,871**
Level 3	DUNE.02.01	Conceptual Design	4,472
	DUNE.02.02	Project Management	2,066
	DUNE.02.03	Beamline Measurements	2,418
	DUNE.02.04	DAQ & Computing Systems	1,386
	DUNE.02.05	Near Neutrino Detector	10,529
Level 2	**DUNE.03**	**Far Detector***	**98,499**
Level 3	DUNE.03.01	Management	7,781
	DUNE.03.02	Time Projection Chamber	33,798
	DUNE.03.03	DAQ & Monitoring	1,558
	DUNE.03.04	Installation & Commissioning	28,491
	DUNE.03.05	Photon Detector	9,713
	DUNE.03.06	Cold Electronics	17,158
		DUNE Subtotal	**148,850**
		Contingency	383,998
		LBNF/DUNE DOE Total Project Cost (TPC)	1,456,617

- The project team recommends a DOE cost range from $1,259M (-15% work to-go) to $1,732M (+20% work to-go) based on a point cost estimate of $1,461M and $1,352M to-go. [Note: the table above does not exactly match slide in B. O'Sullivan's presentation.]

- The DOE Funding profile is shown at the bottom of the slide below, together with the planed costs and available contingency.

FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18	FY19	FY20	FY21	FY22	FY23	FY24	FY25	FY26	FY27	FY28
13	21	21	18	26	22	20	70	110	150	180	180	180	180	110	50	50	35	20



- The DOE portion of the project is estimated using standard DOE estimating techniques resulting in a Total Project Cost (TPC) that includes all burdens and escalation. "CORE" accounting methods were used to estimate the entire LBNF/DUNE international project.

- In response to a query from the Cost and Schedule subcommittee, the project team provided the following breakdown showing the DOE and contributed resources using the CORE accounting method:

Level 0	WBS#	LBNF/DUNE WBS NAME	DOE Total M&S FY15$K (CORE)	DOE Total Hours K (CORE)	Non-DOE Total M&S FY15$K (CORE)	Non-DOE Total Hours K (CORE)
Level 1	**XXX**	**LBNF Project**				
Level 2	**XXX.01**	**Project Office**	**$16,195 K**			
	XXX.02	**Far Site Facilities**	**$294,714 K**	**3 K**	**$260,703 K**	**13 K**
Level 3	XXX.02.01	Far Site Facilities Management				
	XXX.02.02	Far Site Conventional Facilities	$245,528 K			
	XXX.02.03	Cryogenic Infrastructure	$49,186 K	3 K	$260,703 K	13 K
Level 2	**XXX.03**	**Near Site Facilities**	**$231,067 K**	**184 K**	**$10,907 K**	**60 K**
Level 3	XXX.03.01	Near Site Facilities Management				
	XXX.03.02	Near Site Conventional Facilities	$199,121 K			
	XXX.03.03	Beamline	$31,946 K	184 K	$10,907 K	60 K
		LBNF Subtotal	**$541,976 K**	**187 K**	**$271,611 K**	**73 K**
Level 1	**YYY**	**DUNE Project**				
Level 2	**YYY.01**	**Project Office**				
	YYY.02	**Near Detector Systems**	**$3,823 K**	**18 K**	**$43,327 K**	**138 K**
Level 3	YYY.02.01	Conceptual Design				
	YYY.02.02	Project Management				
	YYY.02.03	Beamline Measurements	$546 K	3 K		
	YYY.02.04	DAQ & Computing Systems	$406 K	6 K		
	YYY.02.05	Near Neutrino Detector	$2,871 K	8 K	$43,327 K	138 K
Level 2	**YYY.03**	**Far Detector***	**$16,200 K**	**287 K**	**$97,344 K**	**892 K**
Level 3	YYY.03.01	Management				
	YYY.03.02	Time Projection Chamber	$3,902 K	111 K	$21,794 K	384 K
	YYY.03.03	DAQ & Monitoring			$20,072 K	42 K
	YYY.03.04	Installation & Commissioning	$5,832 K	108 K	$4,698 K	306 K
	YYY.03.05	Photon Detector	$2,800 K	52 K	$5,881 K	95 K
	YYY.03.06	Cold Electronics	$3,666 K	16 K	$44,898 K	65 K
		DUNE Subtotal	**$20,023 K**	**305 K**	**$140,671 K**	**1,030 K**
		LBNF/DUNE Total Project Co	**$561,999 K**	**492 K**	**$412,281 K**	**1,104 K**

- A lifecycle cost analysis was posted.

- During the review, cost drill downs were conducted against the following WBS elements:
  - 130.02.01 – Beamline Project Management
  - 130.02.02.03 – Magnet Power Supplies
  - 130.02.03.08 – Target Hall Shield Pile
  - 130.05.04 – Time Protection Chamber (TPC)
  - 130.05.06 – FD Installation and Commissioning
  - 130.06.02.04 – NSCF Final Design
  - 130.06.02.05 – NSCF Construction
  - 130.06.03.05 – FSCF Construction
  - 130.07.05 – Cryogenics System

- During the Director's Review two new independent and reconciled cost estimates were received for the Far Site Conventional Facilities excavation and construction scope and range from approximately +4% to -9%.

- Just before Director's Review the size of the Near Site Target Hall size enlarged. Time was not available to make the changes before the review.

- The high level schedule milestones were presented to the review team as follows
  - CD-0 , Approve Mission Need - 1/8/2010 (A)
  - CD-1, Approve Alternative Selection and Cost Range - 1/8/2010 (A)
  - CD-1, Approve Alternative Selection and Cost Range (Update) - 1st Quarter, FY2016
  - CD-3a, Approve Long Lead Procurement (LLP) - 2nd Quarter, FY2016
  - CD-3b, Approve LLP - 3rd Quarter FY2018
  - CD-2 , Approve Performance Baseline - 1st Quarter, FY2020
  - CD-3c, Approve Start of Construction - 1st Quarter, FY2020
  - CD-4a, Approve Completion, Far Site caverns - 2nd Quarter FY2025
  - CD-4, Approve Project Completion - 4th Quarter FY2030

- The native resource loaded schedule file was provided to the review team and showed the following:

  - The schedule is fully resource loaded and maintained within the Primavera scheduling tool. The schedule contains 9,121 activities.

  - Out of 15,738 relationships there are 1068 activities without successors, 770 of these are not complete. Most of these are to identify obligations, fiscal year activities, and major milestones. Only a handful of the 770 might be considered to be part of a design or assembly path.

  - Activities without predecessors generally have either begun, are date constrained, or have a Late-As-Possible constraint. Many of the activities are milestones related to funding availability.

  - The critical path for the overall project (DOE and Non-DOE) is defined by the longest path which has one date constrained milestone starting on 01 Oct 2015.

  - For CD-4a, the critical path runs through reinforcement of the Ross headframe, then excavation of all four caverns and associated spaces.

  - For CD-4b, the critical path runs through ND design, fab, assembly, and then installation at Fermilab.

  - The schedule has 2 years of schedule contingency on CD-4a and 2 years and 7 months of schedule contingency on CD-4b, all at the end of the schedule. It was presented that this was done based on an analysis recommendation.

- Scope contingency was not specifically presented to the review team.

Comments

- The review team understands that the project has been working hard to refresh their CD-1 estimate and we encourage them to complete any WBS changes, adjust and update any scope changes, and ensure that all milestones are consistent across the schedules to prepare for the upcoming DOE Review.

- The DOE LBNF/DUNE scope, cost and schedule baseline needs to be articulated and presented as part of the larger international project. Worrying about the interfaces and schedule ties to the larger project will be critical to ensuring the success of the DOE portion of the project. It was not made clear to the review team how DOE's portion of LBNF/DUNE ties in with the larger effort. This will need to be described clearly to convince a review team that the DOE portion of LBNF/DUNE can be successful.

- Based on the project plan presented at this review, the near-term funding profile is a concern, as it appears that LBNF/DUNE has to slow work and pause some activities in anticipation of a future increase in funding. Standing army costs and loss of critical talent may adversely impact the project. The project might consider highlighting the schedule adjustments made to accommodate the DOE funding profile and then showing the rough cost and schedule savings that may be achieve with a more favorable distribution of funds.

- The cost contingency estimate ($384M) is 40% of the to-go cost is the result of a structured bottom up method of $271.6M and a risk based top down added contingency of $112.4M, and is sufficient for this stage of the project.

- Cost and schedule drill downs in areas where estimates were completely funded by DOE or mostly funded by DOE, went smoothly with estimators able to walk through their estimates. Backup documentation was well developed.

- The small estimate variances in the Far Site Conventional Facilities (FSCF) reconciled cost estimates validate the Review estimate for this significant portion of the project. The review team supports the plan to update the Review estimate using the A/E estimate and revise the lower level WBS structure to allow for better estimate comparisons with future cost estimates.

- If university hours have been excluded from the cost workbook, they should be added back to accurately describe the effort needed to support DOE's scope.

- Estimators (CAMs) in the Far Detector WBS elements do not appear to understand how their detailed estimates have been rolled up into the larger project cost and schedule. They were not able to track their estimates up above their back up documentation and it seems that it is related to the fact that some portion of the Far Detectors are included in the DOE estimate and other portions are to be contributions by international collaborators. The Project team needs to be able to map their basis of estimate (BoE) documentation to provide and own a DOE and total project estimate split.

- It is normally an expectation from a DOE Review team that the maturity of the estimate is summarized by estimation categories like percent of estimate based on Vendor Quote, Historical Cost, or

Engineering Judgment. The Project team should consider presenting their BoE information in this format or showing how their categorization responds to the maturity issue.

- The schedule has 19 out-of-sequence activities, some of which affect downstream activities. These should be cleaned up.

- The project's resource profile (DOE only) shows a ramp up of technician resources in FY2021-2023 and then drops off quickly. This is primarily driven by installation and commissioning of detector 1 and detector 2 at the far site as well as TPC fabrication and assembly of chambers. The project should determine if the technician resources will be available as scheduled to support the ramp up.

- Schedule milestones for level 0, 1, 2, 3 and 4 are defined and included in the schedule. However, the levels should be reviewed for (1) accuracy, (2) even spreading over time, and (3) proper ties so that lower level milestones provide leading indicators to meeting higher level milestones, without duplication.

- Project team should update the Life Cycle Cost analysis.

- Threshold and objective KPPs were presented but the scope contingency was not specifically discussed. The review team was led to assume that the objective KPPs could serve as or encompass specific scope contingency elements.

Recommendations

19. Prior to the DOE CD-1 Refresh Review, the project team needs to develop, articulate and be prepared to present a clear and coherent picture of how the LBNF/DUNE DOE project fits into the more comprehensive international effort.

20. Prior to the DOE CD-1 Refresh Review, the project management team needs to work with the estimators (CAMs) to ensure that they understand, articulate and document how their lower level WBS element estimates roll up into the larger project estimate.

8.0 Project Management

Charge Questions:

- Have the required project management documents been updated for the CD-1 refresh?

  — Yes (with minor exception of completing some cleanup), the project documents are suitable for CD-1.

- Are the management teams, including partnering institutions, sufficiently defined and staffed?

  — Yes, the key positions within the LBNF and DUNE projects are defined and for the most part staffed at a level sufficient for the CD-1R. The DUNE collaboration leadership is established along with a governance structure. Several positions noted in the findings are not filled and should be filled as soon as possible after CD-1R.

- Have the systems for managing interfaces between LBNF, DUNE, international agencies, and other stakeholders been defined and are appropriate?

  — Yes, for CD-1 approval; however as international partners negotiate agreements with Fermilab to participate in the LBNF/DUNE, Fermilab may need to modify the interfaces to reflect these agreements.

- Has the tailoring strategy for critical decisions been documented and is it justified?

  — Yes, the tailoring strategy appears reasonable and well justified.

- Has a staffing plan been developed and is it sufficient to complete the design and c**o**nstruction of the projects?

  — Yes, a staffing plan exists for the LBNF project, which should allow preparation for CD-3a this fall. Long-term staffing plans were not examined in detail to verify they would meet the design and construction needs of the projects.

- Is procurement planning sufficiently detailed and coordinated across the organizations involved?

  — Yes

- Has an alternatives analysis been performed in support of the selected alternative?

  — Yes, the Acquisition Strategy (AS) presents results of alternatives analysis that supports the selected alternatives. Over the past several years, the team has had multiple technical reviews and down-select processes to get to the current baseline design.

- Have the LBNF/DUNE management teams met all of the requirements of CD-1?

  — Yes, upon completion of the six pre-CD-1 recommendations below.

8.1 Overall considerations

Findings

- The CD-1 approval of the previous Long Baseline Neutrino Experiment (LBNE) Project occurred in December 2012.
- In the meantime, P5 recommended much more ambitious physics goals than the original scope for LBNE and also recommended the formation of a new international collaboration to design and execute this much more capable long-baseline neutrino program.
- A new configuration into a Long-Baseline Neutrino Facility (LBNF) and a Deep Underground Neutrino Experiment (DUNE) has emerged in response to these recommendations, under the leadership of the Fermilab Director and the international neutrino community.
- The management organization for LBNF and DUNE was presented in plenary session during the talks by Nigel Lockyer (Director and LBNF Acting Project Director), Chang Kee Jung (DUNE Resource Coordinator), Eric James (DUNE Technical Coordinator), and Elaine McCluskey (LBNF Project Manager), as well as in the Preliminary Project Execution Plan (PPEP), Project Management Plan (PMP) and CDR.
- Further discussion of change control, configuration control, systems engineering, risk management, QA management, procurement, cost methodologies occurred in breakout sessions.

Comments

- The formation of DUNE and LBNF, the reconfiguration of the long-baseline neutrino program to a four cavern underground concept based on liquid argon TPC technology to meet the P5 requirements has been a remarkable accomplishment over the past 6 months and has far outpaced the most optimistic timeline considered by P5 in its recommendations.
- Overall, a credible organizational, oversight, and project management structure was presented for developing the international partnership to execute the Fermilab- and US-hosted world-class long-baseline neutrino program.
- The plenary talks were sufficiently dense with material to make it difficult for a fresh review panel to absorb the complexity of the DUNE and LBNF projects, the overall driving strategy, cost and schedule assumptions, and international considerations.
- The breakout sessions should have a designated facilitator to ensure that the review schedule is maintained. Adequate time should be provided in the breakout sessions for discussion.
- Some crucial information, such as the distinction between core costing and TPC costing, would be better presented in plenary session to clarify key assumptions early in the review.
- The order of presentations should be carefully reconsidered to provide a better flow of information from science requirements to implementation in the plenary talks.
- Breakout sessions were similarly dense in terms of the number of talks and amount of material and talks often included a lot of boiler plate information at the expense of more crucial discussion.
- More careful consideration should be given to the number of talks, the overlap between sessions, and the need for the review panel to have time for probing questions.

Recommendations

- None

8.2 Management Organization and Staffing

Findings

- LBNF and DUNE presented a high-level organizational structure for the LBNF and international DUNE projects, including relevant advisory boards, the relationship to the Fermilab Directorate as the host laboratory, and the Experiment-Facility Interface Group (EFIG) that is also described in the PPEP, PMP, and CDR.
- The LBNF project has recently been restructured to include two Level-2 [L2] managers for Near Site and Far Site Facilities respectively. The WBS structure has not yet been modified to reflect this change. The L2 managers will also head up two new divisions at Fermilab, reporting to the LBNF Project Director/Fermilab Deputy Director for LBNF.
- The Project Office for the LBNF is largely staffed, with the exception of the Project Director (Nigel Lockyer acting), a Near Site L2 Manager, and an LBNF Procurement Manager. Additional staffing will be required for procurement and engineering support.
- The DUNE management, consisting of Co-Spokesperson, Technical Coordinator and Resource Coordinator, is established. L2 managers and coordinators will evolve with further clarity about international responsibilities for the DUNE project.
- The Project Office for DUNE is partially staffed, but still is in need of a designated Project Manager.
- The composition and roles of the main financial and advisory bodies for LBNF and DUNE have been established, including the International Advisory Council (IAC), the Resources Review Boards (RRB), the DUNE Finance Board and the Long-Baseline Neutrino Committee. The membership of the RRBs and the DUNE RB still need to be designated.
- Currently, the DUNE Technical Coordinator also serves as the Project Director for the DOE portion of the DUNE project.
- The DUNE Collaboration consists of 766 members from 144 institutions and 26 nations.
- The LBNF and DUNE projects have one System Engineer at the project level, who also serves as Risk Manager and QA Manager.
- Near-term staffing plans were presented at a high level and labor estimates were provided as part of the 115 BOEs.

Comments

- While the international nature of the LBNF and DUNE projects leads to a complicated advisory, resource and management structure, the roles of the various components of the organizational structure have been clearly laid out and reflect similar practice by the LHC detector collaborations and CERN.
- EFIG appears to be functioning well in allowing DUNE and LBNF to reach decisions on issues impacting the two projects, for example, in converging rapidly on the new four-cavern strategy for the far site.

- DUNE and Fermilab will be exercising the resource boards over the coming year in a process that is intended to establish multi-agency participation in DUNE and LBNF and corresponding construction responsibilities.
- Further clarification will be needed on the flowchart governing the integrated change control process for DUNE and LBNF, the role of EFIG in advising on changes impacting one or both projects, and mechanisms for resolving disagreements on proposed changes.
- A separate talk dedicated to planning for CD-3a, including definition of relevant project interfaces and the ramp-up of manpower required, would be helpful in evaluating the credibility of being ready for this milestone review.
- If the CD-1 charge includes scrutiny of the overall manpower plan for the project dedicated material should be prepared and made available.

Recommendations

21. [post-CD1] Review and consider significantly augmenting the planned level of systems engineering manpower.
22. [post-CD1] Complete the staffing of key management positions for the LBNF and DUNE projects.

8.3 Project Management Systems

Findings

- The approval of the previous Long Baseline Neutrino Experiment (LBNE) Preliminary Project Execution Plan (PPEP) occurred in December 2012 as part of the LBNE Project CD-1 approval. This approval included a review of the project management systems and determined that they met the requirements for a CD-1 approval.
- Fermilab updated/revised the PPEP to reflect changes in the project based on the issuance of the Particle Physics Project Prioritization Panel (P5) Report, the evolving international character of the project, as well as to incorporate some changes in technical emphasis, such as the change in depth of the detectors and the shift to liquid Argon in the detector.
- The Project provided key project documents for review, including the LBNF/DUNE Preliminary Project Execution Plan (PPEP), Project Management Plan (PMP), Earned Value Management System, Quality Assurance System, Integrated ES&H Plan, Risk Management Plan, Change Control, Configuration Management Plan, DOE Acquisition Strategy, and other documents which are important to the orderly implementation of the LBNF/DUNE Project. The development of implementing procedures is ongoing.
- Some of the project management documents, such as the PPEP, PMP, and Acquisition Plan are in draft form, requiring some slight modifications, and then will be submitted for approval.
- As part of the overall Fermilab Project Management System, Fermilab management conducts a monthly Project Oversight Group (POG) for senior Fermilab Management to status and discuss issues of ongoing projects. In addition, a LBNF/DUNE Project Management Group (PMG) meeting, among the key project participants, is conducted monthly to review status and issues. These meetings are planned to continue throughout the life of the project.

- The LBNF/DUNE Project Management System includes a set of project management tools to support the project planning. The project has a resource loaded schedule based on the Primavera P6 and Cobra for cost reporting. The Fermilab EVMS is based on the certified FNAL system. However, international partners will follow a core costing process with the primary reporting method based on schedule. Full implementation of this system is planned for CD-2. The cost and schedule system is structured to tag costs by core/non-core and DOE/non-DOE.
- The LBNF/DUNE Project conducted a 2-day risk workshop in April 2015 with external facilitators and participants to assess whether significant project risks had been identified for the project and included in the contingency analysis.
- Thirty-four project-level risks have been selected to be actively managed by the LBNF and DUNE Project Managers. The remaining risks are managed by the Level-2 managers. Changes in the Level-2 risks are reported and discussed in the monthly Project Management Group meetings.
- Work continues to refine the risk register by defining the mitigation strategies that will mitigate/eliminate/transfer the risks. A planned follow-on workshop in the fall 2015, to better define mitigation strategies.
- The proposed contingency level of 40% and schedule float are linked to the risk management process.
- The LBNF/DUNE Project includes a large number of complicated interfaces because of the type and number of participants. While plans were developed for managing QA, Systems Engineering, Interface Requirements Management, and Configuration Management the development of procedures is still ongoing and planned for completion well before CD-2. In addition, staffing plans have been developed for the project, including the number of staff required to implement the above systems.
- Fermilab has recently expanded their efforts to perform external reviews of the LBNF/DUNE Project. Independent design reviews were conducted in April/May 2015 to obtain external input on the LBNF/DUNE designs in support of the CD-1 approval.

Comments

- The suite of required LBNF/DUNE Project Management Systems are well developed for CD-1. While full implementation of all of these systems is not required until CD-2, the level of development / implementation of these project management systems is consistent with successfully achieving the CD-1 refresh approval.
- The Review Committee supports the LBNF/DUNE Project effort to review the risk register prior to CD-1 to remove specific contingencies in the US project associated with non-DOE work, as well as to include specific issues identified during this Director's Review. The results of this effort need to be included in the update/revision of the CD-1 supporting documents (i.e. risk register and contingency analysis).
- Prior to CD-2 and consistent with the large number and complicated types of interfaces for this project, priority is needed on the further development of procedures for several key management systems, specifically QA, Systems Engineering, Interface Requirements Management, and Configuration Management to ensure that these key management functions can be effectively performed. In addition, benchmarking against other DOE-SC Projects would be a valuable way to develop and confirm appropriate staffing levels for these functions.

Recommendations

23. [Pre-CD1] LBNF/DUNE Project needs to review and cleanup the risk register, as the risk register directly feeds the development of a proposed contingency level.
24. [As part of the CD-1 approval] Several project management systems documents, such as the PPEP, PMP, and Acquisition Strategy need to be finalized and approved.

8.4 Procurement

Findings

- As defined in the LBNF Procurement Plan
    - Detailed Advance Acquisition Plans are required for all procurements estimated to exceed $10M.
    - A shorter Advance Procurement Plans are required for all procurements estimated to exceed $5M
    - All procurements in excess of $500K are considered significant and subject to additional review and oversight
- LBNF has designated/attached a senior procurement specialist to the project and is actively recruiting a LBNF Procurement manager to support the project.
- Based upon projected spend profile, the plan is to add 2-5 procurement specialists as required.

Comments

- The APP threshold of $5M may not present a true indicator of the volume of significant procurements contained in the project.
- Depending on the type and volume of procurements that will be handled by the main procurement staff, 2-5 additional procurement specialists may not be sufficient in peak funding years.

Recommendations

25. [post-CD1] Benchmark other SC major projects to ascertain thresholds employed by other projects for APP's.
26. [post-CD1] Review which Procurement milestones (requisition, solicitation, contract approvals (FNL, FSO, HCA, etc.), award, delivery/performance, etc.) are included in P6 for significant procurements, so that procurement planning is clear across the organizations involved.

8.5 Critical Decision Strategy

Findings

- The CD strategy was described in the PPEP and discussed in several of the presentations. The justification for this strategy is as follows:

- CD-1 – 1st Quarter FY2016 to establish the substantially altered design and international strategy for LBNF and DUNE in response to the new science requirements laid out by P5
- CD-3a LLP for critical path LBNF Far Site Conventional Facilities and Cryogenic Infrastructure to mitigate risks and minimize delay in providing a facility ready to accept detectors for installation – 2nd Quarter FY2016
- CD-3b LLP for critical path LBNF Near Site Advanced Site Preparation to build embankment requiring 1 year of settling before beamline conventional facilities work proceeds; may include some far site cryogenic infrastructure – 3rd Quarter FY2018
- CD-2/3c to baseline LBNF/DUNE and construction approval for balance of LBNF and full DUNE scope – 1st Quarter FY2020
- The Preliminary project CD-4a date, representing the completion of cavern excavation and supporting utilities at the far site is 2nd Quarter FY2025, which includes 24 months of schedule contingency.
- The preliminary project CD-4b date, representing attainment of all key performance parameters, is 4th quarter FY2030 and includes 31 months of schedule contingency.

- The list of alternative analysis includes the far site location, the Far Detector depth, the cavern size and configurations, the Far detector cryostat structure, the scale and number of cryostats, Near and Far site detector technologies, the proton beam power used to generate the neutrino beam, and so on.
- The Monte Carlo estimate of the cost uncertainty from the risk registry is $148M. The independent top-down contingency shown in the overall LBNF/DUNE budget estimate is $112M. The risk-based estimate includes all risks across the LBNF and DUNE projects, including those associated with international components of the projects.
- The DUNE project assumes that the estimated $80M of liquid argon required to fill the four cryostats in provided by the DUNE Common Fund. This item does not appear on the project risk registry and no budget is included as part of the US TPC.
- The funding limited schedule results in a roughly two-year hiatus in beamline design and a late start for construction of the Near Site detector cavern.
- Many of the original CD-1 documents have been revised to account for the recent major changes in organization. Updates to risks registry and hazards assessment have occurred. The RLS continues to be updated to define the current point estimate and cost range.
- The team provided Risk & QA plans in CD-1 ready form. The Integrated Safety Management Plan and PHAR are complete with major hazards and mitigations listed. The draft PPEP and AS exist, as well as the Preliminary Security Vulnerability Report.

Comments

- The CD approach is logical given the funding profile, the state of design, the critical path analysis and the potential scientific competition outside the US.
- The alternatives analysis for the major items listed appears to have been rather thorough and fully developed for this stage of the project (pre-CD-1). The key alternatives analysis and decisions for the CD-3a (later this year) have already been completed. Further alternatives analysis and value engineering is to be presented in the Technical Design Report due at CD-2.

- Since the separation of CD-3 milestones into two long-lead procurement approvals and then a combined CD-2/CD-3c is somewhat unusual, the arguments for this arrangement may need greater emphasis in presentations and discussion.
- In some cases, the assumed risk probability distributions appear too simple to properly describe the risk profile.
- The possibility of a large DUNE common fund to support the purchase of the required liquid argon for the experiment has not been formally discussed with the IAC and may be a risk as a working assumption.
- The Risk & QA plans are reasonable and sufficient. The PHAR appears to be complete (see EHS subcommittee comments). The PPEP and AS are ready for the CD-1 IPR and they includes a reasonable set of draft KPPs given that a detailed understanding of which partners will build what elements is not yet fully developed.
- The risk registry appears to be quite substantial and complete with more than 150 risks identified, ranked and mitigations outlined. The project tracks these risks at the project level (34) and at the L2/Subsystem level (remainder). The cost/schedule/technical consequences of these risks are also analyzed and utilized in the risk contingency.
- Some further refinement in the cost & schedule impact should be undertaken and the project is planning to do this prior to the CD-1 IPR.
- The presentation of the risk and contingency approach would benefit from an early slide defining how the various components of contingency are rolled together. Estimate contingency + independent top down contingency (related but not equal to the risk contingency) = total project contingency. While the project team understands this, it may not be immediately obvious to the reviewers.

Recommendations

27. [pre-CD1] Update and make consistent the required documents for CD-1.
28. [pre-CD1] Formulate a strategy for procurement of liquid argon and establish its baseline cost implications in the event that this item is not supplied through the DUNE common fund.
29. [pre-CD1] Complete the risk-based contingency estimate for the DUNE and LBNF projects based on the assumed US scope and reconcile this with the planned independent top-down contingency.
30. [pre-CD1] Determine the changes to the DOE funding profile required to achieve a technically limited schedule.

APPENDICES

A. Charge

B. Agenda

C. Review Committee Contact List and Writing Assignments

D. Table of Recommendations

Appendix A

Charge

Director's CD-1 Refresh Review of LBNF/DUNE
June 2-4, 2015

20-May-2015

To: Mike Lindgren, Chief Project Officer

From: Nigel Lockyer, Director

Subject: Director's Review of LBNF and DUNE

Since the approval of CD-1 for the Long Baseline Neutrino Experiment (LBNE) in December 2012, the LBNE project has been recast as the Long Baseline Neutrino Facility (LBNF) and the Deep Underground Neutrino Experiment (DUNE) in order to allow for enhanced capability through increased international participation. As a result, LBNF and DUNE have developed updated conceptual designs, cost and schedule estimates, management plans, and a Critical Decision tailoring strategy. Please organize and conduct a Director's Review to assess whether LBNF-DUNE meets the requirements of DOE Critical Decision (CD-1) "Approve Alternative Selection and Cost Range" in preparation for the DOE Office of Science "CD-1 Refresh Review" planned for July 2015.

DUNE will yield an experimental program in neutrino physics, nucleon decay, and astroparticle physics at LBNF using a deep underground liquid argon detector time-projection chamber (LAr-TPC) with an ultimate fiducial mass of 40 kilotons, to be built in increments of 10 kilotons at the Sanford Underground Research Facility (SURF) in South Dakota. The goal of the international team is for the first 10 kiloton fiducial mass detector to be deployed as soon as possible, followed by expansion to 40 kilotons as soon as possible thereafter.

The project strategy has been developed to meet the requirements set out in the P5 report and taking into account the recommendations of the European ESPP strategy, adopting a model where the DOE and international funding agencies share costs on the DUNE detectors, and CERN provides large in-kind contributions to the supporting infrastructure.

LBNF will provide:

- Excavation in a single subcontract of four underground caverns at SURF, each capable of hosting a cryostat with a 10 kt fiducial mass LAr-TPCs.
- Surface, shaft, and underground infrastructure to support the outfitting of the caverns, four free-standing steel-supported cryostats, and the cryogenic systems. The installation of the first two cryostats allows for a rapid deployment of the first two 10 kt far detector modules. The intention is to install third and fourth cryostats as rapidly as funding will allow.
- The conventional facilities for the near detector systems at Fermilab.
- The conventional and technical facilities for a 1.2 MW neutrino beam for utilizing the PIP-II upgrade of the Fermilab accelerator complex, upgradable to 2.4 MW with the proposed PIP-III upgrade.

DUNE will provide:

- Four LAr-TPCs, each with a fiducial mass of at least 10 kt. The division of the far detector into four equal mass detectors allows the project flexibility in the installation and funding (DOE vs non-DOE) in the case of new resources being identified, mitigates risks, and allows for an early and graded science return.
- The near detector systems, consisting of a highly-capable neutrino near detector and the muon monitoring system to reach the precision requirements needed to fully exploit the statistical power of the very massive FD coupled to the powerful MW-class neutrino beam.

Based on the reference design described the LBNF-DUNE conceptual design report, the project plan will first see the first two 10 kt far detector modules operational, with the beam shortly afterward. At this time the cavern space for all four 10 kt far detector modules will be available, allowing for an accelerated installation schedule if sufficient resources (likely international) for the experiment can be established. The project strategy described above meets the goals of reaching an exposure of 120 kt x MW x yr by 2032, and potentially earlier if additional resources are identified. The P5 recommendation of sensitivity to CP-violation of 3σ for 75% of δ_{CP} values can be reached with an exposure of 850 kt x MW x yr with an optimized beam.

The focus of this review is cost, schedule, management, ES&H, and other identified concerns affecting readiness for the DOE CD-1 Refresh. The review committee should respond to the following questions:

1. **Conceptual Design and Scope.** Have the performance requirements been defined and are they consistent with the Particle Physics Project Prioritization Panel recommendations and the DOE mission need? Have independent design reviews been conducted? Based on the design reviews, are the conceptual designs sound and likely to meet the physics requirements? Are the conceptual designs described in the Conceptual Design Report representative of the entire scope and adequately defined to support the associated cost and schedule ranges?
2. **Cost and Schedule.** Are the cost and schedule estimates, including life-cycle costs, credible and realistic for this stage of the projects? Is adequate scope, cost, and schedule contingency included? Is the proposed funding profile supported by DOE and is it adequate to support the cost and schedule ranges? Has the project identified all scope for which DOE will be responsible? Has a common accounting method been developed to allow for discussions between international funding agencies and for tracking progress of in-kind non-DOE deliverables?
3. **Management.** Have the required project management documents been updated for the CD-1 refresh? Are the management teams, including partnering institutions, sufficiently defined and staffed? Have the systems for managing interfaces between LBNF, DUNE, international agencies, and other stakeholders been defined and are they appropriate? Has the tailoring strategy for critical decisions been documented and is it justified? Has a staffing plan been developed and is it sufficient to complete the design and construction of the projects? Is procurement planning sufficiently detailed and coordinated across the organizations involved? Has an alternatives analysis been performed in support of the selected alternative? Have the LBNF/DUNE management teams met all the requirements of CD-1?
4. **Environment, Safety, and Health.** Are the required environmental approvals and permits on track to meet the project schedule? Have the required ESH documents been updated for the CD-1 refresh? Is ESH being appropriately addressed given the projects' stages?

The committee is asked to present a draft of their report at the review closeout and to issue the final report within one week of the review's conclusion.

Nigel Lockyer
Director
Fermi National Accelerator Laboratory

cc:
G. Bock
E. Gottschalk
E. James
J. Lykken
R. Rameika
J. Strait
E. McCluskey
M. Kaducak

Appendix B

Agenda

Director's CD-1 Refresh Review of LBNF/DUNE
June 2-4, 2015

Tuesday, June 2

EXECUTIVE SESSION – Comitium (WH2SE)

8:00 – 9:00	AM	60	Executive Session	Kem Robinson/Marc Kaducak

PLENARY SESSION – One West (WH1W)

9:00 – 9:10	AM	10	Welcome and the Fermilab Context	Nigel Lockyer
9:10 – 9:40	AM	30	LBNF/DUNE Projects Overview	Nigel Lockyer
9:40 – 10:10	AM	30	LBNF/DUNE International Management	Chang Kee Jung
10:10 – 10:30	**AM**	**20**	**BREAK – One West (WH1W)**	
10:30 – 11:00	AM	30	DUNE Collaboration Strategy & Requirements	Mark Thomson/Andre Rubbia
11:00 – 11:40	AM	40	DUNE Project Overview, Cost & Schedule	Eric James
11:40 – 12:20	AM	40	LBNF Project Overview, Cost & Schedule	Elaine McCluskey
12:20 – 1:20	**PM**	**60**	**WORKING LUNCH – Tables on WH2 Crossover (WH2XO)**	
1:00 – 1:20	PM	20	Conventional Facilities Overview	Tracy Lundin
1:20 – 1:40	PM	20	Beamline Overview	Vaia Papadimitriou
1:40 – 2:00	PM	20	Cryogenic Infrastructure Overview	Barry Norris

PARALLEL BREAKOUT SESSIONS

2:00 – 2:45 PM 105

B01: DUNE Detectors – Snake Pit
B02: LBNF Beamline – Black Hole
B03: LBNF Conventional Facilities – Curia II
B04: LBNF Cryogenic Infrastructure – June 2, One West; June 3, Chiefs (WH2E)
B05: LBNF/DUNE Project Management (Management/Cost&Sched/ES&H) – Comitium
ESH&Q Subcommittee
Cost/Schedule Subcommittee

2:45 – 3:00	**PM**		**BREAK – One West (WH1W)**
3:00 – 4:30	PM	90	Parallel Breakout Sessions Continue – in Breakout Rooms
4:30 – 5:00	PM	30	Subcommittee Executive Sessions – Comitium
5:00 – 6:30	PM	90	Executive Session - Comitium
6:30	PM		Adjourn

Wednesday, June 3

PARALLEL BREAKOUT SESSIONS – continued in same rooms			
8:00 – 9:30	AM	90	
9:30 – 9:45	**AM**	**15**	**BREAK – Outside Comitium (WH2SE)**
PARALLEL BREAKOUT SESSIONS – continued in same rooms			
9:45 – 12:00	PM	135	
12:00 – 1:00	**PM**	**60**	**WORKING LUNCH – Tables on WH2 Crossover (WH2XO)**
1:00 – 2:00	PM	60	Response to Day 1/Morning Reviewer Questions - Comitium (WH2SE)
2:00 – 2:45	PM	45	Parallel Subcommittee Breakout Sessions – continued in same rooms
2:45 – 3:00	**PM**	**15**	**BREAK – Outside Comitium (WH2SE)**
3:00 – 5:00	PM	120	Full Committee Executive Session/Report writing - Comitium (WH2SE)
5:00	PM		Adjourn

Thursday, June 4

8:00 – 10:00	AM	120	Subcommittee Executive Sessions – Comitium (WH2SE)
10:00 – 10:15	**AM**	**15**	**BREAK – Outside Comitium (WH2SE)**
10:15 –12:00	PM	105	Full Committee Executive Session - Comitium (WH2SE)
12:00 – 1:00	**PM**	**60**	**WORKING LUNCH – Comitium (WH2SE)**
1:00 – 3:00	PM	120	Full Committee Executive Session Dry Run – Comitium (WH2SE)
3:00 – 4:00	PM	60	Summary and Closeout – One West (WH1W)
4:00	PM		Adjourn

Appendix C

Review Committee Contact List and Assignments

Director's CD-1 Refresh Review of LBNF/DUNE

June 2-4, 2015

Chairperson

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Appendix D

Table of Recommendations

Director's CD-1 Refresh Review of LBNF/DUNE

June 2-4, 2015

#	Recommendations	Assigned to	Status/Action	Date
	2.0 Environment, Safety, and Health			
1	The crosswalk comparison of the 10CFR851 and OSHA requirements illustrated that the only significant difference is the reporting requirements. Although the 10CFR851 reporting requirements only apply to the DOE leased areas at SURF it is recommended that SURF continue to maintain the current reporting protocols for the SURF non-leased areas with Fermilab which have been utilized between LBNL and SURF management, which are working well, after the operations the transition from LBNL to Fermilab in 2017 (post CD-1).			
2	2. The selection of a Construction Management (CM) contractor is key. As part of the construction management plan it is recommended that the project consider (post CD-1): o Flowing down the safety performance selection criteria to subcontractors o In addition to the safety selection criteria of OSHA recordable rates and Experience Modification Rates, require bidders to submit their safety and health plan o Provide safety incentives in the contract o Use a unified insurance plan o CM should provide a nurse on-site during the construction phase			
	3.0 Detectors			
3	Refine the detector commissioning activities that will be included in CD4. This should be done for the CD-1 refresh review.			

#	Recommendations	Assigned to	Status/Action	Date
4	Work with DOE (and other partners if appropriate) to assure adequate off-project software/computing support is available in order to minimize risk to the project [post CD-1].			
5	Clearly identify the "P5 recommendation" items in the requirements document as it flows down from the science requirements to the performance requirements. This should be done for the CD-1 refresh review.			
6	Seriously consider inclusion in the "reference design" of the photon detector scheme presently considered as "alternative" to allow a better reach in supernova neutrino physics (low energy ~10 MeV). This should be done as quickly as possible.			
7	Hire an ASIC engineer with appropriate experience as soon as possible for the cold electronics [post CD-1].			
8	Address as much as possible all the technical review recommendations before the CD-1 refresh review			
9	Clearly state the assumptions used to define the DOE and non-DOE scope in the detector presentations. This should be done for the CD-1 refresh review.			
	4.0 Beamline			
10	Document the designs and, bases of design, of beamline systems before going into the funding gap period [post CD-1].			
11	Ensure that ongoing design work is brought to a good stopping point before turning off beamline work due to the funding gap [post CD-1].			
12	Proceed to CD-1.			
13	Use every opportunity to gather data from NuMI that can help validate design choices or benchmark simulation codes, even during the two-year funding stop [post CD-1].			
	5.0 Cryogenic Infrastructure			

#	Recommendations	Assigned to	Status/Action	Date
14	Develop an end-of-life disposition concept for the LAr prior to CD-1.			
	6.0 Conventional Facilities			
15	Address the Independent Design Review recommendations related to the conceptual design and cost prior to the July 2015 IPR [pre CD-1R].			
16	Incorporate the reconciled cost estimate from the A/E consultants prior to the July 2015 IPR and ensure the control account managers are familiar with the revised estimate [pre CD-1R].			
17	DUNE and LBNF/CF should continue to engage in interface discussions moving toward the CD-3a review. If cryostat dimensions remain as currently configured, the Conventional Facilities team should consider increasing the horizontal dimensions of the cryostat caverns to accommodate assembly of the cryostat. Continued refinement of designs for the DUNE far site detector(s), particularly cryostat dimensions, loads, and construction sequence would be beneficial to the CF team by reducing uncertainties and potentially opening value engineering opportunities in the CF design [post CD-1R].			
18	The excavation schedule presented by the A/E consultants is aggressive. Schedule contingency for work moving toward beneficial occupancy of the first cryostat cavern should be incorporated into the estimate prior to the CD-3a review [post CD-1R]			
	7.0 Cost and Schedule			
19	Prior to the DOE CD-1 Refresh Review, the project team needs to develop, articulate and be prepared to present a clear and coherent picture of how the LBNF/DUNE DOE project fits into the more comprehensive international effort.			

#	Recommendations	Assigned to	Status/Action	Date
20	Prior to the DOE CD-1 Refresh Review, the project management team needs to work with the estimators (CAMs) to ensure that they understand, articulate and document how their lower level WBS element estimates roll up into the larger project estimate			
	8.0 Project Management			
21	[post-CD1] Review and consider significantly augmenting the planned level of systems engineering manpower.			
22	[post-CD1] Complete the staffing of key management positions for the LBNF and DUNE projects			
23	[Pre-CD1] LBNF/DUNE Project needs to review and cleanup the risk register, as the risk register directly feeds the development of a proposed contingency level.			
24	[As part of the CD-1 approval] Several project management systems documents, such as the PPEP, PMP, and Acquisition Strategy need to be finalized and approved.			
25	[post-CD1] Benchmark other SC major projects to ascertain thresholds employed by other projects for APP's.			
26	[post-CD1] Review which Procurement milestones (requisition, solicitation, contract approvals (FNL, FSO, HCA, etc.), award, delivery/performance, etc.) are included in P6 for significant procurements, so that procurement planning is clear across the organizations involved.			
27	[pre-CD1] Update and make consistent the required documents for CD-1.			
28	[pre-CD1] Formulate a strategy for procurement of liquid argon and establish its baseline cost implications in the event that this item is not supplied through the DUNE common fund.			
29	[pre-CD1] Complete the risk-based contingency estimate for the DUNE and LBNF projects based on the assumed US scope and reconcile this with the planned independent top-down contingency.			

#	Recommendations	Assigned to	Status/Action	Date
30	[pre-CD1] Determine the changes to the DOE funding profile required to achieve a technically limited schedule.			