U.S. DEPARTMENT OF ENERGY

OFFICE OF SCIENCE

Closeout Report on the DOE/SC Status Review of the

High Luminosity LHC Accelerator Upgrade Project (HL-LHC AUP)

Fermi National Accelerator Laboratory

January 14-16, 2020

Frank Gines

Committee Chair

Office of Science, U.S. Department of Energy

http://www.science.doe.gov/opa/

Review Committee Participants

Frank Gines, DOE/ASO, Chairperson

SC1
Magnets

* Probir Ghoshal, TJNAF
Tom Painter, FSU
Al Zeller, FSU

SC2
Crab Cavities

* Ali Nassiri, ANL
Joe Preble, TJNAF
Andrew Burrill, SLAC

SC3
Cost and Schedule

* Elmie Peoples-Evans, ANL
Robert Lopez, SNL

SC4
Project Management and ES&H

* Jon Kotcher, BNL
Kurt Fisher, DOE/OPA
Ken Fouts, SLAC

Observers

Mike Procario, DOE/HEP
Simona Rolli, DOE/HEP
Jerry Kao, DOE/ASO

LEGEND

SC Subcommittee
* Chairperson

Count: 12 (excluding observers)

Charge Questions

1. Is the project making adequate technical progress to ensure that the completed project will perform as planned and the key performance parameters will be met?

2. Are the resource-loaded schedule and the estimate-to-complete up-to-date, accurate, and credible? Is the project on track to advance to the next gate decisions?

3. Does the project understand its dependencies on outside resources such as international collaborators, funding from other agencies, and participation by researchers with other funding sources?

4. Are the major procurements being managed successfully?

5. Is Environment, Safety and Health being handled appropriately?

6. Has the risk analysis been updated to reflect the real risks for completing the project and are the contingencies acceptable?

7. Has the project satisfactorily responded to the recommendations from previous reviews?

8. Are there any other significant issues that require management attention?

Charges

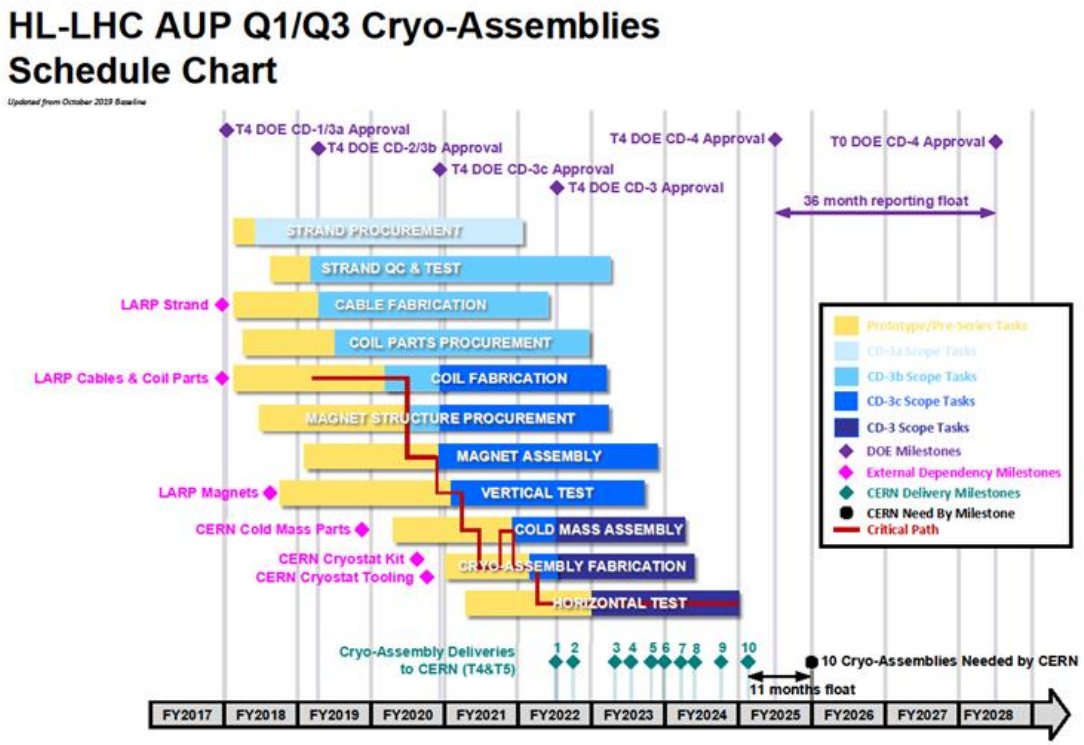
1. Is the project making adequate technical progress to ensure that the completed project will perform as planned and the key performance parameters will be met?
   → **Yes**

7. Has the project satisfactorily responded to the recommendations from previous reviews?
   → **Yes**

8. Are there any other significant issues that require management attention?
   → **Yes (Ref. to BNL liquefaction capacity)**

Findings (Page 1/2)

1. A successful pre-production quadrupole achieved design goals in December 2019 using coils from BNL and FNAL
2. All interface documents presented are all approved.
3. The project plan with critical path highlighted was presented:



Findings (Page 2/2)

4. The magnet and sub-components performance requirements specifications are complete and approved
5. Coil yield efficiency is presently 76%
6. CERN has delayed the long-shutdown from 2024 to at least 2025, but the AUP schedule is unchanged
7. CD-3c requirement: Make two successful pre-series magnets and demonstrated/ test successful to meet specs (CERN acceptance) through vertical tests.
8. Horizontal test will be done after CD-3c.
9. 54% of total strand needed has been received, 76% ordered
10. Cable manufacturing, CD-3b, approved for full production (81 cables), assumed yield: 90%; Actual: ~98%, Insulation Master Agreement (price locked down)
11. CD-3b scope includes fabrication of the first 7 series coils. Coil fabrication to date: 5 coils completed & accepted, 3 coils in progress, 2 coils rejected
12. Iron for all magnets has been procured, ~3/4 of the material has been delivered
13. CD-3b approved full production (81 cables: 022-102)

Comments page 1/3

1. The project team is highly commended for the progress made to date. Significant developments were made compared to Dec 2018 OPA Review
2. The team appears to be highly motivated, enthusiastic and very proactive.
3. The reviewers are again impressed with the quality of the management team, CAMs, technical staff, progress, and management diligence in responding to DOE/OPA comments and recommendations. The above findings support the quality and diligence of the team. The presentations were uniformly of high quality.
4. The experience and lessons learned from other projects are being used effectively within the project.
5. The majority of the ‘Basis of Estimates’ of costs are of an ‘advanced’ nature, supported with CPI and SPI charts.
6. The risk register is kept updated with additional risks when experienced. This has been very proactively managed across all groups.

Comments page 2/3

7. It is suggested revisiting the test voltage safety factor for line to GND (QH), presently showing a factor of about 3.0. Suggest reviewing ITER document "*Magnet Superconducting and Electrical design criteria, N11 FDR 4 01.07.13 Rl.O, Pg.63, Table 1.2.2-1 Factors of safety for insulation systems*"

8. Helium Liquefaction capacity at BNL has been upgraded and is expected to be sufficient to handle the required 3 quenches per day, 5 days per week during full production. Presently it can handle 2 quenches per day for 5 days per week.
   - One additional helium liquefier (Linde 1610) obtained free from PNNL is expected to add 80 l/hr capacity to the present 250 l/hr from the existing CTI4000 to provide the required capacity. Additional Linde 1430 helium liquefier at BNL will provide some margin. Although this is good progress, the additional liquefier/s have not yet been commissioned.
   - Until an additional Linde liquefier/s have demonstrated their expected liquefaction capacity, uncertainty remains in the schedule towards full production testing.

Comments page 3/3

9. There are some noted staffing (resource) needs, additional technicians need to be added and trained as production of the magnet assemblies ramps up at LBNL, and four technicians are needed to replace technician losses from attrition at FNAL. Although plans are in place to meet the project needs, full attention should be kept on these additions and replacements being in the critical path during production.
10. The available resources (skilled and trained personal) needs to be accessed (LBNL and FNAL), being in the critical path during production.
11. The project needs to have better clarity on the test and deliverables for the magnets.

Recommendations

1. Magnet test acceptance documents need to be finalized before the horizontal test.
2. Demonstrate necessary cryogenic production capacity at BNL no later than CD-3c_IPR.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

1. Is the project making adequate technical progress to ensure that the completed project will perform as planned and the key performance parameters will be met? *Yes. The team has made substantial progress since the last DOE review.*
7. Has the project satisfactorily responded to the recommendations from previous reviews? *Conditionally yes. Four recommendations remain open at this time.*
8. Are there any other significant issues that require management attention*? Series cavities fabrication and testing are on critical path. Current schedule leading to CD-3C appears to be tight.*

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Findings

- Dressed Radio Frequency Dipole (RFD) crab cavity project scope includes two prototypes, two pre-series, and ten series.
- The dressed cavities (including RF ancillaries) will go through their final qualification at 2K at FNAL.
- Functional Requirements Specifications (FRS) for RFD dressed crab cavities has been approved by HiLumi LHC and accepted by AUP. Revision of FRS is expected in Feb. 2020.
- RF design changes have been made to RFD to address excessive beam-induced voltage on the rf pick-up probe.
- Changes were needed for the structural integrity of the rf window during vertical testing.
- LARP RFD2 cavity has been successfully tested with all RF ancillaries.
- Initially observed RF leakage causing losses, has been understood and resolved employing special RF gasket.
- Horizontal Higher Order Mode (HHOM) and Vertical Higher Order Mode (VHOM) dampers design has been successfully tested.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Findings

- FTE and resources breakdowns along with estimate quality are adequate and on track for CD3-c.
- RF design of bare cavity and RF ancillaries is the responsibility of AUP. Design is uploaded in EDMS at CERN.
- Mechanical design is responsibility of CERN. Specification/functional drawings provided to AUP.
- L2, L3, CAM & Deputy positions filled
- All materials for prototypes available and being used at E. Zanon S.p.A for prototypes
- Received 15 of 98 Nb sheets for pre-series and series cavities
- Delivery of the first AUP bare cavity prototype are expected in March 2020.
- Delivery of prototype ancillaries are expected from JLab in July 2020.
- A PO was put in place in September 2018 with E. Zanon S.p.A for two prototype RFD cavities with option for additional 12 cavities (2 pre-series and 10 series).
- Series cavities (fabrication and testing) are on critical path.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Findings

- None of the post-CD-2 Baseline risks have been retired or closed. Two new risks were added.
- Risks associated with external dependencies are captured in several documents.
- A final design review of the dressed RFD cavity is required before the CD-3c IPR review.
- CERN final design input for the RFD dressed cavity is scheduled for September 2020.
- The plan is to not use the 2 prototype cavities for the machine.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Comments

- We commend the AUP team for its notable accomplishments since the last DOE review.
- Successful testing of LARP RFD1 cavity at FNAL after bulk and light rotational BCP is very encouraging.
- The successful test of the LARP RFD2 cavity with HOMs at JLAB achieved transverse deflecting voltage of 5.1 MV with Q_0=6.5E9 is a notable milestone for RFD cavity design and performance validation.
- The project could benefit from having an additional resource who can provide vendor oversight and interact with CERN on QA compliance issues.
- Continue to pay close attention to the procurement of raw materials.
- FNAL should continue providing oversight on the bare cavity procurement to avoid further schedule delay.
- Continue to utilize LARP prototype to evaluate and validate the design, processing and performance as needed.
- It is essential for the planned reviews to take place as scheduled prior to fabrication.
- Timely coordination with CERN on RFD scope is critical.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Comments

- Vendor oversight must be kept up, in particular during preparation for complicated cavity welds.
- Potential financial issue with the cavity vendor could have 8-24 Months schedule impact on project.
- Develop a plan to recover the prototype cavities from vendor should the company cease operation before their delivery.
- Developing a second vendor to take over project work may require going back to having vendor qualify on prototypes that cannot be counted on for production yield.
- The plan for building 12 cavities when only 10 are needed is good risk mitigation.
- The dressed cavity FDR should be executed once all dressed cavity designs are frozen, otherwise a delta review will be required.
- The schedule for final CERN design input for the dressed RFD cavity is too late to support the planned CD-3c review.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Comments

- The dates for cavity related milestones are not clear, early and late delivery dates are used without a clear understanding between them.
- Consider using the 2 prototype cavities for the machine if some of the pre-series and series cavities do not meet requirements. There may be things to be done now to make this possible later.
- Agree on the data format that will be transmitted from the vendors to FNAL and on to CERN prior to pre-series fabrication.
- Simulation and measurements of the beam induced voltage on the Double Quarter Wave (DQW) crab cavity rf pick-up probe during beam operations should be further studied to make sure the proposed changes to the RFD pick-up probe will solve the problem.
- A detailed analysis of the thermal properties of the production feedthroughs should be carried out before any vertical testing is done in case the ceramics cannot withstand a large temperature change.
- Implement a solution to avoid potential cracking of feedthrough ceramic exposed to LHe.

Subcommittee 2 : Joe Preble (TJNAF), Andrew Burrill (SLAC) , Ali Nassiri (ANL)

Recommendations

1. Finalize the required documentations needed for Final Design Review and Procurement Readiness Review with CERN to minimize schedule risk for pre-series and series RFD cavities fabrication by May 2020.
2. Provide response and/or close out open recommendations before CD-3c.
3. Hold a final design review of RF ancillary components before launching the series fabrication.

2. Are the resource-loaded schedule and the estimate-to-complete up-to-date, accurate, and credible? Is the project on track to advance to the next gate decisions?
   Yes, and yes.

6. Has the risk analysis been updated to reflect the real risks for completing the project and are the contingencies acceptable?
   Yes.

7. Has the project satisfactorily responded to the recommendations from previous reviews?
   Yes.

8. Are there any other significant issues that require management attention?
   No.

- **Findings**
  - The TPC is $242.72M, which includes $183.9M of BAC and $58.82M of available contingency. BAC increased by $3.7M since the CD-2 PMB.
  - There's 36 months of float between the project's early completion CD-4 date (March 2025) and the DOE CD-4 date (March 2028).
  - Risk analysis indicates the project requires $53.4M of contingency ($22M cost risk + $8.8M schedule risk + $22.6M estimate uncertainty) and 26 months of schedule float to complete the project within a 90% confidence level (CL).
  - The critical path now goes through magnet and cryo-assembly construction and test activities, rather than coil fabrication, due to a 1-yr delay in delivering the cryo-assembly tooling by CERN.
  - The project has 11 months of float remaining, between the early delivery of the last cryo-assembly and the CERN need by date.
  - The project adopted a phased CD-3 strategy. CD-3a and CD-3b are approved and being executed by the project. CD-3c approval is planned for October 2020, and CD-3 approval for all remaining scope is planned for Q1FY22.
  - CD-3c scope includes magnets and RFD cavities construction, cold mass components and the remaining coil fabrication.

- **Findings**
  - The WBS is decomposed into 15 control accounts managed by 13 CAMs.
  - Chargeable task codes (CTCs) are created per BOE and BCR. One each for labor and non-labor.
  - Basis of estimates (BOEs) are provided with BCRs, but are not documented with other BOE information. Actual dollars and estimated hours are included in BOEs, however, this is not clearly stated within the BOE.
  - Fifty baseline change requests (BCRs) were processed through October. Eleven BCRs included current period changes (22%).
  - BCRs are used to split in progress coil fabrication activities to recapture remaining work when a coil fails, which results in current period changes.
  - EVM performance through October for SPI and CPI are .98 and 1.05, respectively. EAC is $184.7M, resulting in an $800K VAC.
  - An error in rating up a couple of resources with FY19 rates, instead of FY20 rates, occurred in Cobra, causing the project to over report ETC by $300K.
  - The project team is actively collecting ETC information on a monthly basis, via EAC sheets provided to CAMs. Production yield models for cables, coils, magnets and cryo-assemblies are used to reflect extra production units required due to failures.

- **Findings**
  - The project has 12 significant procurements (>$500K) remaining, 4 at FNAL and 8 at LBNL.
  - Procurements are tracked, with status updates on a weekly basis.
  - Procurement cycle times, once bid packages reach procurement, are within the estimated processing time > 80% (65/80) of the time.
  - The project has 99 open risks, 14 are opportunities. 16 risks are closed, including 1 opportunity.
  - The project plans to institute an approved modified accrual process for items the project has yet to accept. The goal is to allow the project time to perform QA before accepting deliverables, and minimize false variances because the financial system is unable to do the requested four-way match on deliverables. The result is a mismatch between the actuals reported into PARSII and the actuals reported by the lab into the DOE STARS financial data repository.
  - Acceptance criteria for incoming inspection at CERN still needs to be documented, and will include visual inspections and measurements. Acceptance costs are covered by CERN. Standing army costs waiting on CERN acceptance are covered by the project.
  - The project has been notified about a one year delay in LS3 within the CERN schedule, and plans to perform what-if scenarios to evaluate this delay.

- **Comments**
  - The project appears to have excellent communication across disciplines. This results in more complete data sets and analyses, and is evident in the presentations.
  - The project support team is commended for responding to all the review committee requests in a timely manner, and assuring the information provided answered the questions asked. The team is strong and very supportive to the project.
  - CAMs demonstrated a strong understanding of their scope, schedule and EVMS processes. While their performance was good, the project is still encouraged to do thorough drilldown practice before the upcoming EVMS Review.
  - Using multiple CTCs setup by labor and non-labor for each BOE and BCR is a great approach. This is beneficial because CAMs gain the ability to perform variance analysis themselves, cost issues are easier to recognize and thus corrections made in a more timely manner.
  - The review committee agrees with starting the bottom up ETC exercise before the upcoming surveillance review, as it will help with demonstrating compliance to EVM rules, and provides more accurate data to use for EAC and risk analysis.
  - The project should consider adding CERN acceptance complete milestones to the schedule.
  - The review committee agrees with the project's approach to perform what-if scenarios to better understand the impact of the LS3 delay.

- **Comments**
  - For future reviewers, provide information regarding the project's practice(s) for updating BOEs. This helps reviewers understand how to properly perform data traces to assess the credibility and accuracy of estimates, including ETC.
  - BOEs need to be clear and concise. Explanations should include what the numbers represent, and what activities or WBS elements the BOE covers. Comments about BOEs have been made before. Please update the BOEs as required to make sure they clearly state what aspects of the BAC they represent, and where modifications to estimates can be found.
  - Given the project is past CD-2, reviewers are tasked with evaluating progress to date. As such, it would be beneficial if the project would provide forecast data for everything, including schedules and dates.
  - Consider including total float & planned duration metrics in the Acumen Fuse analysis reports, as these items are part of the Defense Contract Management Agency (DCMA) 14-point schedule assessment as well.

- **Comments**
  - At times, the project support team had to consult with the review committee to figure out ways to provide requested data due to solely using the CAM eToolbox. The application is really great, but it may be limited in reporting capabilities, and snapshots from the tool can be blurry and hard to read. The project should work with FNAL-OPSS to figure out alternatives for providing all aspects of project data that may be requested.
  - Shipping schedules for some items, such as the cryo-assemblies, still require development and incorporation into the baseline to fully understand the total impact to the project delivery dates and total float. The project is encouraged to perform what-if scenarios to gain better insight into likely schedule impacts.
  - A risk for delays with accepting deliverables by CERN is a good idea. However, the project should consider extending the duration impact on this risk. At a minimum, run scenarios with various durations to truly understand the project's limitations with the available contingency.

- **Comments**
  - Procurements seem to be well managed and the team has incorporated processes that reduce risk of procurement slips.
  - Allowing the team to properly QA deliverables before accepting them is a best practice. However, the proposed approach may be questionable to the external EVMS community. The project is encouraged to present this process at the upcoming EVMS Review. Access to clear and concise documentation is key to the acceptance and success of this process.
  - It's possible there may be advantages for the project to pursue a full CD-3 instead of a CD-3c before the full CD-3. Consider revisiting the pros and cons of the current strategy to help with reducing risk on the project by starting work earlier than planned, allowing more float.

- **Recommendations**
  - Proceed with the bottom up ETC exercise, and update the BOEs as required to clarify what's included in the estimates, and what the estimates cover before the upcoming CD-3c IPR.

PROJECT STATUS		
Project Type	MIE	
CD-0	Planned:	Actual: April 13, 2016
CD-1/3a	Planned:	Actual: October 13, 2017
CD-2/3b	Planned:	Actual: February 11, 2019
CD-3c	Planned: Sept 2020	Actual: N/A
CD-3	Planned: Nov 2021	Actual: N/A
CD-4	Planned: Mar 2028	Actual: N/A
TPC Percent Complete	Planned: 28.4%	Actual: 27.8%
TPC Cost to Date	$48.6M	
TPC Committed to Date	$60.5M	
TPC	$242.72M	
TEC	$235.7M	
Contingency & MR Cost	$58.8M	43.5% (BAC-to-go)
Contingency Schedule on CD-4	36 Months	36%
CPI Cumulative	1.05	
SPI Cumulative	0.98	

3. Does the project understand its dependencies on outside resources such as international collaborators, funding from other agencies, and participation by researchers with other funding sources? **YES**, the project team appears to be keenly aware of all dependencies that may impact the performance.

4. Are the major procurements being managed successfully? **YES**

5. Is Environment, Safety and Health being handled appropriately? **YES**

7. Has the project satisfactorily responded to the recommendations from previous reviews? **YES**

8. Are there any other significant issues that require management attention? **YES** (see **r**ecommendations)

4. Project Management and Environment, Safety and Health

J. Kotcher, BNL K. Fisher, DOE K. Fouts, SLAC / Subcommittee 4

Findings

- The HL-LHC AUP Project is budgeted to achieve the objective KPPs.
- The difference between Threshold and Objective KPPs is approximately 5M$ which has been identified as scope contingency.
- AUP is complete when 10 Q1/Q3 Cryoassemblies and 10 RFD Dressed Cavities are delivered to CERN and have undergone inspection to exclude shipment damage.
- AUP does not contain any activity of Installation or Commissioning at CERN.
- The project team is actively and assertively managing the project including any proposed changes from CERN and will formalize this process through a Steering Committee and Technical Subcommittee agreement to be signed in February, 2020.
- The project has implemented a staged or staggered approach to procuring key components in order to address funding issues.
- The critical path (CP) has moved from “Coil Fabrication” to combination of Magnets/CAs construction/Test activities as a result of a 1-year delay in delivery of CryoAssembly Tooling from CERN.

Findings

- CD-3c (end FY20) is needed to maintain Magnet and Cavity production to meet the Delivery Dates agreed upon with CERN.
- CD-3c approval will be sought after 2 successful pre-series magnets (MQXFA03 to MQXFA07) and successful RFD bare cavity.
- On Dec 13th 2019, US HL-LHC effort received notification from the CERN DG of the change to the LS3 schedule (postponements from 2024-mid2026 to 2025-mid2027).
- Prototype crab cavities are on track for delivery in March 2020
- The project will deliver 20 magnets, 16 installed and 4 commissioning/spares.
- Coil/magnet yield is 76% which is ~12% below estimated yield.

Comments

- The project management team is seasoned and capable, and have demonstrated a commitment to the project.
- The senior managers continue to exhibit a desire to be fully engaged in the management of the project and maintain an in depth knowledge of the PM tools used on the project.
- The tailored approach being used by the project team is being used to address less than optimum budget realities and to ensure that the design efforts are at the appropriate levels.
- The project has benefitted from the LARP program, and as components from LARP have a zero cost.
- The institutional agreements with FNAL, BNL, and LBNL have been demonstrably beneficial to all parties.
- Liquefier upgrades at BNL have been problematic and have the potential to drive the AUP delivery schedule. This off-project activity has had a number of delays due to 2 separate incidents of shipping damage from PNNL and Linde.

Comments

- The project is commended for their efforts to develop the shipping and transportation plan in this early phase of the project. Completion of the necessary engineering, design and verification planning tasks will require a significant engineering effort to ensure safe delivery to CERN. Detailed engineering requirements should be developed and documented.
- The project has made significant progress since CD-2/3b and project cost and schedule performance has been very good through this early stage of the project.
- The project risk registry is comprehensive and risks are reviewed and updated on a monthly basis.
- The HL-LHC AUP is technically and managerially challenging. There is a significant international dimension, with CERN as the lead laboratory; multiple US laboratory involvement, centrally managed out of Fermilab; exacting technical requirements; etc. The project is doing an excellent job of navigating this complex space, in conjunction with capably managing the US effort in accordance with DOE and 413.3b expectations.

Comments

- HL-LHC AUP project is tightly and attentively managed by a strong and skilled management team. Problems and issues are anticipated, lessons learned and corrective actions are being integrated as part of the project culture, and project tools and techniques are used throughout the project to advance project goals.
- The full project team is technically strong and proficient, and highly engaged and invested in using, and benefitting from, project management systems and tools.
- National laboratories are a centerpiece of the DOE program, and are heavily relied upon in many contexts, both domestic and international. The successful and effective use of this expertise in projects like AUP underscores this strength of the US capability.
- The project team works as a cohesive unit along with project management. The efforts at the sister laboratories – BNL and LBNL -- are very well integrated technically, managerially, and in the support functions (financial reporting, ES&H, procurement, etc.)
- The project management is to be commended for marshalling and utilizing resources throughout the laboratory that span the suite of project needs and for playing a proactive role in effectively managing these resources.

Comments

- The Committee believes that changes to specifications – functional requirements, acceptance and testing criteria, design modifications, etc. – by all parties (AUP, CERN, etc.) should be considered only if/as absolutely necessary, as dictated by carefully evaluated technical needs. The US cost and schedule are both capped: the potential delays and costs associated with such reconsiderations, adopted or not, can ultimately force reductions in US scope.
- The proposed Steering Committee, as called out in the draft CERN-FNAL MoU, is a much-needed and appropriate means of formalizing the management of any changes to AUP/HL-LHC requirements. This draft was submitted by AUP to CERN in August 2019 and awaits their adjudication.
- OHEP is to be commended for working closely with the project to provide the necessary support to enable them to keep pace with delivering on their international commitments and to adapt to the considerable uncertainties that can arise.
- The change control process is effectively implemented and well managed.

Comments

- The project is planning a Final Design Review in May 2020 of the remaining production components (coils and magnets, cold masses and cryo-assemblies, RFD cavities), followed by a DOE CD-3c IPR review in July. This is driven by their need for obligation authority for these components in October 2020 in order to prevent delays to the US deliverables. This plan was clearly presented, and is well-motivated and understood in detail.
- Design or other changes should be assessed with increasing scrutiny, and only sparingly considered, after the May 2020 FDR is complete.
- There will be the tendency for HL-LHC project personnel to fill the time made available by the one-year delay in the start of LS3 recently announced by CERN. Vigilance on the part of all parties – CERN, US, other HL-LHC collaborators – will be required in order to maintain the current project plan and schedule. A one-year delay represents 1/3 of the float from early to late CD-4 and erodes the available float to <90% CL limit from the schedule Monte Carlo. Unforeseen downstream delays in the CERN schedule may exacerbate this issue.
- External milestones – CERN need-by dates, etc. – are well integrated into the project plan and its execution.

Comments

- A top down analysis of the possible upcoming contingency draws was presented during the Q&A. The exposure described further confirms the need for the level of contingency currently held by the project and makes clear that the continued conservative allocation of these funds by the PO is warranted.
- The ES&H effort and approach is thorough, and the strengths and capabilities of labs are being appropriately integrated and overseen. The plan and its implementation are practical and reality-based – regular walkthroughs, integration of lessons learned, etc.

Recommendations

- Work with CERN counterparts to expedite final convergence of the CERN-FNAL MoU by February 2020. Continue developing the Interim Steering Committee model until the MoU is finalized.

- Install and commission a baseline capacity liquefier system at BNL by the DOE CD-3c IPR review. Develop fallback options while this work continues.

- Proceed with a DOE CD-3c IPR review as soon as the project is ready.