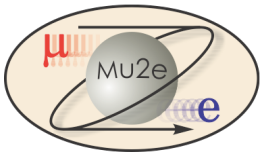

Design Reviews in Mu2e

December 15, 2014

R. Ray
Mu2e Project Manager

Fermilab

Introduction

Design review is one of many tools employed by projects to ensure successful completion. Design reviews provide an independent assessment of the likelihood that systems will meet their technical specifications and perform as required. The Mu2e Project follows the graded approach described in the Fermilab Engineering Manual [1] where high risk systems require more independent scrutiny than lower risk systems. The Mu2e Project has developed a tailored design review plan according to this prescription. This document describes the plan for final design reviews that will take place prior to CD-3c.

Final Design Reviews will be held when designs and drawings are 80-90% complete. The design is mature enough to be reviewed but it is still possible to make adjustments based on feedback. A Final Design Review provides assurance that the completed design will meet all functional and performance specifications as well as interface agreements.

Construction Readiness Reviews will be held prior to the start of procurement or fabrication of major components. Designs must be final and the evaluation of pre-production prototypes, where appropriate, should be complete. Procurement specifications must be complete and QA, test and acceptance plans must be in place. Construction Readiness Reviews ensure that procurements will be successful.

Additional peer review for the Solenoids has been provided by the Solenoid External, Independent Acquisition Oversight Committee (AOC). The AOC meets several times a year to provide input to ensure that the Solenoids continue on track. The AOC includes experts in magnet technology, superconductors, procurement, cryogenic systems and QA. Meetings are often scheduled to coincide with important milestones and activities, such as the release of the DS/PS bid package. We are planning to establish similar advisory committees to oversee progress on the Tracker, Calorimeter, Cosmic Ray Veto, DAQ and Accelerator. We expect to have these committees in place by the summer of 2015, in advance of final design reviews leading up to CD-3c.

The Level 2 managers are responsible for seeing that the design reviews and Construction Readiness Reviews are held in accordance with the Mu2e review plan. The Level 2 Manager will work with the Systems Integration Managers to schedule and coordinate the execution of the design and Construction Readiness Reviews. These review committees are required to include experts from outside of Mu2e.

To ensure communication throughout the project as well as compliance with various standards and procedures, the following members of the Project Team will be invited to all reviews:

- Mu2e Project Manager
- Mu2e Deputy Project Manager
- Mu2e Project Mechanical Engineer
- Mu2e Project Electrical Engineer
- Mu2e ES&H Manager

- Mu2e ES&H Coordinator
- Mu2e Procurement Manager
- Mu2e Quality Assurance Manager
- Mu2e Risk Manager.

The technically challenging components that require external independent review are listed below. They are discussed in more detail in what follows.

Accelerator Subsystems
- 475.02.04 Radiation Safety
- 475.02.05 Resonant Extraction System
- 475.02.08.02 External Extinction System
- 475.02.08.03 Extinction Monitoring
- 475.02.09 Target Station

Solenoids Subsystems
- 475.04.02 Production Solenoid
- 475.04.03 Transport Solenoid
- 475.04.04 Detector Solenoid
- 475.04.05 Cryogenic Distribution

Muon Beamline Subsystem
- 475.05.02 Muon Beamline Vacuum System

Detector Subsystems
- 475.06 Tracker
- 475.07 Calorimeter
- 475.08 CRV
- 475.09 Trigger and DAQ

Radiation Safety

The primary objective of the Radiation Safety subsystem is to design and implement the radiation safety upgrades that are required to permit the increase of facility beam power from 13 watts to 8 kW to maintain the level of radiation protection required by the Fermilab Radiological Controls Manual [2]. The scope of work includes:

- Design, fabrication, and implementation of an AP1 to Delivery Ring Total Loss Monitor (TLM) radiation safety system.
- Design, fabrication, and implementation of the Delivery Ring radiation safety system upgrades, which includes a Delivery Ring TLM radiation safety system and in-tunnel shielding of known beam loss points.
- Design, fabrication, and implementation of the external (M4) beamline radiation safety system, which includes M4 beamline safety system interlocks, M4 beamline TLM system, and M4 beamline in-tunnel shielding.
- Design, fabrication, and implementation of the Mu2e proton target hall radiation safety interlock system.

The design of the subsystem is based primarily on MARS simulations and the performance will depend, in part, on the implementation of a Total Loss Monitor system. A final design review will evaluate the fidelity of the MARS simulations by MARS experts from outside of Mu2e and a review of the TLM system, including evaluation of prototype performance. A Construction Readiness Review will be held prior to construction of the TLM system.

Resonant Extraction System

The Resonant Extraction System must slow-extract pulses of ~10^7 protons from the Delivery Ring to the External Beamline every 1695 ns, corresponding to the revolution period in the Delivery Ring. This must be accomplished with losses that are less than 1% and with pulse-to-pulse intensity variations of less than 50%. A similar system has been constructed at J-PARC where losses at the 0.5% level have been achieved. We have been in contact with the technical experts at J-PARC and our resonant extraction team traveled to J-PARC in December 2014 for several days of discussions.

Resonant Extraction is a complicated and technically challenging system that will require a two-day review to cover all of the relevant issues. Accelerator physicists, engineers and safety professionals will be needed for the review committee. A Construction Readiness Review will be held prior to fabrication of the extraction septum. A prototype of the septum was constructed and evaluated prior to completion of the preliminary design.

External Extinction System

The External Extinction System has the challenging task of eliminating out-of-time beam to the level of 10^{-10}. The system consists of complex magnetic elements, collimators and power supplies and relies heavily on beam simulations. Prior to a design review an independent evaluation of the simulations will be made. The review itself will cover the requirements, specifications and final design of the Extinction System as well as its critical interfaces to the External Beamline. Accelerator, magnet and power supply experts will be needed for this review. A Construction Readiness Review will be completed prior to fabrication of the AC Dipole.

Extinction Monitoring

The Extinction Monitor must measure scattered protons from the Production Target as a function of time to assure that the required level of beam extinction (10^{-10}) is being achieved. The Extinction Monitor consists of a momentum filter constructed from collimators and a permanent dipole magnet followed by a spectrometer consisting of planes of silicon strips, trigger counters, a dipole magnet, a muon range stack and a stand-alone DAQ. A final design review to evaluate the underlying simulations, detector design and triggering scheme is necessary. The review committee will require scientists and engineers with silicon expertise. A construction readiness review will be held prior to construction of the silicon strip detectors.

Production Target and Remote Handling

The Production Target is a radiatively-cooled tungsten rod that resides in the evacuated warm bore of the Production Solenoid and is designed to withstand an 8 GeV, 8 kW incident proton beam distributed into pulses of 10^7 protons separated by 1695 ns. The design relies on simulations, material measurements and evaluation of prototypes. The remote target handling system is designed to remove spent targets after a year of operation, when the target, the Production Solenoid and the surrounding area are activated, restricting human access. The review committee will require scientists and engineers with experience in targeting systems as well as radiation safety experts. A Construction Readiness Review will take place prior to initiating fabrication of the remote handling system.

Detector Solenoid

A detailed reference design for the Detector Solenoid (DS) was prepared at Fermilab and CD-3a was obtained in FY14 for the DS conductor. General Atomics is responsible for completing the final design and, after review and CD-3c authorization, will fabricate the DS. A review of the final design is required to ensure that it satisfies all requirements and specifications and to ensure that all interfaces have been adequately specified. A field map will be calculated and distributed to the Collaboration simulations group to validate the physics performance. The review committee will require scientists and engineers with experience in the design and fabrication of superconducting magnets and cryogenic systems. This review could be combined with a similar review of the Production Solenoid.

After completion of the final design a prototype DS coil will be fabricated and evaluated using the final tooling and vacuum impregnation hardware. A construction readiness review will be held after evaluation of the prototype.

Production Solenoid

A detailed reference design for the Production Solenoid (PS) was prepared at Fermilab and CD-3a was obtained in FY14 for the PS conductor. General Atomics is responsible for completing the final design and, after review and CD-3c authorization, will fabricate the PS. A final design review is required to ensure that it satisfies all requirements and specifications and to ensure that all interfaces have been adequately specified. A field map will be calculated and distributed to the Collaboration simulations group to validate the physics performance. The final design review committee will require scientists and engineers with experience in the design and fabrication of superconducting magnets and cryogenic systems. This review could be combined with a similar review of the Detector Solenoid.

After completion of the final design a prototype DS coil will be fabricated and evaluated using the final tooling and vacuum impregnation hardware. The same tooling will be used for the both the PS and DS. A Construction Readiness Review will be held after evaluation of the prototype.

Transport Solenoid

The Transport Solenoid (TS) is fully designed at Fermilab. CD-3b is expected in early FY15 for the TS Modules that form the cold mass of the TS. An external, independent final design review [3] was held for the TS Modules in December 2014 when the design was 90% complete and the drawings were 70% complete. A prototype TS Module was fabricated and delivered to Fermilab in December 2014. A Construction Readiness Review will be held in April 2015 once the final design and drawings have been completed and the prototype has been fully tested.

The remainder of the TS will be evaluated for CD-3c in FY16. Prior to CD-3c a full design review of the TS cold mass, cryostat assemblies, power and quench systems will be required. The review committee will require scientists and engineers with experience in the design and fabrication of superconducting magnets and cryogenic systems. A construction readiness review will be held prior to initiating construction on these items.

Cryogenic Distribution

The cryogenic distribution system for the solenoids includes the Muon Campus Cryo Plant in the MC1 building, a distribution box that directs cryogens to the different feedboxes, feedboxes that feed particular solenoids and the cryogenic systems for each solenoid. An external, independent preliminary design review of the cryo system was held in June 2013. A final external, independent design review will be held prior to CD-3c. The review committee will require cryo engineering expertise. Construction Readiness Reviews will be held prior to fabrication of the Distribution box and the feedboxes.

Muon Beamline Vacuum System

The Muon Beamline Vacuum System is established in the warm bore of the solenoids, spanning the entire length from the upstream (relative to the muon beam) edge of the PS to the downstream edge of the DS. The system includes pumps, vacuum lines, seals, windows, enclosures and cable penetrations. The system has to operate in the fringe field of the solenoids and a radiation environment. The review committee would require vacuum engineering expertise.

Tracker

The Tracker should be reviewed as a single subsystem. The tracker includes designs for straw tubes, a gas manifold, mechanical support, a preamp, digitizer, readout controller, power and cooling systems and should be reviewed as a complete system. A prototype panel will have been constructed and operated in vacuum by the time of the final design review. FE electronics and straws must operate in a vacuum and in a radiation environment. Replacement of damaged components will be difficult. Radiation validation and longevity tests must be performed prior to the final design approval. The review committee should include experts in tracking and electronics. A Construction Readiness Review will be required before procurement of production parts begins. Prior to the Construction Readiness Review a pre-production prototype plane will have been constructed and evaluated.

Calorimeter

The Calorimeter consists of scintillating crystals, a mechanical support structure, photosensors, digitizers, readout controllers, power, cooling, and calibration systems. Prior to the final design review there will be technical reviews to evaluate the performance of prototype crystals and the R&D to develop a UV-extended solar-blind APD to optimize the readout of BaF2 crystals. The final design review will focus on the overall calorimeter system, prototype performance in test beams and interfaces. FE electronics and crystals must operate in a vacuum and in a radiation environment. Replacement of damaged components will be difficult. Radiation validation and longevity tests must be performed prior to the final design approval. The review team should include experts in crystal calorimetry, photosensors and electronics. A Construction Readiness Review will be required prior to initiation of procurement.

Cosmic Ray Veto

The Cosmic Ray Veto (CRV) is constructed from extruded scintillator and read out with SiPMs through wavelength shifting fibers. There are digitizers, readout controllers and power systems. The technology is very similar to systems that have been deployed for MINOS, Minerva and T2K, but the operating environment for Mu2e is much different. The final design review will focus on the overall CRV system, simulations, prototype performance in test beams and interfaces. Scintillator, fiber, and FE electronics must operate in a radiation environment. Radiation validation and longevity tests must be performed prior to the final design approval. The review team should include members who have experience with the extruded scintillator technology, as well as SiPM and electronics experts. A Construction Readiness Review will be required before procurement of production parts begins.

Trigger and DAQ

The Mu2e Data Acquisition system is constructed primarily from commercial parts but requires a substantial amount of custom programming. The DAQ employs a streaming architecture with no hardware trigger. All trigger decisions are made in software. A small prototype system has been developed and tested and by the time of CD-3c a larger pilot system will have been deployed and evaluated. The review team should include members who are DAQ experts.

References

[1] The Fermilab Engineering Manual, http://www.fnal.gov/directorate/documents/FNAL_Engineering_Manual.pdf

[2] The Fermilab Radiological Control Manual, http://esh.fnal.gov/xms/ESHQ-Manuals/FRCM

[3] Mu2e-doc-5039, http://mu2e.fnal.gov/public/project/reviews/TSCoilModuleTDR%20/TSCoilModuleReview.shtml