Department of Energy
Office of Science
Washington, DC 20585

MAR 0 6 2015

MEMORANDUM FOR: JAMES SIEGRIST
ASSOCIATE DIRECTOR
OF THE OFFICE OF SCIENCE
FOR HIGH ENERGY PHYSICS

FROM: STEPHEN W. MEADOR
DIRECTOR
OFFICE OF PROJECT ASSESSMENT

SUBJECT: Final Report on the DOE/SC Review of the Mu2e Project, February 2015

Attached for your consideration and use is the final report on the Department of Energy/Office of Science review of the Muon to Electron Conversion Experiment (Mu2e) project. The Mu2e review was conducted February 4, 2015 at the Fermi National Accelerator Laboratory in Batavia, Illinois.

If you have any questions or would like to discuss the report further, please contact me.

Attachment

cc:
K. Fisher, SC-28
T. Maier, SC-28
M. Procario, SC-25
T. Lavine, SC-25
M. Weis, DOE/FSO
P. Carolan, DOE/FSO
P. Philp, DOE/FSO

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bcc: S. Pepper, V. Bibbs, K. Yarmas, SC-25

SC-28:caw:34840:02/27/15:o:SC-28 Projects:Mu2e:1502CD2-3brev:transmittal.docx

SC-25	SC-28	SC-28
See Attached		
TLavine	KFisher	SMeador
3/4/15	3/5/15	3/6/15

Office of Project Assessment
Review Committee Report on the

Muon to Electron Conversion Experiment (Mu2e) Project

at Fermi National Accelerator Laboratory

February 2015

EXECUTIVE SUMMARY

A Department of Energy/Office of Science (DOE/SC) review of the Muon to Electron Conversion (Mu2e) project was conducted on February 4, 2015 at the Fermi National Accelerator Laboratory (Fermilab). The review was conducted by the Office of Project Assessment (OPA), and chaired by Kurt W. Fisher at the request of Michael Procario, Director of Facilities for High Energy Physics. The purpose of the review was to evaluate the project team's readiness for Critical Decision (CD) 2 and 3b, Approve Performance Baseline and Approve Start of Phased Construction/Fabrication. CD-2 would set the project baseline and CD-3b would allow the Mu2e project team to utilize up to $24 million to initiate civil construction of the detector hall and to approve and commence fabrication of the Transport Solenoid (TS) Modules (which are on the critical path). The Committee recognized the overall progress made by the project team and supports the project proceeding to CD-2/3b.

Technical—Superconducting Solenoids

The Committee noted that an independent TS Design Review was held on December 5, 2014, and resulting comments and recommendations are being incorporated into the project's plans. Of the six recommendations, three have been completed and the remaining will be completed within the next few weeks, prior to the construction readiness review. The TS Prototype was completed and delivered to Fermilab on December 23, 2014. The Committee judged that the project team has made excellent progress towards TS Module validation; however, the aggressive procurement schedule is contingent on timely completion of the TS Prototype test. The procurement plan and documents were presented to Acquisition Oversight Committee on January 26, 2015.

Cost and Schedule

The Total Project Cost has been increased by $2.67 million to $273.67 million and the contingency has been increased to $56.2 million. The CD-4 date has been pushed back one month to December 2022, with 24 months of schedule contingency remaining.

The Committee observed that the project Earned Value Management System (EVMS), variance reporting, and the change control system have been fully implemented and functioning well for the past two months. It appeared that the project team and management are embracing EVMS and using it as a tool to help manage the project. The project team was commended for this effort.

Management

The Committee acknowledged that a strong response was made by Project Management in regards to the findings from the October 2014 DOE/SC Review. The engagement of a "Chief Project Officer" by Fermilab management is a very positive addition for Mu2e and other Fermilab projects. The cost exposure due to the Project Management marching army should be well-covered within the contingency allocation. Dedicated ES&H and Quality Assurance professionals have been added to the project. All management recommendations required for CD-2/3b have been addressed satisfactorily.

CONTENTS

Appendices

1. INTRODUCTION

With the discovery of non-zero neutrino masses and flavor mixing, the fact that individual lepton-flavor quantum numbers (electron-number, muon-number, and tau-number) are not conserved has been established. All such flavor-violating effects have been observed to-date in the neutral lepton sector, through the phenomenon of neutrino oscillations. Charged lepton flavor violation (CLFV), on the other hand, has been the subject of intense experimental searching since the discovery of the muon but no evidence for it has ever been uncovered. The Muon-to-Electron Conversion Experiment (Mu2e) at Fermilab will search for CLFV in coherent conversion of muons into electrons in the field of a nucleus. With experimental sensitivity 10,000 times greater than previous searches, this experiment will probe new physics at mass scales that exceed the reach of the Large Hadron Collider.

In its 2008 report, "U.S. Particle Physics: Scientific Opportunities, A Strategic Plan for the Next Ten Years," the U.S. High Energy Physics Advisory Panel (HEPAP) and its U.S. Particle Physics Project Prioritization Panel (P5) identified this opportunity as a top priority:

> *"A muon-to-electron conversion experiment at Fermilab could provide an advance in experimental sensitivity of four orders of magnitude. The experiment could go forward in the next decade with a modest evolution of the Fermilab accelerator complex."*

The Mission Need Statement for the Mu2e experiment was approved in September 2009 by the Director of the Office of Science (SC), Department of Energy (DOE). The Conceptual Design and selection of alternatives was approved in June 2012. This challenging project has been in the design-development stage since then.

Now, in 2015, the Mu2e project has advanced through the preliminary design phase and is proposing a Performance Baseline incorporating scope, cost and schedule, and a plan to commence civil construction and technical fabrication activities. The new HEPAP Strategic Plan for U.S. Particle Physics ("Building for Discovery," 2014) has reiterated the priority of the Mu2e program as an immediate target of opportunity in the drive to search for new physics, with its science case undiminished relative to the earlier prioritization.

2. TECHNICAL SYSTEMS EVALUATIONS

2.1 Findings

In response to previous recommendations, an independent Transport Solenoid (TS) Design Review was held on December 5, 2014. The comments and recommendations from the October 2014 DOE/SC review are being incorporated into the project's plans. Of the six recommendations, three have been completed and the remaining will be completed within the next few weeks, well before the construction readiness review.

The TS Prototype was completed and delivered on December 23, 2014. The test facility is ready for the test. A test and acceptance plan for the prototype TS module was prepared and sent to the review Committee on November 7, 2014 in response to a previous recommendation. The procurement plan and related documents were presented to the standing Acquisition Oversight Committee (AOC) on January 26, 2015.

The project team has begun to pursue procurement and testing options that could reduce TS schedule risk and a key personnel requirement has been included in the procurement contracts.

2.2 Comments

There has been excellent progress towards the TS Module validation. The Committee noted that the aggressive procurement schedule is contingent on timely completion of the TS Prototype test.

There are still a few recommendations in process. The main remaining item from the recommendations of the October review is the successful test of the TS prototype module. It may be necessary to incorporate design changes based on the prototype test and modify drawings accordingly. This would be followed by a final TS coil module procurement readiness review.

2.3 Recommendations

1. Proceed to CD-2/3b.

2. Upon completion of previously noted "in process" recommendations, seek approval for TS procurement.

3. COST and SCHEDULE

3.1 Findings

PROJECT STATUS as of December 2014 Pre-CD 2 Baseline		
Project Type	Line Item	
CD-1	Planned: 4QFY12	Actual: 7/2/2012
CD-2	Planned: Mar 2015	Actual: TBD
CD-3a	Planned: 4QFY12	Actual: 7/10/14
CD-3b	Planned: Mar 2015	Actual: TBD
CD-3c	Planned: Jun 2016	Actual: TBD
CD-4	Planned: Dec 2022	Actual: TBD
TPC Percent Complete	Planned: ~25%	Actual: ~25%
TPC Cost to Date	$56.5M	
TPC Committed to Date	$65.1M	
TPC	$273.7M	
TEC	$250.0M	
Contingency Cost (w/ Mgmt. Reserve)	$56.2M	35% to go
Contingency Schedule on CD-4	24 months	33% to go
CPI Cumulative	N/A	
SPI Cumulative	N/A	

Some changes in cost and schedule have occurred since the October 2014 DOE/SC review. The project Total Project Cost (TPC) has been increased $2.67 million to $273.67 million and contingency has increased to $56.2 million. The CD-4 date has been pushed back one month to December 2022 and 24 months of schedule contingency still remains. Due to a delay in the award of the Production and Detector Solenoids, the critical path currently runs through all the solenoids, Production, Detector, and Transport. The overall schedule still remains the same.

An external Fermilab Annual Earned Value Management System (EVMS) Surveillance review was performed in December 2014. The Mu2e project was chosen to be reviewed, and no Corrective Action Requests (CARs) were found for the project. This is a significant accomplishment. In addition, the reported monthly project Estimate at Completion (EAC) is now calculated via manual input from Control Account Managers (CAMs) vs. an automatic Cost Performance Index (CPI) calculation.

3.2 Comments

The Committee found that all nine Cost and Schedule recommendations from the October review have been satisfactorily addressed. More notably, the project EVMS, variance reporting, and the change control system have been fully implemented and functioning well for the past two months. It appears the project team and management are embracing EVMS and using it as a tool to help manage the project. They were commended for this effort. In addition, the project is now having monthly CAM/project control status meetings and is manually updating the Estimate to Complete (ETC) monthly. This is considered a best practice.

The Committee discovered that the management EAC is $2.6 million higher than the proposed Budget at Completion (BAC). This increase in EAC is mainly due to addressing recommendations from the October review, the delayed CD-2/3b approval, and the TS test cryostat cost increase. At the time of baselining, the BAC should match the EAC to accurately reflect what the CAMs and project management will be measured against.

3.3 Recommendations

3. Before CD-2 approval, process a change request to have the BAC match the current EAC, and update all documentation (i.e., Project Execution Plan) with the new numbers.

4. Proceed to CD-2/3b.

4. PROJECT MANAGEMENT

4.1 Findings

The responses to all Project Management recommendations were posted prior to the review and progress was presented at the review. Those recommendations required for CD-2/3b were completed and details about progress since the October 2014 DOE/SC review was evident; a few notable items are:

- Laboratory Project Management Groups (PMGs) and Project Oversight Groups (POGs) are in place with monthly meetings scheduled. Fermilab is deeply involved in the project management oversight of Mu2e.

- The EVMS system is in place and monthly reports for the last quarter are available. The Mu2e management team was successfully reviewed by the Fermilab Surveillance Team.

- Design Reviews are being scheduled and the review teams are being assembled. Overall project review templates are being created by Fermilab, which should make for an economy of scale. That economy should also be realized as common Project Management tools are put in place throughout Fermilab.

4.2 Comments

A strong response was made by the Project Management team in regards to the findings of the October review. The engagement of a Chief Project Officer is a very positive effort for Mu2e and other Fermilab projects. It is evident that Fermilab has ownership of the Mu2e project.

The project management total cost is about 18% of the total cost. The cost exposure due to the project management marching army should be well covered against schedule slippage within the contingency allocation.

Given the highly matrixed and multi-divisional aspects of the project, the Interface Control Documents (ICD) and ICD milestones now in progress, should be vigorously pursued and treated as controlled documents. Since Mu2e crosses several divisions within Fermilab, the ICDs should help to tie together all aspects of the project.

Of the four recommendations to be assessed for CD-2/3b, all were stated to be completed and reasonable evidence was presented.

Of the four recommendations to be assessed later, three were completed and one was said to be in progress. That recommendation called for the project to convene external, expert advisory groups. This recommendation should be vigorously pursued because of the importance of a fresh view to be afforded by outside groups at all stages of design, procurement, construction, installation, and commissioning.

Environment, Safety and Health

ES&H issues were not explicitly presented at this review. The Mu2e project team did; however, address the recommendations specific to ES&H that were raised at the October review.

There were seven recommendations. Six were stated to have been completed and evidence for their completion was presented. The laboratory responded to a key concern of the previous review committee by appointing a new ES&H leader to the Mu2e project. The new ES&H lead is one of the most experienced ES&H professionals with extensive project experience at the laboratory. The one remaining recommendation concerned remote target handling and robot operations. The project should consider consultation with and perhaps recruitment of experts outside Fermilab in order to strengthen this effort since Fermilab has little experience in these specific matters.

4.3 Recommendation

5. Proceed to CD-2/3b after responding to the recommendations of the other subcommittees.

Appendix A Charge Memo

Department of Energy
Washington, DC 20585

DEC 9 2014

MEMORANDUM FOR STEPHEN MEADOR
DIRECTOR, OFFICE OF PROJECT ASSESSMENT

FROM: MICHAEL PROCARIO
DIRECTOR OF FACILITIES
FOR HIGH ENERGY PHYSICS

SUBJECT: REQUEST TO CONDUCT AN INDEPENDENT PROJECT REVIEW OF THE Mu2e PROJECT

I request that you conduct an Independent Project Review of the Muon-to-Electron Conversion Project (Mu2e) in February 2014, on a date to be determined. The purpose of this review is to evaluate the project's readiness for Critical Decision CD-2 which will approve of the proposed Performance Baseline for technical scope, cost and schedule, as well as the project's readiness for Critical Decision CD-3b which will approve the continuation of procurement and fabrication, with respect to the experimental hall and the superconducting magnet modules of the Transport Solenoid. Critical Decision CD-3a (approved July 10, 2014) permitted the initial procurement of superconductor for the project.

This will be a follow-up to the previous Department of Energy (DOE) review held October 21-24, 2014, that resulted in a number of recommendations that required time to implement. The purpose of the review is to evaluate the progress in resolving the recommendations from the previous review. In particular:

1. Have the Project and the Laboratory responded satisfactorily to the recommendations of the previous DOE review?
2. Is the detailed design sufficiently mature and appropriately reviewed so that the project can continue, as planned, with the procurement and fabrication work that will be approved by CD-3b?
3. Are there any outstanding issues that need to be addressed?

Dr. Theodore Lavine is the program manager for the Mu2e Project in this office and will serve as the DOE Office of High Energy Physics contact person for the review.

We appreciate your assistance in this matter. As you know, these reviews play a
important role in our program. I look forward to receiving your Committee's rep

cc: M. Weis, FSO
P. Carolan, FSO
P. Philp, FSO
P. Dehmer, SC-2
J. Siegrist, SC-25
T. Lavine, SC-25
J. Kogut, SC-25
K. Fisher, SC-28
N. Lockyer, FNAL
G. Bock, FNAL
M. Lindgren, FNAL
P. McBride, FNAL
R. Ray, FNAL

Appendix B Review Committee

Department of Energy/Office of Science Review of the
Muon to Electron Conversion Experiment (Mu2e) at Fermilab
February 4, 2015

REVIEW COMMITTEE PARTICIPANTS

Department of Energy

Kurt Fisher, DOE/SC, Chairperson

Review Committee

Subcommittee 1—Technical
*Steve Gourlay, LBNL
Ken Marken, DOE/SC
Bruce Strauss, DOE/SC

Subcommittee 2—Cost and Schedule
*Jerry Gao, DOE/ASO
Ron Lutha, DOE/ASO

Subcommittee 3—Management
*Dan Green, Fermilab
Steve Meador, DOE/SC

*Lead

Observers

Mike Procario, DOE/SC
Ted Lavine, DOE/SC
Pepin Carolan, DOE/FSO

Appendix C Review Agenda

Department of Energy/Office of Science Review of the
Muon to Electron Conversion Experiment (Mu2e) at Fermilab
February 4, 2015

AGENDA

Wednesday, February 4, 2015—Comitium, Wilson Hall

8:00 am	Executive Session ..... K. Fisher
8:30 am	Welcome and Fermilab Context—**Comitium** ..... N. Lockyer
8:45 am	Laboratory Role and Project Support ..... M. Lindgren
9:00 am	Project Overview ..... R. Ray
	• Response to DOE Review Recommendations
10:00 am	Break
10:20 am	Transport Solenoid (TS) ..... M. Lamm
	• TS Module Design Review/Final Design Status
	• TS Prototype Module Status, Test, and Acceptance Plan
	• TS Module Procurement and Fabrication Readiness
11:00 am	Committee Questions and Discussion
11:30 am	Full Committee Executive Session
12:00 pm	Working Lunch
1:00 pm	Committee Reconvene with Project Management (if needed)
2:30 pm	Closeout
3:00 pm	Adjourn

Appendix D Mu2e Funding and Cost Tables

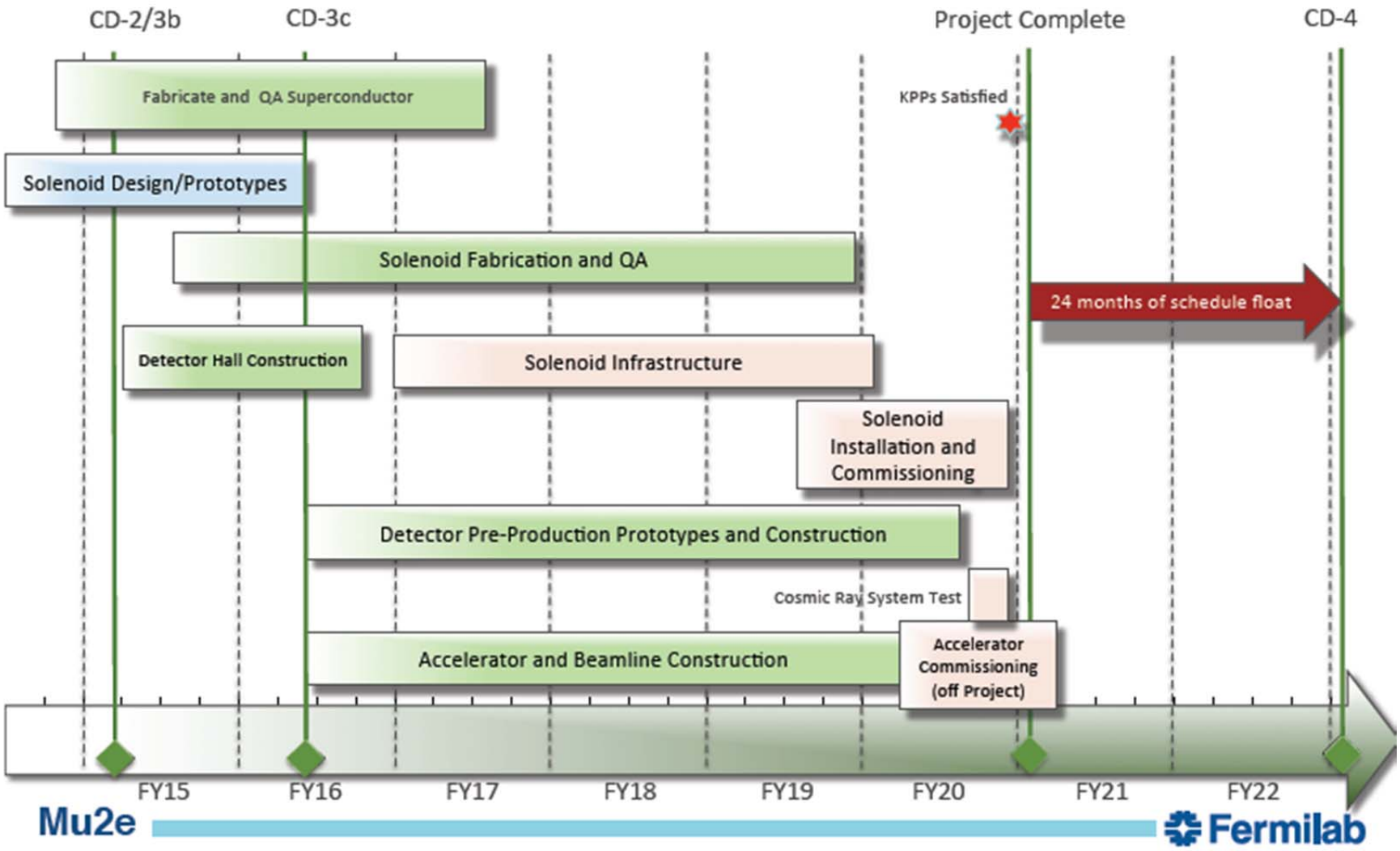
Proposed Funding Profile by Fiscal Year ($M)

	Prior yrs.	FY13	FY14	FY15	FY16	FY17	FY18	FY19	Total
OPC-R&D	1.177	2.5							3.677
OPC-Design	20.000								20.000
TEC-PED	24.000	8.0	15	10					57.000
TEC-Const.			20	15	40.1	43.5	44.4	30	193.000
Total	**45.177**	**10.5**	**35**	**25**	**40.1**	**43.5**	**44.4**	**30**	**273.677**

Cost Breakdown

	Performed	ETC	BAC	Contingency	% Contingency on ETC	TPC
475.01 Project Management	10,263	11,082	21,345			
475.02 Accelerator	12,357	27,118	39,475			
475.03 Conventional Construction	2,642	18,751	21,393			
475.04 Solenoids	17,746	69,943	87,689			
475.05 Muon Beamline	4,609	14,710	19,319			
475.06 Tracker	3,226	8,344	11,570			
475.07 Calorimeter	555	4,363	4,918			
475.08 Cosmic Ray Veto	1,728	5,063	6,791			
475.09 Trigger & DAQ	2,030	2,921	4,951			
Total	**55,156**	**162,295**	**217,452**	**56,225**	**35%**	**273,677**

Appendix E Mu2e Schedule Chart



Appendix F Mu2e Management Chart