Fermilab

Mu2e Cost Estimation

Ron Ray
Mu2e Project Manager
10/21/2014

Cost Methodology

General Procedure

- Activity-based RLS. M&S, labor hours, resources and durations established at activity level.
- Estimators instructed to use 85% C.L. base estimates
- Estimate uncertainty is added to each activity based on the level of design maturity.
- A statistical evaluation of the cost associated with risk exposure adds additional contingency to the Project

TPC = base estimate +
100% estimation uncertainty +
statistical evaluation of risks at 80% C.L.
+ application of burdening and escalation

BOEs

- Support the resources and durations in P6
- Include
  - Definition of scope covered
  - Supporting documents
  - Assumptions

Mu2e
BASIS of ESTIMATE (BoE)

Date of Estimate: 6 / 26 / 2014
Revision Date:

Prepared by: Julie Whitmore
Contributing: Paul Rubinov
Yuri Oksuzian
Craig Dukes

Docdb #: 3912

WBS number: 475.08.05.02 **Control Account**:475.08.05 **WBS Title:** Photodetector Quality Assurance Design and Fabrication

WBS Dictionary Definition: This set of activities includes the labor and materials necessary to design and produce the Quality Assurance SiPM testing fixture for evaluating the SiPMs. The QA tester is needed to test a 10% sample of the production devices before accepting the SiPMs from the vendor. The production SiPMs are then sent to UVA for mounting on counter motherboards. There are a total of 18,816 SiPMs needed for CRV module production with an additional 1,526 SiPMs needed for spare modules. A total of 20,000 SiPMs are needed for production, including wastage, and radiation/longevity acceptance testing. In addition, a total of 5,000 spares will be needed. The cost for these spare devices and the labor for the 10% acceptance testing are off-project.

Supporting Documents (including but not limited to):
see Electronic docdb file referenced above for supporting documentation.
#862 includes the parameters for the CRV system.
#3911 Includes information on the Photodetector Procurement
Vendor summary of invoices for prototype QA jig materials and eng/tech effort to date.
P6 schedule spreadsheet corresponding to this BOE (Excel)

Quality Control Process Applied by: E. Craig Dukes **Date:** 6/26/14

Assumptions:
- BOE only covers activities from the baseline date of May 1, 2014 onward. Activities prior to the baseline date are entered into the schedule as actuals with 0% contingency.
- Costs are in 2014 dollars and do not include indirects.
- Durations are in working days.
- 1 FTE = 1768 hours for an average year. P6 uses the actual calendar for each year with the exact number of workdays.
- SiPMs are fabricated in industry.
- SiPMs are characterized using a custom testing tester (see WBS 475.05.02). Devices will be shipped to UVa for assembly onto SiPM counter motherboards (see WBS in CRV Electronics)

Currently Assigned Personnel

L2 Manager –	E.C. Dukes
Deputy L2 Manager –	J. Whitmore
L3 Manager –	J. Whitmore

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BOEs

- Resources
- Hours
- M&S costs
- Estimate type/ contingency
- Durations at 85% C.L.

Task 475.8.5.2.1050 Fabricate QA prototype tester – M&S

M&S cost for prototype tester.

M&S Cost	$8000	Cost for tester chassis and misc electronics components
Duration	60 days	M&S purchases for rebuild after prototype design changes.
Estimate Type	Advanced	Contingency of 20% based on contingency rule M3. M&S based on fabrication of boards with similar design.

Task 475.8.5.2.1055 Fabricate QA prototype tester – remaining - FNAL

Labor for FNAL electrical engineer and technicians to procure components, fabricate, assemble and test the QA tester. Parts procurement, board layout/design, and board assembly is nearly completed. Tester assembly and testing is not.

Total Labor	292 hours	
Electrical Design Engineer	100 hours	Engineering estimate based on previous experience testing similar items. Assumes EE working 3 months at 0.25 FTE.
Engineering Physicist	80 hours	Engineering estimate based on previous NIU experience.
Electrical Drafter	40 hours	Engineering estimate based on previous board layout work.
Electrical Technician	8 hours	Engineering estimate based on previous experience procuring parts.
Electrical Assembly Technician	24 hours	Engineering estimate based on previous board assembly work.
Electronics Technician	40 hours	Engineering estimate based on previous NIU experience. Assumes 3 month at 10% FTE.
Duration	60 days	Assumes 3 months of above eng/tech effort.
Estimate Type	Preliminary	Contingency of 35% based on contingency rule L4.

Task 475.8.5.2.1062 Fabricate QA prototype tester – Labor – NIU remaining

Labor for NIU undergraduate student to write software for QA SiPM tester.

M&S	$16,131	595 Hours software support remaining. Engineering estimate based on similar projects.
Duration	162 days	Assumes student working for 4 FTE months.
Estimate Type	Conceptual	Contingency of 50% based on contingency rule L5. Higher end of range due to inexperienced student labor.

Task 475.8.5.2.1065 Fabricate QA dark box – Labor - NIU

Labor for NIU electrical technicians to design, procure components, and fabricate temperature stabilized dark box for testing prototype, pre-production, and production SiPMs.

Mechanical Engineer – Northern Ill Univ	120 h	Engineering estimate based on similar projects with large modifications.
Duration	30 days	Assumes tech working for 0.75 FTE month.
Estimate Type	Conceptual	Contingency of 50% based on contingency rule L5. Higher end of range due to design immaturity.

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BOEs

Often include supporting details

<u>Details of the Base Estimate</u>

The activities covered in this BOE include M&S purchases, procurement activities related to the M&S, and labor associated with producing a Quality Assurance tester for the Cosmic Ray Veto photodetectors. M&S estimates are based on previous experience with fabricating prototype testers used at NIU for the proton tomography project.

The plan for SiPM Quality Assurance testing is to measure the I-V curves of 10% of the 20,000 production SiPMs. This SiPM QA testing procedure has been used previously on a joint NIU/FNAL proton tomography project with a SiPM test facility at NIU. SiPMs for the Fall 2013 FNAL beam test were also tested at this facility. Based on the experience from that facility, a stand-alone test tester has been designed that does not require the additional support infrastructure (power supplies, picoammeter, etc.) that the NIU test stand needs to test the SiPMs.

The QA testing box is a stand-alone tester that will be used to simultaneously apply bias voltages to 32-SiPMs, measure the currents of each SiPM, and send the data off to a PC via a USB connection. The 32 SiPMs are mounted in a reusable waffle-pack fixture, with electrical connections to each surface mount SiPM being made by elastometric ZEBRA connectors. The SiPMs fixture will be placed in a temperature stabilized dark box.

A prototype of the QA tester is being developed and will be used to test the initial 320 SiPMs for radiation damage studies. Modifications to the final production design will come from experience with that prototype tester and dark box. The production tester will be built by Fermilab. NIU is responsible for producing the temperature controlled dark box. Production SiPMs will be tested at NIU with NIU undergraduates. Ten percent of the SiPMs will be QA tested before accepting the production devices.

Estimate SiPM Tester jig Labor and M&S

This document summarizes the labor and M&S for fabricating the SiPM tester jig that Fermilab is developing. It does not include the cost for the dark box that NIU is developing. The documentation includes a summary of the labor from the initial development of the prototype SiPM tester jig. Also attached is a parts list for the prototype jig. The total amount for the components is ~$8k. We assume that this is the cost for the components for the production testers.

Labor summary:
Estimate for remaining development work is based on the actuals from the initial development work.
Prototype jig
Fabrication
FNAL Electrical Design Engineer (David Huffman + Mark Kozlovsky) – 100 hours
FNAL Engineering Physicist (Paul Rubinov) – 80 hours
FNAL Electrical Drafter (Nina Moibenko) – 40 hours
FNAL Electrical Technician (Johnny Green) – 8 hours
FNAL Elec Assembly Technician (Paula Lippert) – 24 hours
FNAL Electronics Technician (Merle Watson) – 40 hours

Production Jig
Fabrication
FNAL Electrical Design Engineer (David Huffman + Mark Kozlovsky) – 55 hours
FNAL Engineering Physicist (Paul Rubinov) – 40 hours
FNAL Electrical Drafter (Nina Moibenko) – 40 hours
FNAL Electrical Technician (Johnny Green) – 24 hours

FNAL Electrical Assembly Technician (Paula Lippert) – 32 hours

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Contingency

- Contingency is the combination of estimate uncertainty and risk exposure.
- Estimate Uncertainty Rules for labor and M&S posted on review web site (Mu2e-doc-459)
  - Standard rules, similar or identical to those used by other Fermilab projects.
  - Do not reflect risk.
- Risk was addressed in a quantitative analysis process using a Monte Carlo
  - Primavera Risk Analysis Tool used to evaluate cost and schedule risk.

Fermilab Estimate Uncertainty Rules

M&S

Code	Type of Estimate	Contingency %	Description
M&S Guidelines			
M1	Existing Purchase Order	0%-15%	Items that have been completed or obligated. Non-zero contingency may be appropriate in some cases because of potential changes that may occur over the life of the procurement.
M2	Procurements for LOE / Oversight work	0%-20%	M&S items such as travel, software purchases and upgrades, computers, etc. estimated to support LOE efforts and other work activities.
M3	Advanced	10%-20%	Items for which there is a catalog price or recent vendor quote based on a completed or nearly completed design or an existing design with little or no modifications and for which the costs are documented.
M4	Preliminary	20%-40%	Items that can be readily estimated from a reasonably detailed but not completed design; items adapted from existing designs but with moderate modifications, which have documented costs from past projects. A recent vendor survey (e.g., budgetary quote, vendor RFI response) based on a preliminary design belongs here.
M5	Conceptual	40%-60%	Items with a documented conceptual level of design; items adapted from existing designs but with extensive modifications, which have documented costs from past projects
M6	Pre-Conceptual - Common work	60%-80%	Items that do not have a documented conceptual design, but do have documented costs from past projects. Use of this estimate type indicates little confidence in the estimate. Its use should be minimized when completing the final estimate.
M7	Pre-Conceptual - Uncommon work	80%-100%	Items that do not have a documented conceptual design, and have no documented costs from past projects. Its use should be minimized when completing the final estimate.
M8	Beyond state of the art	>100%	Items that do not have a documented conceptual design, and have no documented costs from past projects. Technical requirements are beyond the state of the art.

Fermilab Estimate Uncertainty Rules

Labor

Code	Type of Estimate	Contingency %	Description
LABOR Guidelines			
L1	Actual	0%	Actual costs incurred on activities completed to date.
L2	Level of Effort Tasks	0%-20%	Support type activities that must be done to support other work activities or the entire project effort, where estimated effort is based on the duration of the activities it is supporting.
L3	Advanced	10%-25%	Based on experience with documented identical or nearly identical work. Development of activities, resource requirements, and schedule constraints are highly mature. Technical requirements are very straightforward to achieve.
L4	Preliminary	25%-40%	Based on direct experience with similar work. Development of activities, resource requirements, and schedule constraints are defined at a preliminary (beyond conceptual) design level. Technical requirements are achievable and with some precedent.
L5	Conceptual	40%-60%	Based on expert judgment using some experience as a reference. Development of activities, resource requirements, and schedule constraints are defined at a conceptual level. Technical requirements are moderately challenging.
L6	Pre-conceptual	60%-80%	Based only on expert judgment without similar experience. Development of activities, resource requirements, and schedule constraints are defined at a pre-conceptual level. Technical requirements are moderately challenging.
L7	Rough Estimate	80%-100%	Based only on expert judgment without similar experience. Development of activities, resource requirements, and schedule constraints is largely incomplete. Technical requirements are challenging.
L8	Beyond state of the art	>100%	No experience available for reference. Activities, resource requirements, and schedule constraints are completely undeveloped. Technical requirements are beyond the state of the art.

Total Project Cost

(Values in AY $k)	Performed	ETC	Contingency EU + Risk	% Cont on ETC	Total
Project Management	9,565	11,104	2,125	19%	**22,794**
Accelerator	11,790	29,016	9,433	33%	**50,239**
Conventional Construction	2,642	18,603	2,825	15%	**24,070**
Solenoids	16,743	71,225	24,322	34%	**112,290**
Muon Beamline	4,406	15,161	5,922	39%	**25,490**
Tracker	2,941	8,582	3,760	44%	**15,283**
Calorimeter	522	4,406	1,164	26%	**6,092**
Cosmic Ray Veto	1,543	5,229	1,963	38%	**8,735**
Trigger & DAQ	1,829	2,971	1,207	41%	**6,007**
Total	**51,982**	**166,296**	**52,722**	**32%**	**271,000**

Contingency

- Overall contingency of 32% on cost to go, but risk is not evenly distributed
- $39M of Project Management costs spread throughout the Project
  - $24M cost-to-go
  - Primarily LOE based on assigned personnel and well established need, so contingencies are low
    - Example: I'm assigned at 100%. No contingency.
  - Conventional Construction is a big ticket item with low risk that is well understood. We have a bid that we are about to turn into a PO. Cost known.
- If we remove PM costs and contingency, the contingency on the remaining cost-to-go is 35%.
- If we remove PM and Conventional Construction, the contingency on the remaining "technical scope" of the Project is 37%.

Scope Contingency

- By running at 5x lower beam power we could eliminate ~$3M of heavy concrete shielding around the TS and DS.
  – Shielding is purchased late in project
  – Shielding could be added later.
- The second calorimeter disk could be eliminated, deferred or provided by another agency or International partner. Saves ~$5M but reduces acceptance by ~40%.
  – Second disk could be added later.
- We are pursuing additional opportunities that, if realized, would effectively increase available contingency
  – other agencies provide some part of existing scope
  – move more work from laboratory to university group
  – potentially an additional $11M in contingency is possible
- More detail in Management Breakout

Independent Cost Estimate (ICE)

Muon to Electron Conversion Experiment (Mu2e) Project
Independent Cost Estimate Agenda
August 26-28, 2014
Fermi National Accelerator Laboratory

Location: Hornet's Nest (WH8X) Meeting Room
ReadyTalk – 866-740-1260
Access Code 5571684

Tuesday, August 26

Start	*Topic*	*Speaker*
08:00	**Executive Session**	ICE Team/FPD
08:15	**ICE Team Intro; begin Project Briefs**	ICE Team/Proj
	(FPD/Project Team Overview Briefings)	Mgr/FPD
	- Project Execution, Acquisition and Funding Plan	P. Carolan
	- Overall Project Scope and Cost Estimate Development	R. Ray
10:00	*Break*	
10:15	**Level 2 WBS Briefs**	
	(Briefly describe scope, any risks or technical concerns in each area)	
	- Project Management	R. Ray
	- Accelerator	S. Werkema
	- Conventional Construction	T. Lackowski
	- Solenoids	M. Lamm
	- Muon Beamline	G. Ginther
	- Tracker	A. Mukherjee
	- Calorimeter	D. Hitlin
	- Cosmic Ray Veto	C. Dukes
	- Trigger & Data Acquisition	M. Bowden
12:00	*Lunch*	
1:00	**Site Tour** (Project Site/Utility Tie-in Locations)	
2:15	Schedule Discussion (Overview of BOP schedule development, Critical Path, How project Resource Loaded the schedule.) Q&A	F. Leavell
3:15	*Break*	
3:30	Escalation Basis Discussion	D. Keiner
3:45	Risk/Uncertainty Discussion (Overview of Process, Key Risks, Method to develop cost and schedule uncertainty, how risk/uncertainty translates into management reserve and contingency. Controls for use of MR and Contingency.) Q&A	M. Dinnon/R. Ray
4:45	Conventional Construction Discussion	
5:15	ICE Team (Only) Discussion	

Wednesday, August 27

WBS Drilldowns

Start	*Topic*	*Speaker*
08:00	1.1.4 – Project Management Implementation	R. Ray
09:00	1.2.9 – Accelerator Target Station	R. Coleman
10:30	*Break*	
10:45	1.4.3 - Transport Solenoids	M. Lopes
12:15	*Lunch*	
1:00	1.4.4 - Detector Solenoid	M. Buehler
2:00	1.4.12 - Solenoids Integration, Installation & Commissioning	J. Brandt
2:45	*Break*	
3:00	1.8.6 - Cosmic Ray Veto Electronics	C. Dukes
3:15	1.8.7 - Cosmic Ray Veto Module Fabrication	C. Group (Remote)
3:45	1.6.4 - Tracker Front End Electronics	V. Rusu
4:15	1.7.2 - Calorimeter Crystals	D. Hitlin
4:30	1.7.6 - Calorimeter Calibration System	D. Hitlin
5:00	*Adjourn*	

Thursday, August 28

WBS Drilldowns Cont.

08:00	ICE Team (Only) Discussion	ICE Team
9:00	1.5.9 - Muon Beamline Downstream External Shielding	G. Ginther
9:30	1.5.10 - Muon Beamline Detector Support Structure	G. Ginther
10:00	1.9.3 - Data Acquisition	K. Biery
10:30	*Break*	
10:45	Open Issues/General Discussion	ICE Team, Proj Mgr, FPD Other Proj Team as Req'd
12:00	*Lunch*	
TBD	Closeout Meeting	

ICE

- From Draft ICE Report:

“The ICE was conducted in two parts: Conventional Facilities (WBS 1.3) and BOP (Remainder of WBS elements). For the conventional facilities, the ICE was performed using a bottom-up technique—a DOE Type V ICE as defined in reference (a). For the BOP, a detailed cost review— a DOE Type II ICE— was performed concentrating on the Mu2e technical systems. The WBS elements for the detailed review exceeded 40% of the remainder of the total project cost (TPC) estimate (TPC less CF portion). Additionally, the Type II ICE identified the technical work key cost drivers and completed a top-down review of the project’s cost estimates for sufficiency and reasonableness.”

ICE

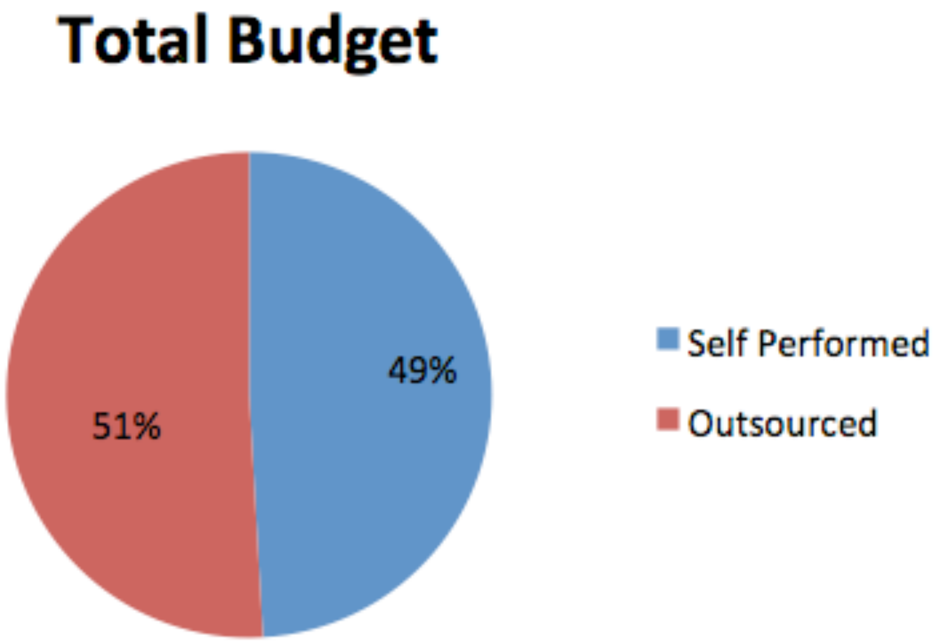
Based on the results of the ICE, the ICE Team concludes the following:

- The project estimate appears sufficient to complete the project as planned.
- The cost estimating procedures and assumptions used by the Project Team are reasonable, and have been consistently applied in the cost estimate.
- The escalation rates used for the project estimate are reasonable, based on comparison with other DOE projects and independent studies.
- The ICE for conventional facilities is within 0.4% of the project estimate, so there is excellent agreement.
- The ICE Team recommends no adjustments to the cost estimate for BOP direct costs. The cost estimate is complete. The level of detail and backup information is impressive. The strength of the BOP cost estimate lies in the planning and definition of the work to be performed for each WBS activity. Likewise, materials and supplies (M&S) are very well identified. Quotes and purchase orders are available for all large procurements.
- The project schedule is well-built and provides a reasonable and valid representation of the sequence of work. Moreover, there is a clearly traceable connection between the scope described in the Basis of Estimate (BOE) documents and the activities in Primavera. The critical path of the Mu2e project schedule appears reasonable and valid.

ICE

While the ICE team validated our base cost estimate, they felt our contingency analysis was too conservative (too high). This arises from an unfamiliarity with Office of Science Projects where contingencies of 30 – 40% are typical at CD-2.

Self Performed Work



Based on cost and includes labor and M&S

Summary

- Detailed cost estimate developed in P6
- Supported by detailed BOEs and other backup information
- Quotes and purchase orders are available for large procurements.
- Base cost estimate validated by ICE Team.
- Overall contingency of 32% on cost to go. Contingency of 37% on remaining *technical scope*.
- Additional scope contingency available if needed.