**Detailed Controls Costing Breakdowns:**

Labor and M&S estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Experts and a detailed breakdown of those costs are outlined here. Costing spans three WBS areas:

1. **Transport**: Controls for these areas span the MI-60, F0, F1, F23, F27, and AP-0 service buildings. The BoE for this area can be found in Mu2e Document 1572.
2. **Delivery Rings**: Controls for those areas that span the AP-10, AP-30 and AP-50 service buildings. The BoEs for this area can be found in Mu2e Document 1468 and 1639.
3. **External Beam Line**: Controls for the areas that span the MC-1 and Mu2e Service Buildings. The BoE for this area can be found in Mu2e Document 2136. **Note that this document does not cover the Extinction Collimator portion of Doc #2136.**



Figure 1: Controls Layout

The existing controls system infrastructure is pictured in figure 1. Control system computers exist in the cross gallery, and communicate to the various accelerators via fiber optic and Heliax cables. The Muon Rings service building controls in AP-10, AP-30 and AP-50 originate from the cross gallery to the AP10 service building via a path the includes communication ducts, the Central Utility Building (CUB), further communication ducts and the Muon Rings enclosure. One of these communications ducts will be interrupted with the construction of the muon extraction beam lines. One fiber optic bundle and 18 Heliax cables will need to be either spliced or replaced to restore communication. From AP10, fiber optic and Heliax cable is connected to AP30, AP50 and AP0 via the Muon/Pbar rings enclosure and Muon/Pbar Transport enclosure. The radiation environment for Mu2e operations is expected to be much higher than that of former Pbar operations, so as a result , some portions of fiber optic controls cables that run through the accelerator enclosures may need to be upgraded to a more radiation hardened variety and/or shielded from the radiation losses. The segment of Ethernet that connects AP10 to AP0 is a legacy 10mbps Thickwire that runs through the Muon Rings and Transport enclosures. Controls to the beam line buildings F23 and F27 come from Heliax cable that originates at MI60/F0 and traverses through accelerator enclosures. There is no fiber optic Ethernet cabling available, so Ethernet to F23 and F27 is provided via a 10mpbs wireless system originating from MI60. F23, F27 and AP0 controls Ethernet may need to be updated for g-2 and Mu2e operations. In addition new controls will need to be established in the MC-1 service building and Mu2e experimental hall.

**Transport Controls:**

Controls for these areas span the MI-60, F0, F1, F23, F27, and AP-0 service buildings and can be broken down into the following general categories:

1. **Links and Camac**: Estimate includes inventory of existing serial links and Camac crates1 to determine if the current infrastructure can be repurposed for Mu2e operations, as well as constructing and implementing a plan to move CAMAC crates, cards and links for Mu2e operation. We have an ample supply of spare Camac cards and crates, and the current crate and link structure is believed to be adequate. A large portion of the implementation effort will involve technician time for moving crates and cards and computer professional time to update parameter database information.
	1. **Beam Synch Clock:** F0, F1 and F2 service buildings will need both 53MHz clock for SY120 operation as well as 2.5MHz clock for muon operations. The fiber links that feed F0, F1 & F2 already support multiple beam sync clocks (MIBS, TVBS & APTVBS). What we will do is replace the TVBS feed at MI-60 CR with a RRBS feed. The MIBS fiber link will be unchanged. That will provide both MIBS & RRBS at all three service buildings. Recycler 2.5MHz clock will need to replace the current Main Injector 53MHz clock in the Muon Buildings covering downstream of the P2 line. The current beam synch path is copper, going through tunnels, and goes F0 ->F23->AP0-> (AP0 -> F27) AP50 -> AP30. The MIBS feed at F0 will be replaced with RRBS.
2. **Hot Rack Monitor (HRM)**: A number of Camac modules are nearing end of life and if funding is available could be upgraded to a VME platform that talks to the controls system via Ethernet. In this scenario, Camac 190/290 cards would be replaced by HRM installations. Installing HRMs will provide 16 bit A/D readbacks, DAQ, I/O and clock channels. Though this upgrade path is desirable, the cost is considered too great to be economically feasible.
3. **Network**: Estimate includes analysis of current network infrastructure to determine if the existing network equipment1 is adequate for Mu2e operations, planning and implementing the upgrade of legacy equipment. The controls wireless networks at F23 and F27 and the shared 10MBps network at AP0 are believed to be marginally adequate but could be upgraded if funding is available. The most economical upgrade path would be to run single mode fiber optic cable from AP30, through the Muon tunnel enclosures to these three service buildings. New network switches would then need to be installed in the buildings. A large portion of the implementation labor effort will involve technician time to make Ethernet connections from each end node to the central network switch in each service building.
	1. **Legacy Networks:** With the descoping of other upgrades that would add Ethernet traffic, the network in AP0, F23 and F27 may be marginally adequate for operations. Due to budget constraints; therefore, we are not going to complete the network fiber upgrade to these buildings. There is an inherent risk with taking this approach which will be added to the risk registry.
	2. **Controls Cable Path**: In addition, there is some risk that the cabling that provides controls to AP0 will be interrupted in the building of the M2 and M3 lines. The controls cabling path currently goes from the AP30 service building, through the transport tunnel enclosure to AP0. This is an inherent risk that is also included in the above mentioned risk registry item.
	3. **Radiation:** The existing network cable path goes from building to building via the tunnel. It is not certain if we will be able to continue to use the existing cable path and fiber during Mu2e operations. There are risks associated with this due to potential radiation damage and interference. This will be defined in the risk registry, but as a separate item than the one mentioned in the above two topics.

These efforts do not include upgrades to the beam permit system, which are covered by the machine protection BoE. These efforts include consultation with controls experts from existing systems to determine an initial conceptual design.

**Transport Controls Labor:**

**Conceptual Design: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Conceptual Design |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~10~~ |  |
| Network |  | 10 |  |  | 10 |  |
| Totals |  | 20 |  |  | 20 |  |

|  |
| --- |
| Conceptual Design |
|  | Engineer (hours) |
| Serial Link and Camac |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |
| Network |  | 10 |  |
| Totals |  | 20 |  |

**Preliminary Design: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Preliminary Design |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~10~~ |  |
| Network |  | 10 |  |  | 10 |  |
| Totals |  | 20 |  |  | 20 |  |

|  |
| --- |
| Preliminary Design |
|  | Engineer (hours) |
| Serial Link and Camac |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |
| Network |  | 10 |  |
| Totals |  | 20 |  |

**Final Design: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Final Design |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 20 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~20~~ |  |
| Network |  | 10 |  |  | 20 |  |
| Totals |  | 20 |  |  | 40 |  |

|  |
| --- |
| Final Design |
|  | Engineer (hours) | Technician (hours) |
| Serial Link and Camac |  | 20 |  |  | 10 |  |
| HRM Installation |  | ~~20~~ |  |  | ~~10~~ |  |
| Network |  | 20 |  |  | 10 |  |
| Totals |  | 40 |  |  | 20 |  |

**Implementation and Closeout: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Implementation & Close-out |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 150 |  |
| HRM Installation |  | ~~10~~ |  |  | \* |  |
| Network |  | 10 |  |  | 50 |  |
| Totals |  | 20 |  |  | 200 |  |

\*Covered in HRM labor estimate below.

|  |
| --- |
| Implementation & Close-out |
|  | Engineer (hours) | Technician (hours) |
| Serial Link and Camac |  | 20 |  |  | 300 |  |
| HRM Installation |  | \* |  |  | \* |  |
| Network |  | 20 |  |  | 200 |  |
| Totals |  | 40 |  |  | 500 |  |

\*Covered in HRM labor estimate below.

**HRM assembly, testing and installation (EDIA and Implementation).** Installation of HRMs in MI60, F0, F1, F23, F2, F27 and AP0 connected to the beam lines. Does not include storage ring buildings nor the Mu2e experimental hall. Labor estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| Labor Hours  |
|  | Optional Plan(1 installations) | Base Plan(8 installations) | Optional Plan(20 installations) |
| Electrical Engineer (1 week/installation) | ~~40~~ | ~~320~~ | 800 |
| Electrical Technician (2 weeks/installation) | ~~80~~ | ~~640~~ | 1600 |
| Computer Professional (1 week/installation) | ~~40~~ | ~~320~~ | 800 |

\*Existing buildings will not be upgraded to the HRMs. Risk associated with this action will be covered in the risk registry.

**Transport Controls M&S:**

**Camac M&S (EDIA and Implementation):** Upgrading Camac hardware in MI60, F0, F1, F23, F2, F27 and AP0 connected to the beam lines. Does not include storage ring buildings nor the Mu2e experimental hall. Labor estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| M&S Implementation & Closeout |
|  |  | Base Plan |  |
| Camac Equipment |  | $20K |  |
| Totals |  | $20K |  |

**HRM Installation M&S (EDIA and Implementation):** Installation of HRMs in MI60, F0, F1, F23, F2, F27 and AP0 connected to the beam lines. Does not include storage ring buildings nor the Mu2e experimental hall. Labor estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| M&SImplementation & Closeout |
|  | Optional Plan(1 installations) | Base Plan(8 installations) | Optional Plan(20 installations) |
| VME 7 crate slot/power supply | ~~$4.5K~~ | ~~$36K~~ | ~~$90K~~ |
| Processor cards | ~~$3.0K~~ | ~~$24K~~ | ~~$60K~~ |
| HRM (128 analog inputs/HRM) | ~~$7.0K~~ | ~~$56K~~ | ~~$140~~ |
| Fan In box | ~~$1.0K~~ | ~~$8K~~ | ~~$20K~~ |
| Totals | ~~$15.5K~~ | ~~$124K~~ | ~~$310K~~ |

\*Existing buildings will not be upgraded to the HRMs. Risk associated with this action will be covered in the risk registry

**AP30 to AP0-F23-F27 Network M&S (EDIA and Implementation):** Installation of network fiber from AP30 to the AP0, F23 and F27 Service Buildings. This is a new network installation. Base cost assumes that standard single mode fiber can be used. Maximum cost assumes rad hardened fiber optic cable is needed. The cost for this installation should be covered by transport line BoE, but is just put here for future reference. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| Implementation & Closeout |
|  | Base(96 count standard fiber) | Option 1(24count rad hardened fiber) |
| Singlemode Fiber from AP30 to AP0 (1,200 feet at $1.50/foot for standard, or1,200 feet at $21.50/foot for rad hardened) | $1.8K | $25.8K |
| Inner duct (1,200 feet at $1.00/foot) | $1.2K | $1.2K |
| AP0 Fiber Termination Shelf | $0.275K | $0.275K |
| AP0: 2 Adapter Panel, 12 LC | $0.3K | $0.3K |
| AP0: Corning Single Mode LC connector (24 x $15) | $0.36K | $0.36K |
| Contract Electrician (AP0 Termination: 24 connectors)2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K |
| Singlemode Fiber from AP0 to F23 (300 feet at $1.50/foot for standard, $21.50/foot for rad hardened) | $0.45K | $6.45K |
| Inner duct (300 feet at $1.00/foot) | $0.3K | $0.3K |
| F23 Fiber Termination Shelf | $0.275K | $0.275K |
| F23: 1 Adapter Panel, 12 LC | $0.30K | $0.30K |
| F23: Corning Single Mode LC connector (24 x $15) | $0.36K | $0.36K |
| Contract Electrician (AP0 Termination: 24 connectors)2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K |
| Singlemode Fiber from AP0 to F27 (650 feet at $1.50/foot for standard, $21.50/foot for rad hardened) | $0.975K | $13.975K |
| Inner duct (650 feet at $1.00/foot) | $0.650K | $0.3K |
| F27 Fiber Termination Shelf | $0.275K | $0.275K |
| F27: 1 Adapter Panel, 12 LC | $0.30K | $0.30K |
| F27: Corning Single Mode LC connector (12 x $15) | $0.36K | $0.36K |
| Contract Electrician (AP0 Termination: 24 connectors)2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K |
| Contract Electrician (Cable Pull)4 workers @ 1 day [$3500] x number of days | $35.0K(10 days) | $35.0K(10 days) |
| Network Switches ( $3K/48 port switch) x 3 switches | $9K | $9K |
| Totals | $53.98K | $96.98K |

**\***It is assumed that we can run AP0, F23 and F27 on legacy networks and the network path to AP0 will not be interrupted during M3 line construction. The risk associated with this decision is outlined in the risk registry.

**Delivery Ring Controls:**

Controls for these areas span the AP-10, AP-30 and AP-50 service buildings and can be broken down into three general categories:

1. **Links and Camac:** Estimate includes inventory of existing serial links and Camac crates1 to determine if the current infrastructure can be repurposed for Mu2e operations, as well as constructing and implementing a plan to move CAMAC crates, cards and links for Mu2e operation. We have an ample supply of spare Camac cards and crates, and the current crate and link structure is believed to be adequate. A large portion of the implementation effort will involve technician time for moving crates and cards and computer professional time to update parameter database information.
	1. **Beam Synch Clock:** Recycler 2.5MHz clock will need to replace the current Main Injector 53MHz clock in the Muon Buildings. The current beam synch path is copper, going through tunnels, and goes F0 ->F23->AP0-> (AP0 -> F27) AP50 -> AP30. The MIBS feed at F0 will be replaced with RRBS.
2. **Hot Rack Monitor (HRM):** A number of Camac modules are nearing end of life and if funding is available could be upgraded to a VME platform that talks to the controls system via Ethernet. In this scenario, Camac 190/290 cards would be replaced by HRM installations. Installing HRMs will provide 16 bit A/D readbacks, DAQ, I/O and clock channels. Though this upgrade path is desirable, the cost is considered too great to be economically feasible at this time.
3. **Network**: Estimate includes analysis of current network infrastructure to determine if the existing network equipment1 is adequate for Mu2e operations, planning and implementing the upgrade of legacy equipment. A large portion of the implementation labor effort will involve technician time to make Ethernet connections from each end node to the central network switch in each service building.
	1. **Cable Duct:** The existing cable duct from the MAC Room to AP10 (includes network, camac, etc…), goes through CUB, through the concrete manhole in the road between AP10 and AP30 and in the tunnel on the Debuncher side in the middle of the D20 straight and then along the Debucher side cable trays to AP10.
		1. The cable duct will be dug up for the installation of the M4 and g-2 lines. The result is 18 controls Heliax cables and one network fiber optic cable will need to be spliced or replaced.
		2. FESS will provide a new communications duct between the AP-30 service building and the manhole outside of Booster West Tower. There are two possible plans being considered to reconnect the controls network:
			1. Base Plan: New fiber optic cable (24 multimode/72 single mode) will be pulled from the MAC Room through the manhole, through the new duct work to AP30. Single mode fiber will be used to restore Ethernet connectivity and multi-mode fiber will be used to restore the serial link connectivity that was provided by the Heliax.
			2. Backup Plan: New single mode fiber optic cable will be pulled from the MAC Room through the manhole, through the new duct work to AP30. The Heliax cable will be cut at the manhole, a second manhole will be provided, if necessary, by FESS to allow room for splicing of Heliax cable into new Heliax cable that will be pulled to AP30. These two actions will restore controls to the AP10, AP30 and AP50 service buildings.
	2. **Radiation:** The existing network cable path goes from service building to service building via the tunnel enclosures. It is not certain if we will be able to continue to use the existing cable path and fiber during Mu2e operations. There are risks associated with this due to potential radiation damage and interference. This will be defined in the risk registry.
		1. New standard single mode fiber optic cable will be pulled through the existing fiber optic path that goes through the rings tunnel on the Accumulator side which provides additional distance between the beam loss points and the fiber optic cable. The single mode fiber is more resistant to the radiation environment than expected for Mu2e operations than the existing multimode fiber optic cable, but is a fraction of the cost of the radiation hardened cable. There are risks associated with there still being radiation damage and interference that are covered in the Risk Registry.

These efforts do not include upgrades to the beam abort permit system or software application upgrades, which are covered by the machine protection section of operational preparedness. These efforts include consultation with controls experts from existing systems to determine an initial conceptual design.

**Delivery Ring Controls Labor:**

**Conceptual Design: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Conceptual Design |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~10~~ |  |
| Network |  | 10 |  |  | 10 |  |
| Totals |  | 20 |  |  | 20 |  |

|  |
| --- |
| Conceptual Design |
|  | Engineer (hours) |
| Serial Link and Camac |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |
| Network |  | 10 |  |
| Totals |  | 20 |  |

**Preliminary Design: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Preliminary Design |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~10~~ |  |
| Network |  | 10 |  |  | 10 |  |
| Totals |  | 20 |  |  | 20 |  |

|  |
| --- |
| Preliminary Design |
|  | Engineer (hours) |
| Serial Link and Camac |  | 10 |  |
| HRM Installation |  | ~~10~~ |  |
| Network |  | 10 |  |
| Totals |  | 20 |  |

**Final Design: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Final Design |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 20 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~20~~ |  |
| Network |  | 10 |  |  | 20 |  |
| Totals |  | 20 |  |  | 40 |  |

|  |
| --- |
| Final Design |
|  | Engineer (hours)  | Technician (hours) |
| Serial Link and Camac |  | 20 |  |  | 10 |  |
| HRM Installation |  | ~~20~~ |  |  | ~~10~~ |  |
| Network |  | 20 |  |  | 10 |  |
| Totals |  | 40 |  |  | 20 |  |

**Implementation and Closeout: Engineering Oversight (Management), Camac and Network:**

|  |
| --- |
| Implementation & Close-out |
|  | Engineering Physicist (hours) | Computer Professional (hours) |
| Serial Link and Camac |  | 10 |  |  | 200 |  |
| HRM Installation |  | ~~10~~ |  |  | ~~\*~~ |  |
| Network |  | 10 |  |  | 200 |  |
| Totals |  | 20 |  |  | 400 |  |

\*Covered in HRM labor estimate below.

|  |
| --- |
| Implementation & Close-out |
|  | Engineer (hours) | Technician (hours) |
| Serial Link and Camac |  | 20 |  |  | 300 |  |
| HRM Installation |  | \* |  |  | \* |  |
| Network |  | 20 |  |  | 200 |  |
| Totals |  | 40 |  |  | 500 |  |

\*Covered in HRM labor estimate below.

\*HRM upgrade will not be completed. Risks associated with this decision will be documented in the risk registry.

**HRM assembly, testing and installation (EDIA and Implementation) :** Installation of HRMs in AP10, AP30 and AP50. Does not include beam lines nor the g-2 or Mu2e experimental hall Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| Labor Hours  |
|  | Option 2 (6 installations) | Base Option(12 installations) | Option 3(30 installations) |
| Electrical Engineer (1 week/installation) | ~~240~~ | ~~480~~ | ~~1200~~ |
| Electrical Technician (2 weeks/installation) | ~~480~~ | ~~960~~ | ~~2400~~ |
| Computer Professional (1 week/installation) | ~~240~~ | ~~480~~ | ~~1200~~ |

\*Existing ring buildings will not be upgraded to the HRMs. Risk associated with this action will be covered in the risk registry.

**Delivery Ring Controls M&S:**

**Camac M&S (EDIA and Implementation):** Updating Camac hardware in AP10, AP30 and AP50. Does not include beam lines nor the g-2 or Mu2e experimental hall. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| Implementation & Closeout |
|  |  | Base |  |
| Camac Equipment |  | $10K |  |
| Totals |  | $10K |  |

**HRM Installation M&S (EDIA and Implementation):** Installation of HRMs in AP10, AP30 and AP50. Does not include beam lines nor the Mu2e or g-2 experimental hall. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |
| --- |
| Implementation & Closeout |
|  | Option 1(6 installations) | Base(12 installations) | Option 2(30 installations) |
| VME 7 crate slot/power supply | ~~$27K~~ | ~~$54K~~ | ~~$135K~~ |
| Processor cards | ~~$18K~~ | ~~$36K~~ | ~~$90K~~ |
| HRM (128 analog inputs/HRM) | ~~$42K~~ | ~~$84K~~ | ~~$210~~ |
| Fan In box | ~~$6K~~ | ~~$12K~~ | ~~$30K~~ |
| Totals | ~~$93K~~ | ~~$186K~~ | ~~$465K~~ |

**\***HRM upgrade will not be completed in existing buildings. Risk associated with this action will be covered in the risk registry.

**Main Control Room to AP30 Heliax M&S (EDIA and Implementation):** Replacement and/or splicing of the 18 Heliax controls cables, or replacing Heliax with multi-mode fiber, from the MAC room to AP-30. This is required as a result of the Network communications duct being dug up during extraction line installation. Base cost assumes that we can splice the existing Heliax. Base option is replacing with fiber, with alternate options having us splice the Heliax or replace the Heliax altogether. There is hope that this cost can be covered by the GPP and not in this BoE Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |  |
| --- | --- |
|  | Implementation & Closeout |
|  | Original(splice Heliax) | **Base Option**(Multi-mode uplink)  | Option 1(pull new Heliax) |
| Heliax Pull ($1.42/foot/cable)Base: 800 ft (manhole to AP30) x $142/ft x 18 cablesMaximum: 1600 ft (MAC room to AP30) x $1.42 x 18 | $20.448K |  | $40.896K |
| Multimode Cable Pull (covered in MAC Room to AP30 network fiber pull base option) | N/A | $0K | N/A |
| Fiber Repeaters and Repeater Chassis (including interconnecting cable and fiber jumpers) at Xgallery and AP30 | N/A | $20K | N/A |
| Connectors MAC Room ($16.52/ea) x 18 (new pull only) | $0.0K | N/A | $0.29736K |
| Connectors AP30 ($16.52/ea) x 18 cables | $0.29736K | N/A | $0.29736K |
| Splices (2 connectors x $16.52/connector) + ($9.30/adapter) x 18 cables | $0.76212K | N/A | $0K |
| Manhole material | $0.2K | N/A | $0K |
| Contract Electrician (Terminations)(2 technicians @ $400/day | $4K(10 days) | N/A | $2K(5 days) |
| Contact Electricians (Cable Pulls)(4 electricians [$3200/day] x number of days) | $9.6K(3 days) | N/A | $19.2K(6 days) |
| Totals | $35.3K | $20K | $62.7K |

**\***It is assumed that we are able to splice the Heliax. The risk associated with this decision will be covered in the Risk Registry.

**MAC Room to AP30 Network M&S (EDIA and Implementation):** Installation of network fiber from the MAC room to AP-30. This is required as a result of the Network communications duct being dug up during extraction line installation. Base cost assumes that standard single mode fiber can be used. Maximum cost assumes rad hardened fiber optic cable is needed. There is hope that this cost can be covered by the GPP and not in this BoE. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

|  |  |
| --- | --- |
|  | Implementation & Closeout |
|  | Original Plan(96 count standard single mode fiber) | **Base Plan**(72 count single mode/24 count multi-mode) | Maximum (24 count rad hardened fiber) |
| Singlemode Fiber from MAC Room to AP30 (1,600 feet)$1.50/foot for standard single mode$2.70/foot for 72 fiber single mode/24 fiber multi-mode$21.50/foot for rad hardened single mode | $2.4K | $4.32K | $34.4K |
| Inner duct (1,600 feet at $1.00/foot) | $1.6K | $1.6K | $1.6K |
| AP30 Fiber Termination Shelf | $0.275K | $0.275K | $0.275K |
| 2 Adapter Panel, 12 LC | $0.3K | $0.3K | $0.3K |
| Corning Single Mode LC connector (24 x $15) | $0.36K | $0.36K | $0.36K |
| Contract ElectricianTermination (24 LC connectors)(2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K | $0.6K |
| 4 Adapter Panel, 24 ST | N/A | $0.6K | N/A |
| Multimode ST Connector (24 x $15) | N/A | $0.36K | N/A |
| Contract ElectricianTermination (24 ST connectors)(2 workers @ 1 day [$1200] for 48 connectors) | N/A | $0.6K | N/A |
| MAC Room Fiber Termination Shelf | $0.275K | $0.275K | $0.275K |
| 2 Adapter Panel, 12 LC | $0.3K | $0.3K | $0.3K |
| Corning Single Mode LC connector (12 x $15) | $0.36K | $0.36K | $0.36K |
| Contract ElectricianTermination (24 LC connectors)(2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K | $0.6K |
| 4 Adapter Panel, 24 ST | N/A | $0.6K | N/A |
| Multimode ST Connector (24 x $15) | N/A | $0.36K | N/A |
| Contract ElectricianTermination (24 ST connectors)(2 workers @ 1 day [$1200] for 48 connectors) | N/A | $0.6K | N/A |
| Contract Electrician (Inner-duct Pull)4 workers @ 1 day [$3500] x number of days | $14K(4days) | $14K(4days) | $14K(4days) |
| Contract Electrician (Fiber Pull)4 workers @ 1 day [$3500] x number of days | $10.5K(3 days) | $10.5K(3 days) | $10.5K(3 days) |
| Totals | $31.57K | $36.61K | $63.57K |

**\***It is assumed that we are able operate using standard single-mode fiber. The risk associated with this decision will be covered in the Risk Registry.

**AP10-AP30-AP50 Network M&S (EDIA and Implementation):** Installation of network fiber and switches in AP10, AP30 and AP50. Does not include beam lines or the MC-1 or Mu2e experimental hall. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

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| Implementation & Closeout |
|  | Base(96 count standard fiber) | Option 1(24count rad hardened fiber) |
| Singlemode Fiber to AP10, AP30 and AP50 (2,100 feet at $1.50/foot for standard, $21.50/foot for rad hardened) | $3.15K | $45.15K |
| Inner duct (2,100 feet at $1.00/foot) | $2.1K | $2.1K |
| Fiber Termination Shelves x 3 buildings | $0.825K | $0.825K |
| 2 Adapter Panel, 12 LC, x 3 buildings | $0.9K | $0.9K |
| Corning Single Mode LC connector (12 x $15) x 3 buildings | $1.08K | $1.08K |
| Contract Electrician (Termination: 24 connectors/building x 3 buildings)2 workers @ 1 day [$1200] for 48 connectors) | $1.8K | $1.8K |
| Contract Electrician (Cable Pull)4 workers @ 1 day [$3500] x 10 days | $35.0K(7 days) | $35.0K(7 days) |
| Totals | $44.855K | $86.855K |

**\***It is assumed that we are able operate using standard single-mode fiber. The risk associated with this decision will be covered in the Risk Registry.

**External Beam Line Controls:**

This section covers controls costs associated with the MC-1 and Mu2e service buildings. It is important to note that this document does not cover controls costs for the Extinction Collimator (Mu2e-Doc-2136).

 **MAC Room-Mu2e Network M&S (EDIA and Implementation):** Installation of network fiber from the MAC room to the Mu2e service building. This is a new network installation. Base cost assumes that standard single mode fiber can be used. Maximum cost assumes rad hardened fiber optic cable is needed. The cost for this installation should be covered by the extraction line BoE, but is just put here for future reference. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

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| Implementation & Closeout |
|  | Original Plan(96 count standard single mode fiber) | **Base Plan**(72 count single mode/24 count multi-mode) | Risk (24 count rad hardened fiber) |
| Fiber from MAC Room to Mu2e (1,650 feet) $1.50/foot for standard single mode$2.70/foot for 72 fiber single mode/24 fiber multi-mode$21.50/foot for rad hardened single mode | $2.475K | $4.455K | $35.475K |
| Inner duct (1,600 feet at $1.00/foot) | $1.650K | $1.650K | $1.650K |
| AP30 Fiber Termination Shelf | $0.275K | $0.275K | $0.275K |
| 2 Adapter Panel, 12 LC | $0.3K | $0.3K | $0.3K |
| Corning Single Mode LC connector (24 x $15) | $0.36K | $0.36K | $0.36K |
| Contract ElectricianTermination (24 LC connectors)(2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K | $0.6K |
| 4 Adapter Panel, 24 ST | N/A | $0.6K | N/A |
| Multimode ST Connector (24 x $15) | N/A | $0.36K | N/A |
| Contract ElectricianTermination (24 ST connectors)(2 workers @ 1 day [$1200] for 48 connectors) | N/A | $0.6K | N/A |
| Cisco Ethernet Switch | $3K | $3K | $3K |
| MAC Room Fiber Termination Shelf | $0.275K | $0.275K | $0.275K |
| 2 Adapter Panel, 12 LC | $0.3K | $0.3K | $0.3K |
| Corning Single Mode LC connector (12 x $15) | $0.36K | $0.36K | $0.36K |
| Contract Electrician Termination (24 LC Cconnectors) 2 workers @ 1 day [$1200] for 48 connectors | $0.6K | $0.6K | $0.6K |
| 4 Adapter Panel, 24 ST | N/A | $0.6K | N/A |
| Multimode ST Connector (24 x $15) | N/A | $0.36K | N/A |
| Contract ElectricianTermination (24 ST connectors)(2 workers @ 1 day [$1200] for 48 connectors) | N/A | $0.6K | N/A |
| Contract Electrician (Inner-duct Pull)4 workers @ 1 day [$3500] x number of days | $14K(4days) | $14K(4days) | $14K(4days) |
| Contract Electrician (Fiber Pull)4 workers @ 1 day [$3500] x number of days | $10.5K(3 days) | $10.5K(3 days) | $10.5K(3 days) |
| **Totals** | **$34.695K** | **$39.795K** | **$67.695K** |

**\***It is assumed that we are able operate using standard single-mode fiber. The risk associated with this decision will be covered in the Risk Registry.

**MAC Room-MC-1 Network M&S (EDIA and Implementation):** Installation of network fiber from the MAC room to the MC-1 service building. This is a new network installation. Base cost assumes that standard single mode fiber can be used. Maximum cost assumes rad hardened fiber optic cable is needed. The cost for this installation should be covered by the extraction line BoE, but is just put here for future reference. Estimates were determined via a series of phone calls, email and meetings with Accelerator Division Controls Engineers.

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|  | Implementation & Closeout |
|  | Original Plan(96 count standard single mode fiber) | **Base Plan**(72 count single mode/24 count multi-mode) | Risk (24 count rad hardened fiber) |
| Singlemode Fiber from MAC room to MC-1 (1,500 feet) $1.50/foot for standard single mode$2.70/foot for 72 fiber single mode/24 fiber multi-mode$21.50/foot for rad hardened) | $2.25K | $4.05K | $32.25K |
| Inner duct (1,500 feet at $1.00/foot) | $1.5K | $1.5K | $1.5K |
| AP30 Fiber Termination Shelf | $0.275K | $0.275K | $0.275K |
| 2 Adapter Panel, 12 LC | $0.3K | $0.3K | $0.3K |
| Corning Single Mode LC connector (24 x $15) | $0.36K | $0.36K | $0.36K |
| Contract Electrician (Termination)24 LC connectors 2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K | $0.6K |
| 4 Adapter Panel, 24 ST |  | $0.6K |  |
| Multimode ST Connector (24 x $15) |  | $0.36K |  |
| Contract ElectricianTermination (24 ST connectors)(2 workers @ 1 day [$1200] for 48 connectors) |  | $0.6K |  |
| Cisco Ethernet Switch | $3K | $3K | $3K |
| MAC Room Fiber Termination Shelf | $0.275K | $0.275K | $0.275K |
| 2 Adapter Panel, 12 LC | $0.3K | $0.3K | $0.3K |
| Corning Single Mode LC connector (12 x $15) | $0.36K | $0.36K | $0.36K |
| Contract Electrician (Termination)24 LC connectors 2 workers @ 1 day [$1200] for 48 connectors) | $0.6K | $0.6K | $0.6K |
| 4 Adapter Panel, 24 ST |  | $0.6K |  |
| Multimode ST Connector (24 x $15) |  | $0.36K |  |
| Contract ElectricianTermination (24 ST connectors)(2 workers @ 1 day [$1200] for 48 connectors) |  | $0.6K |  |
| Contract Electrician (Inner-duct Pull)4 workers @ 1 day [$3500] x number of days | $14K(4days) | $14K(4days) | $14K(4days) |
| Contract Electrician (Fiber Pull)4 workers @ 1 day [$3500] x number of days | $10.5K(3 days) | $10.5K(3 days) | $10.5K(3 days) |
| **Totals** | **$34.32K** | **$39.24K** | **$64.32K** |

**\***It is assumed that we are able operate using standard single-mode fiber. The risk associated with this decision will be covered in the Risk Registry.