Fermi National Accelerator Laboratory

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PIP-II MEBT line Quality Control Plan

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Revision History			
Author	**Version**	**Revision Date**	**Description of Change**
L. Prost	1.0	12/1/22	Initial release

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1.0 Scope of Quality Control (QC) Plan

The Medium Energy Beam Transport (MEBT) line comprises a variety of beam line components, either procured from external vendors, international partners or fabricated in-house. It includes quadrupole and dipole magnets, bunching cavities, scrapers, kickers, a beam absorber, and a suite of beam instrumentation.

This QC plan covers the fabrication and assembly of the MEBT line as an integrated system. As such, this plan does not describe acceptance tests or criteria for each individual component. These are described elsewhere. This document focuses on the integration of these components into a *beam line*. Ultimately, successful beam commissioning of the MEBT, which is beyond the scope of this QC Plan, determines if the MEBT line meets its specifications. The commissioning plan can be found in Ref. [1].

2.0 QC Tests and Measurements

Given the scope of this QC plan, most of the tests and measurements to be performed take place just after installation in the High Bay Building (HBB) lower level. In other words, individual components, which fabrication/procurement may or may not be within the scope of the Warm Front End (WFE) Work Breakdown Structure (WBS) are assumed to have passed an Installation Readiness Review (IRR) as applicable, according to the Project's policies, from the components WBS to Linac Installation (LI). Thus, the LI team leads the QC effort.

2.1 Vacuum

The MEBT operates under Ultra-High Vacuum (UHV) conditions. Therefore, all beam tubes and vacuum chambers will be UHV certified before installation into the beam line. During installation multiple vacuum leak checks will be conducted following Fermilab's standard leak checking procedure [2] for UHV vessels. The WFE Installation Plan [3] describes the specific stages (and beam line configurations) when leak checking is required.

2.2 Water connections

Several components in the MEBT are water-cooled: scrapers vacuum chambers, kickers, bunching cavities and the beam absorber. Fluids personnel shall ensure that all water connections are completed, with the appropriate fittings/adapters, before establishing water flow.

Once water flows through a component, checks for water leaks will be conducted. Purges should be done as necessary. Fluids personnel shall also check that the water lines instrumentation reports properly to the controls system. However, they are not responsible for checking interlocks.

2.3 Electrical connections (magnets)

Quadrupole and dipole magnets are powered by supplies located in the High Bay Building (HBB) gallery. Electrical personnel shall verify that cables are properly labeled and affixed to

the proper magnets. Electrical continuity shall be verified. Prior to the Operation Readiness Clearance (ORC), protective covers shall be (re)install on all magnet leads and electrical connectors. Once the ORC is approved magnets can be energized and the magnetic field polarity will be checked.

2.4 Movable components/stepper motors

Scrapers, tuners (for bunching cavities) and some beam diagnostics are movable devices, which use stepper motors, and are controlled via the Motor Control Center (MCC). Electrical/Controls personnel shall verify that power cables are properly labeled and connected to the proper components. Once the ORC is approved, range of motion shall be verified for all scrapers and beam diagnostics, as well as that any collision is prevented (where a collision is physically possible) and that limit switches operate properly.

2.5 Electrical connections (signals and biasing)

Most components in the MEBT return some sort of signal to the controls system (from beam diagnostics, RF pickup loops and various other readbacks). Electrical personnel shall verify that cables are labeled properly and that all connections are secure. In addition, there are several electrodes (e.g. scrapers, kicker masks) that are biased to up to 100 V. Beam Instrumentation personnel shall check for electrical continuity, isolation from ground and ensure that all connections are secure and that protection resistors are properly attached. Once the ORC is approved, the corresponding modules can be turned on and calibrated.

2.6 RF connections (high power)

Bunching cavities are connected to RF power amplifiers via coaxial cables. RF personnel shall verify that the coaxial cables are properly connected to the power couplers and appropriately supported (mechanically). Once connected and the corresponding ORC is complete, RF personnel shall check for RF power leakage to atmosphere per OHSA and FESHM requirements.

In addition, prior to turning the beam line over to the Beam Commissioning team, at a minimum, all bunching cavities will be conditioned to their operational voltage. Preferably, bunching cavities should be conditioned to their maximum voltage capability.

2.7 Alignment

Prior to installation in the HBB, MEBT girders positions are staked out by the Alignment and Metrology Group (AMG). Girders, which may or may not be fully loaded with components, are positioned according to the stake-out locations. Rough alignment of the components takes place once all components for a given section of the beam line is complete but before the beam line is under vacuum. Then, vacuum connections are made, and the corresponding section of the beam line is pumped down and vacuum leak check.

Once the beam line has been pumped down and under vacuum, AMG personnel will complete a final alignment of the components as specified in assembly drawings and “lattice” files generated by Accelerator Physics (AP) personnel.

Several installation phases will take place and are detailed in the WFE Installation Plan [3], including when final alignment can occur.

2.8 Summary of checkouts

Checks and measurements presented in the previous sub-sections are summarized in the table below.

Vacuum	Leak check after installation per prescription given in WFE Installation Plan [3]
Water connections	Check water connections before valving in water supply
Water connections	After water supply has been valved in, check for water leaks, as well as temperatures, pressures and flows read backs
Electrical connections (magnets)	Check cables labels, electrical continuity; check field polarity (*after ORC*)
Movable components/stepper motor	Check cables labels, connections, and visually confirm positions
Scrapers/beam diagnostics drives	Check range of motion, limit switches and anti-collision algorithm (*after ORC*)
Electrical connections (all signals)	Check cables labels and connections
Biased electrodes	Check electrical continuity and isolation from ground; check that bleeding resistor is secure; carry out calibration (*after ORC*)
RF connections (high power)	Check for RF power leakage; condition bunching cavities (*after ORC*)
Alignment	Perform final alignment after the beamline has been under vacuum

3.0 Requirements Traceability

Requirements for the MEBT are found in the MEBT Functional Requirements Specification (FRS) [4] and the MEBT Technical Requirements Specification (TRS) [5]. However, it should be noted that most of the requirements contained in the MEBT TRS are defined at the sub-system level and merely copied to that TRS. Consequently, requirements verification may occur well before the beamline installation or its commissioning.

On the other hand, the PIP-II Injector Test (PIP2IT) demonstrated that the MEBT line and components meet the Project's requirements and is documented as part of Ref. [6].

4.0 Travelers, Procedures, and Checklists

All the QC testing performed during fabrication/assembly of the MEBT line shall be defined and listed in the appropriate installation traveler being developed and will be managed within the Vector system. Note that more than one traveler will be needed to capture the breadth of the activities being undertaken to complete the MEBT.

Traveler/Procedure title	Document number

Standard Fermilab procedures and practices shall be followed throughout the fabrication and installation of the MEBT. Special installation/assembly procedures might be developed for certain sub-components (e.g. MEBT kickers) as judged necessary by experts and the Linac Installation team.

5.0 Acceptance Tests & Criteria

In the context of this QC Plan, only alignment and vacuum criteria may be considered for determining “acceptance”. Most sub-components/sub-systems have been validated at PIP2IT. Acceptance criteria for alignment and vacuum are described in their respective Physics Requirements Document [7, 8]. Note that vacuum criteria are defined for the beam line in its operating conditions; in particular, it implies that the bunching cavities have been fully conditioned and are at their nominal gradient.

Ultimately, successful beam commissioning will constitute the definitive acceptance criterion. Details regarding the commissioning procedures, acceptance criteria for the beam parameters (to be achieved simultaneously) and transfer to Operations are discussed in the “PIP-II Accelerator Commissioning and Start-Up Plan” [1] and “PIP-II Acceptance Criteria and Transfer of Systems” document [9].

6.0 In-process monitoring and measurement activities

By definition, all activities covered by this QC Plan can be considered as “in-process monitoring” and are therefore describe elsewhere within this document.

There will be no vendor or Partner involvement for the scope of this QC Plan. All of the individual devices provided by Partners and vendors have their own associated QC plans, which detail the in-process monitoring and measurements activities.

7.0 Verification Plans: Methods & Activities

Individual requirement and interface verification methods and plans are provided in the TRS [5] and ISD [10] metadata sheets.

8.0 Deliverable Documentation and Records

The complete list of documents created throughout the design and fabrication lifecycle of the MEBT is documented in the MEBT Engineering Process Document Management (EPDM) [11] and the sub-systems' EPDM within Teamcenter.

Installation and associated activities, as well as overall progress, will be documented in a set of travelers stored in the Vector system. Concurrently, results of specific tests and/or completion of milestone stages defined in the WFE Installation Plan [3] shall be recorded in the appropriate traveler.

9.0 Associated Equipment

The equipment utilized for the fabrication and installation of the MEBT is owned by Fermilab's Accelerator Division or the PIP-II Division. Both are subject to standard and regularly scheduled calibration recall or procedure ensuring good and safe operation of the equipment.

The equipment to be utilized for the fabrication and installation of the MEBT includes but is not limited to: vacuum leak detector, RF detector, overhead crane, rigging equipment, digital voltmeter, general tools and, portable cleanroom.

10.0 Traceability Requirements

All components to be installed in the MEBT line will be uniquely identified. Fermilab will affix a serial number upon receipt for components either procured from an external vendor or provided by an international partner.

Location of those components in the beam line will be recorded in the appropriate traveler and PIP-II Inventory Database (or its equivalent).

11.0 Training and Qualification

Fabrication and installation of the MEBT will be carried out by Fermilab personnel and installation will be done under the leadership of the Linac Installation team. Experts (RF engineer, accelerator physicist, mechanical engineer, electrical engineer…) will assist technicians as needed and ensure that proper procedures and travelers are followed.

Supervisors are required to provide the appropriate level of training and qualification for their respective areas.

12.0 Planned Partner and Vendor Communication & Visits

Partner and vendor communication and visits are planned at the sub-system level as necessary (e.g. quadrupole magnets, bunching cavities). There will be no planned Partner or Vendor communication or visits for the scope covered by this QC plan as the sub-systems will have already been received and verified from Vendors and Partners.

13.0 Control of Nonconformances

Nonconformances which are identified while completing a Traveler shall be documented via a Discrepancy Report in Vector. These reports are generated within the Vector database and shall be directly linked to the inspection step in which they are identified. Any nonconformance identified outside of a process specific Traveler shall be documented as a Discrepancy Report within the appropriate general Traveler as described in the PIP-II Nonconformance Handling Procedure [12].

14.0 Transportation/Shipping

Necessity of a transportation and shipping plan is determined at the sub-system level. However, given that some of those components have been integrated, used at PIP2IT and stored partially assembled on girders, special procedures might be documented if there is an increased risk for damage and/or hazard. Transportation will be performed and documented in accordance with contemporary FESHM requirements.

15.0 Risk Analysis Documentation

Most risk assessments are carried out at the sub-systems level. Nevertheless, a Failure Mode and Effect Analysis was performed for the MEBT as an integrated beam line [13].

16.0 References

	Description/Title	Document #
1	PIP-II Accelerator Commissioning and Start-Up Plan	PIP-II-doc-5420
2	PIP-II Warm Front End Installation Plan	ED0020527
3	Fermilab Standard Leak Checking Procedure for UHV Vessels	TBD
4	MEBT Functional Requirements Specification	ED0001303
5	MEBT Technical Requirements Specification	ED0014432
6	PIP2IT Commissioning Report	PIP-II-doc-5622

7	PIP-II Misalignment Tolerances Physics Requirements Document	ED0010231
8	PIP-II Vacuum Physics Requirements Document	ED0010228
9	PIP-II Acceptance Criteria and Transfer of Systems	PIP-II-doc-2166
10	MEBT Interface Specification Document	ED0022346
11	MEBT Engineering Process Document Management	ED0001228
12	PIP-II Nonconformance Handling Procedure	PIP-II-doc-3100
13	Failure Modes and Effect Analysis – MEBT Line	PIP-II-doc-6454