Fermi National Accelerator Laboratory

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PIP-II 121.03 Accelerator Systems Quality Assurance (QA) Plan

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Paul Derwent	1.0	26 Dec 2018	New Document
Elvin Harms	2.0	29 May 2020	post-IPR update, first reviewed & approved version
Elvin Harms	2.1	1 November 2021	Miscellaneous updates throughout; updated organization chart

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1.0 Purpose

The purpose of this document is to provide Quality Assurance Planning details and expectations for the L2 area 121.03 Accelerator Systems. All elements in this document are in alignment with the *PIP-II Quality Assurance Plan* [1]. As applicable, some elements of this document have been determined collaboratively with Partners responsible for subsystems deliverables within the Accelerator Systems WBS.

2.0 Scope - Description of System, KPPs, Deliverables

This Quality Assurance Plan (QAP) adheres to the requirements described in the PIP-II Quality Assurance Plan. All Quality Assurance activities performed by or for WBS 121.03, Accelerator Systems, will follow this plan. Additional QAPs developed by vendors/subcontractors will govern work in their areas of responsibilities but must comply with the requirements contained in this plan. The compliance of a vendor/subcontractor QAP with this QAP is verified as part of the procurement process.

This QAP is based upon the following principles.

- Quality is assured and maintained in an integrated and effective manner with management support in all aspects such as planning, organization, resources, and control.
- Compliance with this QAP is the worker's responsibility. Management exercises its support through periodic assessments and corrective actions.
- PIP-II personnel work together to minimize negative impacts on ESH, while maximizing reliability and performance.
- Trained and qualified personnel are assigned or approved to perform work per this Accelerator Systems QA plan, and subsystem QC Plans.

As described in the 121.03 *Accelerator Systems System Function and Configuration* [2], this L2 area covers design, fabrication, and commissioning of systems to support the operation of the linac, transfer line, and test facilities. These systems include all operator interfaces to PIP-II devices, power (both RF and electrical) to accelerating cavities and accelerator magnets, devices to establish and maintain beam and insulating vacuum, instrumentation and beam diagnostics, and machine protection and personnel safety systems. Elements of Accelerator Systems are required to meet all the Key Performance Parameters documented in the *Project Execution Plan* [3].
Among the key deliverables of 121.03 Accelerator Systems are:

- Machine Protection system including connections to the existing accelerator complex

- RF amplifiers and power distribution (including ancillary components) for all accelerating cavities
- Timing and control of all accelerating cavities
- Magnet power supplies (including integrated Quench Protection Monitor) for cold and warm magnets beginning at the Warm Front End (WFE) through the Beam Transfer Line (BTL)
- Warm magnets in the sections between the 650 MHz Cryomodules and the BTL
- Beamline vacuum from the ion source to the Booster Injection area
- Insulating vacuum for cryomodules
- Beam instrumentation/diagnostics from the ion source to the Booster injection area
- Electrical, Radiation, Laser, and Oxygen Deficiency Hazard Safety Systems/interlocks
- Network and communication infrastructure
- Controls interfaces, data acquisition, archiving, and clock systems.

3.0 System Organization – WBS Overview

Accelerator Systems ties together the main pieces of the PIP-II accelerator. The various aspects of this level 2 structure provide for protection of accelerator components from beam-induced damage and activation, for RF power and control of the accelerating cavities in the Linac, for magnets and associated power supplies to focus and steer the H- beam, for beam and insulating vacuum systems, for instrumentation to measure beam characteristics, for safety systems to protect personnel, and for control and user interface to all the various components. These systems are also integral to the various test stands necessary to test prototype and production components. The organization chart for this L2 area is shown in

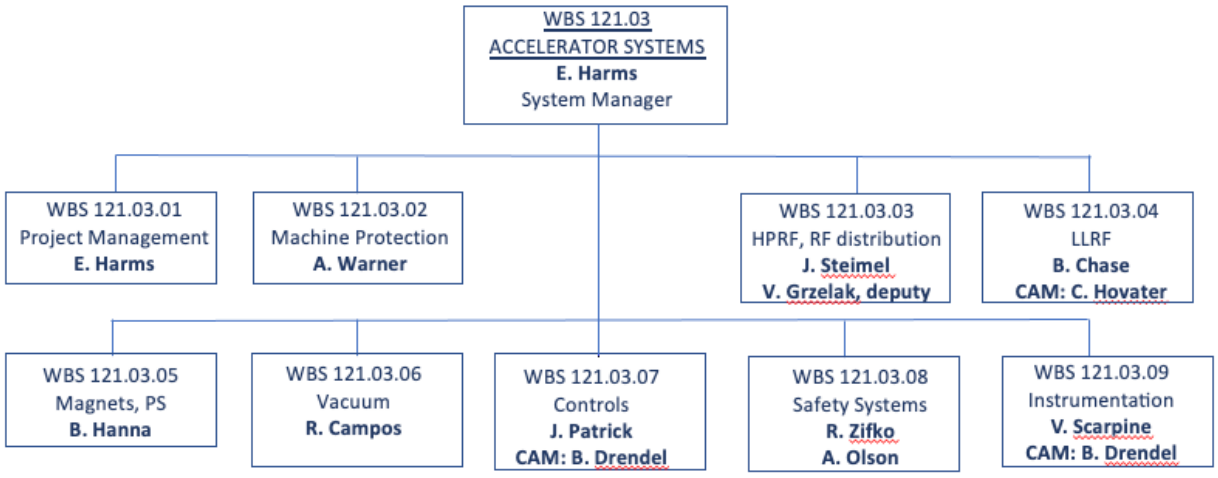

Figure 1.

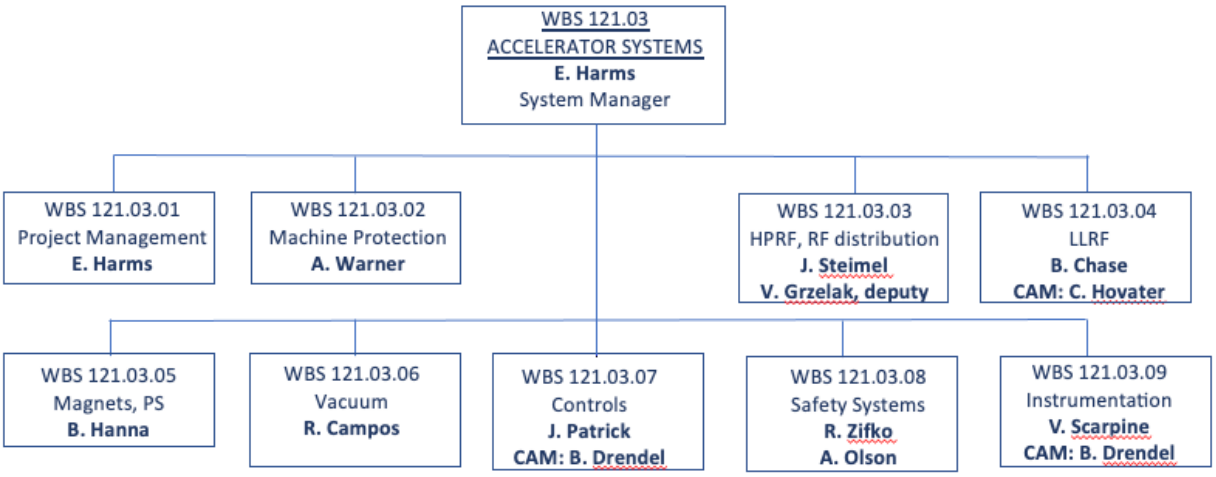

Figure 1: Organization (to L3/CAM) of 121.03 Accelerator Systems

Nine sub-systems comprise WBS 121.03:

121.03.01 Project Management and Coordination (PM)
121.03.02 Machine Protection Systems (MPS)
121.03.03 High Power Radio Frequency and RF Distribution (HPRF-RFDist)
121.03.04 Low Level Radio Frequency (LLRF)
121.03.05 Magnets and Power Supplies (MagPS)
121.03.06 Vacuum (Vac)
121.03.07 Controls (Cntrl)
121.03.08 Safety Systems (SS)
121.03.09 Beam Instrumentation (BI)

WBS 121.03.01 Project Management and Coordination

Provides project management for Accelerator Systems, including the overall coordination of the technical effort, project planning and scheduling, cost estimating, risk and contingency analysis, and reporting.

WBS 121.03.02 Machine Protection Systems

The Machine Protection System will protect the machine from beam induced damage; it is not intended to protect personnel. The MPS will inhibit the beam in cases of excessive beam loss, equipment failures, and upon operator request or error.

WBS 121.03.03 High Power Radio Frequency and RF Distribution

High Power Radio Frequency and RF Distribution is concerned with the design, procurement, fabrication, and testing of the linac RF power amplifiers and transmission hardware. It includes systems at 162.5 MHz, 325 MHz, and 650 MHz, for both test infrastructure and linac systems. The majority of the amplifiers, for SSR1, SSR2, LB650 and HB650, are to be provided as in-kind contributions by DAE. Transmission hardware including circulators, coaxial transmission lines and waveguide, connectors, elbows, adapters, directional couplers, and loads together with controls and interlocks for all systems is provided by Fermilab. Fermilab also provides amplifiers for warm cavity systems and the HWR cryomodule.

WBS 121.03.04 Low Level Radio Frequency

By means of this WBS all hardware, firmware, and expert software utilities, to satisfy system requirements for the Low Level RF used to drive all accelerating cavities is provided. For PIP2IT and the test stands this includes the Master Oscillator and LO generation, RF field control for all copper and SRF cavities, Resonance control for the RFQ and all SRF cavities, RF Interlocks for all SRF systems, and Beam pattern generator and interface to the Booster. For PIP-II itself the LLRF Software/Firmware Deliverables are Data acquisition firmware, Field control firmware, Resonance control integration, Beam Pattern Generator, Controls (EPICS-based) interface, Beam-based energy stabilization jointly with Instrumentation and Booster, RF Interlocks firmware, and Expert systems software for all systems.

WBS 121.03.05 Magnets and Power Supplies

This WBS addresses design, procurement, fabrication, integrated system installation and testing of all magnets and power supplies, integrated quench protection monitoring for same where necessary, and high voltage bias power supplies for cavity fundamental power couplers. Components required for PIP2IT, to support test stand measurements and the PIP-II linac and BTL are included.

WBS 121.03.06 Vacuum

Design, procurement, fabrication, and testing of all vacuum systems and their associated components including pumps, valves, gauges and other instrumentation, beampipe, etc. for PIP2IT, the PIP-II linac, BTL, and Beam Absorber Line are part of this WBS.

WBS 121.03.07 Controls

This WBS deals with the overall coordination of the technical effort, project planning and scheduling, cost estimating, risk and contingency analysis, and reporting for all facets of the PIP-II Control systems. This spans an EPICS-based general control system architecture; Network infrastructure including a central switch plus remote switches for field equipment and the cryoplant network infrastructure; Computing Infrastructure comprising consoles for the linac area and servers for central processes; Console and Server software identified as application framework, archiving, alarms, and other infrastructure and service software; Application software including high level software for control and monitoring, a drag and drop framework for status displays, a framework for rich applications; both hardware and software for Front-end systems; PLC-based controls for Vacuum, LCW, RAW, cryogenic distribution; controls matched to accelerator design; General Purpose Data Acquisition comprising general purpose digitization/digital I/O for basic control and monitoring, an updated version of the current 'Hotlink Rack Monitor', and dedicated power supply control for higher density systems; Motion Control for collimators, scrapers; and Timing systems including a new central Accelerator Clock (ACLK) with interfaces to both PIP-II linac and current timing networks, a new Linac Clock (LCLK) for PIP-II synched to the linac RF with a distribution network to local hardware that requires it.

WBS 121.03.08 Safety Systems

Safety systems for personnel protection including RSIS (Radiation Safety Interlock System), ESS (Electrical Safety System), ODHSS (Oxygen Deficiency Hazard Safety System), LSS (Laser Safety System), Safety DAQ (Data Acquisition system) and ESH system on AD Controls network for remote status and real-time monitoring of safety systems are facets of this WBS. Specifically, Radiological personnel protection instrumentation and monitoring systems including Interlocked instrumentation, Scanning stations for radiological contamination and survey instruments, and a so-called MUX (multiplexing) DAQ system for remote radiological status, monitoring, and recording are included.

WBS 121.03.09 Beam Instrumentation

Design, procurement, fabrication, and testing of beam instrumentation systems for the commissioning and operation of the PIP-II linac and beam line complex as well as PIP2IT devices are included here. Devices and electronics to characterize beam properties in the warm front-end, linac and linac-to-booster transfer line include beam position (BPM), beam

loss (BLM), and beam current (BCM) monitors, transverse and longitudinal profile monitors, and wire and laser-based profile monitors.

4.0 List of Partners, Vendors, or Subcontractors

Partners will provide commensurate Quality Assurance Plans that align with those of the PIP-II Project. It is the expectation of the Project that vendors and subcontractors submit QA and/or QC Plans respective to their scope of work during technical evaluation and subcontracting process. Many of the systems will be working with the Fermilab Procurement department in the process of procuring, fabricating, and assembling components. The systems will follow standard laboratory protocol for procurement, bidding, and quality (counterfeit items).
Partner Institutions include:

- Bhabha Atomic Research Centre (BARC), Mumbai India
- Raja Ramanna Centre for Advanced Technology (RRCAT), Indore India.

International In-Kind contributions (deliverables) for WBS 121.03 from these partners include:

- RF amplifiers to power the superconducting RF cavities which comprise PIP-II
- a subset of Low-Level RF equipment including RF Protection systems
- magnetic components (quadrupoles and correction dipoles) for the Warm Front End and warm units between cryomodules.

The above list will evolve as the Project progresses and new partners are identified. The complete list of vendors and subcontractors is exhaustive and beyond the scope of this document.

5.0 Quality Assurance (QA) Requirements

5.1. Roles and Responsibilities

This QA plan defines the responsibility, authority and interrelation of personnel who manage, perform, and verify work that affects quality. Roles and Responsibilities addressed in this plan include the following:

- **Responsibility for performing work** – All providers of both goods and services are responsible for the quality of the materials supplied and the work that is done be they PIP-II project task leaders, managers, partners, or vendors.
- **Responsibility for QC Plans** – L3 Managers are responsible for developing QC Plans for their

areas of responsibility. Quality Control tests, inspection, evaluation, acceptance, and procedures will be identified based on the criticality, risk, or technical complexity of the component or activities in their subsystem. Risk Assessments, *Prevention through Design* (PtD), FMEA data, adherence to accepted standards, as well as subject matter expertise serve as input to the assessment of the criticality, risk, or technical complexity [4]. The L2 Manager in coordination with L3 managers will strive for consistent QC plans across all Accelerator Systems sub-systems commensurate with technical scope and types of deliverables.

- **Responsibility for acceptance** – The L2 manager is ultimately responsible for individual components or sub-systems and is required to determine their acceptance criteria and to ensure that the necessary procedures and related tools are developed, and effective documentation is realized. Determination of these criteria will be conducted in coordination with the responsible L3 manager and others subsystem leaders as deemed necessary.
- **Responsibility for assessing work** – The L3 manager is responsible for evaluating quality control effectiveness by way of self-assessments and other means deemed appropriate. Project management may request independent assessments.
- **Periodic reporting** – The PIP-II L2 Manager has the responsibility to periodically report on the performance of his/her individual subsystems with regards to quality to the PIP-II QA Manager, Technical Director, IKC Technical Integration Manager, and/or Project Director. Elements of this reporting may include nonconformances, lessons learned, and QA Program updates. This output prompts feedback which serves as an input to the improvement of the Quality program.
- **Responsibility for addressing nonconformances and seeking/implementing opportunities for improvement –** L2 and L3 managers are responsible for addressing discrepancies, nonconformances, and opportunities for improvement identified from incoming, in-process, or acceptance testing activities, assessments, reviews, lessons-learned or other inputs.

Each L3 system within the Accelerator Systems WBS will carry out work on this project in accordance with this QA plan. Each L3 sub-system is expected to develop a Quality Control Plan (QCP) for each deliverable of her/his WBS. In section 6 of this document requirements that go within a QC plan are further discussed.

5.2. Communication Planning

Proper communication is crucial to achieve success. It is envisioned that meetings will be carried out between all parties involved when working on a task in order to obtain status updates, discuss any incidents, delays, issues, concerns, nonconformances, design changes and so on. The L2 Manager shall be invited for every meeting. Minutes will be written and logged, preferably in each L3 web site area in SharePoint.

A graded approach for vendor interactions, based on technology maturity, cost, and schedule, is expected. Mature technologies (e.g., printed circuit board production, catalog items) will have less oversight than new design and development (e.g., amplifier or magnet production).

5.3. Partner / Vendor Visits

Visits to partners and vendors will occur as necessary to facilitate direct and timely communication as well as immediate issue resolution. The frequency of visits and meetings will depend on the sensitivity/complexity of the equipment under consideration and will be detailed in the QC plan of each deliverable at the L3 level. Visits may occur for reasons such as:

- witness hold points
- collaboration on testing procedures
- direct and timely communication when deemed necessary
- issue resolution of an immediate nature

The duration of such visits will vary depending on the nature of the visit and the complexity of the matter to be addressed.

5.4 Performance Measures

The performance requirement monitoring applicable to the work to be performed within this WBS consist of:

- Incidents/near-misses
- Schedule status
- Design change requests
- Procurements (status) (FNAL only)
- Nonconformances (open/closed/overdue)
- Successful hold/witness points
- Effectiveness assessments (effective / not effective)
- Other

Time will be allocated at weekly WBS 121.03 meetings to review these performance measures. Frequency of review of specific measures will depend on the activity status but will occur at least quarterly.

5.5 Nonconformance (NC) Management

Nonconformances shall be identified and processed in a standardized way [5]. Documentation will occur by means of the (Vector) traveler system. All NCs will be captured in the *PIP-II Master NC Log* [6]. NCs will be shared with L2 managers on a monthly basis.

Subsystems will collaboratively agree on the method for Partners to communicate and manage nonconformances as well as the subsequent actions. This method shall be documented in the subsystem QC Plans and Partner QA Plans. For any Partner utilizing a different traveler system the method for documenting NCs shall be mutually determined and agreed on by the Partner and L3 manager with concurrence by the In-kind coordination team**.**

For fabrication or procurement via vendors, then the vendor shall also provide their method of managing nonconformances with their QA Plan submittals during the evaluation process.

5.6. Risk Management

Risks are actively monitored and managed. For each subsystem, new or emerging risks shall be communicated appropriately and logged in the *Risk Register* [7] in accordance with the *PIP-II Risk Management Plan* [8].

5.7 Lessons Learned

The PIP-II Lessons Learned process shall be employed. The method for communicating lessons learned to/from Partners shall be developed in collaboration with the Partners for each subsystem. Lessons learned shall be identified from best practices, nonconformances, process gaps, safety incidents, design reviews, etc. and documented per the *PIP-II Lessons Learned Process* [9]. The L2 Manager has the responsibility to discuss lessons learned in the Technical Integration Meetings and L2/L3 Meetings.

6.0 Subsystem (L3) Quality Control (QC) Requirements

Each subsystem will create a Quality Control Plan (QCP), in separate documents, that encompasses all fabrication/assembly processes. References to any Partner or Vendor Manufacturing Inspection Plans must be included where appropriate.

QC is the systematic implementation, based on a graded approach, of a program of inspection, tests, and controls pertinent to various technical specifications to attain the required standards of quality and to preclude problems resulting from noncompliance. The objectives of QC are to:

- Describe guidelines for inspection and documentation of activities
- Provide reasonable assurance that the completed work will meet or exceed the requirements and specifications
- Describe how any unexpected changes or conditions that could affect the deliverable quality will be detected, documented, and addressed during the work period.

Throughout the design process, engineers and designers work with L3 Managers to determine QC inspection criteria of fabricated products, including installation. Design is verified and validated to an extent commensurate with its importance to safety, risk, complexity of design, degree of standardization, state of the art, and similarity to proven design approaches. Acceptable verification methods include but are not limited to any one or a combination of (1) design reviews, (2) alternative calculations, (3) prototype qualification testing and/or comparison of the new design with a similar proven design if available, (4) adherence to universally accepted safety and design standards. Verification work shall be completed before approval and implementation of the design.

QC Plans will be collaboratively developed (with Partners as applicable) to the subsystem. QCPs shall consist of incoming inspection processes whose level of detail is commensurate with the incoming items, in-process tests, hold/witness points, nonconformance reporting procedures, and final acceptance criteria/tests. The QC Plans shall be verified by a designated Subject Matter Expert (SME) and reviewed by the L2 Manager, the Quality Engineer or Quality Manager, and the Project Engineer. The QC Plans shall highlight the respective traveler numbers/titles for those processes. In the case of collaborating with vendors and subcontractors, inspection/verification documentation will be stored in the SharePoint site, after being reviewed by the responsible L3 or their designee. L3 Managers have flexibility in choosing the specific format for the various sections of their deliverables.

The following elements and respective details shall be included in each QC Plan for each deliverable in the scope of the QC Plan:

- Scope of QC Plan
- QC test or measurement, including who is responsible for performing test
- Traceability of test or measurement to requirement

  - Reference Requirements Verification Matrix and/or FRS metadata sheet as appropriate
- Reference travelers, procedures, or checklists to be developed
- Inspection or Acceptance Tests & Criteria
  - Inspection and Test Plan
  - Inspection and Test Plan Methods
  - Acceptance Methods and Criteria
  - Final Acceptance Testing
  - Roles and Responsibilities
- In-process monitoring and measurement activities
  - Reference Manufacturing Inspection Plans developed/to be developed in collaboration with Partners
- Verification Plans: Methods & Activities
  - Verification of performance and technical requirements
  - Inspection and Test Plan verification
  - Inspection and Test method verification
  - Critical in-process verification steps
  - Roles and Responsibilities
- Deliverable Documentation and Records
  - Completed Manufacturing Inspection Plans / Travelers
  - Verified Test Plans
  - Data, Test Results, Simulations
  - Nonconformances & Resolution
  - Assembly configuration
  - Equipment Test & Calibration Records
  - Bill of Materials
  - Certificate of Conformance (as applicable)
- Associated equipment to be used, including hardware, firmware, software
- Calibration Plans and Methods for Equipment used within the scope of this QC Plan (Partner and Vendor Quality Plans must have this information)
- Traceability requirements for parts and components with clear traceability in traveler (e.g., labeling)
- Training and Qualification specific to the elements in the QC Plan
- Planned or potential Partner, and/or vendor visits
  - Hold/Witness Points, Collaboration, Otherwise
- Control of Nonconformance
  - Roles & Responsibility for communication, root cause analysis, corrective action/preventive action planning (timely communication is imperative)
- Reference to Handling, Control, Transportation/Shipping (as applicable) requirements, procedures, and plans.
- Risk Analysis Documentation
  - Reference to PtD, FMEA, and any other risk analysis documentation

Software provided as a deliverable or part of a deliverable, must be developed and released within applicable *PIP-II Software Development and Deployment Guidance Documents* [10]. At a minimum, alignment with *Quality Assurance Manual - Chapter 12003 - Software Quality Assurance* is required [11]. QC plans developed should include responses to the following:

- Software Requirements/Specifications
- Purpose
- Who is responsible for the development
- Who are the users of the software
- Related documentation
- How will the code and/or functionality be verified against requirements
- Who and how will code and/or functionality be maintained
- Backup method
- Roles and Responsibilities.

7.0 Training

Each L3 Manager within their WBS shall identify the training activities that will be provided to meet the needs of QA on this project. L3 Managers are responsible for identifying proper resources and ensure that their team members are adequately trained and qualified to perform their assigned work. Before allowing personnel to work independently, they are responsible to ensure that their team members have the necessary experience, knowledge, skills, and abilities. Personnel qualifications are based on the following factors:

- previous experience, education, and training
- performance demonstrations or tests to verify previously acquired skills
- completion of training or qualification programs
- on-the-job training.

ESH-specific qualifications and training requirements are provided in *PIP-II Integrated ESH Management Plan* [12]. All PIP-II Partners are responsible for ensuring that their training and qualification requirements are fulfilled, including periodic re-training to maintain proficiency and qualifications.

Suggested training may include:

- Project orientation on roles, responsibilities, and quality assurance staff authority
- Project standards, procedures, and methods
- Understanding and using automated tools
- Training of all concerned with the operation of the accelerator components.

8.0 References

[1] *PIP-II Quality Assurance Plan*
[2] 121.03 *Accelerator Systems System Function and Configuration* document, TC ED0008104
[3] *PIP-II Project Execution Plan*
[4] *Prevention through Design*
[5] *PIP-II Project Nonconformance Handling Procedure*
[6] *PIP-II Master Nonconformance Log*
[7] *PIP-II Risk Register*
[8] *PIP-II Risk Management Plan*
[9] *PIP-II Lessons Learned process*
[10] *PIP-II Software Development and Deployment Guidance Documents*
[11] *Quality Assurance Manual - Chapter 12003 - Software Quality Assurance*
[12] *PIP-II Integrated ESH Management Plan*