# PIP-II 650 MHz β=0.61 Jacketed Cavity Prototype Final Design Review & Procurement Readiness Review Report

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## Document Approval

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## Revision History

| Revision | Date Release | Originator: Role: | Description of Change |
|---|---|---|---|
| - | 8 Nov 2019 | L. Ristori, Review Chair | Initial Release |
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*Revision control is managed via Fermilab Teamcenter Workflows.*

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## 1. Introduction

The PIP-II Project's superconducting linear accelerator (Linac) will fuel the next generation of intensity frontier experiments at Fermilab. Benefitting from the high efficiencies of superconducting radio-frequency (SRF) technology, the linac shall consist of five types of superconducting cavities and cryomodules. They will accelerate H– ions to 833 MeV for injection into the Booster Complex of Fermilab. Upgrades to the existing Booster, Main Injector, and Recycler Rings will enable them to operate at a 20 Hz repetition rate and provide a 1.2 MW proton beam for the Deep Underground Neutrino Experiment (DUNE) at the Long Baseline Neutrino Facility (LBNF). The superconducting Linac shall operate at harmonic frequencies of 162.5 MHz, 325 MHz, 650 MHz, with energy ranging from 2.1 MeV to 833 MeV. The relativistic $\beta$ for the H– ions goes from 0.07 to 0.854 over this energy range.

The PIP-II Linac shall consist of one half wave resonator (HWR) cryomodule, two single spoke resonator of type 1 (SSR1) cryomodules, seven single spoke resonator of type 2 (SSR2) cryomodules, nine low beta elliptical cavity cryomodules (LB650), and four high beta elliptical cavity cryomodules (HB650). The LB650 cryomodules contain four 5-cell cavities each, with geometric beta of 0.61 and operating at 650 MHz.

The PIP-II linac is to operate with continuous wave (CW) RF, and a pulsed beam. Having pulsed compatibility is encouraged, to lower operations costs. In both regimes cryomodule shall support peak currents of 10 mA chopped with arbitrary patterns to yield an average beam current of 2 mA.

PIP-II is the first US Department of Energy particle accelerator project with significant international in-kind contributions from France, India, Italy, and the United Kingdom. The LB650 section of the linac has contributions from CEA in France for the cryomodule design and hardware, VECC in India for the cavity design and hardware, and INFN in Italy for the bare cavity design and jacketed cavity hardware. Fermilab owns the end groups for the cavities and the helium vessel design, as well as the interfaces for the cavity with the coupler, tuner, and cryomodule.

Due to the complex design of the cryomodules as well as the international partnerships, PIP-II requires a significant design coordination and integration oversight. As part of the oversight strategy, a design review plan specific to PIP-II has been developed [3]. The primary goal of the Project design reviews is to ensure optimized and safe design by identifying potential or actual design problems as early as possible to minimize the cost, schedule, and performance impact.

This review comprises of the Final Design Review for the prototype LB650 cavity (bare and jacketed) and the Niobium Procurement Readiness Review to fabricate these prototype cavities. Per the PIP-II Design Review Plan,

1. Final Design Reviews (FDRs) are technical and programmatic reviews to provide assurance that the completed design of the selected configuration meets all functional and performance specifications as well as interface agreements. The technical areas addressed during the review include the design configuration and integrity of the selected design; verification planning, requirements, and compliance; operations planning; support equipment; and systems compatibility.
2. Procurement (or Production) Readiness Reviews (PRRs) are held prior to the start of manufacturing and testing of major sub-system assemblies. PRRs are largely technical reviews, but include assessment of the planned cost, schedule, and personnel needs to complete the manufacturing processes that are covered.

## 2. Review Agenda

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| Location: | Hermitage Conference Room, ICB 2nd floor East, & on Zoom |
| Date: | 7 & 8 November 2019 |
| Indico Site: | https://indico.fnal.gov/event/22161/ |
| Zoom: | https://fnal.zoom.us/s/703251375 |
| Reviewers: | Leonardo Ristori, Fermilab (Chair) |
| | Michael Kelly, ANL |
| | Joel Fuerst, SLAC |

## 3. Review Charge Statement

The review committee is charged to evaluate the design and programmatic readiness of the PIP-II 650 MHz β=0.61 prototype jacketed cavities to approve fabrication, processing, jacketing, and validation activities. The jacketed cavity is defined as the niobium and niobium titanium of the bare cavity, the titanium helium vessel with chimney, including the tee connection to the 2-phase pipe, and necessary safety restraints (e.g. the helium vessel bellows safety bracket). The review committee is urged to evaluate by responding to the following questions:

1. Technical Scope
    a. Are all design & performance specifications and requirements approved and released?
    b. Are the designs mature and technically sound to satisfy design & performance specifications?
    c. Have all the major interfaces been identified and incorporated into the design?
    d. Are the cavity fabrication, processing, and validation steps appropriately mature for prototype final design stage?
    e. Is the development of associated drawing packages sufficiently mature for final design stage?

2. Design Management
    a. Is the design team organized and staffed to successfully complete the project?
    b. Have all the major risks been identified and managed?
    c. Are procurements appropriately planned?
    d. Are all related ES&H aspects being properly addressed?
    e. Are appropriate QA and QC steps being implemented?

3. Overall Readiness
    a. Is the design sufficiently mature to allow *Prototype* Final Design Review approval?
    b. Is the procurement package ready to allow for procurement of bare and/or jacketed cavities from industry?

## 4. Reference Documents

List any relevant documents reviewed by the Committee.

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| 3 | |
| 4 | |

## 5. Findings

General, factual observations about material presented which require no response.

## 6. Comments

*The review committee comments are appended within the review charge below, with distinction made by color and font.*

The review committee is charged to evaluate the design and programmatic readiness of the PIP-II 650 MHz β=0.61 prototype jacketed cavities to approve fabrication, processing, jacketing, and validation activities. The jacketed cavity is defined as the niobium and niobium titanium of the bare cavity, the titanium helium vessel with chimney, including the tee connection to the 2-phase pipe, and necessary safety restraints (e.g. the helium vessel bellows safety bracket). The review committee is urged to evaluate by responding to the following questions:

*Committee response: The committee finds inconsistencies in the review charge statement and language in the introduction with respect to design vs. procurement readiness on the niobium material and the prototype cavity. The committee has decided, based on two days of discussions, to evaluate the procurement readiness for niobium material and the final design for the prototype cavity.*

1. Technical Scope
    a. Are all design & performance specifications and requirements approved and released?
    *Committee response: Yes. The Cryomodule Technical Requirement Specification ED0009658 is approved and contains requirements for the LB650 cavity. There were, however, minor inconsistencies in the cavity acceptance criteria (see recommendation).*
    b. Are the designs mature and technically sound to satisfy design & performance specifications?
    *Committee response: Yes.*
    c. Have all the major interfaces been identified and incorporated into the design?
    *Committee response: Yes, interfaces are clearly defined with one exception (see recommendation)*
    d. Are the cavity fabrication, processing, and validation steps appropriately mature for prototype final design stage?
    *Committee response: Yes, the recent HB650 R&D experience provides a strong basis for the upcoming LB650 cavity work.*
    e. Is the development of associated drawing packages sufficiently mature for final design stage?

*Committee response: Yes. Draft drawings for LB650 and approved drawings for the similar HB650 cavity are consistent with Final Design.*

2. Design Management
    a. Is the design team organized and staffed to successfully complete the project?
    *Committee response: Yes, but the team is highly matrixed and may have competing priorities.*
    b. Have all the major risks been identified and managed?
    *Committee response: No, not at the cavity level, see recommendation.*
    c. Are procurements appropriately planned?
    *Committee response: No. The schedule appears too aggressive with respect to niobium procurement (~5mo) and bare cavity procurement (~8mo). See the recommendation.*
    d. Are all related ES&H aspects being properly addressed?
    *Committee response: Yes, the design of the cavity appears consistent with the Fermilab ES&H Manual. Fermilab will accept the european EN standard as equivalent to the ASME BPVC for the cavities coming from Italy.*
    e. Are appropriate QA and QC steps being implemented?
    *Committee response: Yes, QA and QC are being implemented in procedures, travelers and specifications.*
    *QA plans exists for the SRF Linac. However, the details of how such plan will be implemented at the cavity procurement level was not presented and should be addressed in the cavity procurement readiness review.*

3. Overall Readiness
    a. Is the design sufficiently mature to allow *Prototype* Final Design Review approval?
    *Committee response: Yes.*
    b. Is the procurement package ready to allow for procurement of bare and/or jacketed cavities from industry?
    *Committee response: No, the procurement package for the cavity is not yet ready.*

## 7. Recommendations

Items that require formal action and closure in writing prior to receiving approval to move into the next phase of the project, or items that require formal action and closure in writing prior the next review.

1. Review and fix minor inconsistencies with respect to cavity acceptance in the TRS document before the end of calendar 2019.
2. Obtain CEA feedback on cavity interfaces inside the cryomodule before proceeding with cavity fabrication.
3. Prior to proceeding with Niobium procurement in support of the fabrication of 4 prototype bare cavities, approve and release the raw material package ensuring that the drawing for the half-cell sheet specifies a thickness of 4.5±0.1 mm.
4. Draft a plan for the LB650 cavity alignment procedure prior to cavity procurement.
5. Add to the risk register a specific risk related to possible delays in niobium and cavity deliveries.
6. Issue a Request for Information for cavity and niobium procurement and update the schedule if necessary.
7. Confirm that the Helium tanks built in-house at Fermilab are appropriate for operations at Fermilab and will not cause compliance issues at CEA.
8. Ensure that the cavity fabrication and processing plan can accommodate at least one reset.
9. Finalize the procurement package for the cavity prior to holding the procurement readiness review