121.02.02 Linac-HWR (Half-Wave Resonator)

Subcommittee SC 3 SRF and Cryogenics Breakout Session

Zachary Conway

PIP-II IPR

4-6 December 2018

In partnership with:
India/DAE
Italy/INFN
UK/STFC
France/CEA/Irfu, CNRS/IN2P3

Outline

- Scope/Deliverables
- Requirements
- Interfaces
- Design Maturity
- Technical Progress to Date
- ESH&Q
- Risks and Mitigations
- Summary

Argonne National Laboratory - Accelerator Development Group:

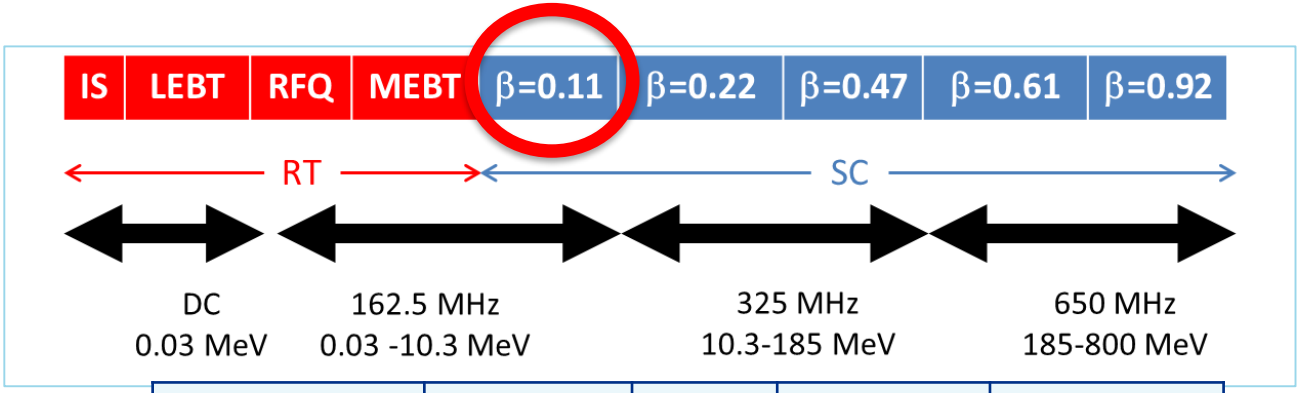
- Designing, building and commissioning superconducting accelerators since 1977.
  - All retired group members still work 1+ days per week.
- My relevant experience:
  - Superconducting resonators spanning ion/electron velocities from 0.05•c to 1.0•c.
  - All superconducting device ancillary hardware.
  - 6 different types of superconducting resonator cryomodules operating at 2.0 or 4.5 K.
  - Superconducting accelerator commissioning.
  - Project Manager (L3) for HWR Cryomodule

Project Organization

- Cryomodule and subcomponents designed by FNAL and ANL.
- ANL is fabricating and assembling the half-wave resonator (HWR) cryomodule.
- At ANL:
  - Accelerator Development Group Leader = Mike Kelly.
  - ANL HWR Cyromodule Manager= Zack Conway.
- FNAL:
  - L2 SRF/Cryo: Genfa Wu
  - CAM/L3 Manager: Joe Ozelis
  - Project Engineer: Allan Rowe

Scope and Deliverables
WBS 121.02.02 Linac – HWR System Req.

Charge #2



Cryomodule type	Cavities per CM	# CMs	CM length (m)	Q_0 at 2K (10^{10})
HWR	8	1	5.93	0.5
SSR1	8	2	5.2	0.6
SSR2	5	7	6.5	0.8
LB650	3	11	3.9	2.15
HB650	6	4	9.5	3

Beam-Line-Flange to Beam-Line-Flange Length

- ANL is responsible for design, procurement, sub-component testing, assembly of HWR CM, and final room temperature leak checking.
- The HWR cryomodule will operate continuous wave with a beam current of 2 mA to accelerate the beam from 2.1 – 10.3 MeV.

WBS 121.02.02 L3 System Requirements

Charge #2

- Cavity performance:
  - 2 MV per cavity, @ P_{cavity} < 2 W in offline testing.
- Solenoid operation:
  - 6 T solenoids.
- Power couplers:
  - Offline testing demonstrating 7 kW forward power on resonance. Check off resonance conditions.
- Cryogenic loads:

		Static Loads per CM, (W)			Dynamic Loads Per CM, (W)	Total Load at 2 K per CM, (W)
CM Type	# of CMs	70 K	5 K	2 K	2 K	2 K
HWR	1	198	90	30	24	54

- Delivery in Q3FY19, no contingency.

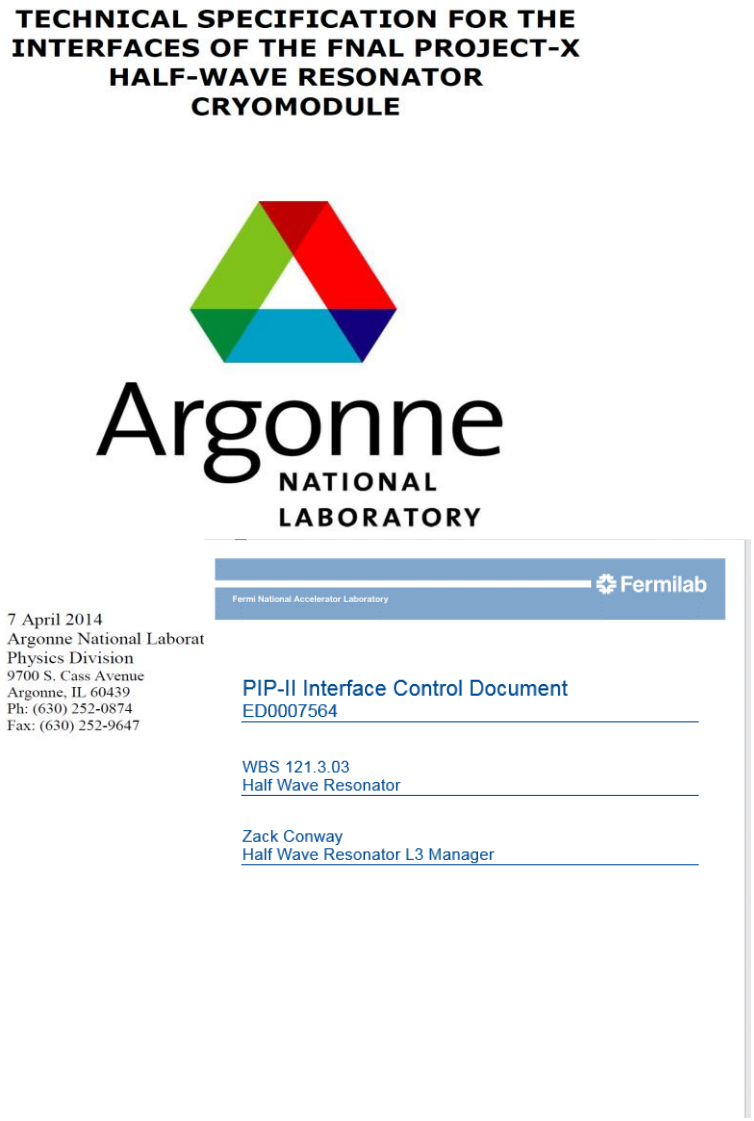
Interfaces

Charge #2

- The HWR Cryomodule must successfully interface with a number of other systems within the PIP-II Accelerator Complex.
- These interfaces take the form of:
  - Mechanical
  - Electrical
  - RF (HP & LL)
  - Controls & Software
  - Cryogenic systems
  - Safety systems
  - Accelerator Physics (Requirements)
- In addition, there is an Organizational Interface between ANL & FNAL, that actively jointly manages the HWR CM project.
  - Daily contact (phone/email)
  - Weekly (or more often) visits to ANL site
    - This will expand to multiple days/week, and include additional FNAL staff assisting with CM assembly
  - Bi-Weekly Management meeting

Interfaces

Charge #2



TECHNICAL SPECIFICATION FOR THE INTERFACES OF THE FNAL PROJECT-X HALF-WAVE RESONATOR CRYOMODULE

Argonne NATIONAL LABORATORY

7 April 2014
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Physics Division
9700 S. Cass Avenue
Argonne, IL 60439
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Fax: (630) 252-9647

Fermilab
Fermi National Accelerator Laboratory

PIP-II Interface Control Document
ED0007564

WBS 121.3.03
Half Wave Resonator

Zack Conway
Half Wave Resonator L3 Manager

- Interfaces agreed upon and defined in April 2014.
  - Interfaces are documented in TC ED0007564
    - Technical Specification for Interfaces
    - Interface Control Document
  - Minor revisions ongoing
    - Communicated via L3 to affected WBSs
- Physical Interface Boundary corresponds to the physical envelope of the HWR CM
- Functional Interface Boundary is defined via FRS.

Interfaces for the HWR Cryomodule	
121.02.02 – HWR CM	121.03.08 – Safety Systems
121.03.03 – HPRF	121.03.09 – Beam Instrumentation
121.03.04 – LLRF	121.02.05 – Cryoplant
121.03.05 – Magnets/PS	121.02.06 – CDS
121.03.06 – Vacuum	121.04 – Test Infr, Install, & Comm.
121.03.07 – Controls	121.06 – Conventional Facilities

HWR Cryomodule Design History

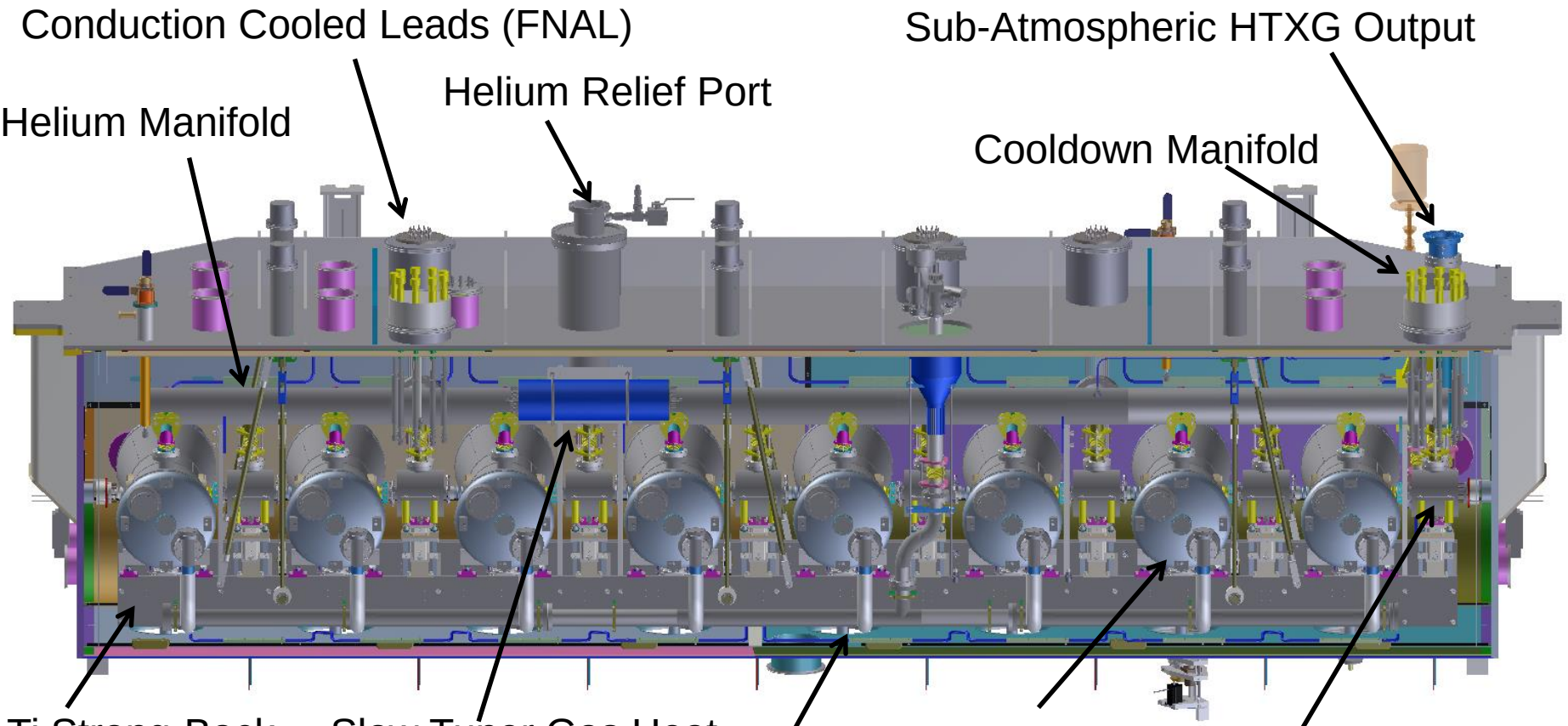
Charge #2

- Design/safety reviews for the HWRs and cryomodule were held at Argonne (ANL) with FNAL and ANL subject matter experts performing the reviews:
  - HWR review 5/17/2012, and
  - cryomodule review 5/16/2013.
- All design reviews were conducted in compliance with ANL's procedures, LMS-PROC-305.
- Procurement readiness reviews were carried out at ANL per ANL controls.

HWR Cryomodule Mock Assembly

HWR Cryomodule Design

Charge #2



2.2 m X 2.2 m X 6.2 m (overall)
18,650 pounds

Progress to date – Past activities

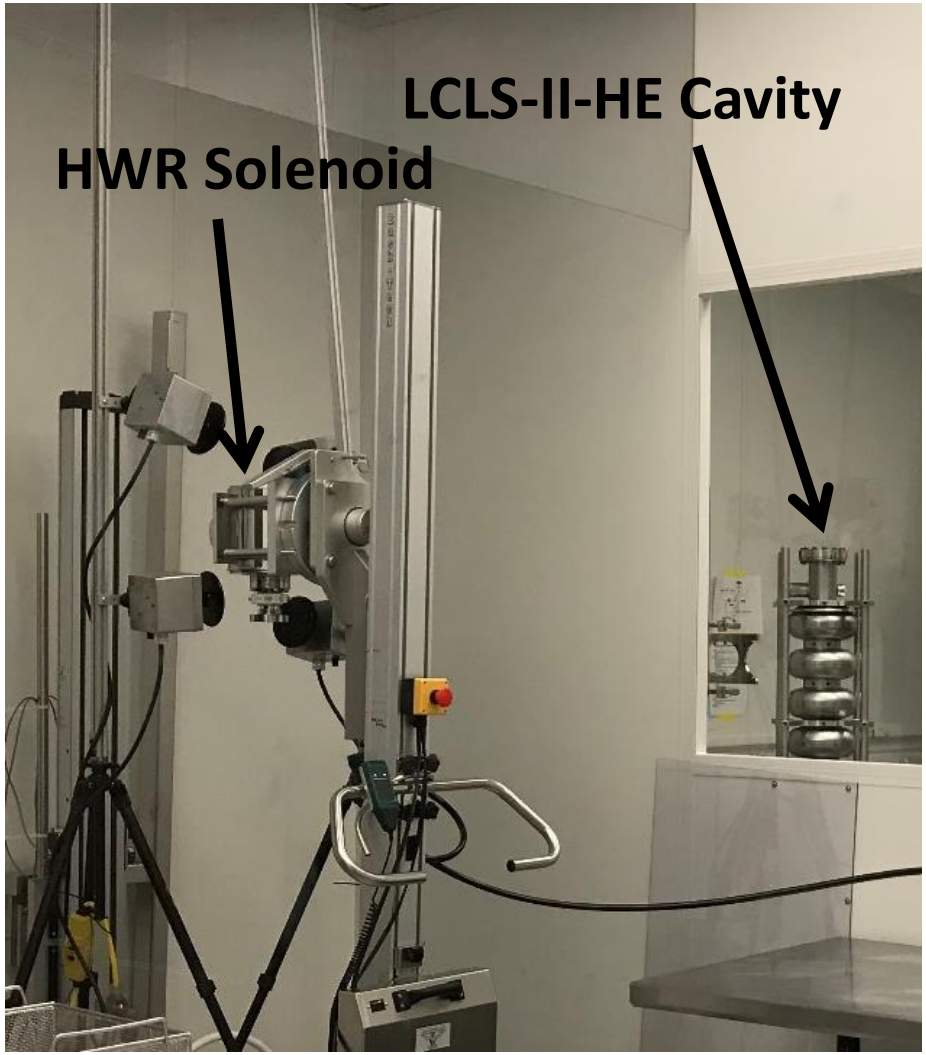
Charge #1

- Design finished
- All HWR cavities qualified
- All HWR cavities/couplers/tuners qualified as a system
- All solenoids tested, including one cavity/solenoid test
- CM mock assembly performed including LN2 cooldown and alignment verification
- Work Control Documents in place with final document pending ANL ESHQ approval.
- New clean room for string (“clean”) assembly has been qualified
- Baseline schedule developed, adopted, and being used to track progress
  - HWR schedule (zero internal float) reviewed on 30 August 2018.
- Shipping company engaged with FNAL/ANL to develop and evaluate shipping plan, preliminary Transport Readiness Review held, 14 August 2018

Progress to date – Current activities

Charge #1

- Presently we are cleaning components for final assembly.
  - Solenoid cleaning = finished.
  - Cavity cleaning next.
  - Cavity vacuum manifold, beam-line gate valves and clean instrumentation last.
- Next steps: clean assembly → final assembly → Transportation



Cryomodule Progress

Charge #1

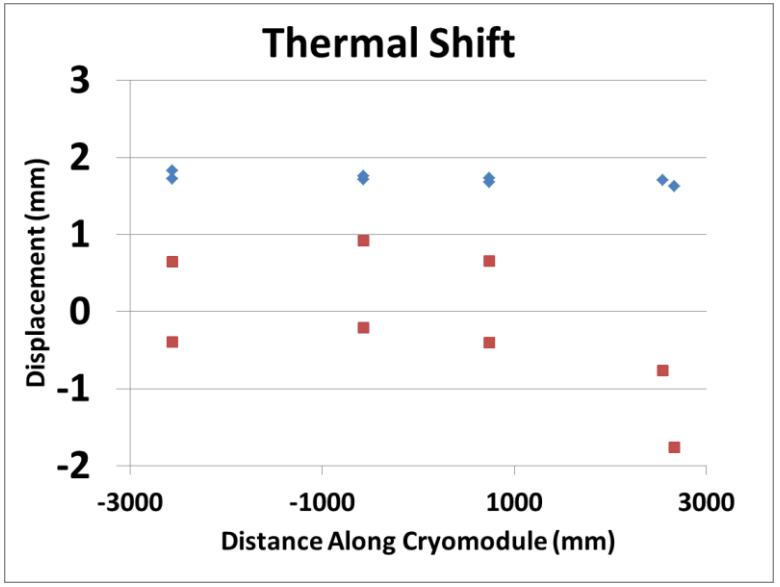
HWR Cryomodule Mock Assembly

Cryomodule Testing

Charge #1

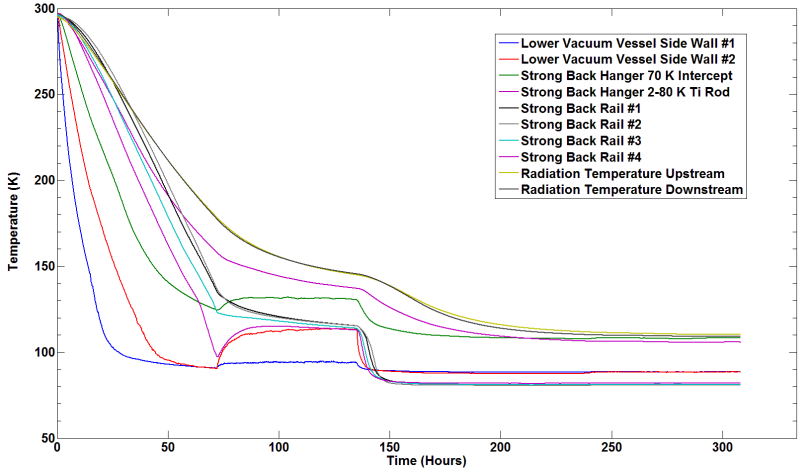
Cryomodule Alignment

Alignment Measurements

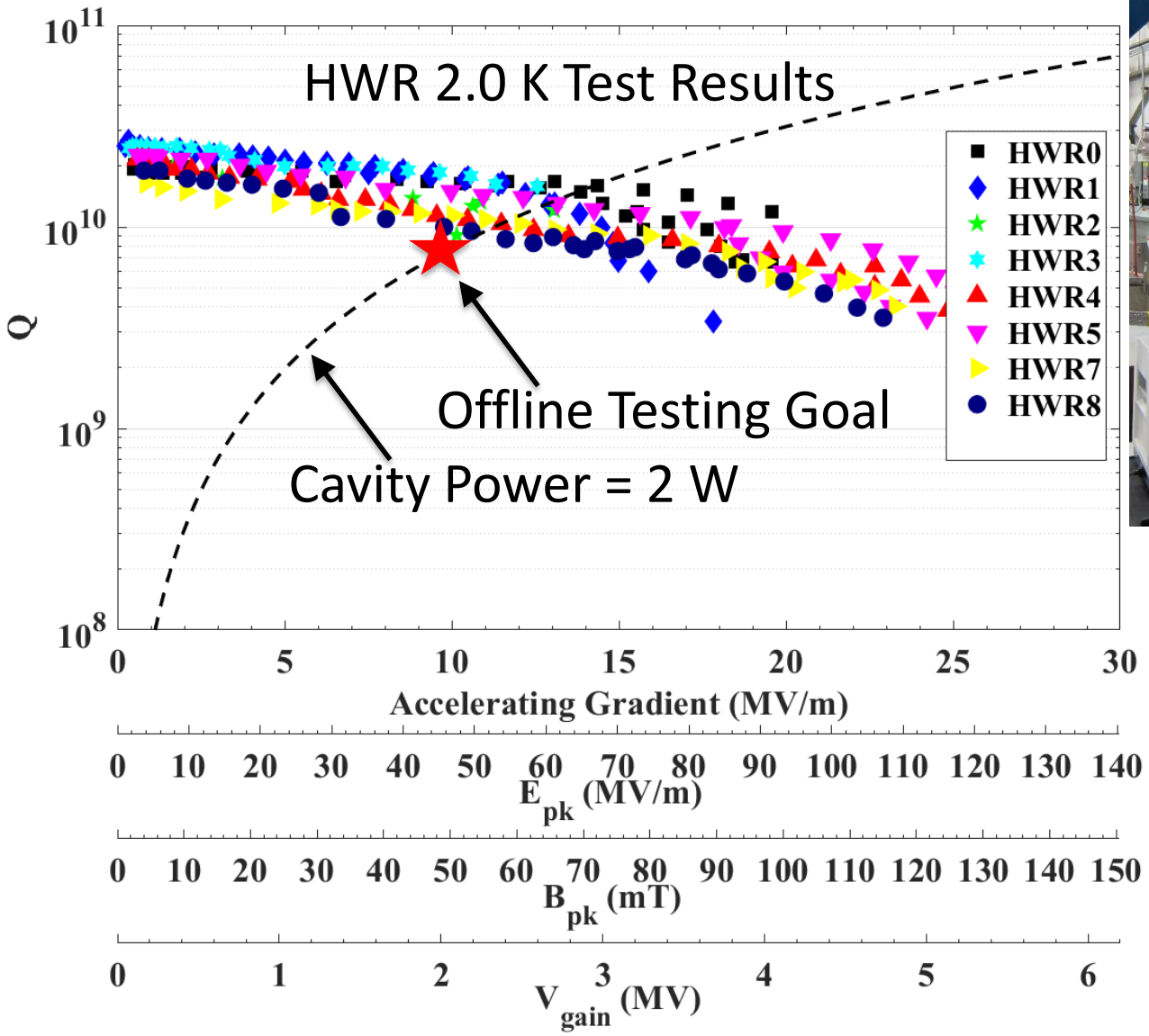


Cryomodule Assembly

Cool Down Data



Q Curves



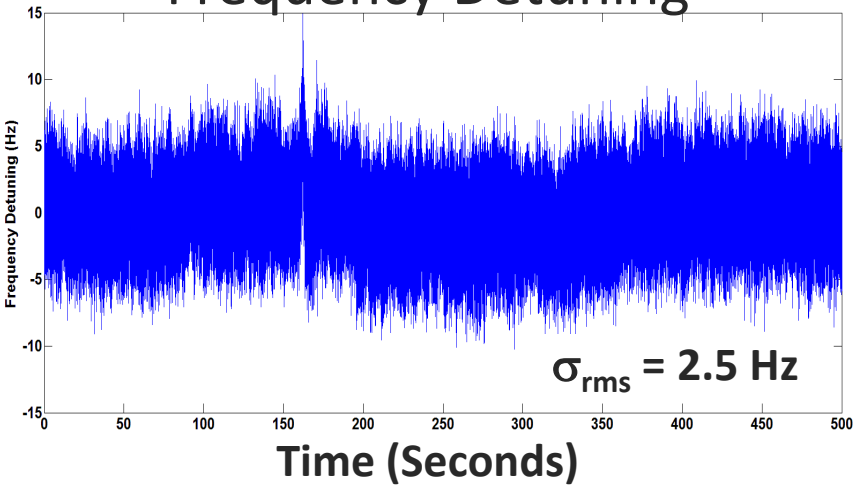
- All HWR acceptance tests are finished.
- Cavities are being fiducialized and cleaned for final assembly now.

Half-Wave Resonator Microphonics & RF Power

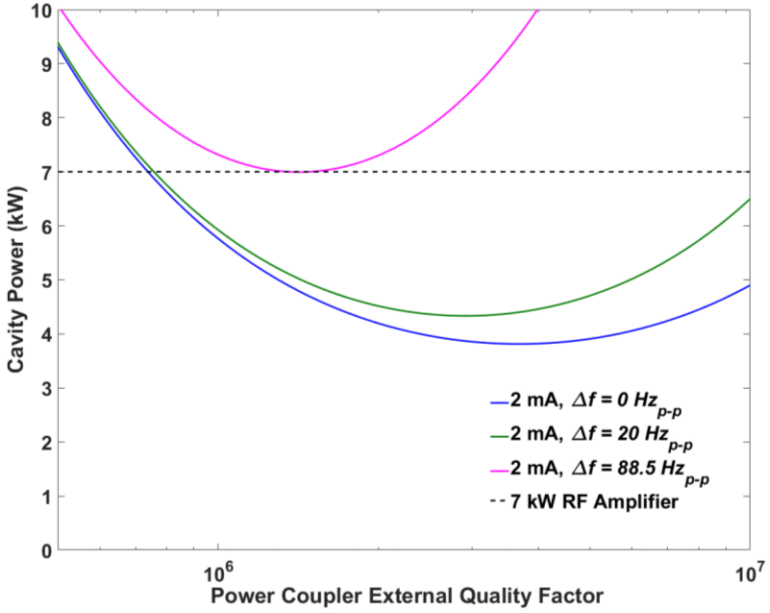
Charge #1

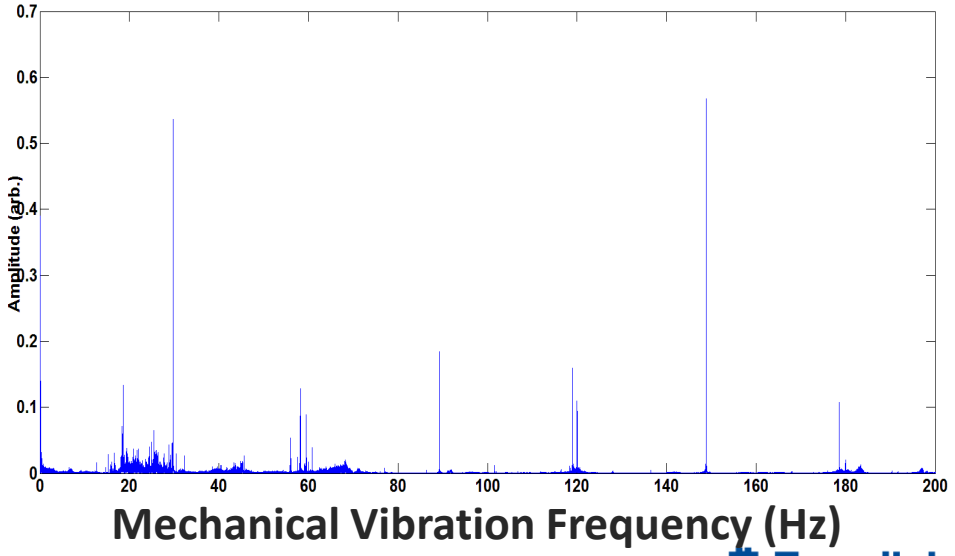
- All HWR tested have a $df/dP \sim 11$ Hz/mbar.
- With a helium pressure stability of 0.1 mbar $\rightarrow \Delta f = 1.1$ Hz.

Measured HWR1 Microphonic Frequency Detuning



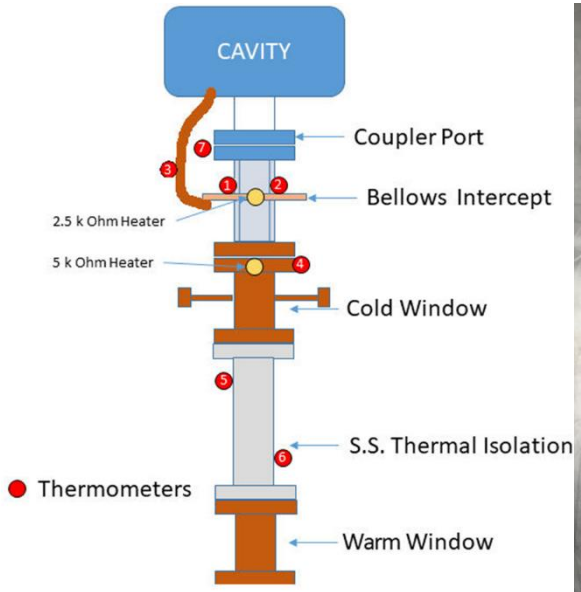
HWR Cavity Power

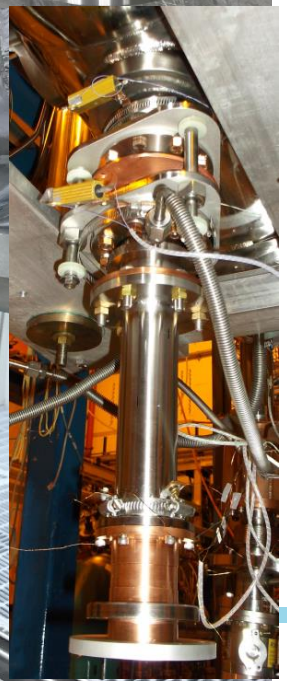


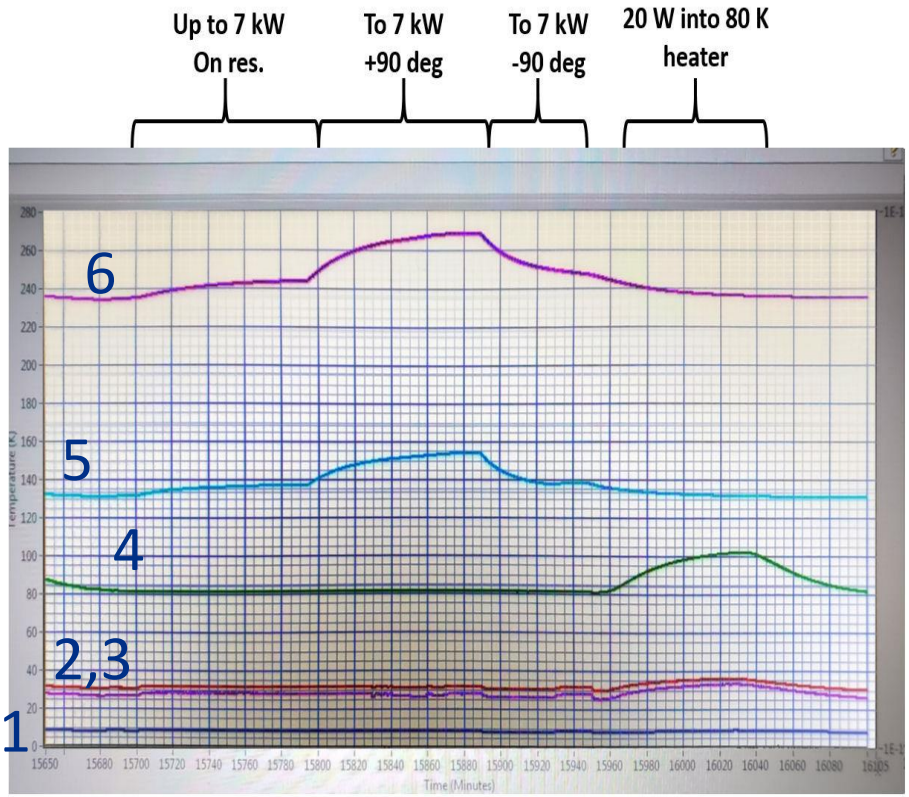


Half-Wave Resonator w/ Coupler Offline Testing

Charge #1





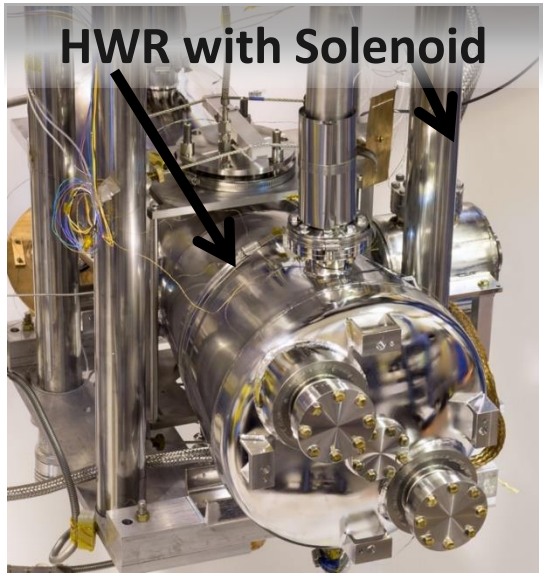


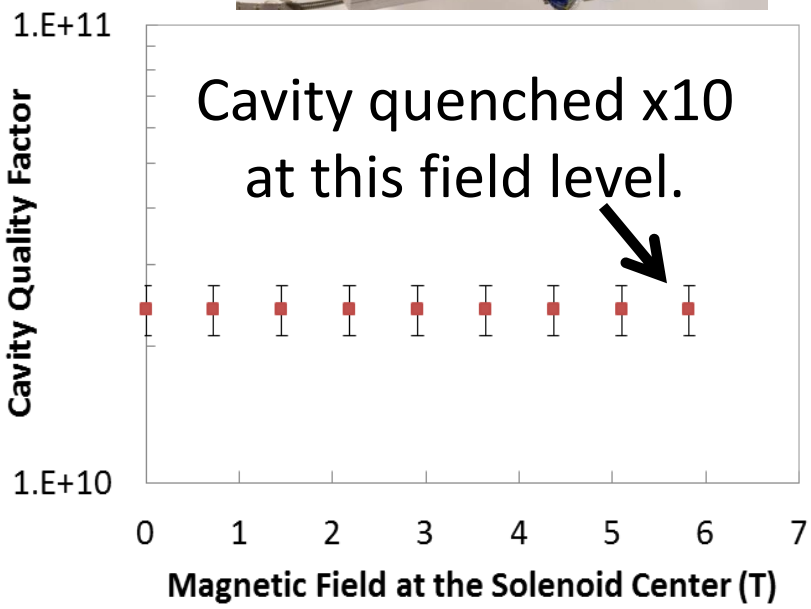
- All 8 cavity/coupler pairs are tested and meet acceptance criteria: 7 kW, on resonance, off resonance by ±90 degrees
- All hardware now being prepared for clean assembly

Half-Wave Resonator w/ Solenoid Offline Testing

Charge #1

- To decrease the accelerator lattice length we have integrated x-y steering coils into the focusing solenoid package.
- Important design issue:
  - Minimize stray field @ the RF cavity to prevent performance degradation due to trapped magnetic flux.
- Measured RF surface resistance with a sensitivity of ±0.1 nOhm before and after each quench of the cavity.
- The cavity was quenched with the solenoid and the steering coils energized.
- No quantifiable change to the cavity RF surface resistance.



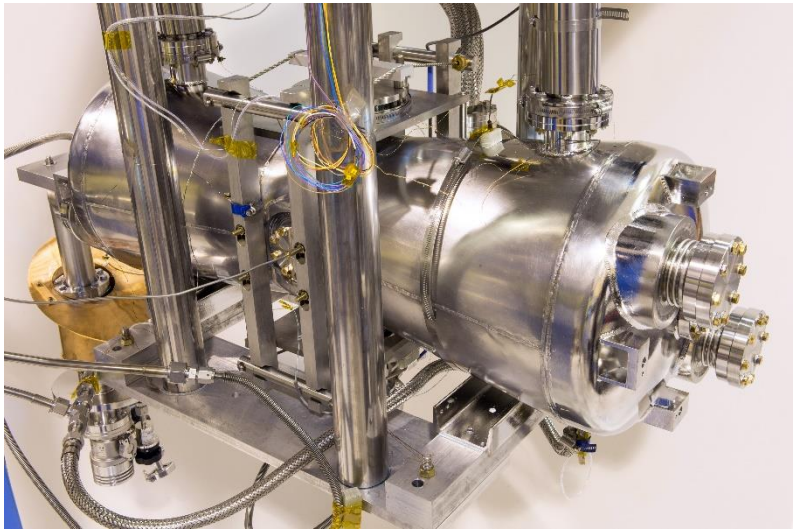


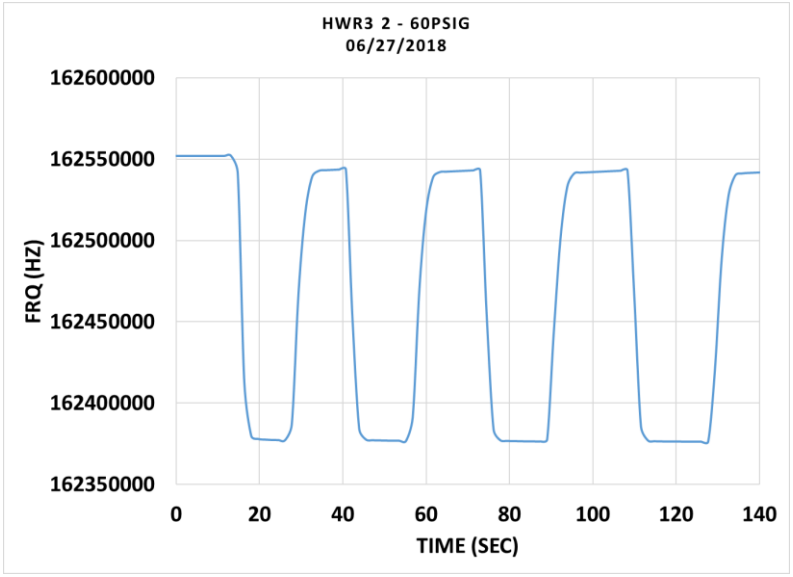
Half-Wave Resonator & Slow Tuner Offline Testing

Charge #1

- The HWR cryomodule will use pneumatic slow tuners → pneumatic slow tuners have been in operation at Argonne on superconducting cavities since the 1970s.
- Slow tuners are installed on all HWRs during offline testing.
  - Slow tuners are actuated through their full range to verify response.
  - 162.5 MHz ± 60 kHz is exceeded for all HWRs.
  - The tuner resolution is < 0.1 Hz, our measurement limit.
- Slow tuners are operating as planned and testing has demonstrated this.

HWR with Slow Tuner

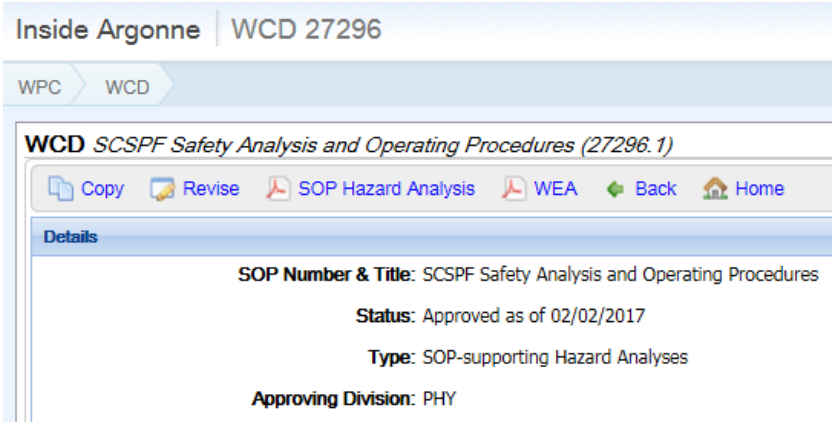




ESH

Charge #6

- Safety is our highest priority.
- Work at Argonne is done in compliance with ANL ES&H.
- Providing a working piece of hardware goes hand-in-hand with work planning and control at ANL.
- ESH requirements and protocols governing the FNAL and ANL collaboration on SRF are documented in the FNAL/ANL MOU on SRF Cavity Surface Processing, signed 4/21/2006 with addendum added on 8/15/2014.
- Hazards addressed at ANL include:
  - Chemical safety,
  - Cryogenic safety,
  - Pressure systems safety,
  - Radiation safety, and
  - Cryomodule component testing and assembly work control documents.



ESH

Charge #6

- Designs and Engineering Calculations have been reviewed by ANL ESH staff and relevant committees to ensure compliance.
- FNAL is beginning review of ANL documentation in preparation for FNAL ORC process
  - Engineering notes (cavity, vacuum vessel, etc.)
  - Piping Engineering notes
  - FMEA (to be completed)
  - What-If analysis (to be completed)

Quality Management

Charge #6

- HWR CM QA strategy includes the following
  - Design and production/procurement reviews
  - Development, review, and approval of FRS, TRS, and Interface documents
  - Critical vendor evaluation and oversight
  - Process/procedure review
  - Training
- HWR CM QC strategy includes the following
  - Inspection of parts, components, to ensure conformance with requirements
  - Component and sub-components testing/qualification
  - Work Control Documents, FNAL documentation of work performed
  - Use of FNAL Vector system to track non-conformances, dispositions, corrective actions
  - Vendor QA/QC compliance monitoring
- Comprehensive CM testing at PIP2IT prior to CD-3

Quality Management

Charge #6

- Work quality will be quantified in the PIP-II Injector test (PIP2IT).
- Testing all major components prior to cryomodule final assembly.
  - ANL: Cavities, couplers, solenoids, etc
  - FNAL: BPMs, magnet conduction cooled leads, sub-atmospheric heat exchanger
  - 1 optional cavity/coupler test with spares is pending. Does not affect schedule.

Applying the Graded Approach to Quality for Procured Items or Services
Laboratory-Wide Argonne Procedure LMS-PROC-125, Rev. 6
Effective Date: 06/05/2017

1 Purpose

Establish the process for applying a graded approach to quality assurance for Laboratory procurement activities for items or services in support of Laboratory operations and research activities.

2 Scope

This procedure applies to the following Argonne activities and entities.

LMS core processes:	Governance
Organizations:	all
Buildings:	all
Specific locations:	all
Other applicability factors:	none
Exclusions:	Items that have been screened and assigned a Quality Level on the Nuclear and Waste Management Master Equipment List, controlled by NWM-CM-305, Master Equipment List Maintenance. Suppliers working to the Argonne Quality Assurance Program (staff augmentation) are exempt from this grading approach. Graded approach applicable to project risk management. See instead PROJECT-12, *Risk Management*. Graded approach applicable to safety software. See instead the Argonne *Safety Software Quality Assurance Program Plan*.

3 Work Process

3.1 Introduction

The graded approach to quality is integrated with Laboratory work activities through the implementation of work planning and control in accordance with LMS-PROC-200, *Local Work Planning and Control Implementing Procedures*. This procedure is used to determine the appropriate quality level for procurement of items or services in support of Laboratory operations and research activities. The four quality levels are:

- Quality Level A (QL-A) – Very High Risk, Safety Class
- Quality Level B (QL-B) – High Risk, Safety Significant
- Quality Level C (QL-C) – Moderate Risk, Important to Safety
- Quality Level D (QL-D) –Low Risk, General Activities

The graded approach must not be used in the following circumstances:

- To downgrade to a lower grade, i.e., eliminate requirements, without sufficient justification
- In implementing the unreviewed safety question (USQ) process in nuclear facilities
- In implementing technical safety requirements in nuclear facilities

Risk Management

Charge #2,7

- HWR WBS responsible for one Project Risk:
  - RT-121-02-008 - HWR Cryomodule does not meet technical performance requirements
- This risk is mitigated/retired upon successful testing of the HWR cryomodule in the PIP2IT Test Facility (4QFY19, 1QFY20)
  - Cryomodule performance demonstrated under operational conditions (2K, all 8 cavities & solenoids powered simultaneously, full LLRF control)
- This risk has no technical impact on other CM designs
- This risk is retired before CD-3
- Risk probability is reduced via component and subsystem testing prior to full assembly (QA/QC program).

Risk Management

Charge #2,7

- Risk mitigation prior to PIP2IT testing:
  - HWR cavity performance
    - Each HWR cavity is tested offline to determine RF performance and intrinsic cryogenic load
  - Power coupler performance
    - Every HWR/coupler pair is tested offline prior to installation in the cryomodule.
  - Solenoid operation
    - First article tested at vendor (Cryomagnetics) and ANL.
    - Following 7 units tested at Cryomagnetics.
  - BPMs tested at FNAL
  - CM Assembly Dry Run validates assembly & alignment strategy
  - Frequent contact between ANL & FNAL teams.

Summary

- Design developed by collaboration between FNAL and ANL
- HWR Cryomodule FRS created and approved in 2014.
- Design reviews conducted in 2012 and 2013:
  - FNAL experts sat on panels.
  - Found the HWR design addressed the PIP-II injector requirements
- Risks are mitigated by sub-component testing and testing in PIP2IT
- ESH and QA plans are in place and being followed
- Plan on delivering cryomodule to FNAL in Q3FY19.
- Thank you for your attention

We are on track for CD-2/3a and look forward to your feedback