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Standardization of the PIP-II Cavity String Assembly Procedure and Quality Assurance

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6/10/2026

Outline

- Introduction
- Standardization on Cryomodules
- Standardization on Cavity String Assemblies
- Summary

FERMI NATIONAL ACCELERATOR LABORATORY

4 cryomodules already assembled

- HWR
- SSR1 prototype
- HB650 prototype
- SSR2 pre-production (complete end of June 2026)



Single Spoke 1
SSR1 325 MHz
2 Cryomodules

Single Spoke 2
SSR2 325 MHz
7 Cryomodules

Elliptical
LB650 650 MHz
9 Cryomodules

833 MeV
 $\beta=0.92$

516 MeV
 $\beta=0.61$

SRF technology

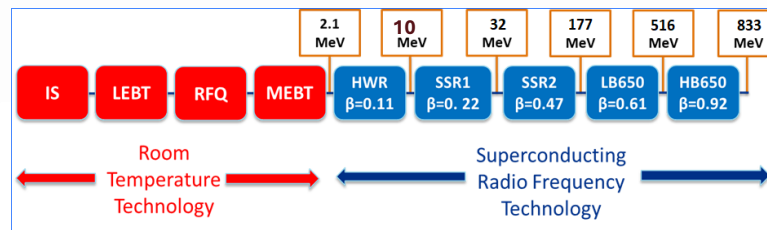
177 MeV
 $\beta=0.47$

32 MeV
 $\beta=0.22$

10 MeV
 $\beta=0.11$



RT technology*



The in-kind contribution (IKC) from our international partners is substantial.

- LB CMs from CEA
- HB CMs from UKRI
- LB cavities from INFN
- SSR cavity testing at IJCLab
- CM components from India

Cryomodule Standardization

- Niobium Material
- Cavity Testing and Acceptance
- Coupler Testing and Acceptance
- **Cavity String Assembly**
- Cryomodule Assembly
- Cryomodule Testing and Acceptance



Cavity String Standardization

- RGA Quality Control Standardization
- Venting
- Purging
- Particle counter and N2 blowing

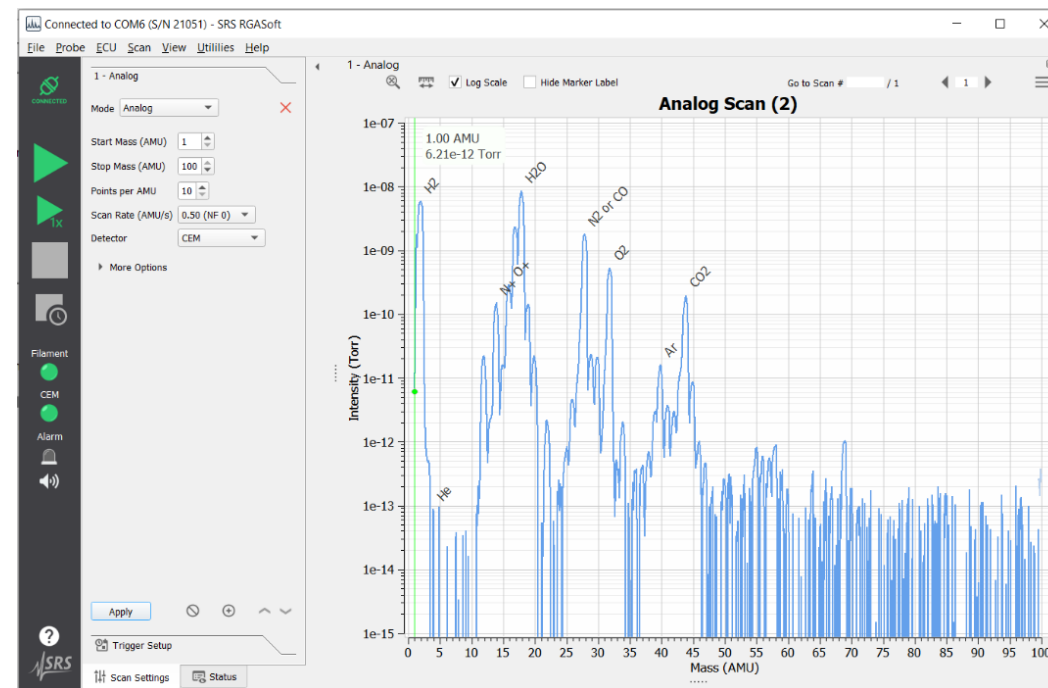
RGA Quality Control Standardization

Procedure

- After base pressure reaches $<5\text{e-}7$ mbar, turn on the RGA with the filament multiplier on.
- Initiate the **analog** scan at a rate of **1 amu/s** from 1 to 100.
- Collect data for one hour, with the last 10 scans, and average the data per amu unit.

Quality Acceptance

- Base pressure shall be $<5\text{e-}7$ mbar
- The sum of the partial pressure from 45 - 100
 - Shall be less than 3/1000th of the total pressure, **or**
 - Individual peak partial pressure shall be less than 1/1000th of the total pressure



RGA Quality Control Standardization

- The string assembly component list is subject to standardization

	Leak check	RGA scan	RGA criteria	Note
Cavity with RF probes	Y	Y	Y	after the final assembly for the vertical test
Cavity with HP coupler	Y	Y	Y	CTC bound; doesn't apply to string assembly
Coupler	Y	Y	Y	At every incoming inspection
BPM/MAG (SSR only)	Y	Y	Y	
Gate Valves	N (vendor data)	N	N	Vendor leak check mandatory. An in-line leak check is optional.
Unity coupler	Y	N	N	Incoming QC stage
Field probe	Y	N	N	Incoming QC stage
String end group	Y	Y	Y	String assembly
Inter cavity bellows	Y	Y	Y	STFC Process
Right angle valve	Y (vendor data)	N	N	In-line leak check is NOT optional. Single-use valves series 57.
Whole string assembly	Y	Y	Y	



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PIP-II RGA Analysis Acceptance Criteria for String Assembly Components-Record of Decision

Author: Genfa Wu on behalf of the ICE 1 team

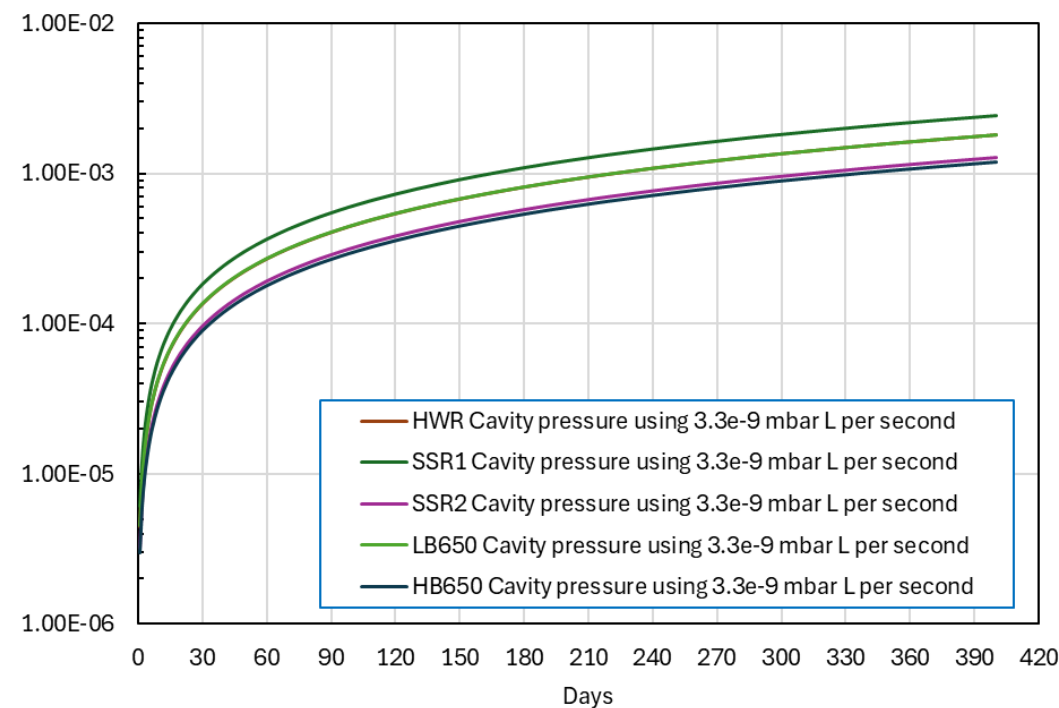
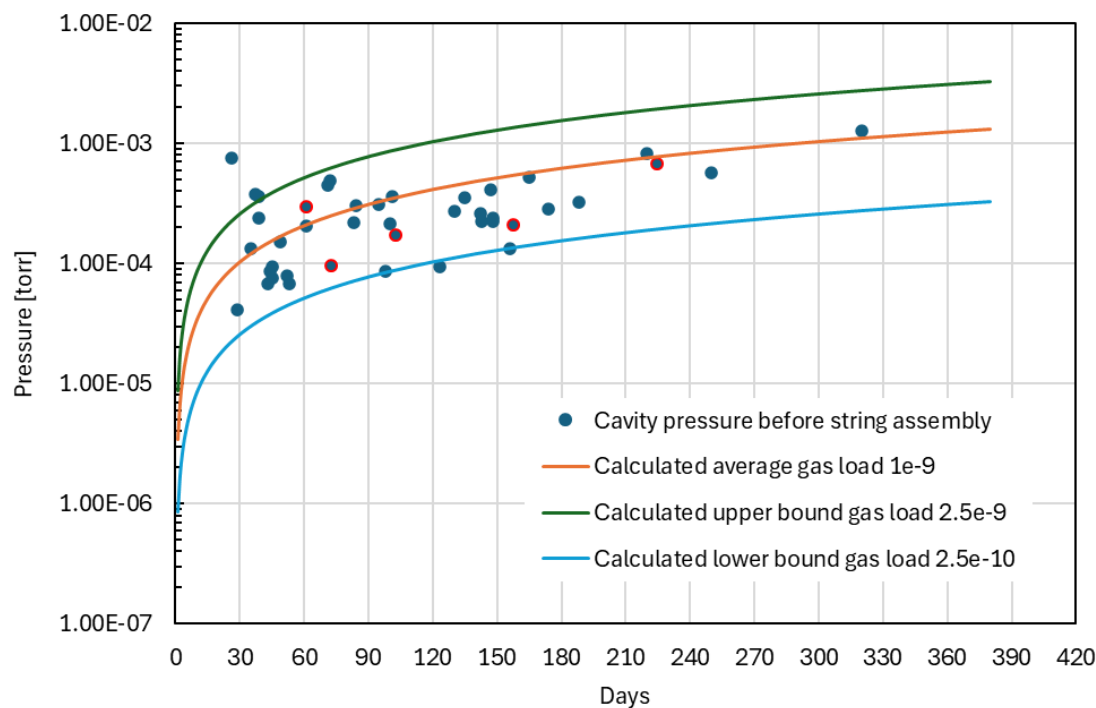
Document Number: ED0041864

Document Approval		Date Approved
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Concurred	Julien Drant, CEA	Email approval
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Concurred	Damon Bice, FNAL	As in Teamcenter
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Venting

- Cavity Right Angle Valve (RAV) may leak after cold cycles in the cavity qualification tests.



PIP-II Cavity Pressure Acceptance before String Assembly – Record of Decision

Author: Genfa Wu on behalf of the PCE 1 team

Document Number: ED0045593

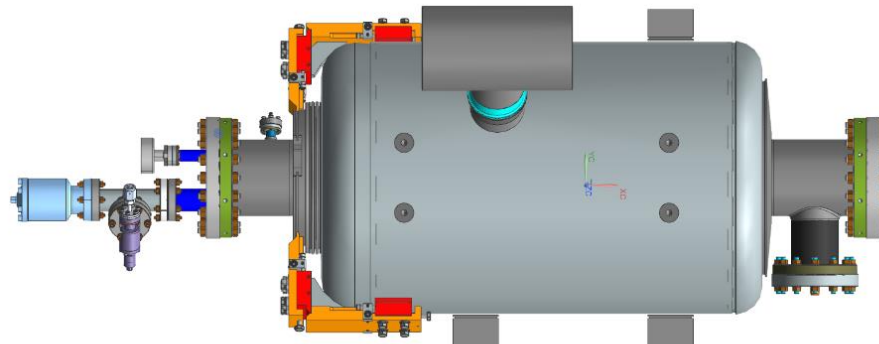
❖ Purging standardization is in progress

- Purging rate
- Purging path design and procedure
 - Purging through a cryogenic-compatible filter/diffuser.
 - Right-angle-valve is only used for slow evacuation
 - Particles in the right-angle-valve are bypassed

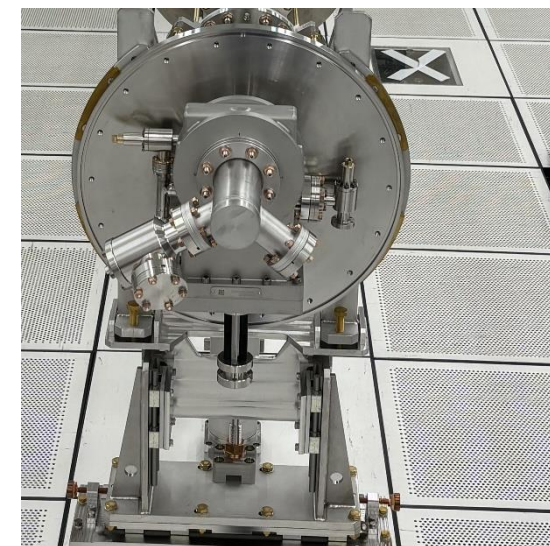
The purging standardization has not been implemented yet for all partner labs.



CEA/Saclay designed filter diffuser (Stephane Berry)



Venting and purging were through the build-in filter during the coupler assembly. It was validated at CEA/FNAL



The end sub-assembly with a filter.

Particle counter and N2 blowing

Ionized N2 Setting

- In the SRF facilities, finely filtered N2 was mostly used for venting and purging. It is commonly used for an ionized N2 gun as well. It is acceptable to use finely filtered, dry air when available. (99.9999% filtration of 0.1 μm)
- Past experience indicates that a 200 L/min ionized N2 flow rate effectively removes surface particles. The discharging time shall be ≤ 2 seconds at 6-in distance. For a Simco IonTM, a 90 psi inlet could provide around 200 L/m ionized flow. The distance between the N2 gun and the object's surface should be less than 6 in.

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PIP-II Particle Counter and Ionized N2 Setting Standardization – Record of Decision

Author: Genfa Wu on behalf of the PCE 1 team

Document Number: ED0048228

Document Approval		Date Approved
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✚ Particle counter and N2 blowing

Particle Counter Setting

- In the SRF best practice, the counts need to be zero within two sampling periods. In some cases, it is difficult to reach zero, even after extended part blowing. The maximum counts for the 12-second period need to be ≤ 5 for the 100 L/m air flow of the particle counter.
- The particle counter receptacle and the N2 flow should be in the same line for small parts. For large parts, the receptacle direction and N2 flow should be mirrored in the normal plane of the target surface.
- For particle counters that have less than 100 L/m, the sampling period needs to be increased to ensure a minimum volume of 10 L is achieved. With the maximum count no more than 2.



Summary

- PIP-II Cryomodule has standardized many designs and components.
- The string assembly and clean room procedures are mostly standardized.
 - The purging standardization is yet to be converged due to infrastructure challenges (over-pressure, N2 supply, etc.)
- The partner labs are collaborative and constantly improving the best practices.



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