



# Coaching vendors on cavity processing

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PIP-II Technical Workshop

3 December 2020



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India/DAE

Italy/INFN

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# Importance of clear expectations

- Experience from a number of both large and small projects highlights the importance of having **very clear expectations** with SRF cavity vendors.
- CEBAF 12 GeV Upgrade, ILC R&D, EXFEL, **LCLS-II**, **SNS PPU**, **LCLS-II HE**, CEBAF C75 cavities, ...
- It is very important to distinguish for each procurement whether one is
  - (a) "ordering up" the vendor's "standard" process without the requestor having to understand the details, **or**
  - (b) prescribing the detailed process that the vendor is then obligated to implement.
- The vendors are careful to not accept responsibility for "development".
  - They will in (a) repeat what they have done previously without thoughtful adaptation, or, in (b), implement and charge for doing what they are told to do.
  - *Vendor performance accountability is to the implementation of agreed processes, not to the eventual RF performance of delivered cavities.* [But incentive bonuses may help.]

# Importance of clear expectations

- **Component mechanical specification** – dimensional tolerancing
  - Know what you want in detail, and communicate that unambiguously via drawings
- **Component mechanical fabrication** – dimensional and surface finish QA
  - Vendors will want flexibility in fabrication methods for their own efficiency
  - Check them – review their detailed procedures and dwgs and/or set key “hold point” acceptance checks. (Of course respect any proprietary aspects.) *“Coaching” opportunity*
- **Mid-fabrication processes**
  - Cleanliness of EB weld prep is **amazingly important**
  - Actual handling technique and tooling between parts etching/cleaning and EBW is critical
  - Individual personnel training and verification is indicated *“Coaching” opportunity*
  - Don’t rely on general training – technique QA is worth the effort

# Importance of clear expectations

- **Cavity processing** – after mechanical fabrication
  - BCP, US, EP, HPR, HT, and “doping” are various items on the “menu”
  - The details of each are specific to each cavity geometry
  - Beware of simple extrapolations from processes used successfully on other geometries
  - Vendor and lab infrastructures are different, so processing procedures must be thoughtfully adapted to each circumstance *“Coaching” opportunity*
- **Cavity assembly for testing**
  - Final cleaning and clean assembly for delivery
  - Particulate free for field emission free cavity performance
  - Personnel technique is everything – component cleaning, disciplined motion habits, assembly sequence ... *“Coaching” opportunity*

For assured success with each new requirement, qualification runs are required, then Quality Assurance measures must be implemented to ensure that the applied processes are stable over time.

# Importance of clear expectations

- **Example – electropolishing Nb cavities**

- EP of Nb cavities evolved empirically from its introduction on Tristan cavities at KEK, through successful use on EXFEL cavities and some ILC R&D cavities.
- Electrochemical research by Tian @ JLab and Eozénou @ CEA 2005-2010 clarified the basic process [refs. later]
- Implications for various applications have slowly propagated and been refined since then
- Note: There are no “Nb EP experts” in industry *“Coaching” opportunity*

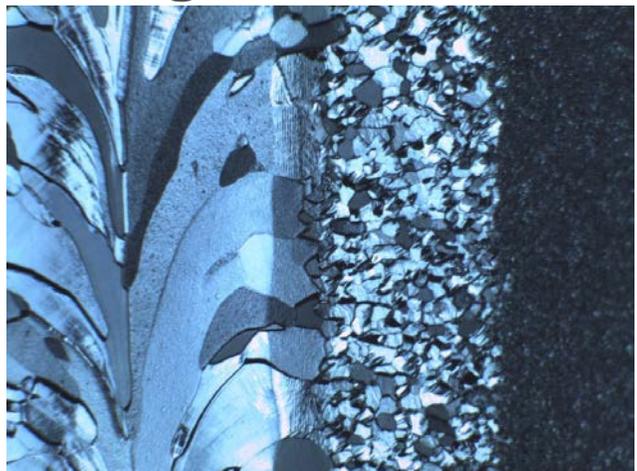
# Importance of clear expectations

- Example – electropolishing Nb cavities
- **Why very geometry specific? - Basic highlights:**
  - Desired “EP” condition is “diffusion-limited”, not etching
    - Local current density depends only on HF concentration and local temperature
  - Local removal rate is thus very sensitive to local temperature
  - Local heat generation is inversely proportional to distance from cathode
    - Beampipes and iris will heat more, but polishing is most important at equators
  - Without external cooling, the acid also serves as process coolant
    - Non-uniform flow = non-uniform cooling = non-uniform temperature = non-uniform removal
    - Must find balance  $\gg$   $V$  high enough for equator EP, but not too high for iris removal
  - Total cavity current = total cathode current
  - Cathode polarization potential is proportional to cathode current density
    - Maximize cathode surface area – else generate Sulfur precipitation  $\gg$  FE source
  - Too low voltage operation loads cavity with H and etches equators
    - Creates both “Q disease” and “Q-slope” !!

# Importance of clear expectations

- Example – electropolishing Nb cavities

HB EP development cavity test at JLab for PPU



HB-71 equator views with Kyoto camera

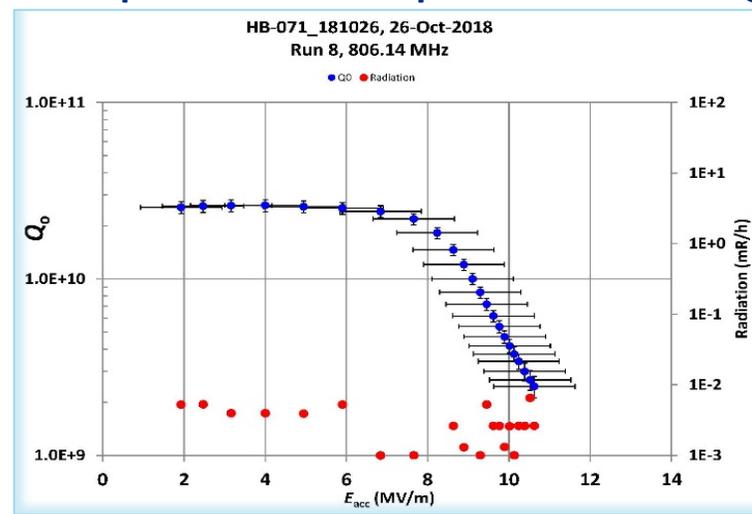


V=17 V, plenty high

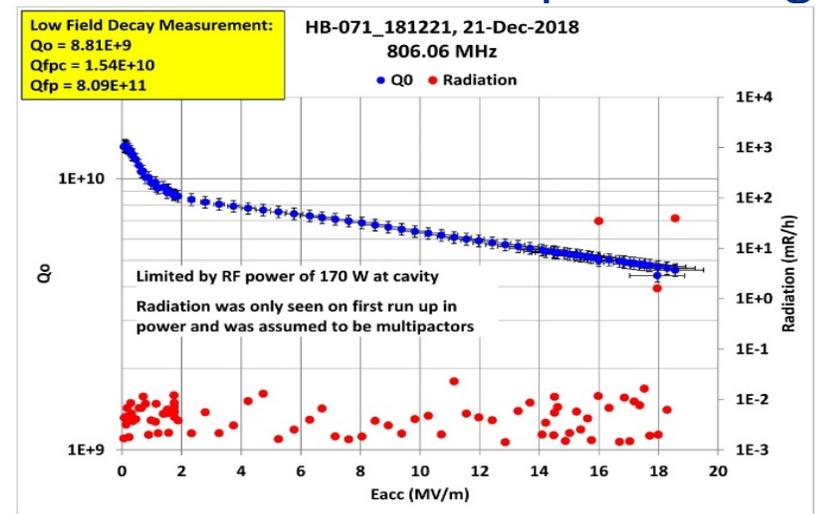


$\beta = 0.81, 805 \text{ MHz}$

“Q-slope” from equator etching



“Q-disease” from 1<sup>st</sup> processing



# Importance of clear expectations

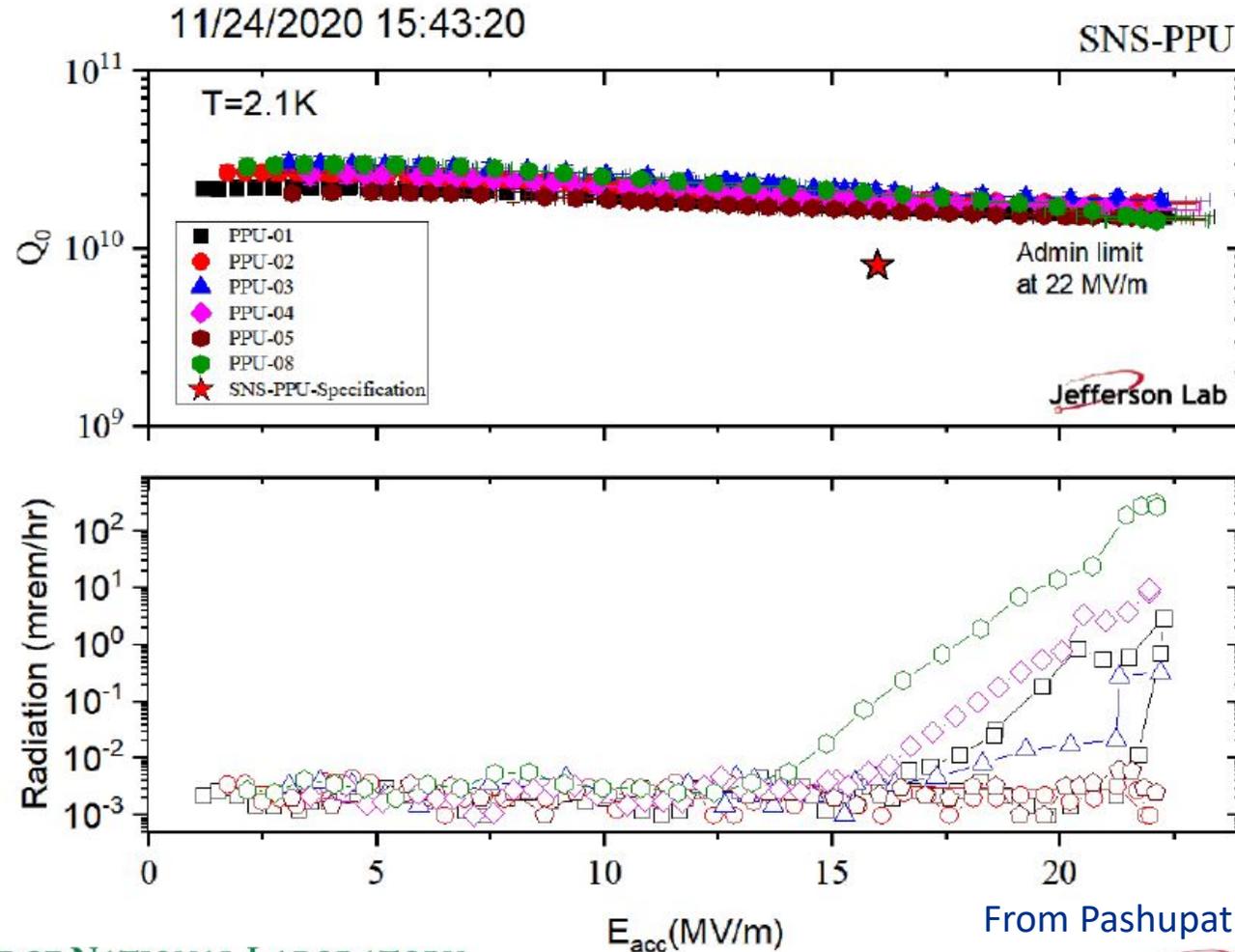
- Example – electropolishing Nb cavities
  - Based on lessons learned, we **coached** PPU cavity vendor during development run at their site to find an implementation on their particular equipment which provided ~uniform temperature and adequate voltage setting for assured polishing at HB cavity equators.

# Importance of clear expectations

## CAVITY PERFORMANCE

Example:

- PPU production cavities
- Vendor electropolishing 805 MHz SNS HB cavities for PPU
- After coaching regarding acid temperature, flow rate, and applied voltage.
- Excellent  $Q \propto v E$ .
- Further coaching for FE reduction was required.



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From Pashupati Dhakal

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- It is very important to distinguish for each procurement whether one is
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  - (b) prescribing the detailed process that the vendor is then obligated to implement.
- There must be detailed involvement with your project's specific implementation details, if you require the best final performance.
- Don't miss your ***“Coaching” opportunities*** when launching vendor work, then follow up with Quality Assurance monitoring.

# References for Nb Electropolish

## USPAS 2015 EP tutorial:

<https://indico.jlab.org/event/98/contributions/7440/attachments/6311/8359/13T - BCP and EP for Nb Cavities v2.pdf>

## Papers:

- [1] C. Xu, H. Tian, C. E. Reece, and M. J. Kelley, "Topographic power spectral density study of the effect of surface treatment processes on niobium for superconducting radio frequency accelerator cavities," *Phys. Rev. ST Accel. Beams* **15**, 043502 (2012) <http://link.aps.org/doi/10.1103/PhysRevSTAB.15.043502>.
- [2] H. Tian and C. E. Reece, "Evaluation of the diffusion coefficient of fluorine during the electropolishing of niobium," *Phys. Rev. ST Accel. Beams* **13**, 083502 (2010) <http://link.aps.org/doi/10.1103/PhysRevSTAB.13.083502>.
- [3] H. Tian, S. G. Corcoran, C. E. Reece, and M. J. Kelley, "The Mechanism of Electropolishing of Niobium in Hydrofluoric--Sulfuric Acid Electrolyte," *Journal of The Electrochemical Society* **155**, D563 (2008) <http://dx.doi.org/10.1149/1.2945913>.
- [4] C. E. Reece, "An Experimental Analysis of Effective EP Parameters for Low-Frequency Cylindrical Nb Cavities," in *SRF2019* (JACoW Publishing, Dresden, Germany, 2019), p. 472. Available from: <http://accelconf.web.cern.ch/srf2019/papers/tup029.pdf>.
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- [6] F. Eozénou, S. Berry, C. Antoine, Y. Gasser, J. P. Charrier, and B. Malki, "Aging of the HF-H<sub>2</sub>SO<sub>4</sub> electrolyte used for the electropolishing of niobium superconducting radio frequency cavities: Origins and cure," *Phys. Rev. ST Accel. Beams* **13**, 083501 (2010) <http://link.aps.org/doi/10.1103/PhysRevSTAB.13.083501>.
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- [8] F. Eozénou, A. Aspart, C. Antoine, and B. Maliki, CARE Report No. 06-10-SRF, 2006. (2006).
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- [10] C. Reece, "Framework for EP Parameter Selection for SNS HB Cavities", JLab Internal Technote, JLAB-TN-19-009.