Processing of Superconducting RF Cavities

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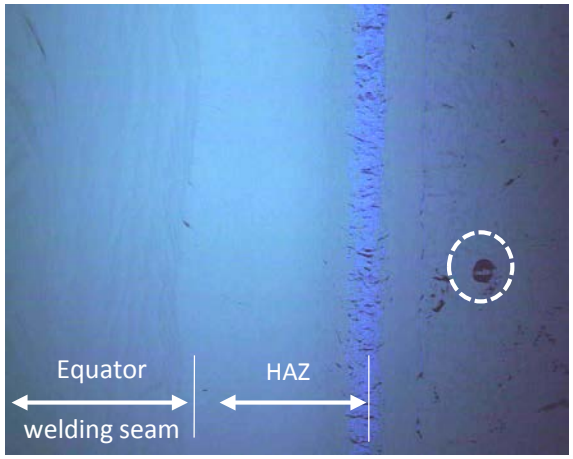
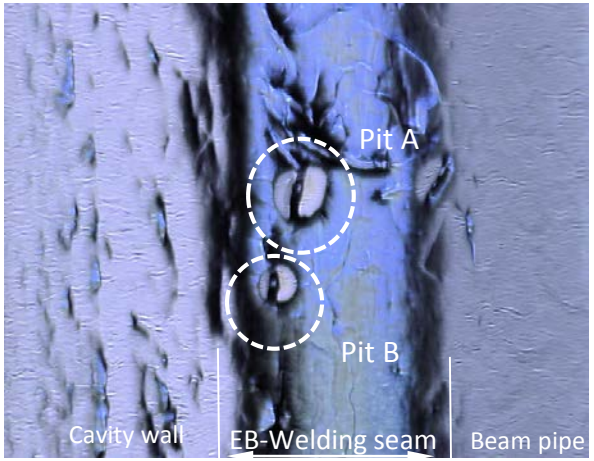
Why is PROCESSING required for cavity ?

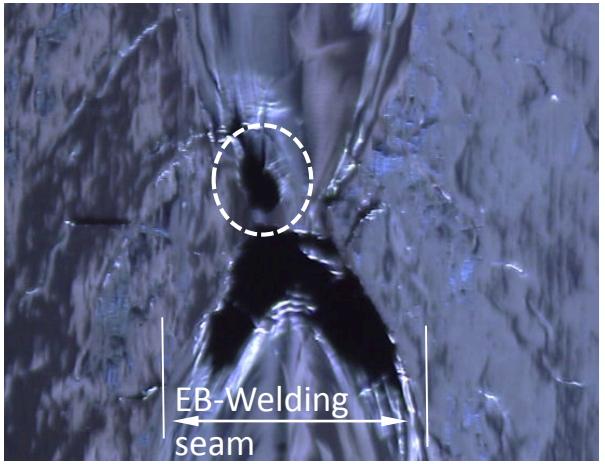
- The performance of a SCRF cavity depends on the *quality of* the RF surface.
- The surface purity gets affected by oil, grease, finger-prints, etc. during forming, machining & RF measurement
- The internal surface of the cavity may also have micron-size surface defects like pits, dents, weld spatter etc.



Pits outside HAZ
Diameter: 400µm,Depth: 60µm



Pits at Iris
Diameter: 400µm, Depth: 37.5µm

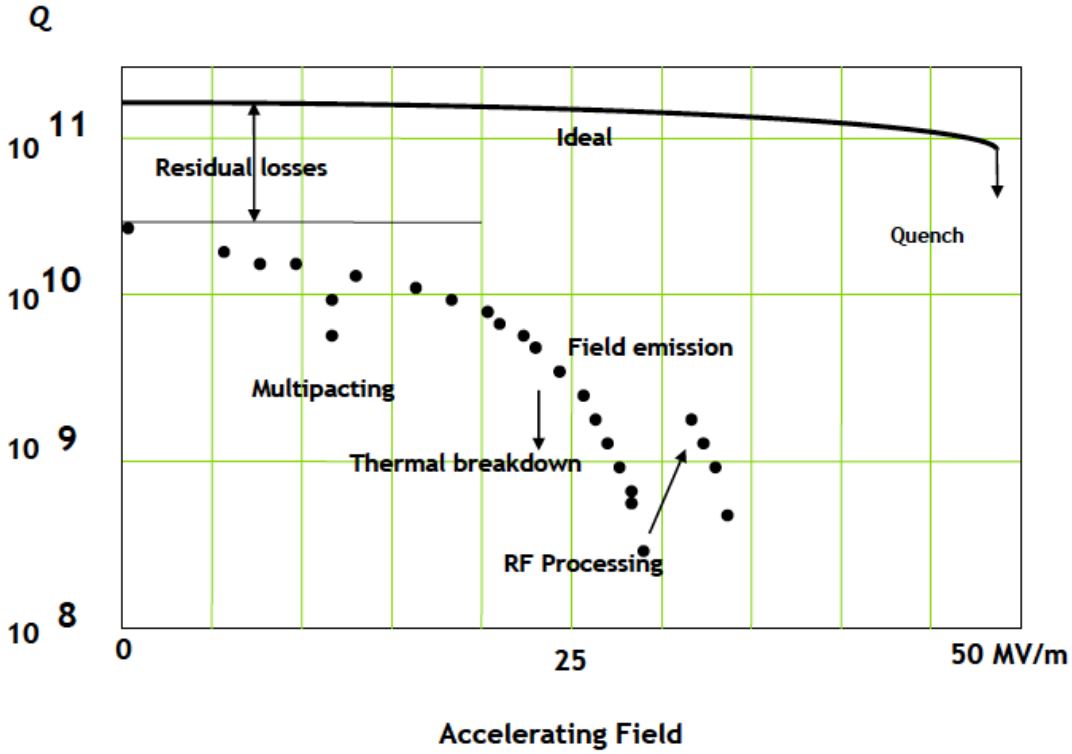


Quench location on equator
120µm deep, 700µm wide on top

Why is PROCESSING required for cavity ?

- Around 100 micron layer on the surface gets damaged & contaminated during fabrication which needs to be removed.
- The main parameters limiting the performance of a superconducting cavity are:
  a) Residual Resistance b) Field Emission c) Q-Slope d) Quench
  e) Multipacting

Processing of the SCRF cavity refers to surface preparation of the cavity by improving its surface purity & quality for optimum cavity performance.



Various Steps of PROCESSING for bare cavity

- Inspection of internal surface of the cavity
- Ultrasonic Cleaning - degreasing of surfaces to remove contaminates
- Polishing of internal surface to remove bulk material (~ 120-150 µm)
- Thermal processing - removal of hydrogen from bulk niobium
- Mechanical tuning
- Light electropolishing – Final polishing step (10-20 µm)
- High Pressure Rinsing (HPR) to remove particulates from internal surfaces (incurred during polishing and handling)
- Drying of cavity for assembly in cleanroom
- Clean assembly and evacuation
- Low-temperature baking
- Preparation for low power RF test at 2 K - VTS testing

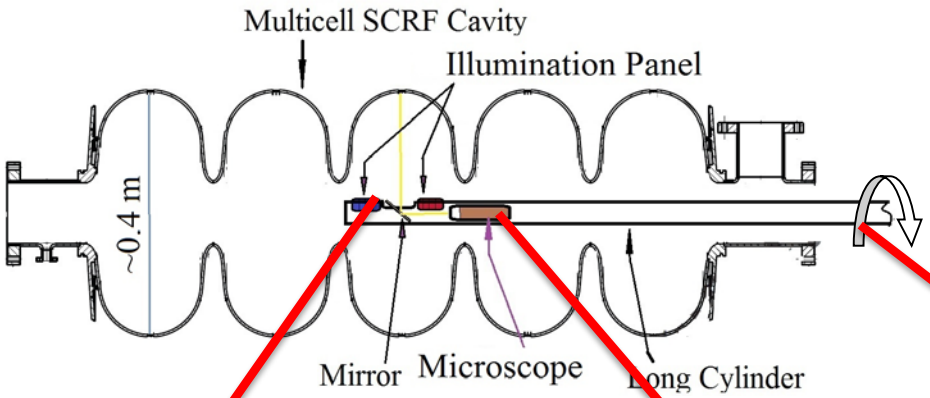
Inspection of internal surface of the cavity

Optical Inspection System

- An optical inspection of the inner surface, leads to a better understanding of limitations of SCRF performance with respect to surface quality. This provides a qualitative analysis of the surface.
- An optical inspection system was developed at KEK and Kyoto University, better known as the "Kyoto camera system". It is an expensive system costing more than Rs. 50 lakhs. The Kyoto camera system is used at KEK (Japan), DESY (Germany), Fermilab (USA), Jlab (USA), etc.
- An optical inspection system has been indigenously developed at RRCAT, which is costing less than 5% of the Kyoto system.

Inspection of internal surface of the cavity

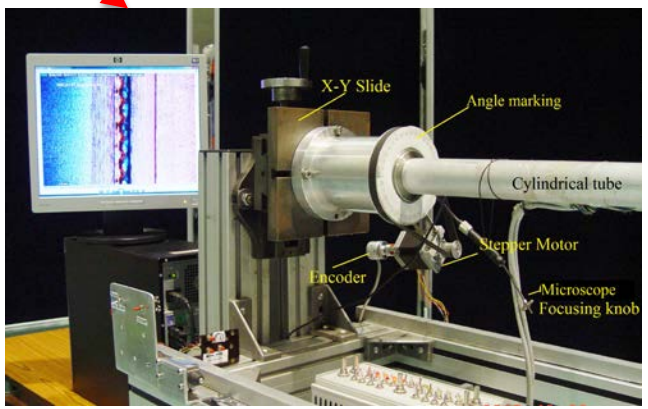
Optical Inspection System



Smallest measurable feature size : 10 microns

Illumination System

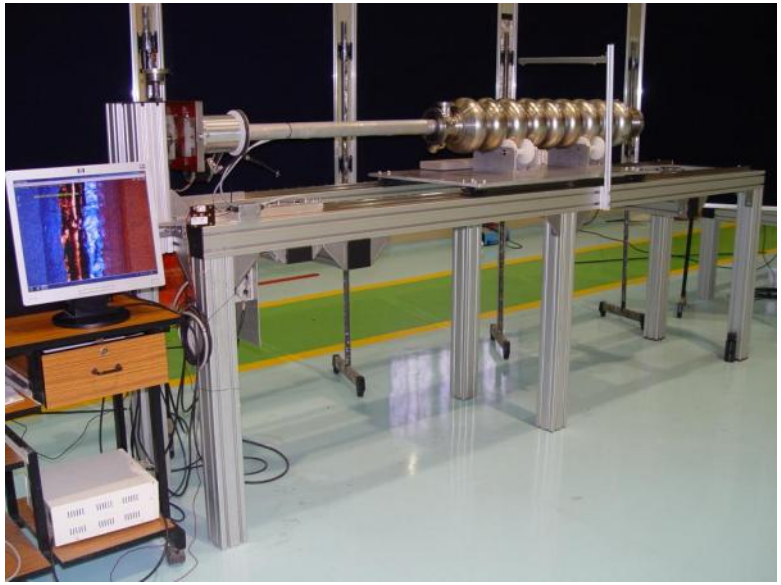
Digital CCD Camera



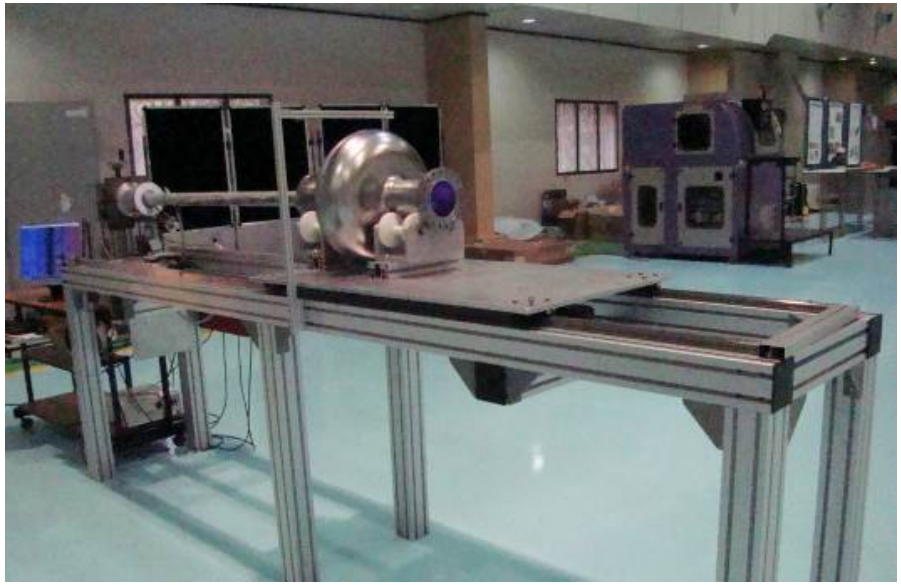
Positioning system

Inspection of internal surface of the cavity

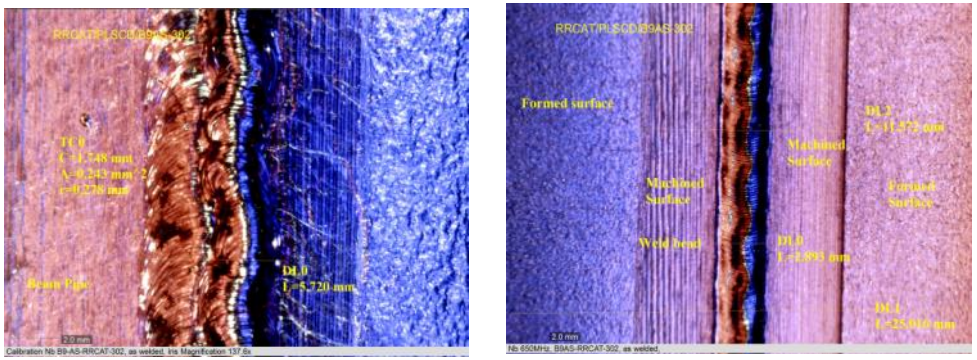
Optical Inspection System



Inspection of nine-cell 1.3 GHz cavity



Inspection of single-cell 650 MHz cavity

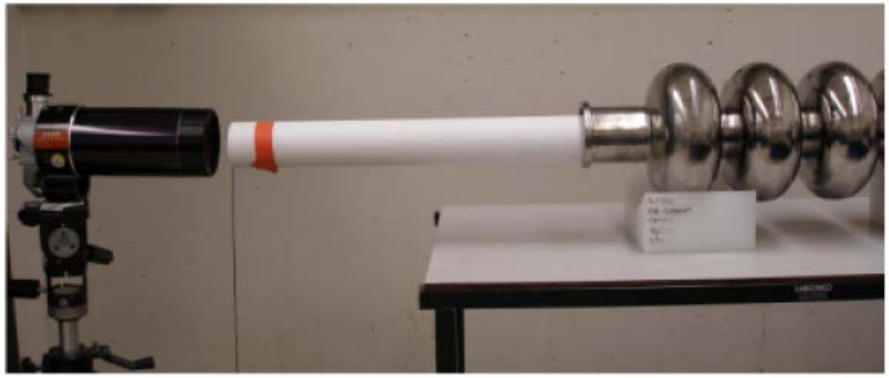


Images from optical bench (650 MHz cavity)

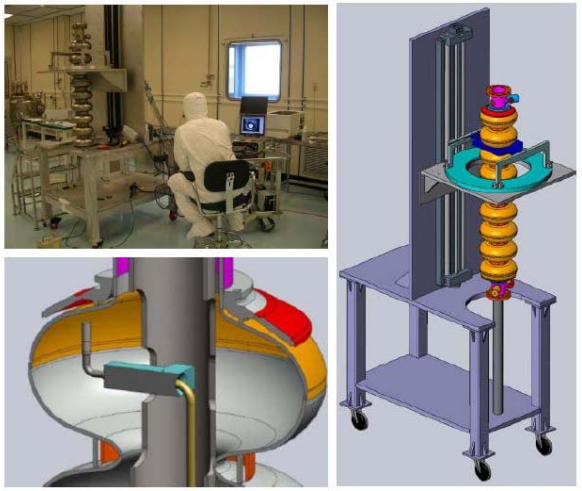
Inspection of internal surface of the cavity

Inspection system at KEK, Japan

Inspection system at FNAL, USA



Inspection system at Cornell University



Inspection system at LANL, USA

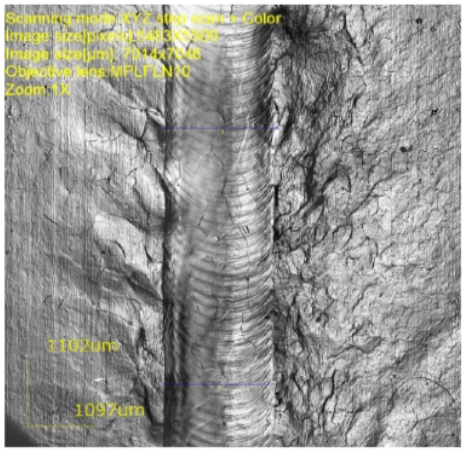
Inspection of internal surface of the cavity

Replica Molding Technique

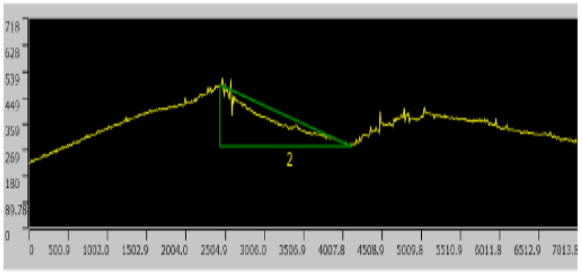
- The technique is use in quantifying the defects on the surface of cavity
- Replica casted at the location of defect identified by optical inspection
- Replica casted using Room Temperature Vulcanized Silicon
- The mold studied using 3D Laser Scanning Confocal Microscope.

Laser Scanning Confocal Microscope

Silicon Mold



Confocal image of replica



	No.	Result	Width[µm]	Height[µm]	Length[µm]
☑	1		1806.831	252.657	1824.410
☑	2		1689.145	212.954	1702.516

Measurement of bead profile

Various Steps of PROCESSING for bare cavity

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Degreasing of components & cavity

Requirement of degreasing at various stages

- **After forming + machining and welding of components**
  - To remove grease, oil and finger prints from cavity surfaces
  - To remove surface contamination due to handling, RF measurements and QA inspection
- **After polishing processes**
  - To remove traces of chemicals and other residues

General method of degreasing – Ultrasonic Cleaning

- Ultrasonic cleaning is a process that uses ultrasound and an appropriate cleaning solvent to clean items.
- Piezo transducers are used to produce standing waves in the solution.
- Wave energy forms microscopic bubbles on component surfaces. Bubbles collapse (cavitation) on surface loosening particulate matter. **These bubbles collapse with enormous energy**

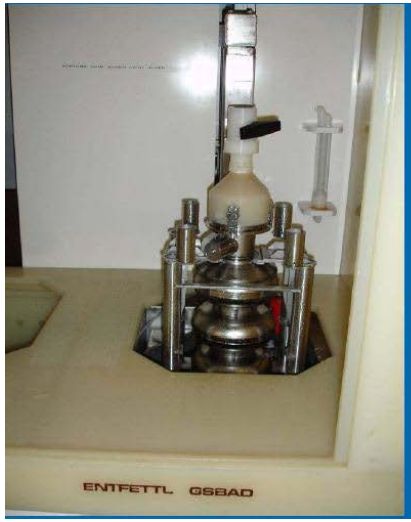
Degreasing of components & cavity

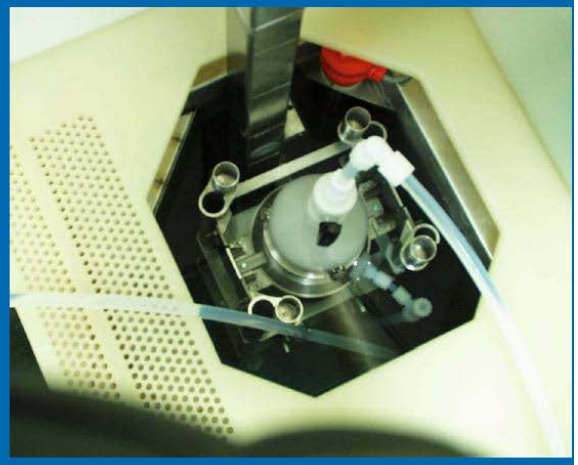
- Ultrasonic cleaning is carried out in mixture of ultra-pure water and special Phosphorous and Sulphur free detergent like Micro-90, Liqui-Nox (1%-2% concentration at 45-50°C.
- The cleaning should be preferably performed in a clean environment.
- Ultra pure water has a high level of purity; Resistivity – 18 MΩ-cm, TOC < 30 ppb

Ultrasonic cleaner for small components & single-cell cavities at RRCAT

Ultrasonic cleaner for five-cell 650 MHz cavity at RRCAT

Degreasing of components & cavity





Pictures of degreasing facilities at few international labs

Degreasing of components & cavity

Megasonic Cleaning

- Ultrasonic operate at lower frequency and random cavitation. Longer duration may damage components to be cleaned.
- Megasonics is like ultrasonics but operates at much higher frequency (typically 0.8–2 MHz). As a result, the cavitation that occurs is gentler and on a much smaller scale, less likely to cause damage
- With ultrasonics, cavitation occurs throughout the tank, and all sides of submerged parts are cleaned. Whereas, with megasonics, the acoustic wave is found only in a line of sight from the transducer surface.
- Hence, more transducers are required for similar volume and also, the process is much slower. This makes it more expensive.
- The efficiency to remove particles of size < 5 microns is lower for this process.

Various Steps of PROCESSING for bare cavity

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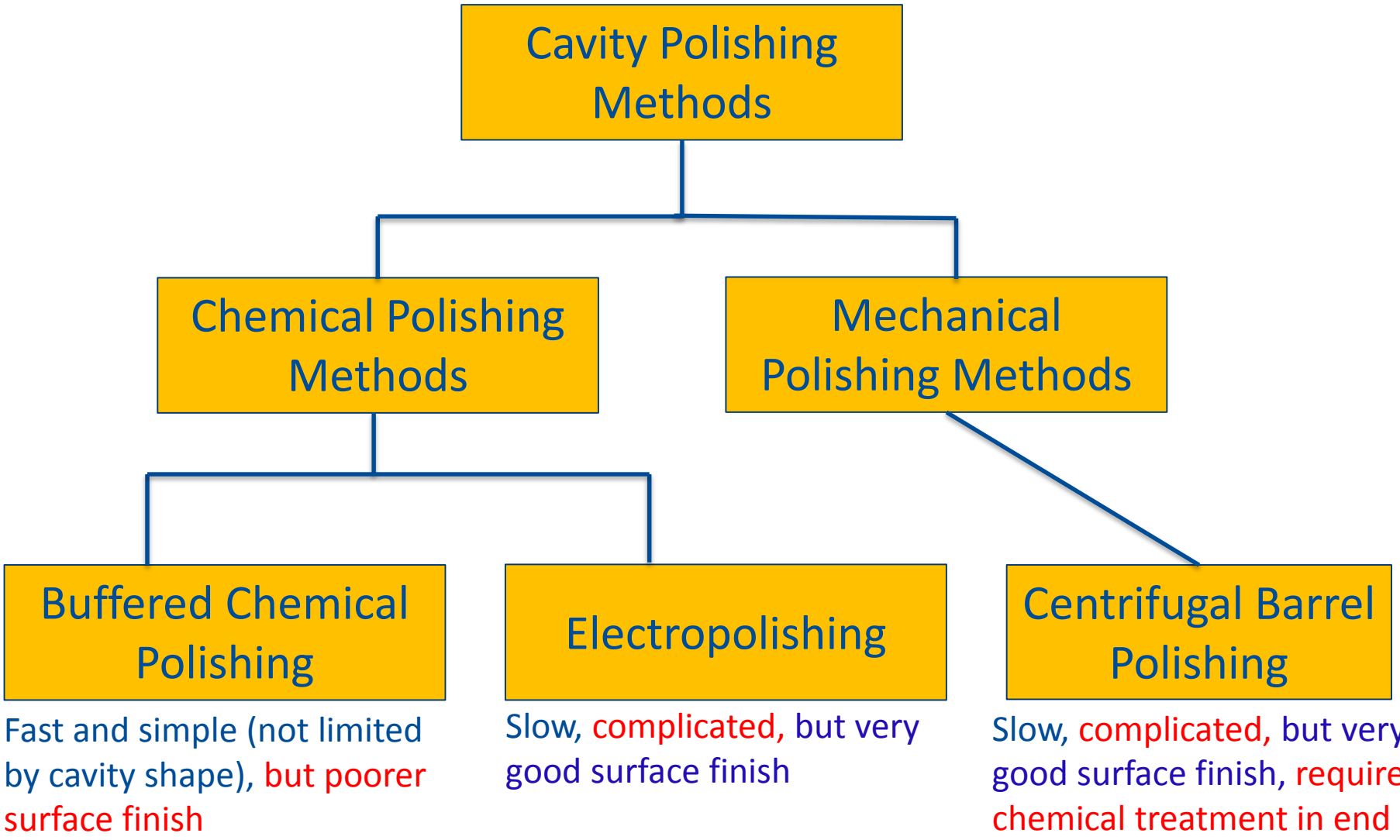
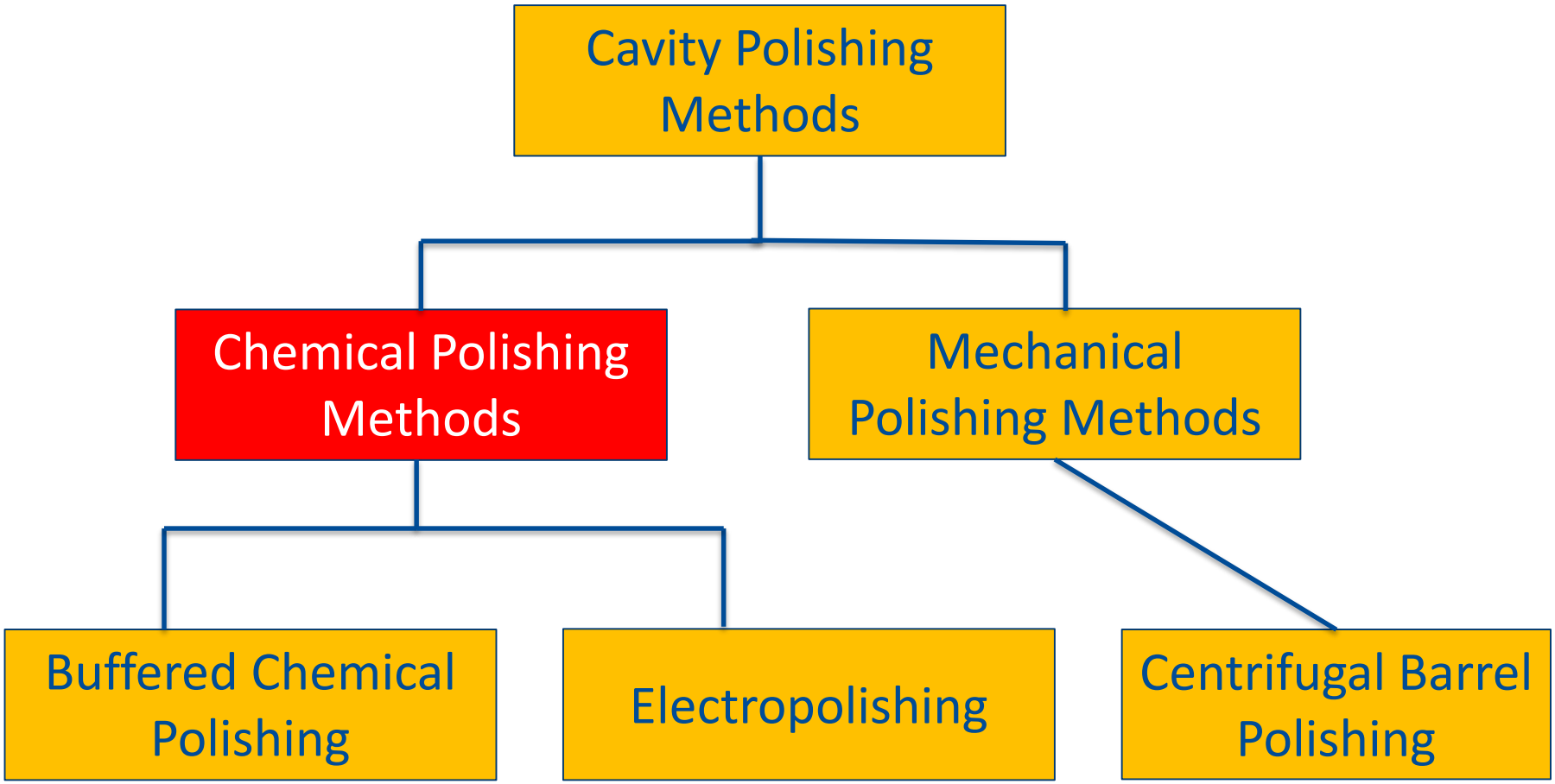
Polishing of internal surface of cavity



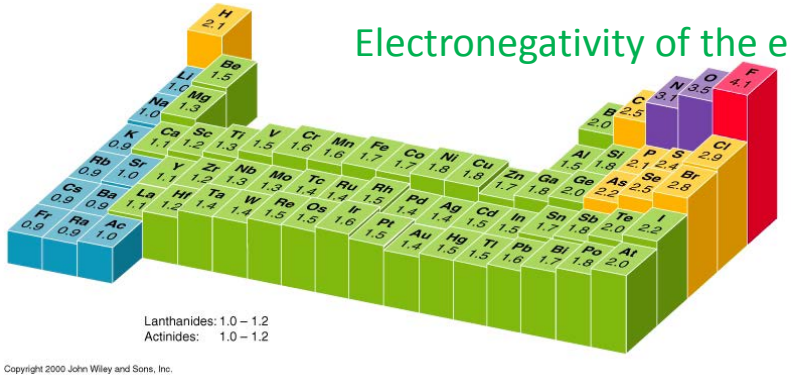
Polishing of internal surface of cavity



Polishing of internal surface of cavity

- As received high purity niobium material is an “Ideal” surface. It has defect-free niobium crystals with only ~ 5 nm Nb_2O_5 layer.
- After cavity fabrication stages like forming, machining and welding, the real surface is “damaged” and “contaminated”.
- Generally full penetration welding is performed from outside of cavity. This produces prominent weld bead of few hundreds of micron on the inside of cavity. This bead needs to be polished to avoid pre-mature quenching and deteriorating quality factor.
- In the process of removal of material, it is also necessary to produce a highly finished (mirror finish) surface with surface roughness of few tens of nano-meters
- The naturally-forming Nb_2O_5 is a very stable oxide – weak acids don’t touch it

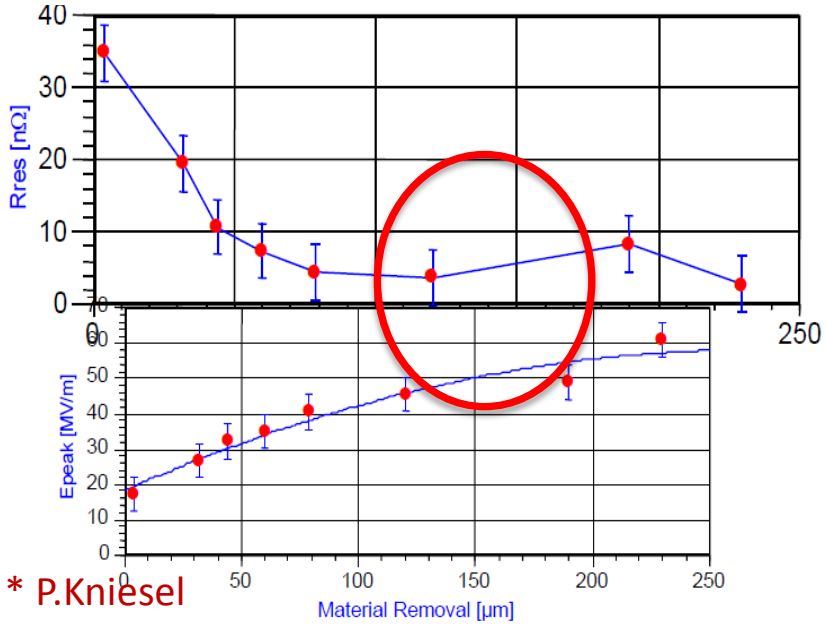
Electronegativity of the elements



Hydrofluoric acid (HF), which is a very strong acid is required in processing of niobium cavities

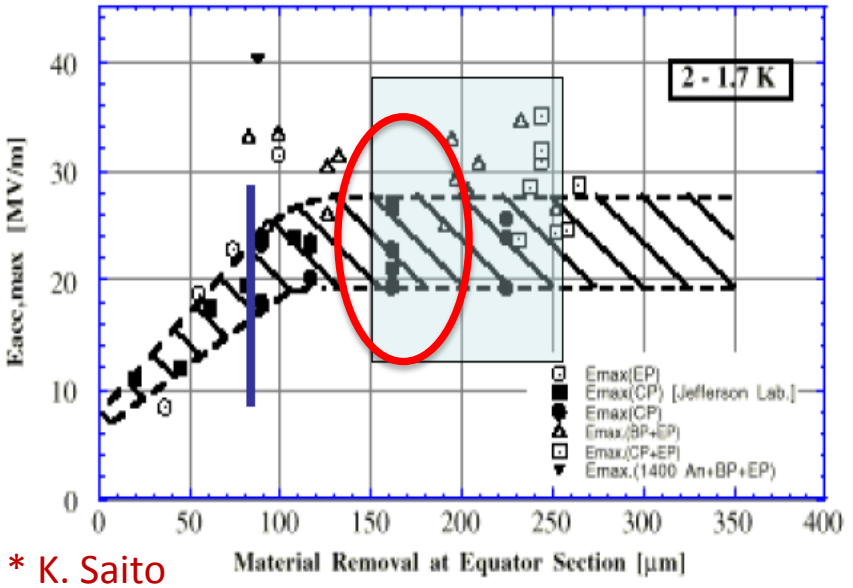
Polishing of internal surface of cavity

- Empirically found that >100 µm removal is typically required to reliably expose “good” bulk Nb material, i.e. predictable SRF performance.



* P.Kneisel

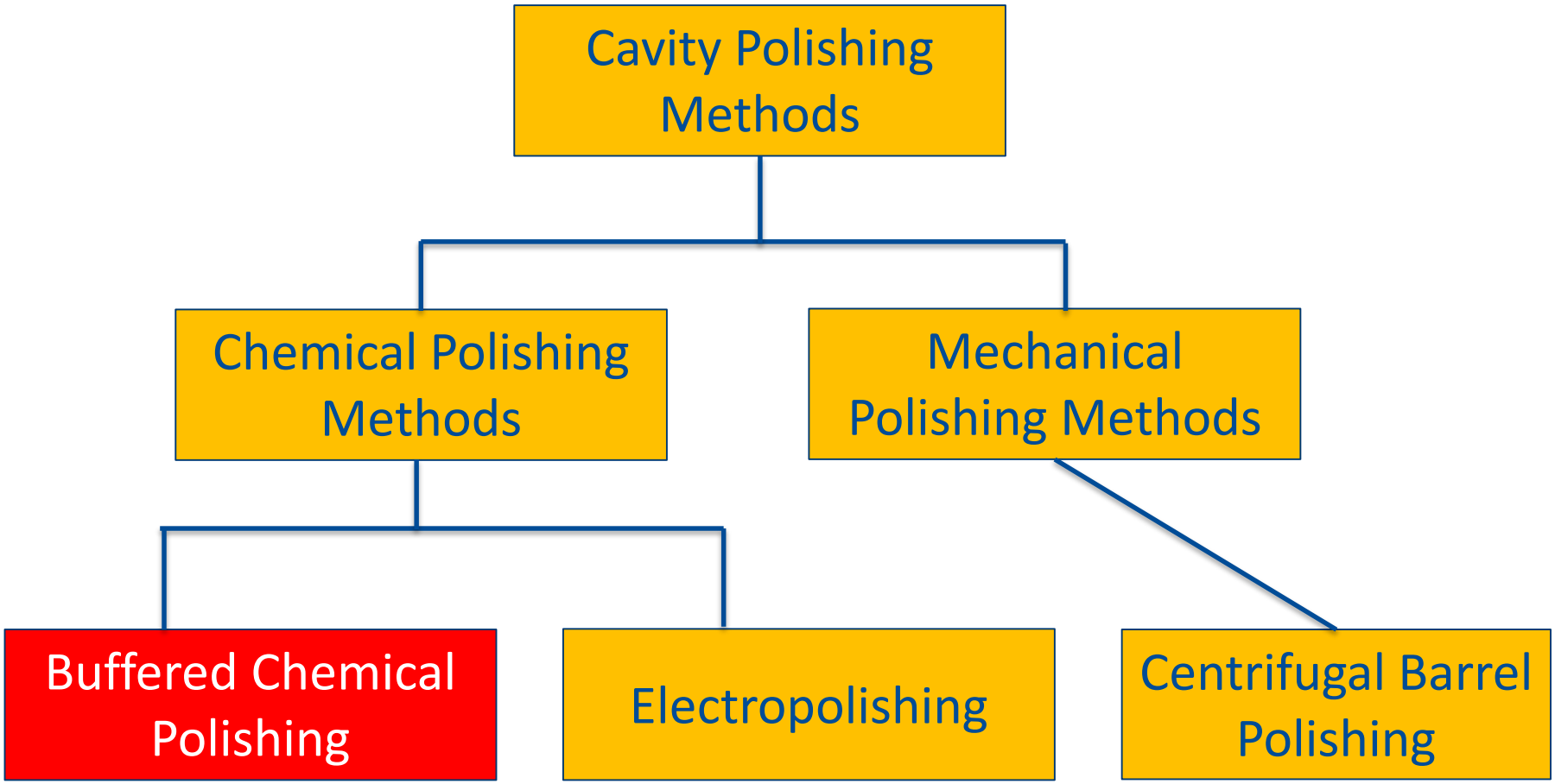
Residual resistance & Peak electric field v/s material removed from equator



* K. Saito

Accelerating gradient v/s material removed from equator

Polishing of internal surface of cavity



Buffered Chemical Polishing (BCP)

Chemical polishing/ etching is required at various stages of cavity development :

Sub-components require

- Pre-weld etch : Removal of contaminants which come from fabrication steps to reduce the losses and improve cavity welding.

Cavities require:

- Internal cleaning/polishing - 100-200 μm

- External cleaning – 20-30 μm material is etched from the outer surface of the cavity by BCP to remove “dirty” layer after fabrication in order to improve the heat transfer at the Nb/LHe interface (Kapitza resistance)

Buffered Chemical Polishing (BCP)

Etching solution used for BCP :

$HF\ (48\%) + HNO_3\ (65\%) + H_3PO4\ (85\%)$

Mixture ratio 1:1:1 - used for etching of subcomponents
(etch rates up to 5 µm/min) – still used at some labs

and 1:1:2 - used for most cavity treatments
(etch rates of 1- 3 µm/min)

Chemical Reaction

Oxidation

$2Nb + 5HNO_3 \rightarrow Nb_2O_5 + 5NO_2$

Reduction

$Nb_2O_5 + 6HF \rightarrow H2NbOF5 + NbO_2F\ 0.5H_2O + 1.5H_2O$

$NbO_2F\ 0.5H_2O + 4HF \rightarrow H_2NbOF_5 + 1.5H_2O$

- Reaction exothermic
- H_3PO_4 used to "buffer" the reaction rate
- Agitation by stirring/ rotation/ continuous flow
- Acid is usually cooled to 10-15 C to control the reaction rate

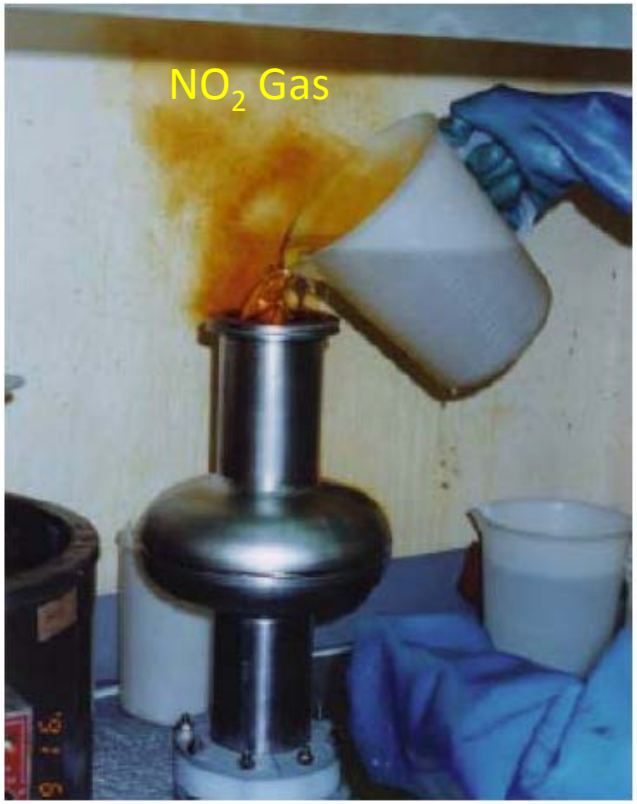
Buffered Chemical Polishing (BCP)

- At RRCAT, BCP is presently used for cleaning of cavity components & pre-weld etch only.

- The present processing recipe for HB 650 cavities does not include BCP

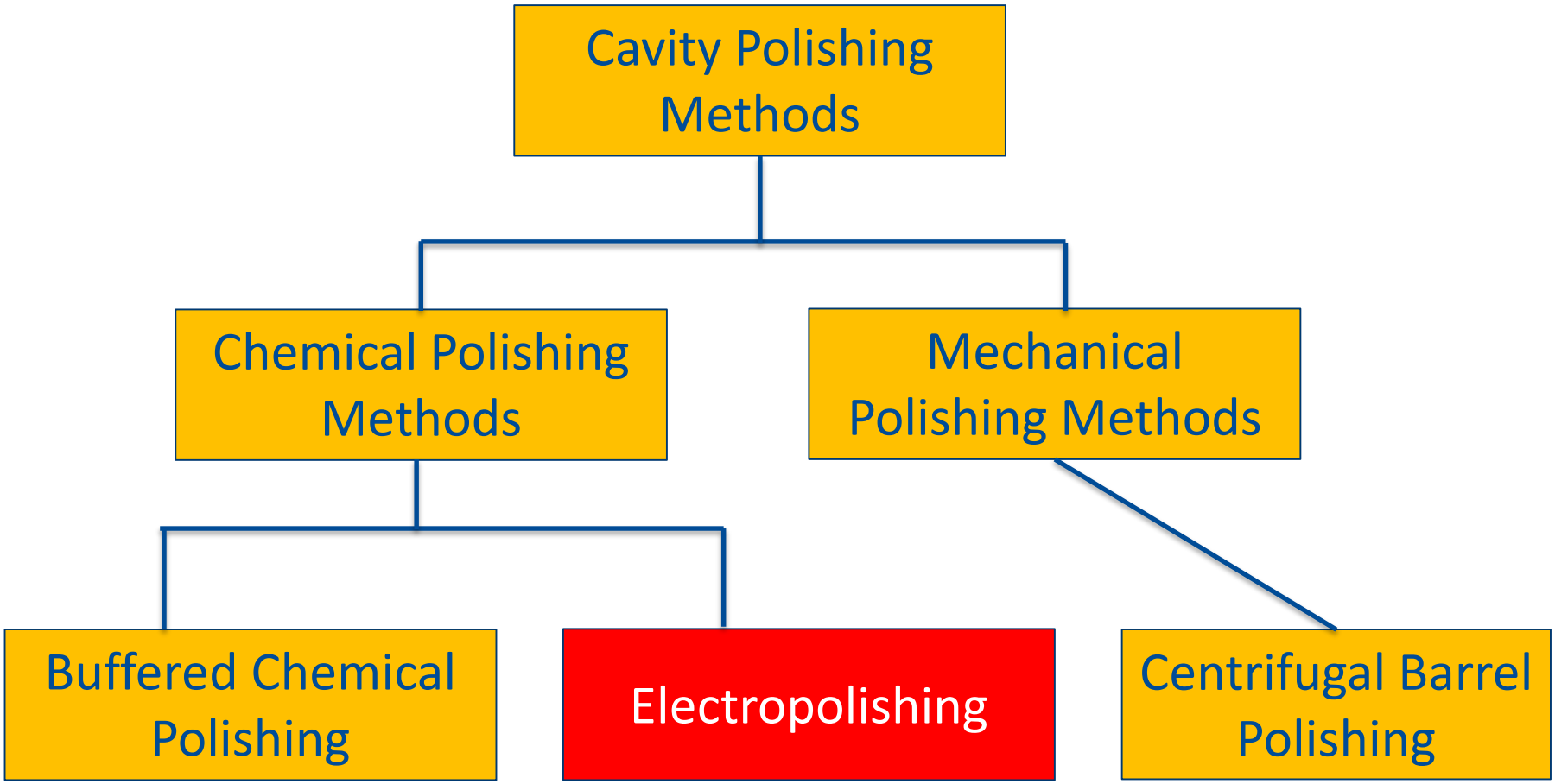
Buffered Chemical Polishing (BCP)

BCP Cabinet at Jlab, USA



BCP of single-cell cavity
in fume hood

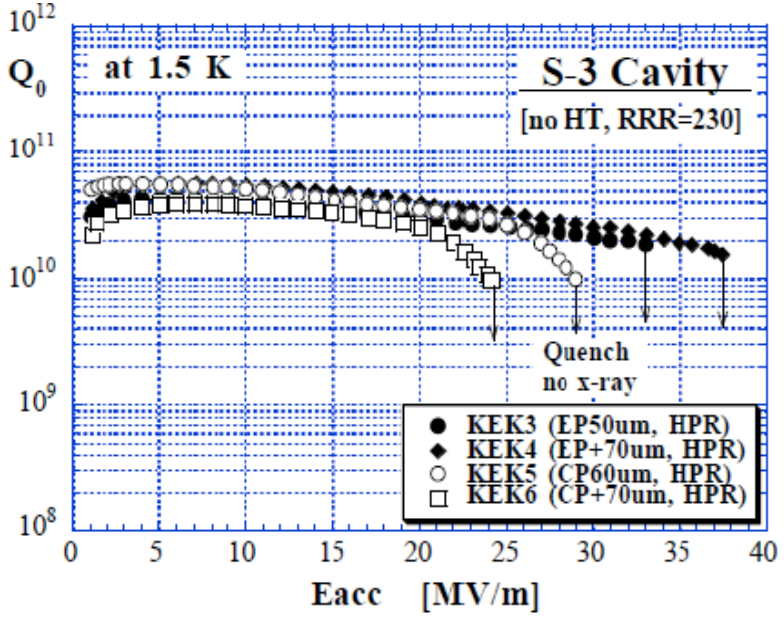
Polishing of internal surface of cavity

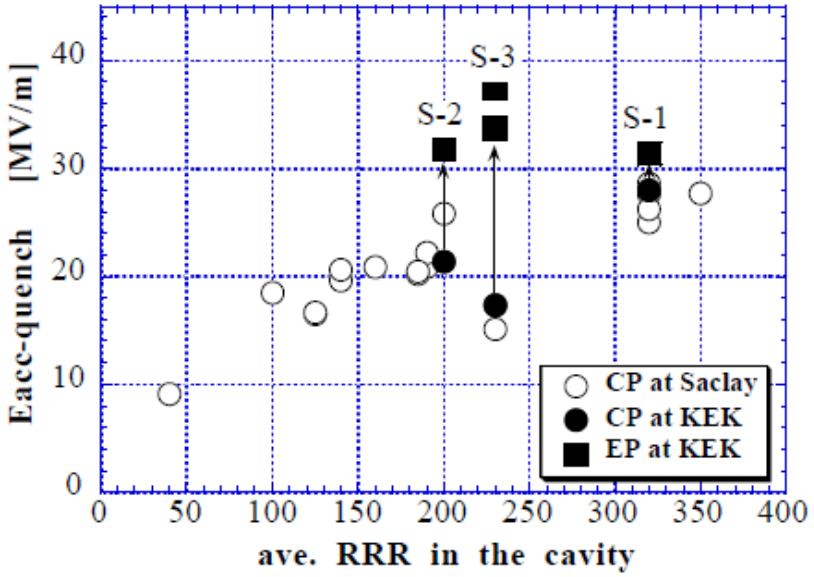


Electropolishing of cavities (EP)

Why electropolishing ?

- Electropolished cavities have quality factor better than chemical polished (BCPed) cavities
- The best accelerating gradients have been achieved with electropolishing
- Better surface finish achieved with electropolishing. An order better !
- Better control over the process.

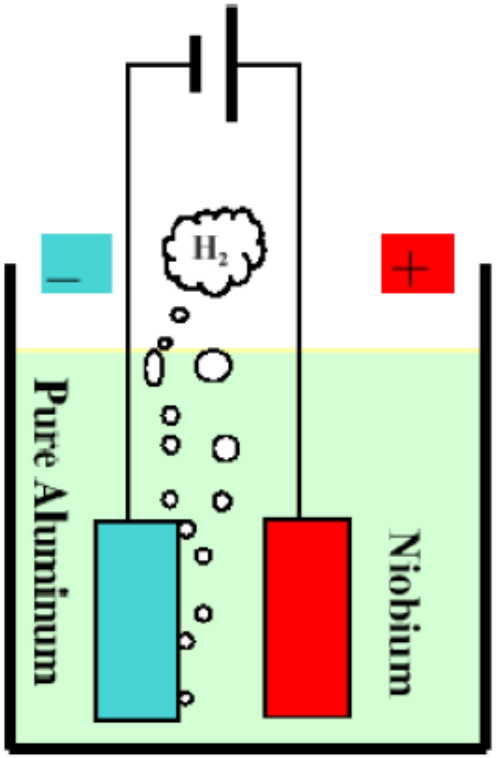




Electropolishing of cavities (EP)

EP is an electro-chemical method of removing thin layers of metal from a surface by anodic dissolution

- Both electrodes are immersed in electrolyte
- A voltage is applied between Nb (anode) and counter electrode (cathode, Al)



Basic reactions:

Oxidation

$2Nb + 5SO_4^{2-} + 5H_2O \rightarrow Nb_2O_5 + 10H^+ + 5SO_4^{2-} + 10e^-$

Reduction

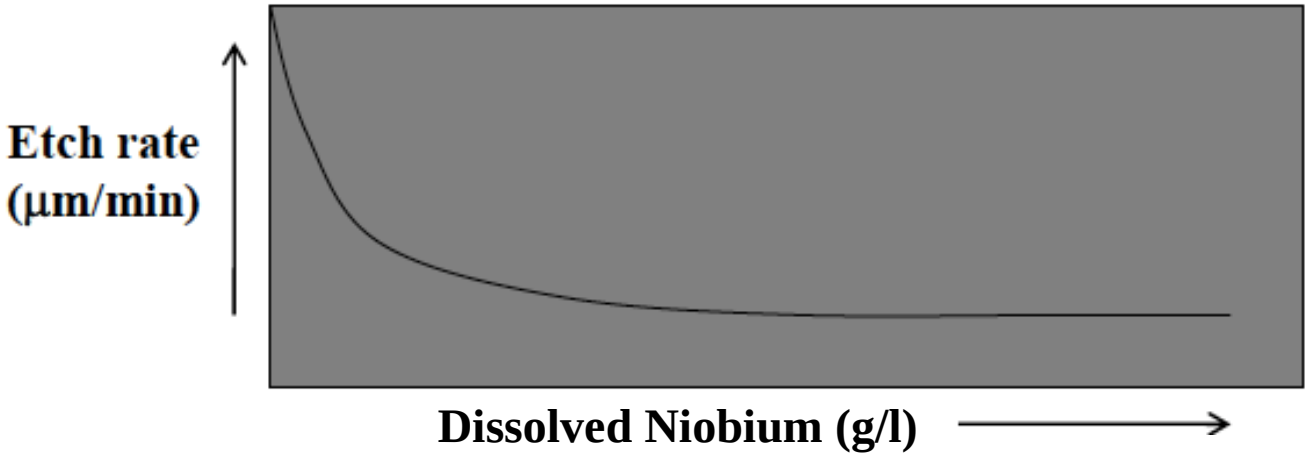
$Nb_2O_5 + 6HF \rightarrow H_2NbOF_5 + NbO_2F\ 0.5H_2O + 1.5H_2O$

$NbO_2F\ 0.5H_2O + 4HF \rightarrow H_2NbOF_5 + 1.5H_2O$

Therefore the overall chemical reaction is:

$2Nb + 10HF + 2H_2O \rightarrow 2H_2NbOF_5 + 5H_2$

Electropolishing of cavities (EP)

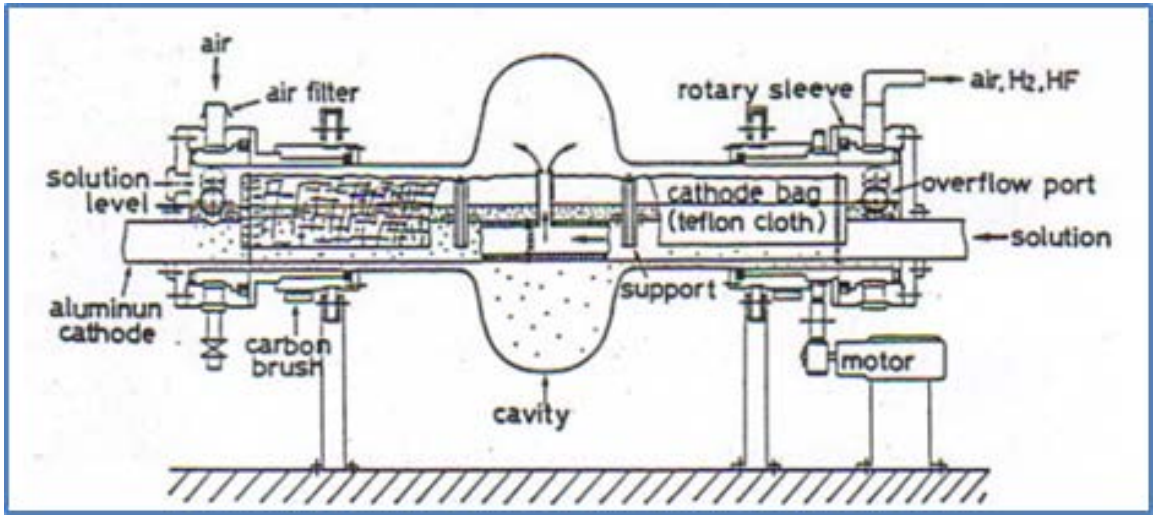


The limiting concentration of dissolved niobium for effective EP is 10 g/l. The acid needs to be changed after the limiting dissolution of niobium

Adding F- in the existing solution is difficult and complicated.

Electropolishing of cavities (EP)

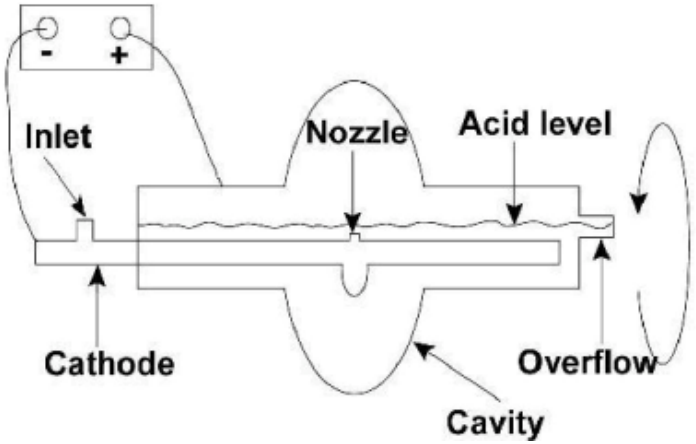
- In the electropolishing process for SCRF cavity, the niobium cavity is the anode.
- The cathode is made from pure aluminium (1100 series).
- The electrolyte is a mixture of hydrofluoric (HF) and sulphuric acid (H2SO4) in a volume ratio of 1:9, using typical commercial strengths HF (48%) and H2SO4 (98%).



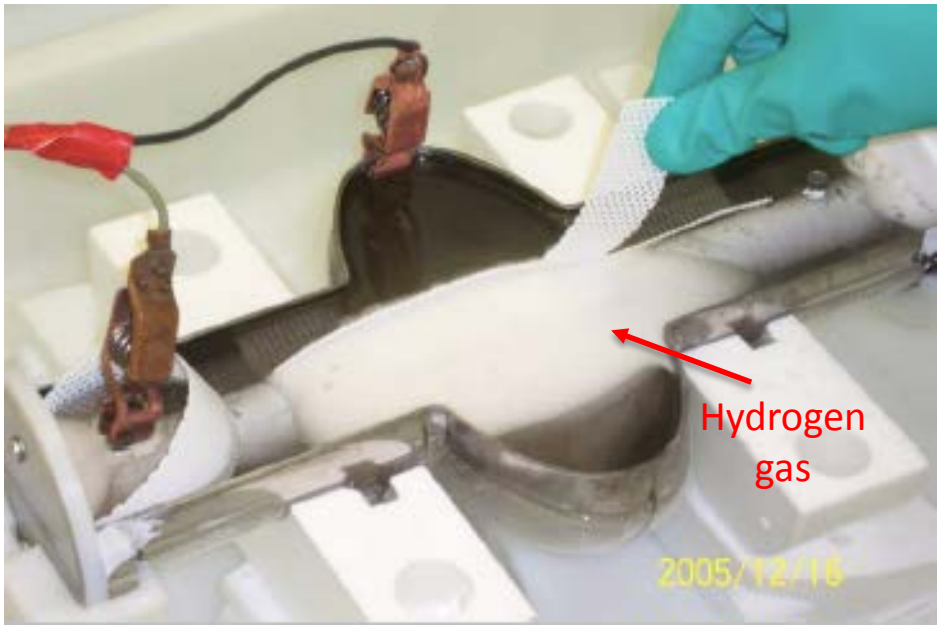
Horizontal electropolishing setup

Hydrogen is released at cathode, which is absorbed by niobium leading to Q-decease

Electropolishing of cavities (EP)

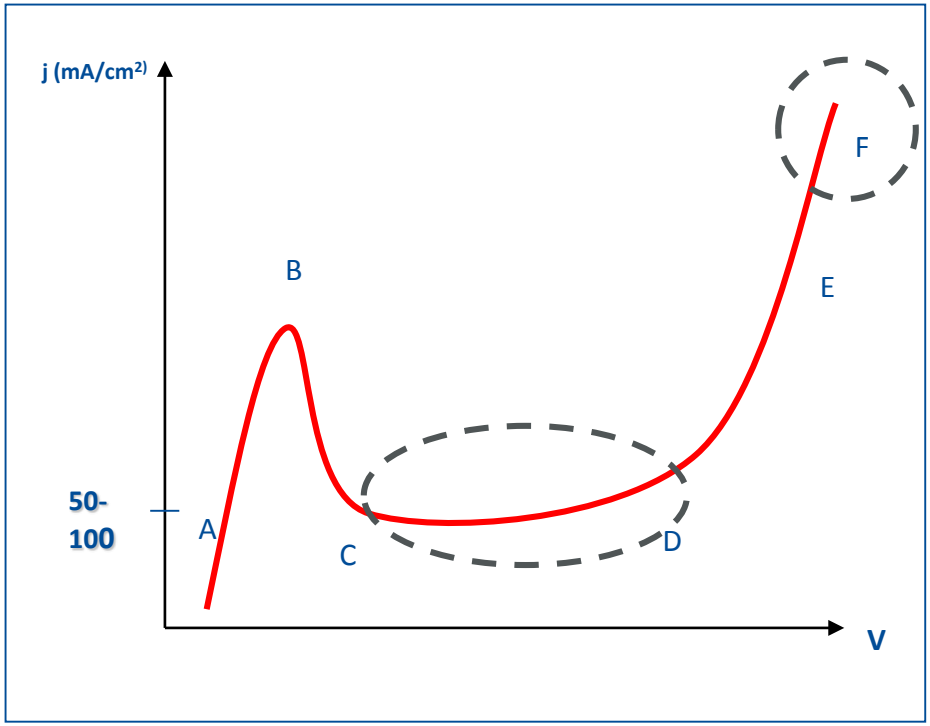


Setup to understand the EP process on single-cell cavity



Electropolishing of cavities (EP)

- Depending on applied voltage and sample geometry, the electropolishing process follows a typical I-V curve, which decides the optimum voltage for a "good" EP:



AB : Active dissolution [Etching]

BC : Instability [Oscillation] (resistive layer builds up)

CD : Plateau = **Polishing** (diffusion limited)

DE : Slow O_2 evolution + pitting

EF : High O_2 evolution + polishing (pitting mechanism)

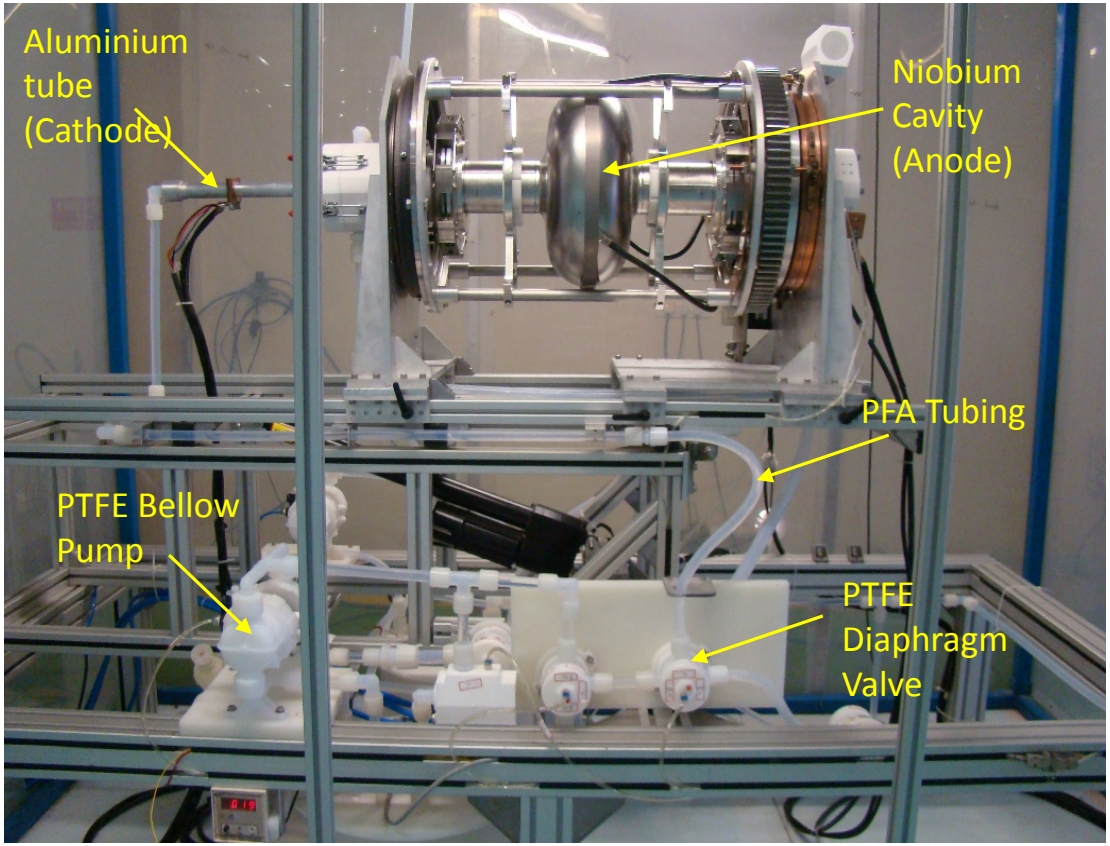
Electropolishing of cavities (EP)

- The current density (30-100 mA/cm2) in the plateau region:
  - –decreases linearly with lower HF/H_2SO_4 ratio
  - –increases with increasing temperature
- Temperature during the process is maintained between 25 – 35 °C
- Current oscillations often observed during polishing (dynamic balance between oxide formation and dissolution). It's not a necessary condition for good surface finishing but indication of good processing parameters (temperature, voltage, agitation, HF concentration)
- Finding the right balance among the processing parameters becomes complicated when polishing multi-cell cavities.

Current density	10-150 mA/cm^2
Voltage	8-25 V
Removal rate	0.1 to 0.4 µm/min
Rotation speed	1-2 rpm
Acid flow rate	2-15 L/min

Electropolishing of cavities (EP)

Electropolishing Setup at RRCAT

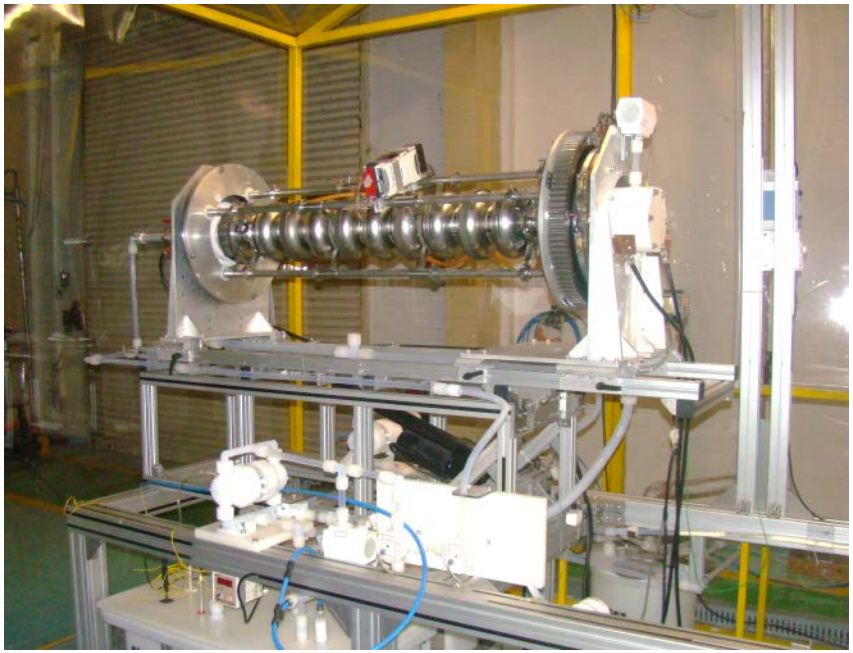


Horizontal electropolishing setup for polishing of 1.3 GHz and 650 MHz SCRF cavities.

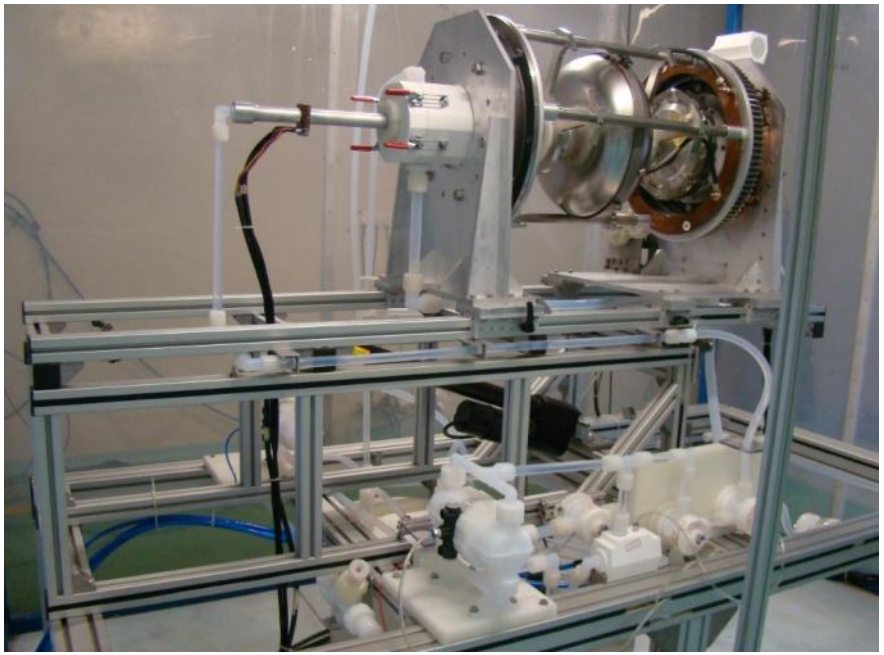
Cavity moved to vertical position for draining of electrolyte, rinsing of cavity and
For insertion/removal of cathode

Cavity Processing Facility

Electropolishing setup for 1.3 GHz & 650 MHz Cavities



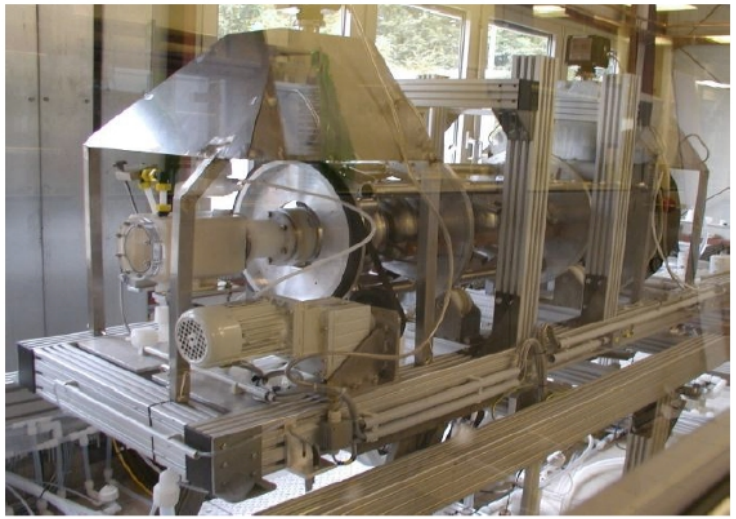
Electropolishing of nine-cell
1.3 GHz cavity



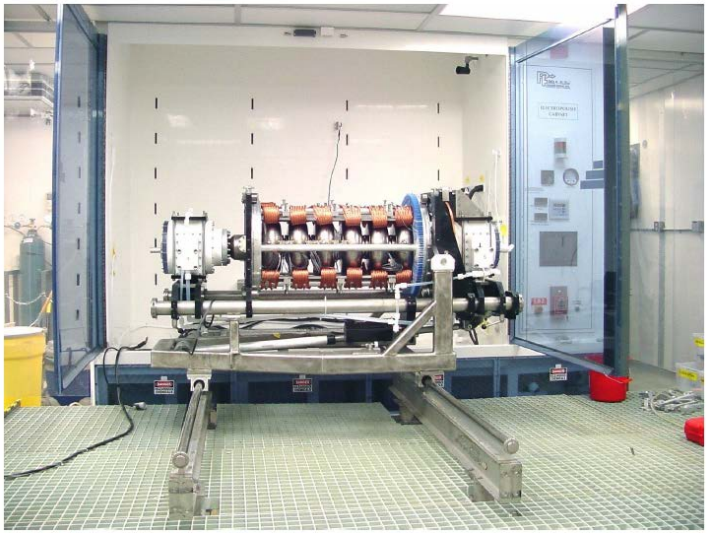
Electropolishing of single-cell
650 MHz cavity

Electropolishing of cavities (EP)

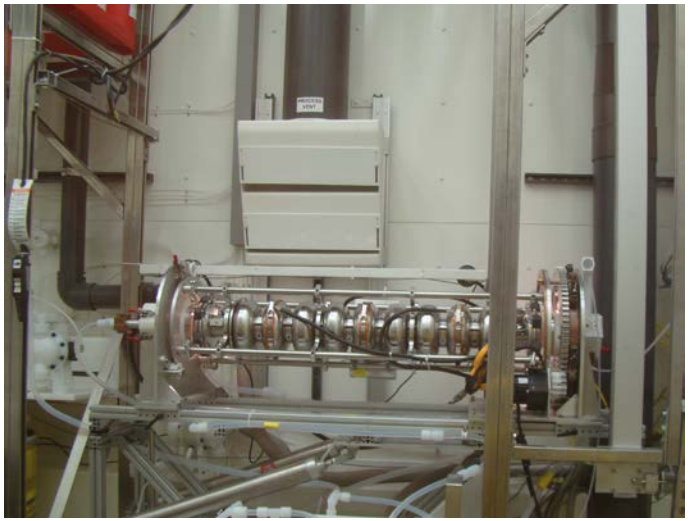
Electropolishing setup at KEK



Electropolishing setup at DESY



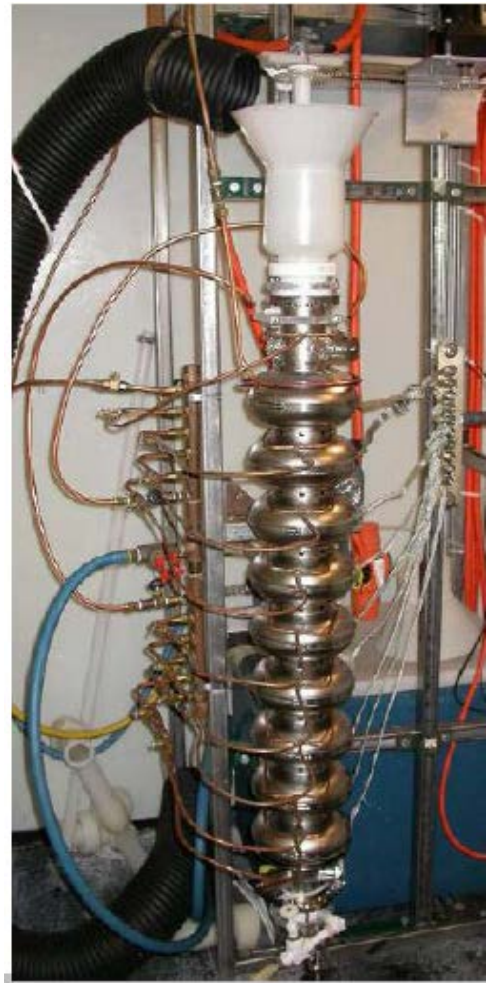
Electropolishing setup at JLab



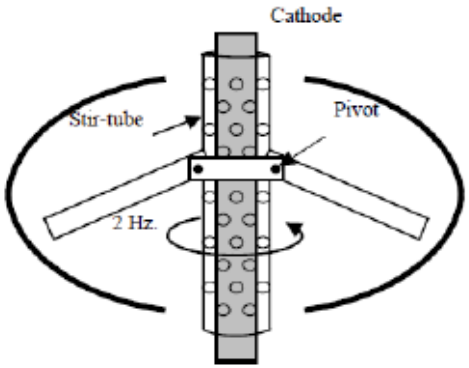
Electropolishing setup at ANL

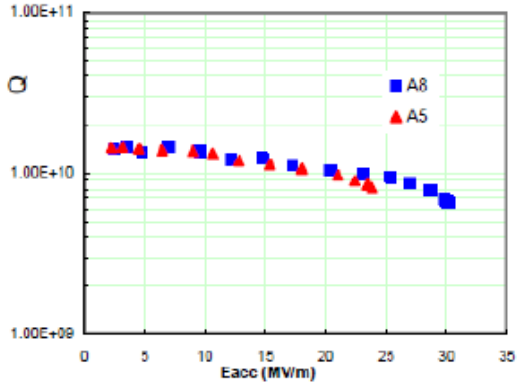
Electropolishing of cavities (EP)

Vertical Electropolishing Setup



Setup at Cornell university, USA





Pros :

- No rotary acid seals
- Twice removal rate than horizontally rotating EP
- No sliding electrical contacts

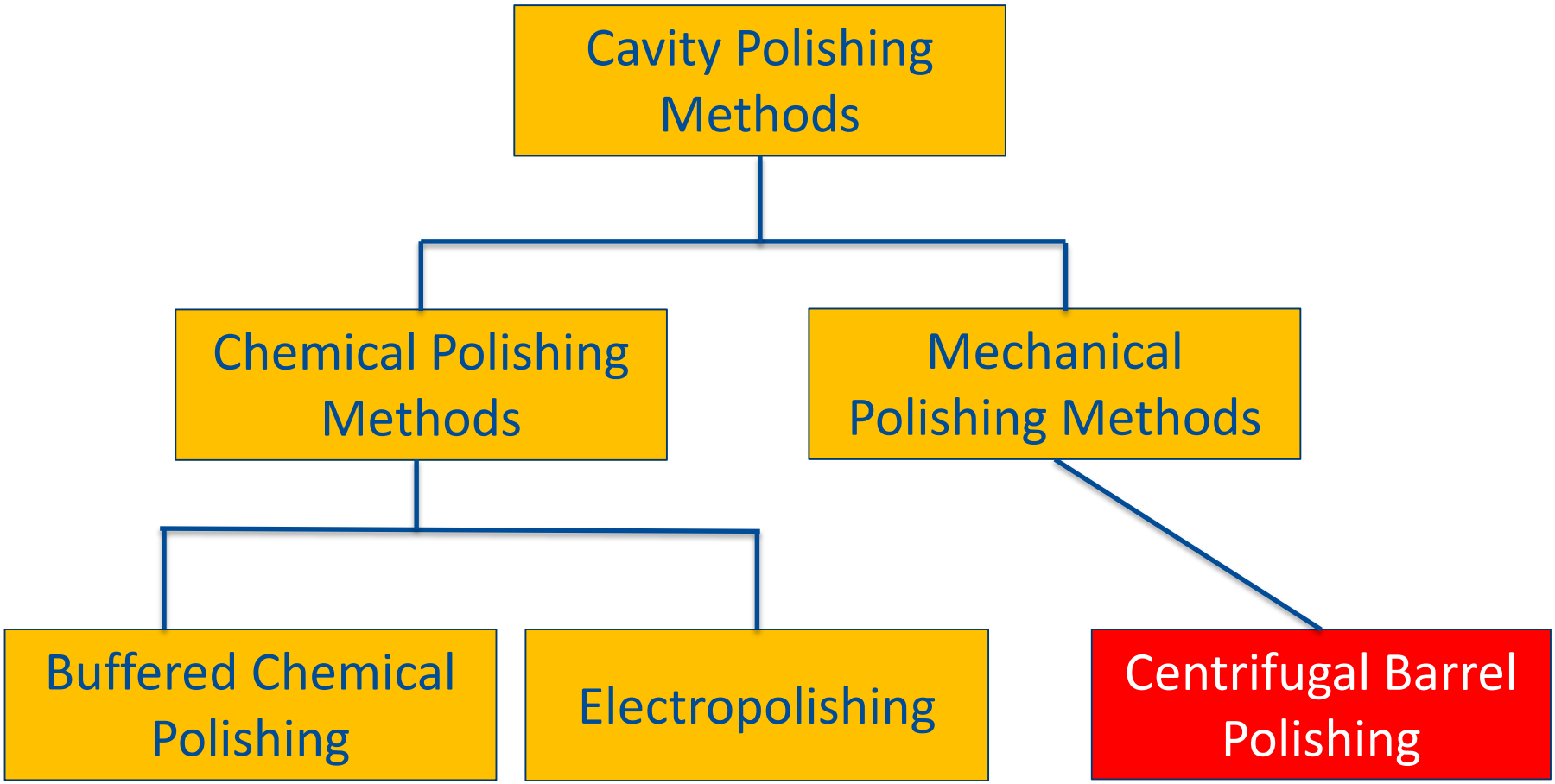
Cons :

- Acid aging is must faster.
- Repeatability of performance of cavity is lower
- Difficult to remove hydrogen → Q-disease

Effluent Treatment of Used EP acid and vapors

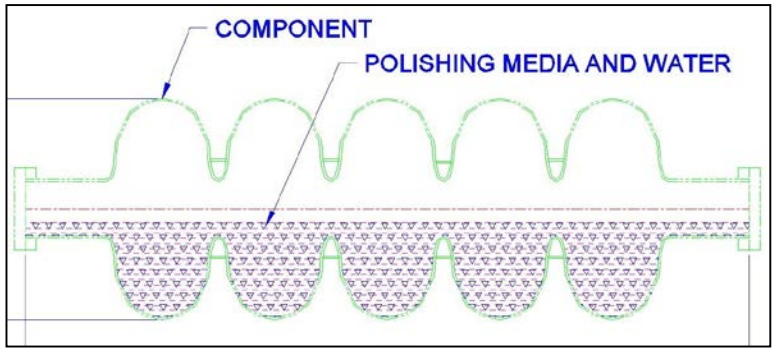
- The gaseous waste like hydrogen, vapours of HF, Sulphuric acid, SO_2, H_2S etc. shall be sucked through the suction blowers and passed through a wet scrubber system.
- Aqueous NaOH (40%) shall be used for scrubbing the acidic gases before discharging them to air through a stack. The gases shall be diluted with fresh air before the scrubbing.
- The scrubbing liquor, rinsed dilute acid waste and used acid shall be treated in an effluent treatment plant (ETP).

Polishing of internal surface of cavity

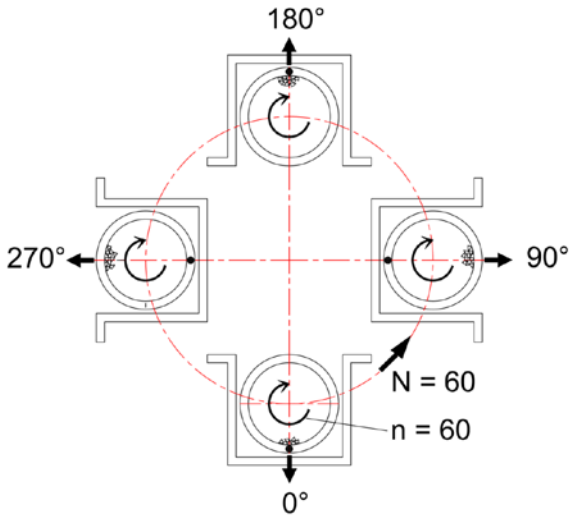


Centrifugal Barrel Polishing

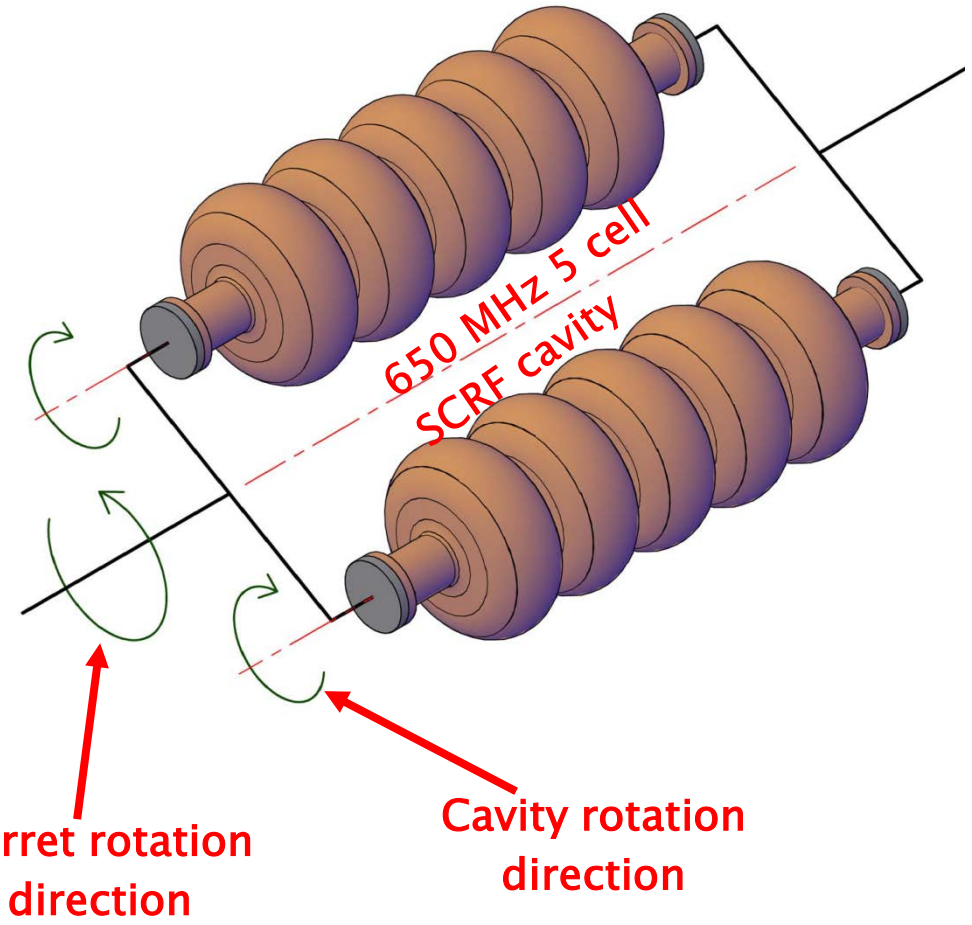
Working Principle



Cavity with water and polishing media



Polishing principle



Centrifugal Barrel Polishing

Typical Polishing Media for Barrel Polishing

Ceramic Media

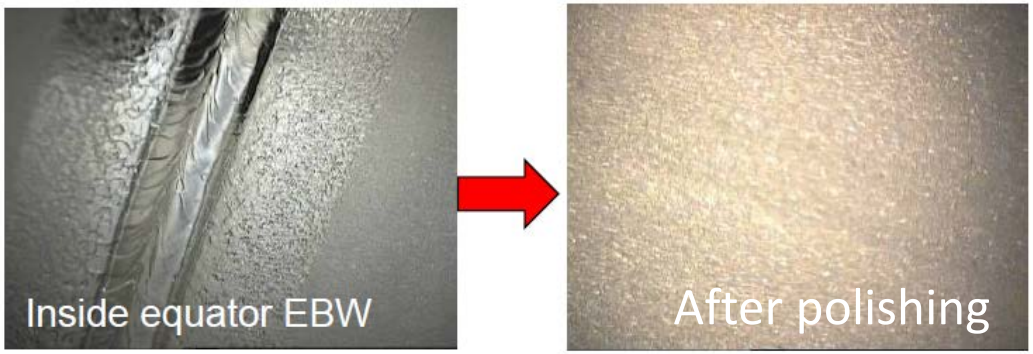
Cutting time depends on the material to be removed.

Plastic/ Polyester Media

Typical cutting time : 24 - 48 hours

Colloidal Silica & Corn Cob

Typical cutting time ~ 75 - 100 hours

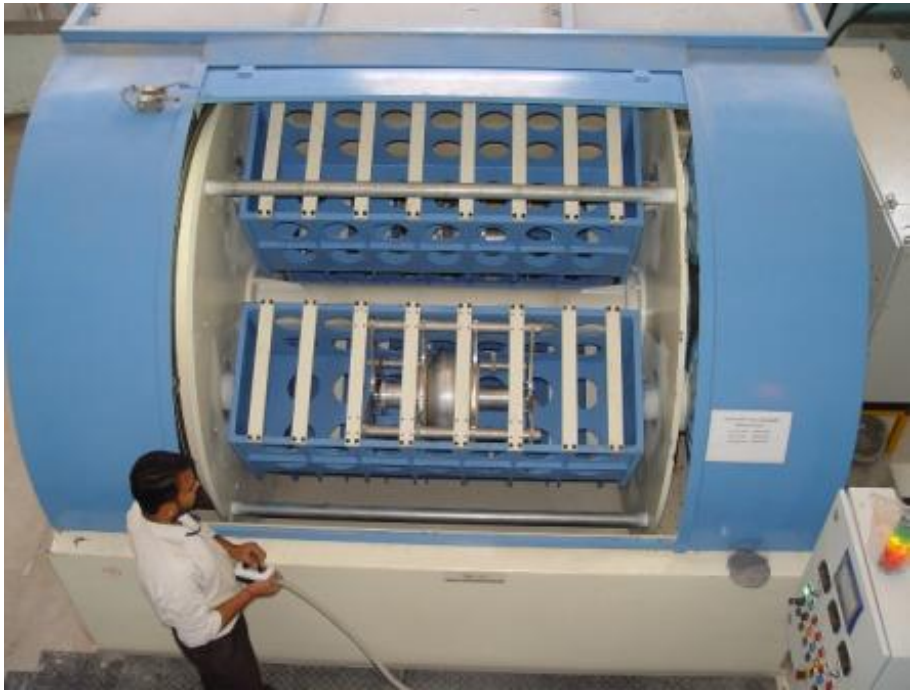


- Very useful process to remove the surface defects.
- Benefit of the process is reducing the chemical polishing process, which reduces handling of large amount of toxic & corrosive acids.

Centrifugal Barrel Polishing

Barrell Polishing Facility at RRCAT

CBP Machine for single-cell 1.3 GHz cavity



CBP Machine for five-cell 650 MHz cavity

The CBP machine for five-cell 650 MHz cavity is the only operating machine in the world for this size of cavity

- Controlled temperature
- Can polish 4 five-cell 650 MHz cavities simultaneously

Centrifugal Barrel Polishing

At Jlab, USA

At Fermilab, USA

At KEK, Japan

Various Steps of PROCESSING for bare cavity

- Inspection of internal surface of the cavity
- Ultrasonic Cleaning - degreasing of surfaces to remove contaminates
- Polishing of internal surface to remove bulk material (~ 120-150 µm)
- Thermal processing - removal of hydrogen from bulk niobium
- Mechanical tuning
- Light electropolishing – Final polishing step (10-20 µm)
- High Pressure Rinsing (HPR) to remove particulates from interior surfaces (incurred during polishing and handling)
- Drying of cavity for assembly in cleanroom
- Clean assembly and evacuation
- Low-temperature baking
- Preparation for low power RF test at 2 K - VTS testing

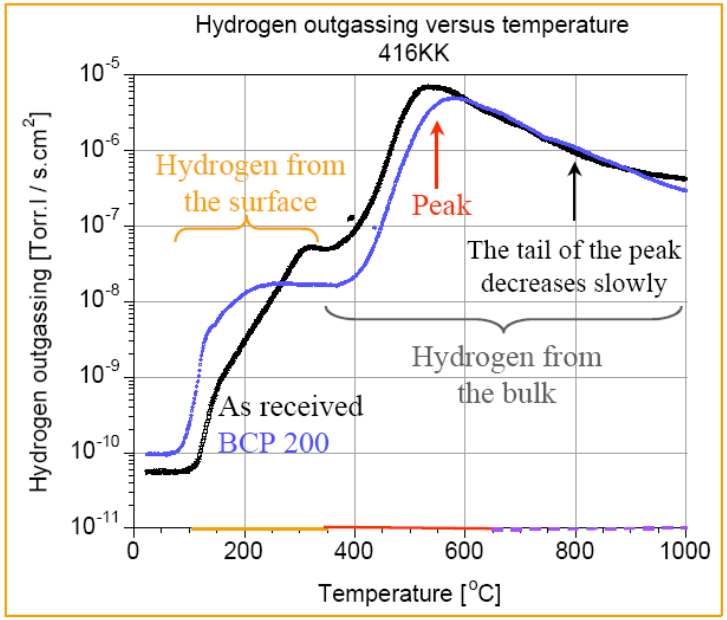
Thermal processing

Hydrogen Absorption and Q-Decease

- Niobium has a natural 5 nm thick passive oxide film .
- This oxide film on the niobium protects it from chemical contamination and it is protective against hydrogen absorption
- This layer is dissolved by F- ions during electropolishing and during barrel polishing
- Hydrogen is absorbed by niobium when it comes in contact with un-protected niobium surface; during electropolishing and barrel polishing
- This increases the chance of hydride formation, which is a normal conducting impurity at 4 K/ 2 K
- When cooling down a cavity, precipitation of dissolved hydrogen (hydrides) occurs around 100 K. The possibility of hydride formation increases multiple times when called around 100 K
- Hydrides increase the surface resistance of the cavity (Q-disease!)
- The cavity quality factor drops suddenly as the field increases due to presence of hydrides, This phenomenon is called Q-Decease

Thermal processing

- A high temperature degassing treatment, in the range 600-1000°C, is necessary to prevent poor cavity operational performance due to formation of hydrides precipitates Nb-H.
- Different parameters at different labs:
  - 600°C for 10 hours/ 800°C for 2 hours at RRCAT
  - 800°C for 2-3 hours at Fermilab
  - 600°C/10 h at JLab
  - 800°C/2 h at DESY
  - 750°C/3 h at KEK
- The heat treatment also “stress-relieves” the niobium. This helps in the tuning of cavity.
- The heat treatments are then followed by a 20-40 µm amount of material removal again with EP or BCP, typically done to remove surface ‘contaminants’ which might be introduced during the furnace treatment.



Thermal processing at RRCAT

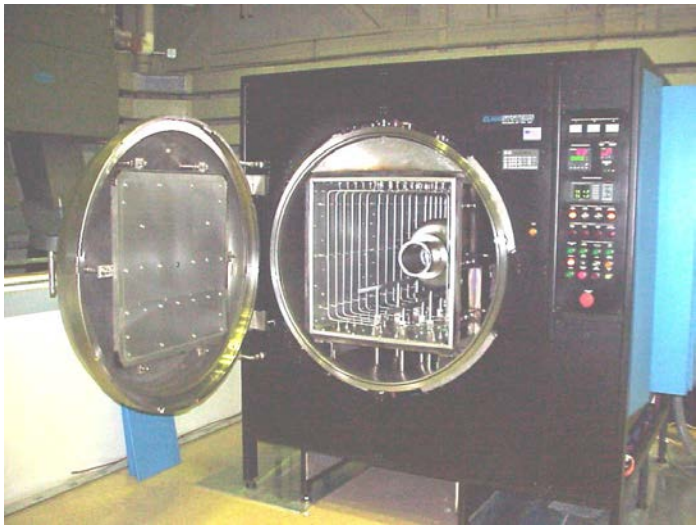
High Vacuum Annealing Furnace at RRCAT

Specification of High Vacuum Furnace	
Orientation	**Horizontal**
Maximum Temperature	**1400°C Max**
Working Vacuum	**<1 x 10^{-7} mbar (600°C -1000°C) <1 x 10^{-6} mbar (> 1000°C)**
Working Volume	**Dia : 825 mm Depth :1500 mm**

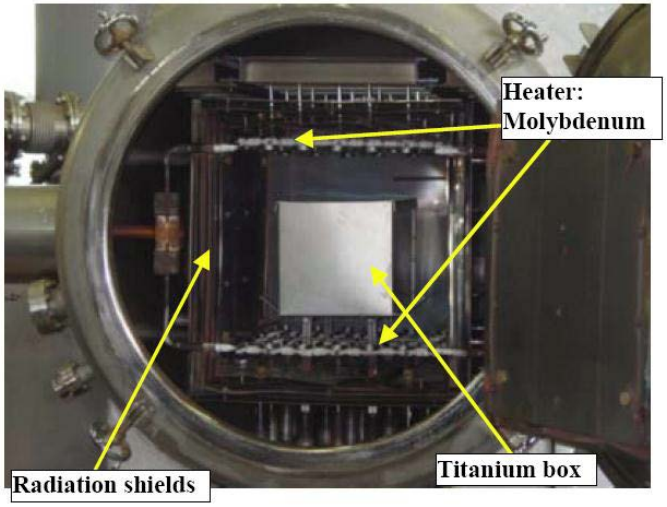
Nine-cell 1.3 GHz cavity prepared for annealing

Thermal processing

Annealing Facility at Fermilab



Annealing Facility at JLab



Annealing Facility at KEK

Thermal processing

Nitrogen Doping for Q & E Improvement

- Nitrogen doping at high temperature of 800-1000°C for a short time helps in improving the quality factor of cavity at medium fields.
- This also helps in improving the accelerating gradient of cavity by 10-15%
- The doped nitrogen goes in the niobium as interstitial element, which displaces hydrogen and prevent formation of hydrides.
- The optimized recipe by Fermilab, which is a part of their processing plan for LCLS-II cavities is as below:

  - 800°C – 3h
  - 2 min @ 800°C + 25mTorr N2
  - 6 min @ 800°C vacuum
  - Cool down
  - 5 microns EP

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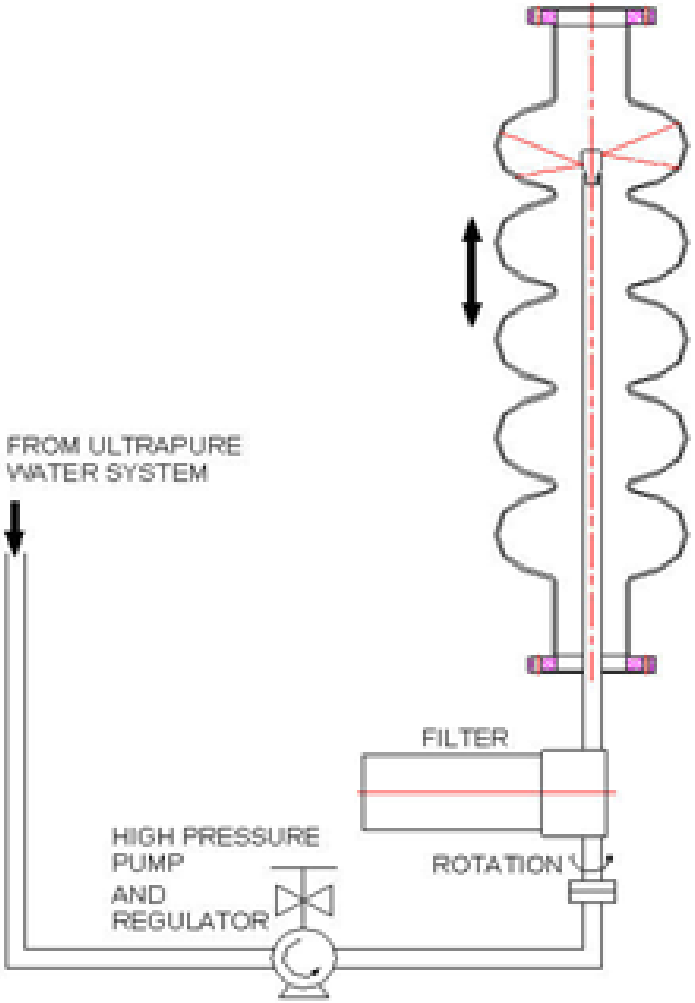
High Pressure Rinsing

- Any dust, chemical residue or other contaminants on the interior of cavity causes “Field Emission”.
- Jets of high pressure ultra-pure water dislodge surface contaminants that normally resist removal with conventional rinsing procedures, leading to substantial reduction in field emission and better cavity performance
- High pressure rinsing at 80 – 100 bar pressure can dislodge particles down to about one micron size

  (# Ref: P. Kinsel and B. Lewis, Proceedings of 1995 Workshop on RF superconductivity)
- HPR is performed in class 100 or better cleanliness.

High Pressure Rinsing



Schematic of high pressure rinsing setup

High pressure water jets during HPR

High Pressure Rinsing

HPR Setup at RRCAT

System Specifications

Water Pressure	: 80-100 bar
Water flow rate	: 10 l/min
Wand rotation	: 2-10 rpm
Cavity movement	: 5-250 mm/min
Filtration	: 0.05 µm after swivel
Enclosure	: Class-100 cleanroom
Nozzles	: 40 ° Fan jet

High Pressure Rinsing

HPR Setups at different labs

HPR Setup at Jlab, USA

HPR Setup at DESY, Germany

HPR Setup at ANL, USA

High Pressure Rinsing

Ultra-Pure Water

Ultra-pure water is used for high pressure rinsing and ultrasonic cleaning of SRF cavities:

Ultrapure Water Parameters

Resistivity	**: 18 M-Ohm.cm**
TOC	**: < 30 ppb**
Bacteria	**: < 1 cfu/100ml**
TDS	**: < 0.03 ppm**

Ultra-pure water plants at RRCAT

Dry-Ice Cleaning

- After HPR, the cavity dries in the clean room for 12 to 24 hours before it is prepared for VTS.
- The cavity is left in a WET state after HPR for prolonged time. This increases possibility of oxidation and also moisture
- Complementary method to HPR, developed at DESY
- Liquid CO_2 (Dry Ice) jet is used instead of water, resulting in a snow/gas mixture at a temperature of 194 K
- This removes hydrocarbons and sub-micron particles while keeping the surface dry
- This method has been tried as a R&D effort

Various Steps of PROCESSING for bare cavity

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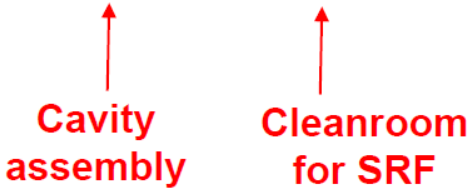
Clean assembly and evacuation

- Cleanroom technology is required to prevent airborne particulates from settling on the surface of SRF cavities
- Cleanroom is a controlled environment in which all incoming air is filtered to meet high standards of purity. Temperature, humidity and pressure are also controlled.
- Humans are a major source of particulate contamination inside a clean room through:
  - Body Regenerative Processes - Skin flakes, oils, perspiration and hair.
  - Behavior - Rate of movement, sneezing and coughing.
  - Attitude - Work habits and communication between workers
- Cleanroom of Class 10 to Class 1000 are required for assembly, cleaning, RF measurement, etc. of SCRF cavities

Clean assembly and evacuation

ISO Classification number	Maximum concentration limits (particles/m³ of air) for particles equal to and larger than the considered sizes shown below					
	>=0.1µm	>=0.2µm	>=0.3µm	>=0.5µm	>=1µm	>=5.0µm
ISO Class 1	10	2				
ISO Class 2	100	24	10	4		
ISO Class 3	1 000	237	102	35	8	
ISO Class 4	10 000	2 370	1 020	352	83	
ISO Class 5	100 000	23 700	10 200	3 520	832	29
ISO Class 6	1 000 000	237 000	102 000	35 200	8 320	293
ISO Class 7				352 000	83 200	2 930
ISO Class 8				3 520 000	832 000	29 300
ISO Class 9				35 200 000	8 320 000	293 000

ISO 14644-1 Classes	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8
FS 209 Classes	Class1	Class 10	Class 100	Class 1000	Class 10, 000	Class 100, 000



Clean assembly and evacuation

- The processed, clean and dried cavity is assembled with RF couplers, vacuum plumbing, burst disc, etc. in a Class 10 (ISO 4) cleanroom facility.
- The cavity is evacuated and leak tested to prepare it for low power RF performance testing in Vertical Test Stand facility.

Cleanroom assembly of 650 MHz cavity at RRCAT

Various Steps of PROCESSING for bare cavity

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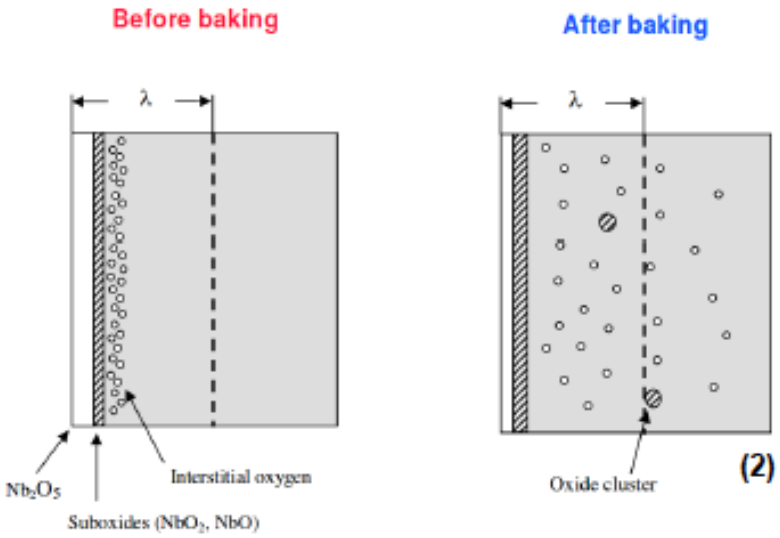
- Clean assembly and evacuation
- Low-temperature baking
- Preparation for low power RF test at 2 K - VTS testing

Low-temperature baking

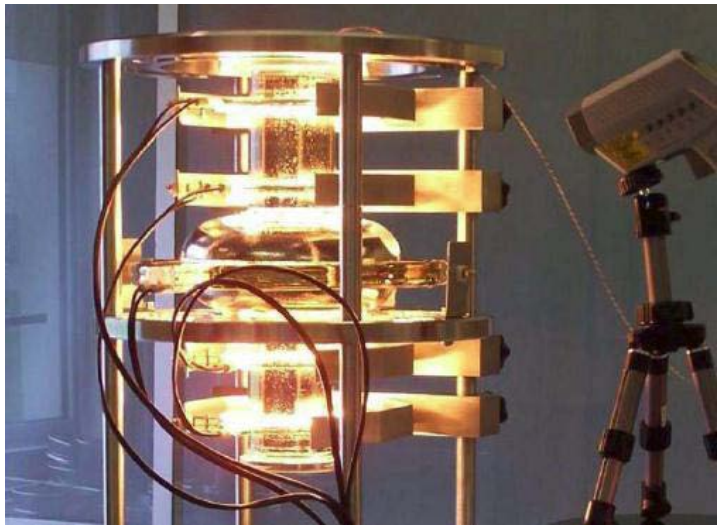
- After the assembly in cleanroom, the cavity is baked at low temperature of 120 C for 48 hours.
- This is the final processing step for the bare cavity before vertical test
- A high vacuum is maintained inside the cavity during the entire baking process.



120 C Hot Air Baking Facility at RRCAT

Low-temperature baking

Hot nitrogen baking facility (JLAB)



Infrared heaters heating (Scalay)

Baking stations (DESY)

Various Steps of PROCESSING for bare cavity

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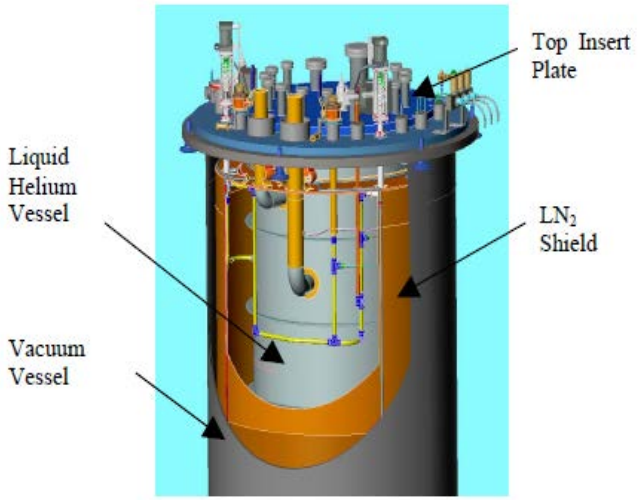
VTS testing

- A Vertical Test Stand (VTS) is a facility to qualify a SRF cavity for its required performance by measuring *quality factor* and cavity *accelerating gradient* at 2K. After qualifying the test, cavity is dressed for cryomodule assembly.
- A vertical test facility has been set up at RRCAT. The VTS cryostat has been designed for performance testing of variety of SRF cavities at 2K, which may include 325 MHz Spoke resonators, 650 MHz and 1.3 GHz multi-cell SRF cavities for proton and electron accelerators.
- The cryostat is magnetically shielded by two layers of magnetic shields to restrict the magnetic field to less than 1 μT at cavity, i.e.
  - External magnetic shield (room-temperature) ,
  - Internal magnetic shield (2K)
- Fabrication of Cryostat was carried out in strict accordance with ASME B&PV code under joint supervision of engineers from RRCAT and Fermilab.

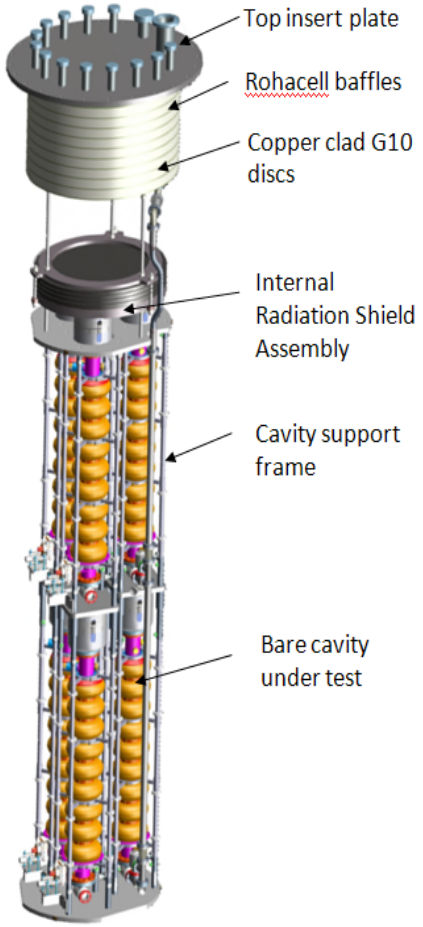
Vertical Test Stand (VTS) Facility

VTS can test following cavities in single cool-down

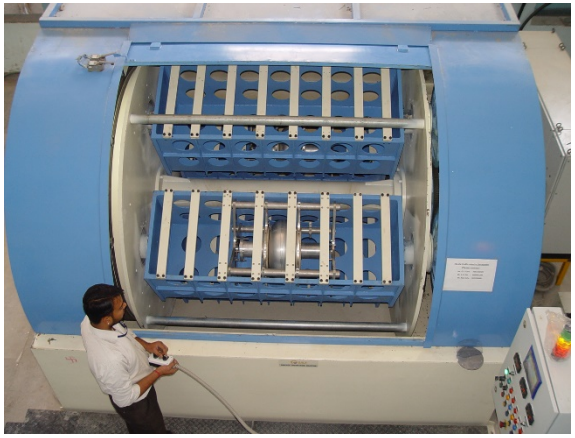
- ✓ 6 Nine-cell 1.3 GHz cavities or
- ✓ 2 Five-cell 650 MHz cavities
- ✓ 2 325 MHz single spoke resonators



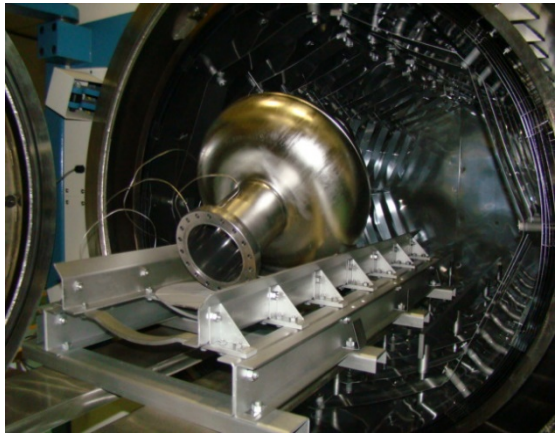
Overall outside diameter of Cryostat	1370 mm
Overall height of Cryostat	5420 mm
Clear aperture of the Helium Vessel	864 mm
Height of liquid Helium Vessel	4860 mm
80K Shield is in between He Vessel & Vacuum Vessel	
Maximum LHe capacity - 2900 liters	



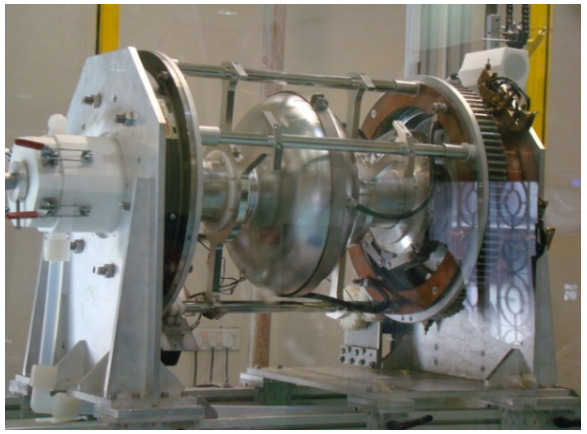
Processing and testing of 650 MHz beta=0.92 single-cell SCRF cavity



Centrifugal barrel polishing
(~ 200 micron)



Cavity loading in high temperature furnace for hydrogen degassing
(@ 600 °C for 10 hrs)



Electropolishing of cavity
(~ 20 micron)

Low temperature baking
(@120°C for 48 hours)

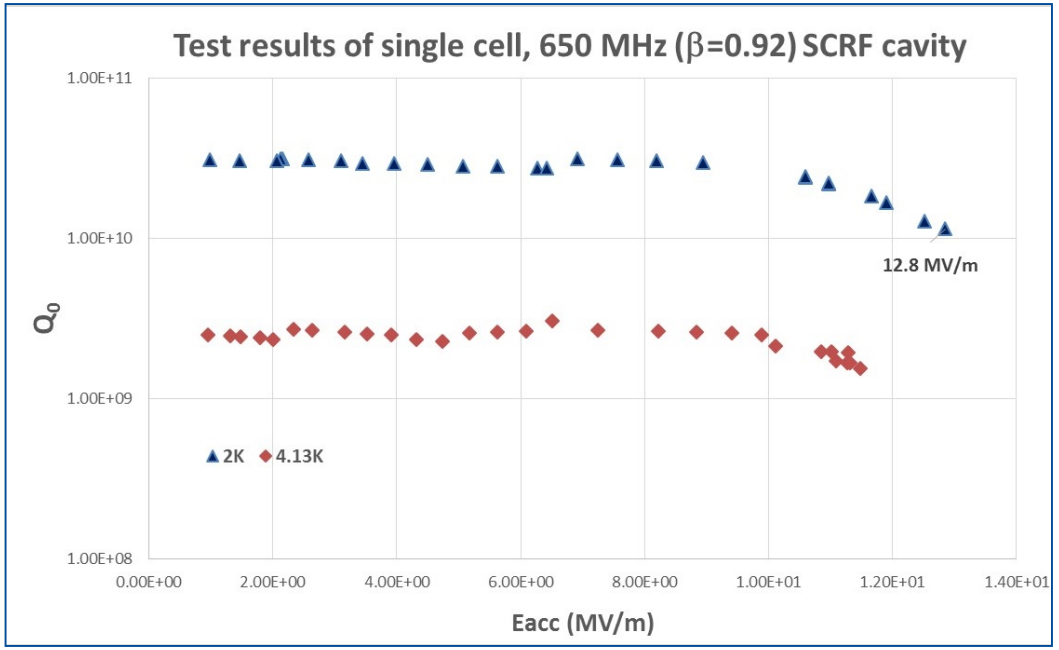
High pressure rinsing
(@ 100 bars pressure)

Cavity loaded on VTS insert assembly for 2 K testing)

VTS Testing of 650 MHz single-cell cavity at RRCAT

Single-cell 650 MHz cavity in VTS Cryostat

VTS Insert assembly



$Q = 3 \times 10^{10}$

$E_{acc} = 12.8$ MV/m

Post processing & Testing of bare cavity

- ✓ He-vessel welding
- ✓ Degreasing
- ✓ Final material removal (10-20 μm)
- ✓ Final HPR
- ✓ Horizontal assembly into cavity-string
- ✓ Evacuation of cavity string

THANK YOU