Superconducting RF Systems III

Techniques and Technologies

Erk JENSEN, CERN

Photo:
Reidar Hahn

Cavity fabrication techniques


Photo:
Reidar Hahn

Materials

- Selection criteria
  - Electrical conductivity
  - Secondary emission yield (SEY)
  - mechanical stiffness/hardness (at cryogenic T)
  - thermal conductivity, thermal expansion
  - machining & joining techniques
  - vacuum tight, low outgassing rate
  - creep resistance,
  - magnetic permeability
  - radiation hardness
  - fatigue stress
  - …
- Important: specify what you need and what you can measure/control at reception!

Photo:
Reidar Hahn

Niobium

- Magnets use NbTi or Nb_3Sn, SC Cavities use mainly Nb!
- Pure Nb has a high critical magnetic field ($H_c = 200$ mT)
- Nb has a high transition temperature ($T_c = 9.3$ K).
- It is chemically inert (surface covered by oxide layer)
- It can be machined and deep-drawn
- It is available as bulk and sheet material in any size, fabricated by forging and rolling
- Large grain sizes (often favoured) obtained by e-beam melting (EBM).
- Instead of bulk or sheet Nb, Nb can also be coated (e.g. by sputtering) on Cu – CERN has built the LEP, LHC and ISOLDE cavities with this technique. Advantages: thermal stability, material cost, optimisation of R_{BCS} possible; disadvantages: difficult technology to master, lower Q_0.

Nb ingot after EBM at Heraeus (D)


Photo: Reidar Hahn

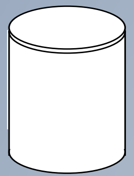
Dielectrics

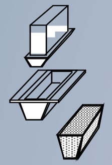

Coax transition through alumina window with traces of breakdown

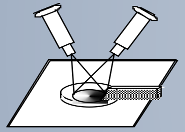
- Aluminium oxide, Al_2O_3, aka Alumina, is often used in vacuum/RF windows and vacuum feed-throughs.
- Isostatically pressed Al_2O_3 is used for leak-tightness (power coupler windows, e.g.).
- To reduce multipactor, it is often coated with titanium or titanium nitride (TiN).
- Other window materials: Sapphire, BeO, quartz, diamond …)
- Silicon carbide (SiC), C-loaded AlN have been effectively used as RF absorbers inside vacuum.
- Different ferrites are used as absorbers and to use their variable magnetic permeability.

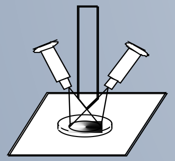
Photo:
Reidar Hahn

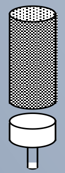
Fabrication of Nb sheets at Tokyo Denkai

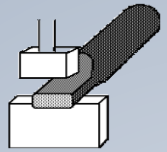

Nb ingot

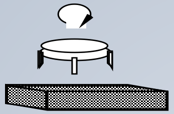

Pressing

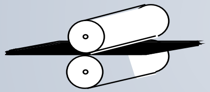

1st EB melting

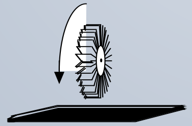

2nd, 3rd … EB melting

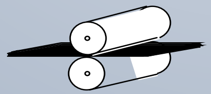

Separate from base plate

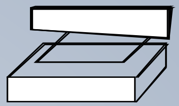

Forging

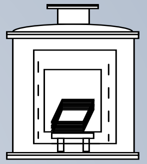

Milling

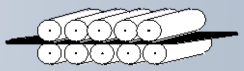

Rolling

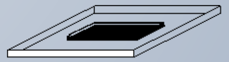

Polishing

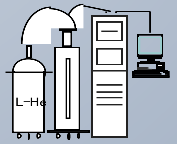

Rolling


Cutting


Annealing


Levering


Chemical polishing

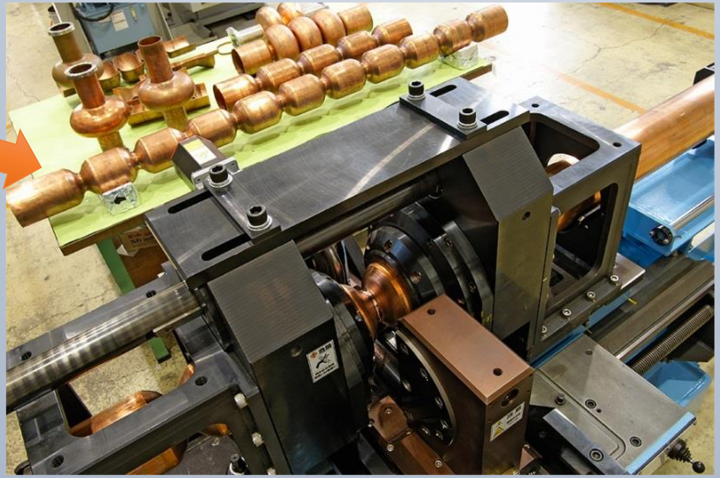


Inspections: (ICP-AES, Gas analysis, RRR, grain size, hardness tensile stress …)

Other forming techniques

- Forging, pressing, deep drawing, …
- Spinning, planing, rolling, …
- lapping, polishing, electropolishing, …
- Electro-forming, hydroforming, explosion forming
- Powder metal techniques, additive manufacturing (3-D printing)
- Sputtering
- Backward extrusion
- Necking

back-extruded Nb tubes for E-XFEL

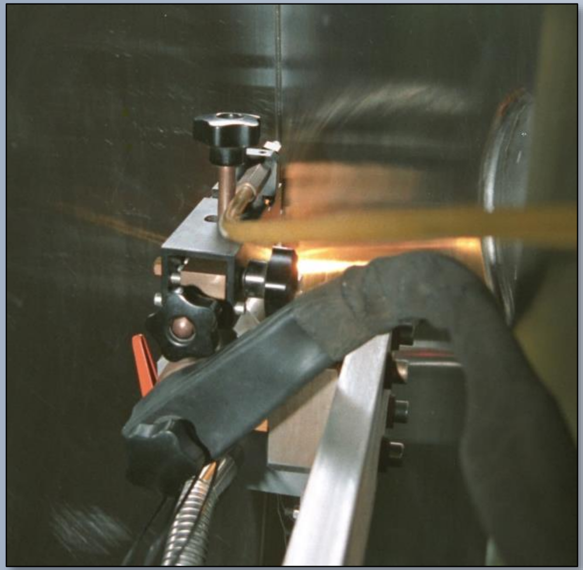


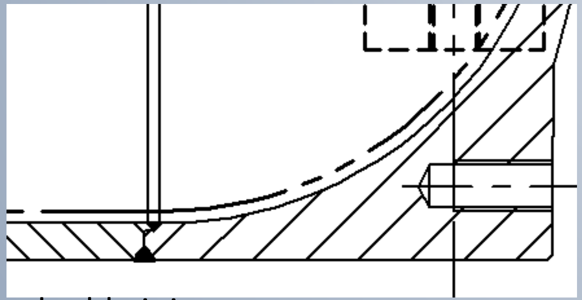
Necking machine at KEK for fabrication of multi-cell seamless cavities

courtesy: Waldemar Singer/DESY

Joining techniques

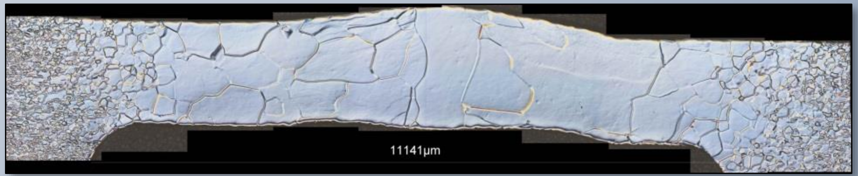
TIG welding





double joint:
inner for vacuum,
outer for mechanical stability

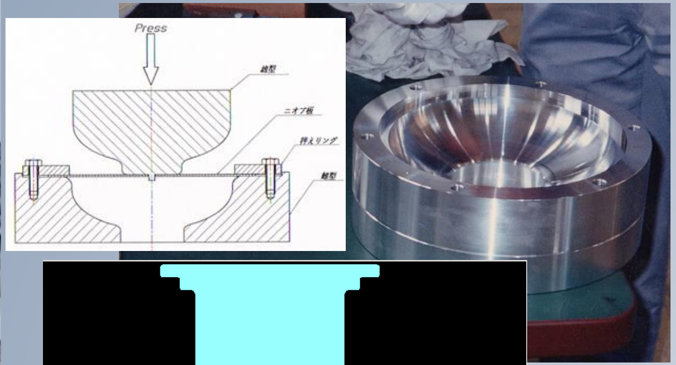
Electron beam (EB) welding

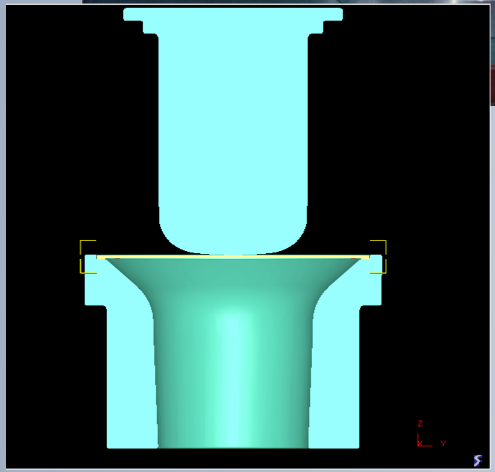


Microstructure of the EB welding area
grain size (50 ÷ 2000) µm


Photo:
Reidar Hahn

Established cavity fabrication technique

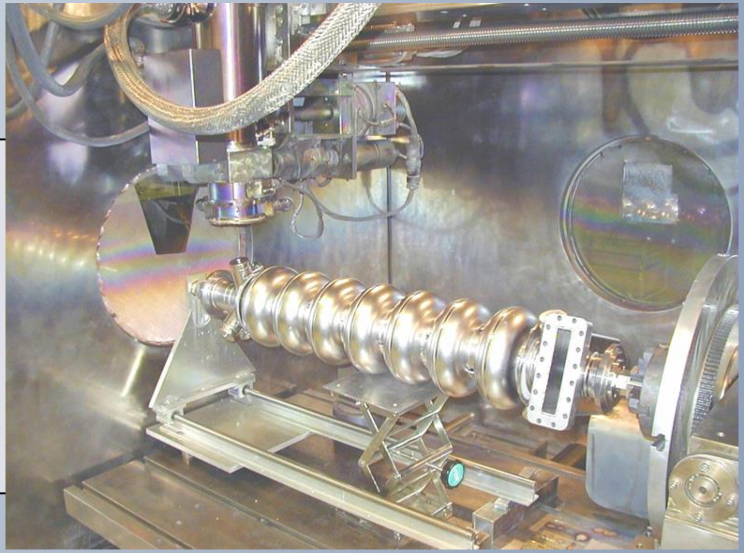




Half cells are shaped by deep drawing.

Dumb bells are assemled by electron beam welding.

After proper cleaning eight dumb bells and two end group sections welded by electron beam together



Important: clean conditions on all steps shape accuracy, preparation and EB welding

courtesy: Waldemar Singer/DESY


Photo: Reidar Hahn

Advances in SCRF Technology

Step	WHY
Forming	
EB Welding	Clean welding
Ti purification	RRR enhancement
Chemical etching 100-200 μm (BCP / EP)	Remove contamination and damage layer
Annealing 800°C, 2h (or 600°C, 10h)	Get rid of hydrogen
Chemical etching 5-20 μm	Remove diffusion layer (O, C, N)
Specific rinsing	e.g. remove S particles due to EP
High pressure rinsing (HPR)	Get rid of dust particles
Assembling	Ancillaries : antennas, couplers , vacuum ports…
Baking, 120°C, 48h	Decrease high field losses (Q-drop)
Post processing	Get rid of "re-contamination" ?
Test RF	Cavity's performance
He processing, HPP	Decrease field emission

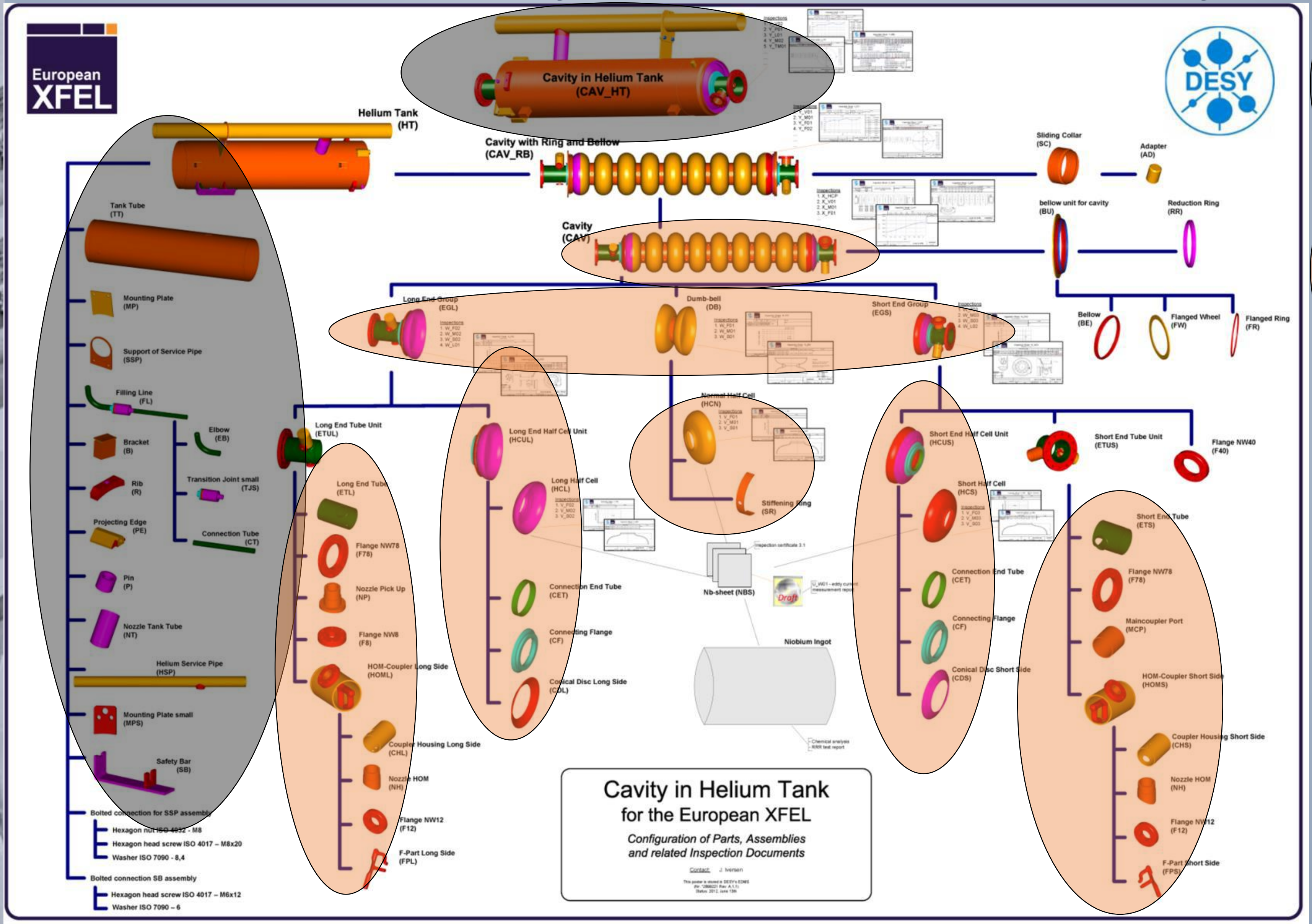
C. Antoine: CAS SC 2013


Preparing for EP (inserting cathode)

Photos: Rongli Geng


Clean room assembly (JLAB)

Parts in a cavity (XFEL 9-cell, courtesy DESY)



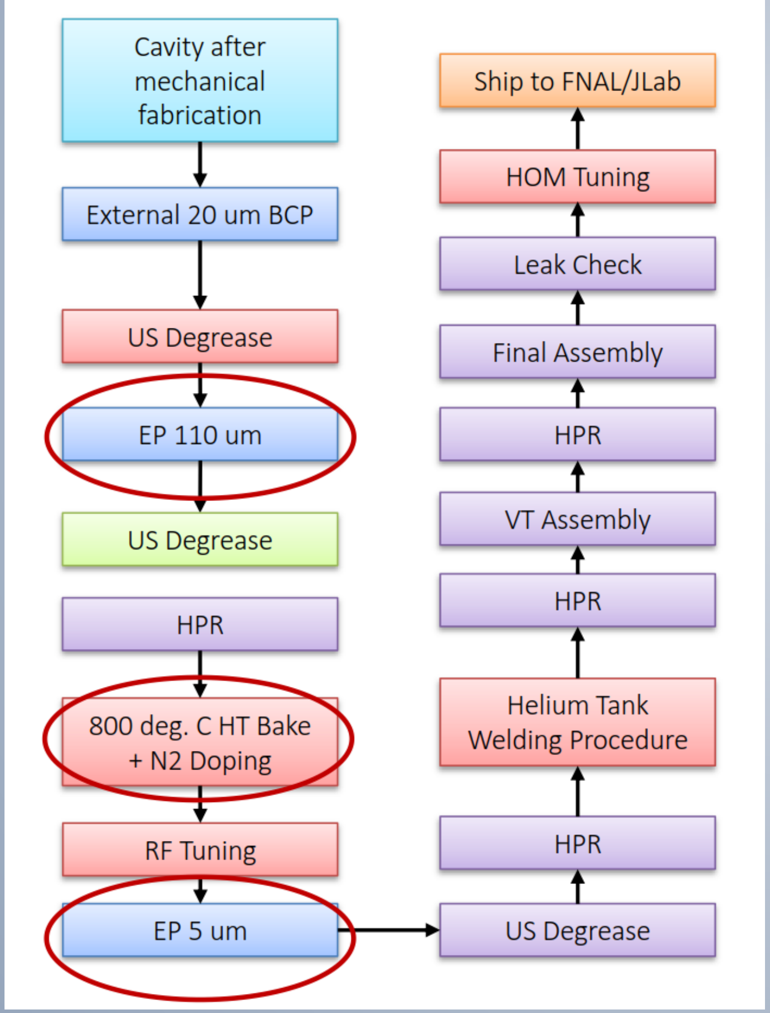
Degreasing

Degreasing, BCP chemistry & in clean room

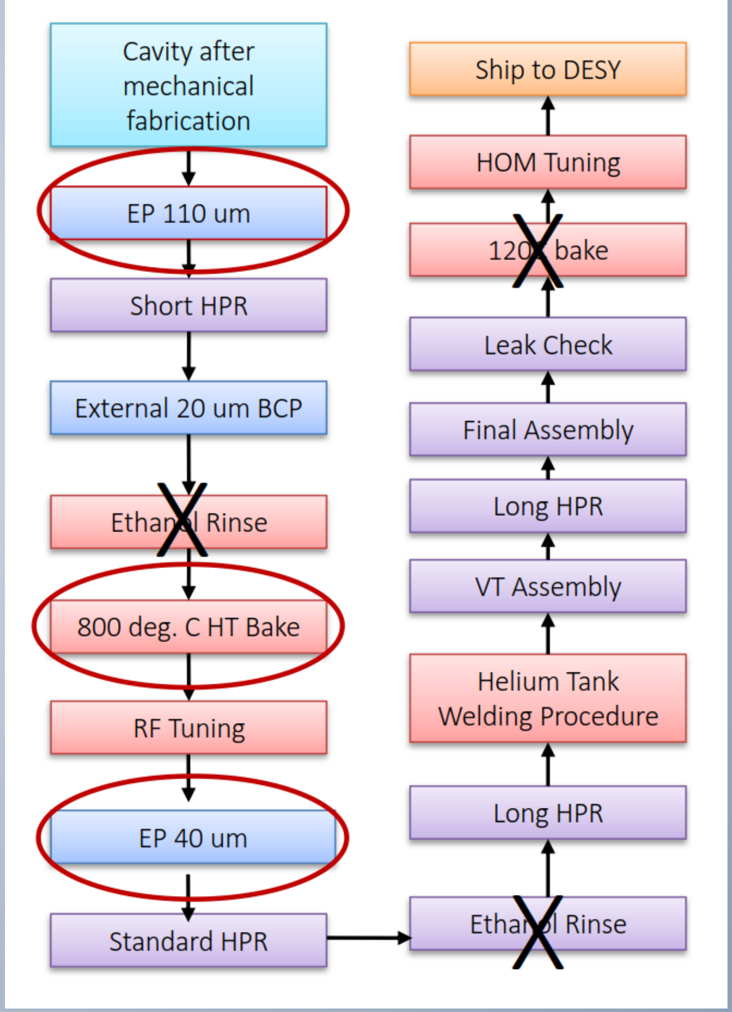

Photo: Reidar Hahn

Post processing flow chart (LCLS-II vs. E-XFEL)

LCLS-II recipe



XFEL recipe (EP scheme)



Clean-rooms – design and use

What is a clean-room?

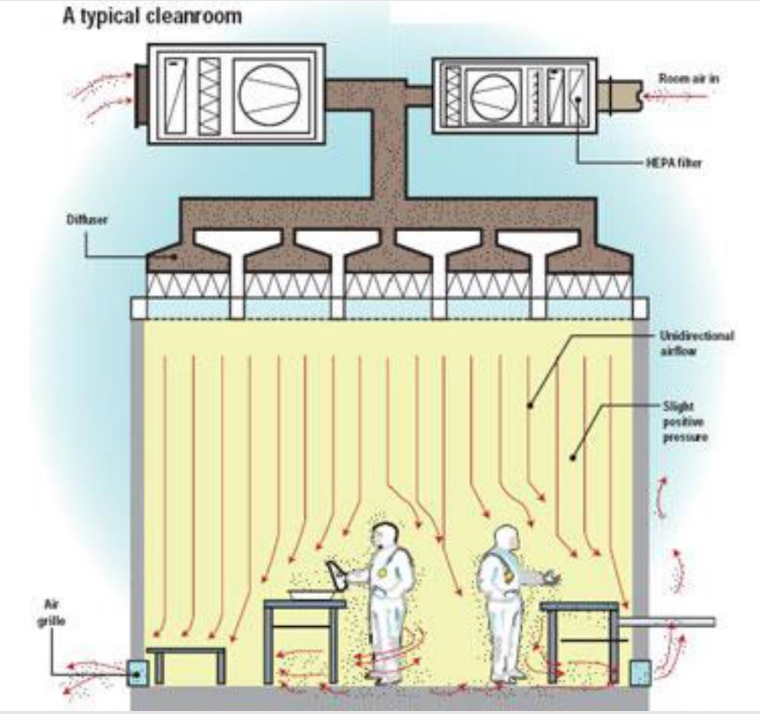
From ISO standard:

- A room in which the concentration of airborne particles is controlled, and which is constructed and used in a manner to minimize the introduction, generation, and retention of particles inside the room and in which other relevant parameters, e.g. temperature, humidity, and pressure, are controlled as necessary.
- “Clean-room” is only defined for room and air, it is your job not to mess it up as **you** are the dirtiest thing in the room and the items you bring into the room are the next dirtiest.

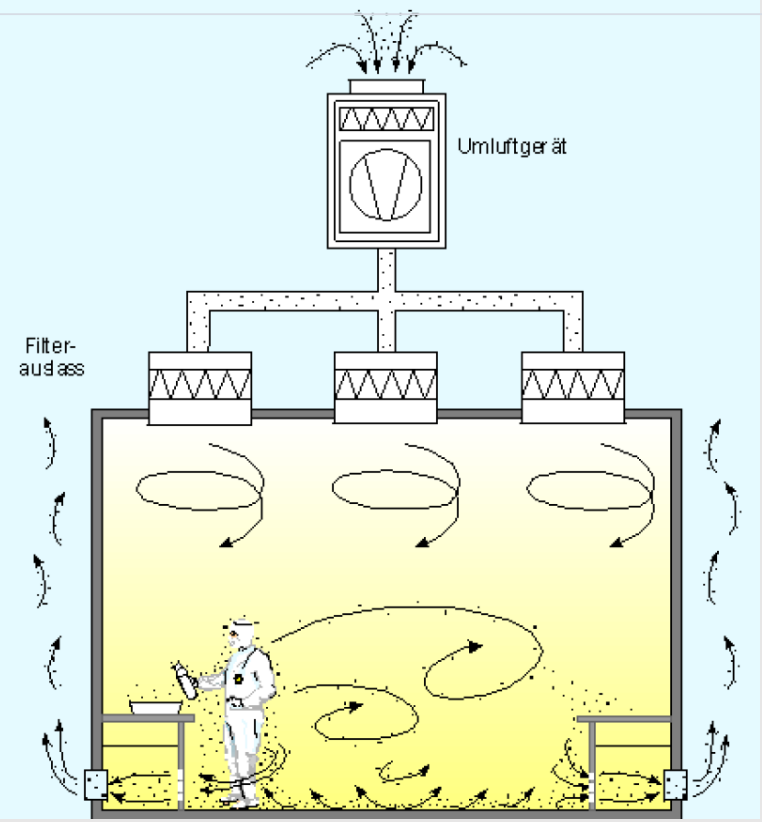
This is what you look like to the cleanroom

Types of clean-rooms

Laminar flow room



Turbulent flow room



Limited to ISO 6 applications, where a large amount of particles is produced.

ISO classifications

Class	ISO 14644-1 Standards						FED STD 209E
	maximum particles/m^3						
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	equivalent
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10^6	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	Room air

ISO 1: Only for very specialized applications and usually very small.

ISO 2/3: Micro-electric manufacturing (usually mini environments and robots only).

ISO 4/5: SCRF cavity assembly.

ISO 6/7: Pass-through, gowning as well as clean parts.

Sizes:
Hair 50-150 µm
Pollen 7 -100 µm
Dust 0.1-100 µm
Sneeze particles 10-300 µm
Bacteria 1.0-10 µm
Best human vision ~10's µm

Photo:
Reidar Hahn

Particle counters

0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0, 10.0µm, 25µm
1.0 CFM (28.3 LPM)
Temperature and humidity sampling
Remote logging
8000 count data storage
Remote hose for local counting

Lighthouse Solair 3100

0.3, 0.5, 0.7, 1.0, 3.0, 5.0, 7.0, 10.0µm
0.1 CFM (2.83 LPM)
Temperature and humidity sampling
3000 count data storage

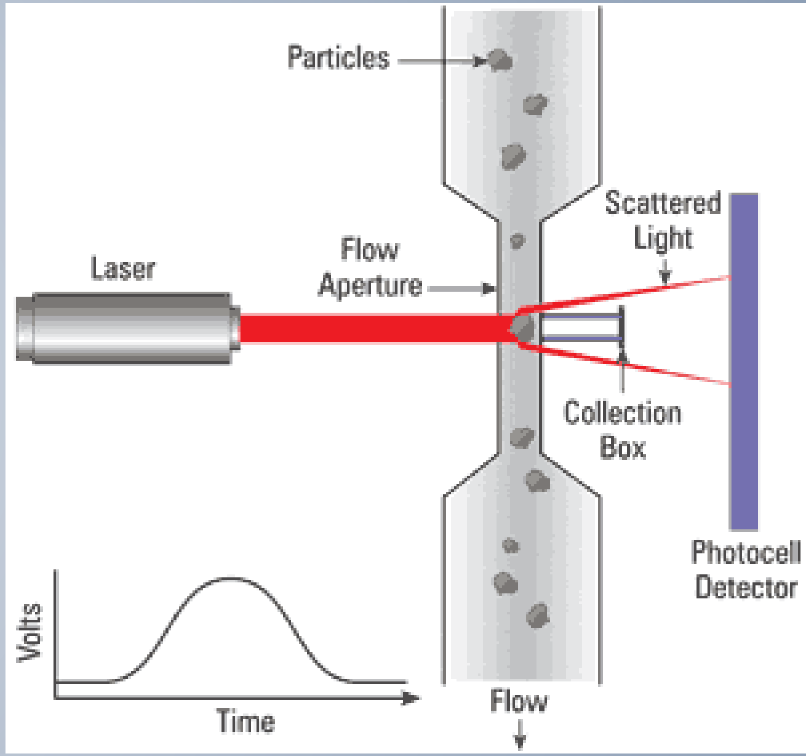
Lighthouse Solair 3100

0.3, 0.5 µm
0.1CFM (2.83 LPM)
Remote sampling to logging computer for real-time clean room monitoring

Lighthouse remote 3014

How particle counters work

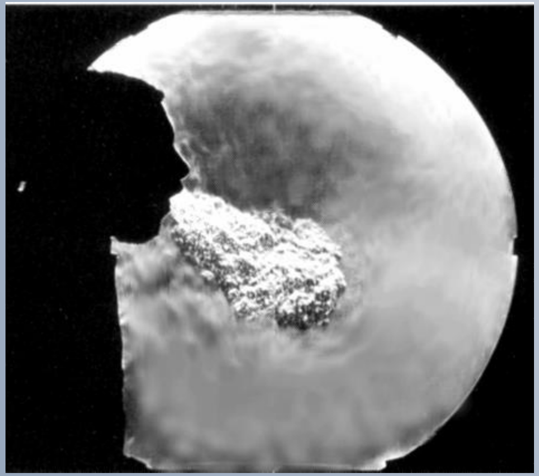
1. Vacuum pump pulls particles through aperture,
2. Laser light is blocked by the incoming particle,
3. Scattered light is detected by a photodetector (camera),
4. The pulse width and intensity for a each particle is recorded,
5. Data is converted into counts/size.



Why we wear clean-room suits

- Full-scale Schlieren flow visualization stills – body flow examples (“differential diffraction images”)

Vertical flow from human
(100K particle per minute)



Open mouth cough in standard room
(wear mask!) cough produce over 1M
particles!

Don’t lean over parts!

Fully suited person
in clean room

Clean-room suits (example JLAB)

- Everyone in clean-room must wear full-body “bunny suit”!
- All suits are clean to ISO-4 standards
- Suits are double bagged (large single bag and smaller item bags)
- Suits are made out of 99% polyester/1% carbon (carbon is added as a drain for static build up)
- Suits are changed out at least once a week (some do every day), with extra change outs when contamination is detected (user discretion).

Clean-room protocol – before entry

- Wash and dry hands thoroughly in rest room – you should probably use the facilities as well,
- Check shoes for dirt, dirty shoes are not allowed,
- Use shoe cleaner to remove dust from shoes and then step on sticky pad until no new dirty is being removed from shoes,
- Only 1 person is allowed in the entry-way at a time,
- External doors are not allowed open when gowning door and/or curtain is open.

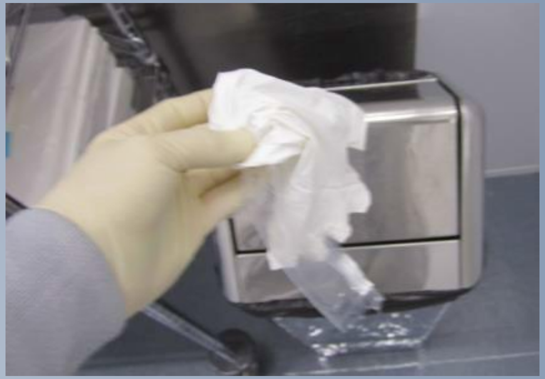
Gowning room door & isolation curtain

Clean-room protocol – entry procedure

- Pick out two disposable clean-room boot covers from the bin on the floor,
- Sit on SS bench in entry-way and place first cover on left foot. After cover is on, move left foot around bench clean room floor without touching the "dirty" side of the floor,
- Place cover on right foot and move to clean side of floor,
- Put on facemask with soft side in (if you don't you will be very uncomfortable)
- Put on clean room Bouffant (hair net), making sure all hair is covered (over or under ears is fine)
- Put on inner latex gloves, from this point on you are not allowed to touch any part of your clothes
- Move through curtains to glowing selection area and pick out boots, gown and hood.

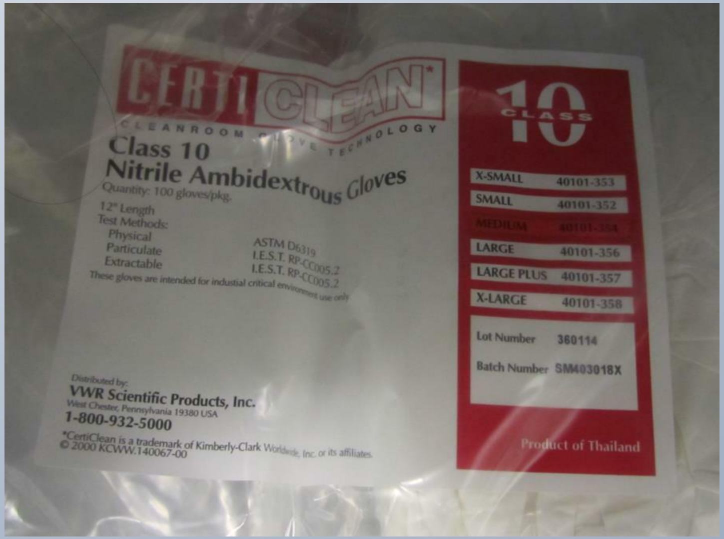
Clean-room protocol – un-gowning

- Remove outer glove and dispose of – do not let inner glove touch trash,
- Remove boot covers and do not allow covers to touch floor,
- Remove hood by pulling inside out,
- Remove covers without letting them touch floor (legs are most difficult, arms are most important),
- Hang on designated rack with booties and head over buttoned to suit



Clean-room consumables

- Special wipers – fabricated in ISO3
- No normal paper allowed in clean-room – there exists 100% synthetic cleanroom bond paper, cellulose free.
- Certified gloves, shoe covers …



Example: JLAB clean-room

All main areas of clean room are 100% ULPA filtered and ISO 4 (design ISO 4, manufacture guaranty ISO 5)

All pass-through areas are ISO 5

Inside chem. room areas are ISO 6/7

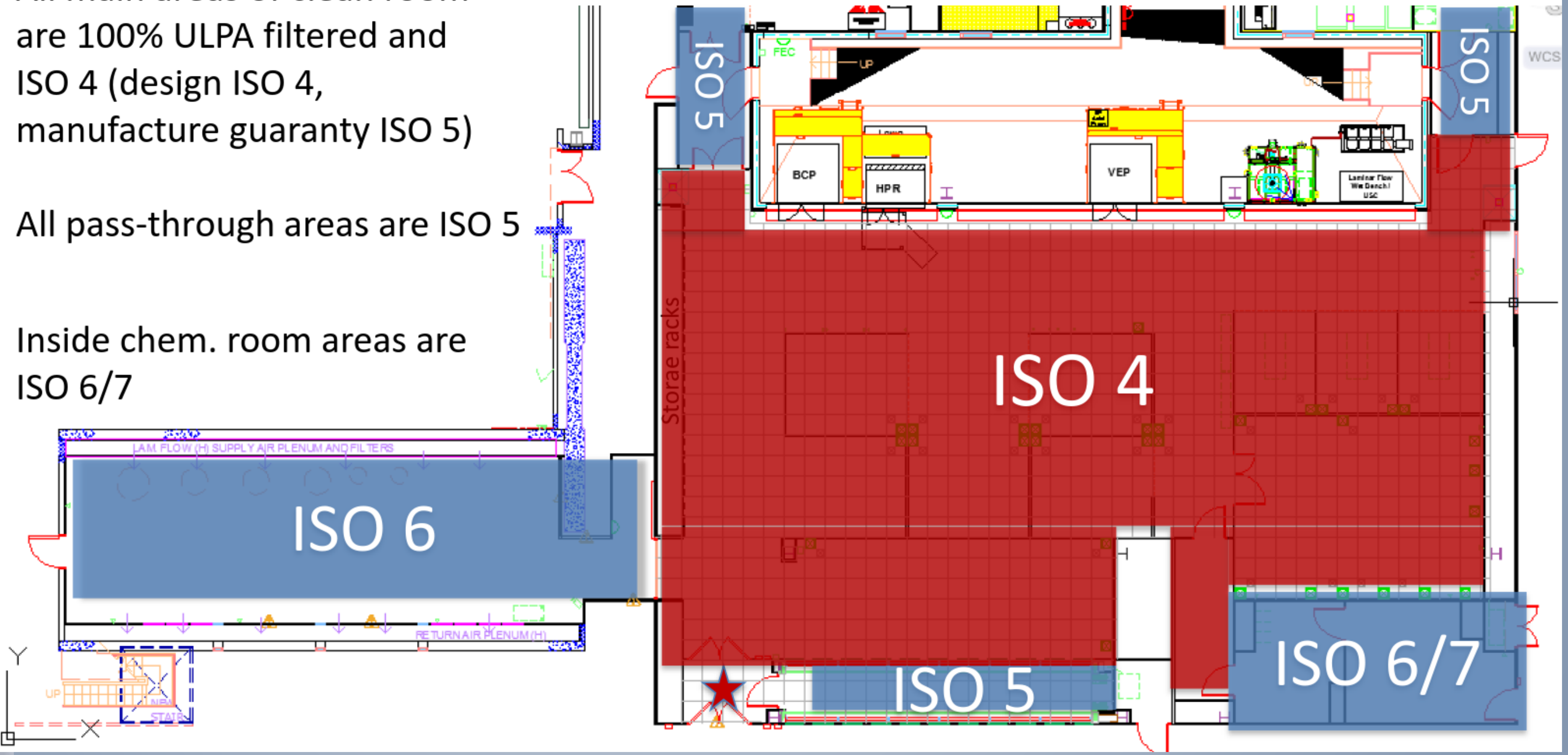


Photo:
Reidar Hahn

Clean-room load-lock entry (for parts)

- All personnel entering load-lock must wear hair net, face mask, shoe cover, gloves and lab coat, put on in the order listed above. Lab coat should not be touched by ungloved hands (or dirty gloves),
- Once shoe covers are on, you are not allowed to stand on floor, only sticky mat!
- Entry is only allowed when inner clean room doors are closed and load-lock is unoccupied,
- Spend as little time as possible in load lock!

Photo:
Reidar Hahn

Ultrapure water (UPW) system

What is ultrapure water?

General description

- Water devoid of any dissolved, suspended, organic or inorganic impurities
- In reality water is never 100% devoid of all impurities
- … so devoid to the detection limits of analytical methods:
  - Detection limits are often expressed in
    - PPM: parts per million (mg/l)
    - **PPB: Parts per Billion (µg/L) – most relevant for SRF applications**
    - PPT: Parts per Trillion (ng/L)
    - PPQ: Parts per quadrillion (pg/ml)

1 ppb is roughly the equivalent of one drop in 250 chemical drums!

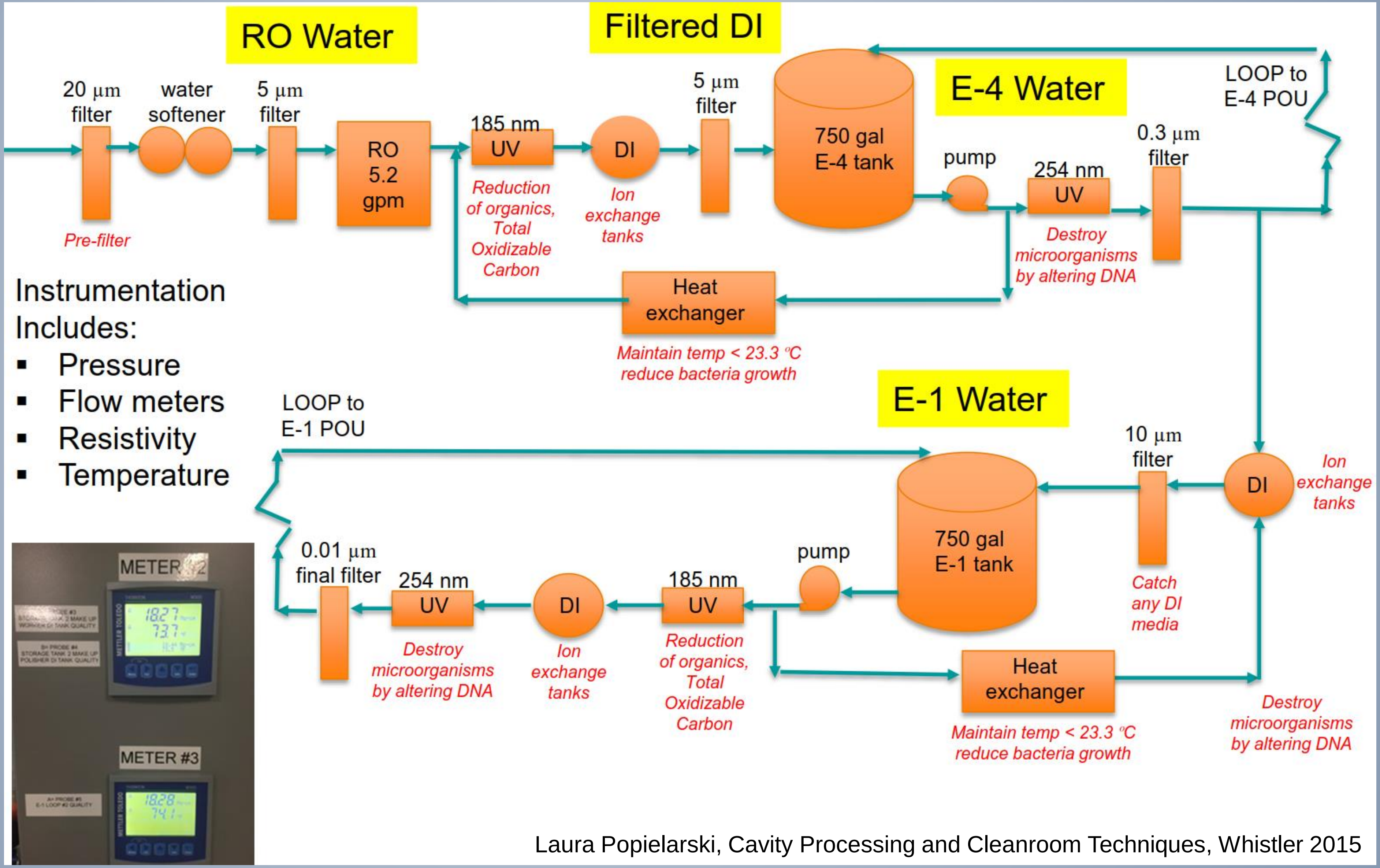
More meaningful definition:

- Water that has been purified to a specific standard or quality specification
- … probably as many definitions as there are specifications…

From tab water to ultrapure water

- Start with the end in mind – UPW specification!
- Quantify the quality of the city drinking water
- Producing UPW is a series of separation steps
  - Remove the dirt, sand and silt,
  - Remove the larger organics and the chemicals the city adds to control harmful bacteria,
  - Remove the dissolved mineral salts,
  - Remove the dissolved solids,
  - Remove the bacteria and microspores,
  - Remove the very small particles,
  - Repeat until ppb levels are achieved

UPW system process diagram



Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

Photo: Reidar Hahn

Ultrapure water specification & experience (JLAB)

Parameter	**Specification**	**typically obtained**	
Resistivity	$> 18.2\ \mathrm{M\Omega/cm^2}$	18.22	
Total organic carbon (TOC)	$\leq 2\ \mathrm{ppb}$	$1.35\ \mathrm{ppb}$	
Particle counts		**weekly average**	**max.**
Channel 1: $(0.05 \ldots 0.1\ )\mu\mathrm{m}$	$\leq 2000\ \mathrm{counts/l}$	6.35	120
Channel 2: $(0.1 \ldots 0.15\ )\mu\mathrm{m}$	$\leq 350\ \mathrm{counts/l}$	1.33	19
Channel 3: $(0.15 \ldots 0.2\ )\mu\mathrm{m}$	$\leq 350\mathrm{counts/l}$	0	0
Channel 4: $> 0.2\ \mu\mathrm{m}$	$\leq 20\ \mathrm{counts/l}$	0	1
	Temperature [°C]	**Pressure [bar]**	**Flow [l/min]**
Ambient UPW	21	4.83	336
Hot UPW	80	4.55	64

Ultrapure water – where and how to use it

Cavity Process Tools

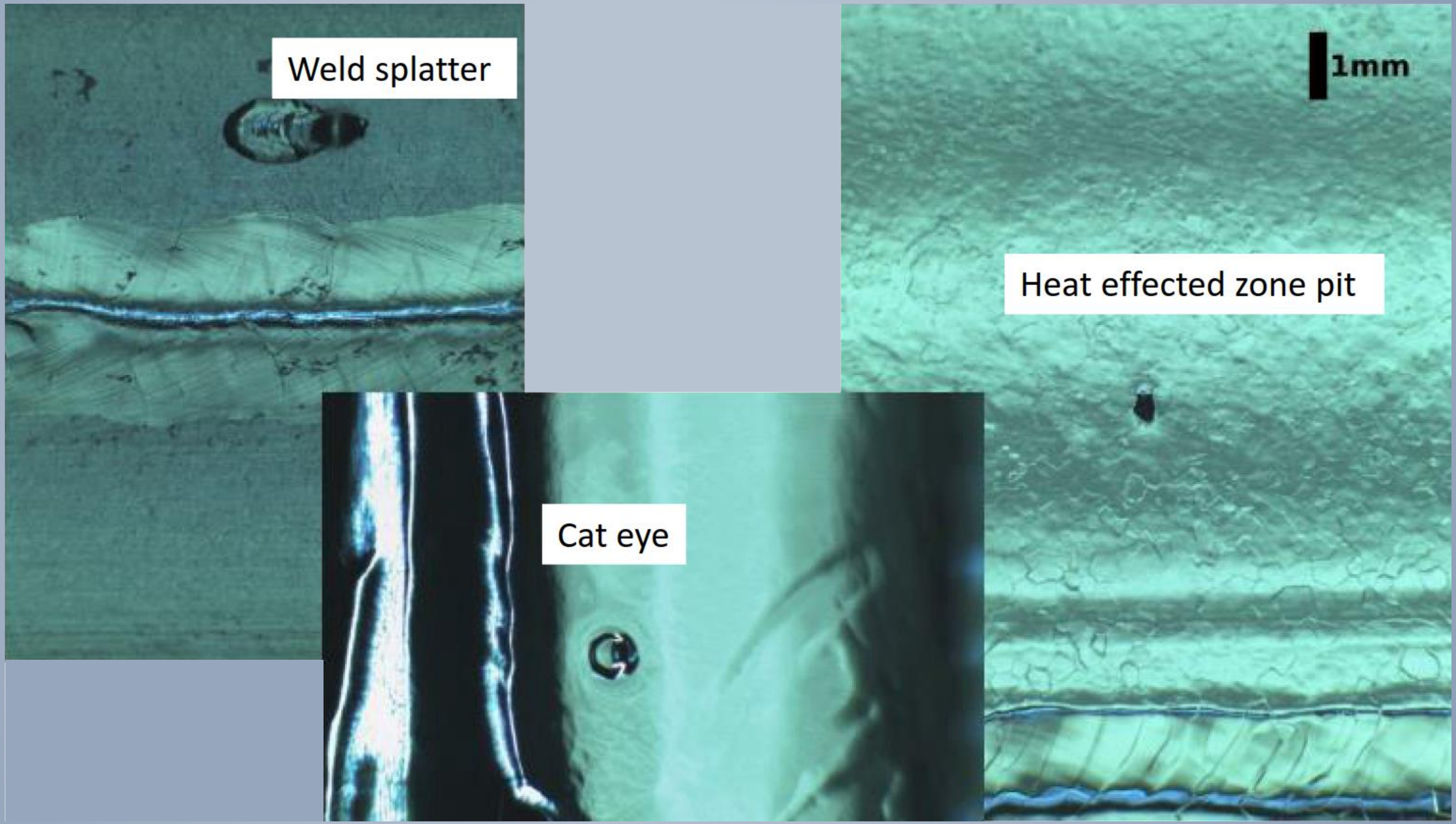
- Horizontal and Vertical Electropolishing (HEP and VEP)
  - Post EP fill and dump cycles, ≈ 21°C
  - Final rinse through cavity to quality, ≈ 21°C
- Buffered Chemical Polish (BCP)
  - Post EP fill and dump cycles, ≈ 21°C
  - Final rinse through cavity to quality, ≈ 21°C and ≈ 80°C (hot UPW)
- High Pressure Rinsing (HPR)
  - Typical pressure is 83 bar, temperature is ≈ 21°C
  - Flow depends on pressure and nozzle configuration

UHV Cleaning

- All ultrasonic cleaning stations
  - UPW + Surfactants (Micro-90 and Liquinox)
  - UPW only
  - Component cleaning prior to cavity assembly
  - Parts clean prior to electron beam welding

Cavity preparation

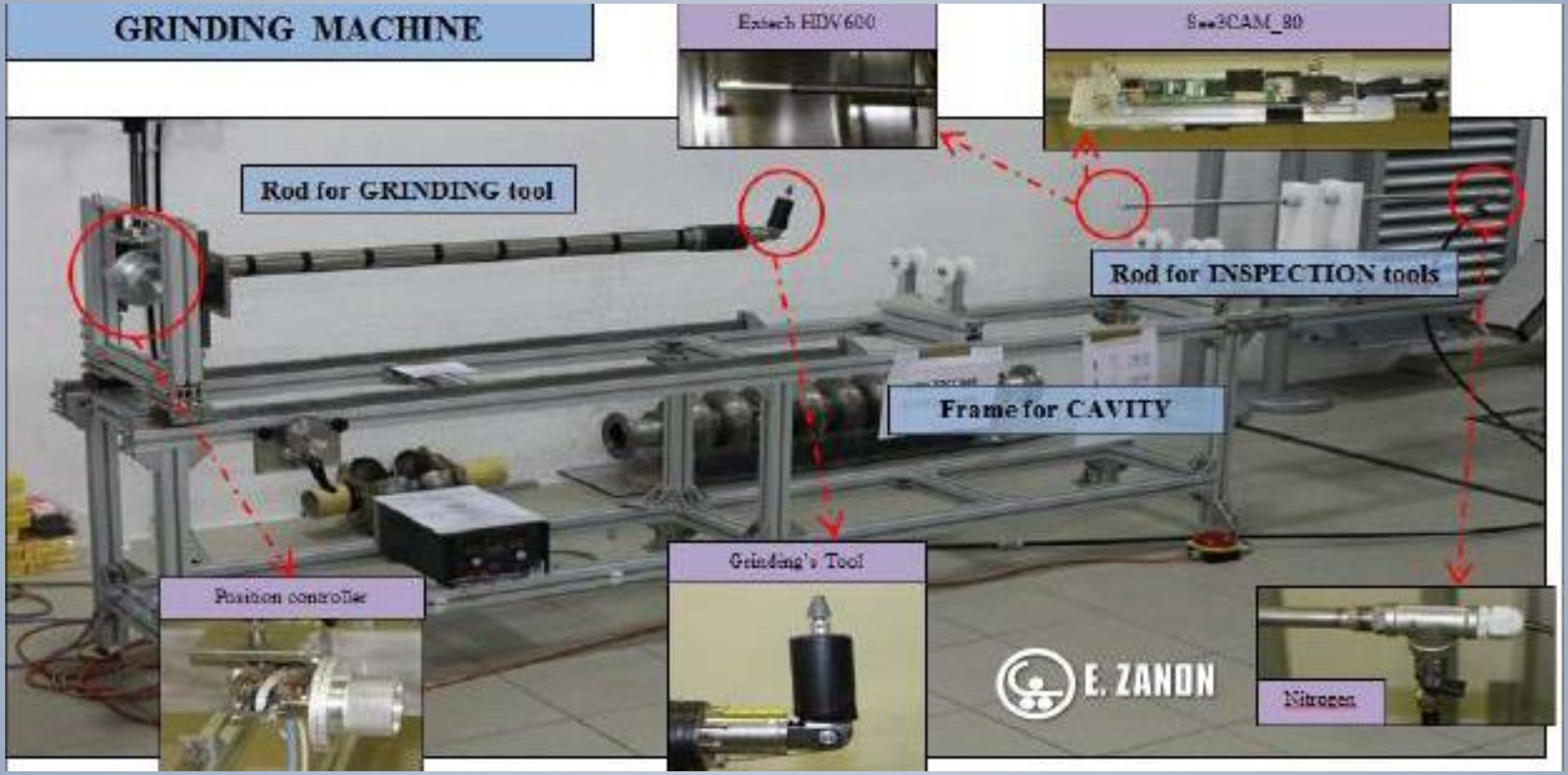
Defects are unavoidable with present techniques



Aliaksandr Navitski "grinding and CBP at DESY", 2014

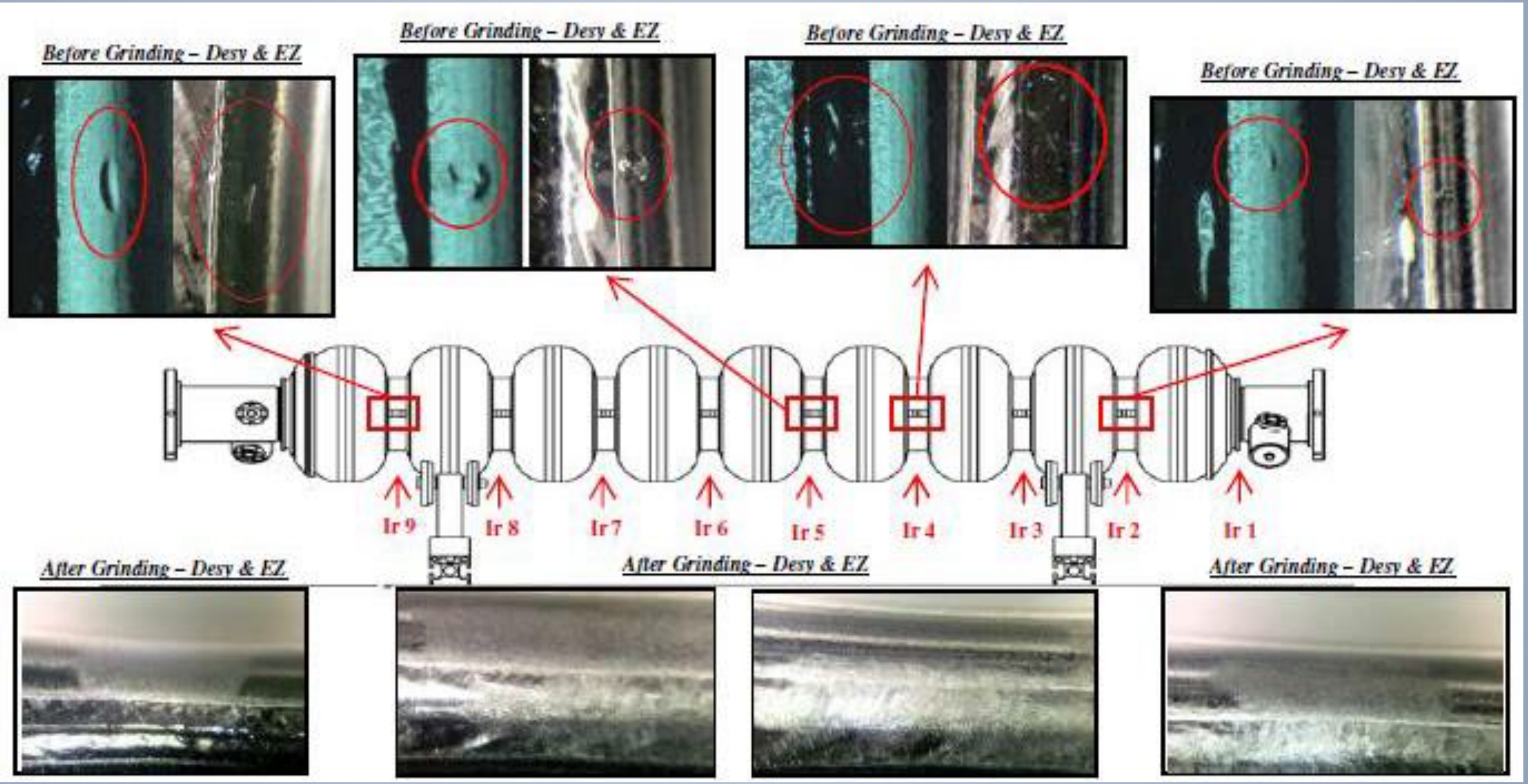
Photo:
Reidar Hahn

Cavity grinding – Ettore Zanon 1



http://accelconf.web.cern.ch/accelconf/srf2015/posters/mopb094_poster.pdf

Cavity grinding – Ettore Zanon 2



http://accelconf.web.cern.ch/accelconf/srf2015/posters/mopb094_poster.pdf

Centrifugal Barrel Polishing – CBP 1

*Only has been used for elliptical cavities

Rough stone : 5 times (15 microns/day removal rate)

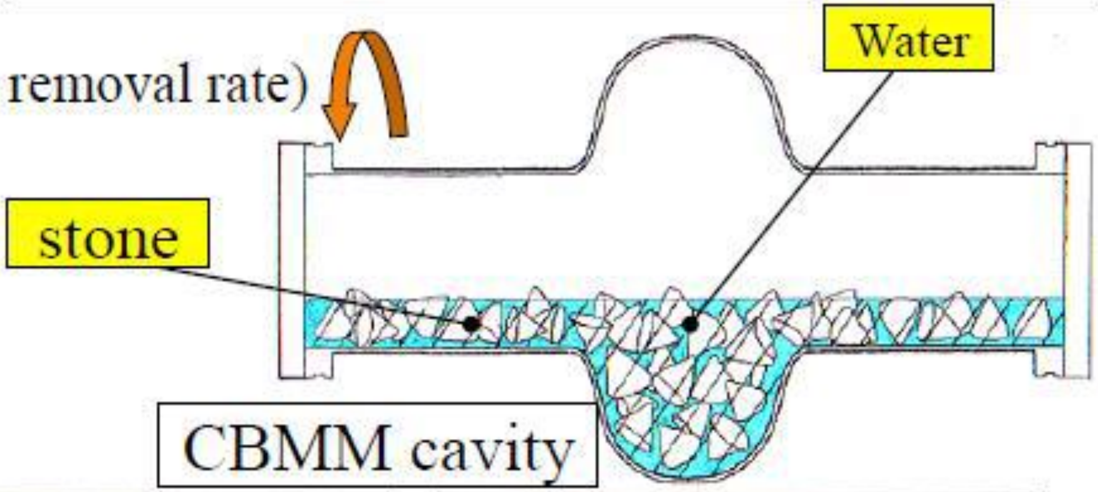
Green stone : Once

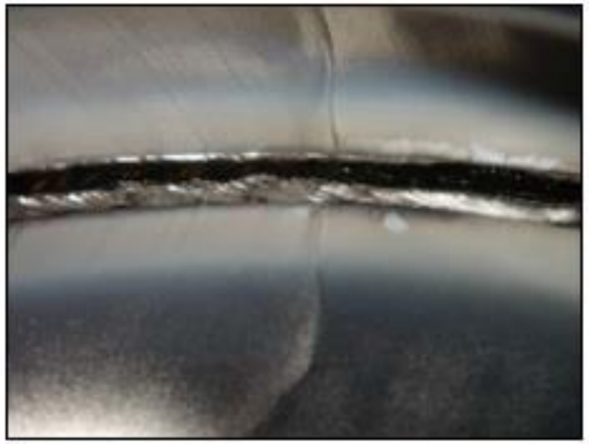
Brown stone : Once

White stone : Once

Totally ~ 200 µm removed @ equator

Rotated ~100rpm on a oppositely rotating table





Before CBP (equator EBW seam)

After CBP

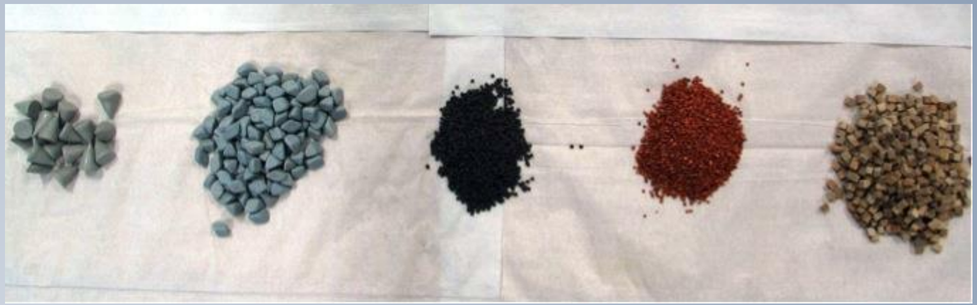
After light CP(10µm)


Photo:
Reidar Hahn

Centrifugal Barrel Polishing – CBP 2

Tumbling machine at Fermilab

The tumbling machine can hold two 9-cell accelerating cavities, rotating them up to 115 rpm. The rinsing device (right) washes the media out. Cavities must be absolutely free of any extraneous material after tumbling.



Medias are tumbled inside. The grey cones (far left) are a plastic with aluminum silicate, used for bulk removal. The powder blue media (second from left) are ceramic abrasives, useful as a first-pass media. A hardwood cut into small cubes (far right) is also a useful abrasive.

Mirror-like finish can be achieved

Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

Grinding tools

- Cratex rubber-bonded abrasives
  - Medium to extra-fine (240 to 400 grit)
- 3M wheel buffing wheels
  - Gray CFFB 3M wheel (600 grit)
  - Red CFFB 3M wheel (400 grit)
- Scotch-Brite pad
  - 7445 - White pad (1000) 1200-1500 grit
  - 7448 - Light Grey (600-800) 800 grit.
  - 6448 – Green (600) 600 grit
  - 7447 - Maroon pad (320-400) 320 grit
  - 6444 - Brown pad (280-320) 240 grit
- Never use sand paper with grit larger than 800 grit!

Buffered Chemical Polishing (BCP)
purpose and recipe

- Purpose of BCP: remove $\mathcal{O}(100\ \mu\mathrm{m})$ of NB off the surface.
- BCP is the standard acid etching method used for Nb SRF cavities
- Chemical mixture reacts with metal surface to “ETCH” away layers of niobium
- Removal of $150\ \mu\mathrm{m}$ is optimum for RF performance
- Recipe “1-1-2”:
  - 1 part hydrofluoric acid (HF)
  - 1 part nitric acid (HNO_3)
  - 2 parts phosphoric acid (H_3PO_4, buffer – not involved in reaction)

The reactant HF is very **TOXIC! → HF**
The product gas is also **TOXIC! → NO_2**

If there is BCP, there is HF!
Much care required – safety first!

Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

Photo: Reidar Hahn

BCP – chemical reaction mechanism

Nitric acid oxidizes the Nb

$$6Nb + 10HNO_3 \leftrightarrow 3Nb_2O_5 + 10NO + 5H_2O$$

Brown NO_2 gas

HF reacts with Nb oxide

$$3Nb_2O_5 + 18HF \leftrightarrow 3H_2NbOF_5 + 3NbO_2F + 6H_2O$$

$$3NbO_2F + 12HF \leftrightarrow 3H_2NbOF_5 + 3H_2O$$

The reaction is exothermic !

HEAT OF REACTION RESULTS SUMMARY		
Average Heat of Reaction =	-607	kJ/mol
Standard Deviation =	17.6	kJ/mol
Theoretical Heat of Reaction =	-678.9	kJ/mol
Percent Error =		*10.5%*

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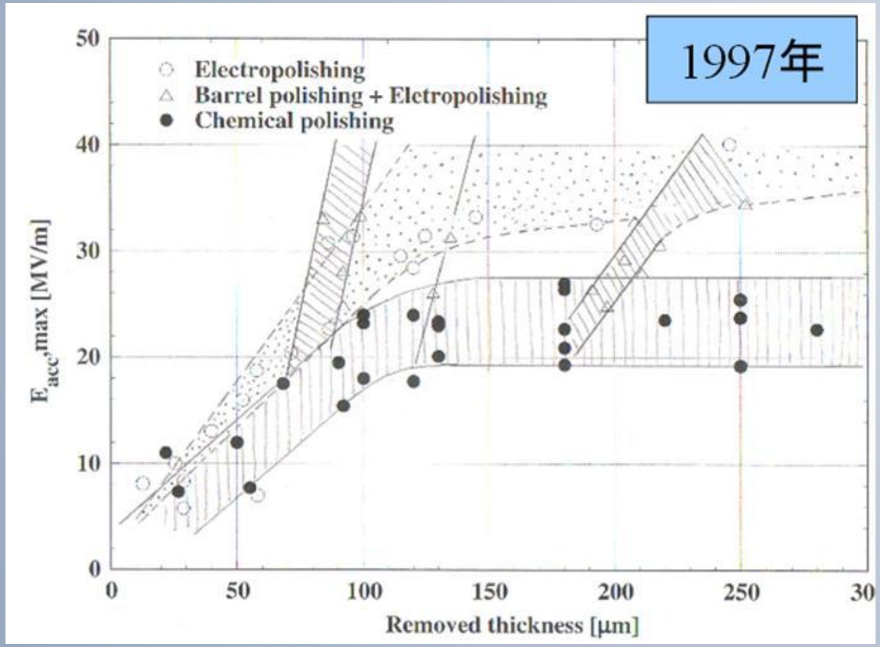
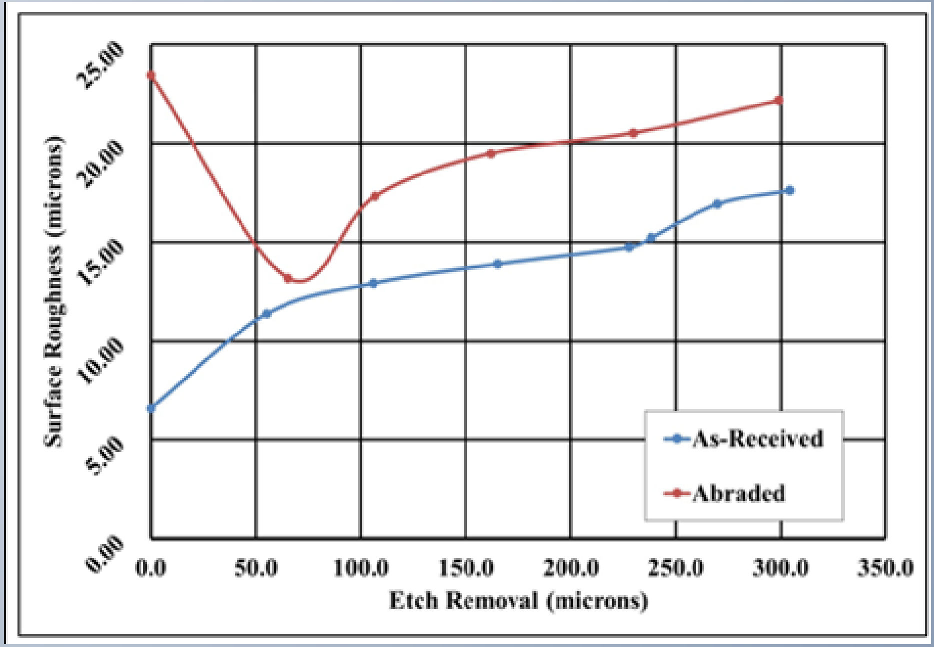
BCP – how much to remove?

- Best performance reached with $(150 \ldots 200)\ \mu\mathrm{m}$ removal
- If more material is removed it becomes thin and mechanically less stable.
- Additional etching does not improve surface roughness



Kenji Saito, Lecture note Tokyo University 2011

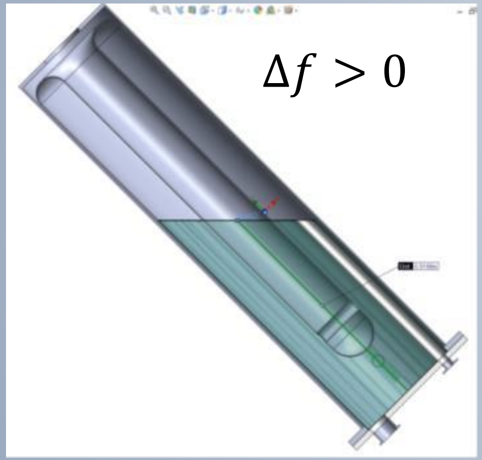


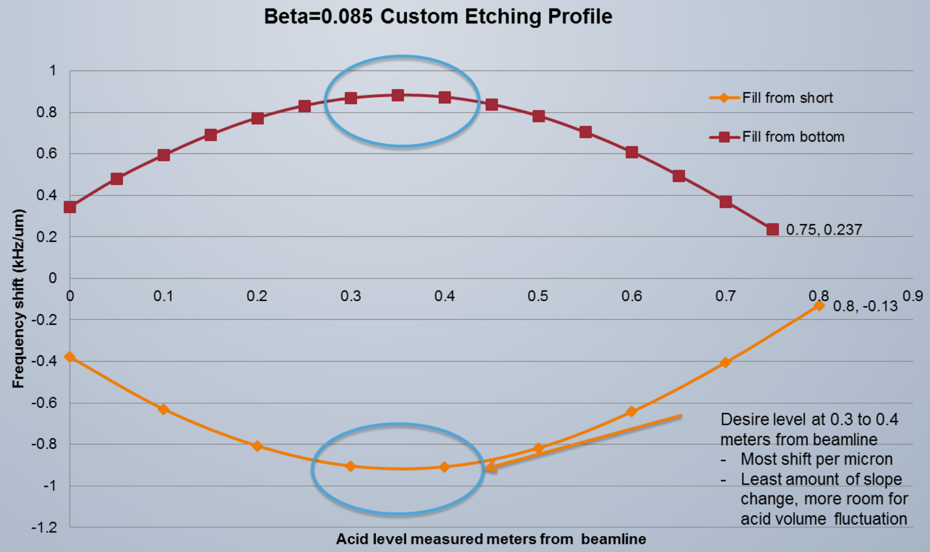
I. Malloch et al., "Study on particulate retention on polished Niobium surfaces after BCP etching", PAC2013

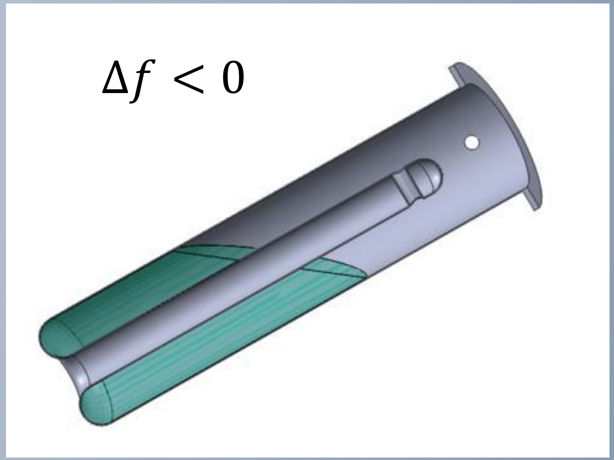
Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

Differential BCP for frequency correction

- Remember Slater's theorem: $\frac{\omega-\omega_0}{\omega} = \frac{\iiint_{\Delta V}(\mu_0|H_0|^2-\varepsilon|E_0|^2)\,dV}{\iiint_V(\mu_0|H_0|^2+\varepsilon|E_0|^2)\,dV}$:
- Surface removal in regions of electric field will shift f down – in regions of magnetic field will shift f up – this can be used by differential etching!







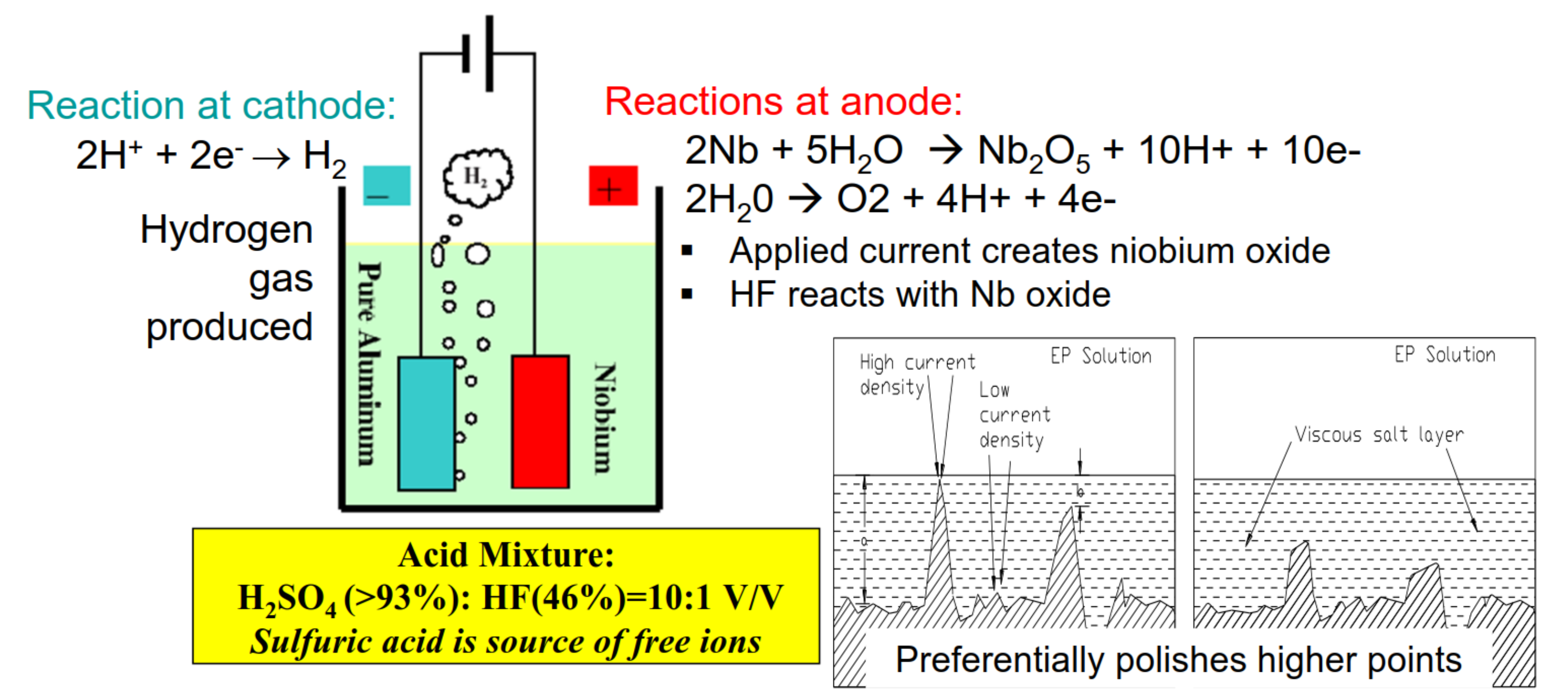
Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

Photo: Reidar Hahn

Electropolishing – EP

- EP applied to reduce surface roughness and create smoother surface
- A DC bias results in a stronger removal near protruding surface features, less in recesses (field enhancement, increased currents on corners and burrs – anodic levelling).

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

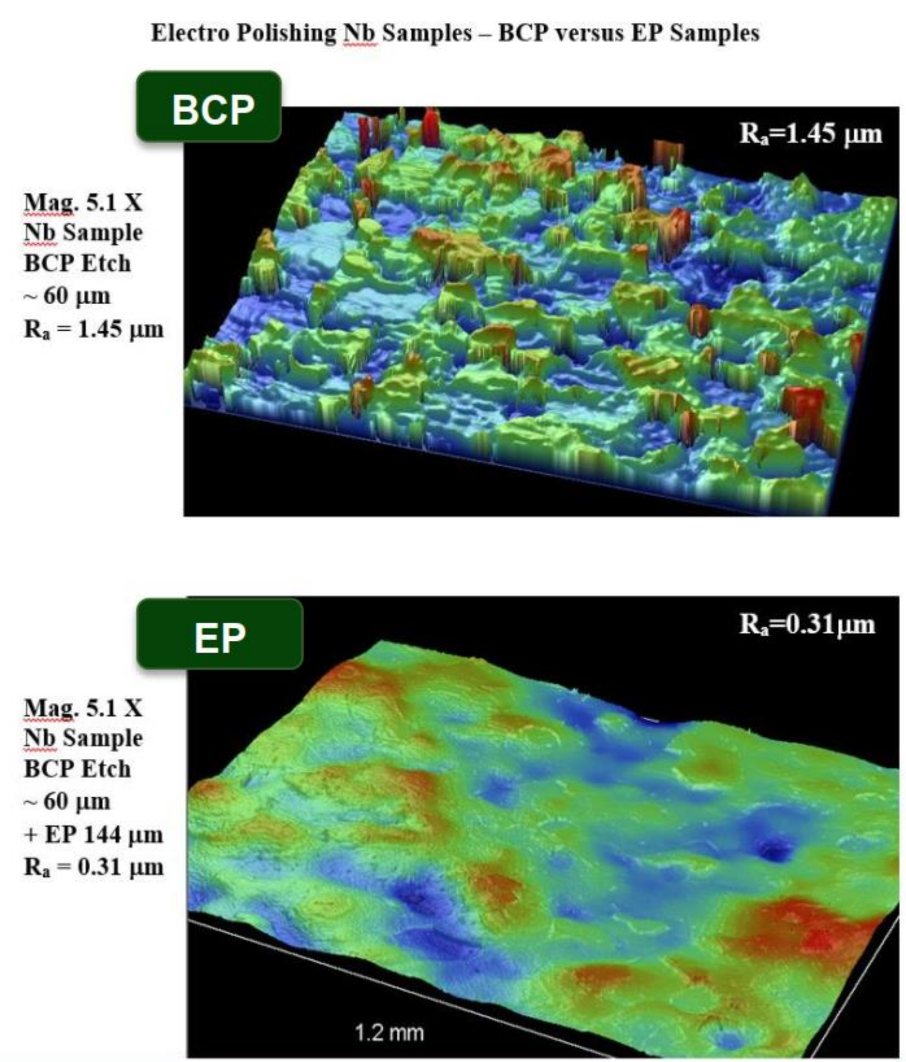


Kenji Saito, Lecture note in Tokyo University on May 2011

Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

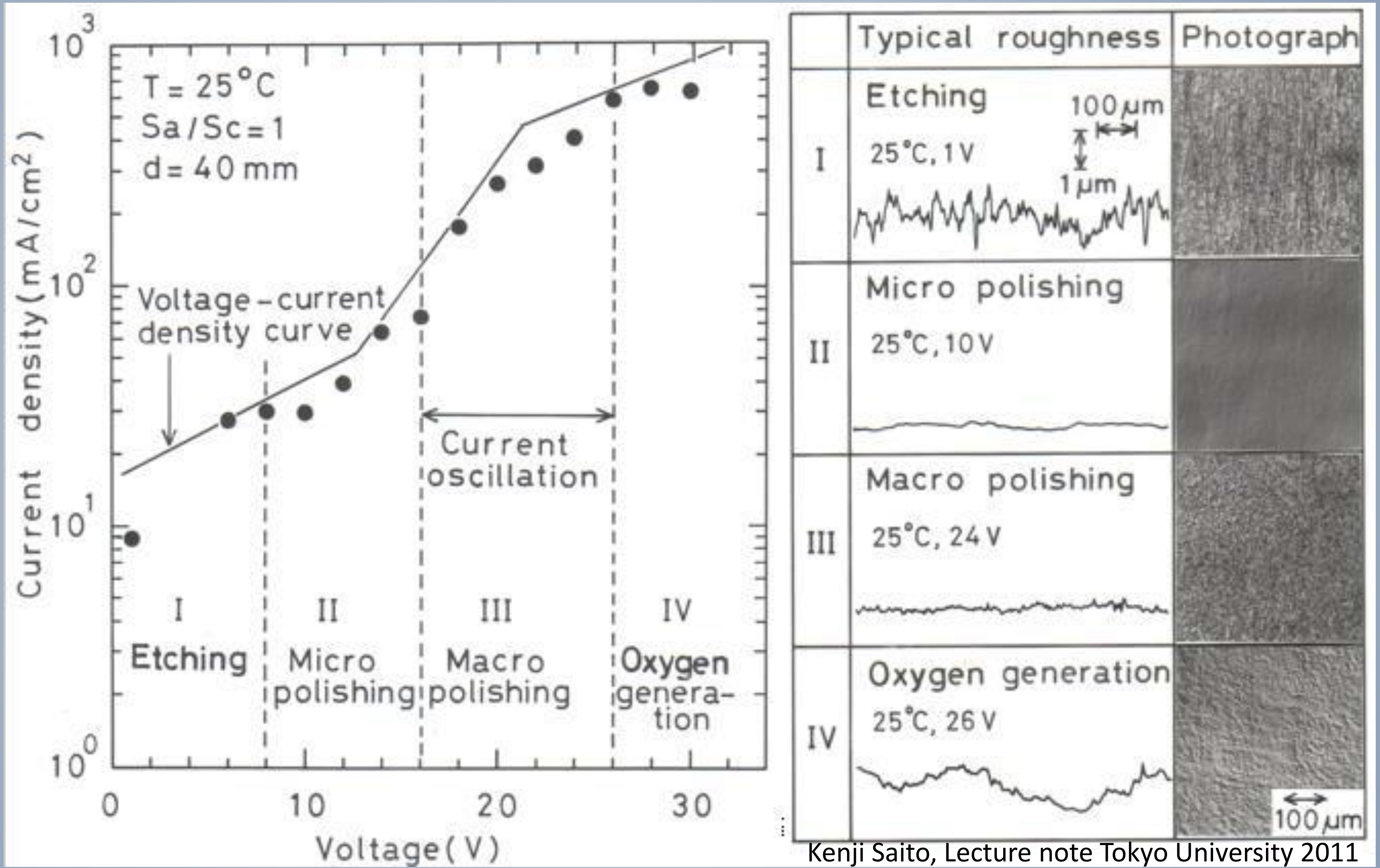
The results of EP

- EP delivers very smooth surfaces.
- On EP samples, surface roughness drops below 1 μm after 150 μm of material removed (L. Lilje, Improved Surface Treatment of SC TESLA Cavities)
- The main difference between BCP and EP is the smoothening of the grain boundaries



Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

EP parameter ranges



Kenji Saito, Lecture note Tokyo University 2011

Laura Popielarski, Cavity Processing and Cleanroom Techniques, Whistler 2015

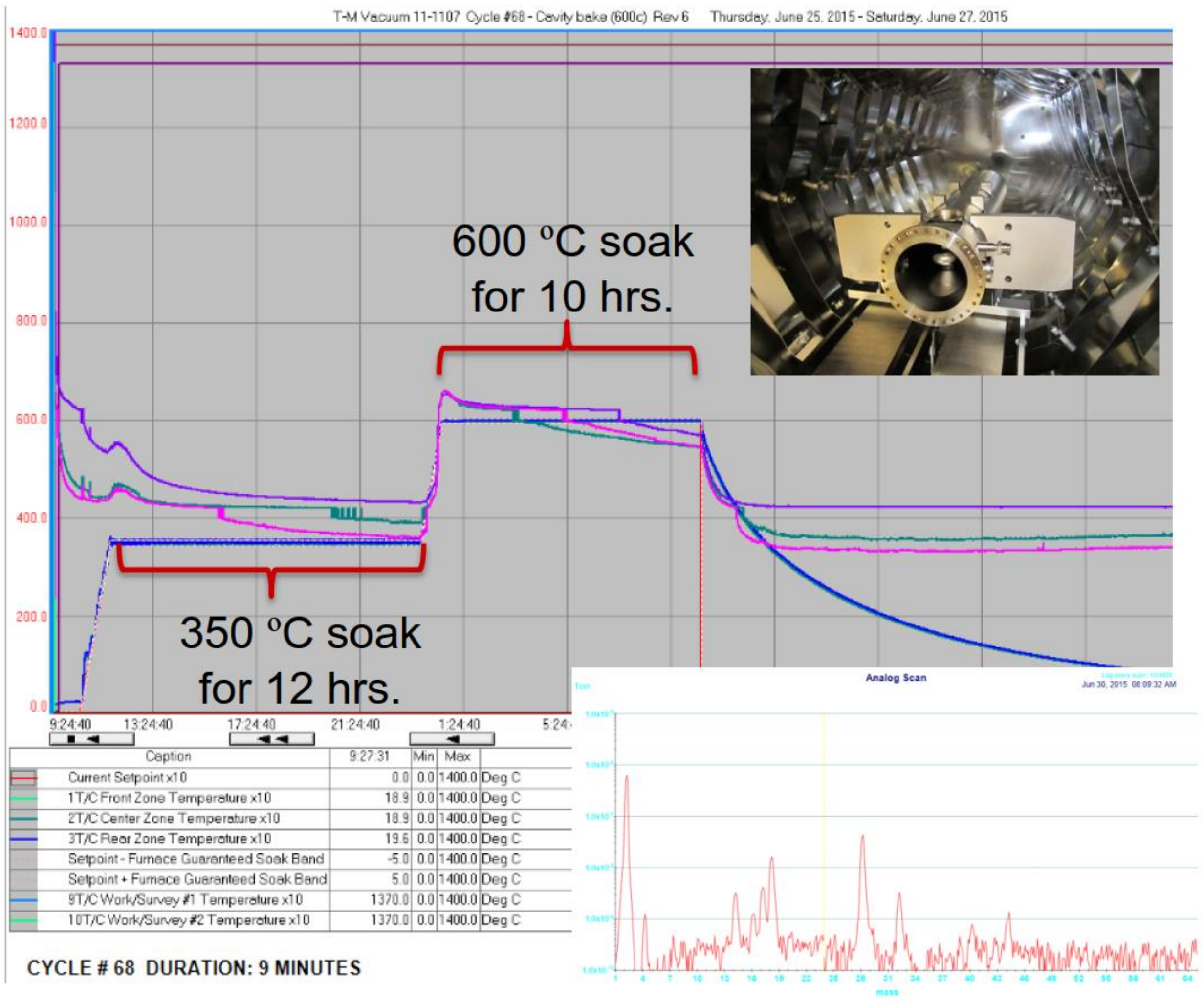
Why heat treatment?

- Clearly observed Q_0 drop after Nb soak around $100\ \mathrm{K}$ for 1+ hours.
- Q_0 drop (also referred to as *Q*-disease) is due to hydrogen uptake during processing.
- Fast cool-down of Nb $(< 1\ \mathrm{hr})$ is required to avoid the Q_0 drop.
- Hydrogen degasification proven to eliminate the Q_0 drop even during slow cool down.
- Effective degassing starts $\approx 600\ ℃$.
- Cavities fired in vacuum furnace for 10 hrs at $600\ ℃$ at 10^{-5} mbar after 12hrs "soak" at $350\ ℃$.
- Cavity must be degreased and dry!
- Furnace must be kept clean and dry, and located in a clean zone

Photo:
Reidar Hahn

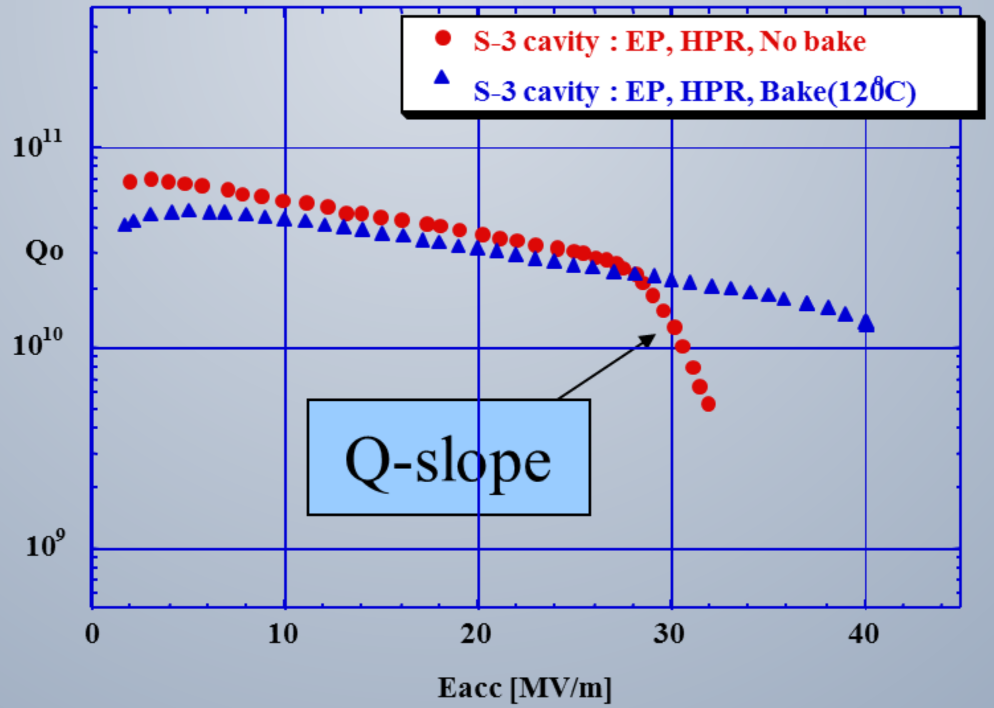
Heat treatment furnace operation

- Partial pressures and temperature recorded vs. time with an RGA.



120 °C "low temperature bake"

- Bake at (100 … 150) °C under UHV for > 24 h has beneficial effects on the BCS surface resistance and the high field Q-drop.
- It has been related to oxygen diffusion into the niobium, causing changes of the structure niobium/oxide interface on a nanometer scale.
- Has proven effective for electropolished elliptical cavities.



High Pressure Rinsing (HPR)

- 70 to 100 bar at point of use,
- Motion → rotation and translation, avoid spiral affect,
- Materials → Clean-room and UPW compatible, low friction – smooth surface,
- Duration → Depends on cavity type and surface area, LCLS-II/XFEL vendors final rinse (6 passes, 12hours),
- Post-Rinse → dry in ISO 5/4 cleanroom, away from all movement or people,
- Ideally cabinet is pressurized above cleanroom levels to ensure particle from operator do not move towards wet cavity,
- Most designed for elliptical cavities – I will show alternatives – making non-elliptical geometry HPR difficult.

https://journals.aps.org/prab/pdf/10.1103/PhysRevAccelBeams.20.042004

Photo:
Reidar Hahn

Existing HPR cabinets

AES (2009)

ORNL (2012)

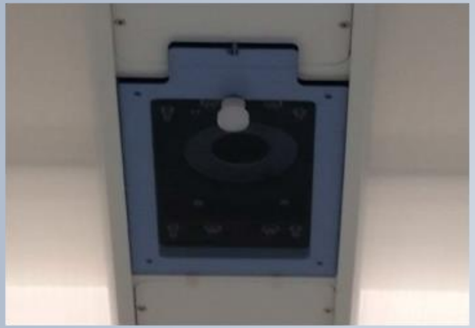
CERN (2013)

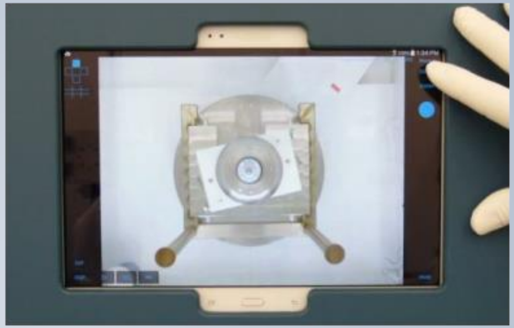
JLAB (2015)

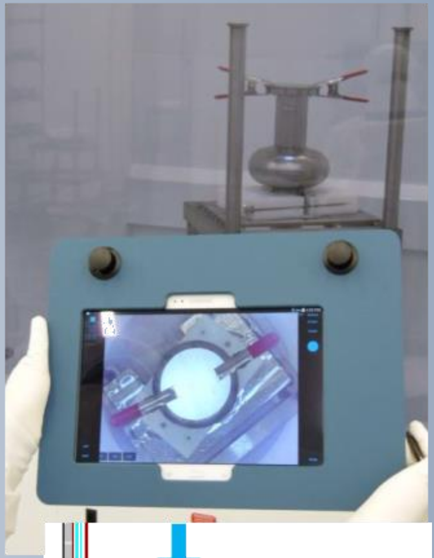
Features of JLAB HPR system

Camera

- Wireless camera to tablet on front panel.
- Zoom, Autofocus, Ring Light

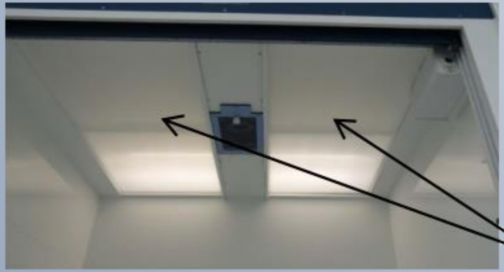






HEPA (ULPA)

- 99.9995% EFFICIENT @ 0.12 MICRON
- 650 CFM@90FPM
- exhausts set at 550 CFM



Air Return

ULPA Supply (PP-Diffuser)

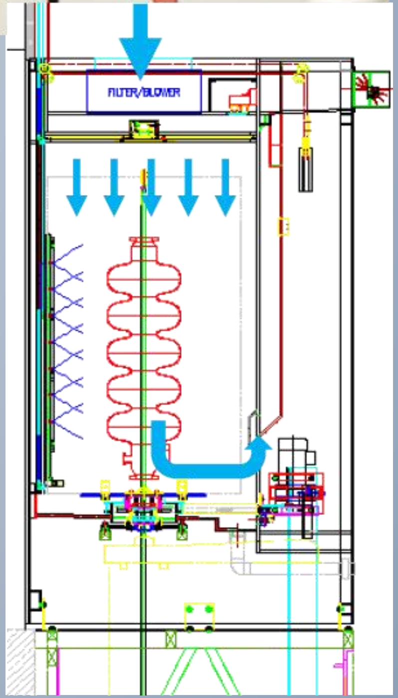
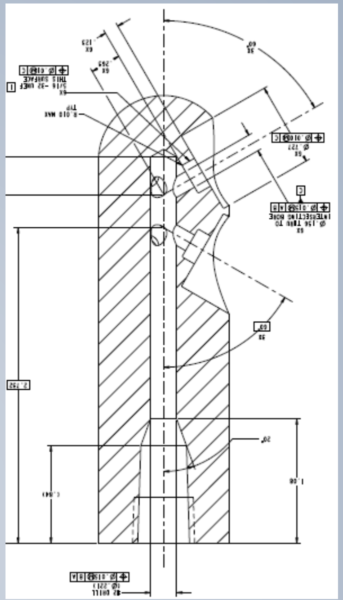


Photo: Reidar Hahn

Wand head/nozzles

- **Wand alignment to table within 0.5 mm at 1.8 m!**
- **Wand Head (Standard)**
  - Based on ORNL design for stability,
  - JLAB head has smaller OD,
  - 6 individual nozzles spaced at 120° apart, angled up/down.
  - JLAB has two designs (60° and 75°)
- **Nozzles**
  - Spray.com
  - TM-TC1501-SS = 15° fan, .75 GPM @ 1000psi
  - TM-TC25015-SS = 25° fan, .75 GPM @ 1000psi
- Nozzle in HPRv2 today = 75° flat with 15° fan

Points to consider for nozzle design:
- Coverage
- Fan spray
- Impact force
- Testing & modelling



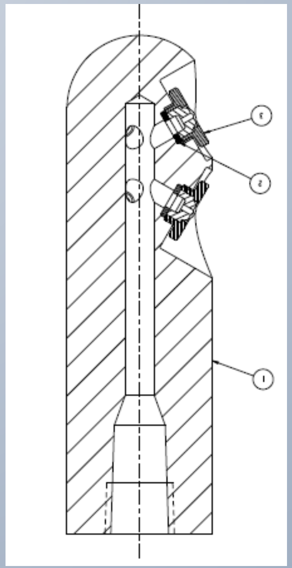
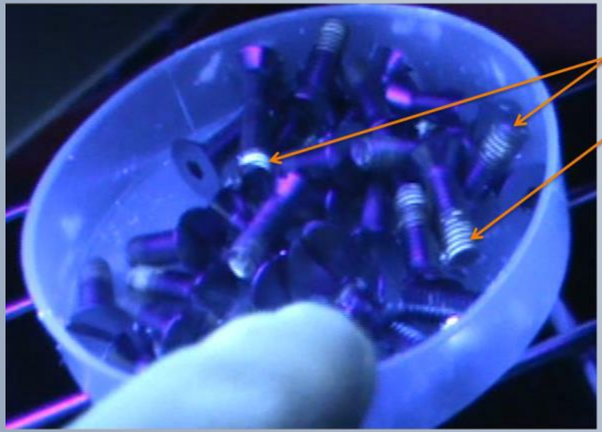
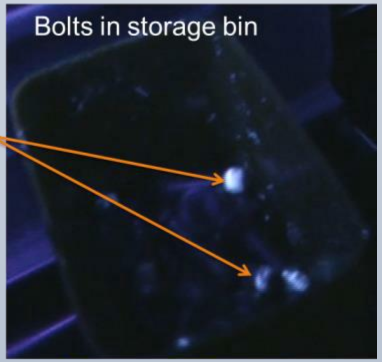


Photo:
Reidar Hahn

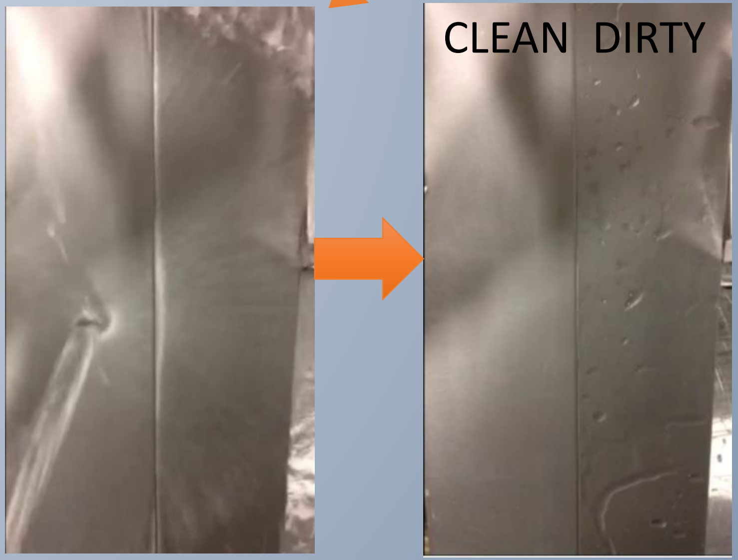
Tests to check cleanliness

- **Total Organic Carbon (TOC) content measurement**
- Visual inspection and white poly wipe
- **Water break free test**
- Clean gas spray & count
- Surface particle counts
- **UV light inspection**
- Residual gas analysis





Grease easily detected on bolt threads
Identify bolts that have not been cleaned properly



Cavity drying (after HPR)

- Single cell cavity are allowed to dry > 3 hours before assembly.
- Multi-cell cavities are dried overnight (>12 hours) before assembly.
- All possible ports on the cavity is open for drying,
- For final assembly only bottom port is left open.

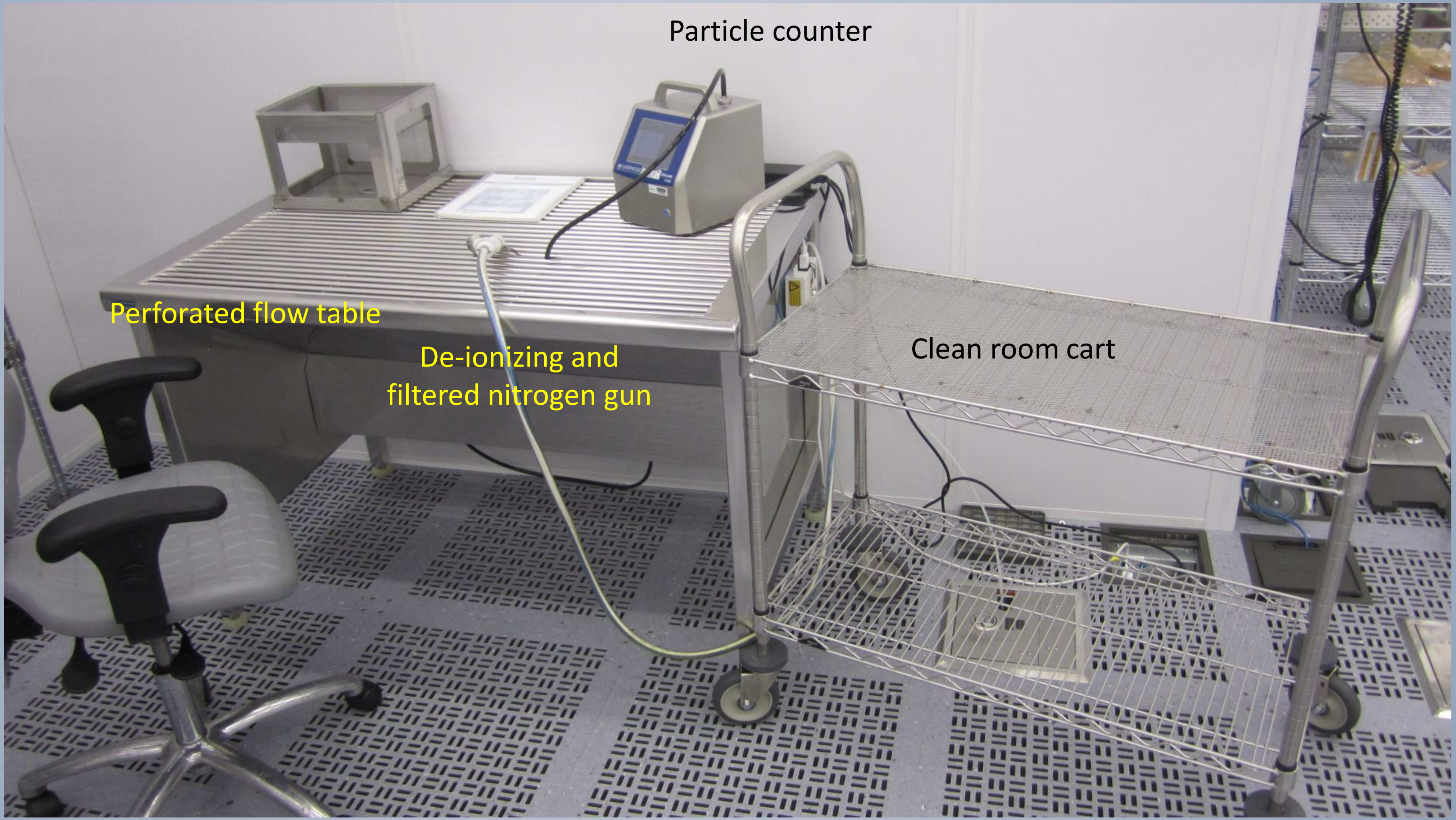
Photo: Reidar Hahn

Parts cleaning before entering clean-room

- All parts are cleaned to remove all grease, particles, and possible other forms of contamination,
- Ultrasonically cleaned for 30 min in detergent and then rinsed with ultra pure water,
- Dried in flow hood and/or blow dry with filtered ionized nitrogen,
- Bagged in antistatic clean room bags,
- Bagged parts are placed in pass-through,
- Larger parts are not bagged but dried in pass-though or ISO6 area.

Photo:
Reidar Hahn

Blow-off station (preparing assembly)



Preparing parts (nitrogen cleaning)





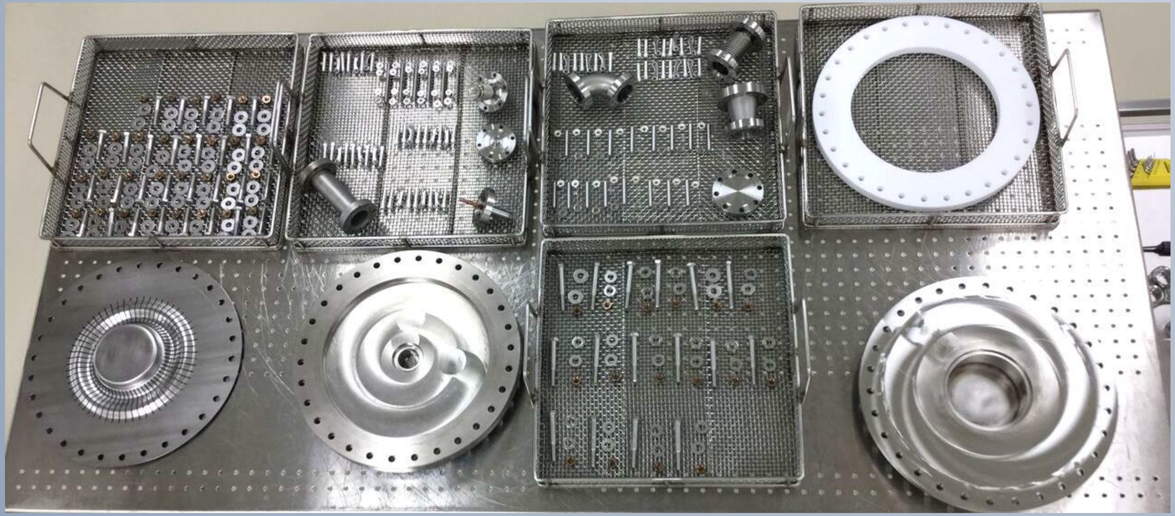


All parts must be on clean room wipe (avoid parts rubbing)
All parts that "see" cavity must be facing up and cleaned last

Clean assembly techniques

- Define part placement so not to reach over clean parts & for repeatable set-up!
- Make particle tight seals with few bolts then move to higher ISO class for other bolts and correct torque.
- Do not touch vacuum or RF surface with gloves, always lift flanges by edges.
- Do not put arms or hands over ports, keep distance from cavity!
- All tools cleaned the same method as components!

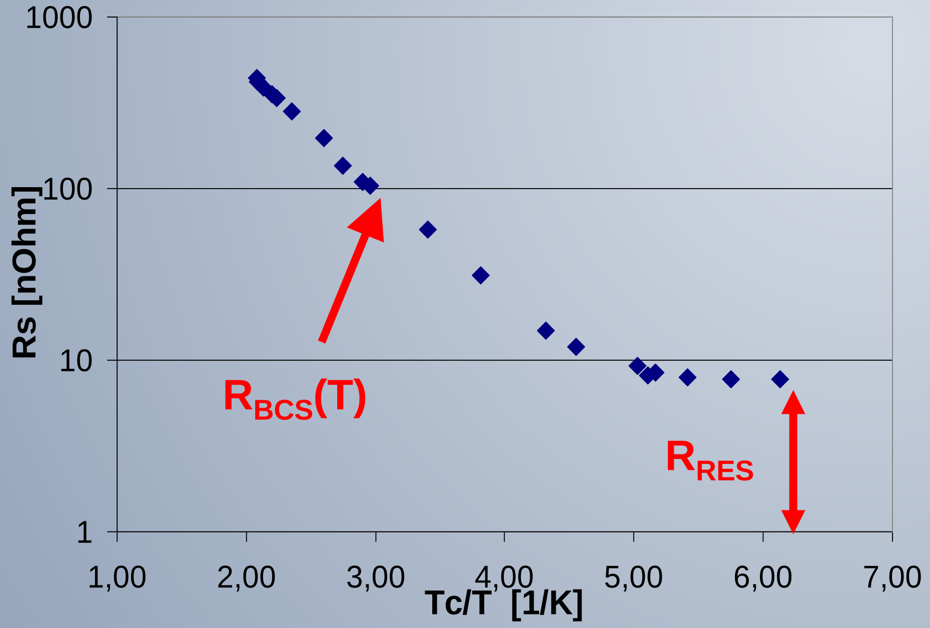
Particle-tight seal with 2 bolts

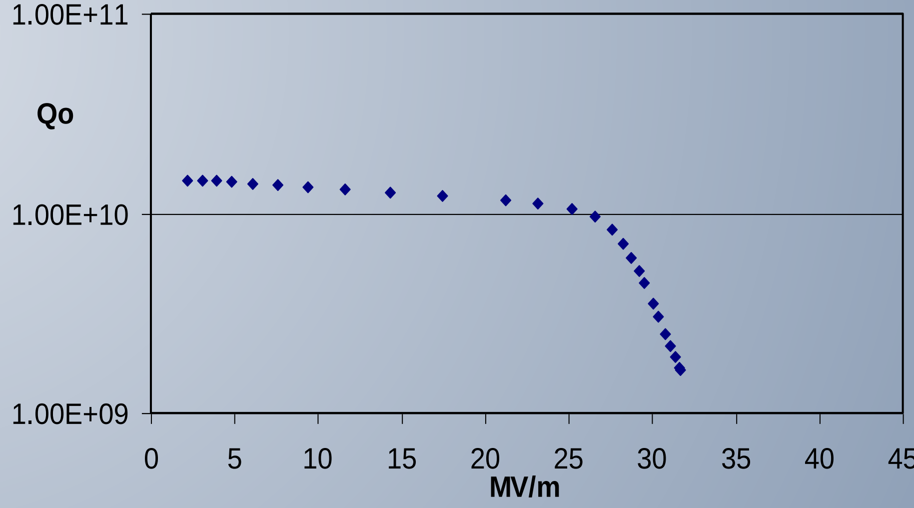


Parts placement before QWR assembly

Vertical test of SRF cavity

- Acceptance test of the cavity received from industry
- Check of a special treatment
- Goals: Determine Q_0 vs. E_{acc} and Q_0 vs. T.
- Operation in CW or with long pulses.





Vertical test preparation

- Cavity ready (after cleanroom work),
- Evacuated, leak-checked to $< 10^{-10}\ \mathrm{mbar} \cdot \mathrm{l/s}$, RGA (residual gas analysis) checked,
- Mechanical assembly to the test insert,
- Vacuum connection, pumping, leak check + RGA,
- Connection of RF-cables incl. checks (short circuit, time-domain reflectometer measurement),
- Assembly + check of diagnostics (Second sound, temperature mapping, x-ray sensors, …),
- Transport to vertical cryostat
- Preparation and test of interlock systems
- Cool-down to $4.5\ \mathrm{K}$ or $2\ \mathrm{K}$, (maybe with holding at $100\ \mathrm{K}$)


Photo:
Reidar Hahn

Vertical test insert

Horizontal Cavity Tests

- Horizontal cavity tests are important in order to a cavity full equipped with its subsystems before a module integration
  - Power coupler
  - Tuner
  - Piezo-Tuners

- Check of cooling conditions + flux trapping

Horizontal cryostat at DESY for high power pulsed operation (without beam)