CERN-LNL-STFC Collaboration kickoff meeting

Program of the LNL Research Activity

CERN, Geneva, June 23, 2015

Tests, actions (INFN-LNL)

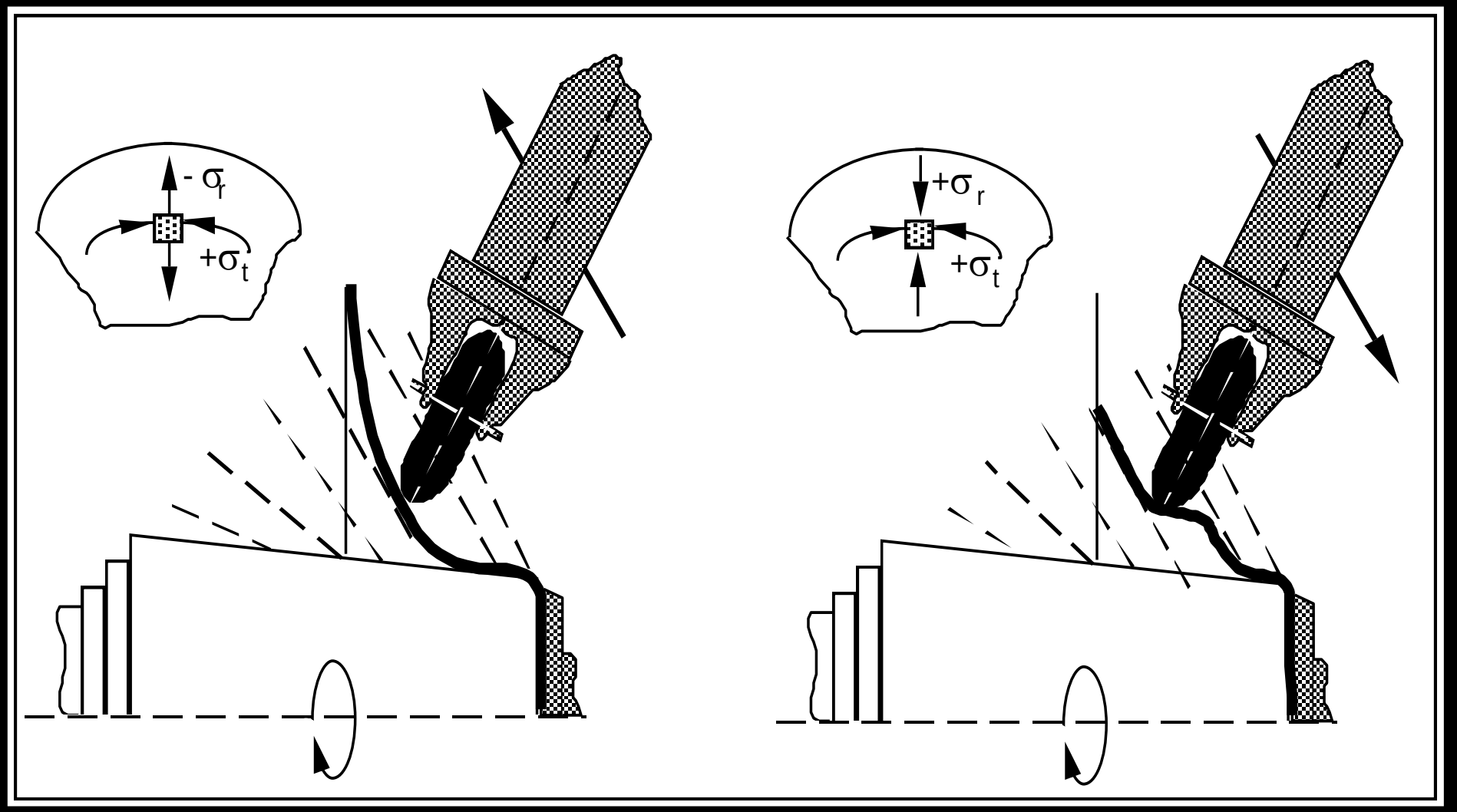
- The fabrication of **4 seamless 800 MHz 5-cell** copper cavities.

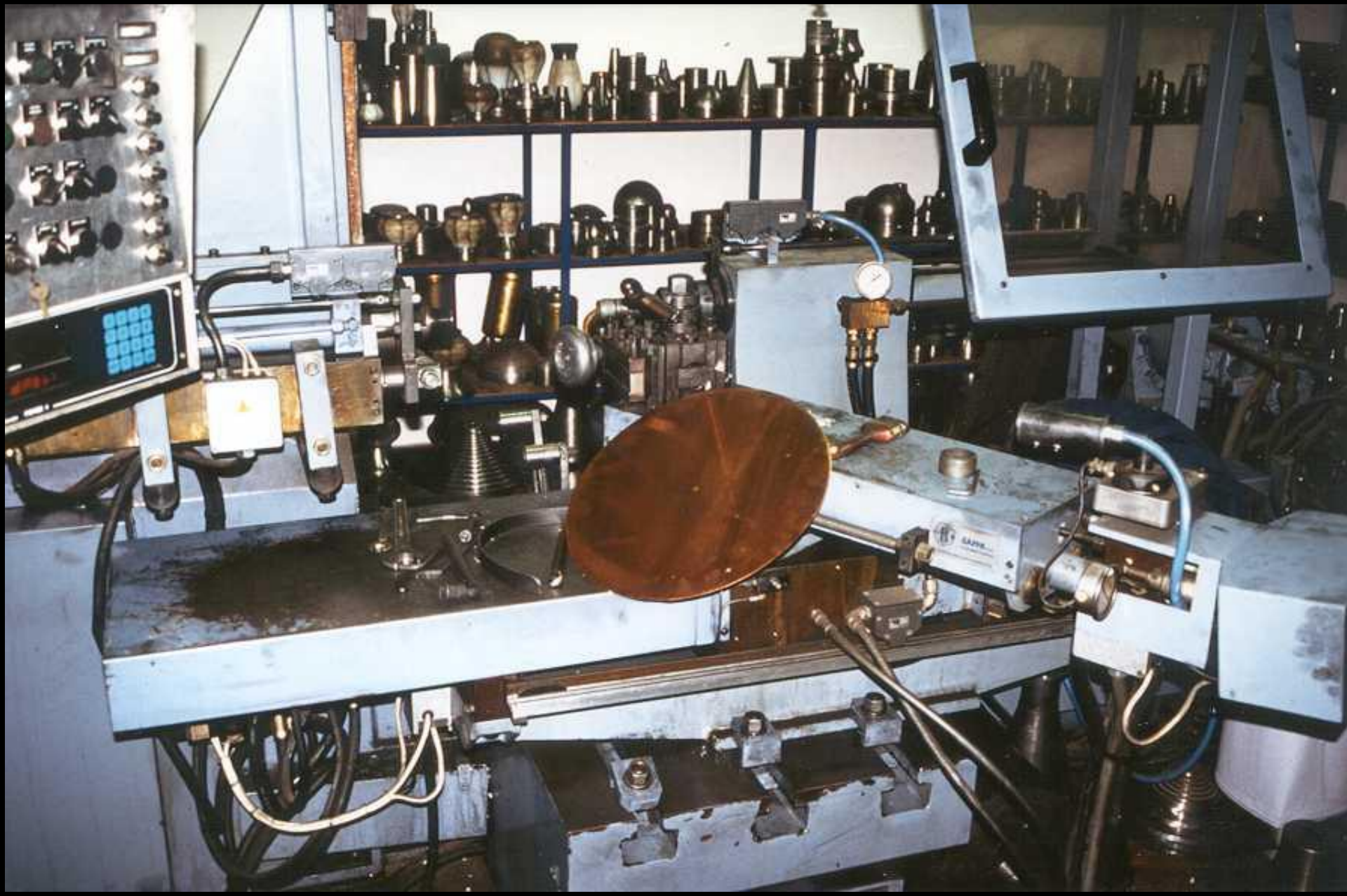
- The **development of surface processing and coating techniques on seamless 6 GHz cavities**, in view of a possible application to 800 MHz cavities, including: the role of the microstructure of niobium at the interface between copper and niobium, the effect of the high deposition temperatures on SRF properties of niobium, the study of improved deposition magnetron sources for the niobium deposition, and the study of thermal boundary resistance between copper and liquid helium.

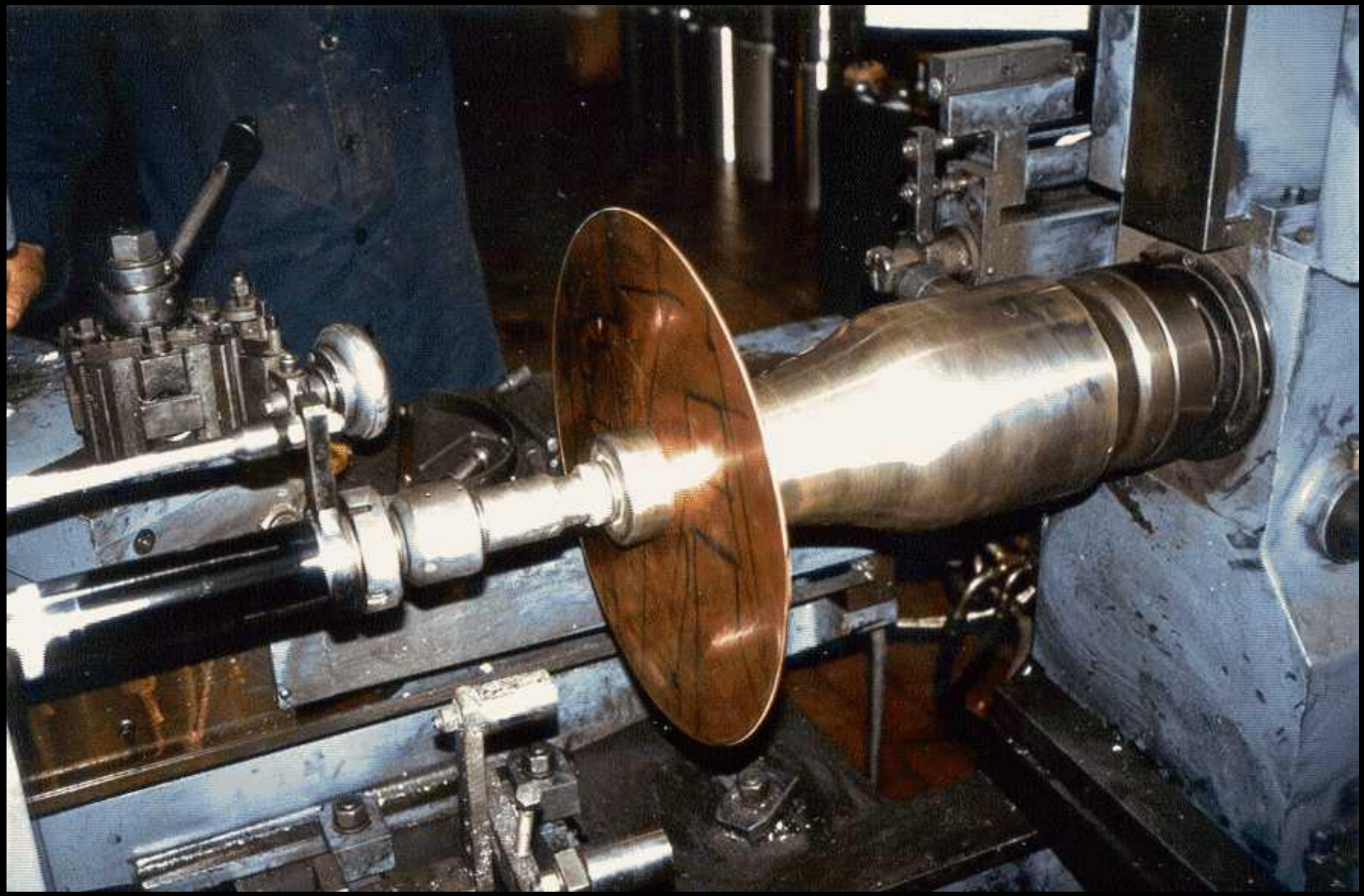
- INFN will also investigate the possible application of either spinning, back-extrusion or alternative seamless fabrication techniques for the production of **a single-cell 400 MHz cavity**. These investigations should be summarised in a feasibility report including first estimates of tooling cost and providing the basis for prototyping activities.

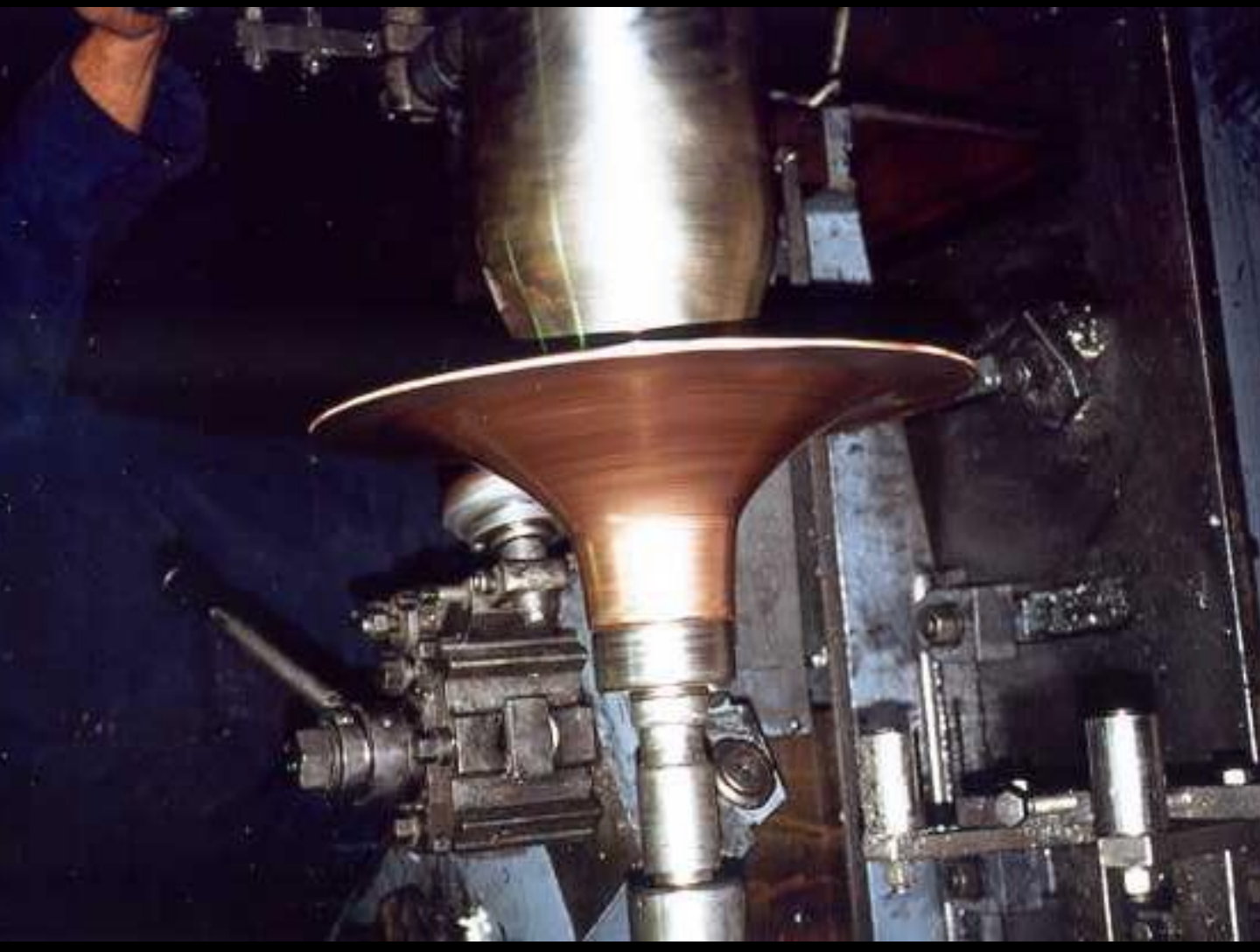
Workpackage on

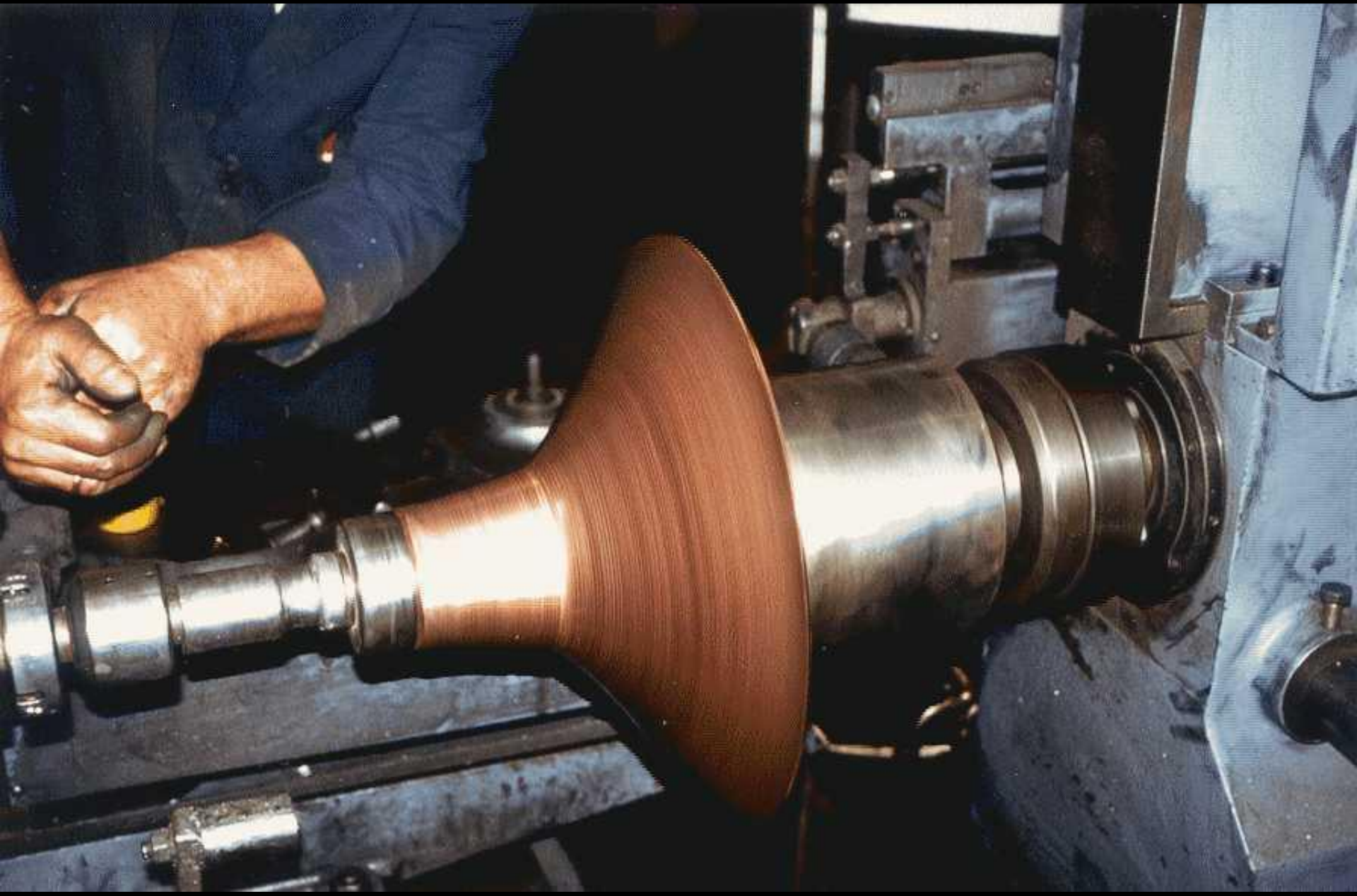
Forming activity

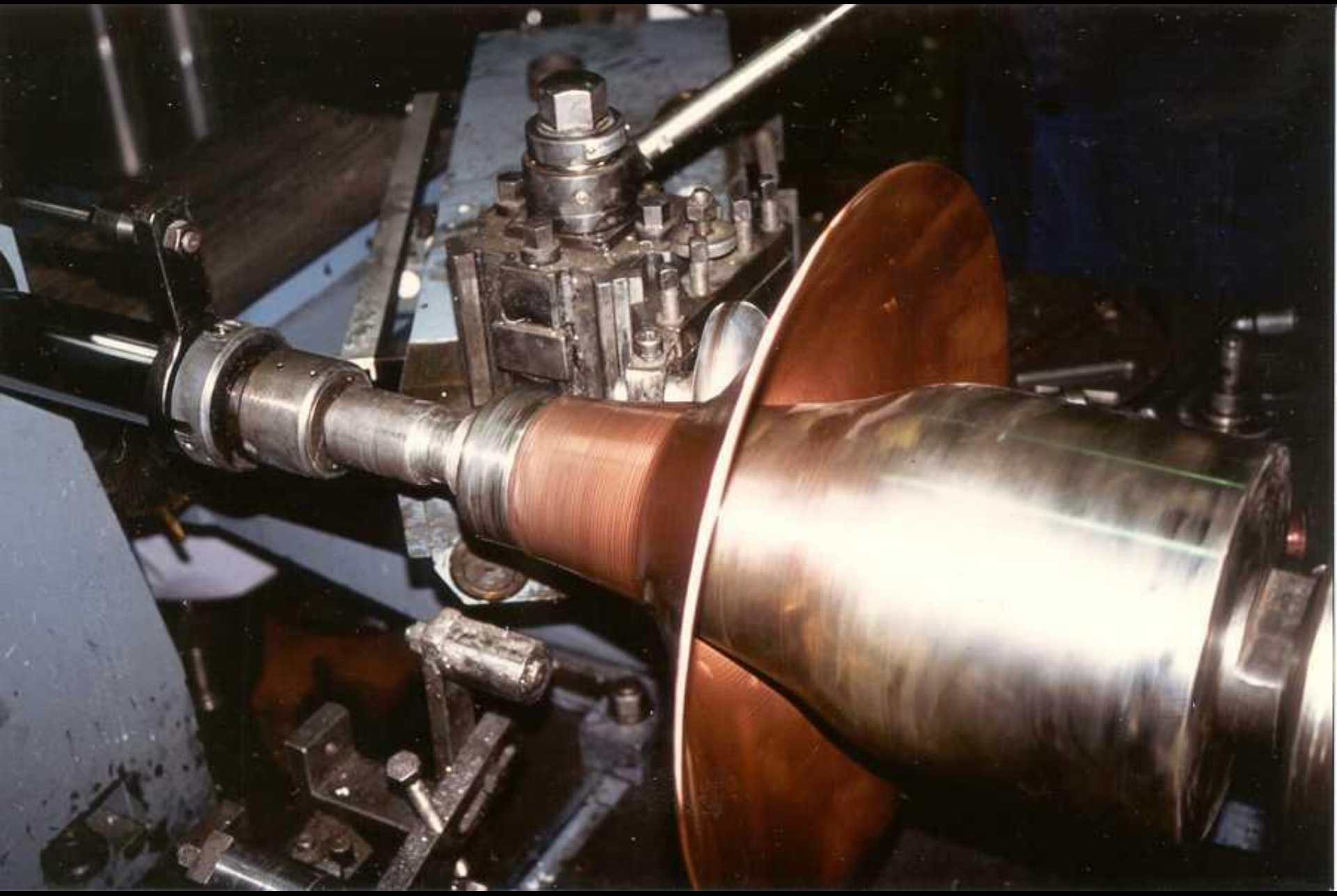

- σr
+σt
+σr
+σt

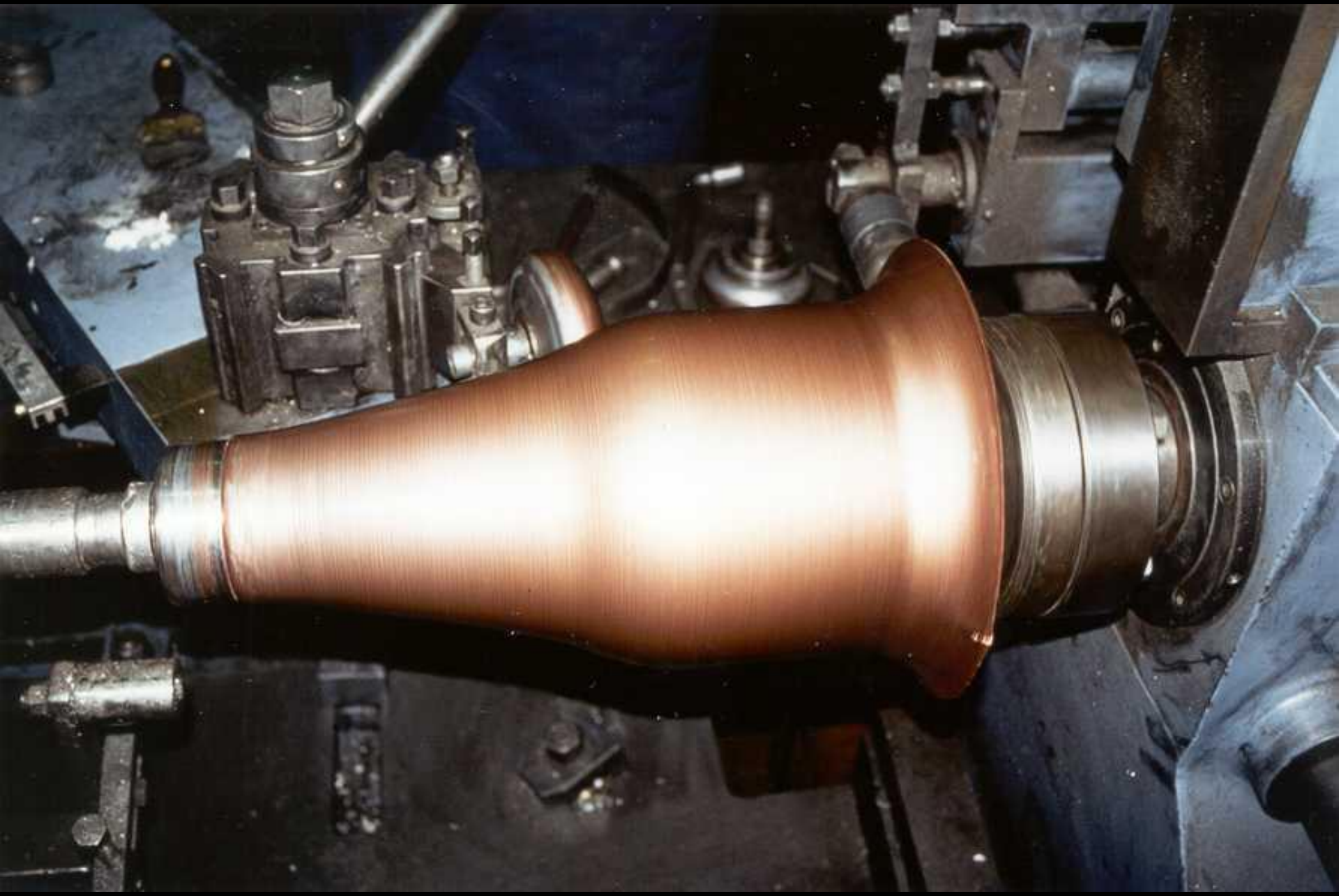


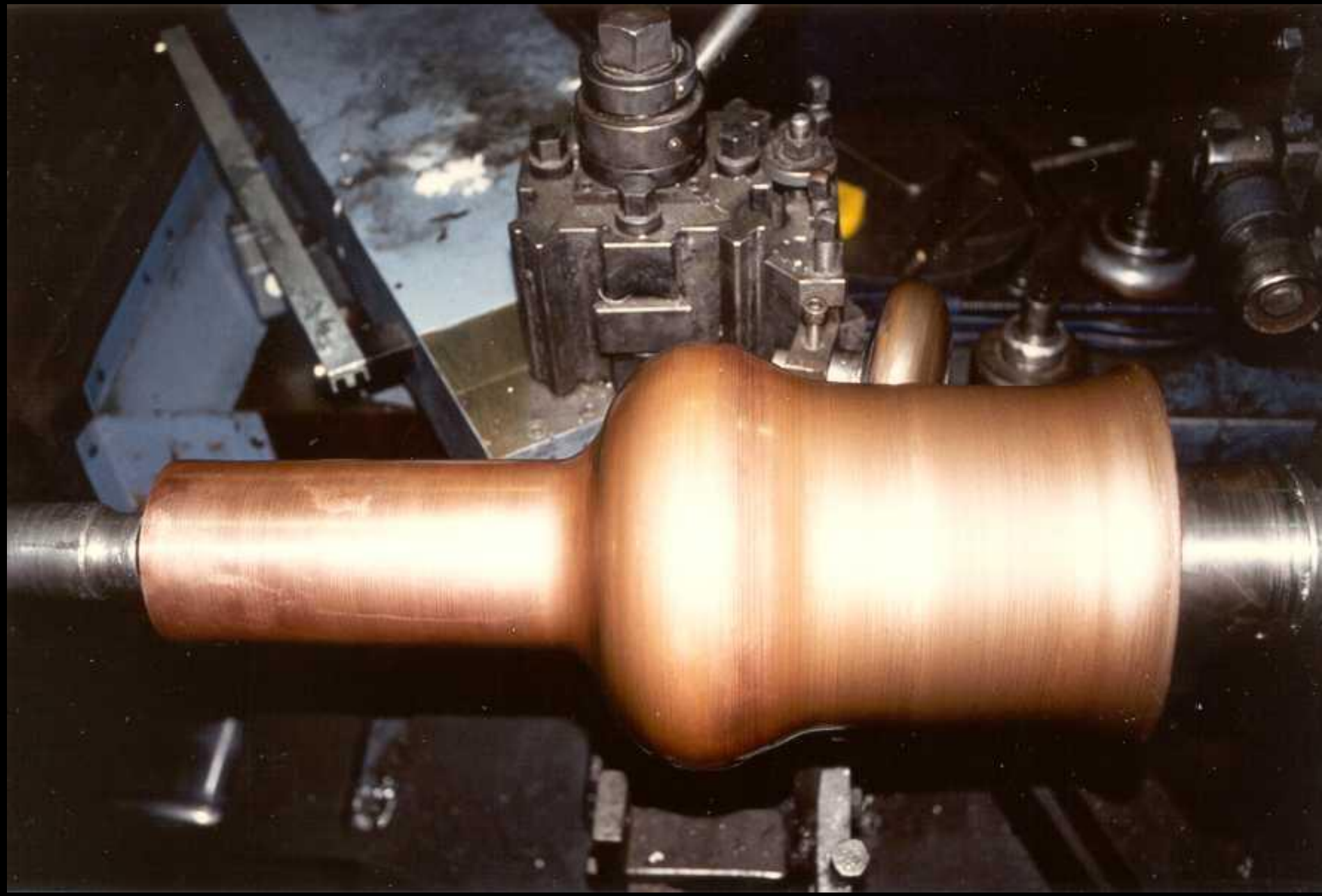


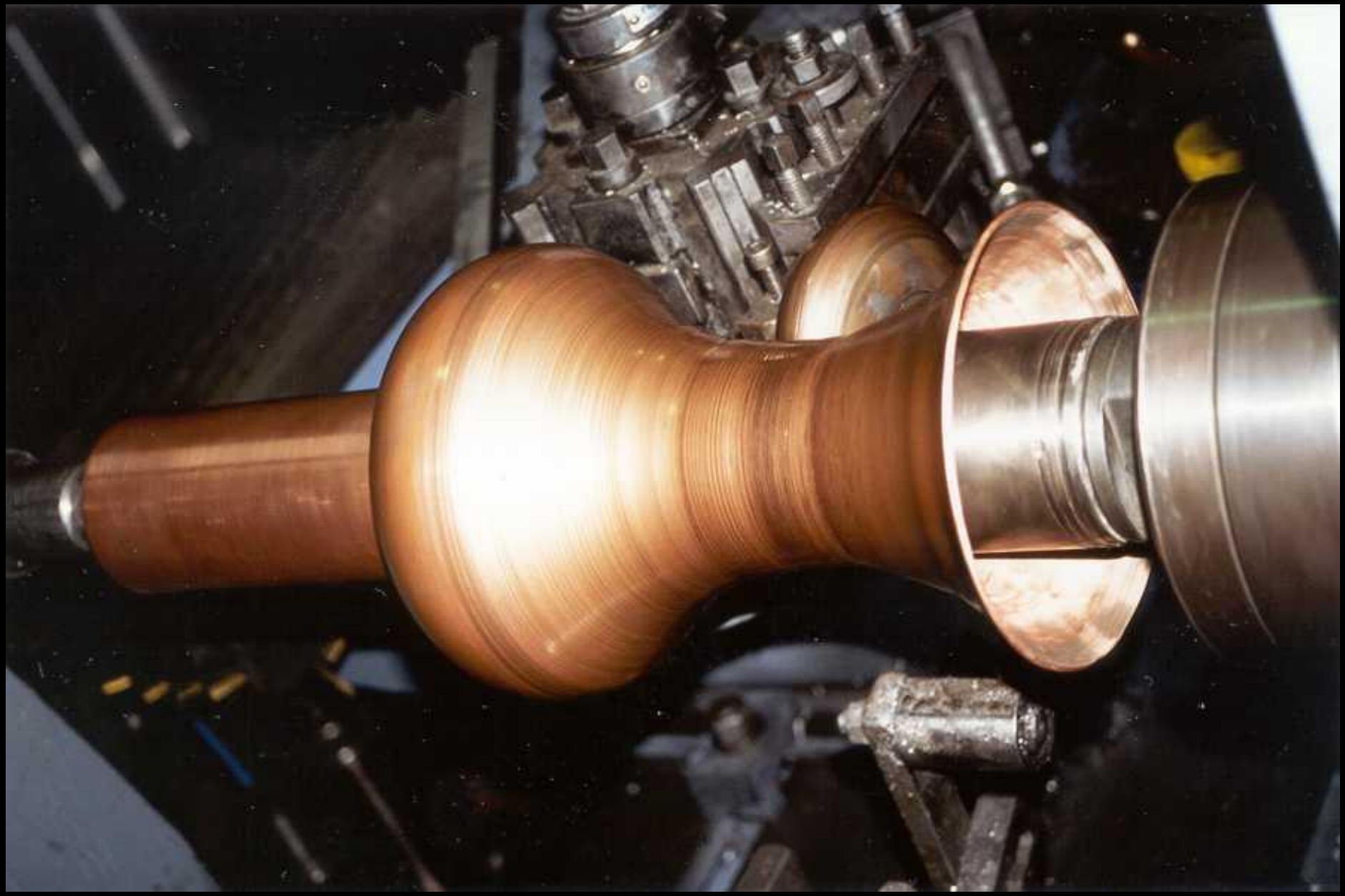


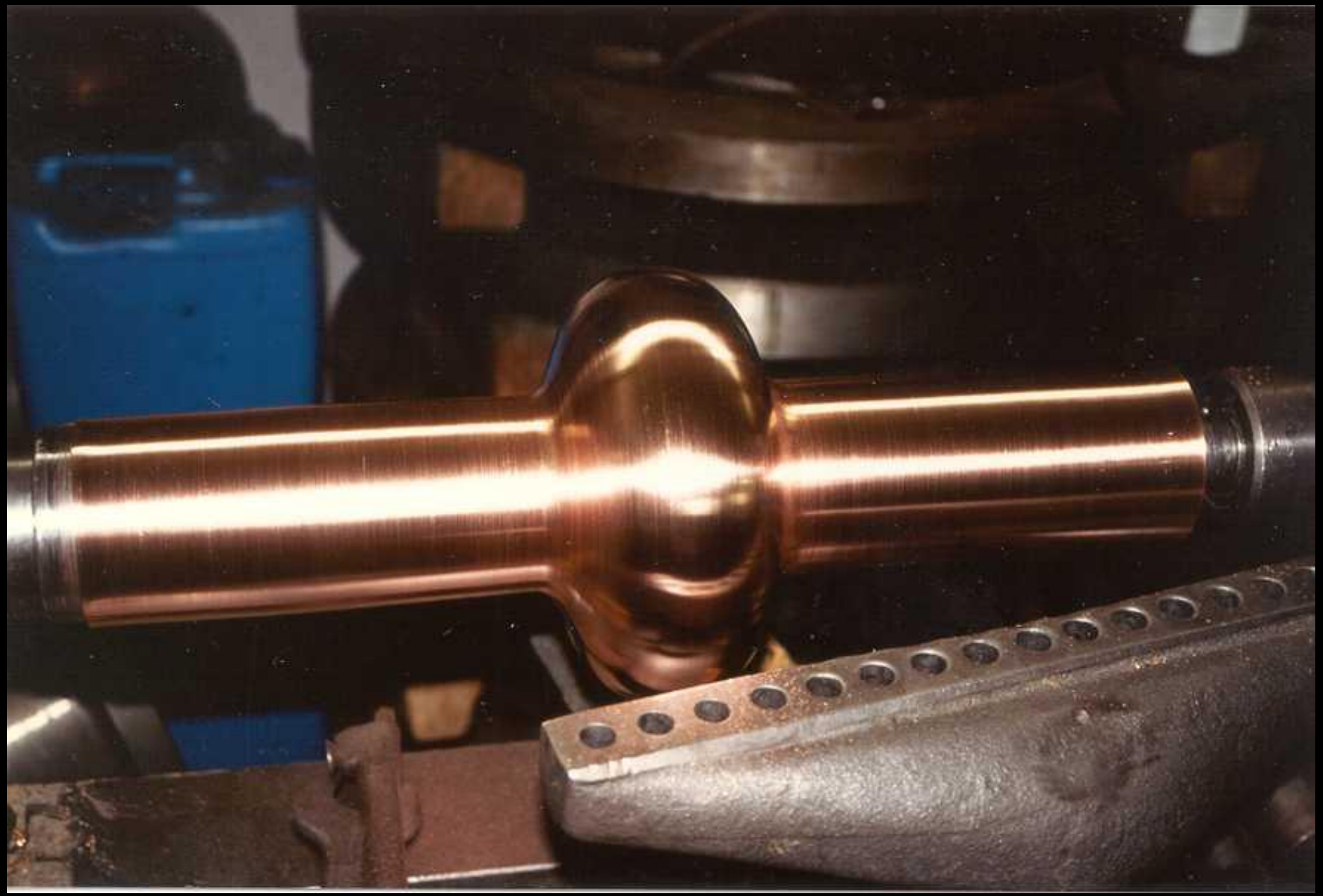


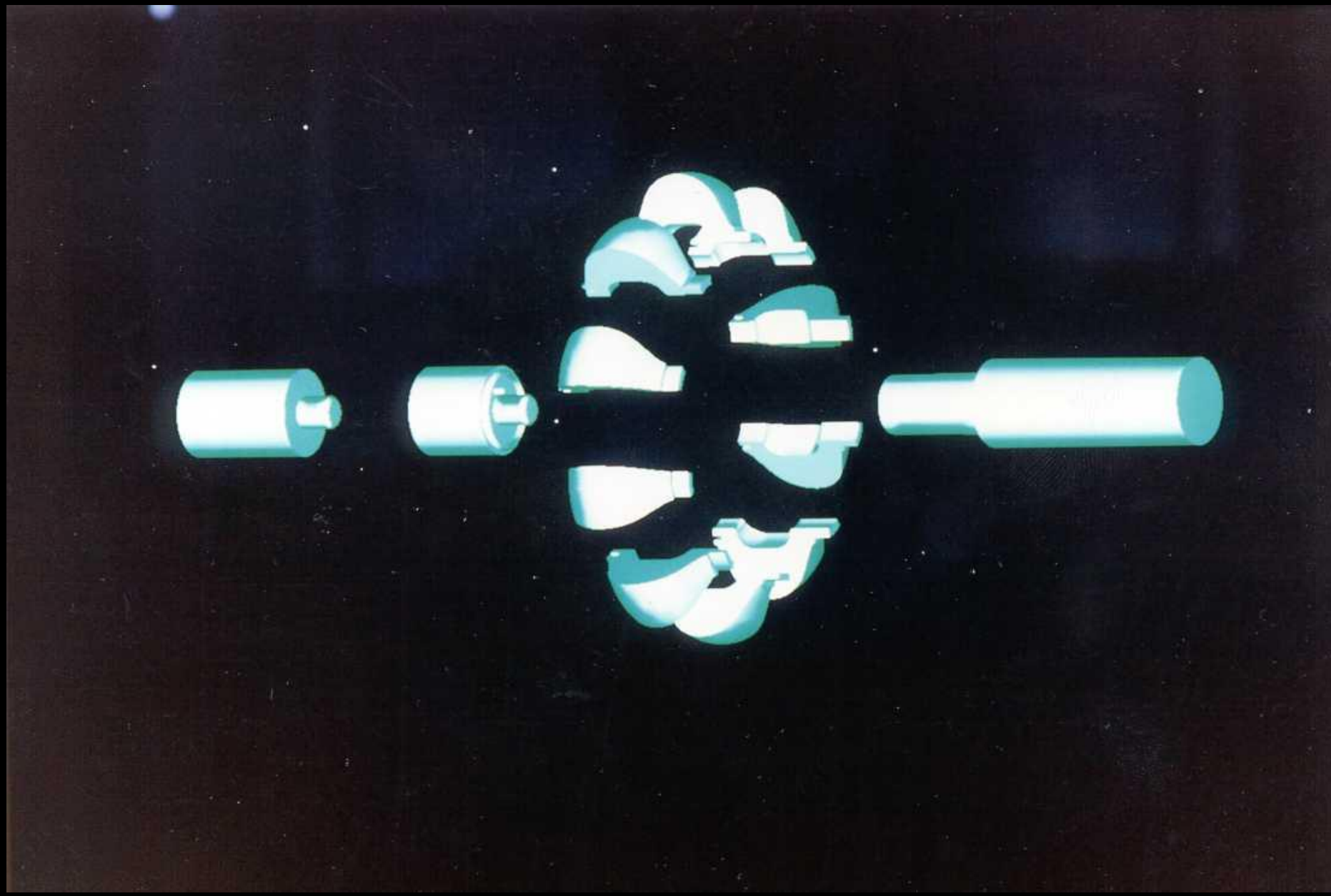


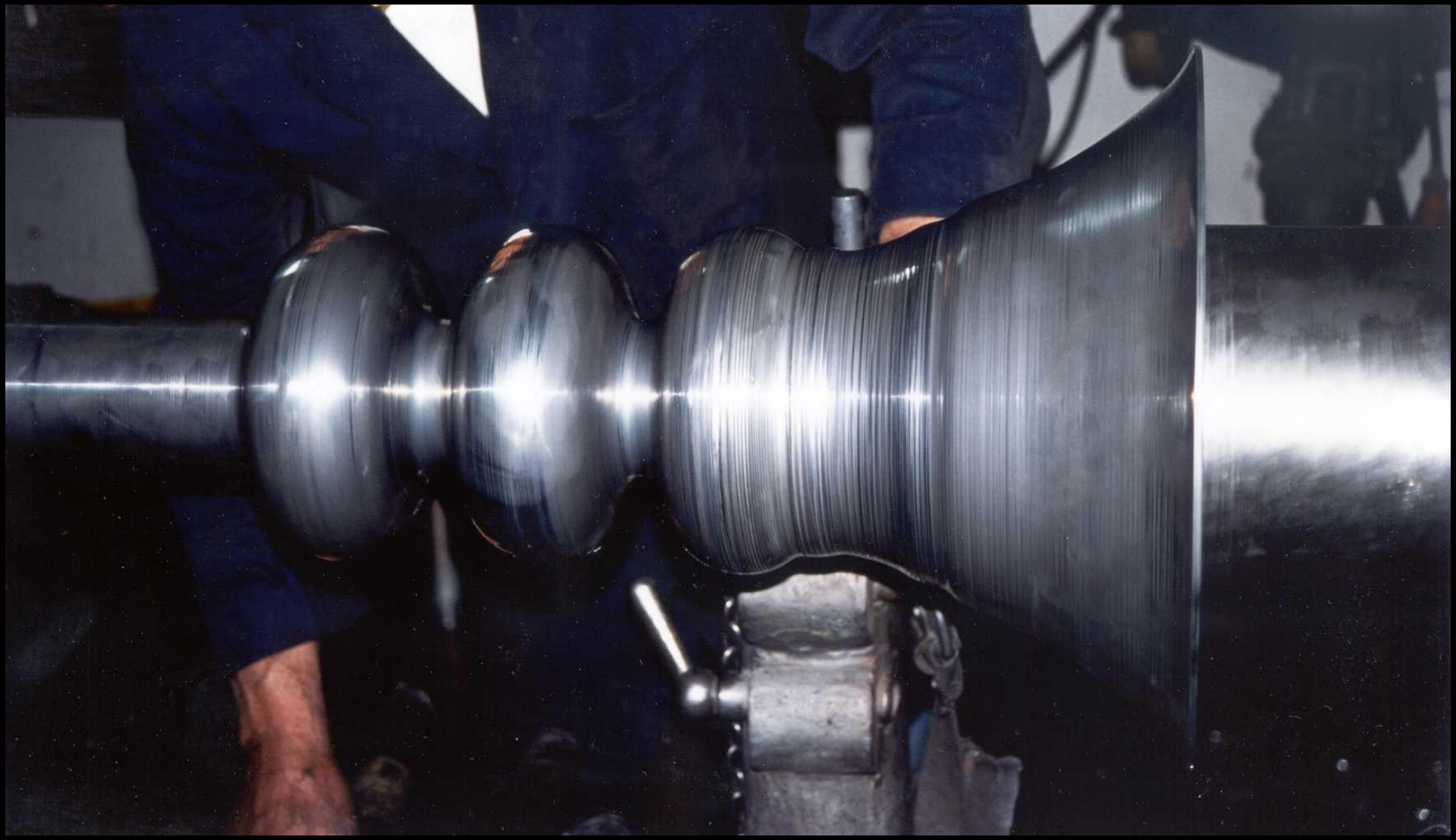


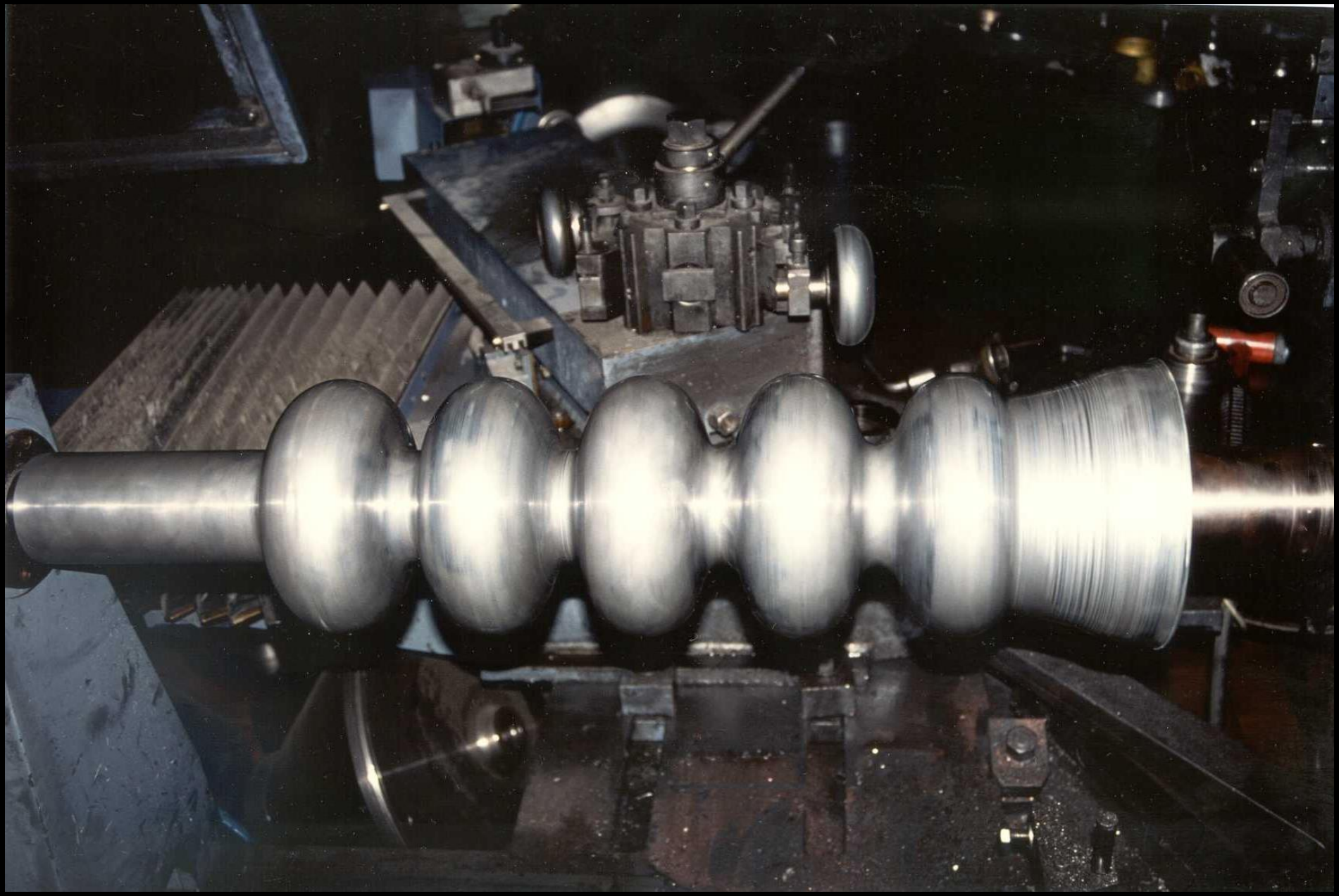


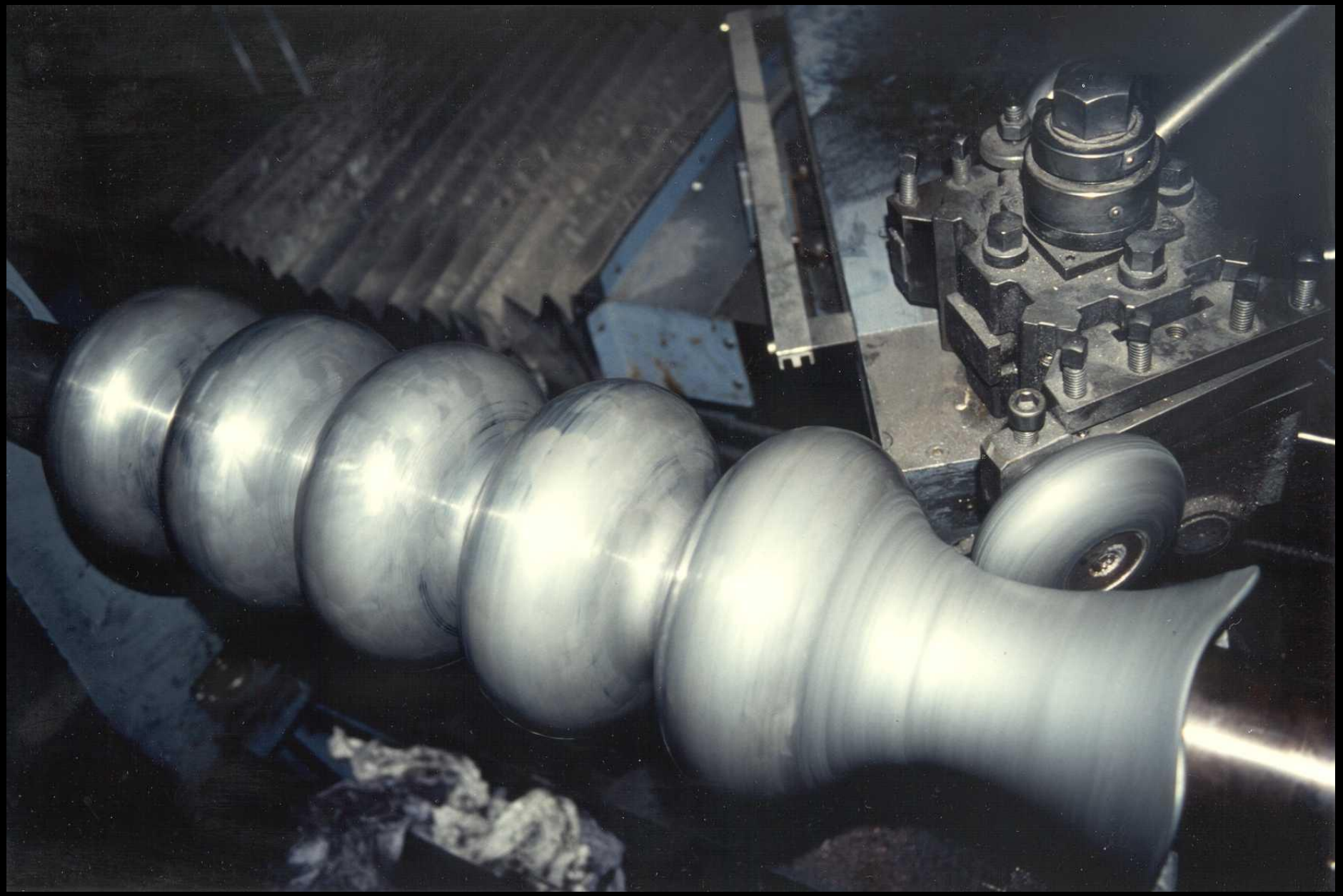


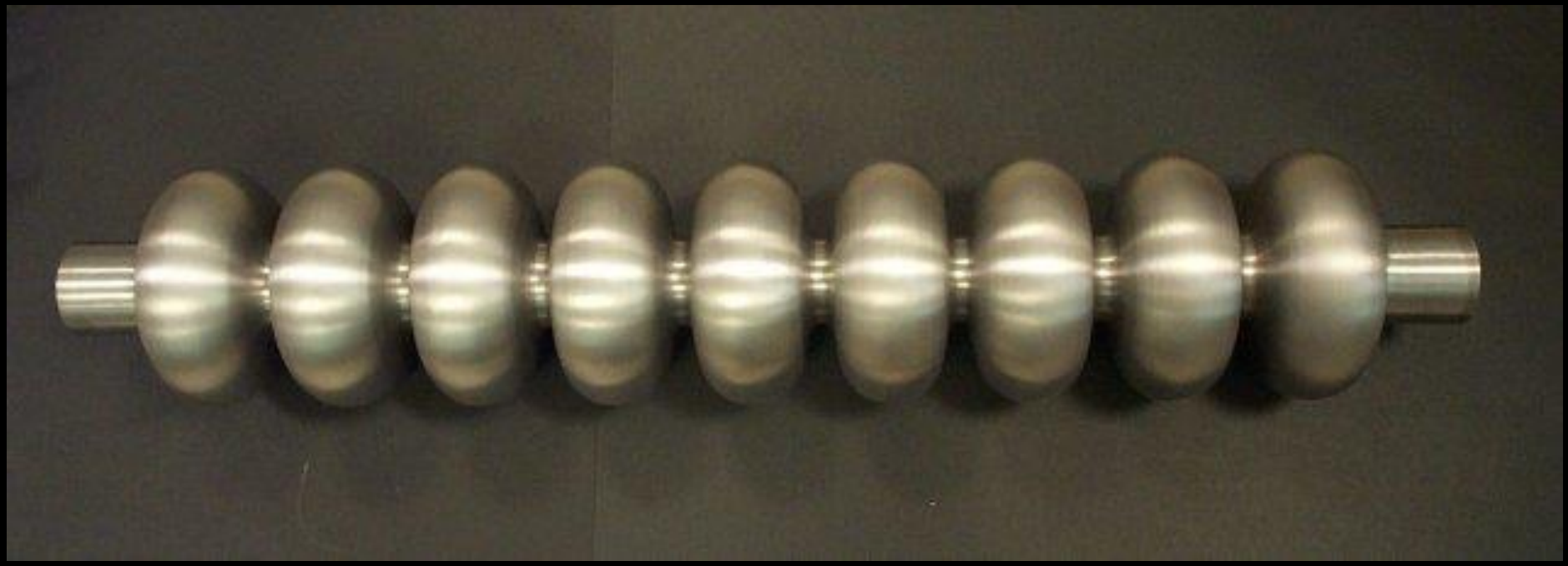


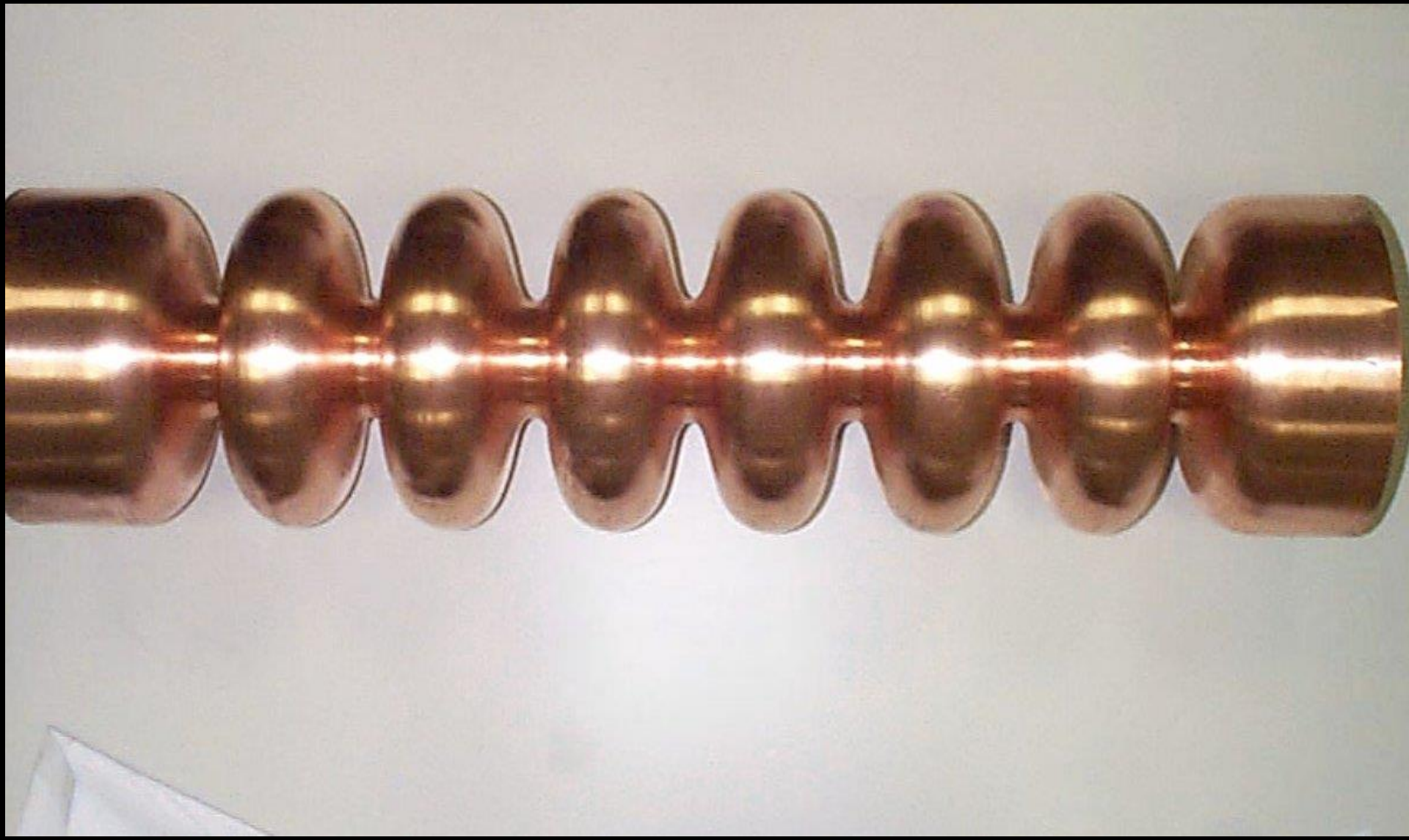








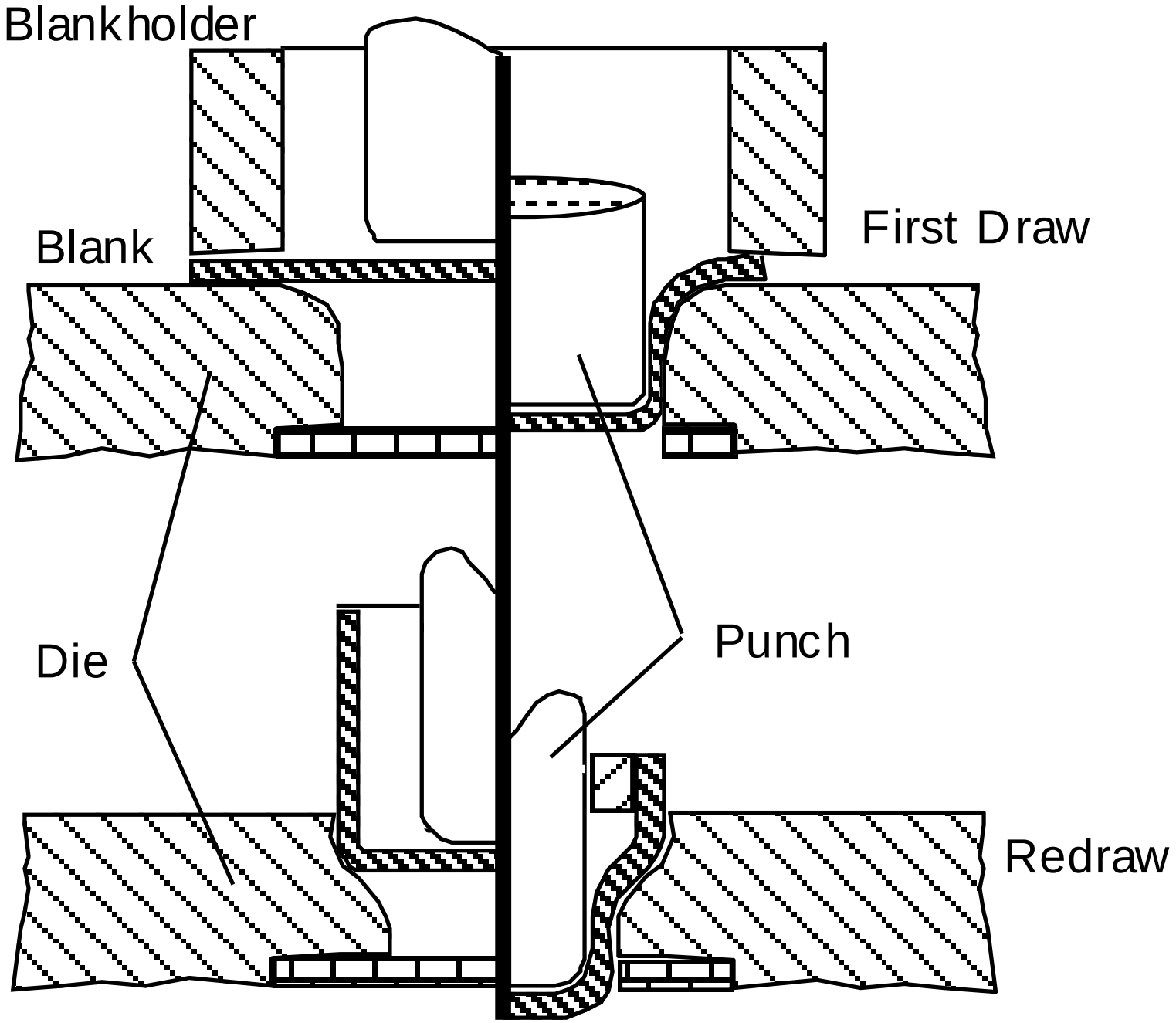




If we loook for a more engineerable process,

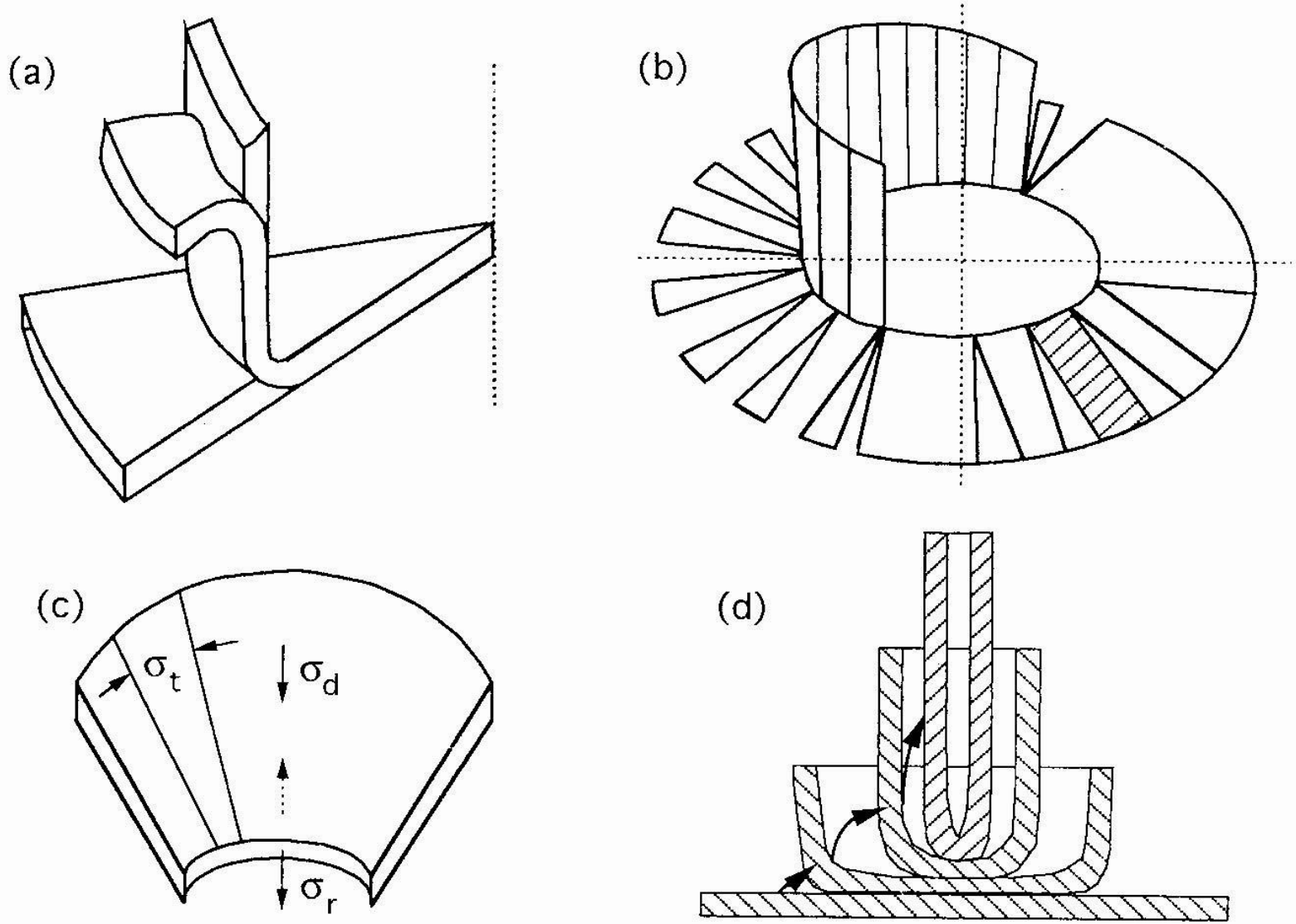
seamless tubes are mandatory

1. The Deepdrawing Process

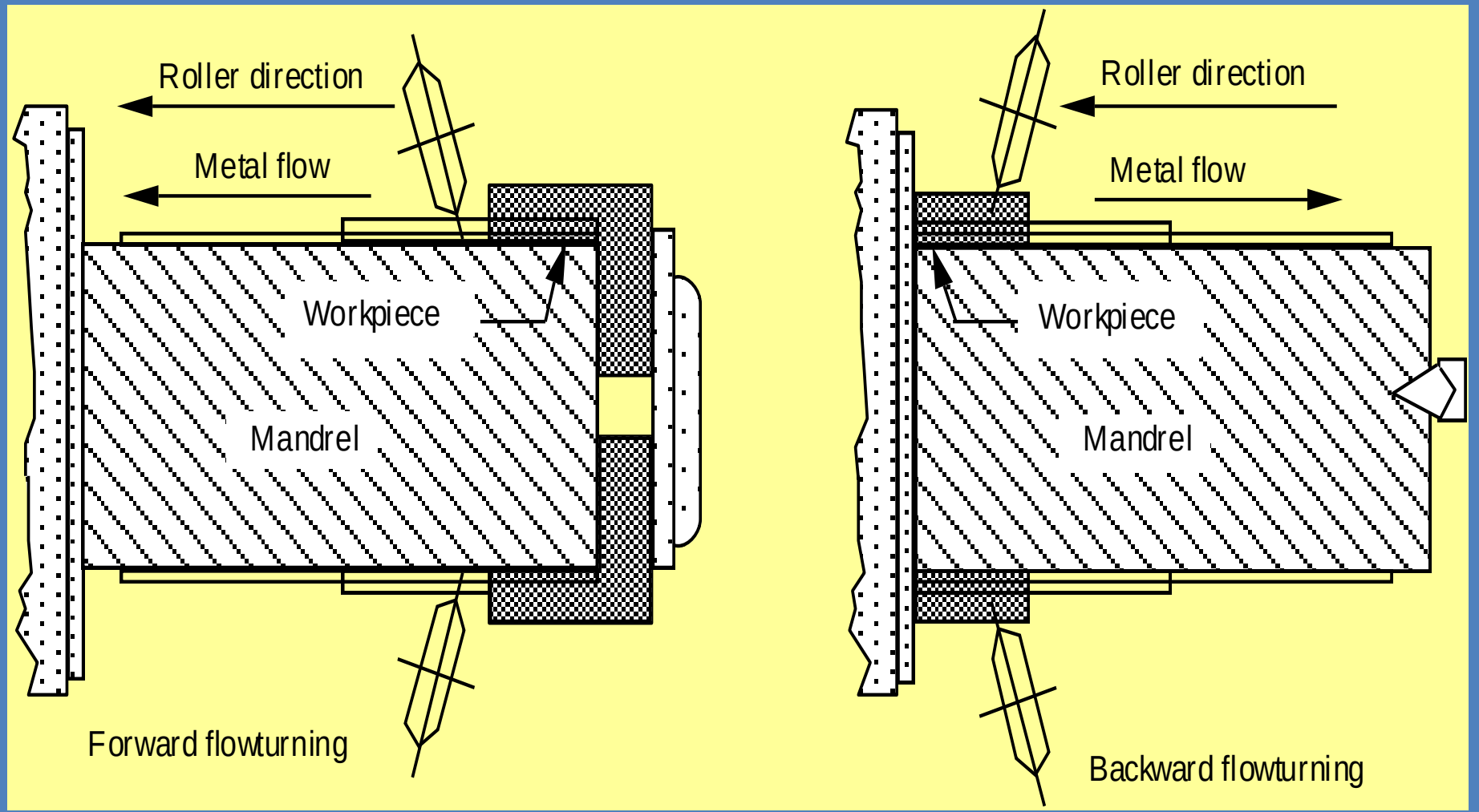

Blankholder
Blank
First Draw
Die
Punch
Redraw

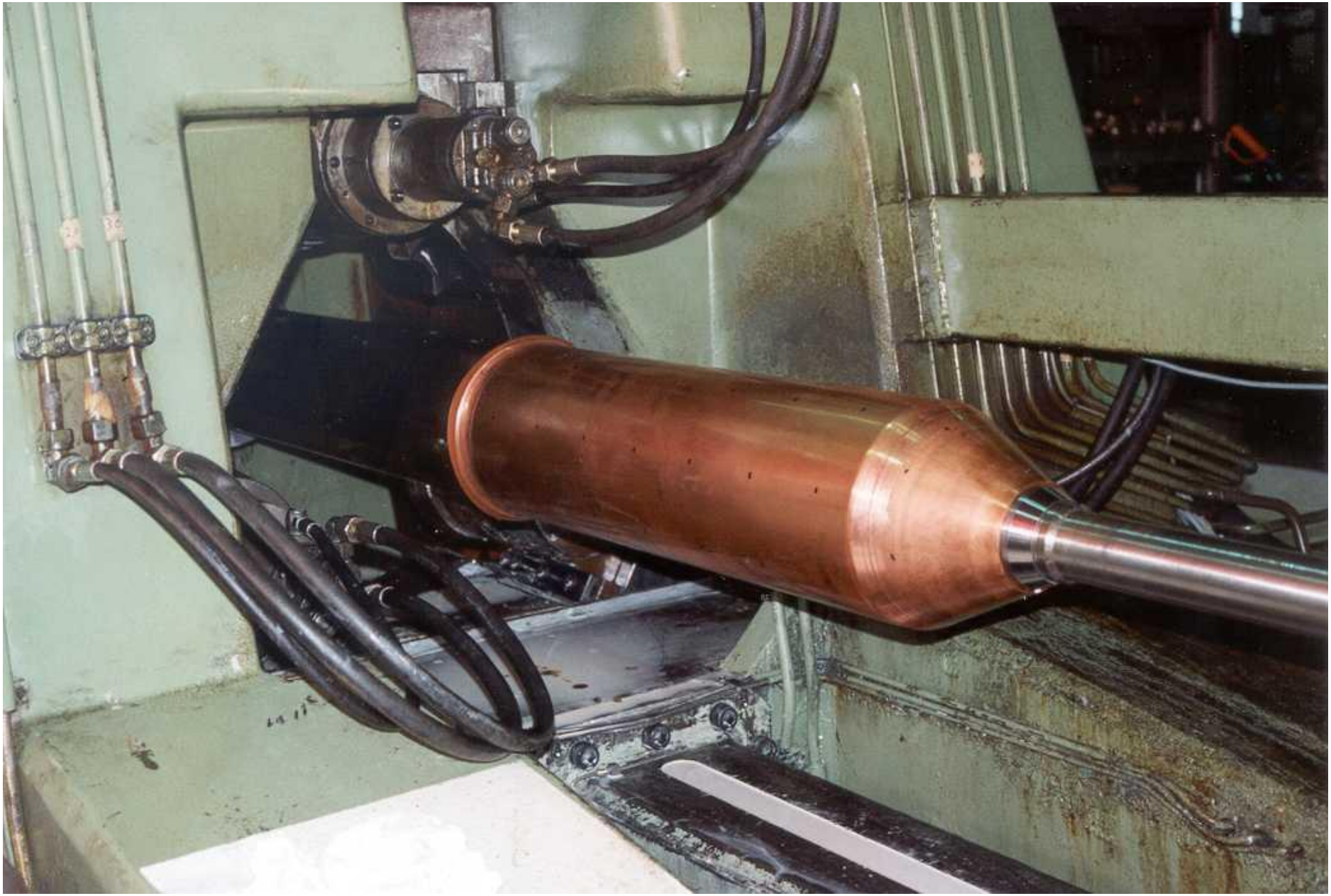


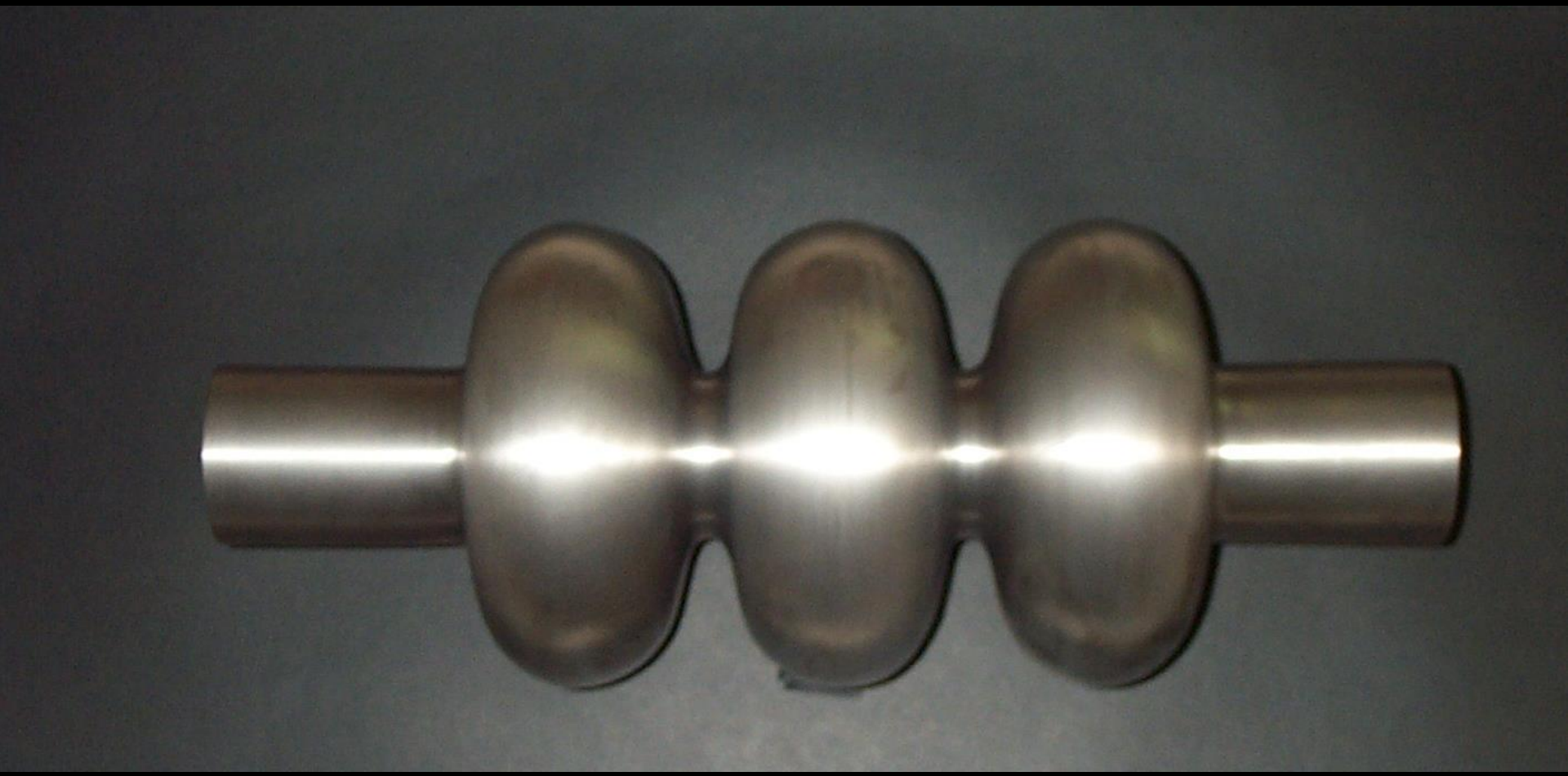




(a)
(b)
(c)
σ_t
σ_d
σ_r
(d)

3. The Flowturning Process


Roller direction
Metal flow
Workpiece
Mandrel
Forward flowturning
Roller direction
Metal flow
Workpiece
Mandrel
Backward flowturning





2 Nb ninecells

fabricated in 2001 for being measured at KEK

Unfortunately both cavities were broken

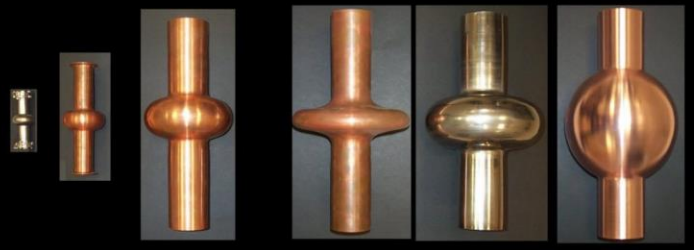
on last cell during tumbling,

then weld to a standard EB weld monocell

in order to have again a 9-cell

Cavities of any shape and any size

Cavities Spun at LNL

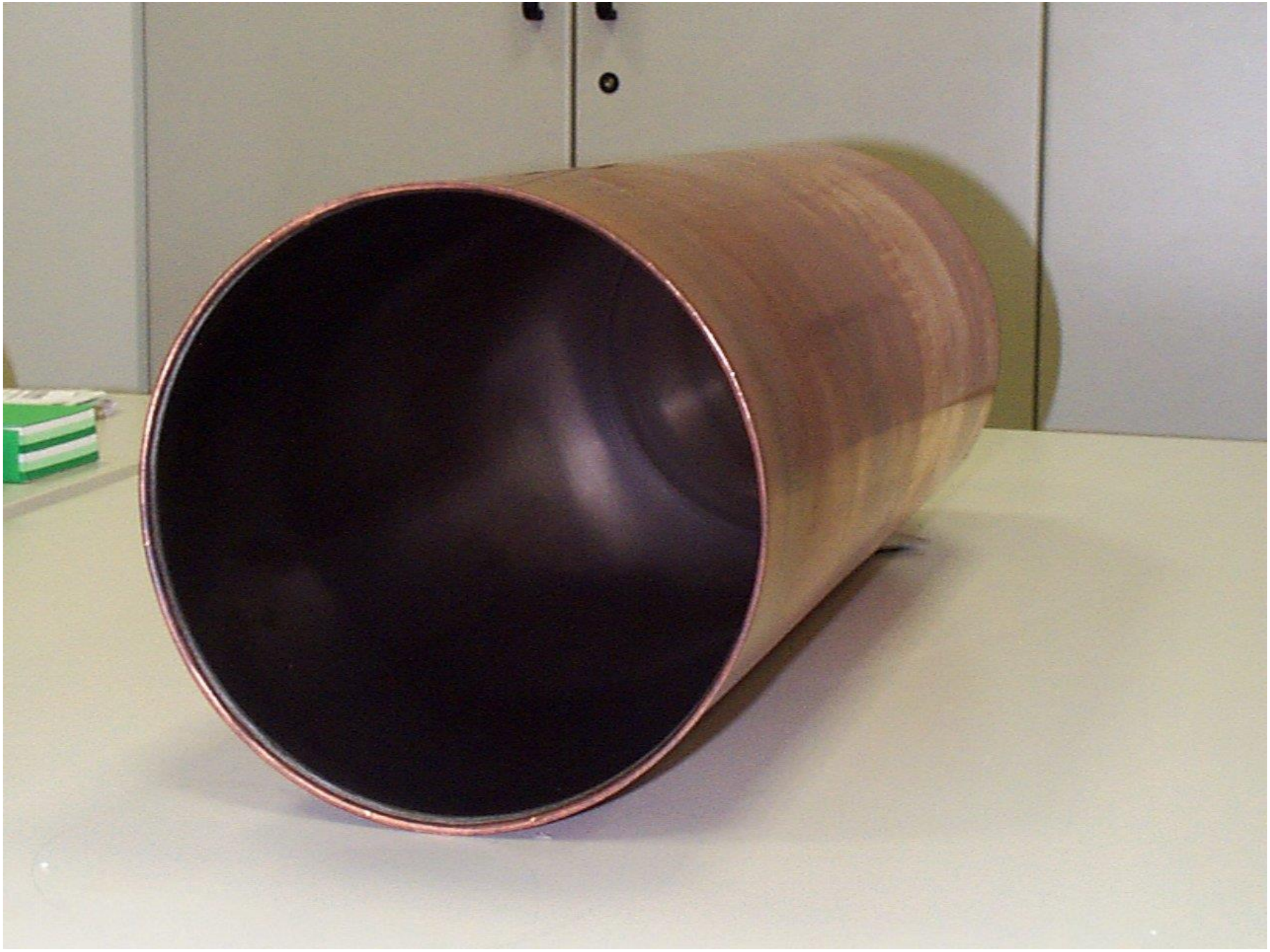


6 GHz

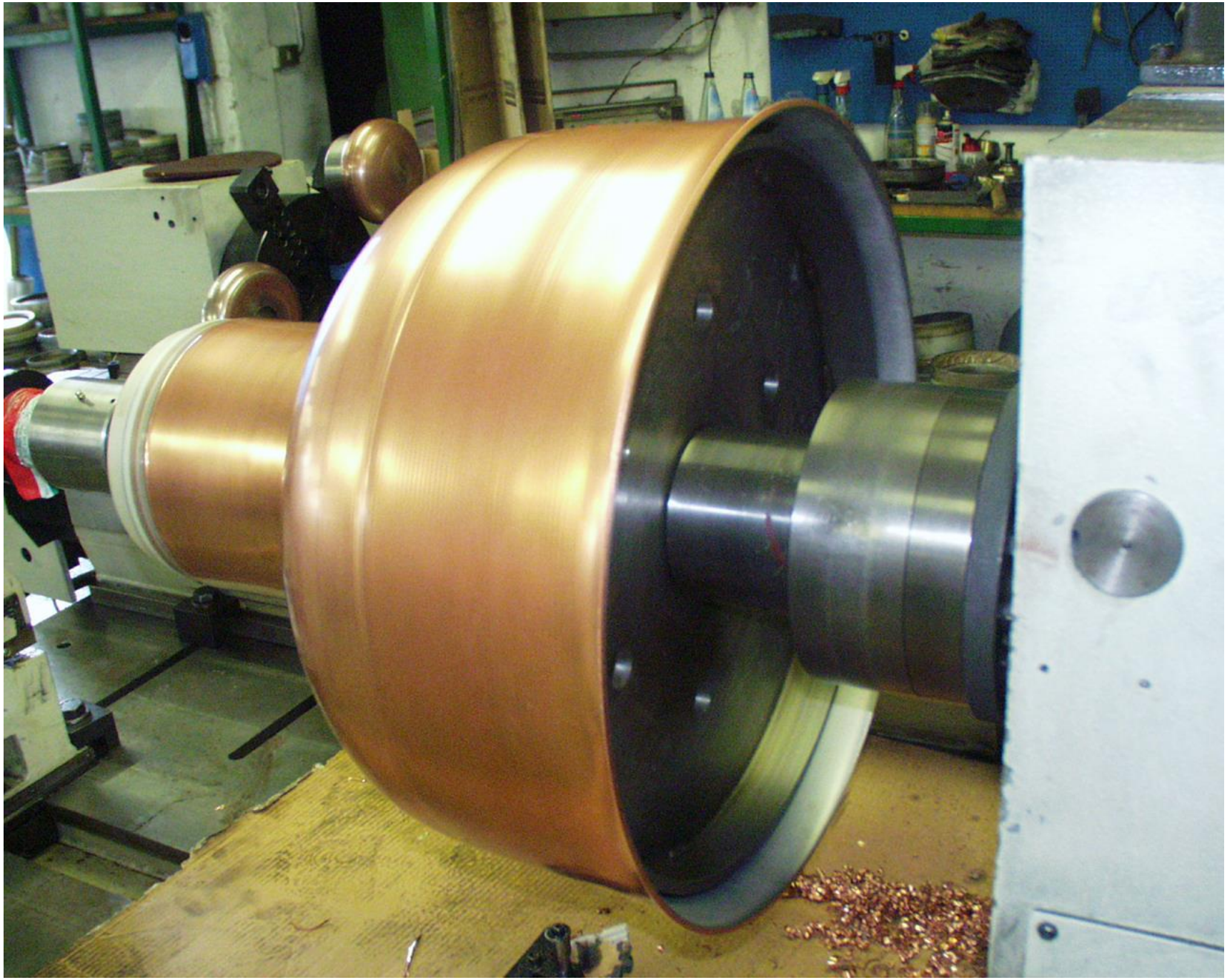
500 MHz

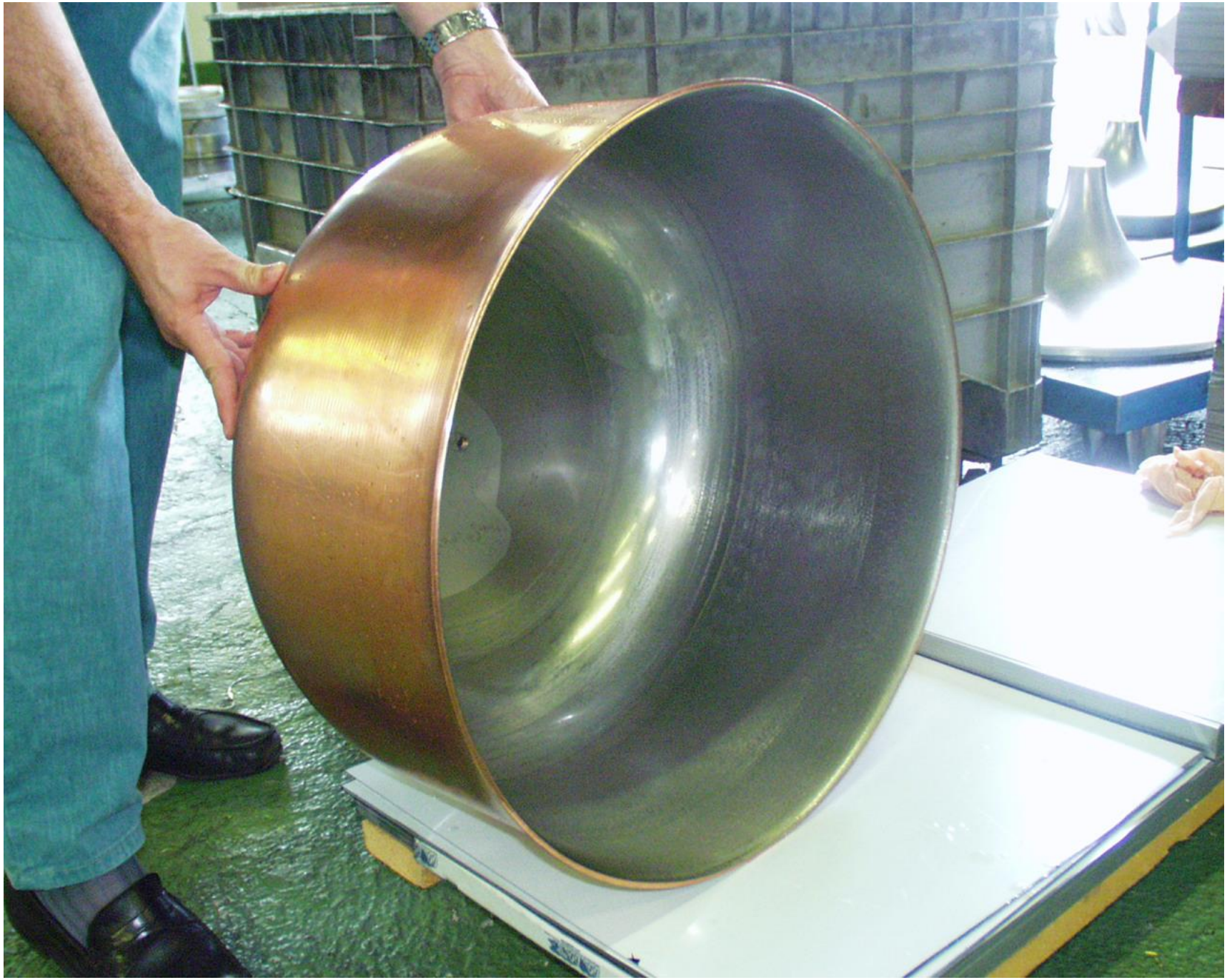
Nb Clad Cu?

No Problem!




4.8.2000

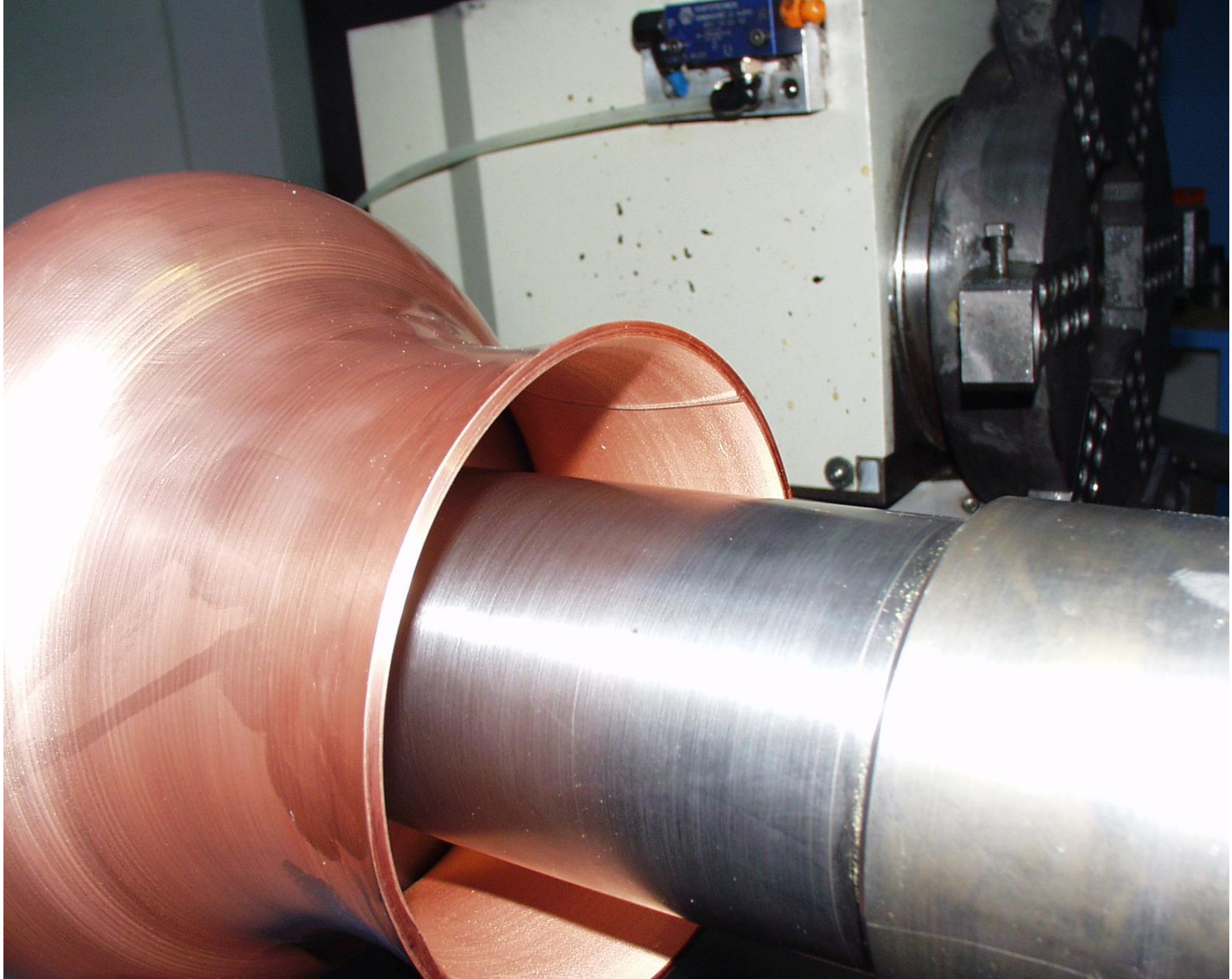




The Spinning Proceedure

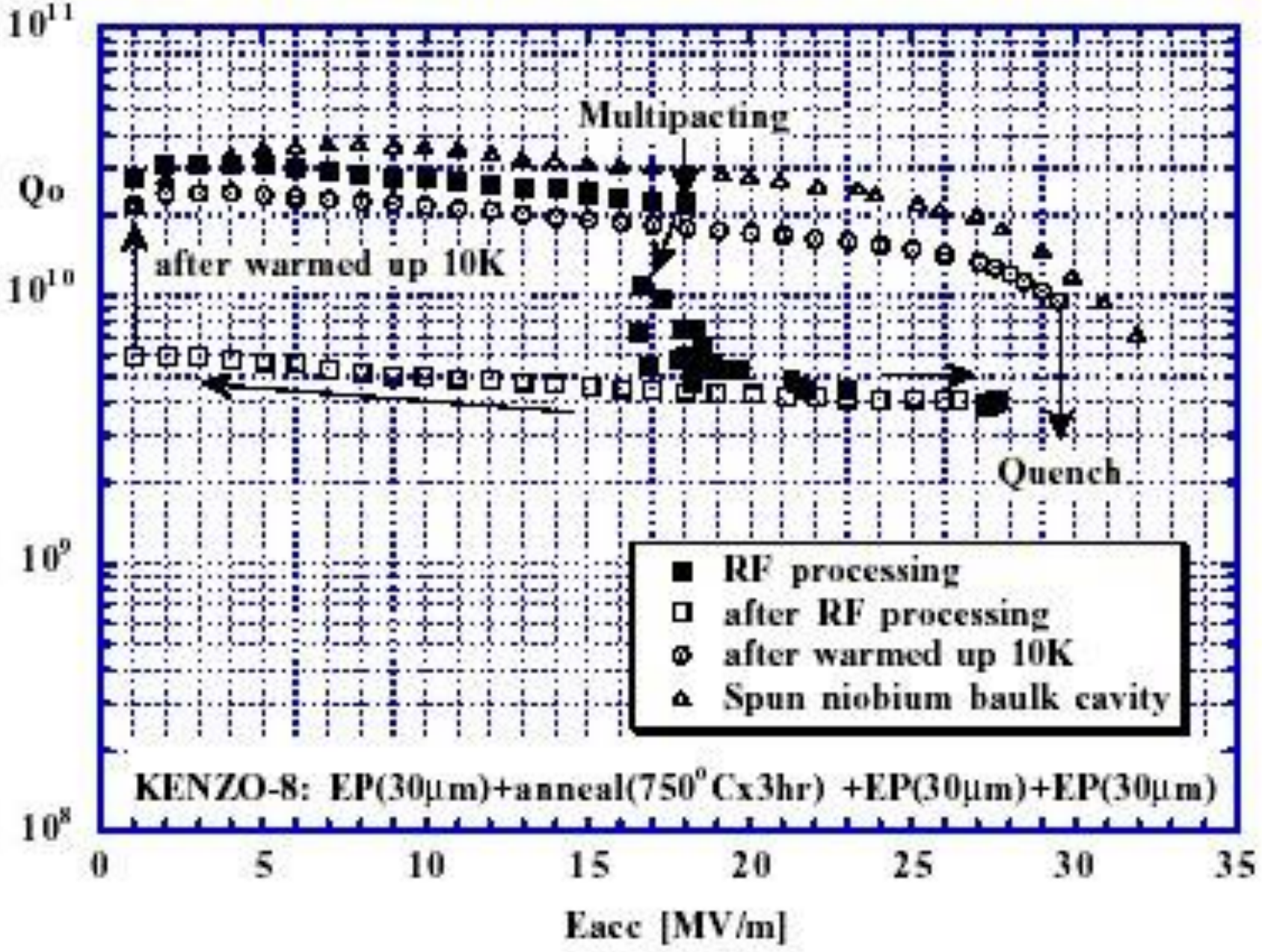
The initial staus of the blank surfaace

must be defect and scratch free

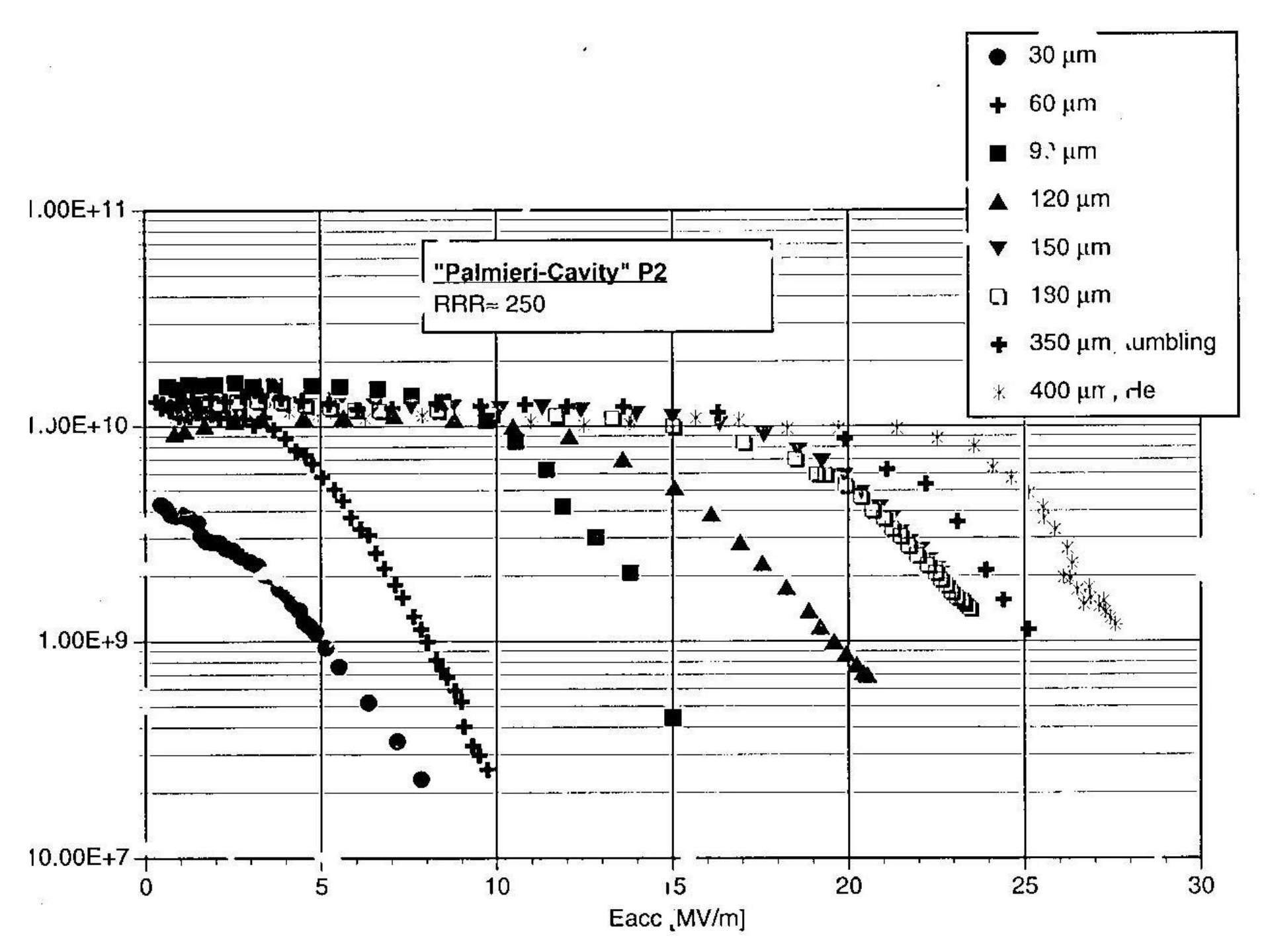


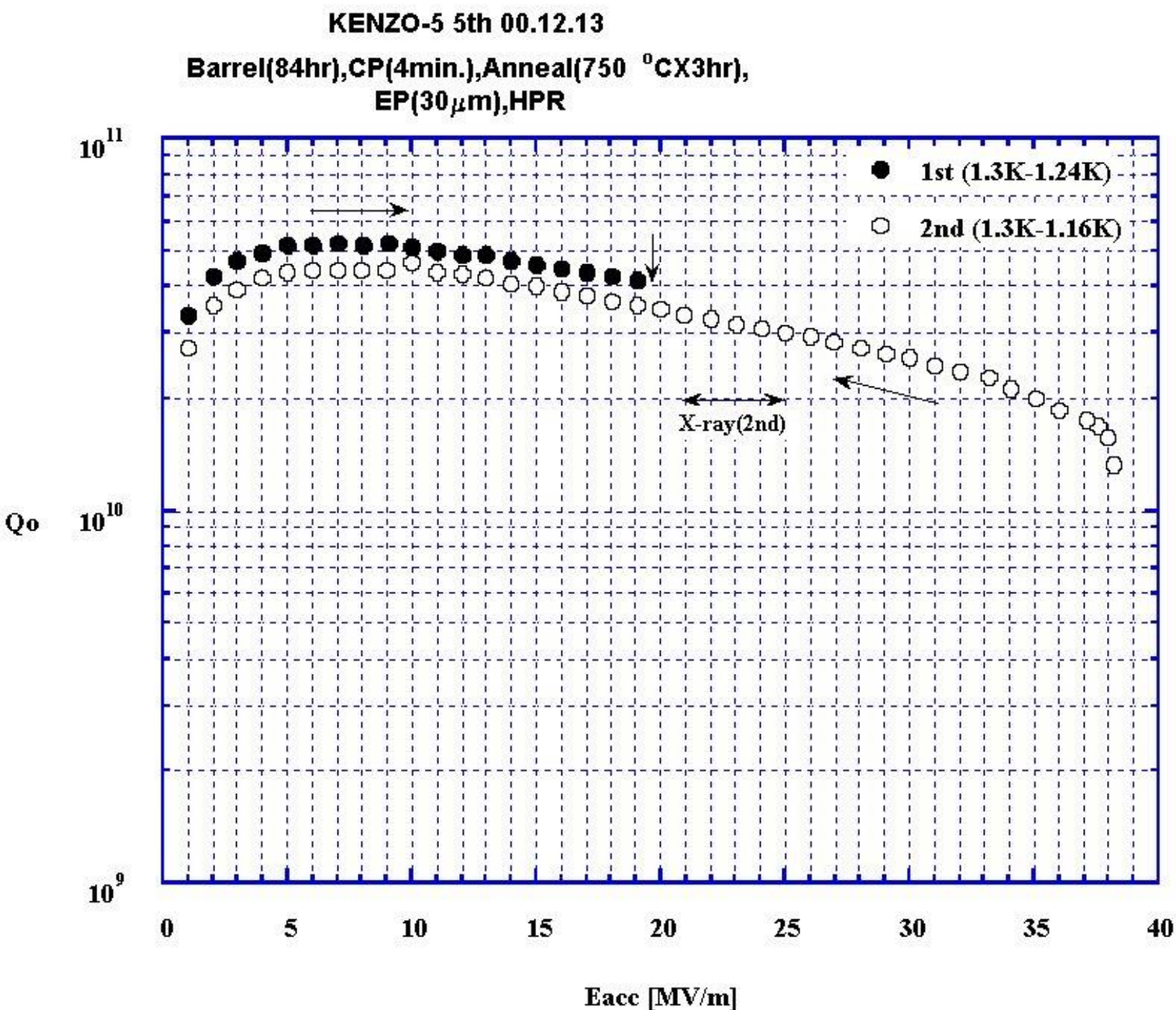
Q vs E_{acc} Results


4.8.2000

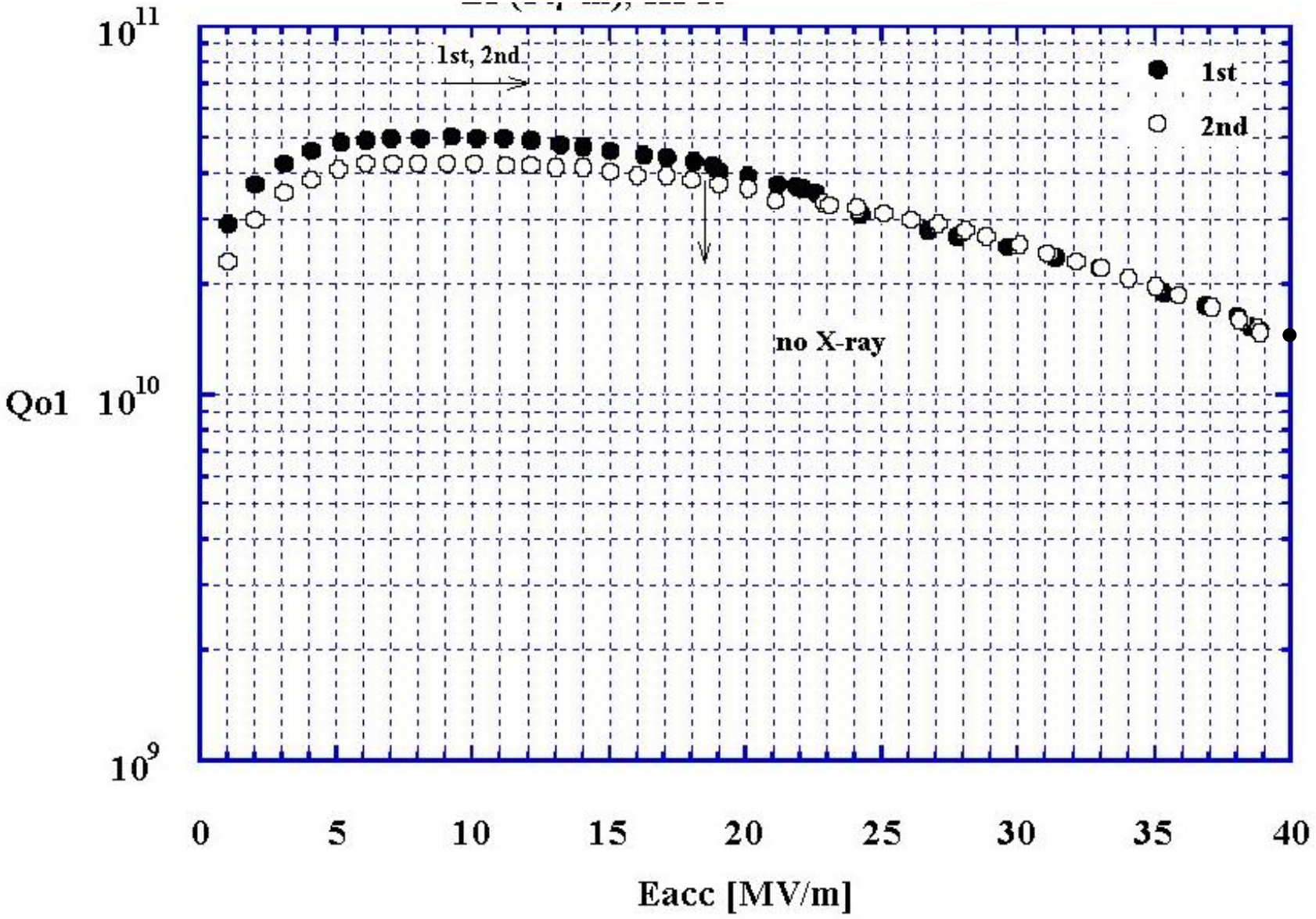

Multipacting
after warmed up 10K
Quench
RF processing
after RF processing
after warmed up 10K
Spun niobium baulk cavity
KENZO-8: EP(30μm)+anneal(750°Cx3hr) +EP(30μm)+EP(30μm)
Qo
Eacc [MV/m]
10^11
10^10
10^9
10^8
0
5
10
15
20
25
30
35

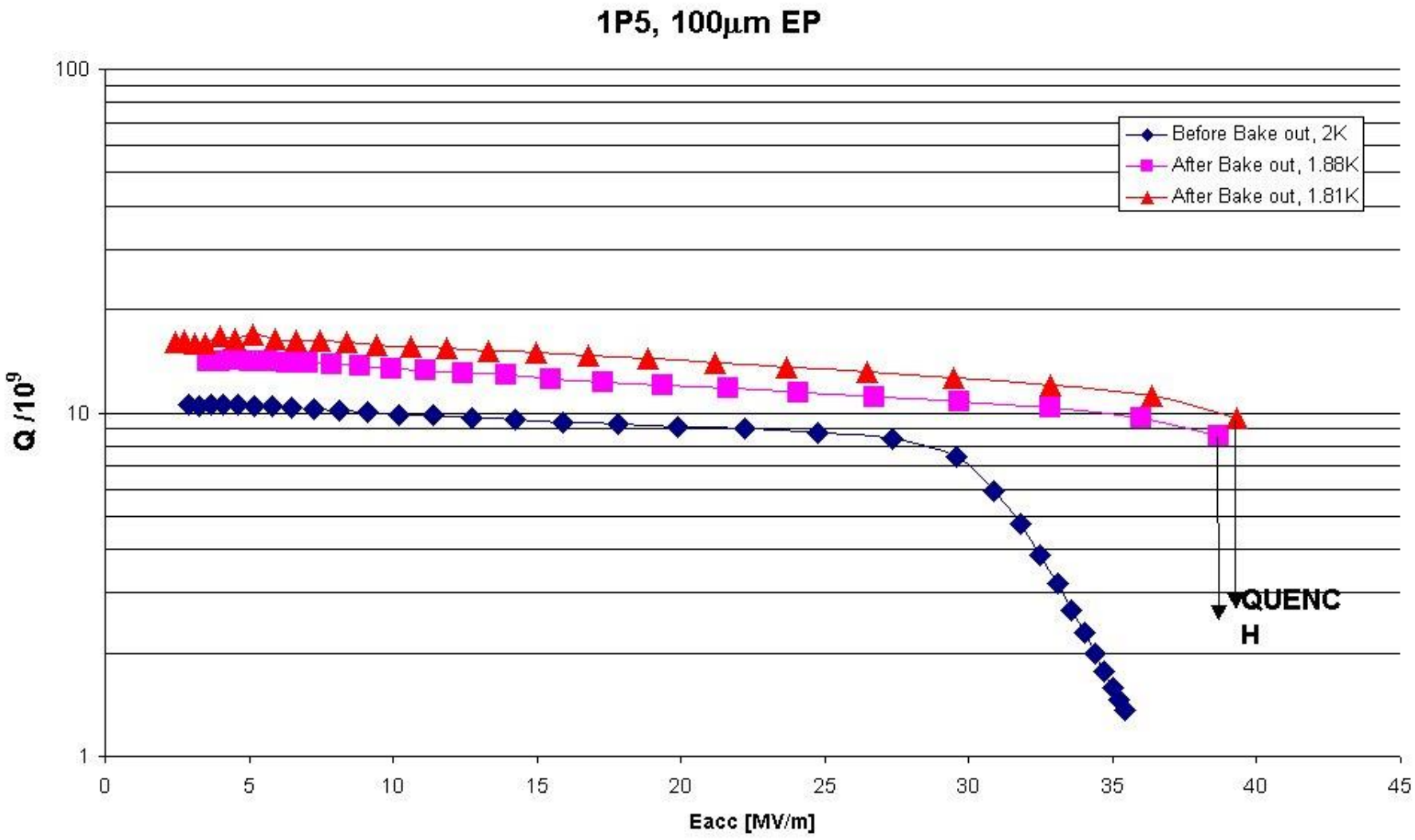
Bulk Nb cavities


"Palmieri-Cavity" P2
RRR= 250
30 µm
60 µm
120 µm
150 µm
180 µm
350 µm, tumbling
400 µm, rle
1.00E+11
1.00E+10
1.00E+9
10.00E+7
0
5
10
15
20
25
30
Eacc [MV/m]

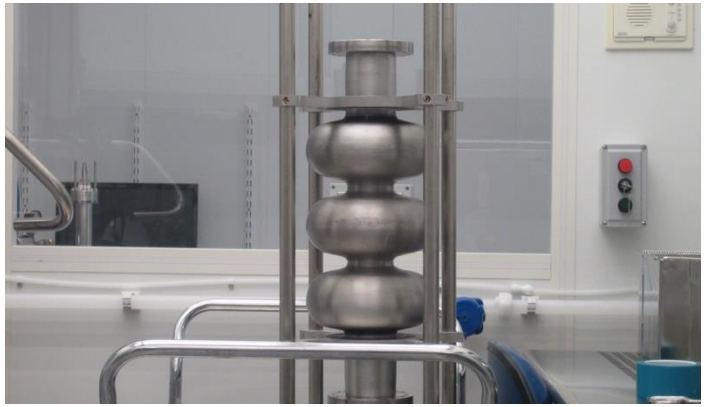

KENZO-5 5th 00.12.13
Barrel(84hr),CP(4min.),Anneal(750 °CX3hr),
EP(30μm),HPR
1st (1.3K-1.24K)
2nd (1.3K-1.16K)
X-ray(2nd)
Qo
10^11
10^10
10^9
0
5
10
15
20
25
30
35
40
Eacc [MV/m]

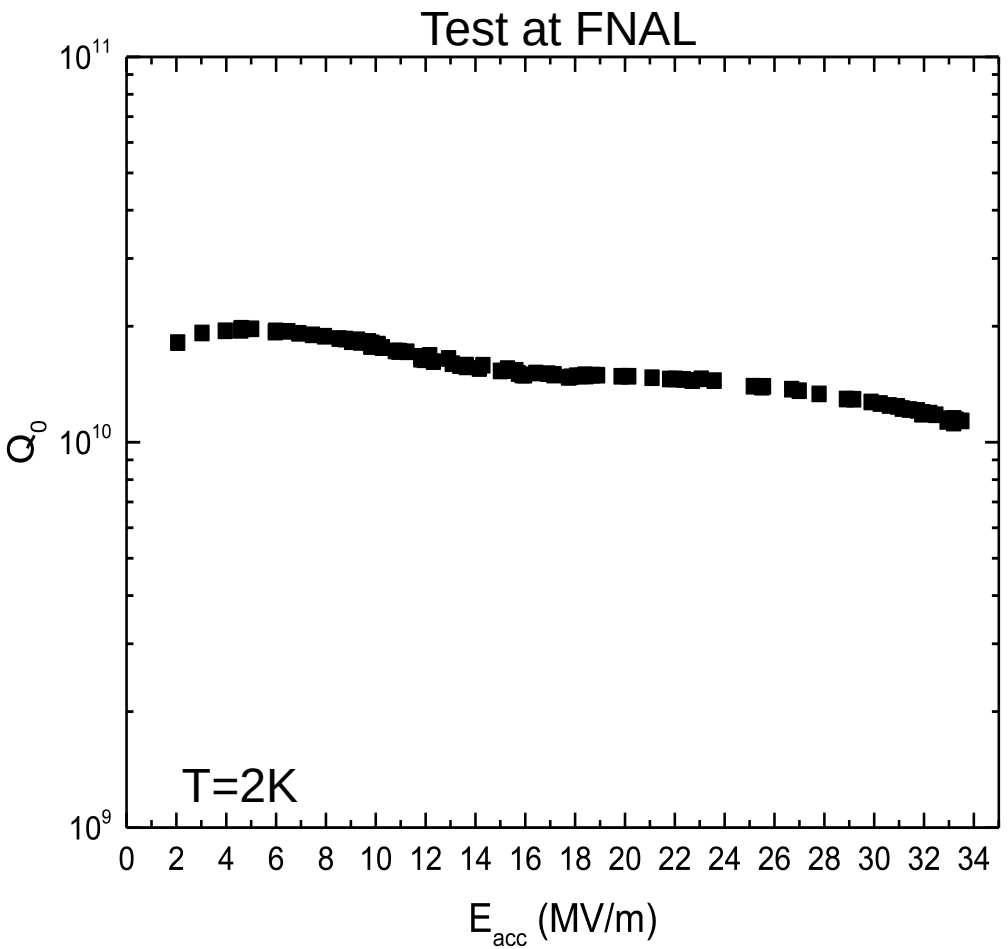
The best result on a LNL monocell spun cavity, measured at KEK by Kenji SAITO




1P5, 100µm EP
Before Bake out, 2K
After Bake out, 1.88K
After Bake out, 1.81K
QUENCH
Q /10^9
Eacc [MV/m]
100
10
1
0
5
10
15
20
25
30
35
40
45

3-cell cavity made from Nb tube by spinning at INFN

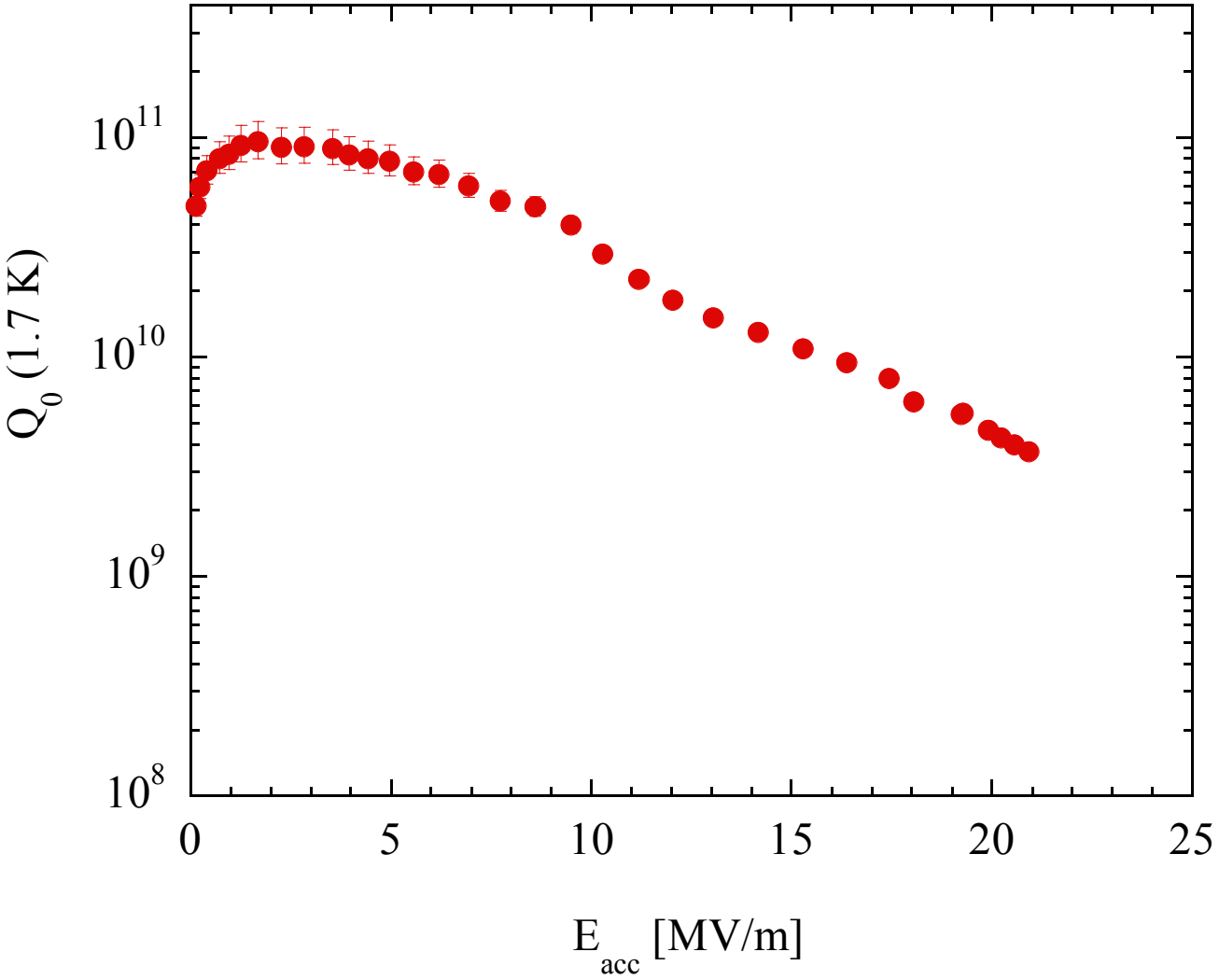




Spinning is mandatory for Nb/Cu Sputtered cavities

Nb film onto hydroformed cavities does not work!

Nb sputtered Cu spun cavity



Current Work:

Tube back-extrusion

directly from from billets

Workpackage on

6 GHz cavity R&D activity

Surface Resistance measurement

The fabrication, surface treatments, RF test of a real cavity require a long preparation time

It is important therefore to speed up research by production and RF test of samples

However all sample Rf measuremts are indirect, based on the subtraction priciple

6 GHz Seamless cavity:
WHY A EASY TOOL ?

No electron beam welding, neither for flanges

Obtained by spinning from Nb scraps

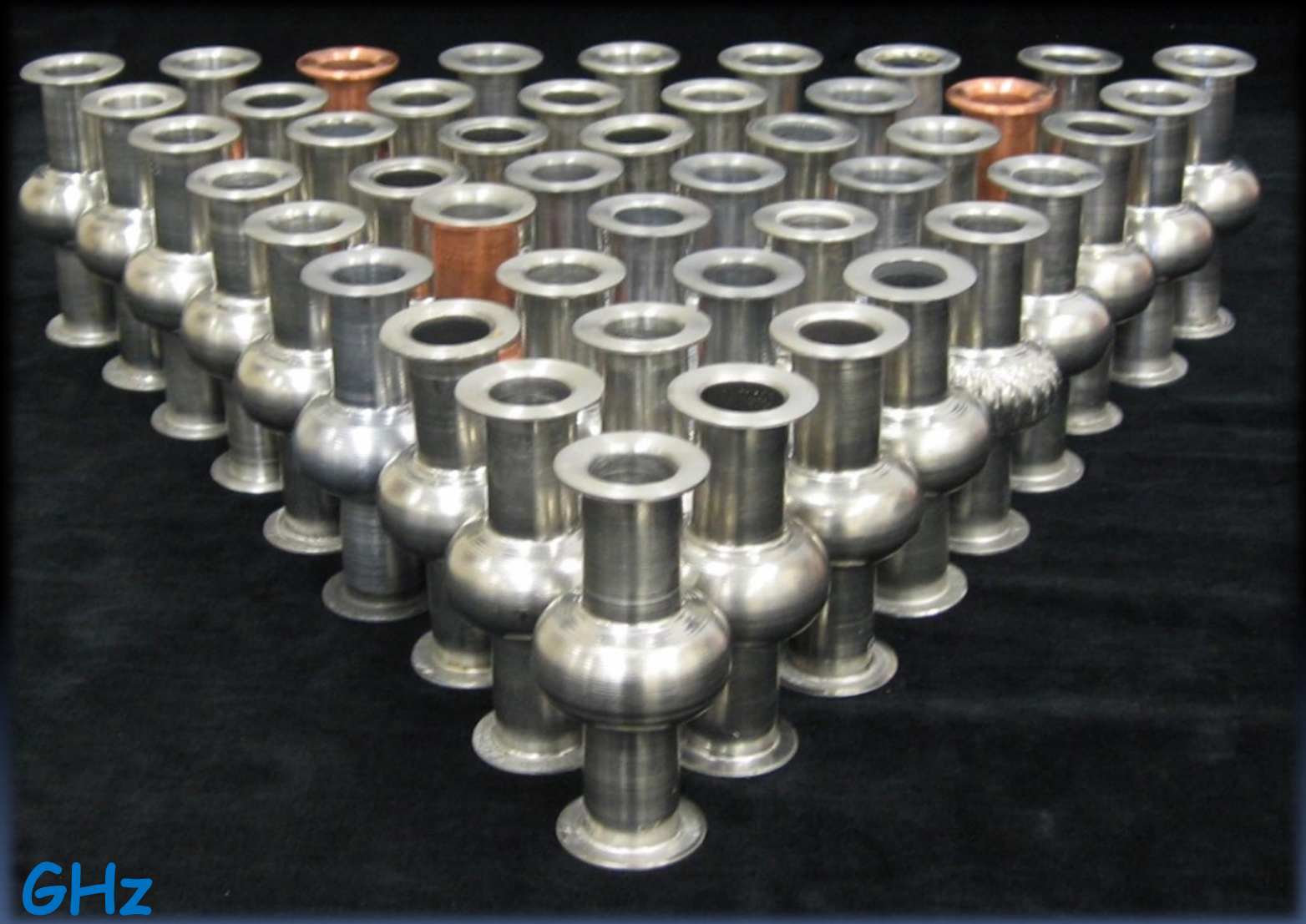
Short fabrication time

Fast and low cost BCP and EP treatments (~ 3lt acids)

Inexpensive Cryogenics, fast cooling and warming up

Quick RF Measurements (traditional rf system)

Low research budget → Large amount of cavities



6 GHz

A seamless flange

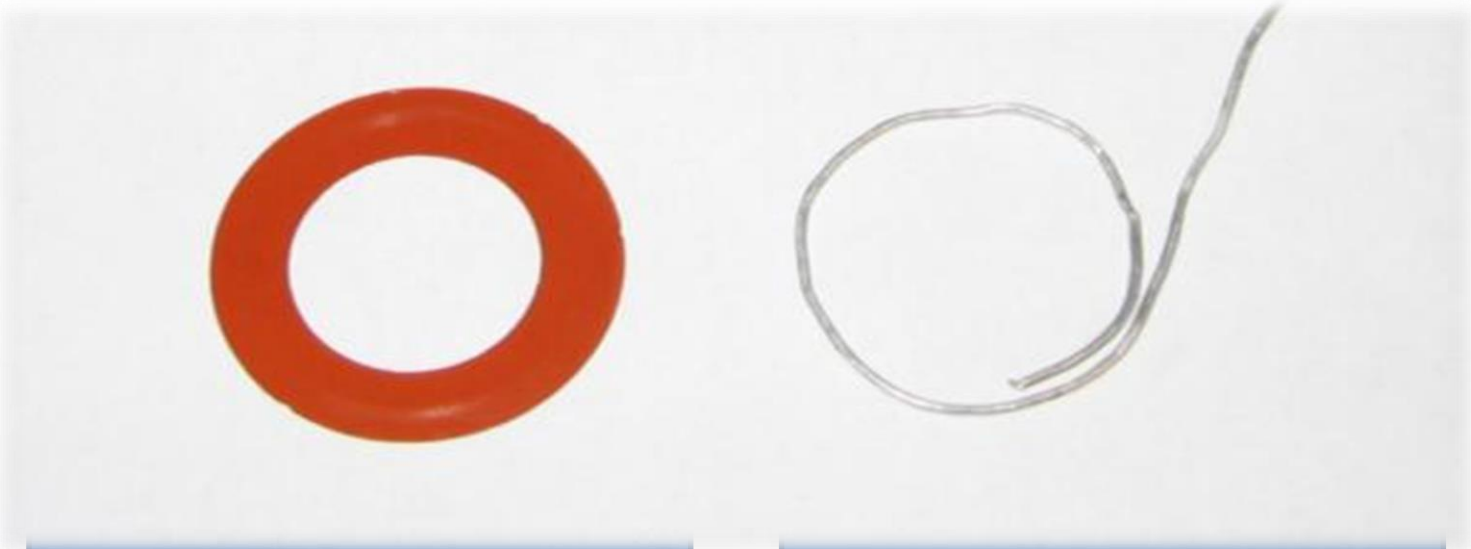
Cheap alternative to welded Nb-Ti

New flange design

Use **Kapton Joints** for sealing cavities

and ...

Life will never be the same!



A 6 GHz low cost Minilab

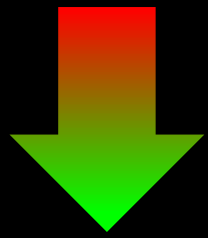
Miniaturized:

- Mechanical Polishing
- Buffered Chemical Polishing
- Thermal Treatment
- Sputtering
- Other Deposition Techniques
- Cryogenics

Mechanical

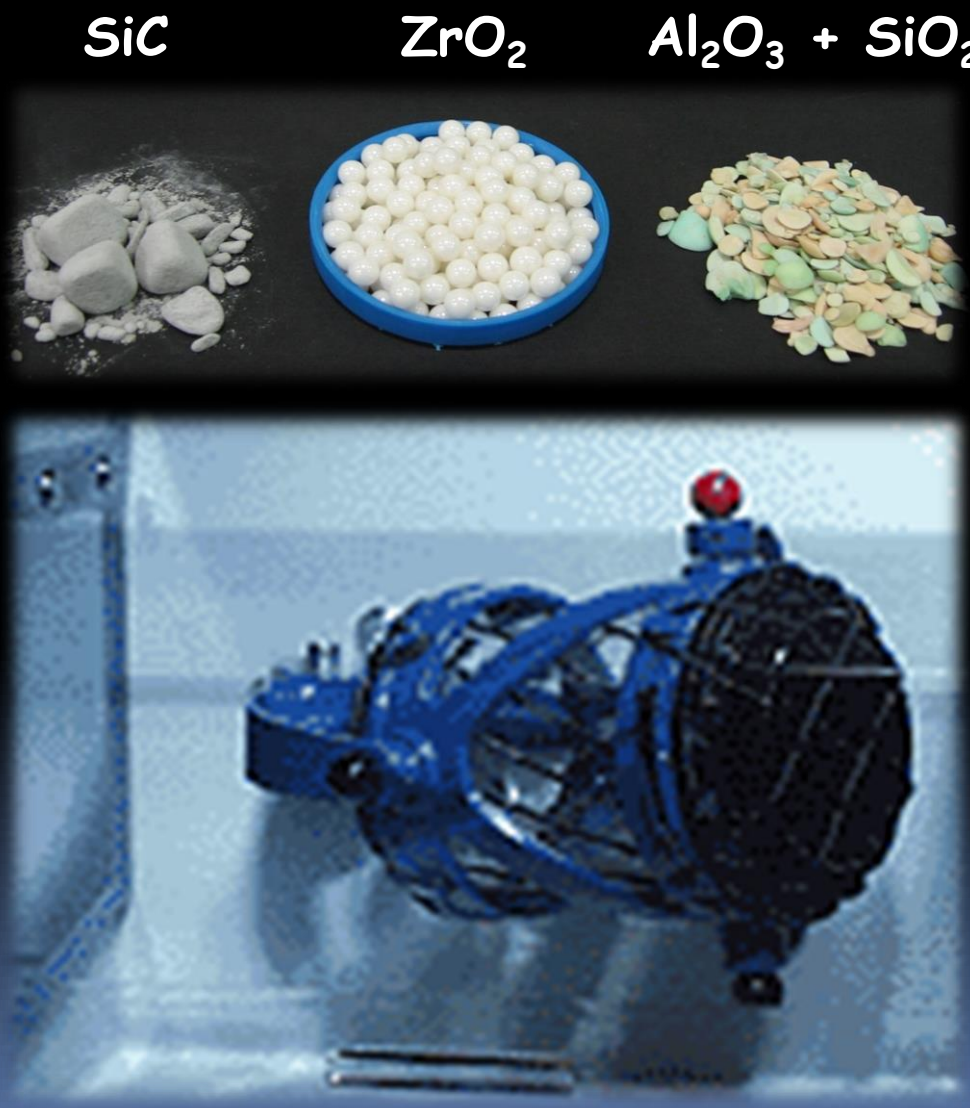
Starting internal surface conditions:

- bad finishing
- presence of contaminants



Streatments:

✓ Mechanical



BCP

Starting internal surface conditions:

- bad finishing
- presence of contaminants

Streatments:

✓ Mechanical
✓ BCP

HF, HNO_3, H_3PO_4
1:1:2

EP

Starting internal surface conditions:

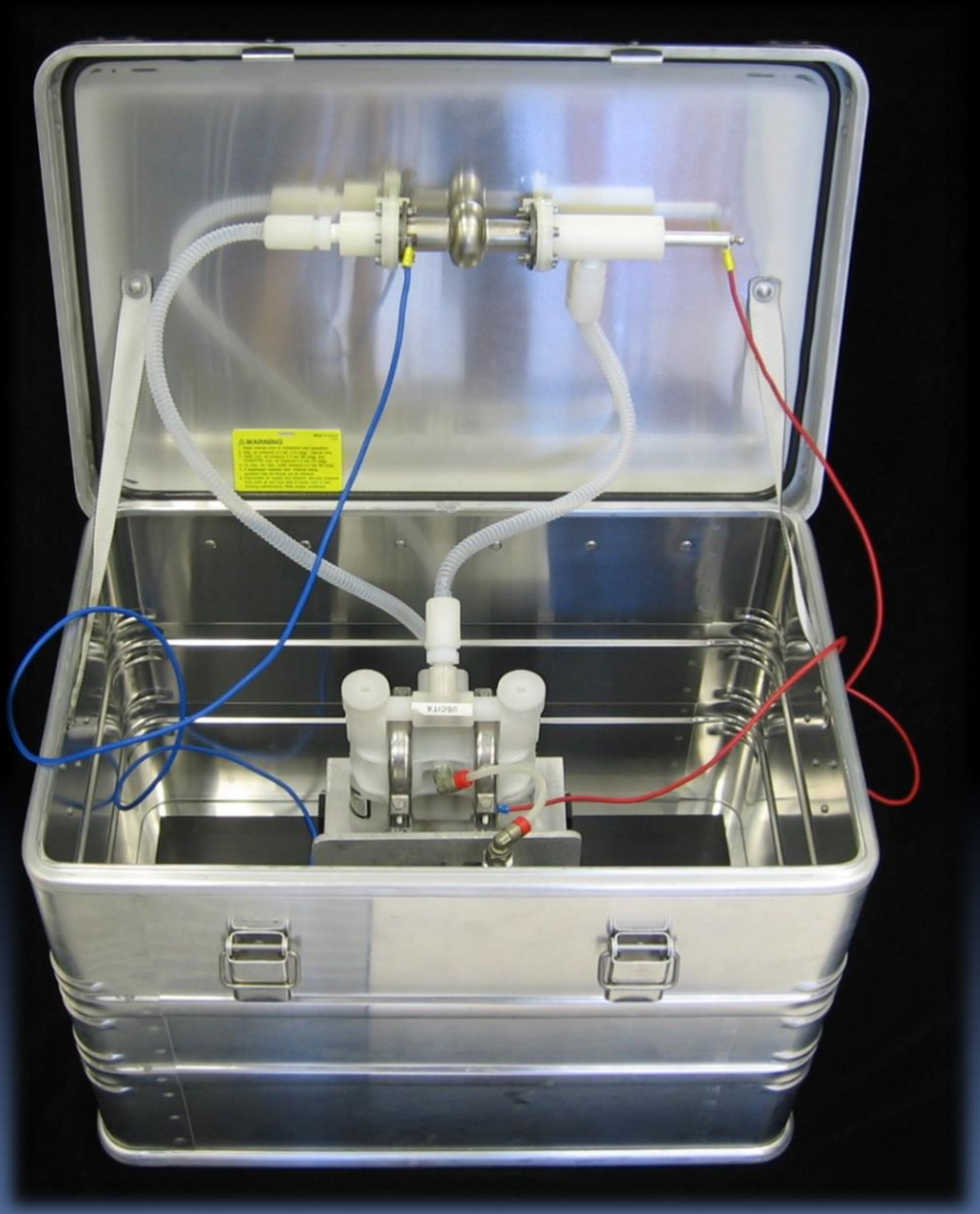
- bad finishing
- presence of contaminants

Streatments:

- ✓ Mechanical
- ✓ BCP
- ✓ EP

HF, H_2SO_4 1:9

A Mini - Chemical/Electrochemical Lab



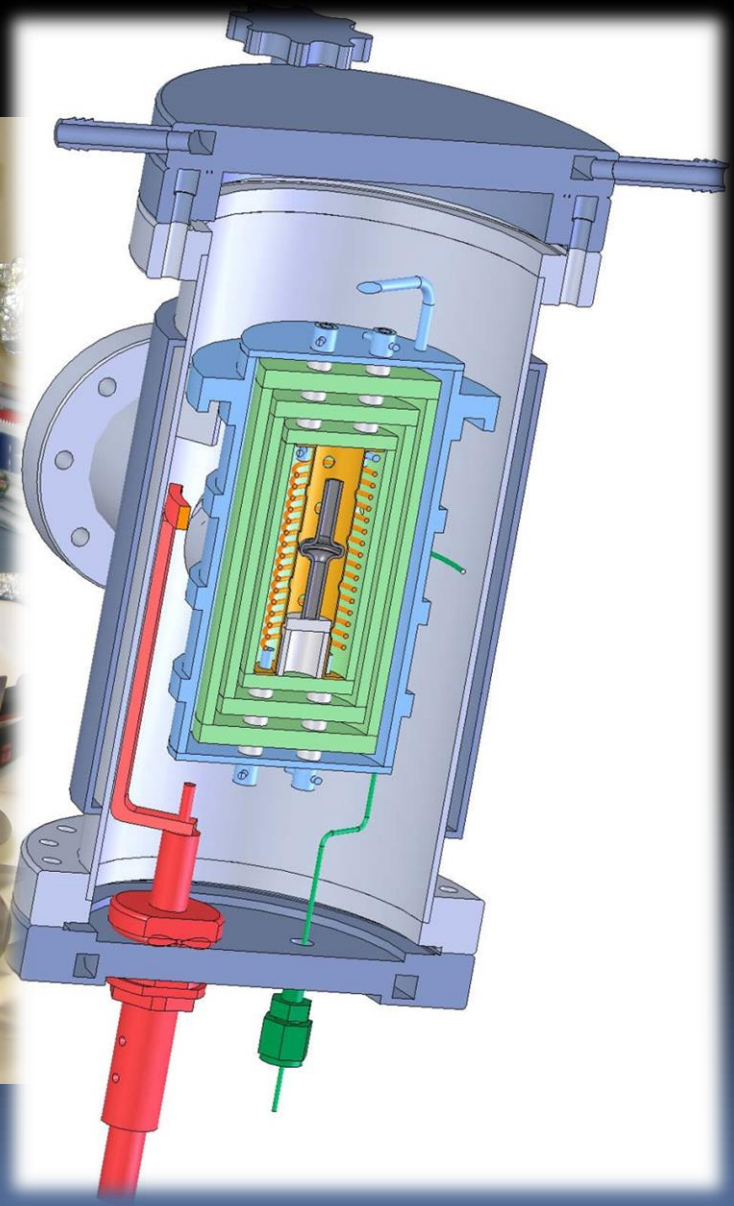
Mini-Furnace: Thermal Treatments

Starting internal surface conditions:

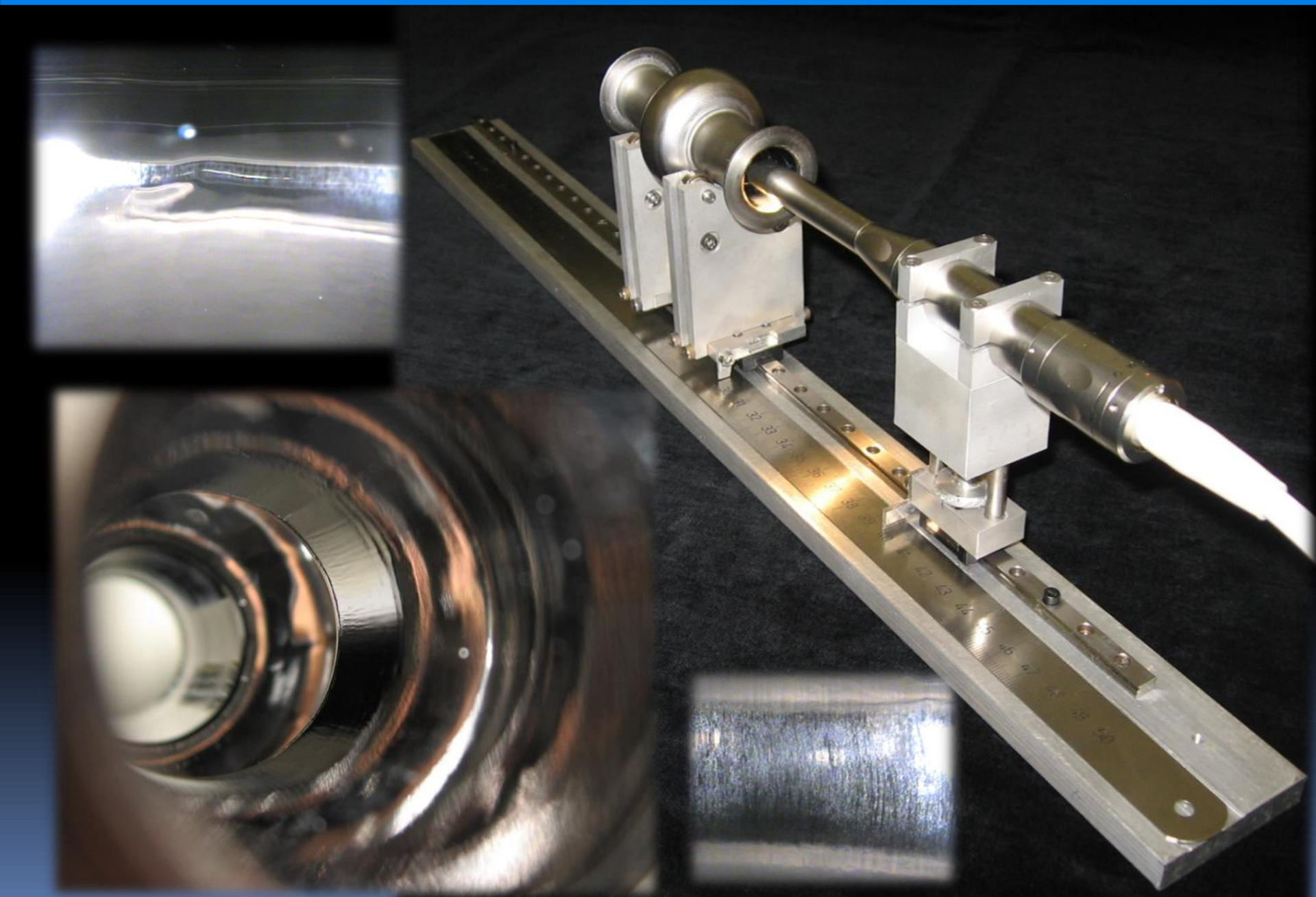
- bad finishing
- presence of contaminants

Streatments:

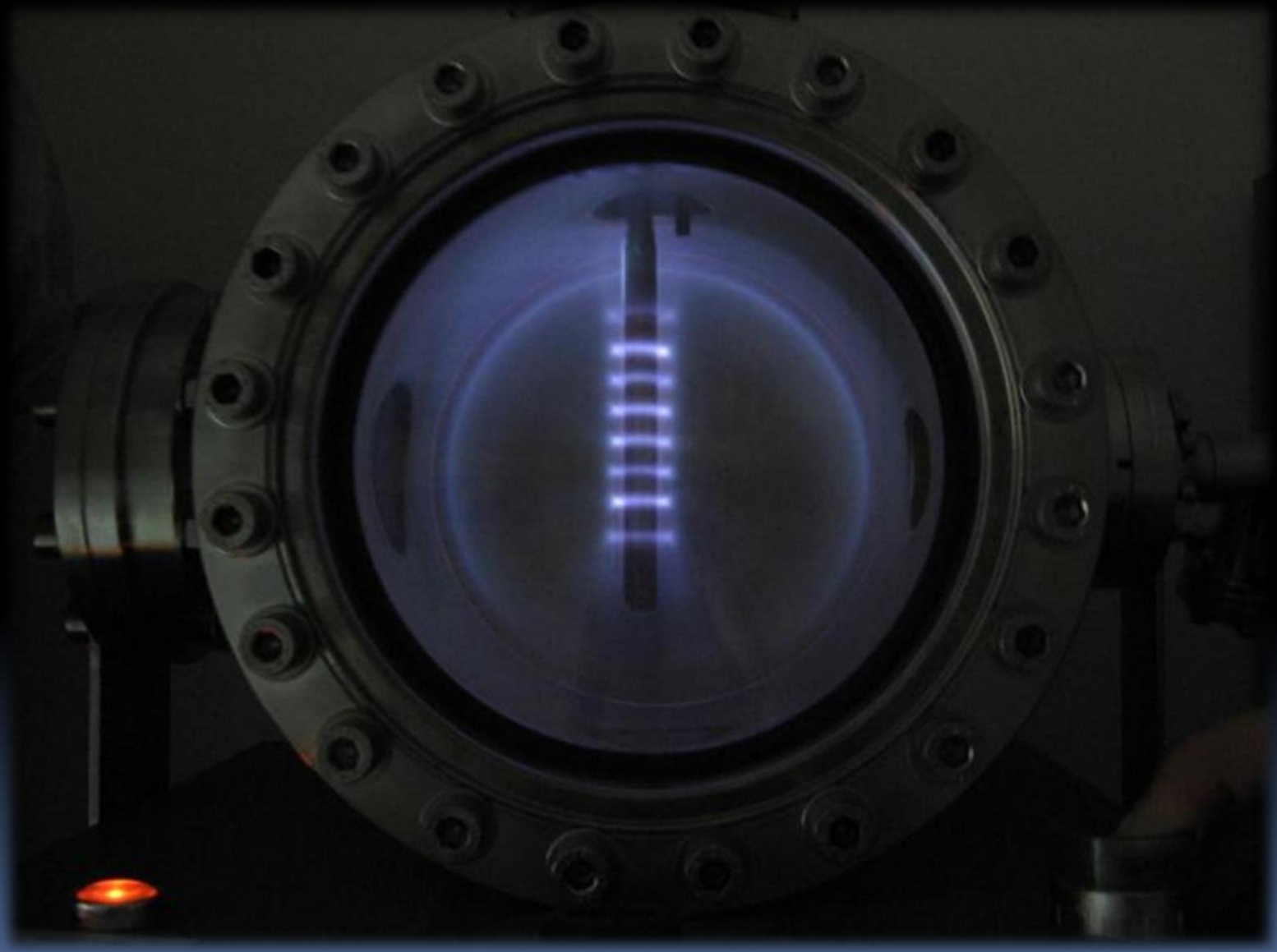
- ✓ Mechanical
- ✓ BCP
- ✓ EP
- ✓ Thermal



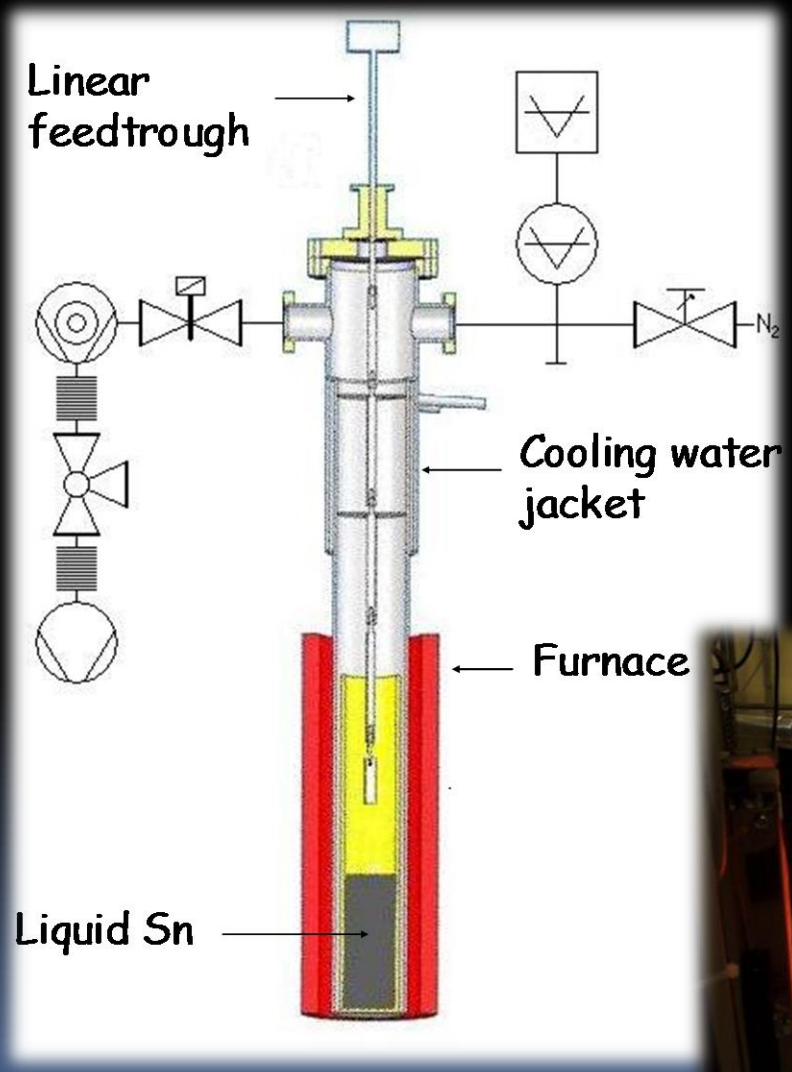
Mini-Camera

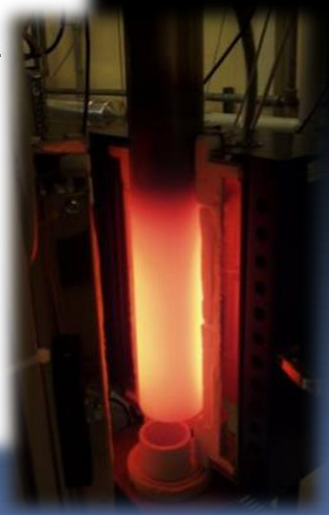


Nb Sputtering



Nb_3Sn Liquid Diffusion





6 GHz Seamless cavity:
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Short fabrication time

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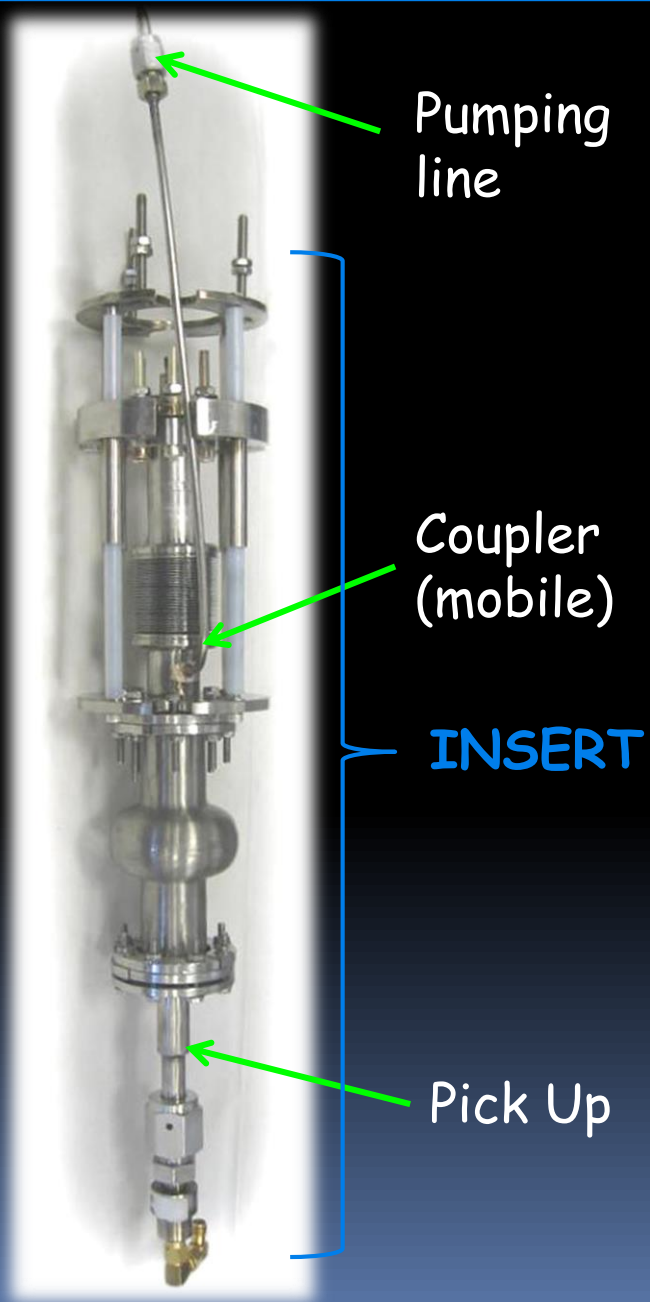
Inexpensive Cryogenics, fast cooling and warming up

Quick RF Measurements

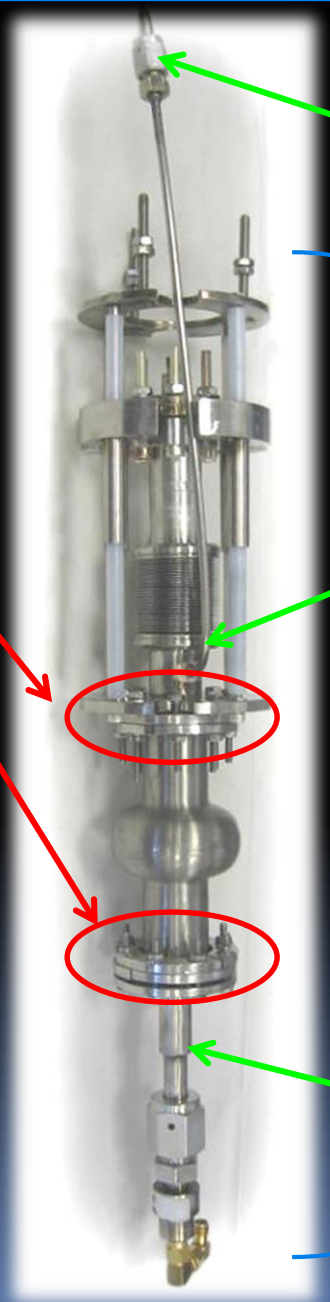
Cryogenic infrastructure



Cryogenic infrastructure

Easy RF Measurement system:

Vacuum seals:
(Two kinds)



Pumping line

Coupler (mobile)

INSERT

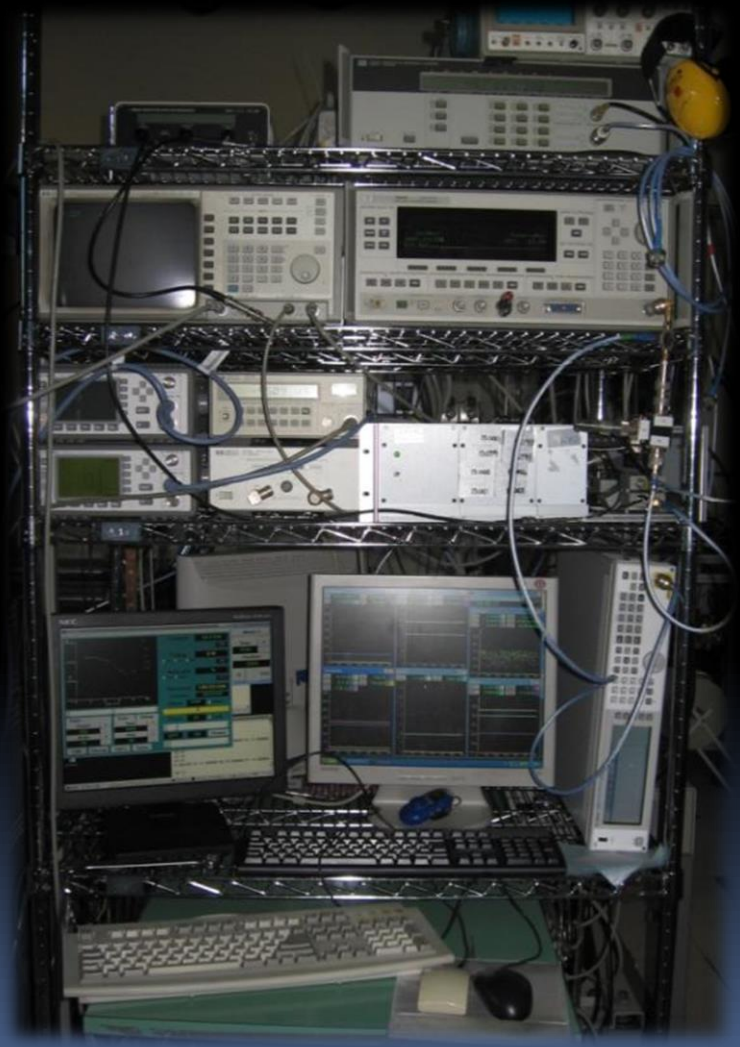
Pick Up

Quick RF Measurements

The insert has been conceived to even enter into a 100 lt Helium dewar

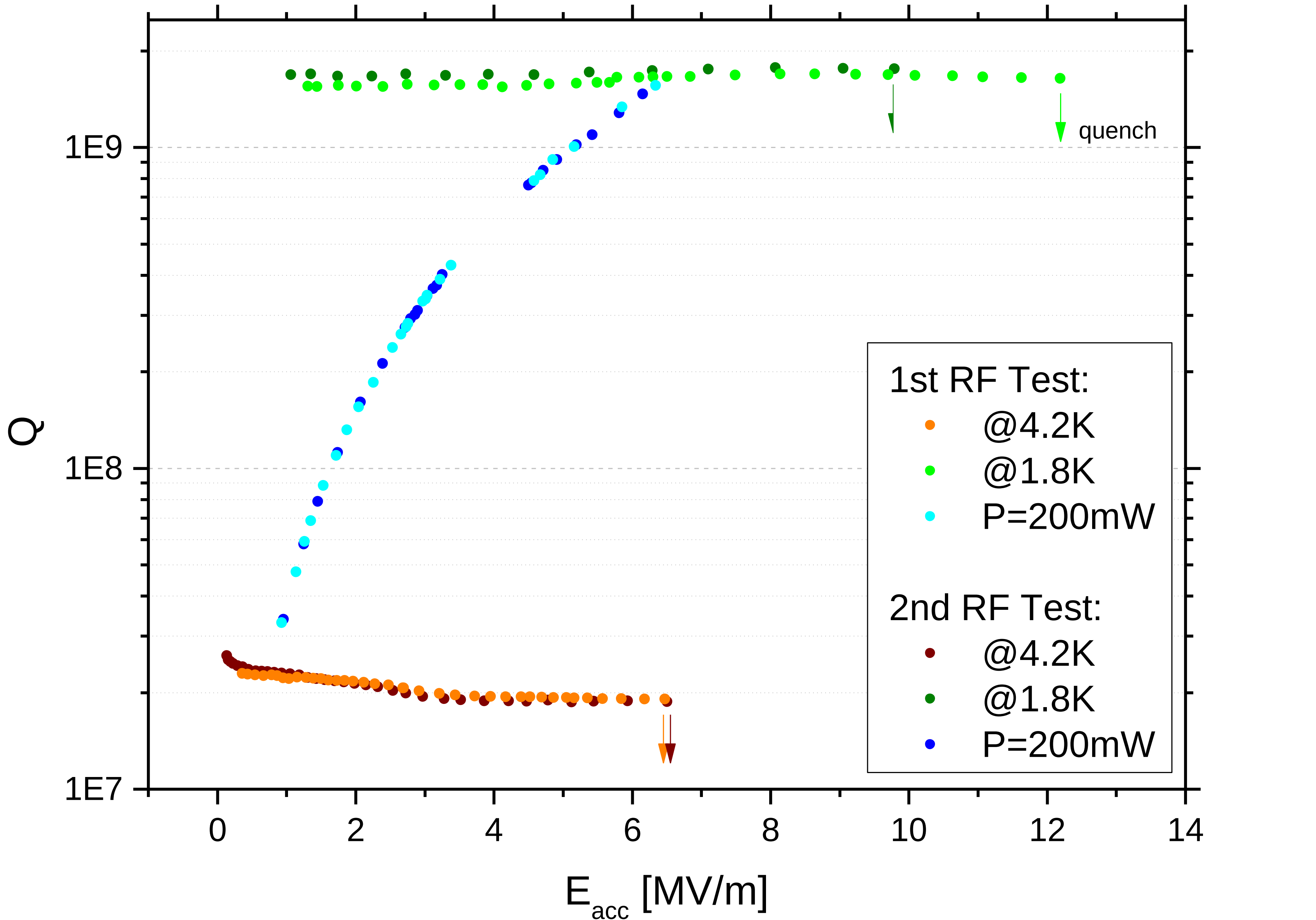
INSERT

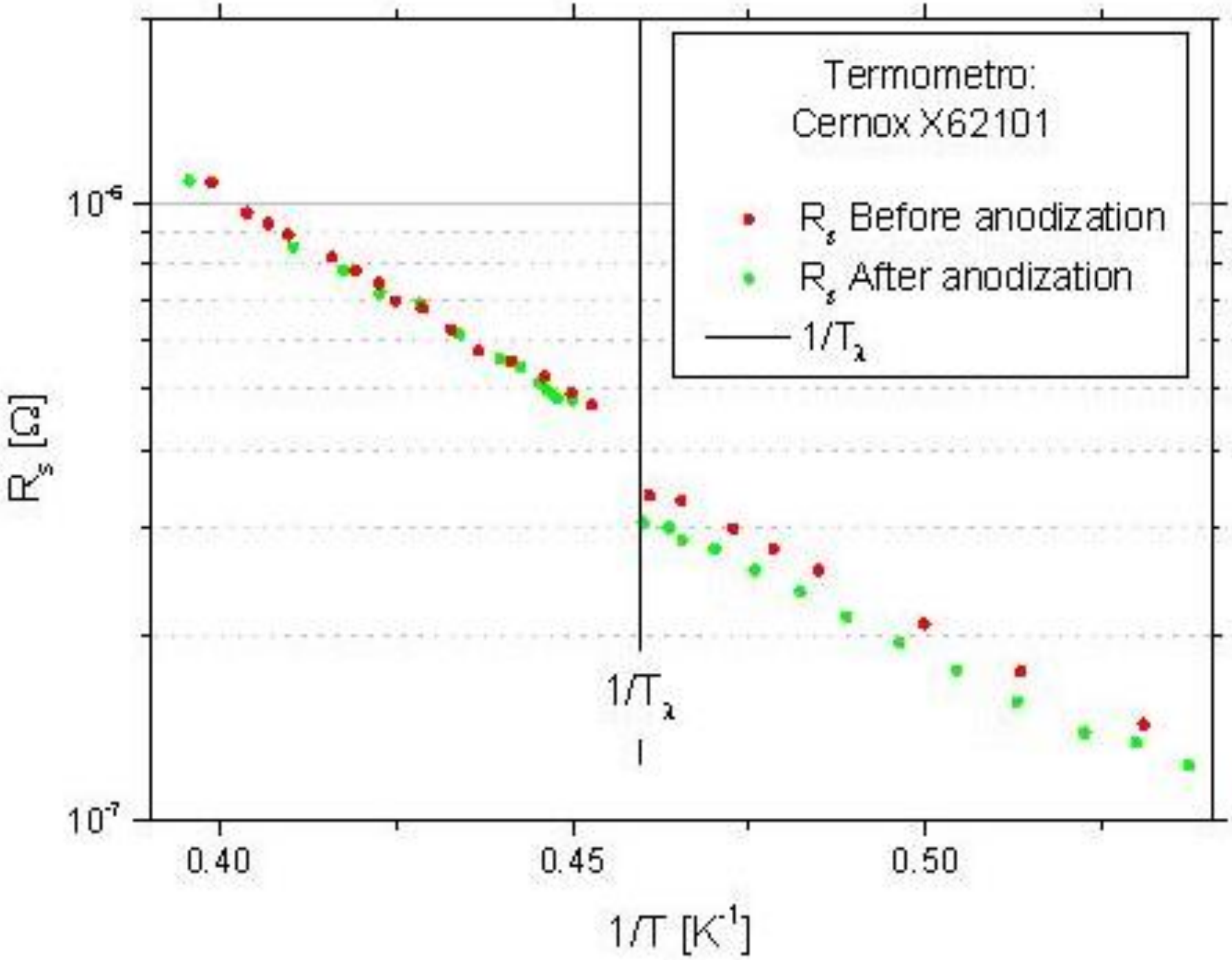
DEWAR

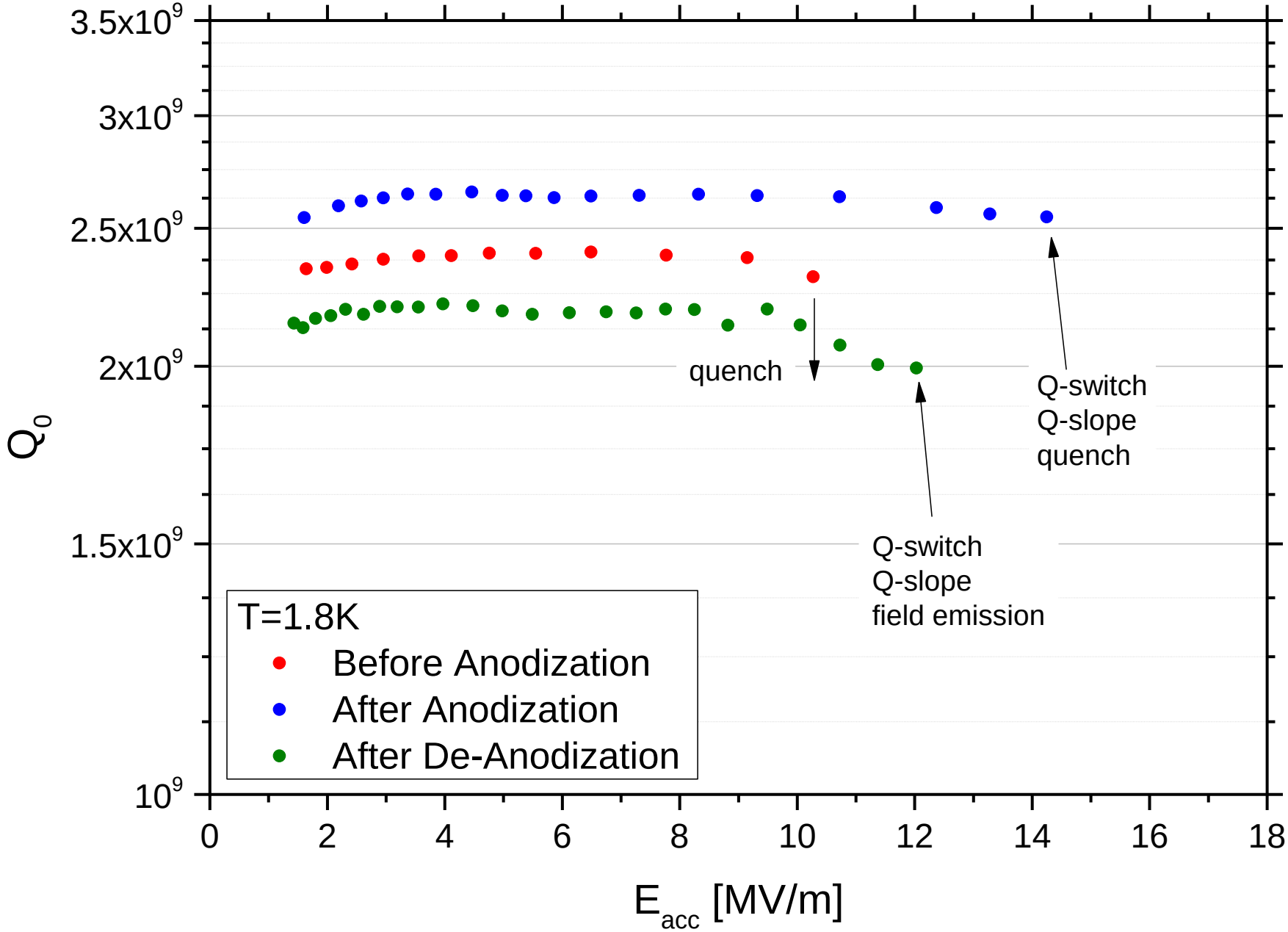


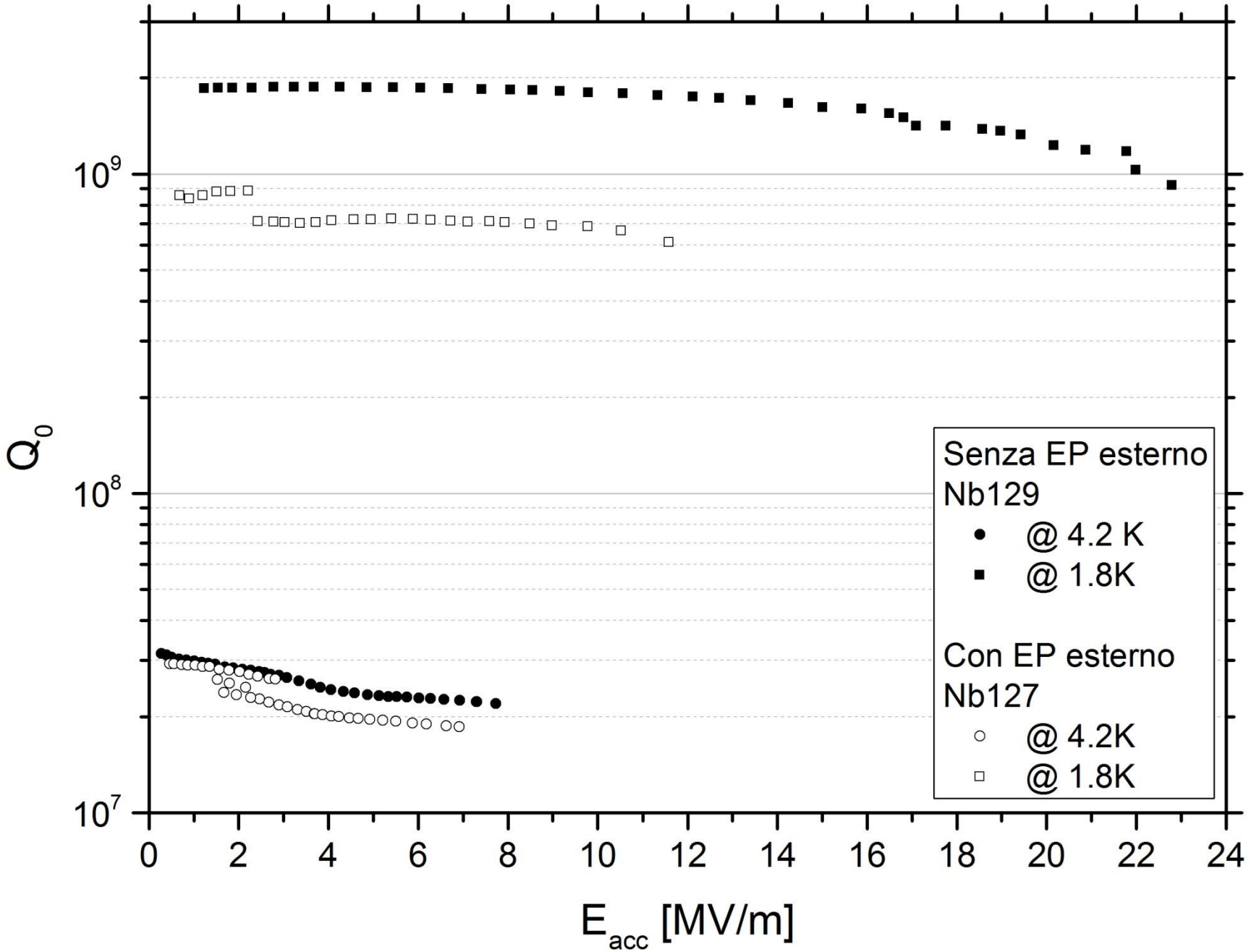
RF measuring system

Measured twice



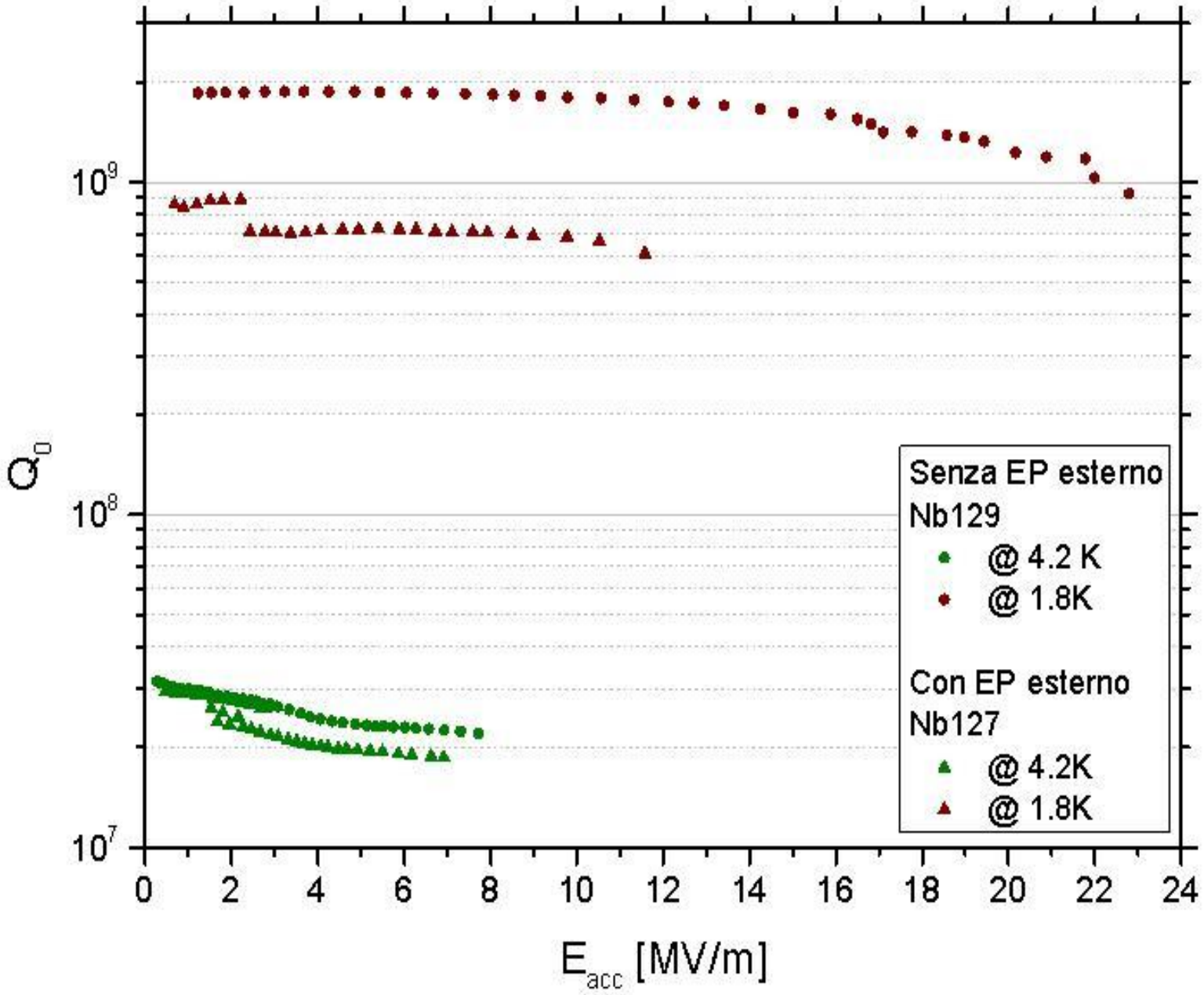


Termometro:
Cernox X62101
R_s Before anodization
R_s After anodization
$1/T_\lambda$
10^{-6}
10^{-7}
R_s [Ω]
0.40
0.45
0.50
$1/T_\lambda$
$1/T$ [K^{-1}]


3.5x10^9
3x10^9
2.5x10^9
2x10^9
1.5x10^9
10^9
Q0
0
2
4
6
8
10
12
14
16
18
Eacc [MV/m]
T=1.8K
Before Anodization
After Anodization
After De-Anodization
quench
Q-switch
Q-slope
quench
Q-switch
Q-slope
field emission


10^9
10^8
10^7
Q_0
0
2
4
6
8
10
12
14
16
18
20
22
24
E_{acc} [MV/m]
Senza EP esterno
Nb129
@ 4.2 K
@ 1.8K
Con EP esterno
Nb127
@ 4.2K
@ 1.8K

If we mirror finish the cavity external surface, ...

this will behave as a Mirror for thermal phonons!

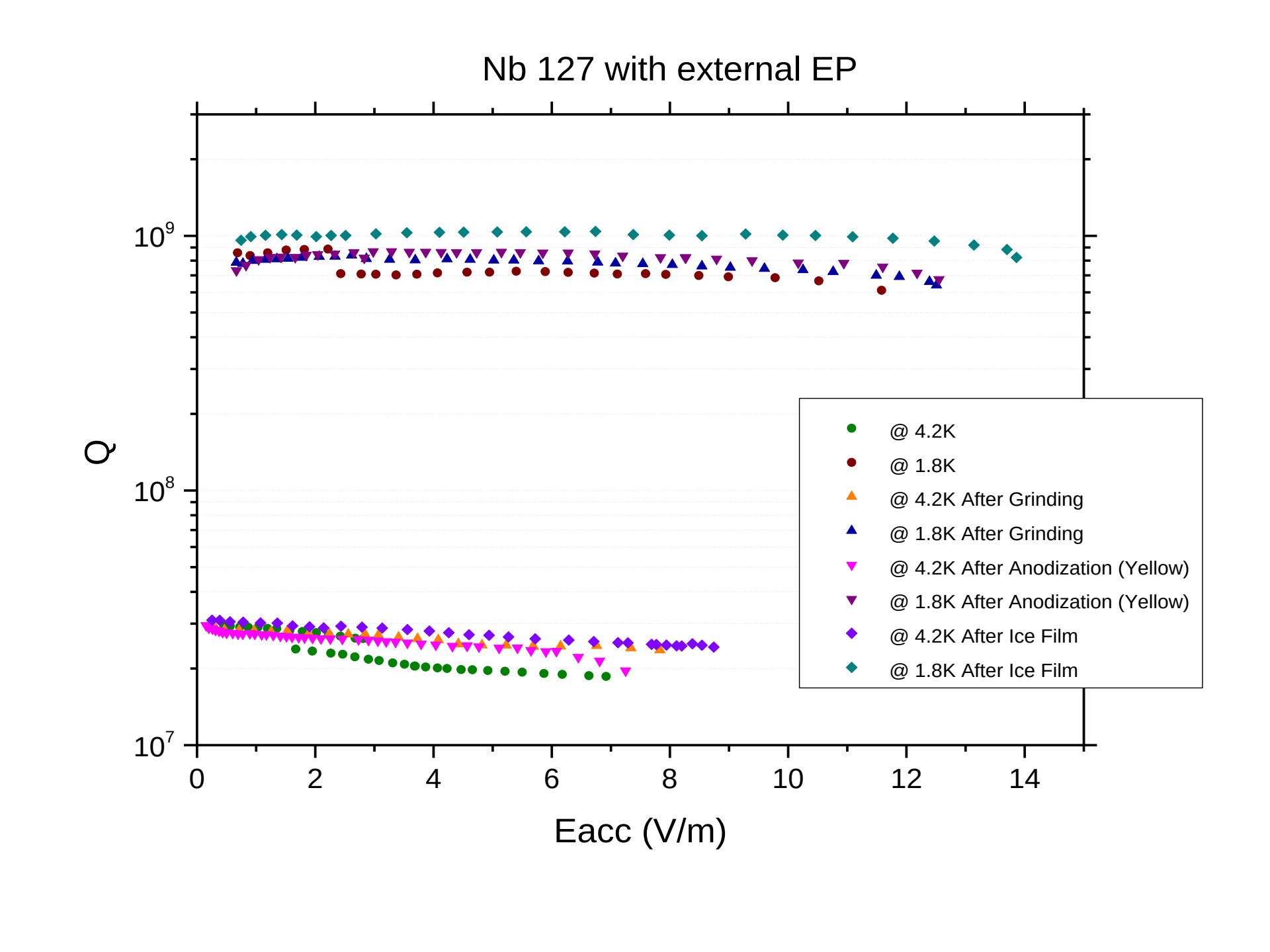

10^9
10^8
10^7
Q_0
0
2
4
6
8
10
12
14
16
18
20
22
24
E_{acc} [MV/m]
Senza EP esterno
Nb129
@ 4.2 K
@ 1.8K
Con EP esterno
Nb127
@ 4.2K
@ 1.8K

A mirror-like external surface will also decrease the nucleation sites for Helium boiling nucleation, promoting then the Liquid He Super-heating

If liquid He Super-heating is detrimental for $Q(E_{acc})$,

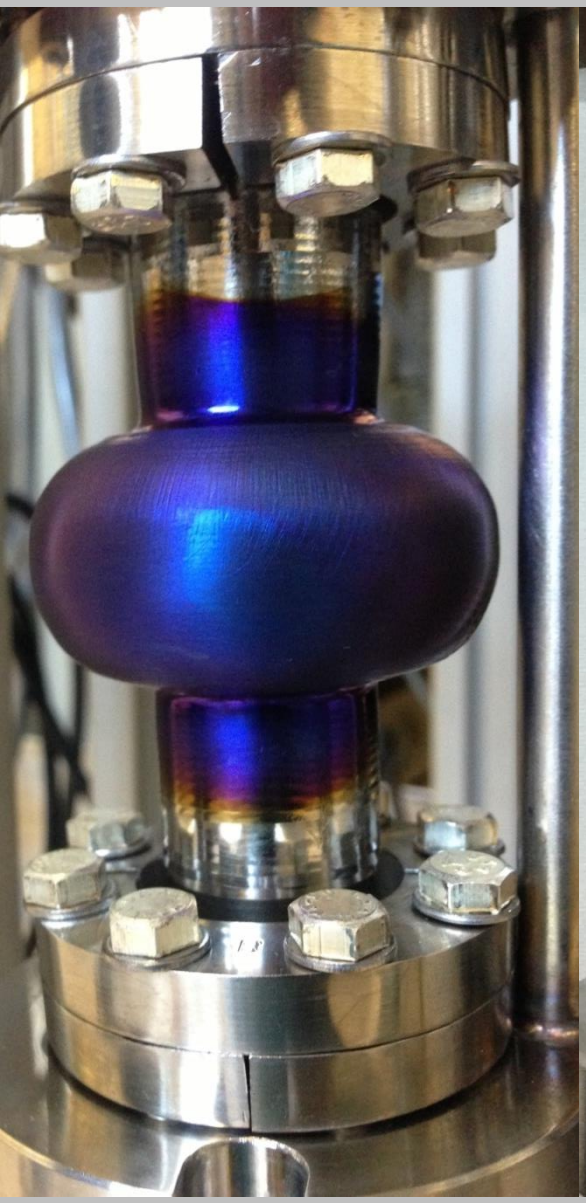
Should we worry more about that type of superheating rather than to the Nb H_{Sh}?

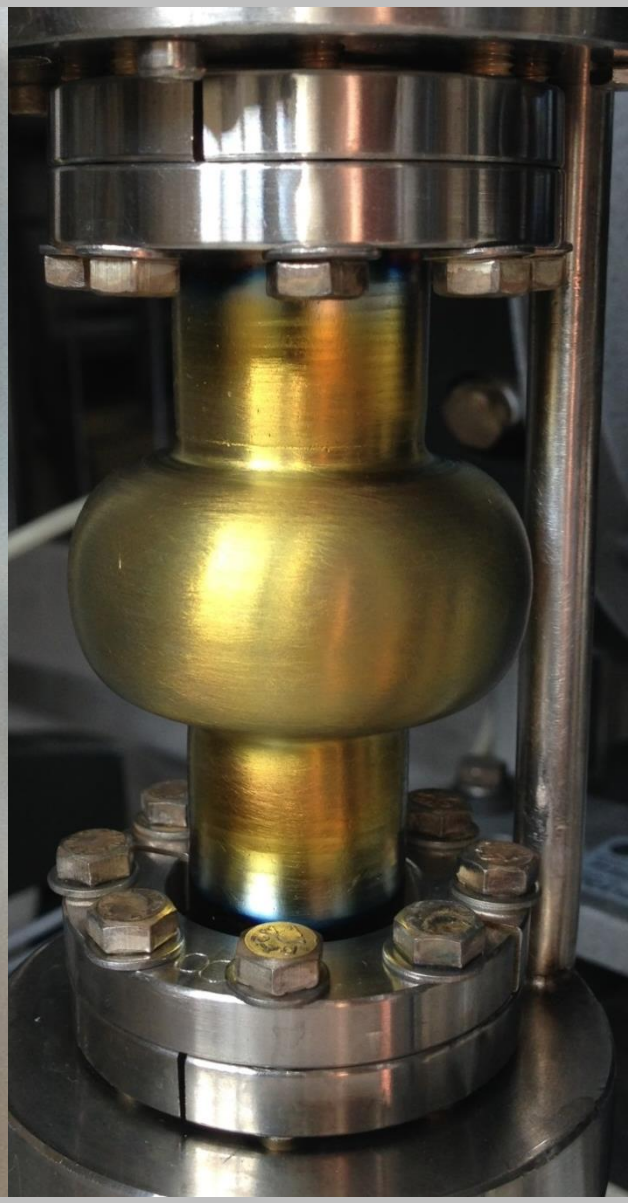
Can water micro-cristallites on the external surface of Nb promote film boiling and then positively affect cavity performances?


Nb 127 with external EP
Q
10^9
10^8
10^7
0
2
4
6
8
10
12
14
Eacc (V/m)
@ 4.2K
@ 1.8K
@ 4.2K After Grinding
@ 1.8K After Grinding
@ 4.2K After Anodization (Yellow)
@ 1.8K After Anodization (Yellow)
@ 4.2K After Ice Film
@ 1.8K After Ice Film

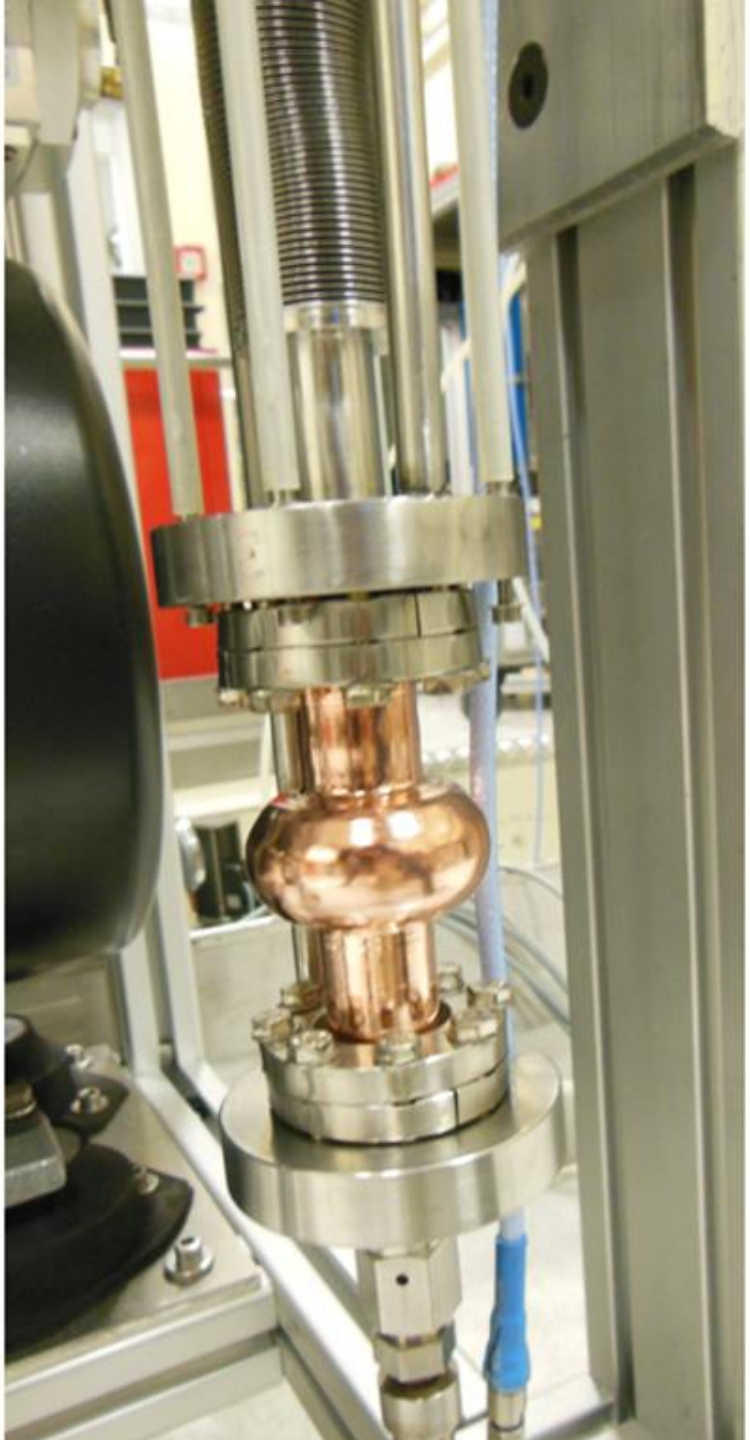
For years we have considered a cavity as an adiabatic system made by the RF fields + Nb, because the He bath has been considered as a stable and infinite reservoir at fixed temperature.

Is it not the time now to consider instead the adiabatic system composed by RF fields + Nb + Liquid Helium ?





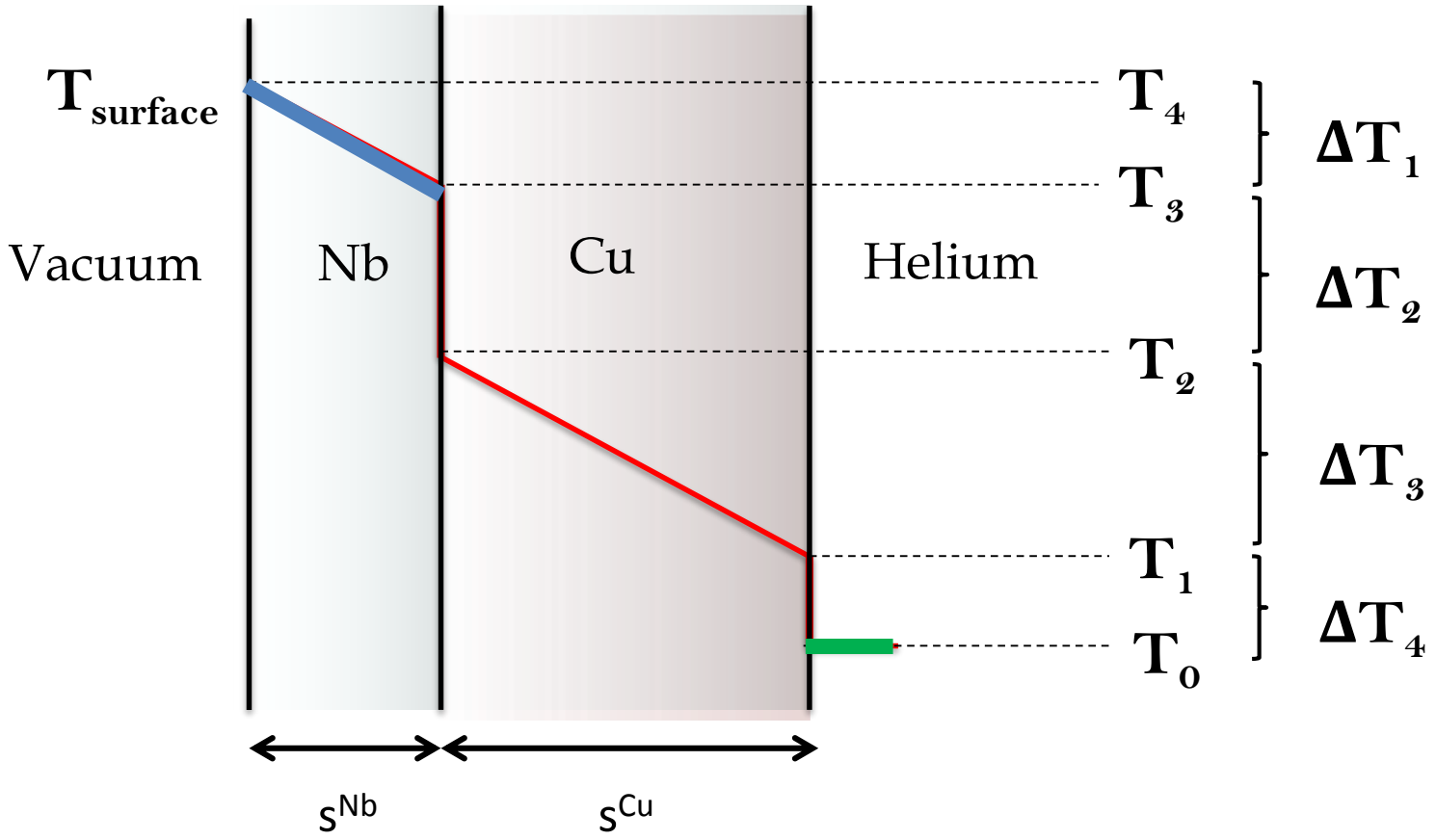
Nb/Cu 6 GHz cavities



The Cathodic Arc coated cavity deposited by Soltan Institute and INFN- Roma2 was never measured ….

do you know why?

Bad adherence between Cu and Nb is a common problem!



$$\Delta T_{TOT} = \frac{R_{thermal} P_d}{\Sigma} = \frac{P_d}{\Sigma}\left(\frac{s^{Nb}}{K^{Nb}} + \frac{1}{h_{Nb/Cu}} + \frac{s^{Cu}}{K^{Cu}} + \frac{1}{h_{Cu/He}} \right)$$

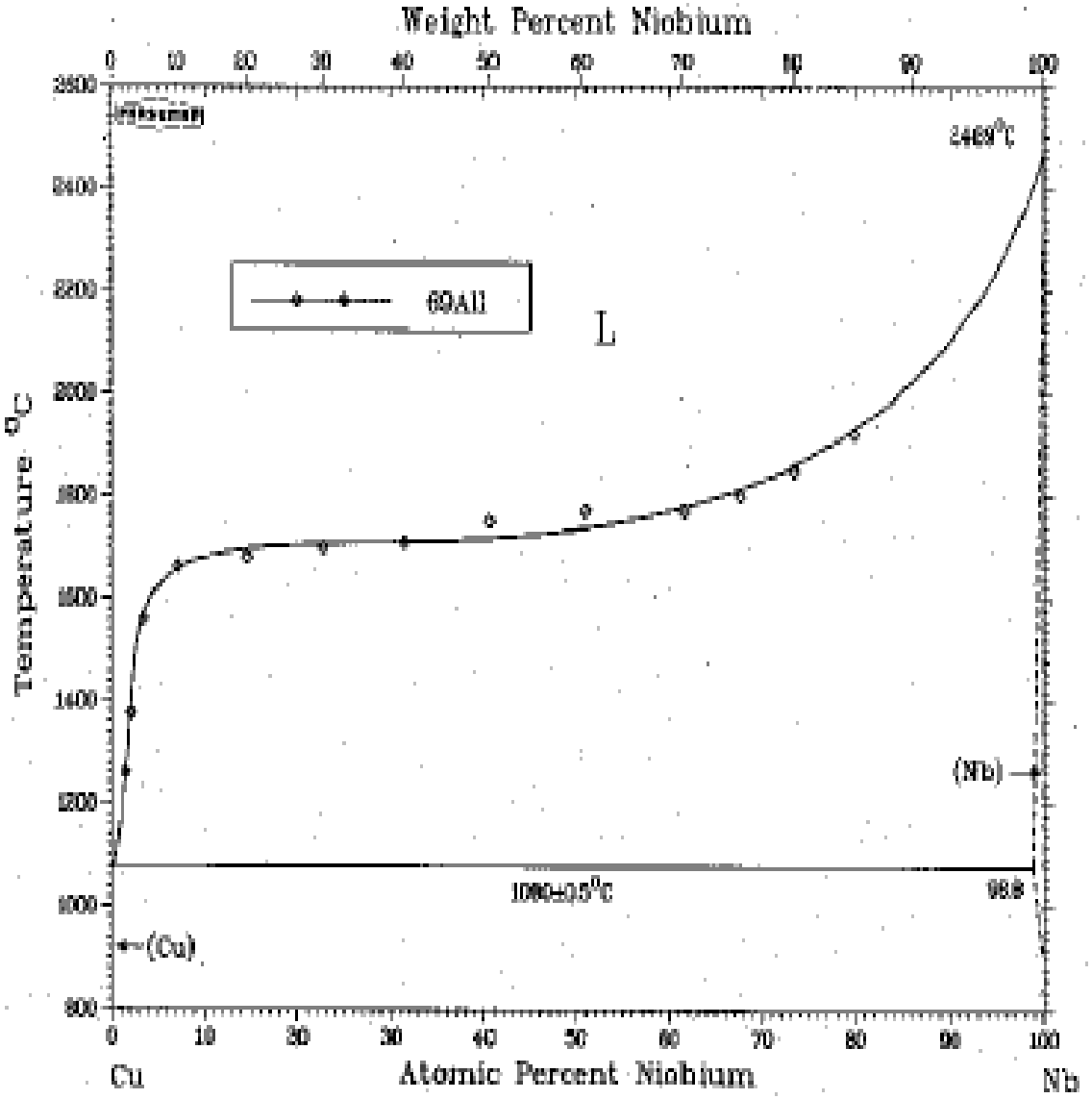
If the adhesion of Niobium to Copper is not good, the cavity will go in thermal runaway!!!!

Thermal Contact Resistance at the Nb-Cu interface as a limiting factor for sputtered thin film RF Superconducting cavities

V. Palmieri[1] and R. Vaglio[2]

[1] Legnaro National Laboratories - Istituto Nazionale di Fisica Nucleare (INFN), Legnaro (PD) ITALY
[2] Dipartimento di Fisica, Università di Napoli Federico II, CNR SPIN e INFN- Napoli (NA) ITALY

Fig. 1 Cu-Nb Phase Diagram



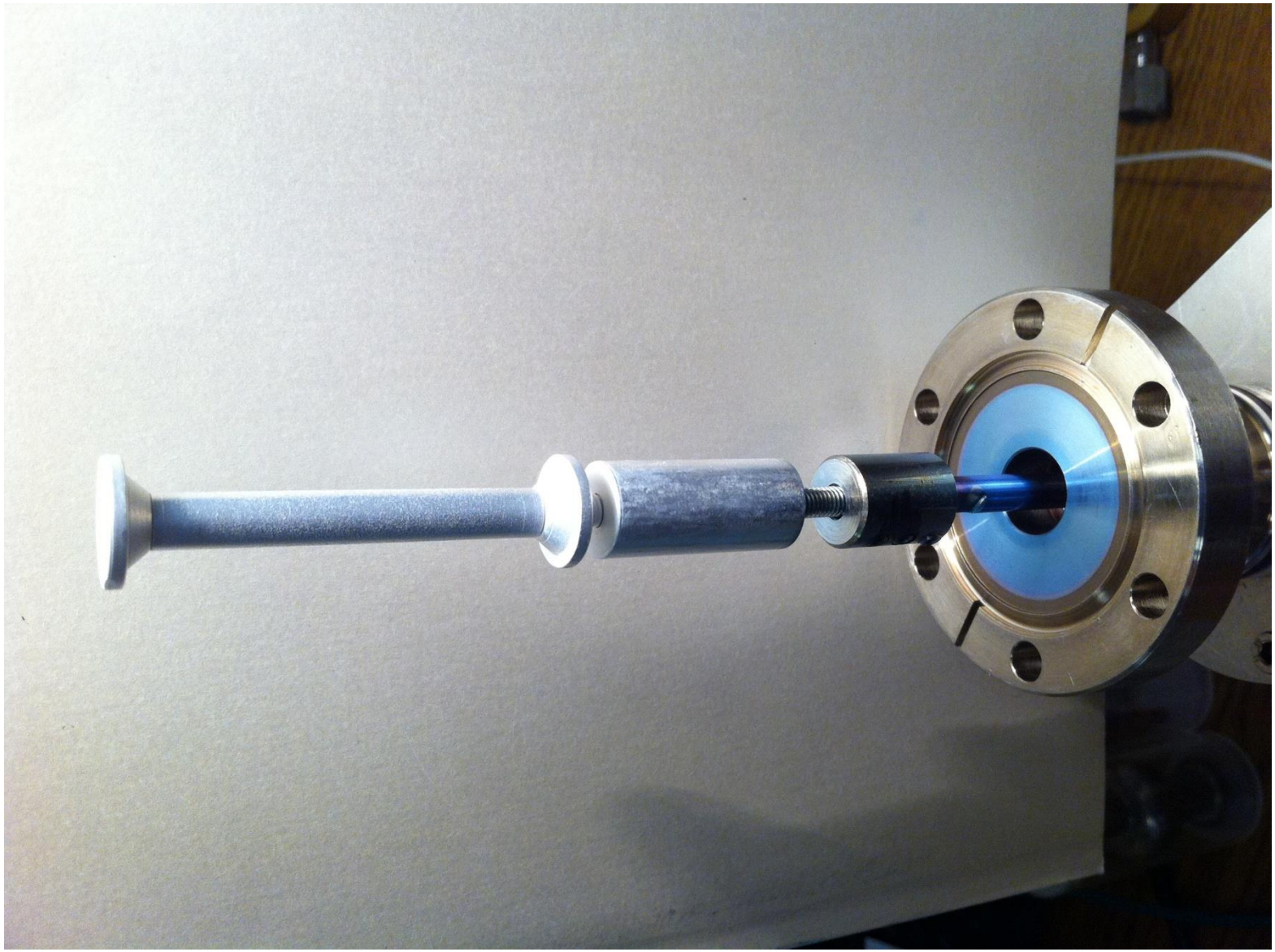
Showing liquidus data of [69All] and 1080 °C isotherm from [79Pet].

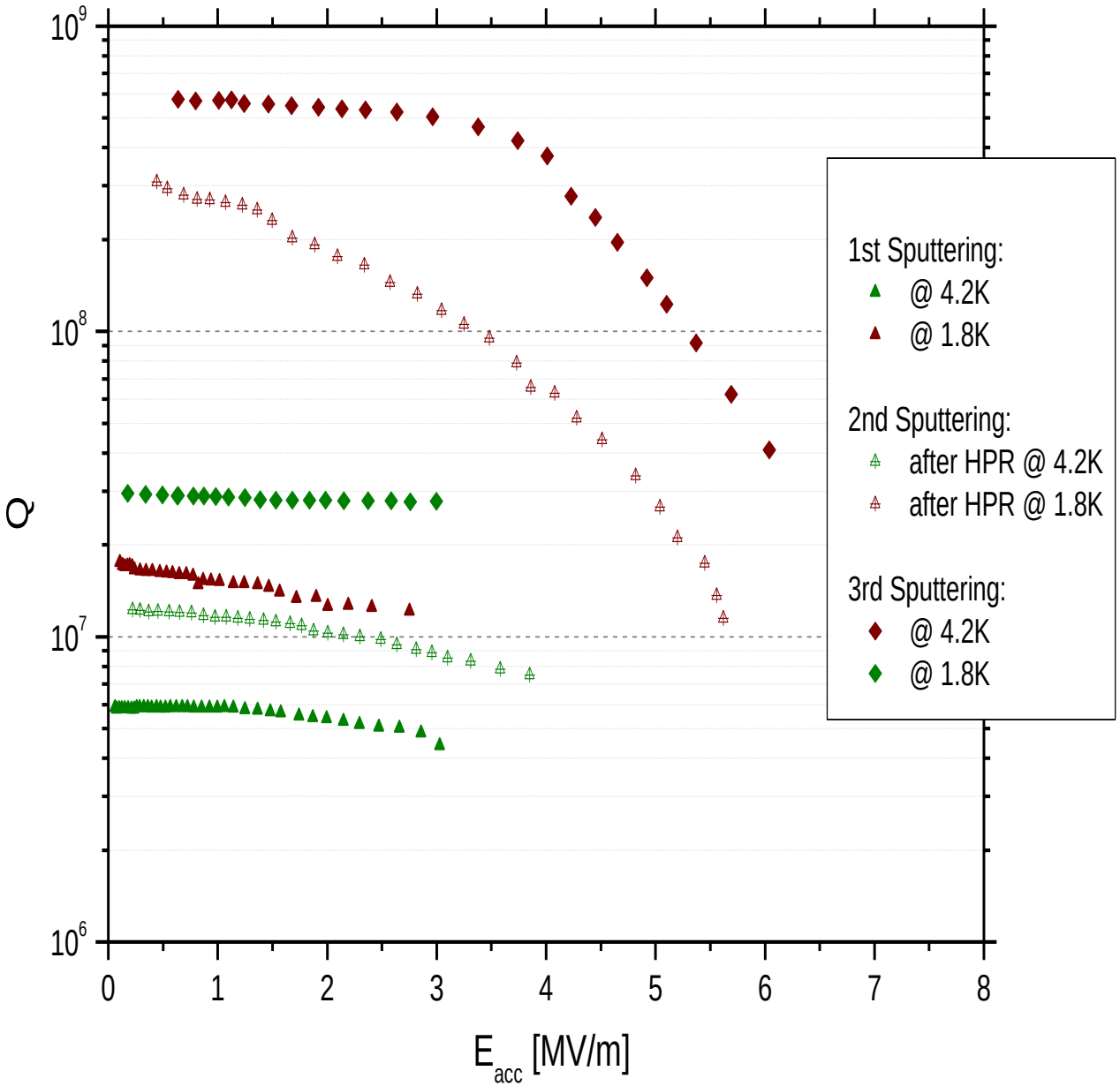
D. J. Chakrabarti and D. E. Laughlin, 1982.

What has high solubility both in Niobium and in Copper?

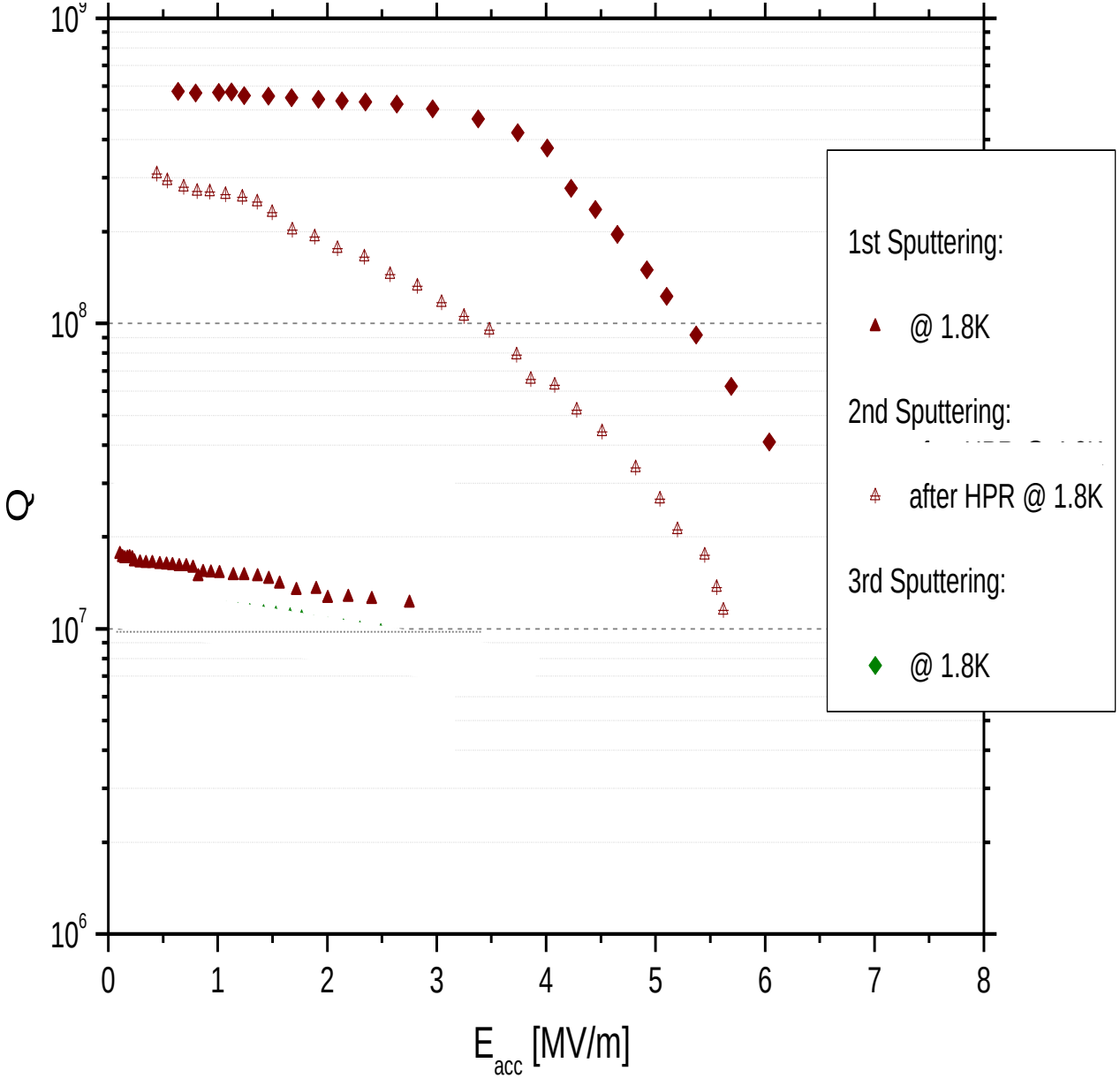
- Palladium
- Silver
- Tin
- Alluminum

“Silver Cathode”




Comparison between 1st, 2nd and 3rd Nb/Cu Sputtering
Q
10^9
10^8
10^7
10^6
0
1
2
3
4
5
6
7
8
E_{acc} [MV/m]
1st Sputtering:
@ 4.2K
@ 1.8K
2nd Sputtering:
after HPR @ 4.2K
after HPR @ 1.8K
3rd Sputtering:
@ 4.2K
@ 1.8K

A palladium underlayer at the Nb /Cu interfce improves performances



If we want to improve SRF performances

we must study more deeply Cryogenics

and precisely Heat Transfer mechanism from a Surface to Liquid Helium

If the adhesion of Niobium to Copper is not good, the cavity will go in thermal runaway!!!!