9th Workshop on RF SUPERCONDUCTIVITY

SANTA FE
NOVEMBER 1-5, 1999

LUTZ LILJE
DESY

1. PROJECTS USING SRF
2. STATE-OF-THE-ART HIGH GRADIENT CAVITIES
3. LIMITATIONS OF SRF CAVITIES AND POSSIBLE CURES
4. OTHER FABRICATION TECHNIQUES
5. CONCLUSION

SRF PROJECTS

"A SELECTION"

EXISTING:

	ATLAS	
	JAERI	ION
	ALPI	
	LHC	PROTONS
	LEP	ELECTRONS
	CESR	
	KEK-B (TRISTAN)	
	HERA e-ring	
	CEBAF	
	TTF	
COMING UP:	RIA	
	IPHI	
	TRASCO	
	APT	
	SNS ?	
	KEK/JAERI	
	TESLA	

HIGH GRADIENT CAVITIES

- NIOBIUM MULTI-CELL CAVITIES

  EXAMPLE: TTF

f	1,3 GHz
Cells	9

- LIMITATIONS:

  FE

  Q-DROP WITHOUT X-RAYS

- UNDERSTANDING THE Q-DROP

  - SURFACE ANALYSIS
    ROUGHNESS, CHEMICAL COMPOSITION, ...
  - IN-SITU BAKING AT 100°C
    LOW FIELD → POSSIBLE O-DIF
    HIGH FIELD → ??? A LOT OF IDEAS

PRIZE:

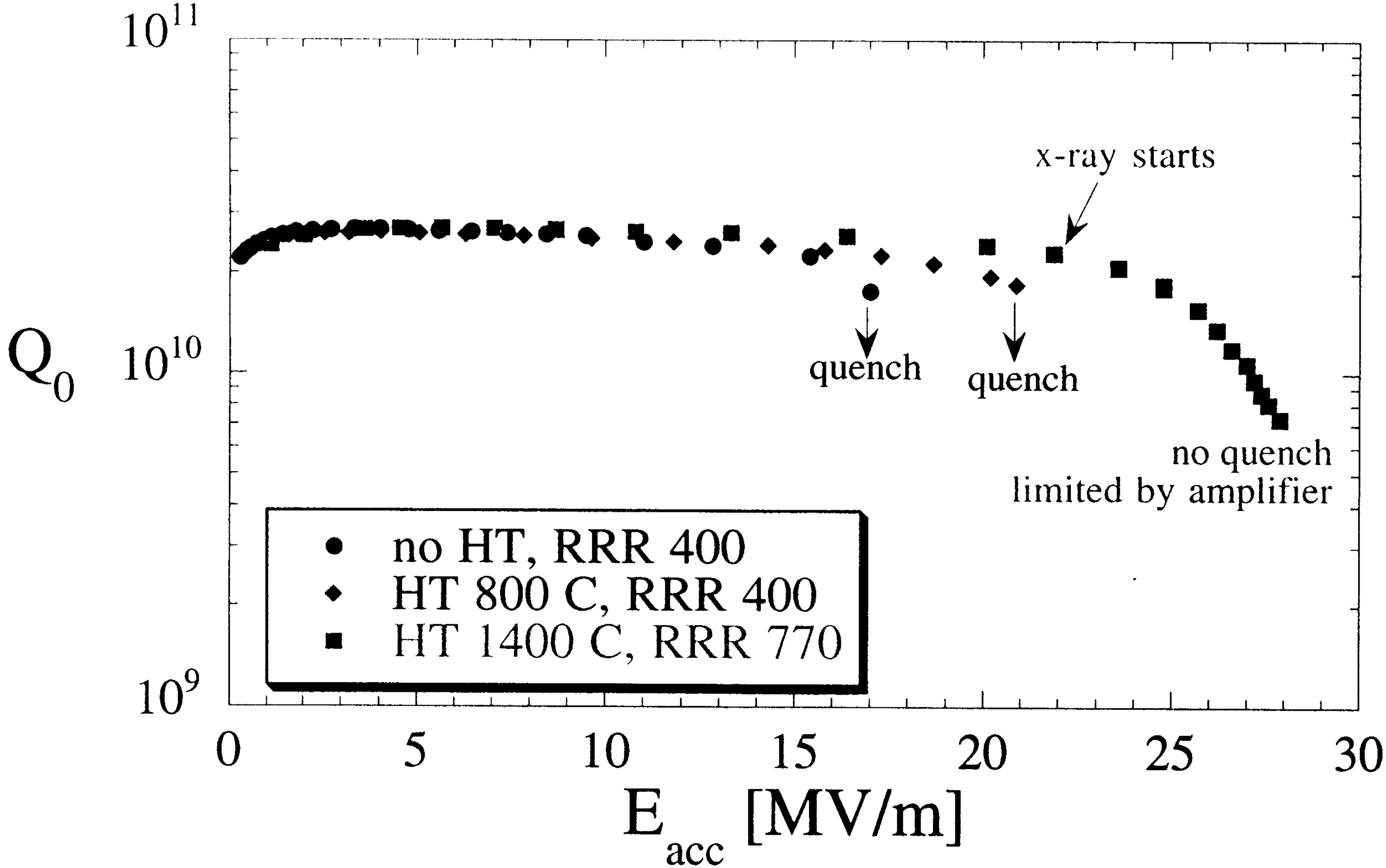
BOTTLE OF **CHAMPAGNE** ⇐

- E-FIELD ENHANCEMEN
- H-FIELD "
- OXYGEN, HYDROGEN
- CHEMICAL RESIDUES
- THERMAL FEEDBACK

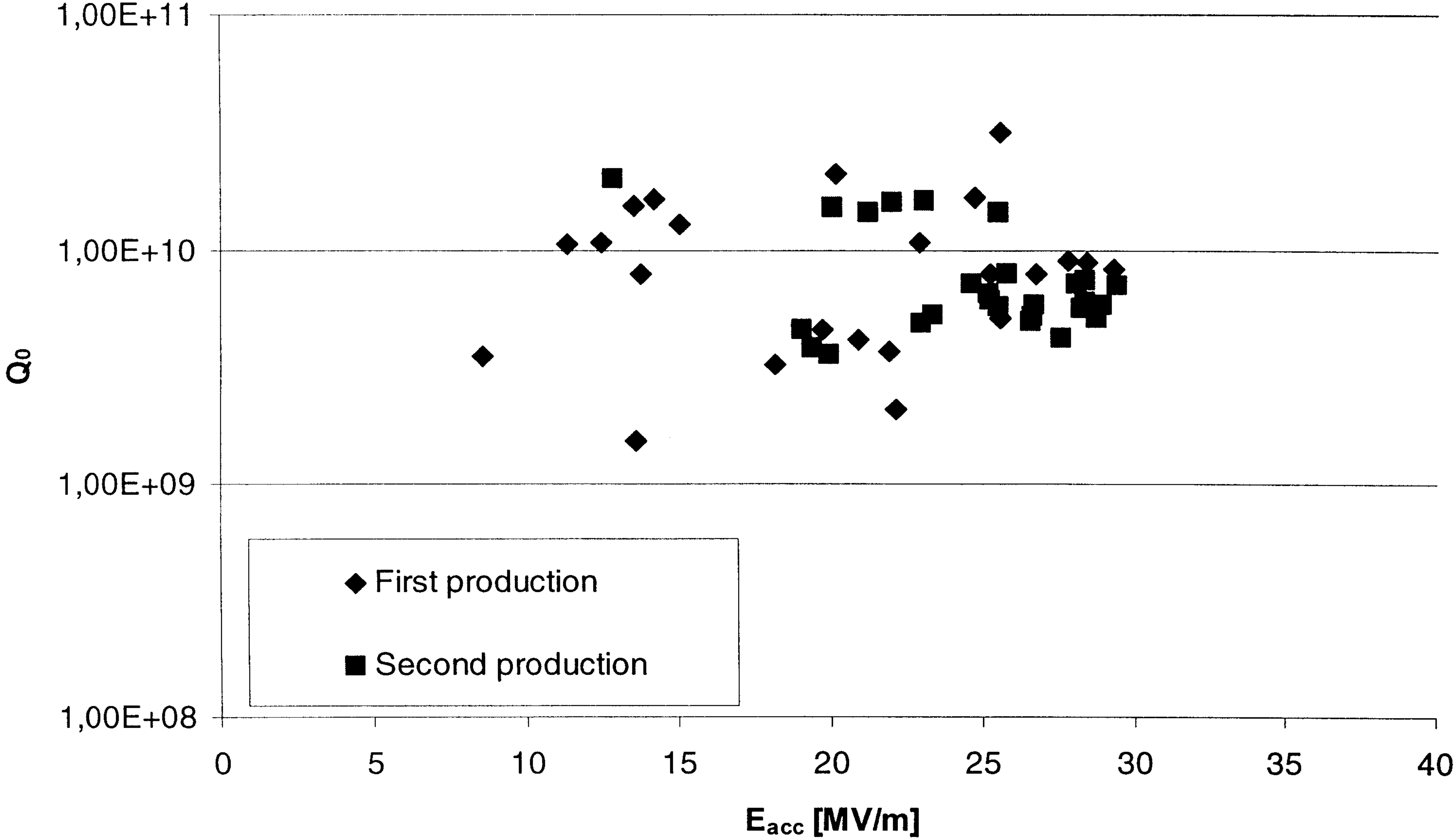
Current cavity production

- Eddy-current scanned niobium sheets (RRR=300) to avoid tantalum and other inclusions (Singer TUA007)
- Electron-beam welding
- 1400 °C heat treatment with titanisation to increase thermal conductivity
- Chemical etching with BCP 1:1:2

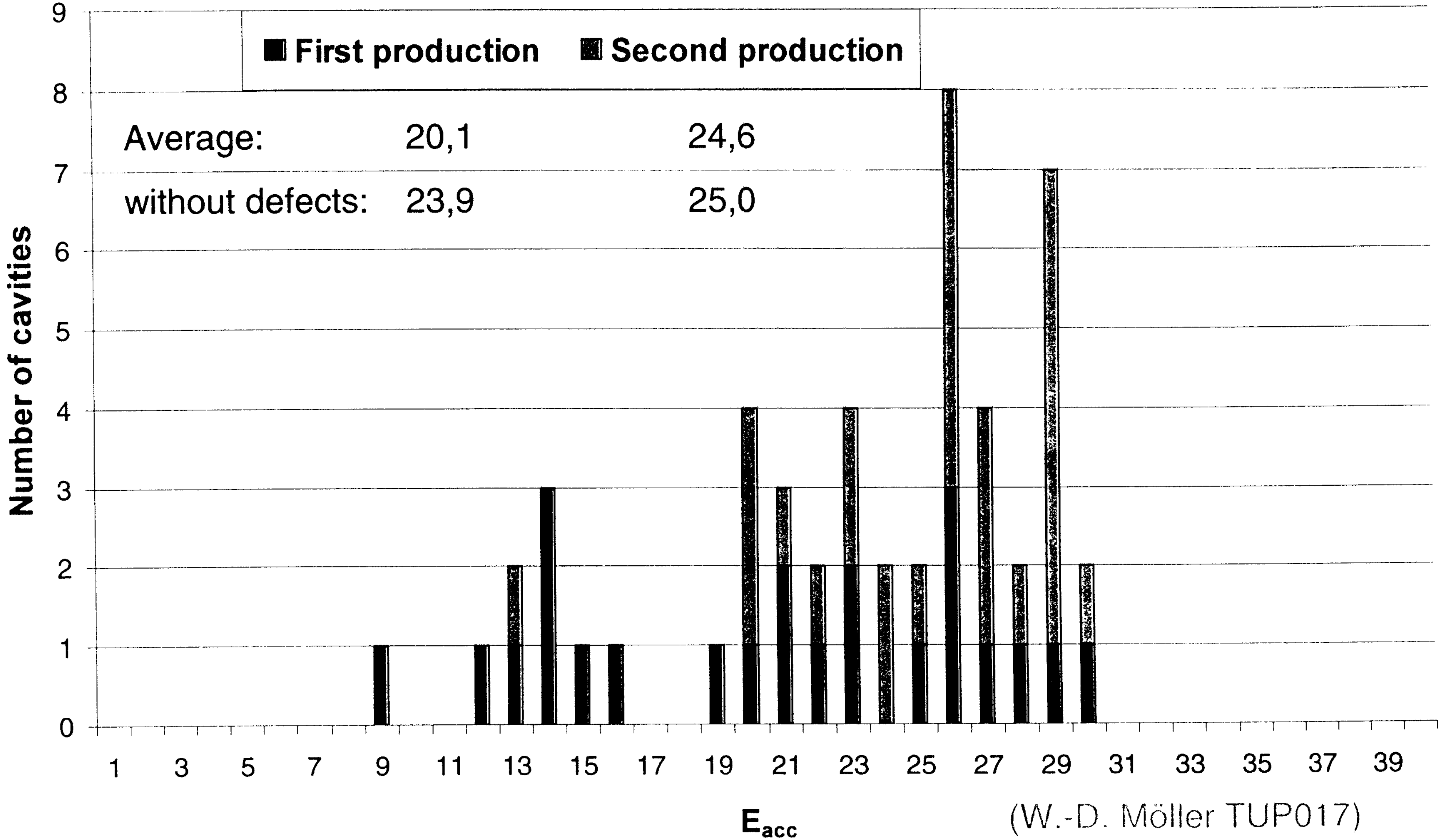
Benefit of heat-treatment on cavity C21



Vertical test results of 9-cells

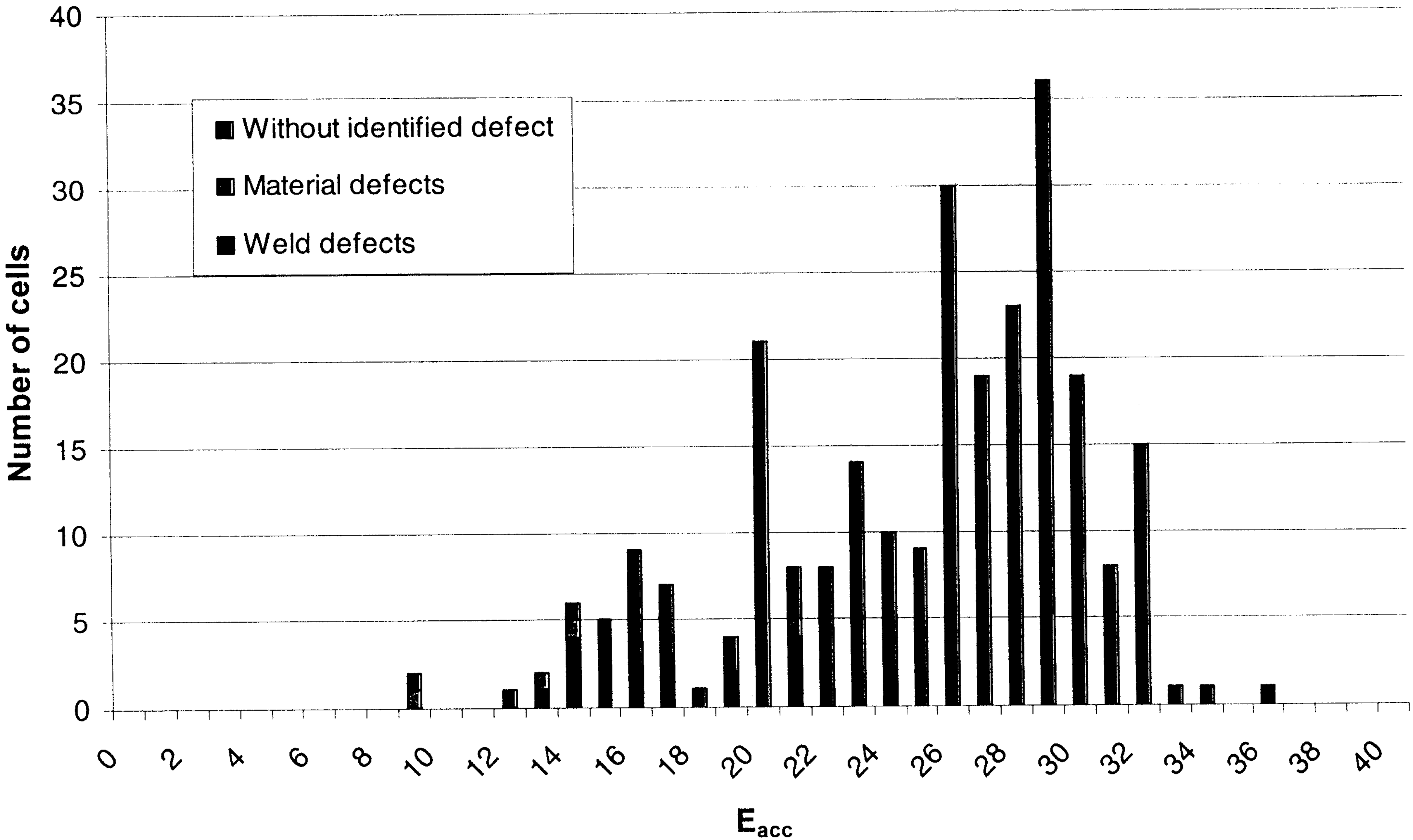


CW test results for 9-cell cavities



(W.-D. Möller TUP017)

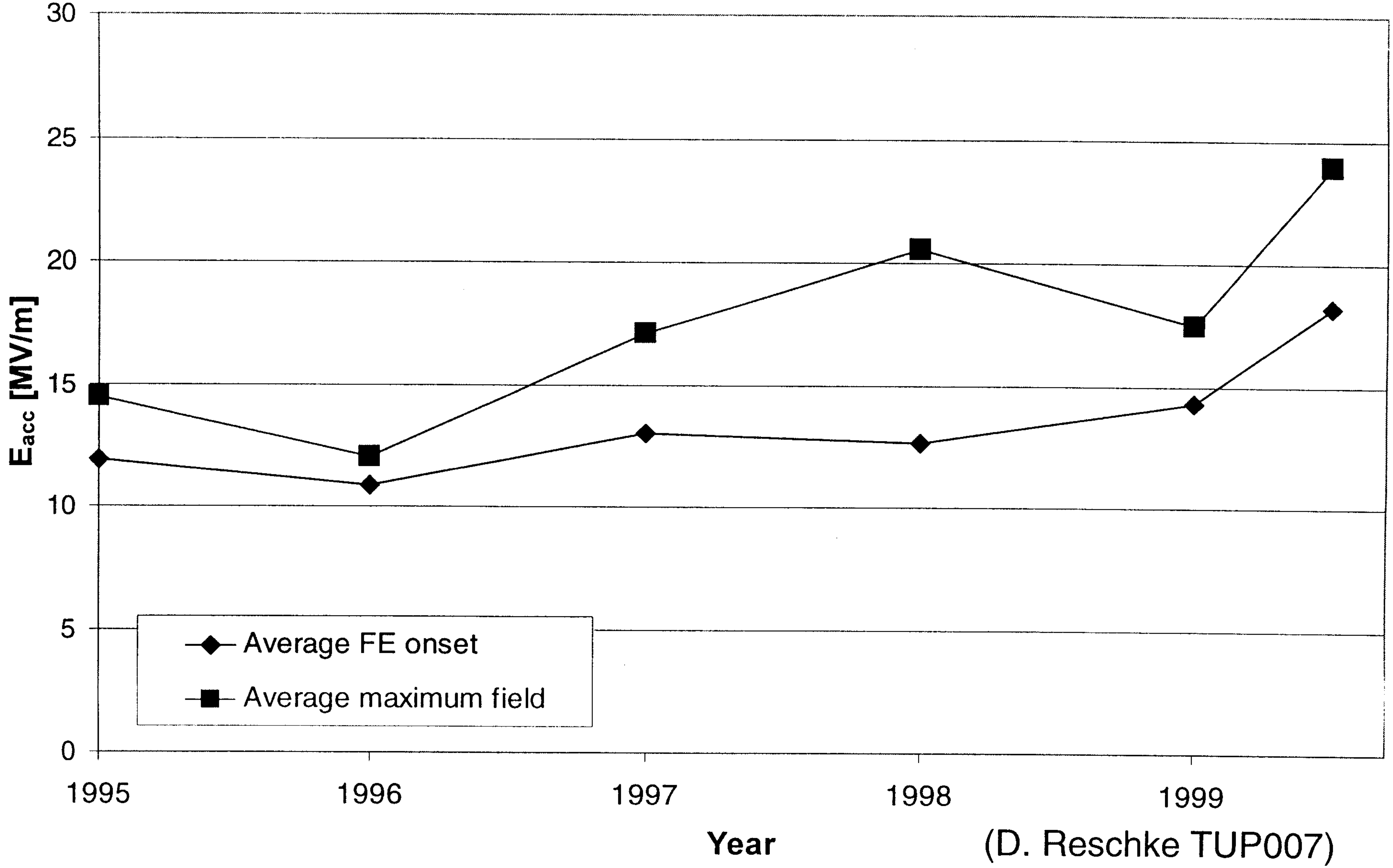
Mode analysis - Identified defects



Lutz Lilje DESY -FDET-

30.10.99

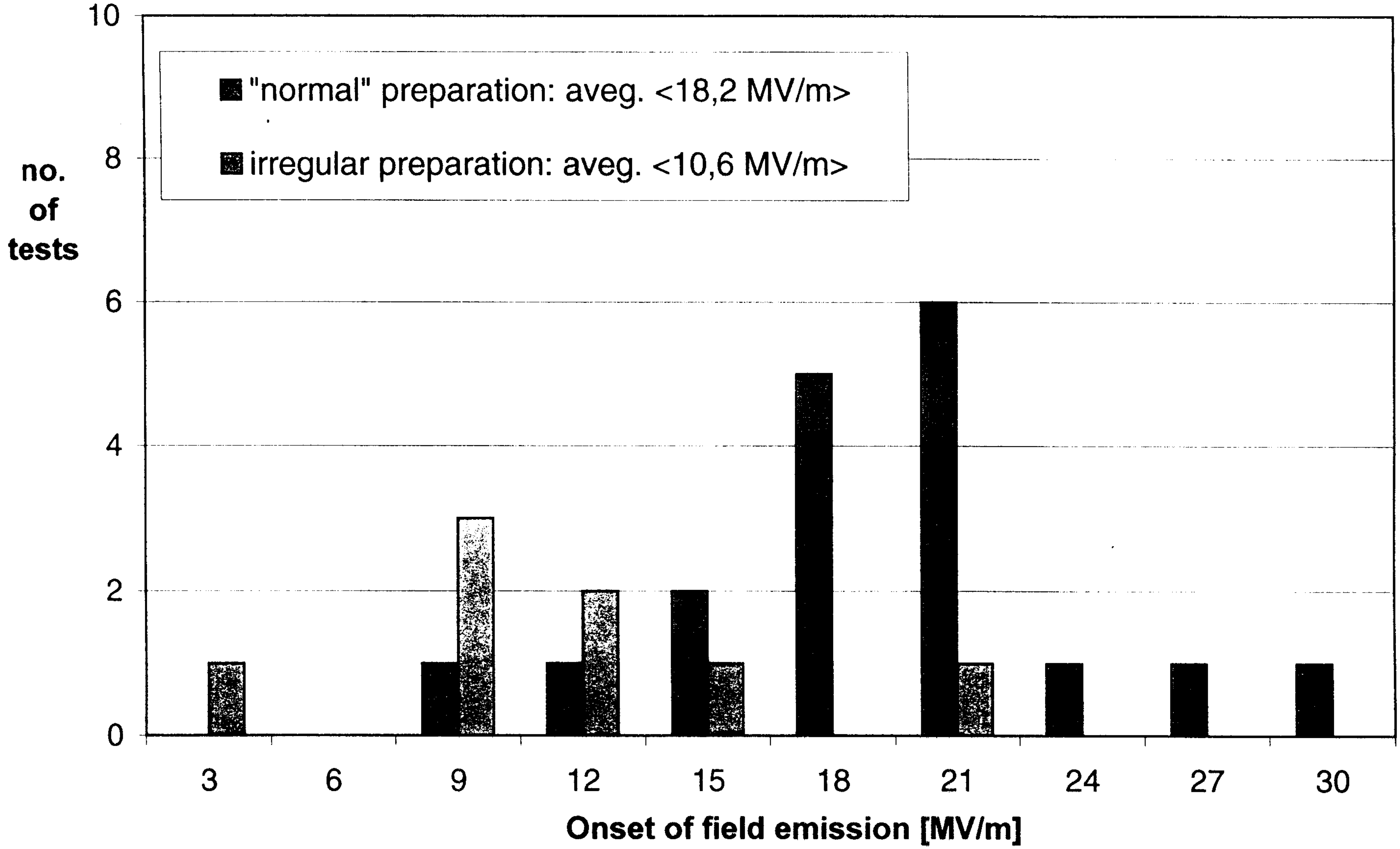
Limitation: Field Emission



(D. Reschke TUP007)

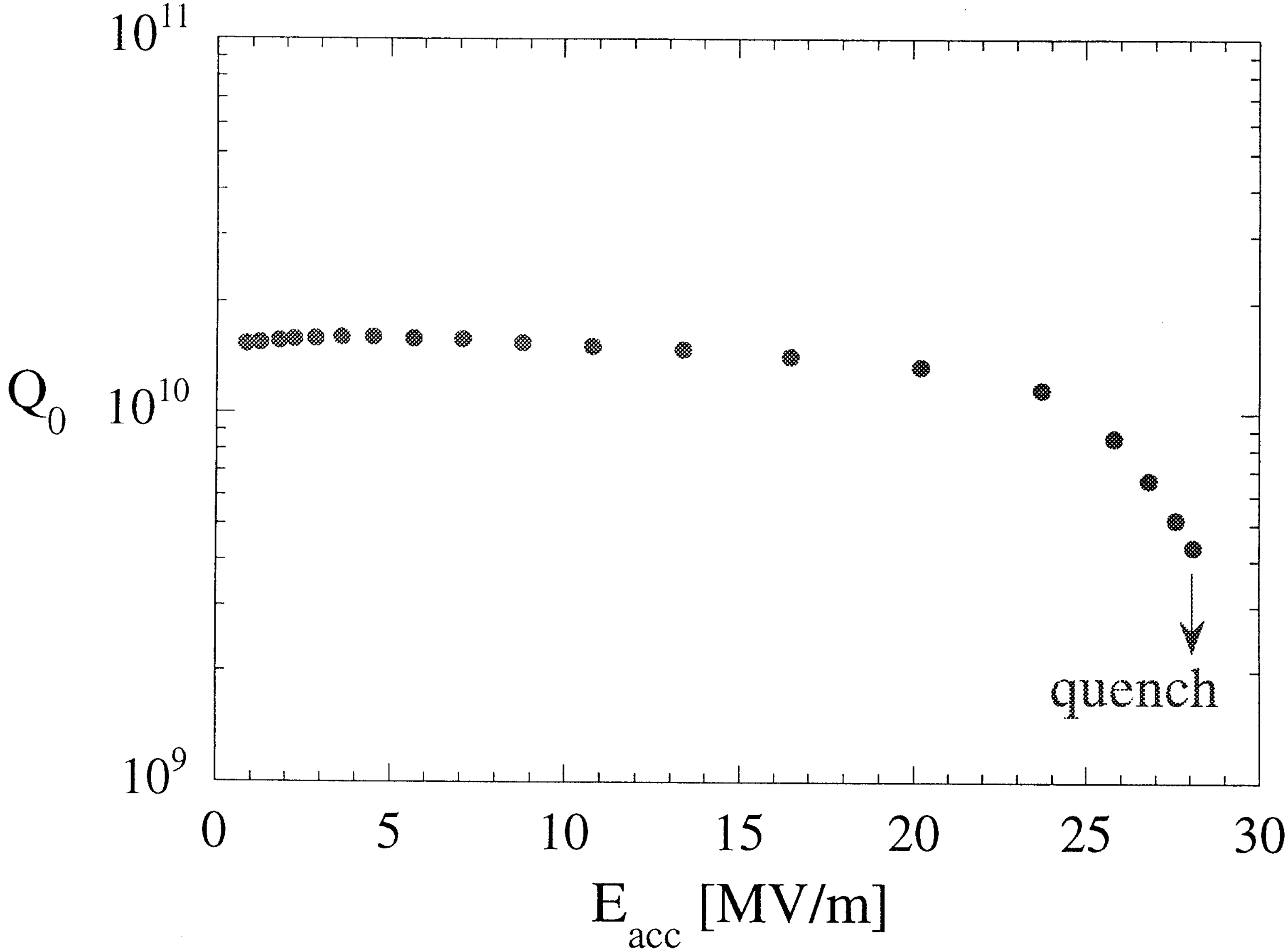
18.10.99

**Comparison of field emission onset (1. power rise)
of "normal" and irregular preparations
(only vertical tests of 9-cell cavities in 1999)**



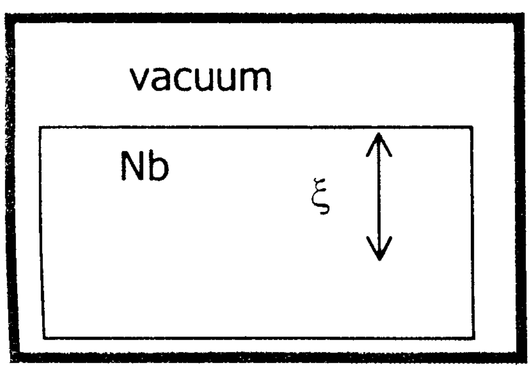
DiaUnregel1.power

TTF 9-cell cavity showing Q degradation above 25 MV/m without any evidence of field emission



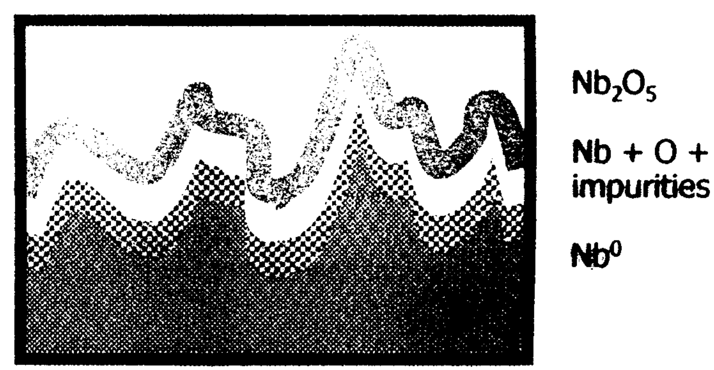
Alternative surface treatment

- Impossible to test all possible surface treatments
- Surface studies on samples : what criteria ?
  - Large scale roughness (influence on magnetic field ?)
  - Small scale roughness (influence on superconducting properties ?)
  - Surface chemical composition (role of impurities ?)
  - Role of the oxide layer (stress induced on the Nb lattice ?)

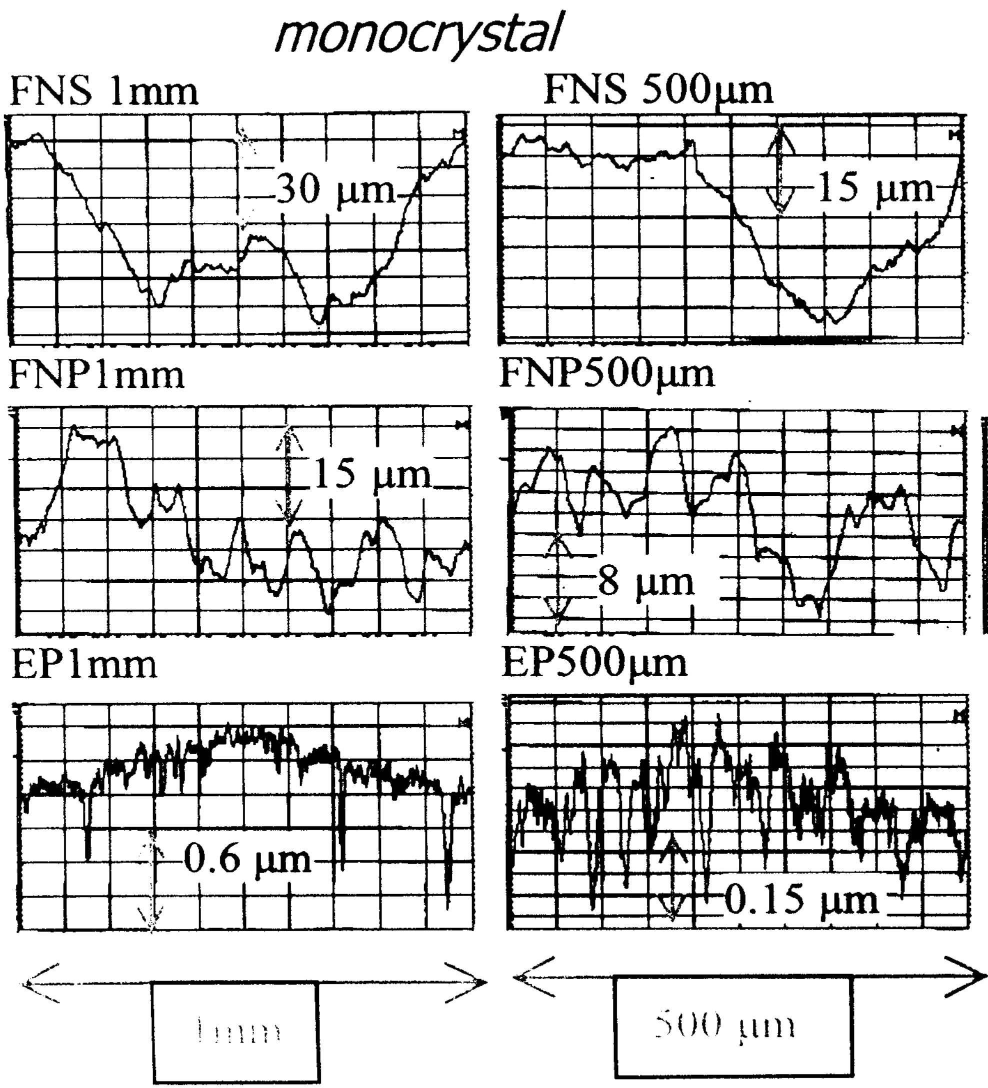


Textbook surfaces

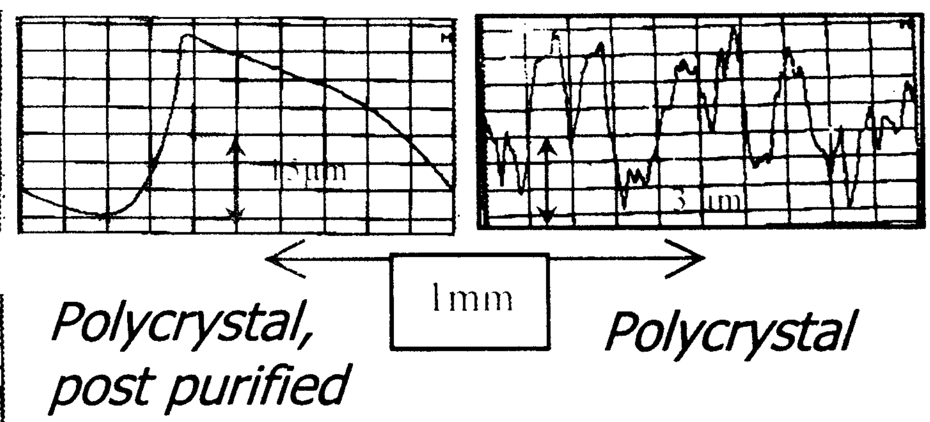
Real surfaces ?



Niobium surface studies



- Roughness
  - depends from the observing scale...

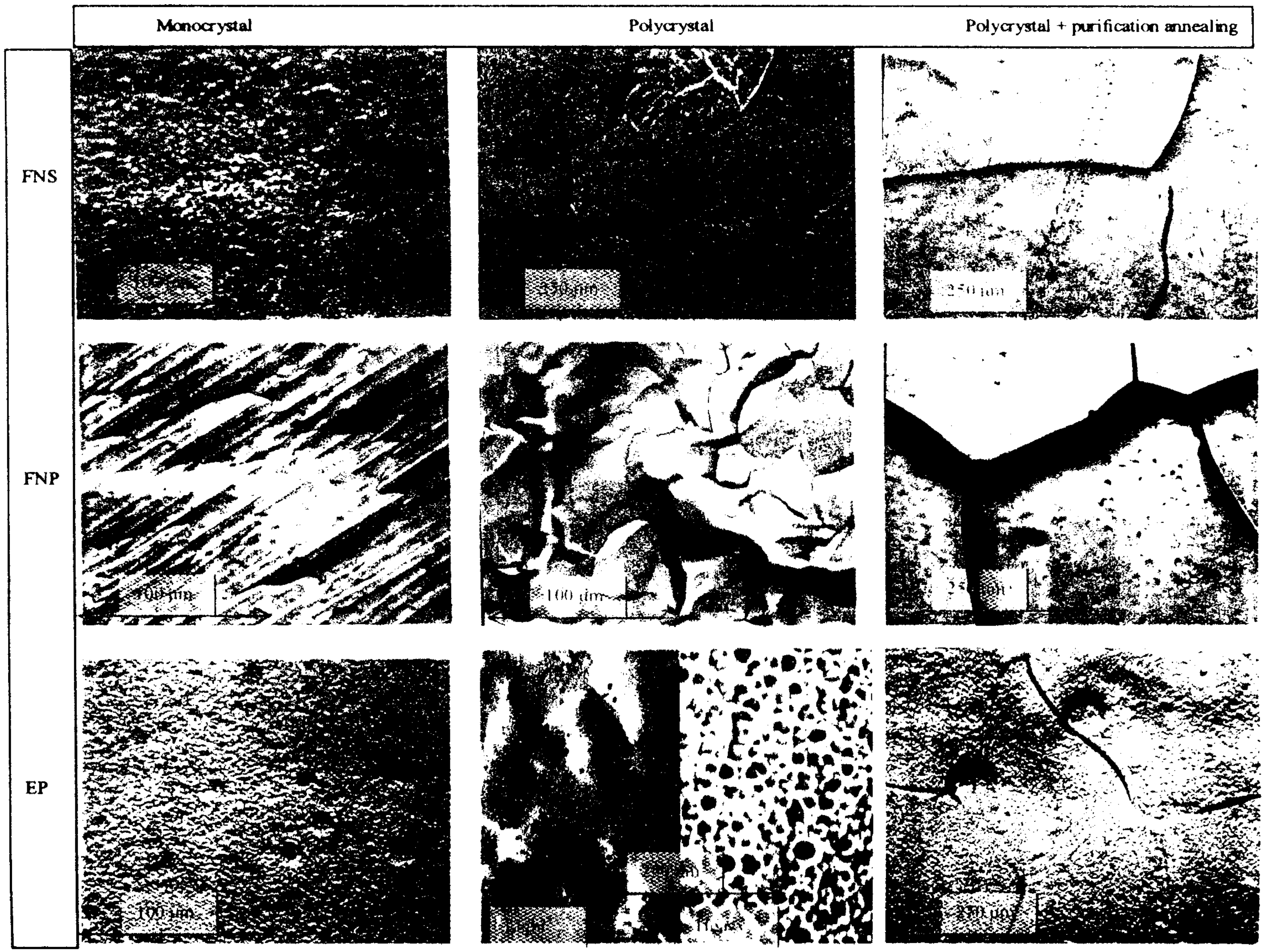


  - ...and the crystallographic state.

Niobium surface studies

- Microscopy

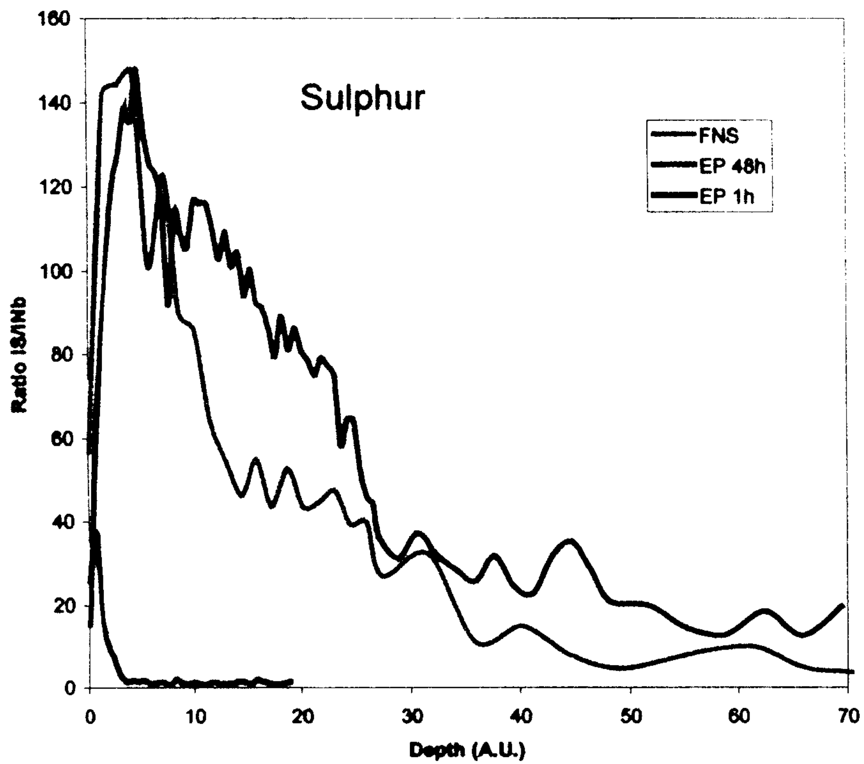
The morphology of the Nb surface is strongly affected par the purity & the crystallo-graphic state

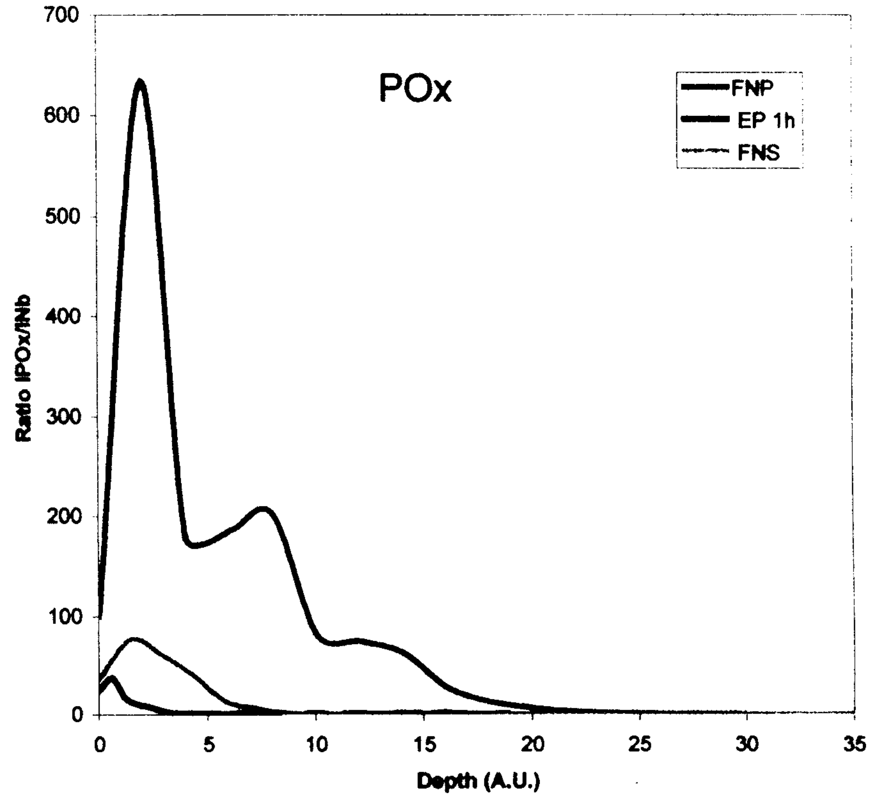


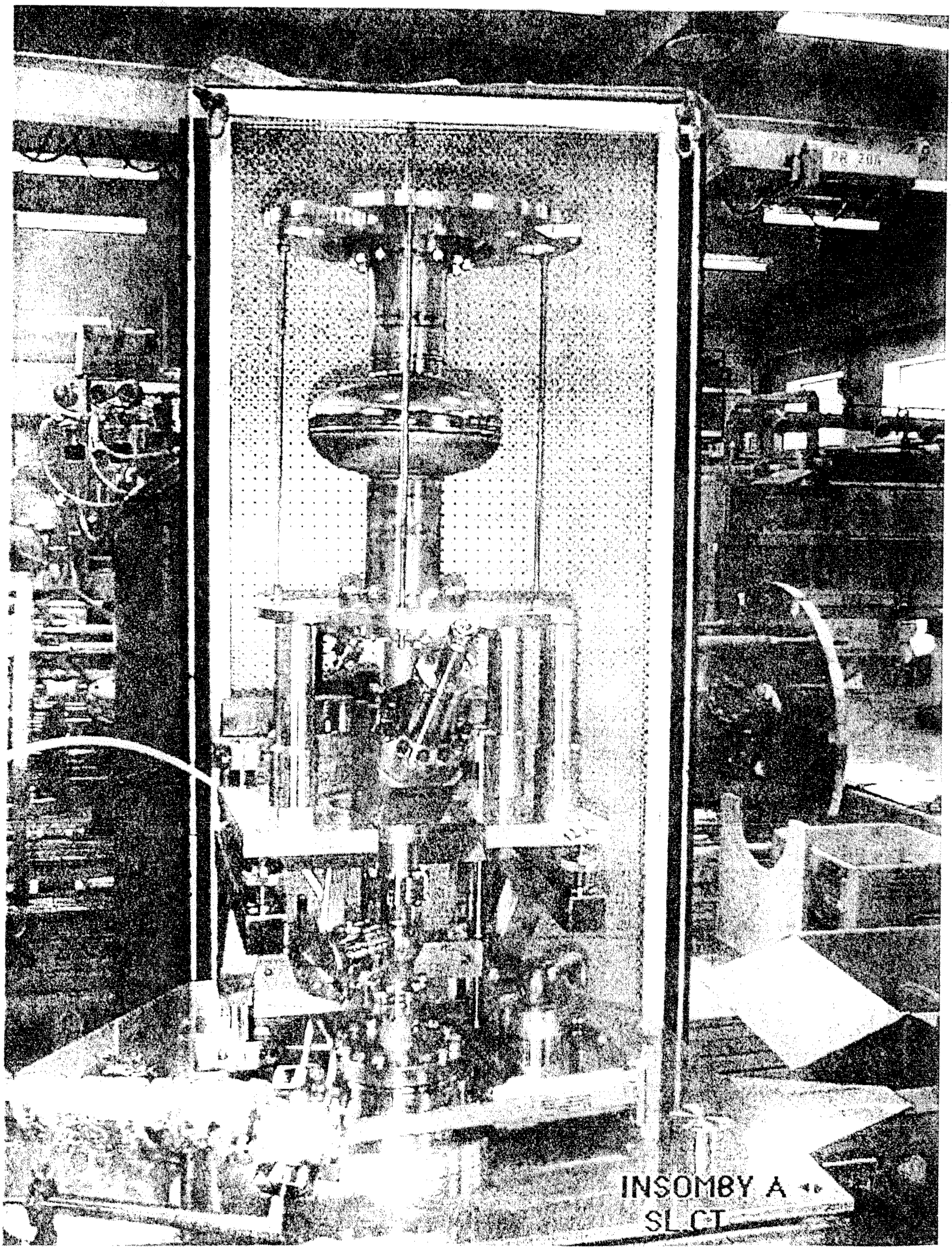
Niobium surface studies

Anion insertion in the oxide layer

- TOF-SIMS



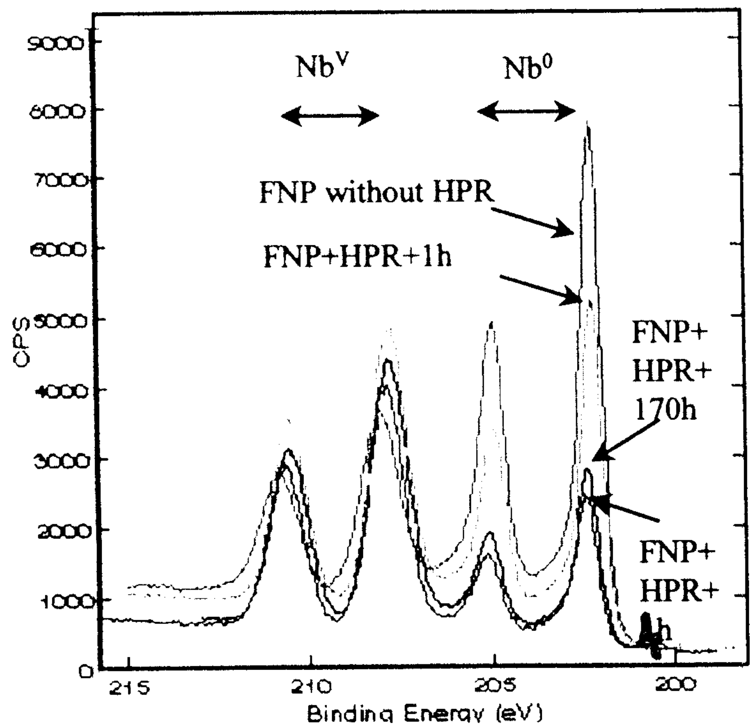



INSOMBY A
SLCT

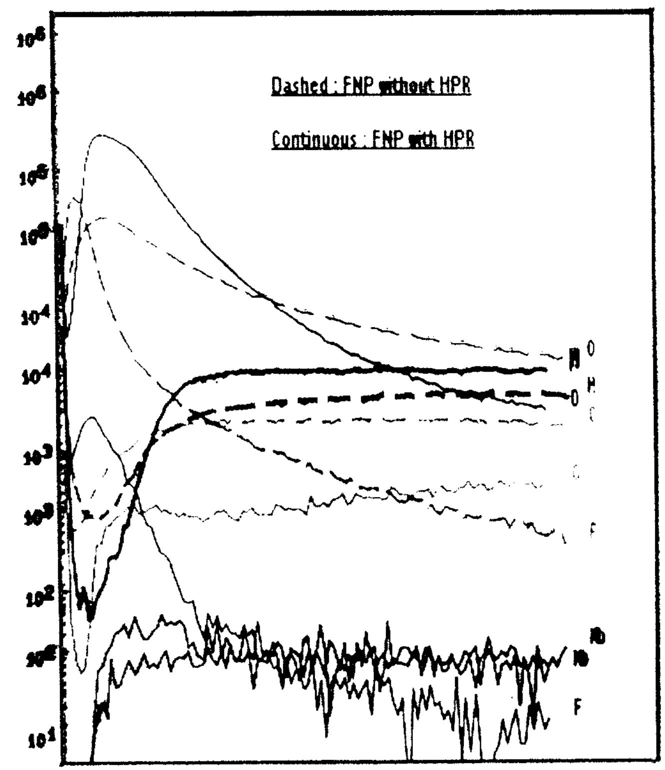
Niobium surface studies

Effect of HPR

- ESCA



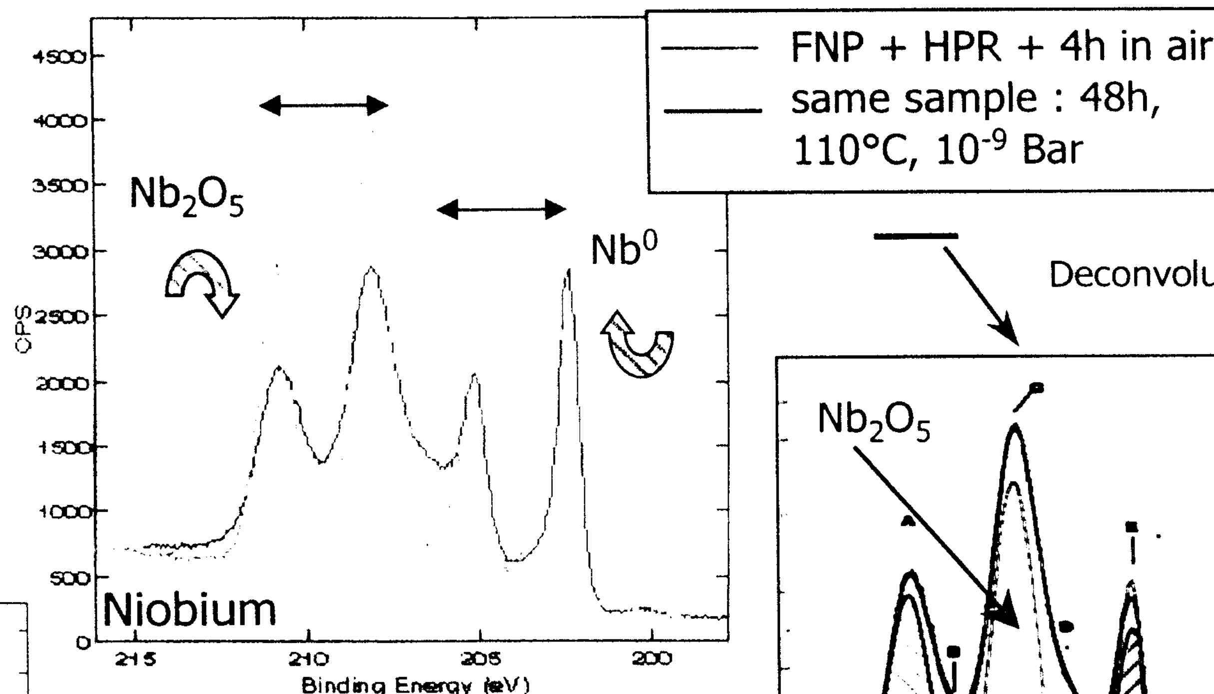
- TOF-SIMS

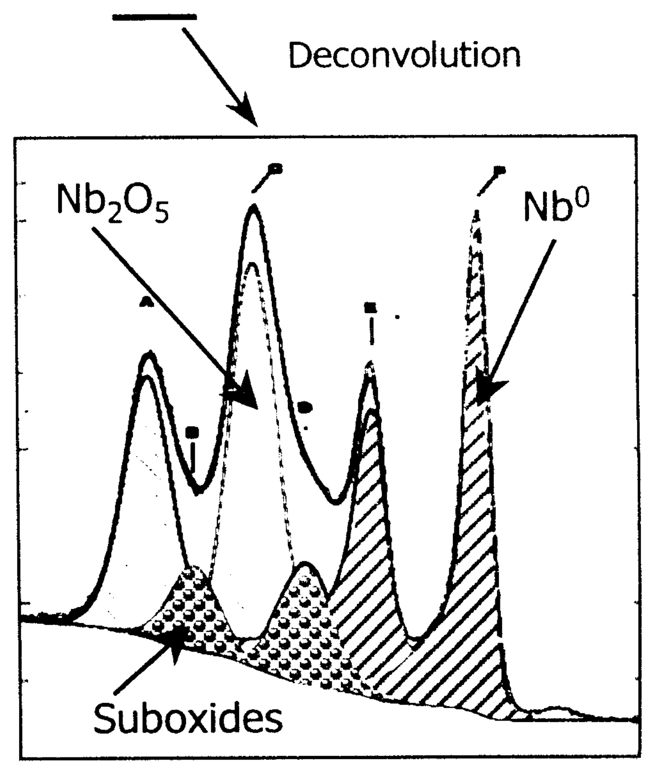


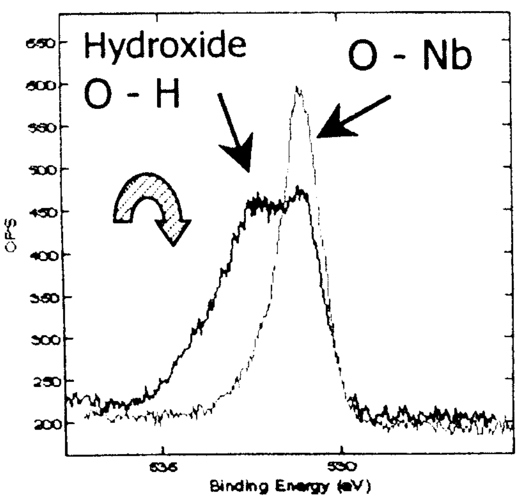
Poster : C. Z. Antoine et al. TUP035

Niobium surface studies

- Effect of baking (ESCA)







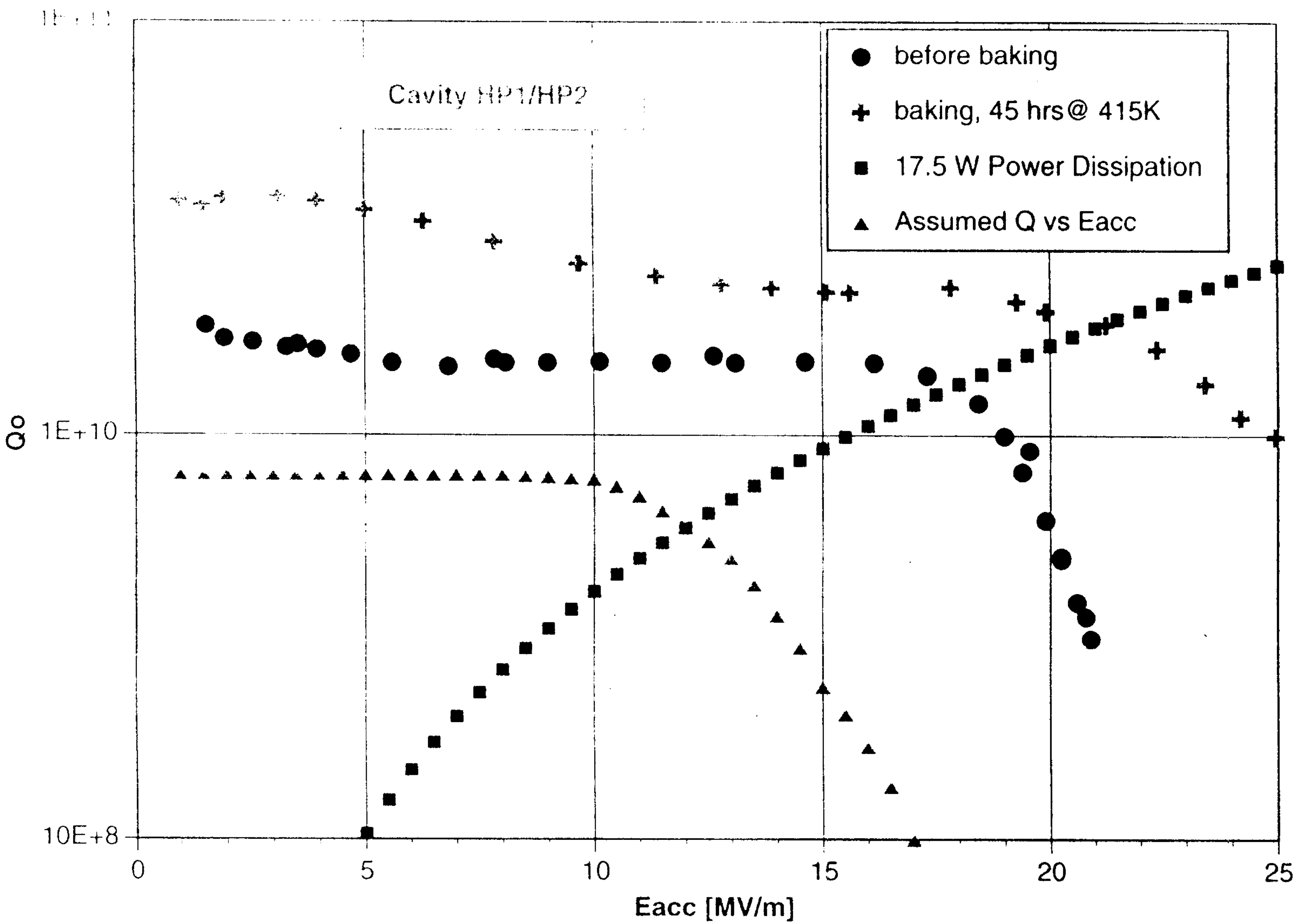
Nb_2O_5 dissociates & gets thinner !

Poster [illegible] et al. TUP018

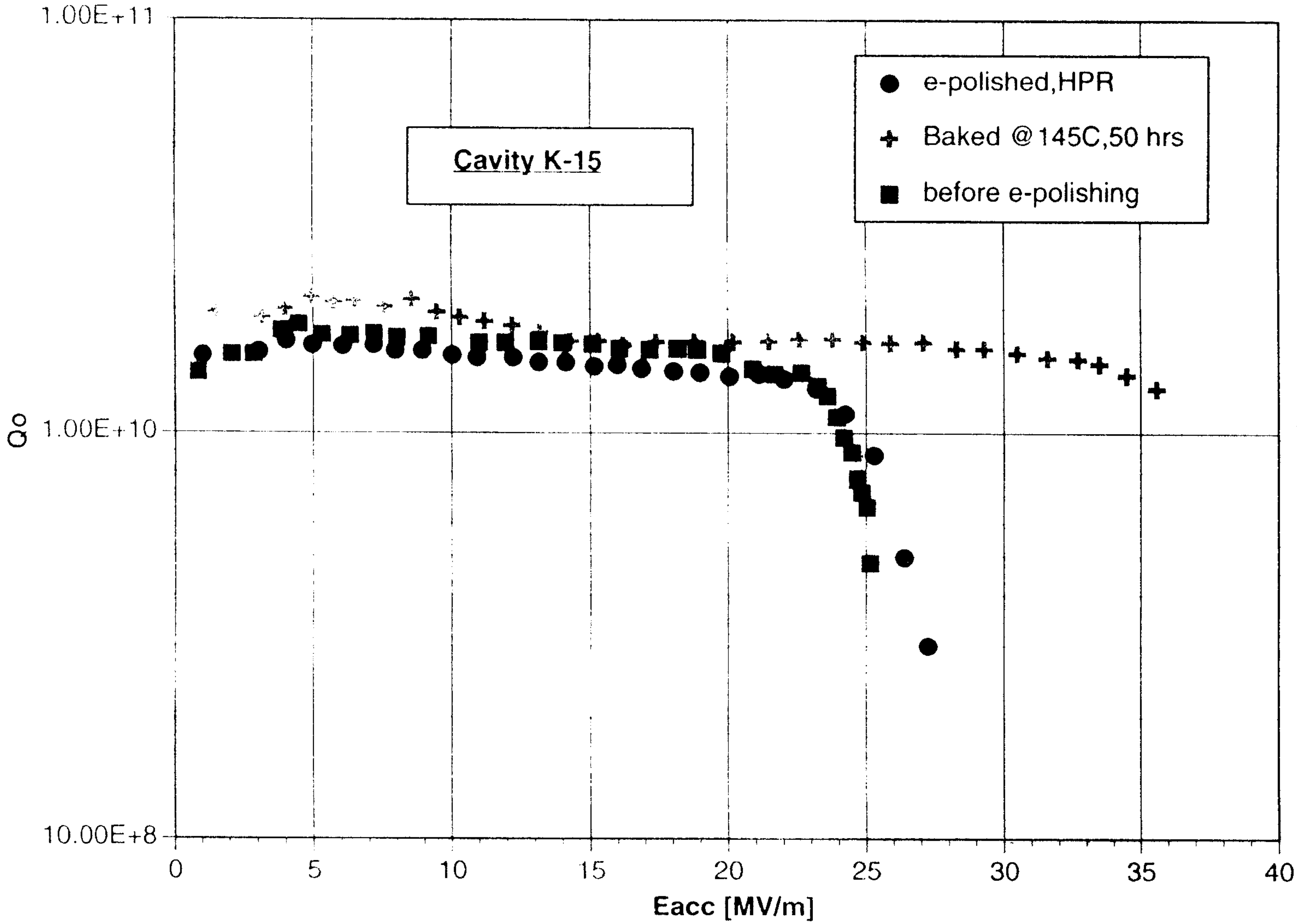
“In-situ” Baking

In a series of measurements on single and multi-cell cavities “in-situ” baking at 145 C was applied to the cavities after a baseline test. Observations are :

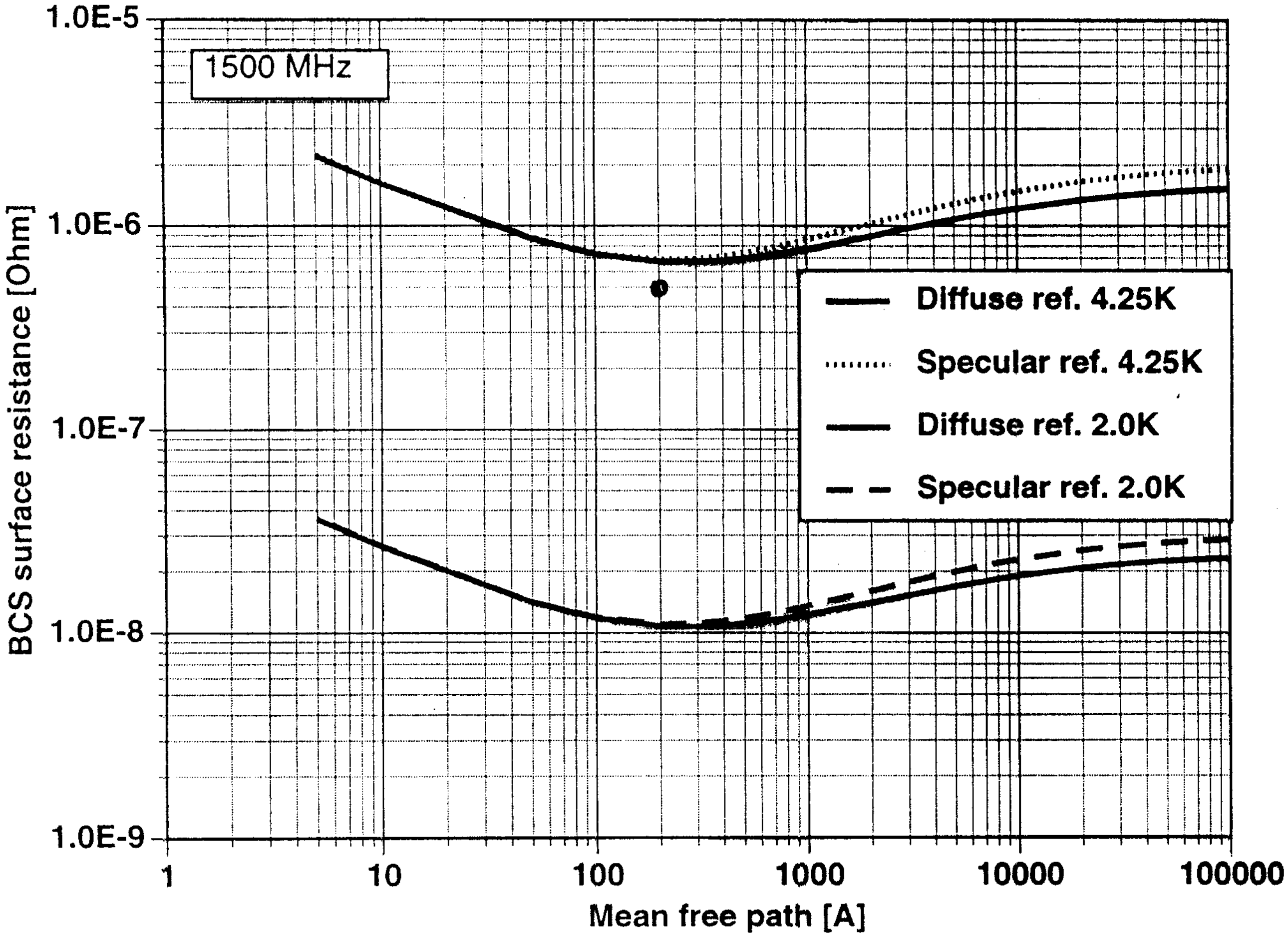
- BCS Surface Resistance improved by nearly a factor of 2
- The improvement remains after exposure to air or HPR
- The thickness of the improved niobium layer is 3000 - 4000 Å
- After removal of this layer the initial the BCS resistance comes back
- The process can be repeated and the same performance is achieved
- Sometimes also the high field behaviour of the cavity improves
- The effect seems to saturate after ≈ 40 hrs
- The effect cannot be explained by a mean free path effect alone
- Several material parameters of the Nb seem to change



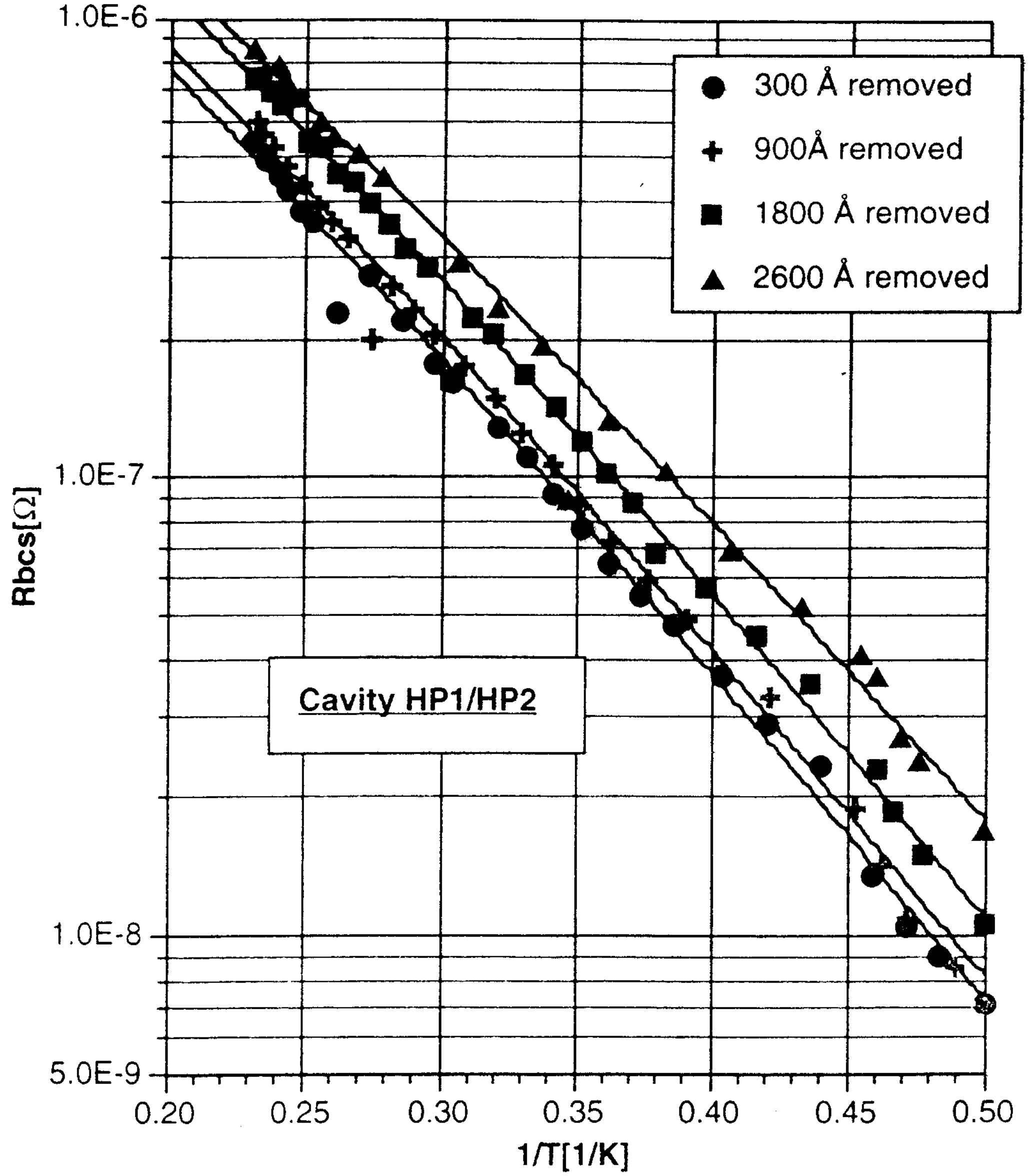
Cavity HP1/HP2
before baking
baking, 45 hrs@ 415K
17.5 W Power Dissipation
Assumed Q vs Eacc
Qo
1E+10
10E+8
0
5
10
15
20
25
Eacc [MV/m]



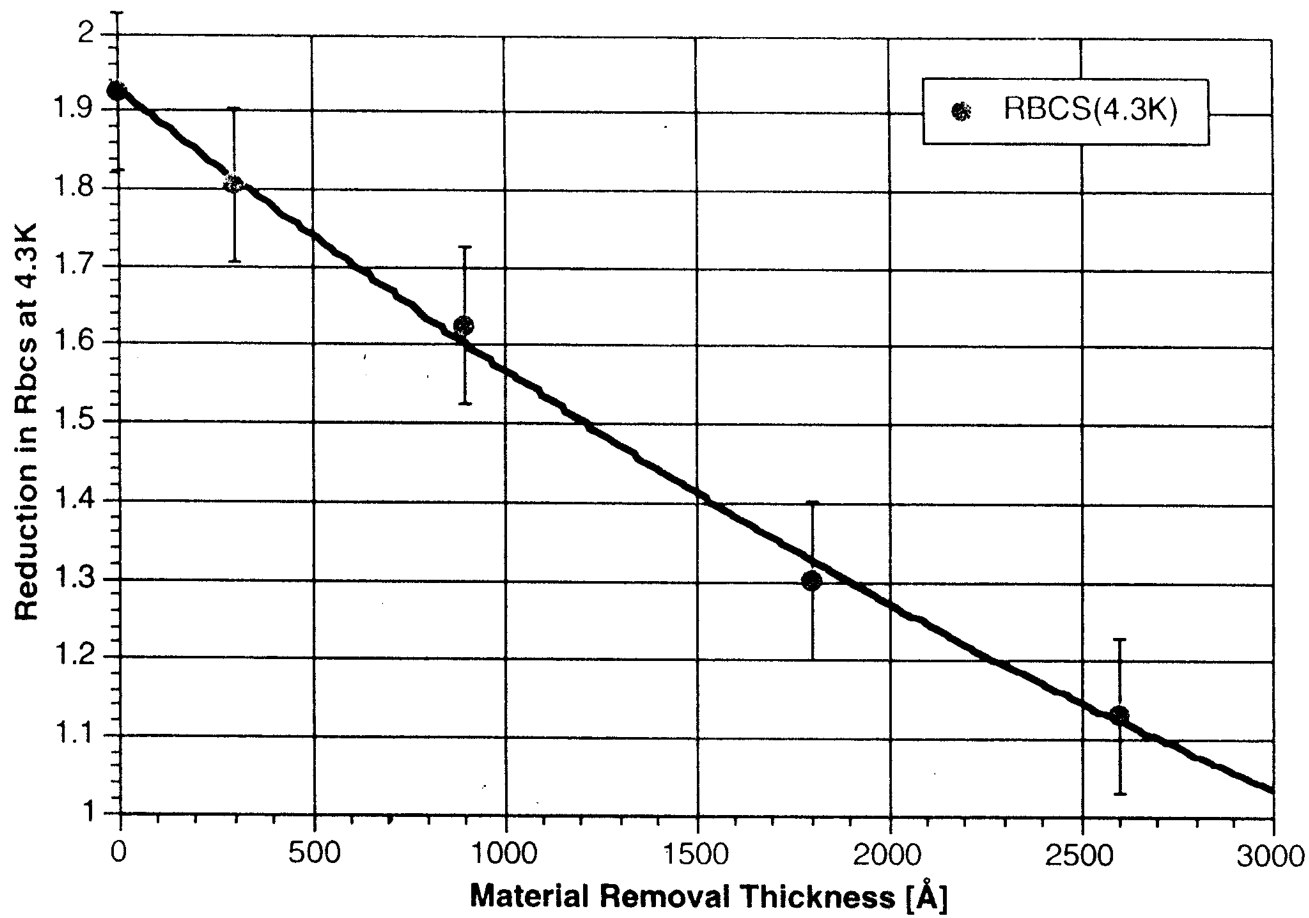
Cavity K-15
e-polished,HPR
Baked @145C,50 hrs
before e-polishing
1.00E+11
1.00E+10
10.00E+8
Qo
0
5
10
15
20
25
30
35
40
Eacc [MV/m]



1500 MHz
BCS surface resistance [Ohm]
1.0E-5
1.0E-6
1.0E-7
1.0E-8
1.0E-9
1
10
100
1000
10000
100000
Mean free path [A]
Diffuse ref. 4.25K
Specular ref. 4.25K
Diffuse ref. 2.0K
Specular ref. 2.0K



1.0E-6
1.0E-7
1.0E-8
5.0E-9
Rbcs[Ω]
0.20
0.25
0.30
0.35
0.40
0.45
0.50
1/T[1/K]
300 Å removed
900Å removed
1800 Å removed
2600 Å removed
Cavity HP1/HP2

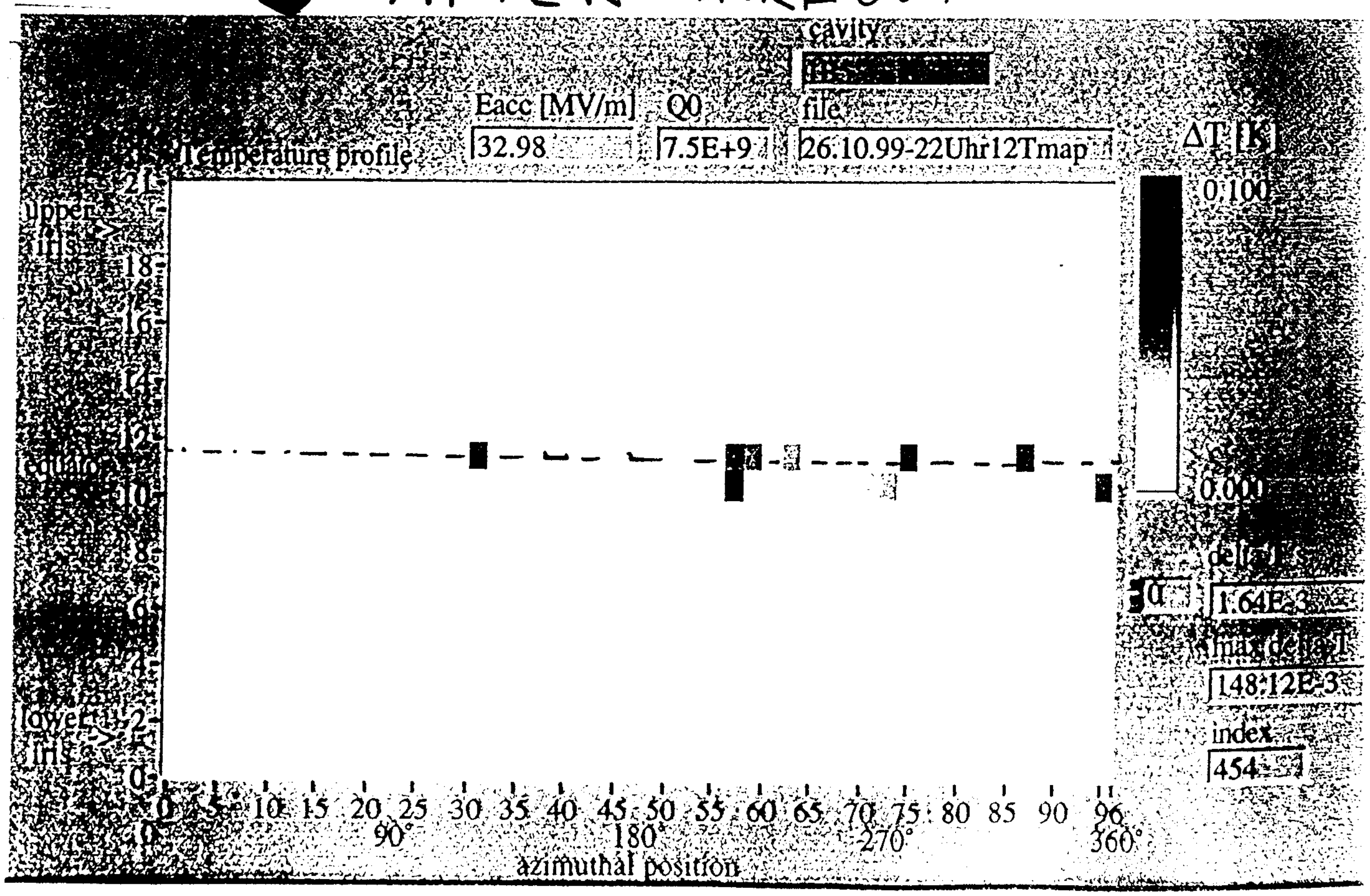


RBCS(4.3K)
Reduction in Rbcs at 4.3K
Material Removal Thickness [Å]
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1
0
500
1000
1500
2000
2500
3000

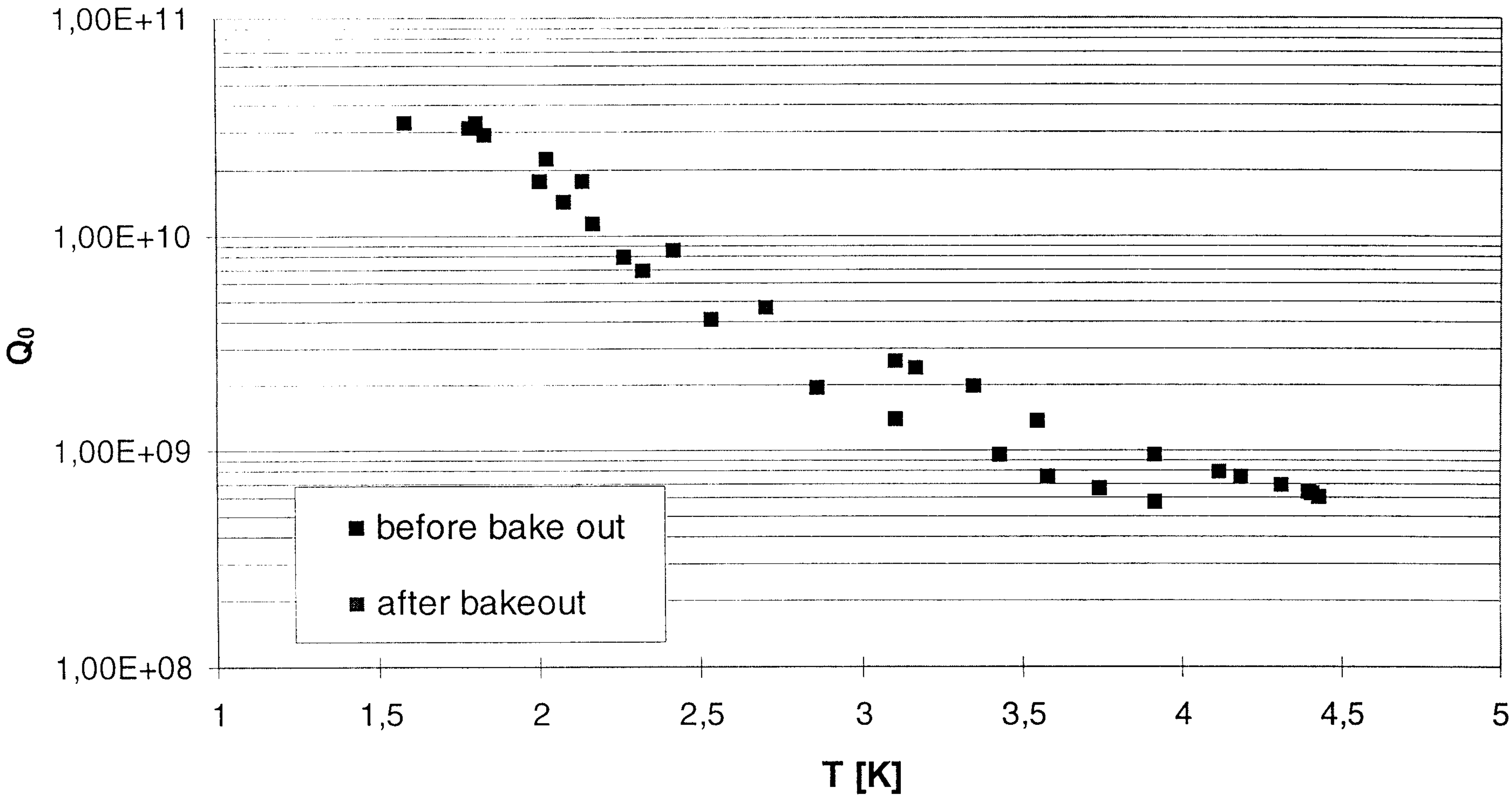
TEMPERATURE MAPPING AT 33 MV/m

BEFORE BAKEOUT

AFTER BAKEOUT



Q versus T before and after UHV bakeout on an electropolished cavity at 120 °C for 48 hours



Lutz Lilje DESY -FDET- TESLA 30.10.99

Q-degradation at High Gradient

- " **High Electric and Magnetic RF Fields in Bulk Superconducting Nb Cavities"**

J. Halbritter+, P. Kneisel++, V. Palmieri* and M. Pekeler**

+ IMF Kernforschungszentrum Karlsruhe ++ Jlab * INFN ** DESY/Acce

- With improved quality of sc surfaces limitations are no longer caused by gross defects (welds, nc inclusions, dust..), but by interfaces Nb/Nb_2O_{5-y}/adsorbates and Kapitza resistance

- The electrric field (E_{perp}) surface impedance becomes important becauseof Interface Tunnel Exchange (ITE) between metal and localized states in the oxides, similar to enhanced FE

$$\Delta Z_E \sim a \exp(-c/\beta E_{perp})$$

Jefferson Lab

Q degradation cont'd

The extend if ITE depends on the "thickness" of the barrier (E-field and enhancement by geometry

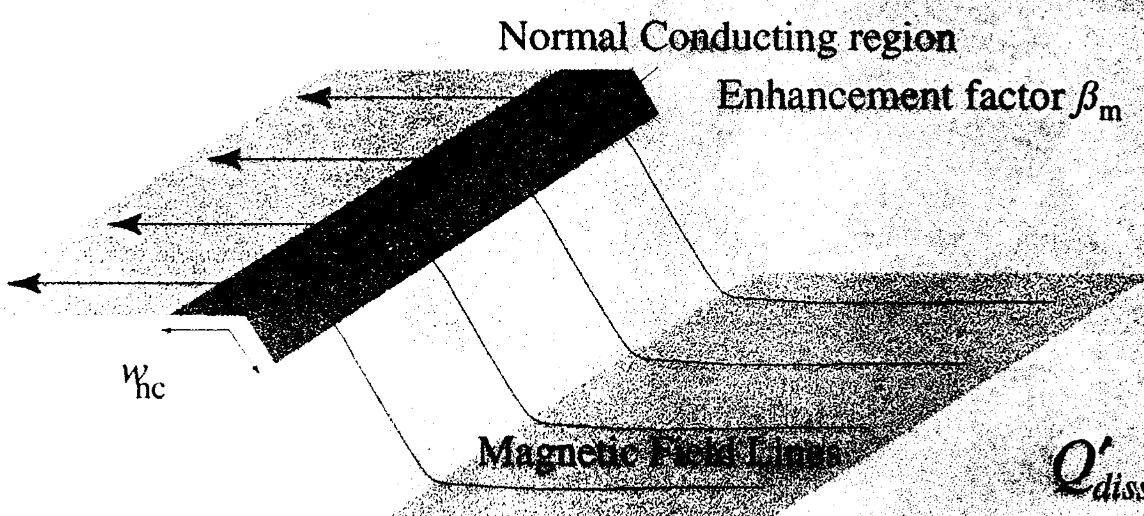
electric surface impedance decreases if less surface states are available

Material removal smoothens the surface (cracks) , less surface fields

Baking might reduce the density of localized states because of oxygen diffusion

Q Slope Mechanism

- Magnetic field enhancement at grain boundaries?

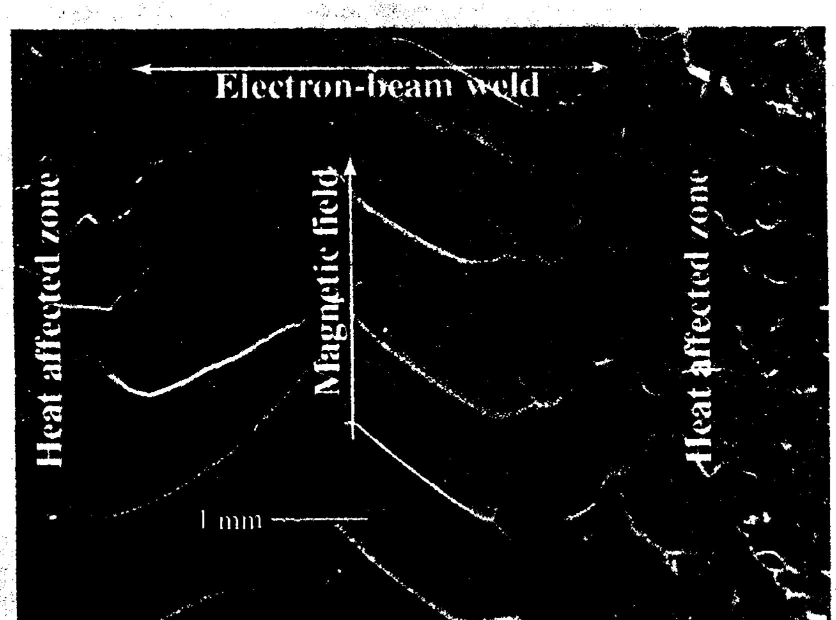


$$Q'_{diss} \approx \frac{1}{2} R_{nc} w_{nc} H^2_{crit}$$

$$R_{nc} \gg R_s$$

Breakdown Field/Location

- BD field from ANSYS is 30 MV/m (for infinite gb).
- Longest gb's with largest steps are in the EBW region.
- GB's not random. Almost perpendicular to field.
- Most P_{diss} at equator gb's.
- Explains consistent BD location in BCP cavities.

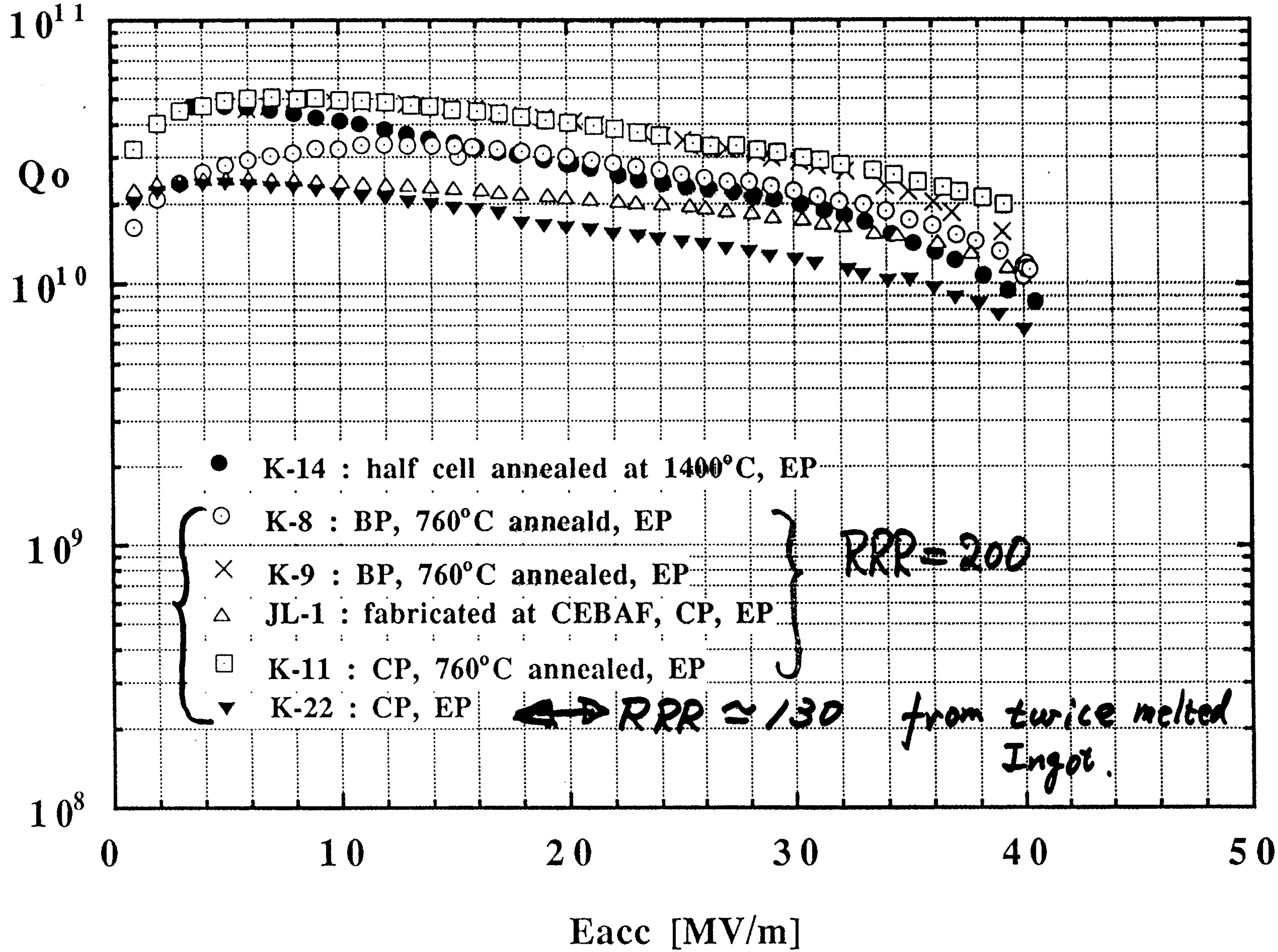


See poster by Geng *et al*.

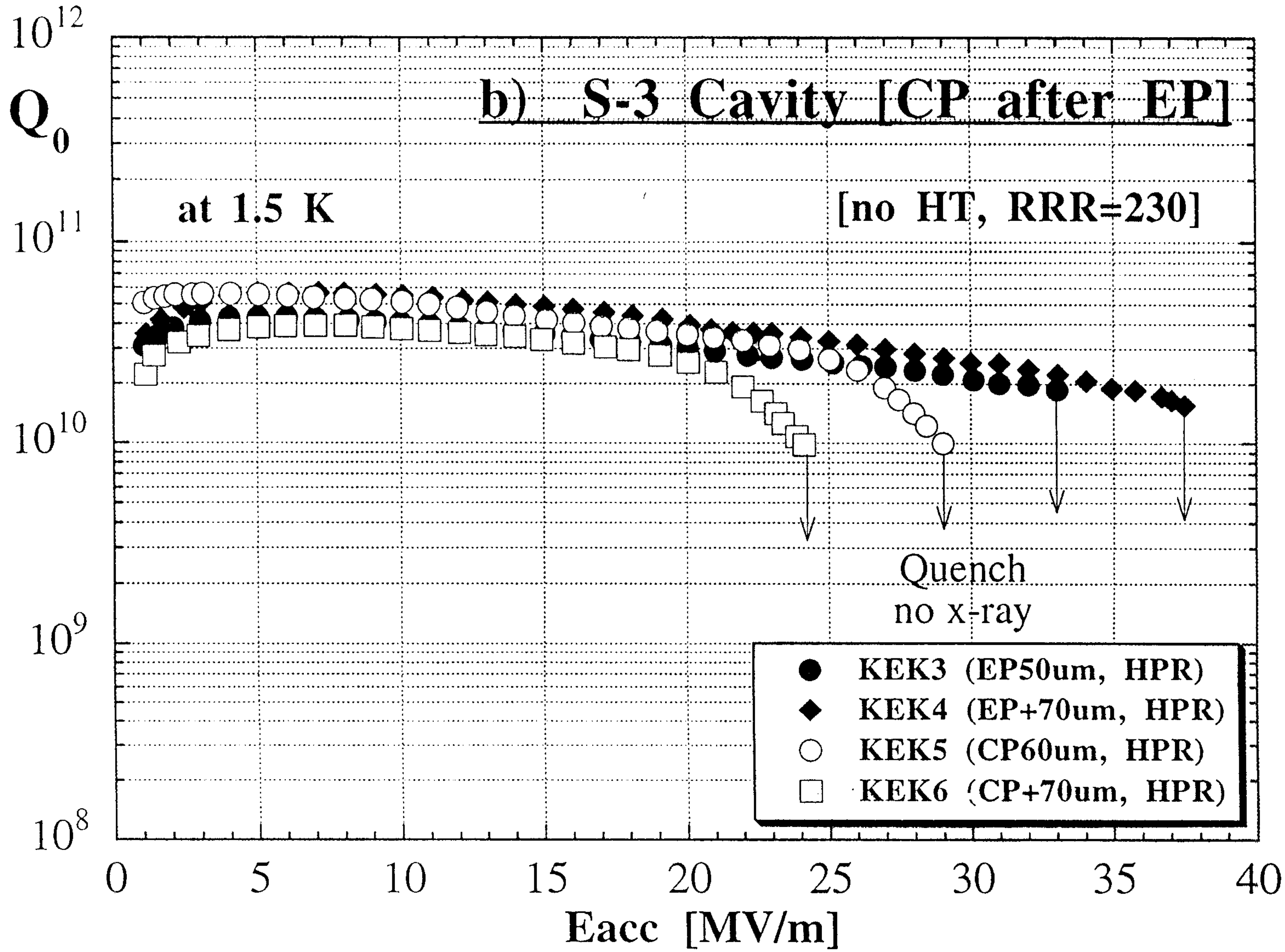
SURFACE PREPARATION

- ELECTROPOLISHING:
  - VERY GOOD ON SINGLE-CELLS
  - DOES NOT SHOW Q-DROP AFTER BAKEOUT AT 100°C
  - MORE DIFFICULT ON MULTI-CELLS
  - AIR EXPOSURE ?

- 'OTHER' CHEMISTRY:
  - NOT TOO MUCH IMPROVEMENT AS COMPARED TO STANDARD BCP

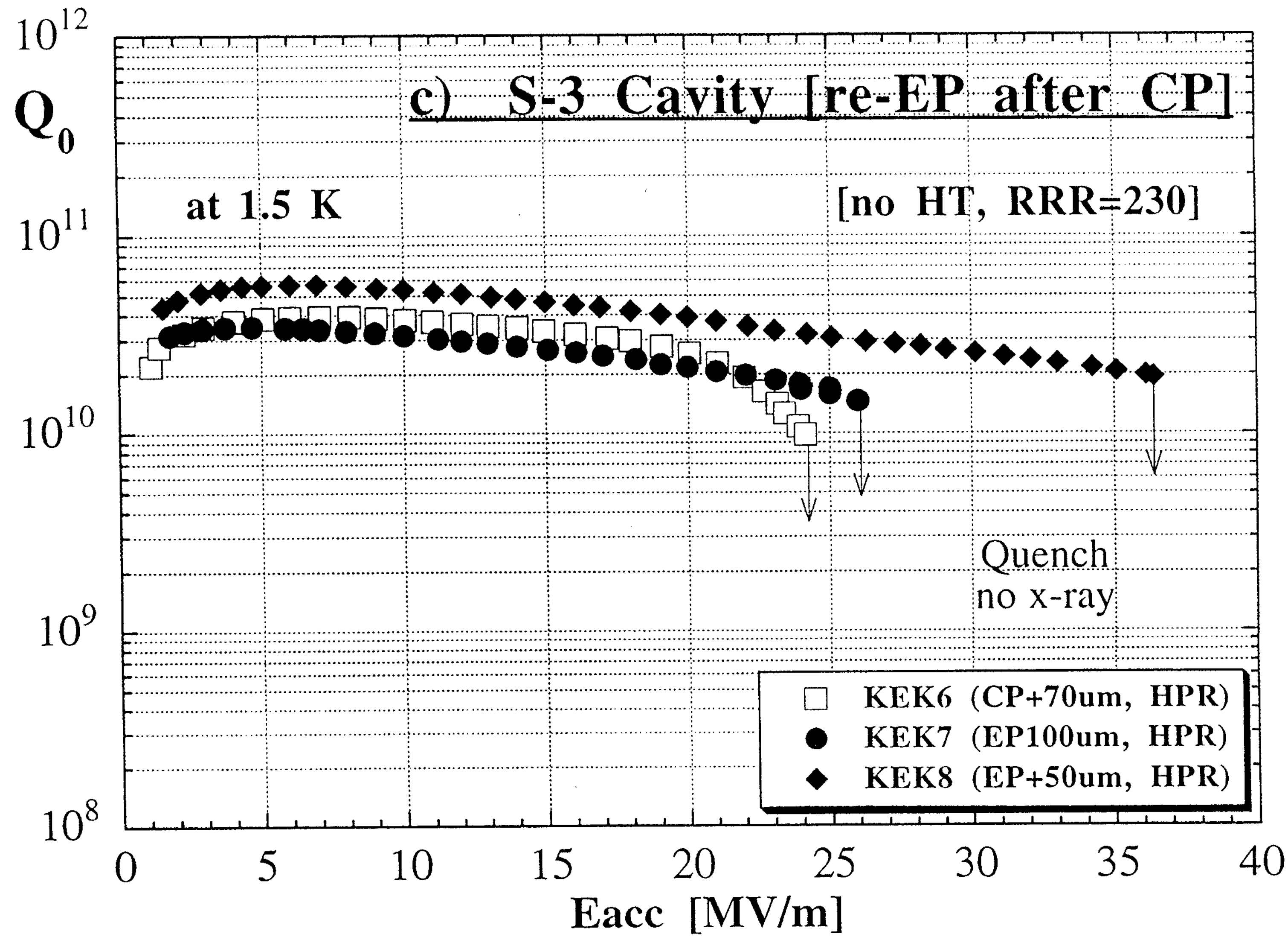


10^11
10^10
10^9
10^8
Qo
0
10
20
30
40
50
Eacc [MV/m]
K-14 : half cell annealed at 1400°C, EP
K-8 : BP, 760°C anneald, EP
K-9 : BP, 760°C annealed, EP
JL-1 : fabricated at CEBAF, CP, EP
K-11 : CP, 760°C annealed, EP
K-22 : CP, EP
RRR = 200
RRR ≃ 130 from twice melted Ingot.



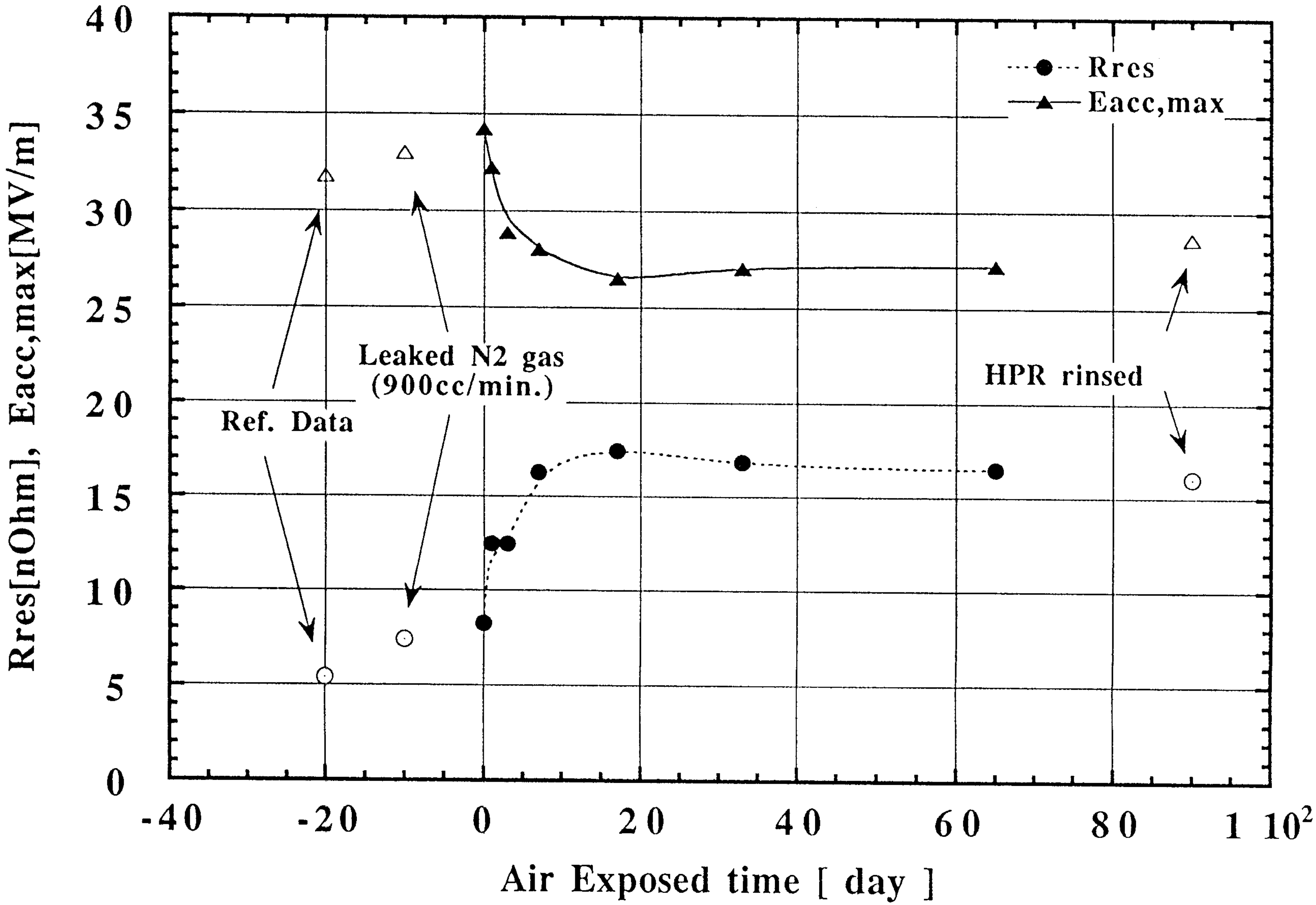
b) S-3 Cavity [CP after EP]
Q_0
at 1.5 K
[no HT, RRR=230]
Quench
no x-ray
KEK3 (EP50um, HPR)
KEK4 (EP+70um, HPR)
KEK5 (CP60um, HPR)
KEK6 (CP+70um, HPR)
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
0
5
10
15
20
25
30
35
40
Eacc [MV/m]

E. KAKO



c) S-3 Cavity [re-EP after CP]
Q_0
at 1.5 K
[no HT, RRR=230]
10^{12}
10^{11}
10^{10}
10^{9}
10^{8}
Quench
no x-ray
KEK6 (CP+70um, HPR)
KEK7 (EP100um, HPR)
KEK8 (EP+50um, HPR)
0
5
10
15
20
25
30
35
40
Eacc [MV/m]

E. KAKO

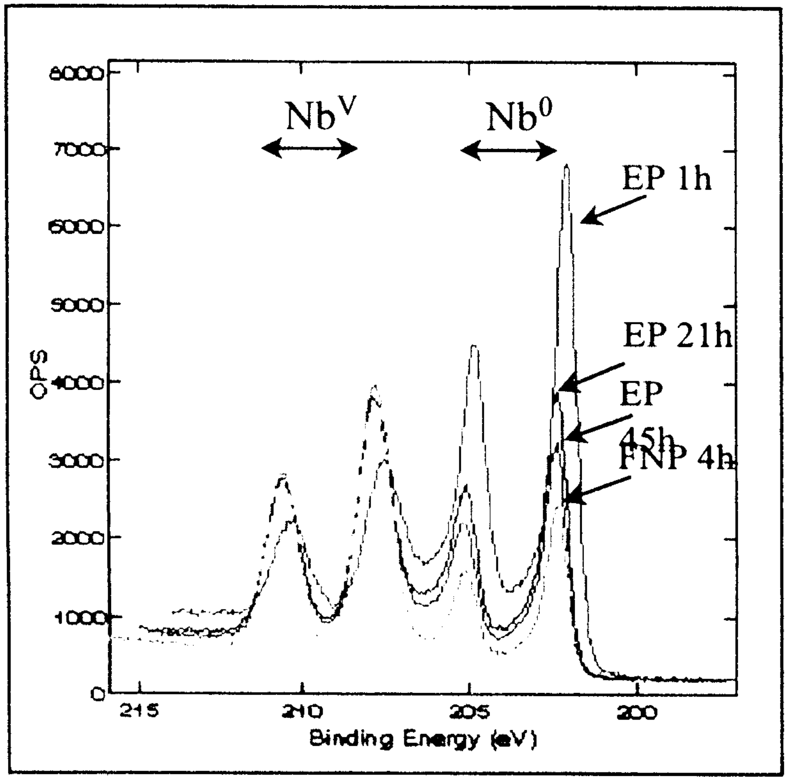


Rres
Eacc,max
Leaked N2 gas
(900cc/min.)
Ref. Data
HPR rinsed
Rres[nOhm], Eacc,max[MV/m]
Air Exposed time [day]
40
35
30
25
20
15
10
5
0
-40
-20
0
20
40
60
80
1 10^2

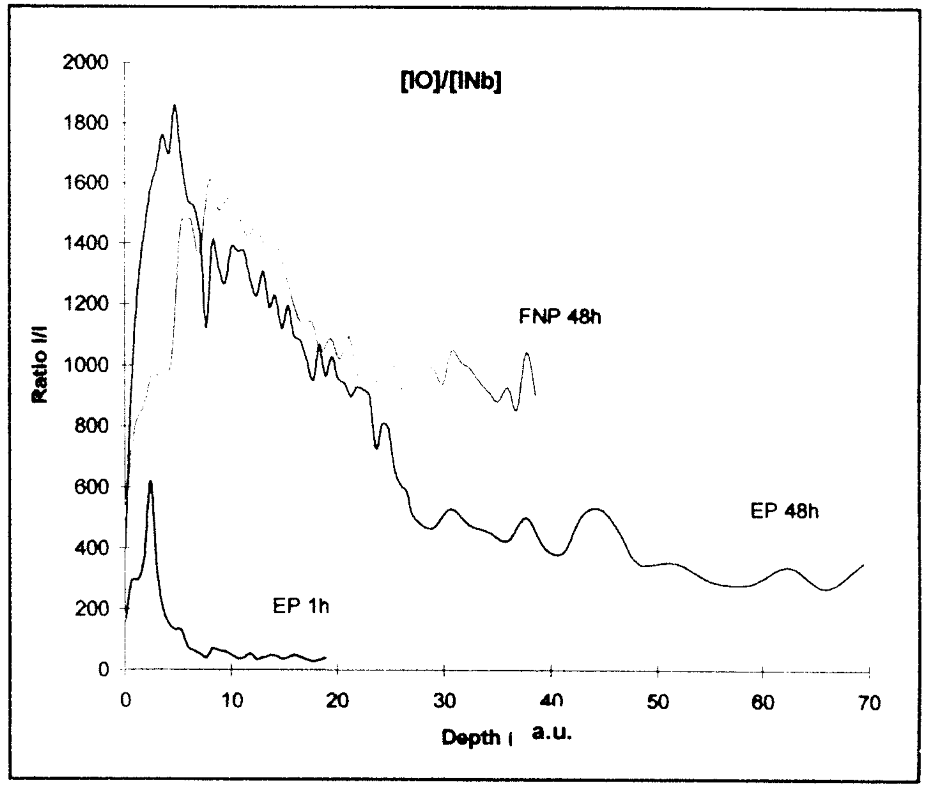
Niobium surface studies

Nb_2O_5 is thinner in EP samples, but reaches ~ 6nm within a week

- ESCA

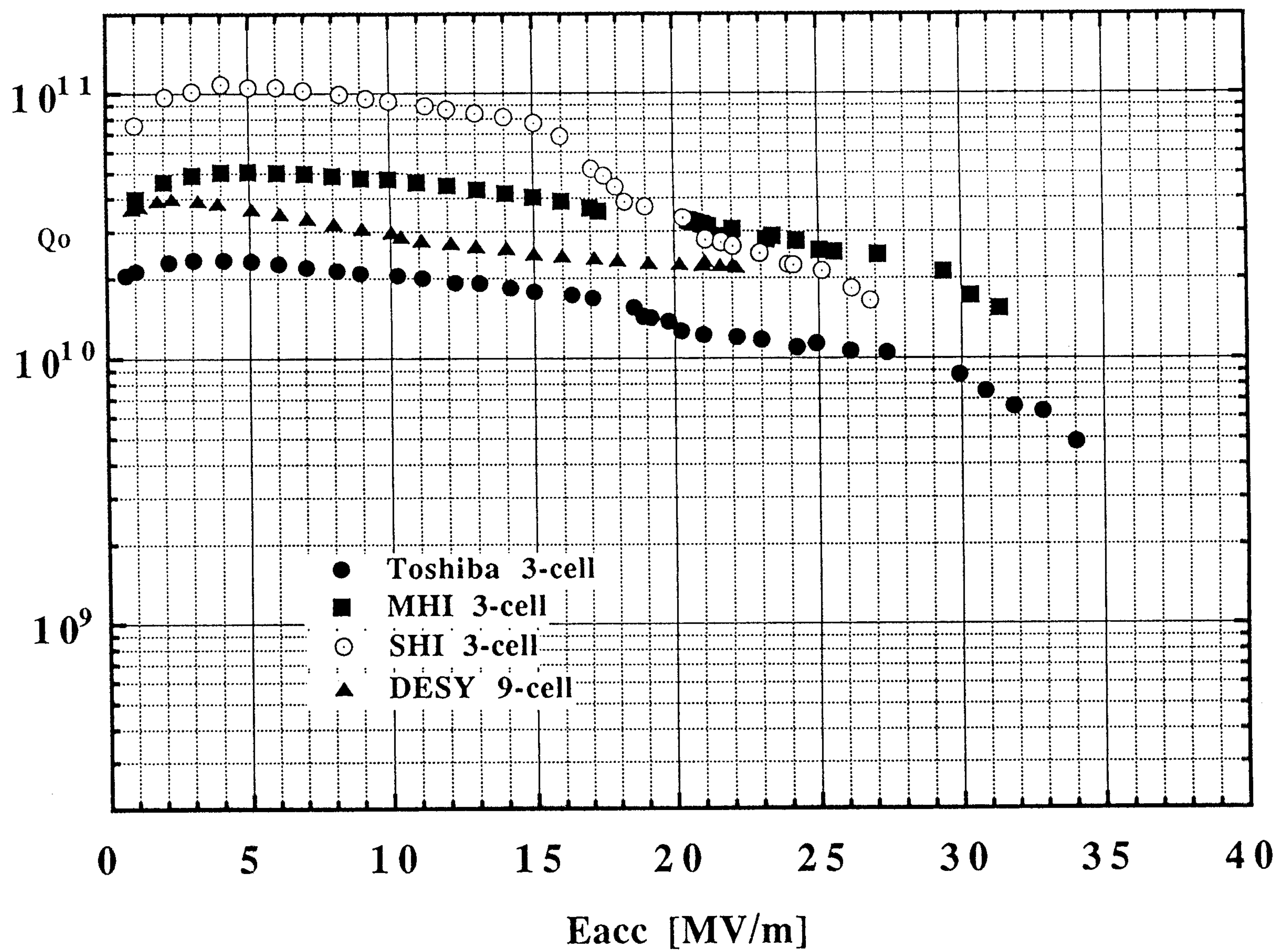


- TOF-SIMS

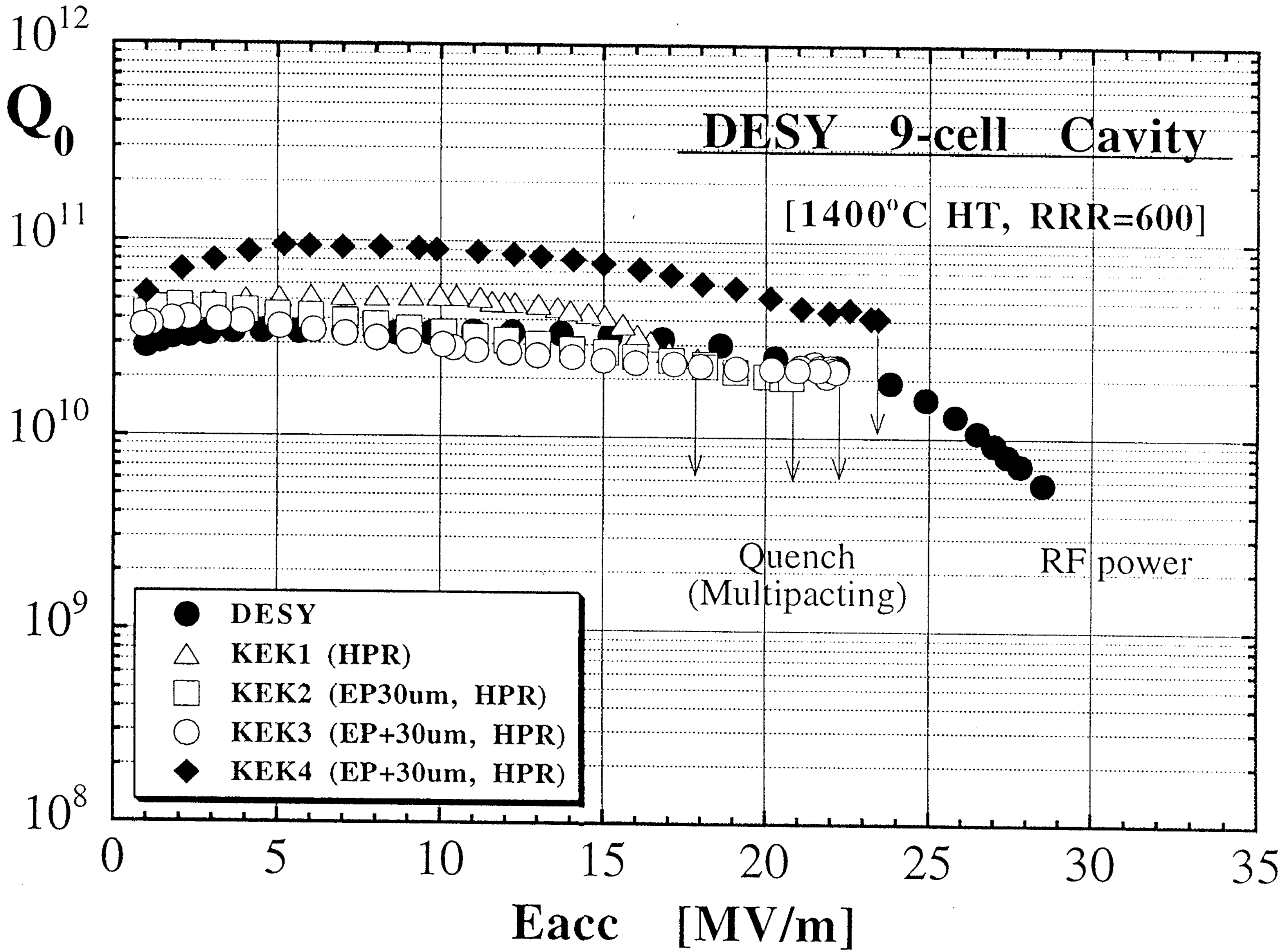


Antoine et al.

& K. SAITO et al. TUP032

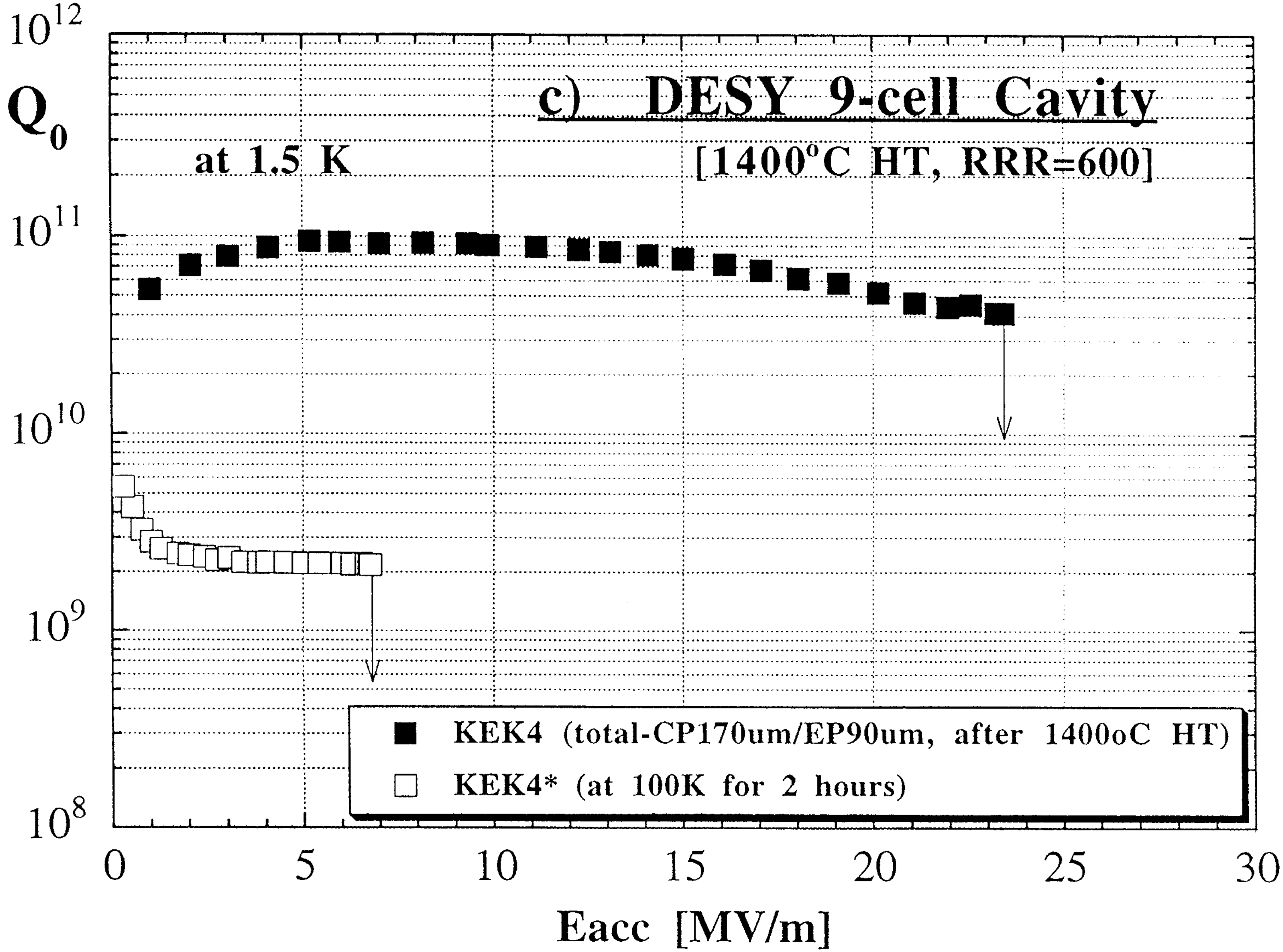


10^{11}
Qo
10^{10}
10^{9}
Toshiba 3-cell
MHI 3-cell
SHI 3-cell
DESY 9-cell
0
5
10
15
20
25
30
35
40
Eacc [MV/m]



Q0
DESY 9-cell Cavity
[1400°C HT, RRR=600]
Quench
(Multipacting)
RF power
DESY
KEK1 (HPR)
KEK2 (EP30um, HPR)
KEK3 (EP+30um, HPR)
KEK4 (EP+30um, HPR)
Eacc [MV/m]

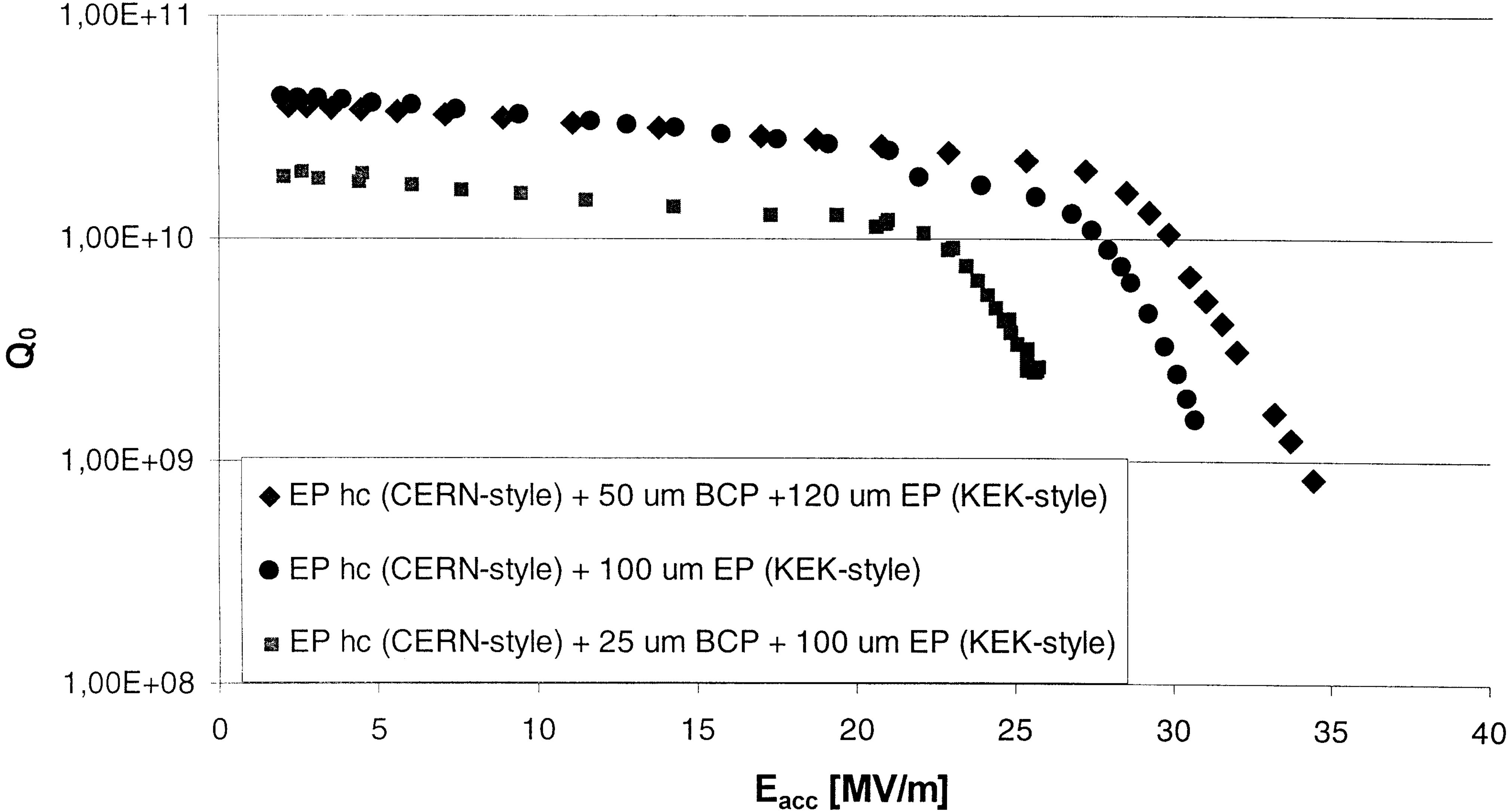
E. KAKO



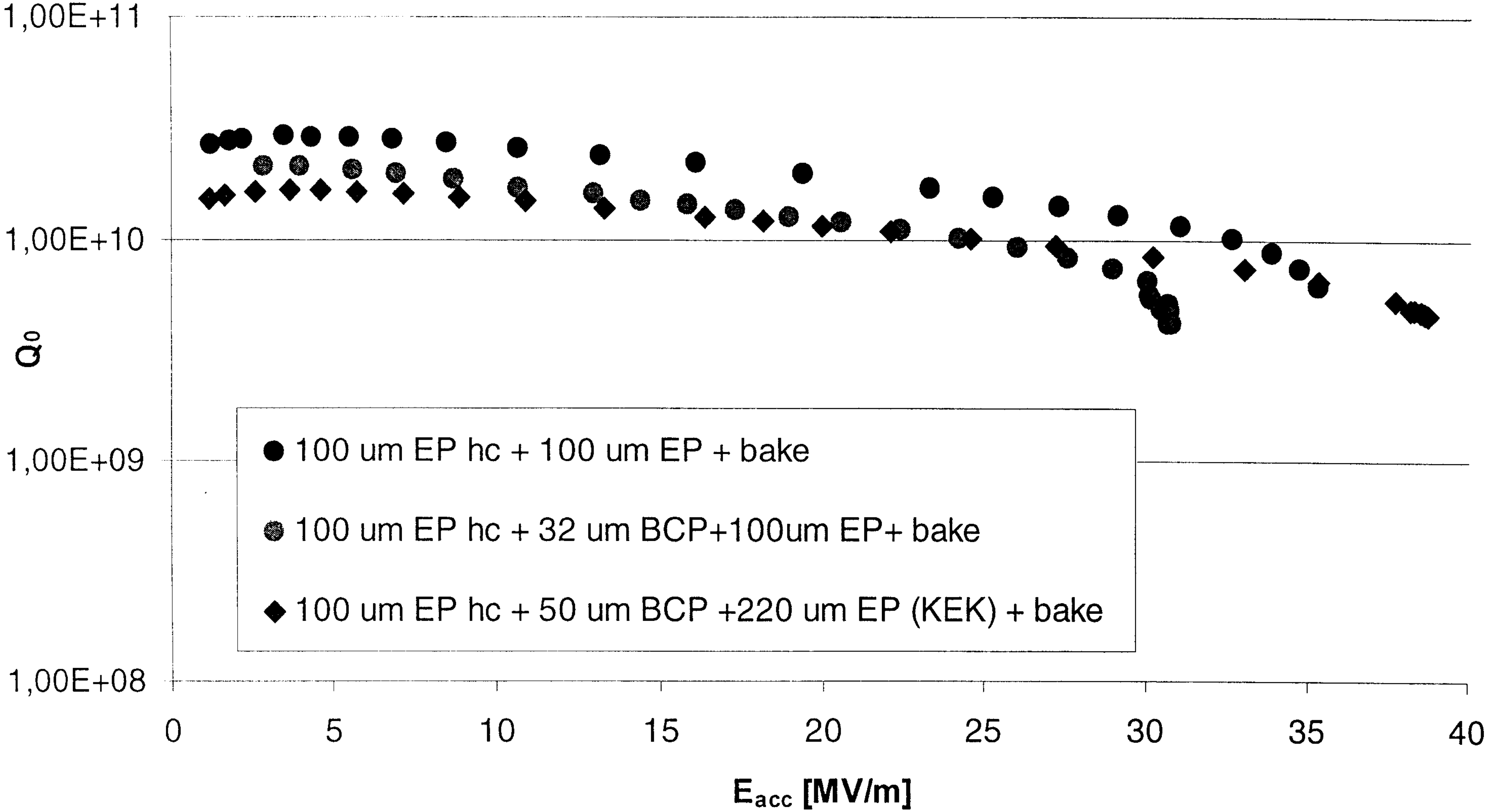
10^{12}
Q_0
c) DESY 9-cell Cavity
at 1.5 K
[1400°C HT, RRR=600]
10^{11}
10^{10}
10^{9}
10^{8}
KEK4 (total-CP170um/EP90um, after 1400oC HT)
KEK4* (at 100K for 2 hours)
0
5
10
15
20
25
30
Eacc [MV/m]

E. KAKO

Electropolished cavities without UHV bakeout

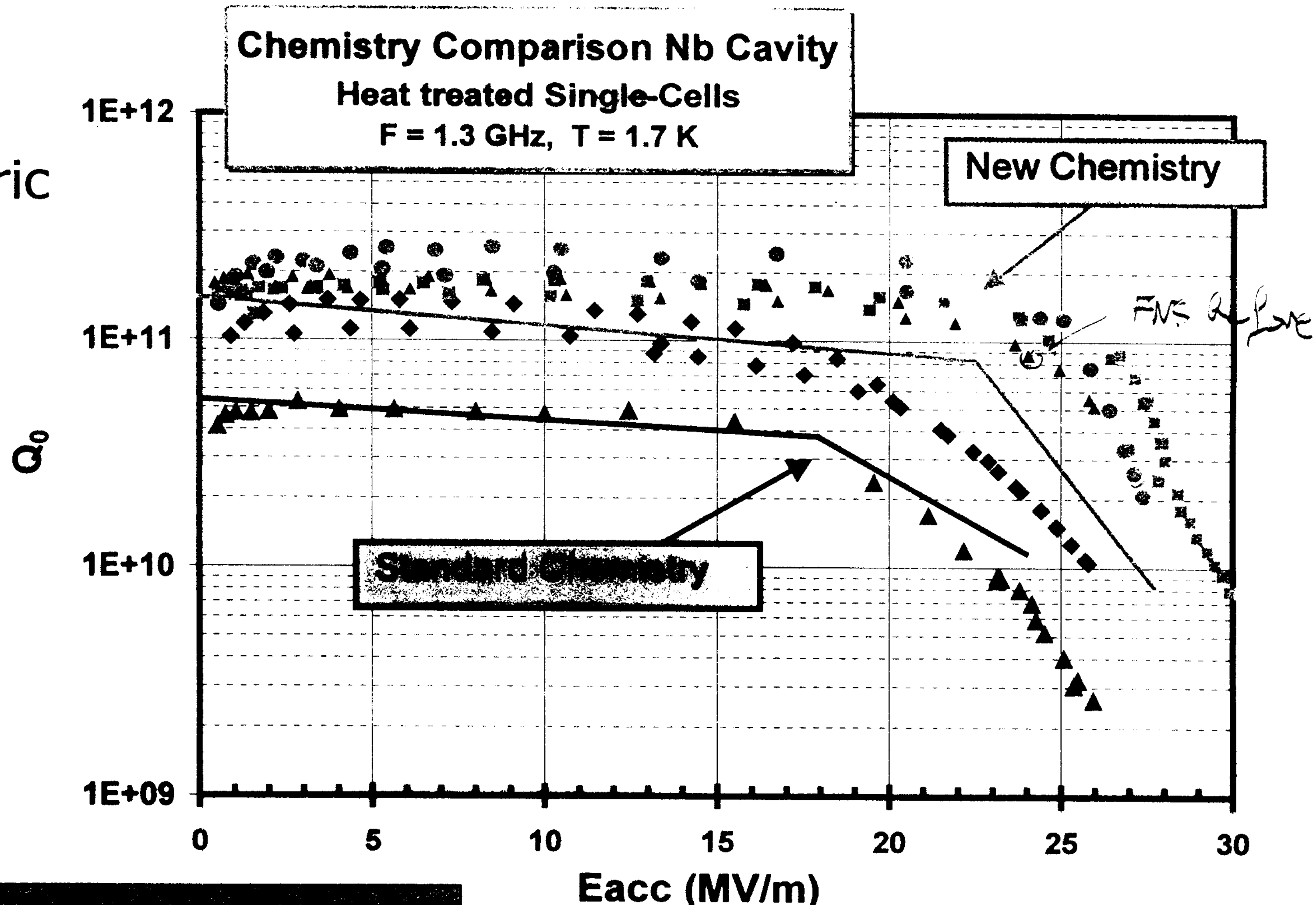


EP + UHV Bakeout at 120 °C for 48 hours



Alternative surface treatment

- FNS...
  - hydro**F**luoric
  - **N**itric
  - **S**ulfuric
    acids

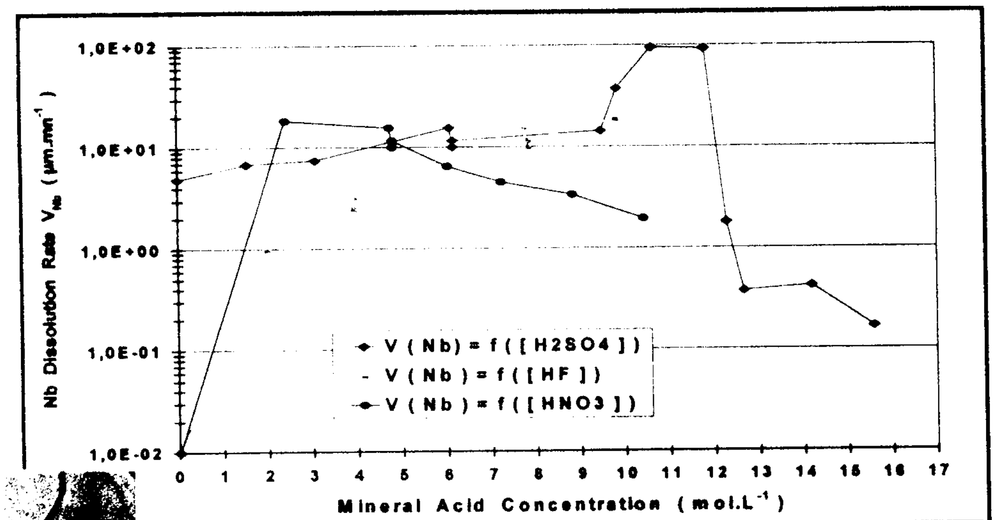


CEA Saclay. SEA / GECS. March 1999

Alternative surface treatment

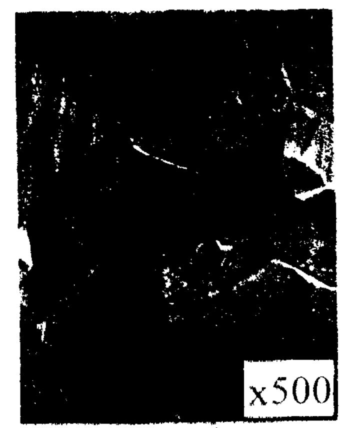
- FNS : a complete chemical study

FNS 1-1-1 :
12 µm/min



FNS 1-0.3-1 :
6.5 µm/min

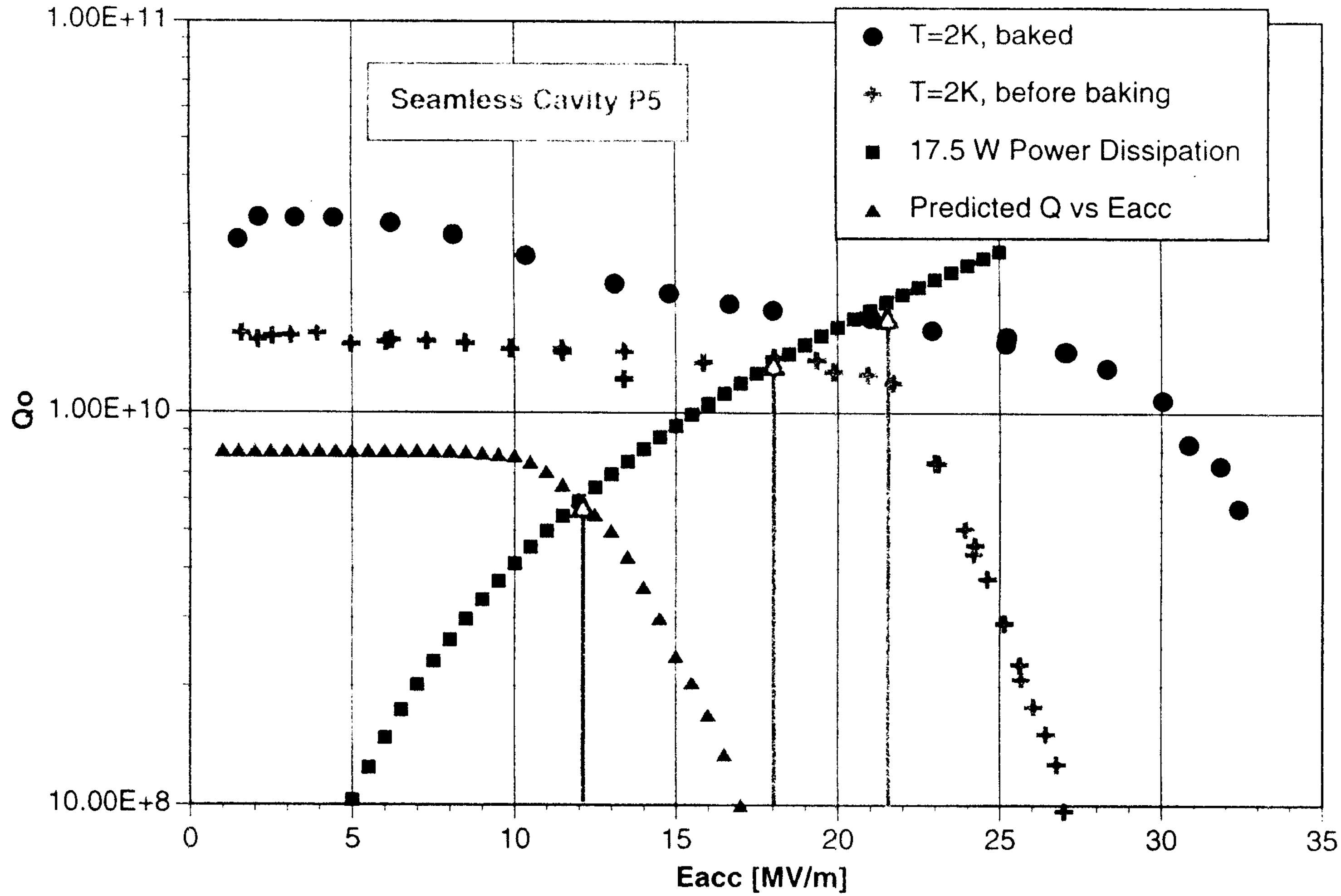
FNS 1.5-1-1 :
18.7 µm/min



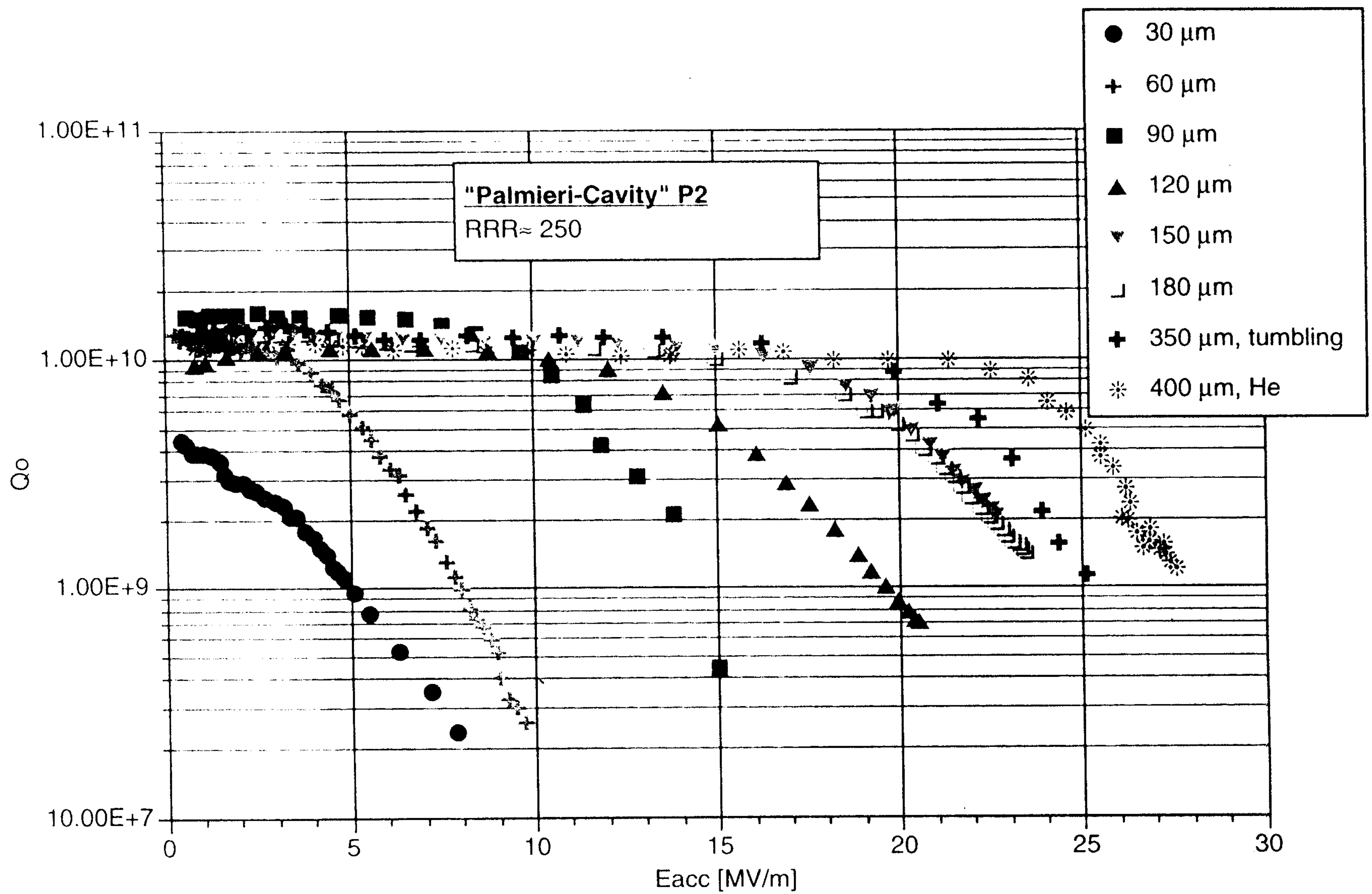
FNS 1-2-10 :
0.18 µm/min

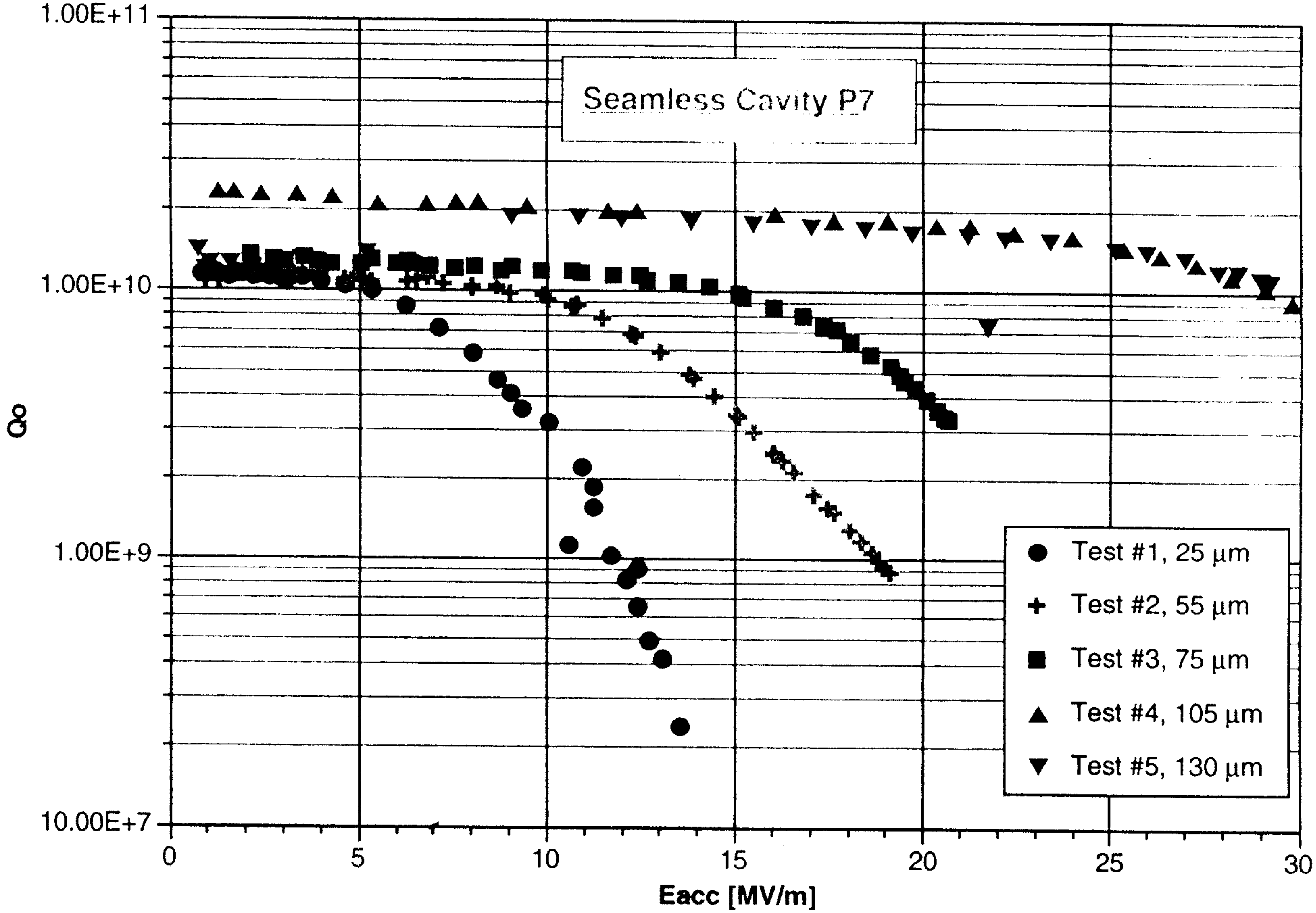
OTHER FABRICATION TECHNIQUES

- SPUN CAVITIES
  - GOOD PERFORMANCE >25 MV/m
  - MULTI-CELLS NEED MORE WORK
  - NEWER CAVITIES NEED LESS SURFACE REMOVAL
- HYDROFORMED CAVITIES
  - MORE WORK NEEDED
- NIOBIUM/COPPER SPUTTERED CAVITIES
  - SUCCESSFUL AT LOW GRADIENTS e.g. LEP <10 MV/m
  - FIRST INDICATIONS FOR GRADIENTS >15 MV/m
  - LIMIT: MULTIPACTING

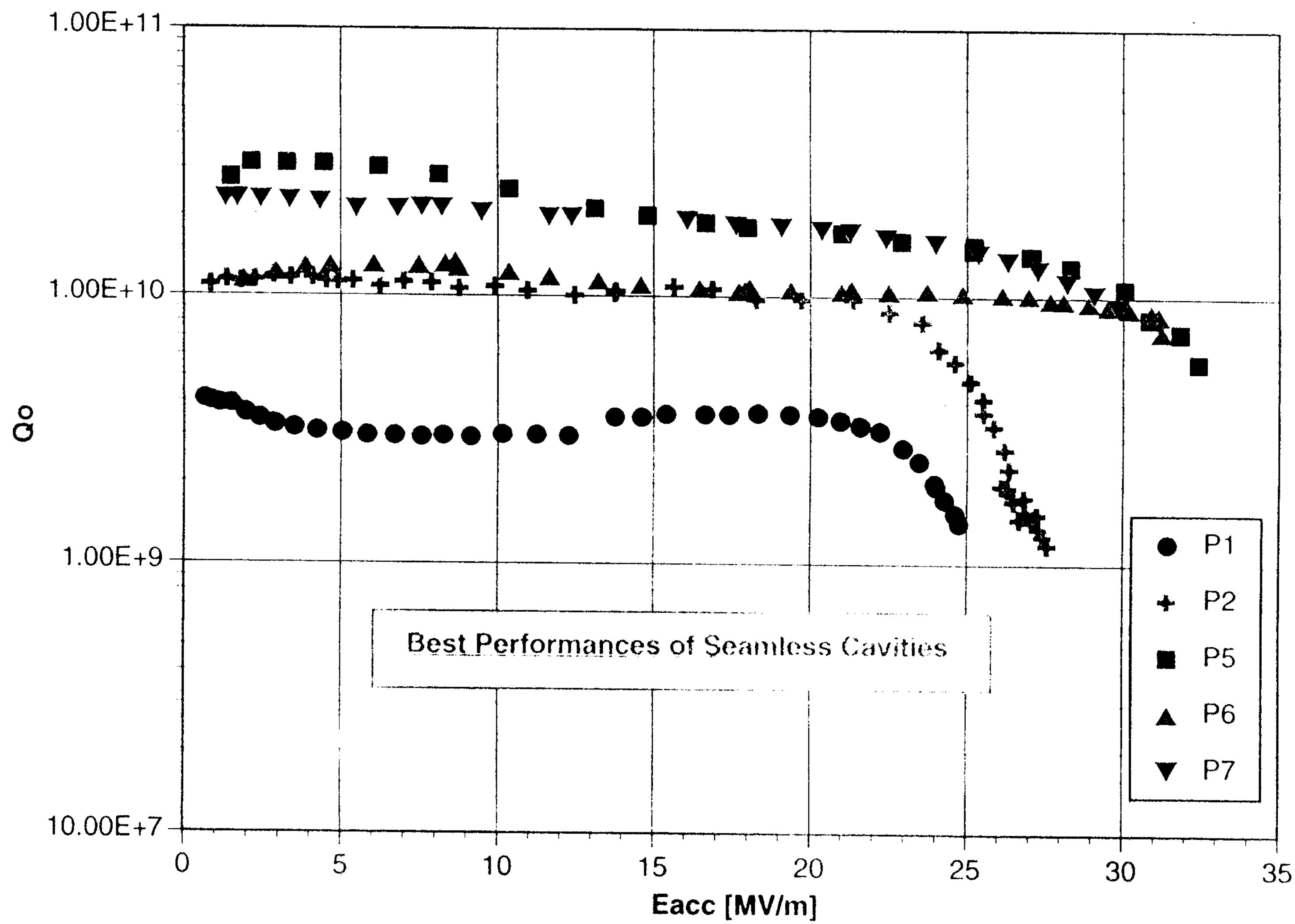


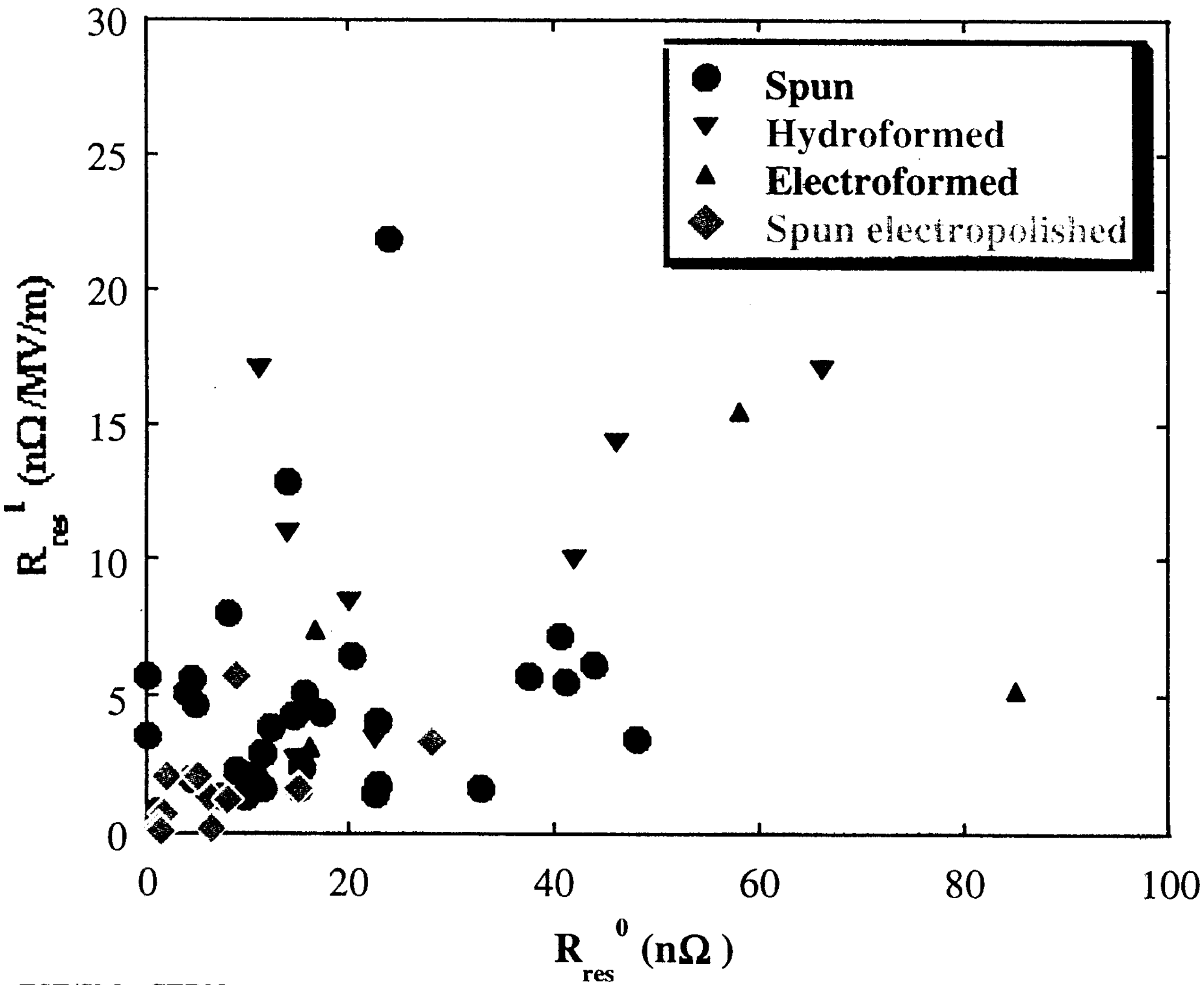
Seamless Cavity P5
T=2K, baked
T=2K, before baking
17.5 W Power Dissipation
Predicted Q vs Eacc
Qo
1.00E+11
1.00E+10
10.00E+8
0
5
10
15
20
25
30
35
Eacc [MV/m]


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



Seamless Cavity P7
1.00E+11
1.00E+10
1.00E+9
10.00E+7
Qo
0
5
10
15
20
25
30
Eacc [MV/m]
Test #1, 25 µm
Test #2, 55 µm
Test #3, 75 µm
Test #4, 105 µm
Test #5, 130 µm

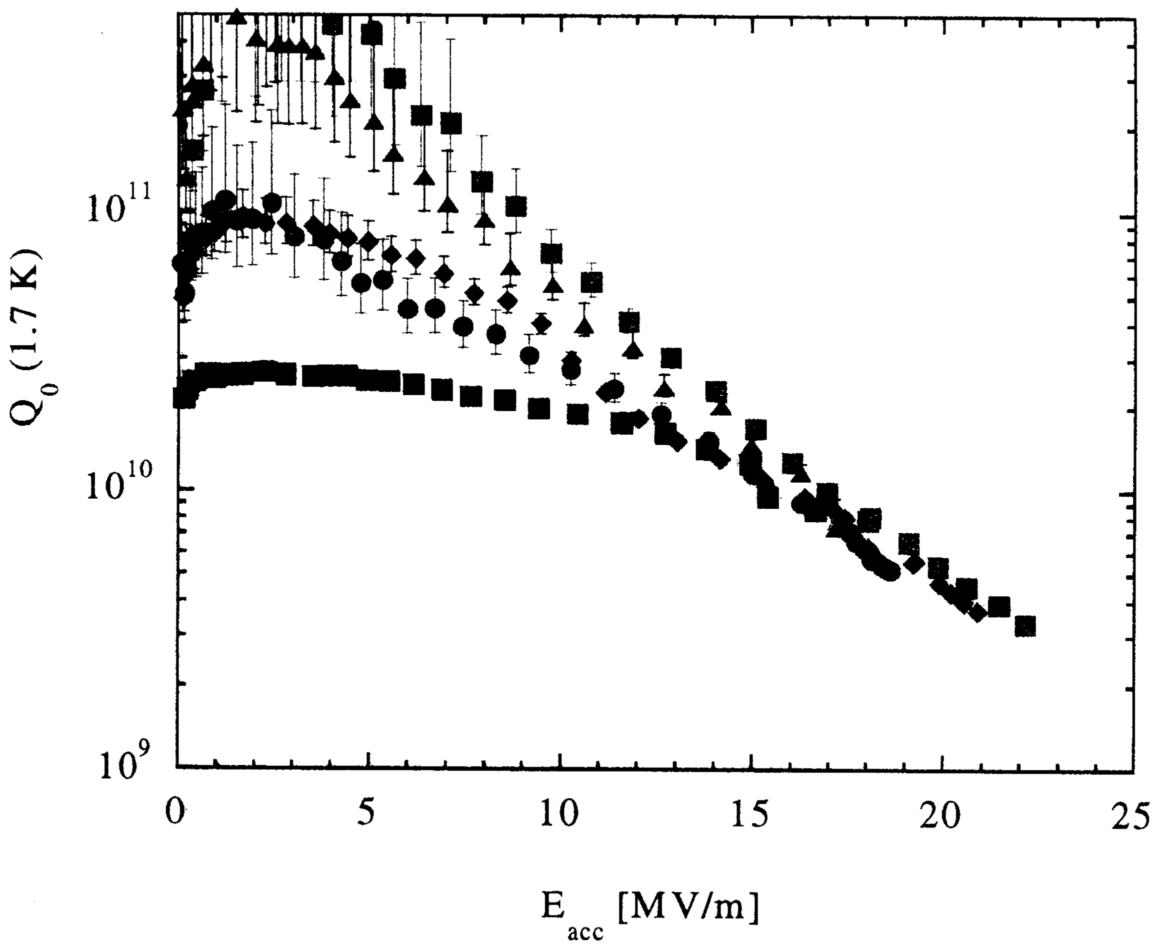

1.00E+11
1.00E+10
1.00E+9
10.00E+7
Qo
0
5
10
15
20
25
30
35
Eacc [MV/m]
Best Performances of Seamless Cavities
P1
P2
P5
P6
P7



Surface treatment :
Electropolishing

R_{res}^0	**6±6 nΩ**
R_{res}^1	**1.5±1 nΩ m MV^{-1}**

High gradient cavities



Coatings performed using krypton

Rinsed with upgraded HPWR installation

- SUBSYSTEMS:
    - HIGH POWER COUPLERS

      APT : 700 kW CW, 700 MHz

      DESY: 1 MW, 1.3 ms, 1.3 GHz

      ↳ processing takes long

      ORSAY/SACLAY: R&D

      CERN : LHC COUPLER
    - TUNERS : MAGNETIC 'SMART' MATERIALS
- OTHER:
    - RELIABILITY DATABASE
    - CAVITY TEST RESULTS DATABASE

CONCLUSION

- 25 MV/m IN TESLA CAVITIES ESTABLISHED
- HIGHER GRADIENTS ≥40 MV/m POSSIBLE WITH ELECTROPOLISHING + BAKEOUT AT 100°C
- LOW-FIELD BEHAVIOUR OF BAKEOUT DUE TO OXYGEN DIFFUSION
- HIGH-FIELD BEHAVIOUR NEEDS MORE UNDERSTANDING
- SPUN CAVITIES SHOW GOOD PERFORMANCE