H-disease in TESLA cavities

- Q-reduction in SC cavities
  - First disastrous findings with HERA cavities and at the Darmstadt SC linac
  - Suspicion of Hydrogen as reason for loss
  - Confirmation of Hydrogen disease
- H disease test in 9-cell cavities
  - List of all tests
  - Discussion of test results
  - Conclusion to XFEL operation
- Recent findings at KEK
- Discussion & Conclusion

Hydrogen Disease in SC Cavities
„Q-disease“

- First observation of anomalous increase of cavity losses
  - At HERA cavities after second or more cool downs at horizontal cryostat in 1991
  - Similar effect seen at the Darmstadt SC accelerator after warm up to 140K due to refrigerator break down and cool down after 20 hours.
  - Was never seen at vertical test stands before, only after very slow cool down during Christmas at Wuppertal
- Systematic investigations were started at several laboratories afterwards.

First observation of Q-disease with HERA Cavities

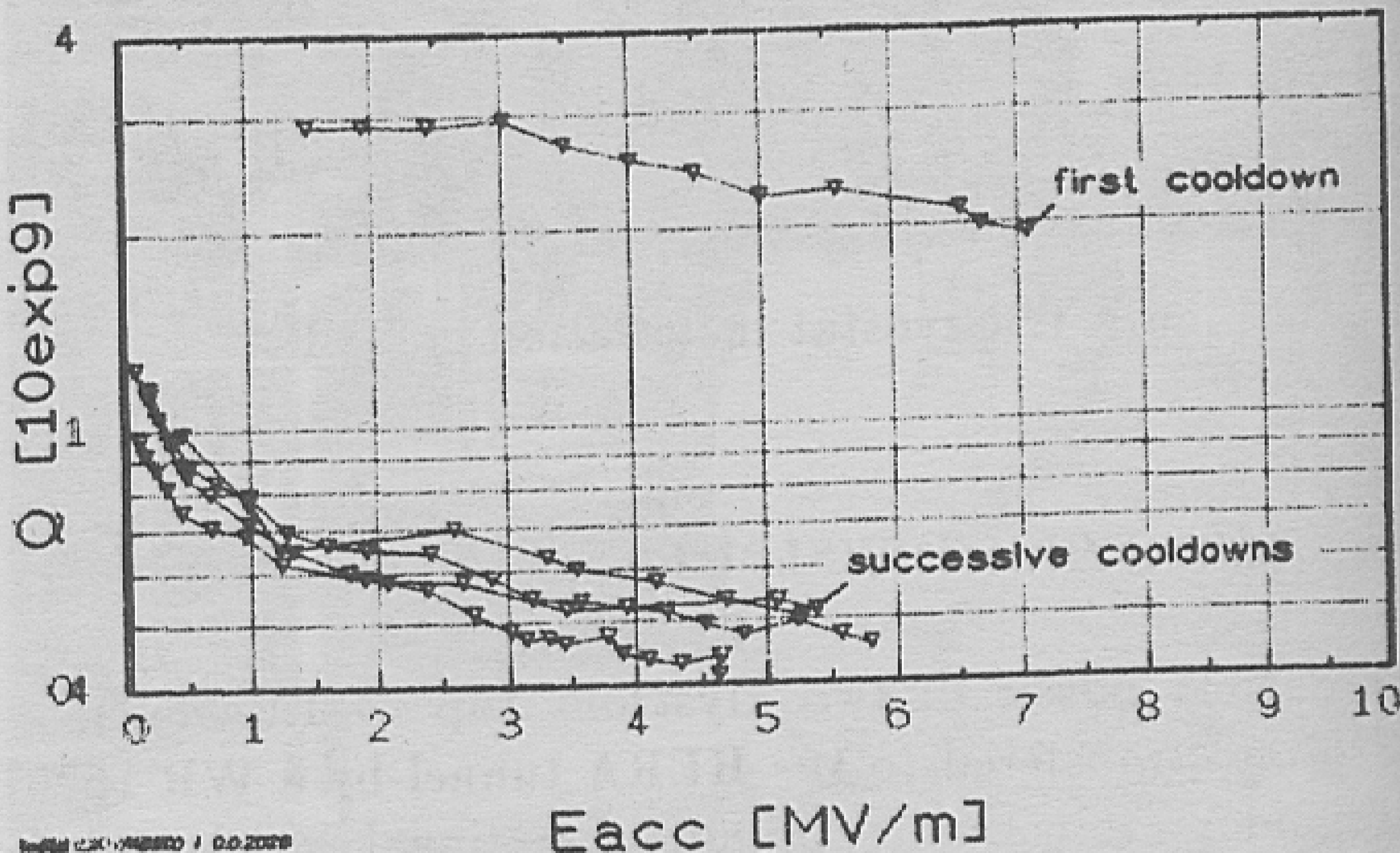
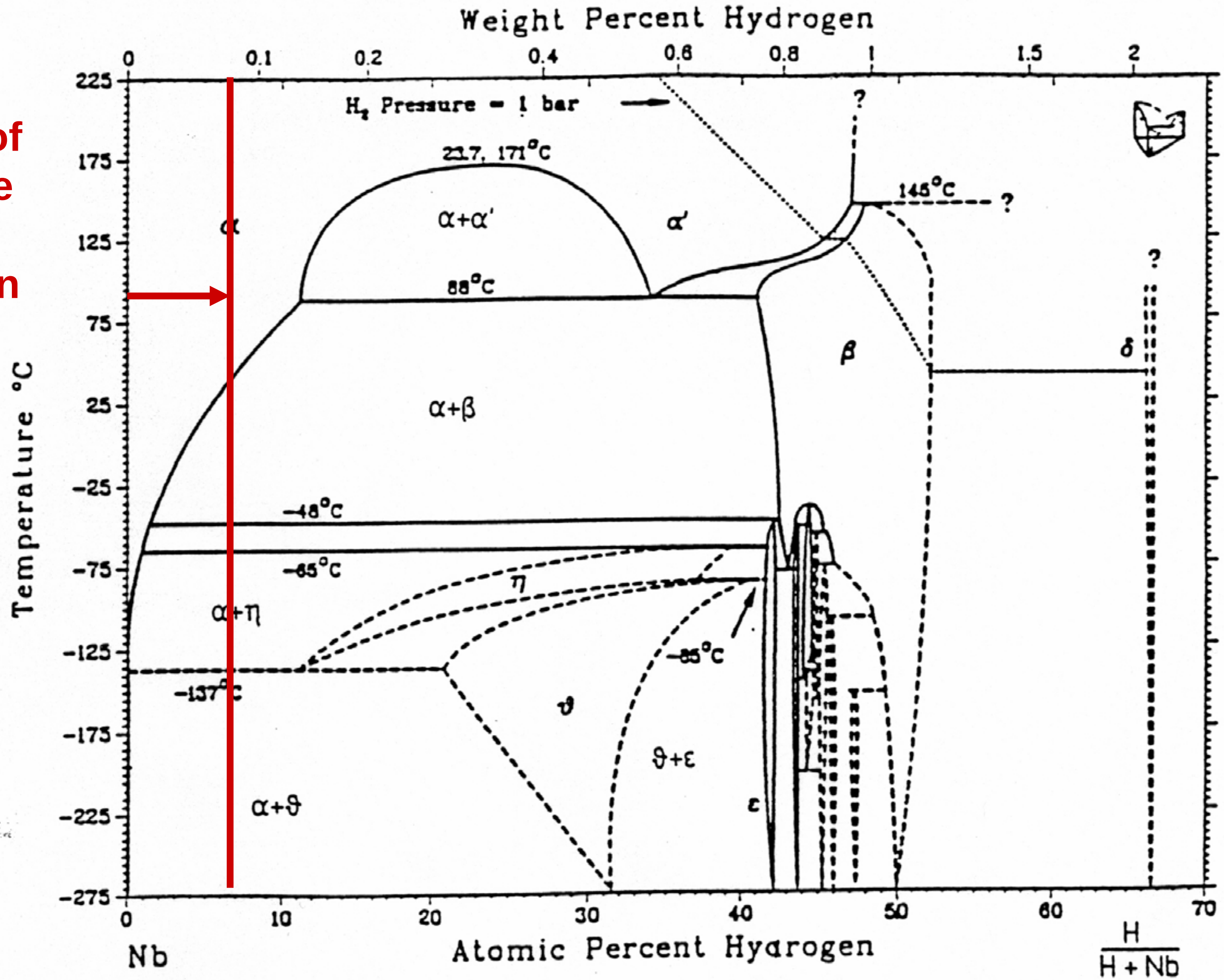


Figure 1: Q degradation after several cooldowns

Range of possible H pollution



Phasendiagramm des Nb –H Systems für chemisch reines rekristallisiertes Nb im thermischen Gleichgewicht

Verification of H-disease effect around 100K with HERA cavities

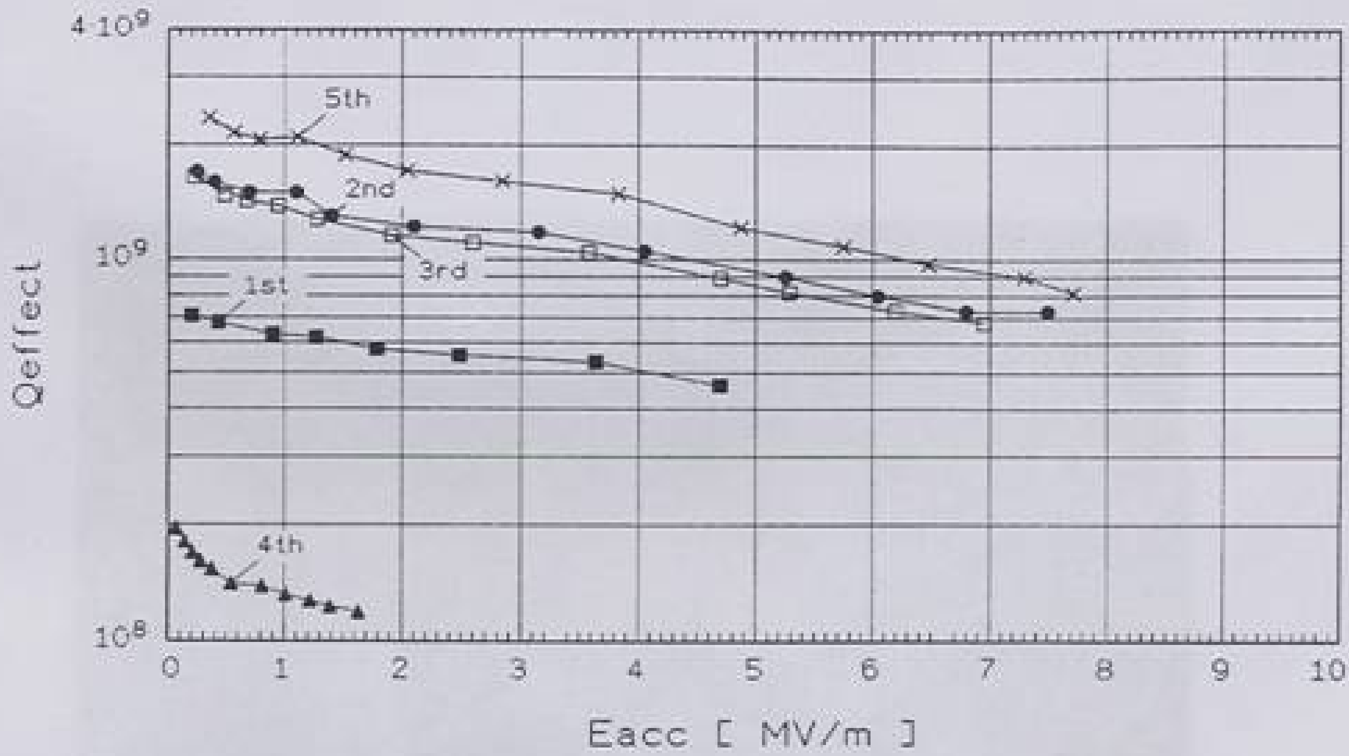


Fig. 3: Measured Q vs E_{acc} curves for different cooldown conditions
1st: continous cooldown from 300 K to 4.2 K in 24 h
2nd (3rd, 4th, 5th): stop during cooldown at 180 K (150 K, 100 K, 150 K) for 20 h; afterwards fast cooldown to 4.2 K in about 1.5 h (1.8 h, 1.5 h, 1.3 h)

H disease investigations (Saclay)

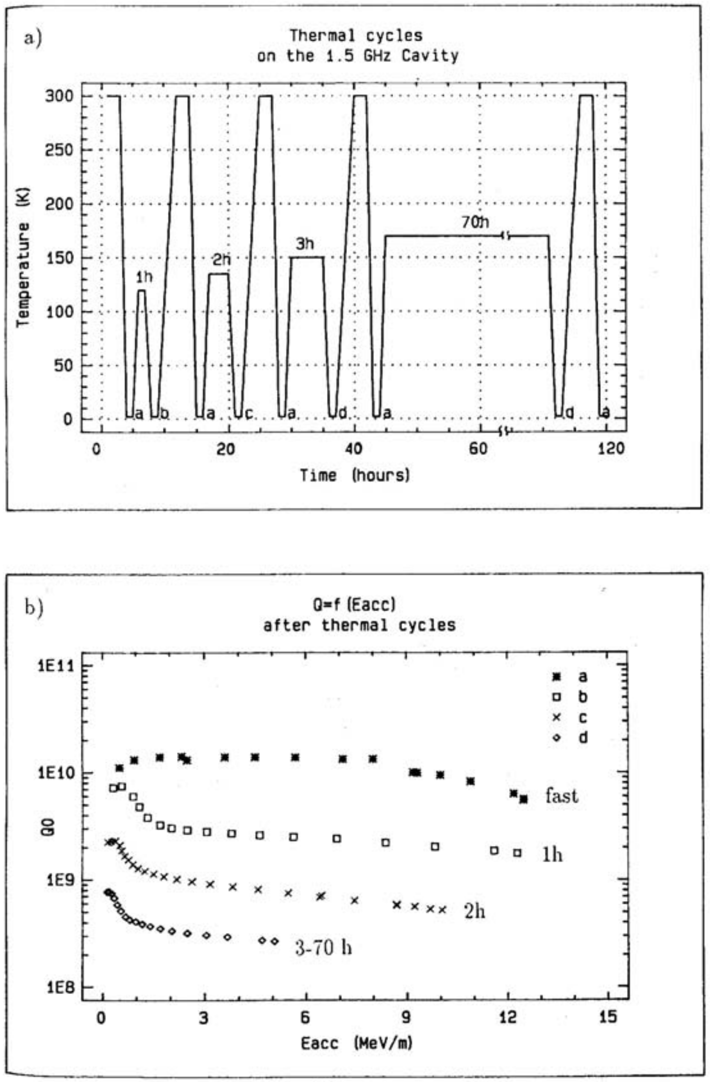


Fig. 1

225

Mechanism of Hydrogen disease

- Hydrogen can move freely in Nb at room temperature as interstitial impurity
- There is a phase transition to NbH_x around 130K
- NbH_x has a slightly larger lattice constant as compared to pure Nb
  - NbH_x will settle at lattice distortions or at the surface
    - Around 130 K NbH_x will migrate to the surface and produce RF losses (it is a normal conductor)
    - At very low temperatures NbH_x will not move any more
- Cure against H-disease
  - Fast cool down (typical condition at vertical test with dewar cooling
  - Degassing of Nb at temperatures around 800°C (or higher)

H-disease test with 9-cell EP cavities

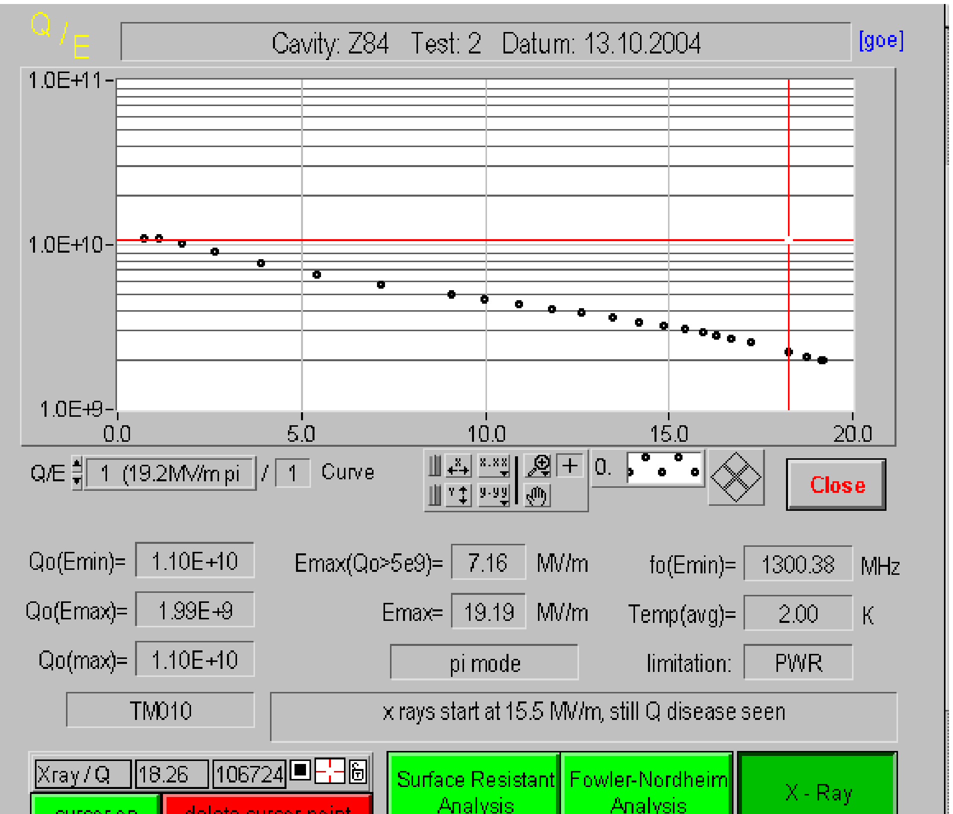
Cavity	Tests	Q-Tests after EP	Q-Test-negativ	Q-Test positiv
AC71	15	4	3	1
AC74	8	1	1	
AC75	5	1	1	
AC76	15	2	2	
AC78	15	4	4	
AC80	6	4	2	2
AC81	8	1	1	
Z 82	6	1	1	1
Z 83	4	2	2	
Z 84	7	5	1	4
Z85	3	1	1	
Z86	3	0		
Z87	4	1	1	
Z88	1	1	1	
Z90	3	1	1	
Sum	103	29	22	8

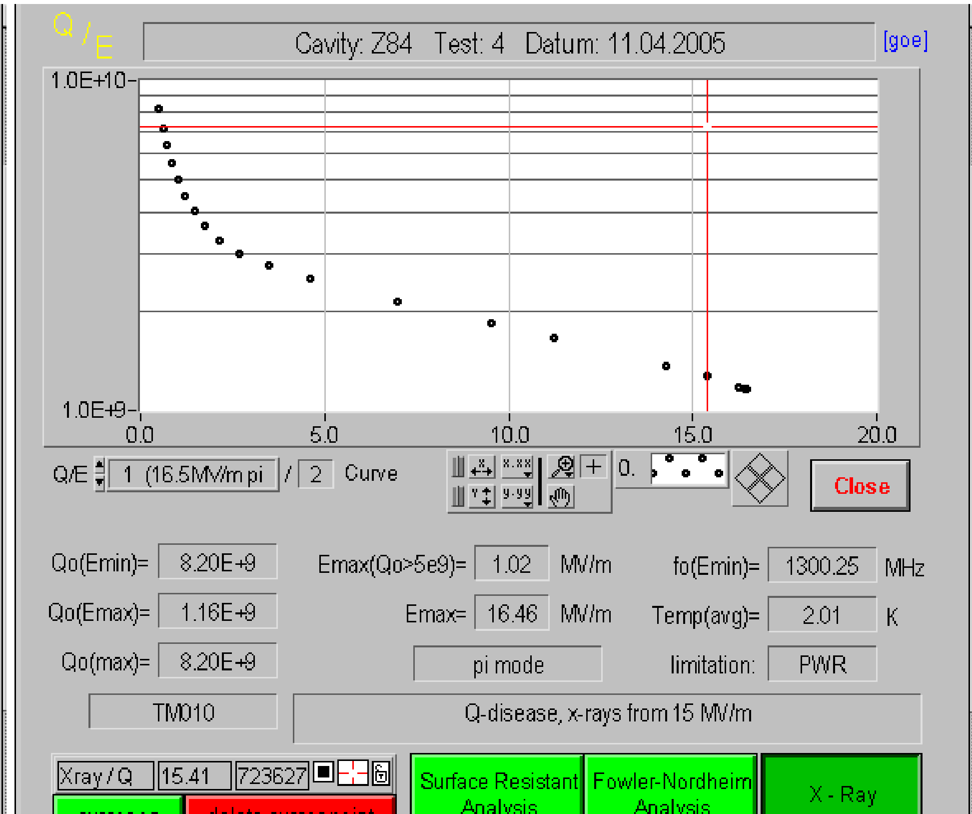
8 more measured cavities with no Q disease

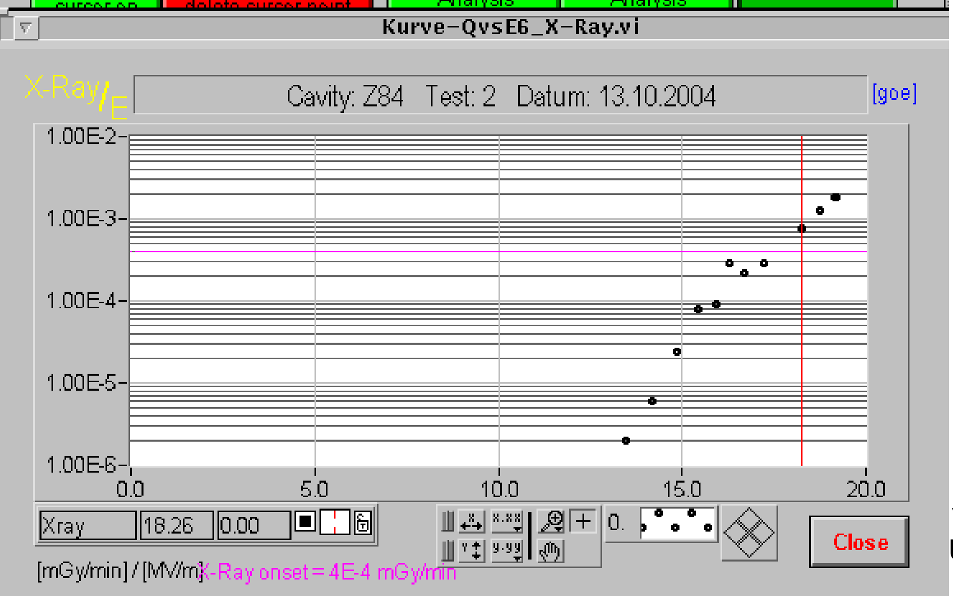
cavity	date	treatment	H-disease	remarks	EP container
AC 71	27.10.05	50 um EP,	yes	cool down condition not listed in data bank (100-120K)	17
	12.01.06	HT 800C, EP 50um	no	cool down condition not listed in data bank	20
AC 80	19.02.04	HT 800C,330 um EP, first test	strong	stored between 90-140K	"0"
	11.03.04	baking 120C	yes	stored between 100-150K	
	04.08.04	new HT 800C, EP 50 um	no	stored between 100-120 K	1
Z 82	24.11.05	HT 1400C, EP 70 um	yes	(70-114K)	17
Z 84	12.10.04	800C, 250um EP, first test	strong	19h between 100-140K during first cool down	4, 5
	13.10.04	re-test	weak	warm up, fast cool down	
	17.11.04	50 um EP	no	stored between 50-100K (only)	7
	11.04.05	50 um EP	yes	stored between 90-160K	9
	12.04.05	re-test	no	warm up, fast cool down	
	14.11.05	HT 1400C, 80um EP	strong	stored between 70-130K	(15, 16) 17
	15.11.05	re-test	weak	warm up, fast cool down	

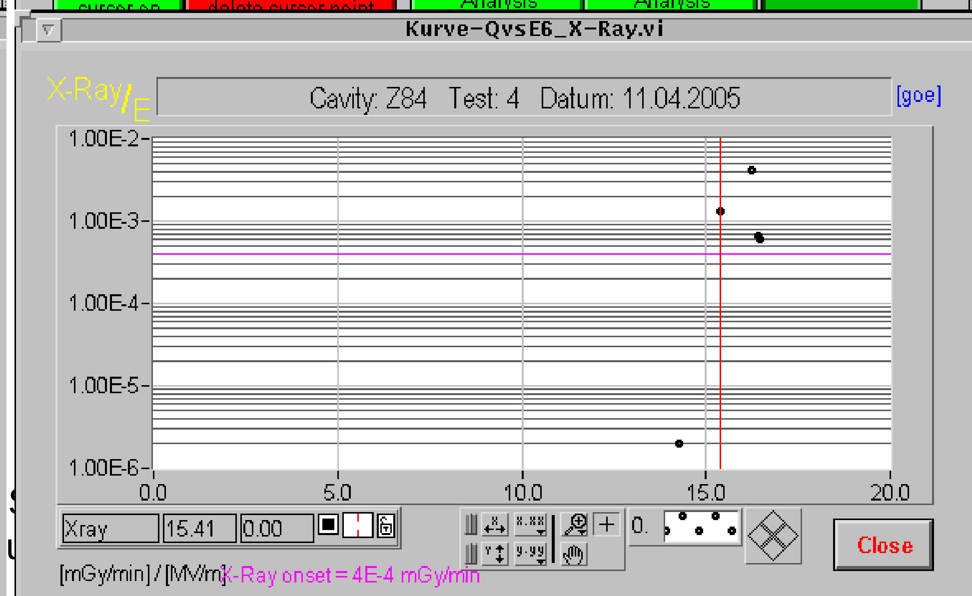
9 – cell Cavities with H disease

Cavity	Q [10^9] at 23MV/m
AC 71	3,5
AC 80	0,2
AC 82	0,5
Z 84, 12.Oct 04	1,3
Z 84,11.April	0,8
Z 84 14. Nov.05	0,1


Q / E
Cavity: Z84 Test: 2 Datum: 13.10.2004
[goe]
Q/E 1 (19.2MV/m pi / 1 Curve
Close
Qo(Emin)= 1.10E+10
Emax(Qo>5e9)= 7.16 MV/m
fo(Emin)= 1300.38 MHz
Qo(Emax)= 1.99E+9
Emax= 19.19 MV/m
Temp(avg)= 2.00 K
Qo(max)= 1.10E+10
pi mode
limitation: PWR
TM010
x rays start at 15.5 MV/m, still Q disease seen
Xray / Q 18.26 106724
Surface Resistant Analysis
Fowler-Nordheim Analysis
X - Ray


Q / E
Cavity: Z84 Test: 4 Datum: 11.04.2005
[goe]
Q/E 1 (16.5MV/m pi / 2 Curve
Close
Qo(Emin)= 8.20E+9
Emax(Qo>5e9)= 1.02 MV/m
fo(Emin)= 1300.25 MHz
Qo(Emax)= 1.16E+9
Emax= 16.46 MV/m
Temp(avg)= 2.01 K
Qo(max)= 8.20E+9
pi mode
limitation: PWR
TM010
Q-disease, x-rays from 15 MV/m
Xray / Q 15.41 723627
Surface Resistant Analysis
Fowler-Nordheim Analysis
X - Ray


Kurve-QvsE6_X-Ray.vi
X-Ray / E
Cavity: Z84 Test: 2 Datum: 13.10.2004
[goe]
Xray 18.26 0.00
Close
[mGy/min] / [MV/m]
X-Ray onset = 4E-4 mGy/min


Kurve-QvsE6_X-Ray.vi
X-Ray / E
Cavity: Z84 Test: 4 Datum: 11.04.2005
[goe]
Xray 15.41 0.00
Close
[mGy/min] / [MV/m]
X-Ray onset = 4E-4 mGy/min

9 – cell Cavities with H disease

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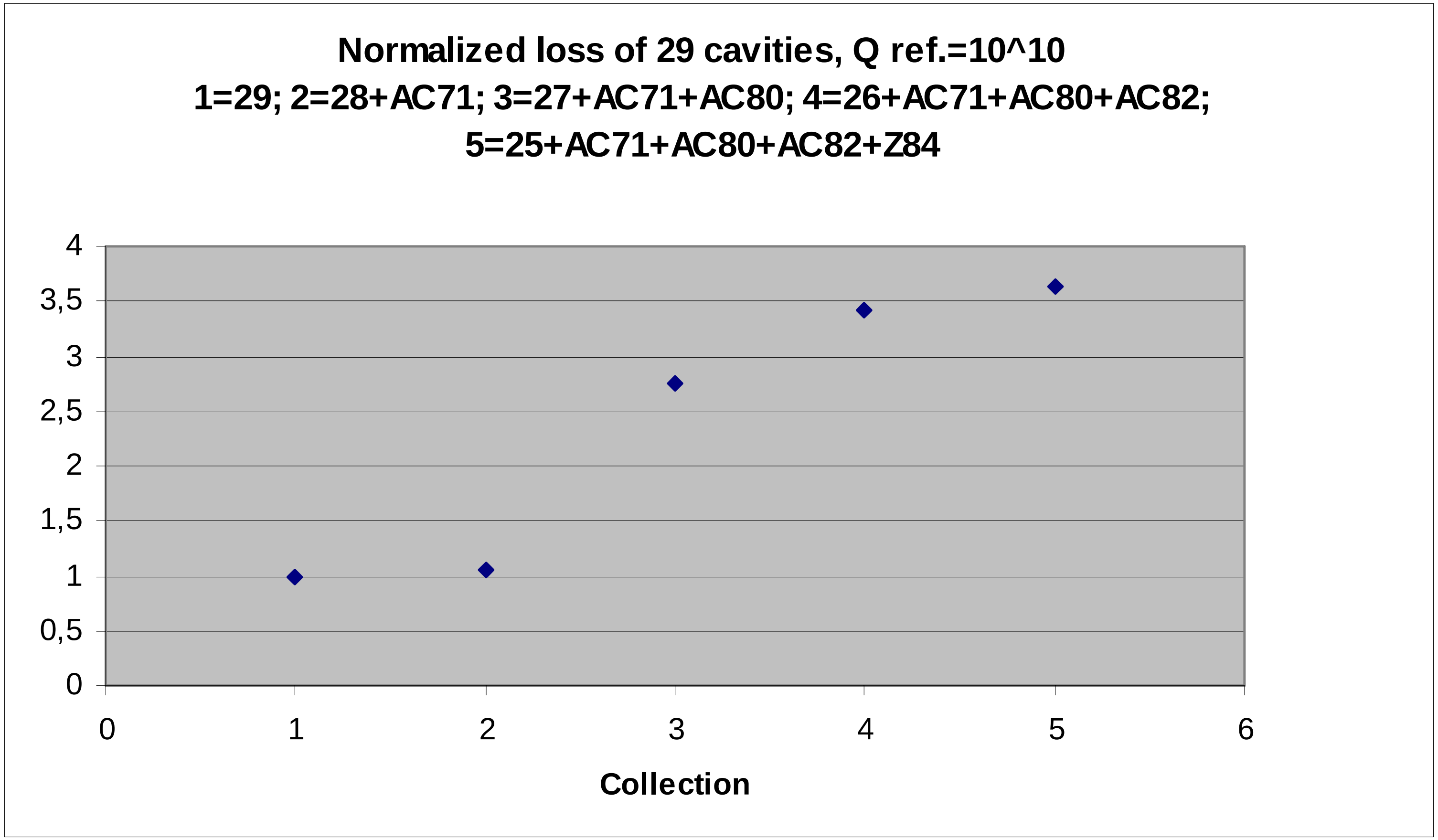


Normalized loss of 29 cavities, Q ref.=10^10
1=29; 2=28+AC71; 3=27+AC71+AC80; 4=26+AC71+AC80+AC82;
5=25+AC71+AC80+AC82+Z84
4
3,5
3
2,5
2
1,5
1
0,5
0
0
1
2
3
4
5
6
Collection


Untitled
File Data Plot Options Help
G0: X, Y = [1.75971e+06, 326.159]
Draw
AutoT
AutoO
ZX ZY
AX AY
PZ Pu
Po Cy
SD:1
CW:0
Exit
V1
Temperaturen oben unten
V_1.VI.TOP
V_1.VI.BOT
AC 71
K
300
200
100
0
00:00:00
12:00:00
00:00:00
12:00:00
00:00:00
time
DESY -MKS1- Juergen Eschke 23.02.2006 11:23
ferrari06, localhost:13.1, Thu Feb 23 11:23:13 2006, Untitled
ktop_Controls
Keyboard Style M
ferrari06:~/ccf$ CalcCobra -i -e v1-pt100-oben-unten2 -a 0510 -f 0510260800 -t 0510272355&
[1] 21521
ferrari06:~/ccf$ arcfiles 0510, from 0510260800 to 0510272355 CobraNr 0 Channels 057,058
xmgr v4.1.2
(C) Copyright 1991-1995 Paul J Turner
(C) Copyright 1996-1998 ACE/gr Development Team
All Rights Reserved
ls: /local/cobra/C.0/actual/0510*.sq: No such file or directory
CobraCalculator::CobraChin(): CobraNr = 0 CobraChannel = 36 missing
CobraCalculator::CobraChin(): CobraNr = 0 CobraChannel = 36 missing
CobraCalculator::CobraChin(): CobraNr = 0 CobraChannel = 36 missing
2355&
[2] 21803

Where does the H contamination come from?

- RRR300 Nb from companies is free of H (spec. reqires less than 10 Wppm),
- Grinding under water will inject H from H_2O (reason for HERA cavities) [DESY, KEK,…]
- EDM will inject H [DESY, KEK, Jlab,…]
- BCP above 22 °C [DESY, Heraeus]
- EP produces H at cathode [chemistry]
- EP chemistry after switching off current) [KEK, Heraeus]

How to avoid H contamination

- Grinding with water free liquid [FC77, KEK]
- BCP below 22 °C [DESY]
- EP: venting of H, protection with cloth [KEK, DESY,..]
- EP: add HNO_3 to EP chemistry to protect the Nb surface by oxidation against H penetration [KEK]

KEK Investigations on H disease :EP/BCP after grinding

circulating.

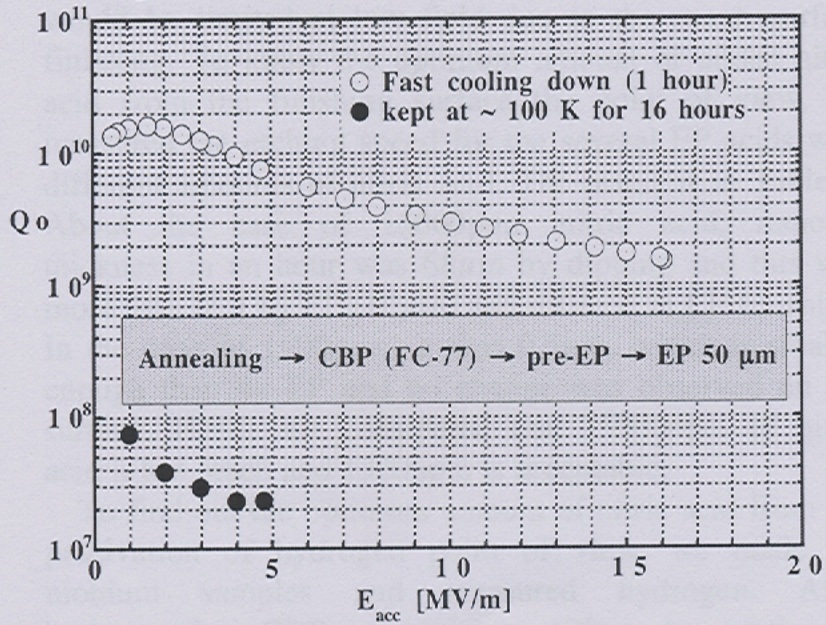


Figure 4: Heavy hydrogen Q-disease did occur when hydrogen-free CBP and EP were combined

combination of the hydrogen-free CBP and CP.

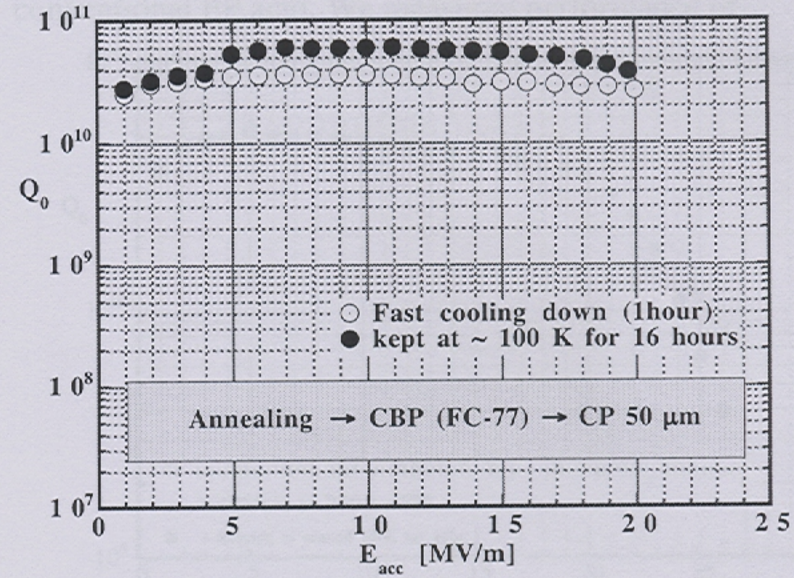


Figure 6: Hydrogen Q-disease did not occur with combination of hydrogen-free CBP and CP

KEK Investigations on H disease :EP(+HNO_3) after grinding

conventional EP acid. We measured performance of

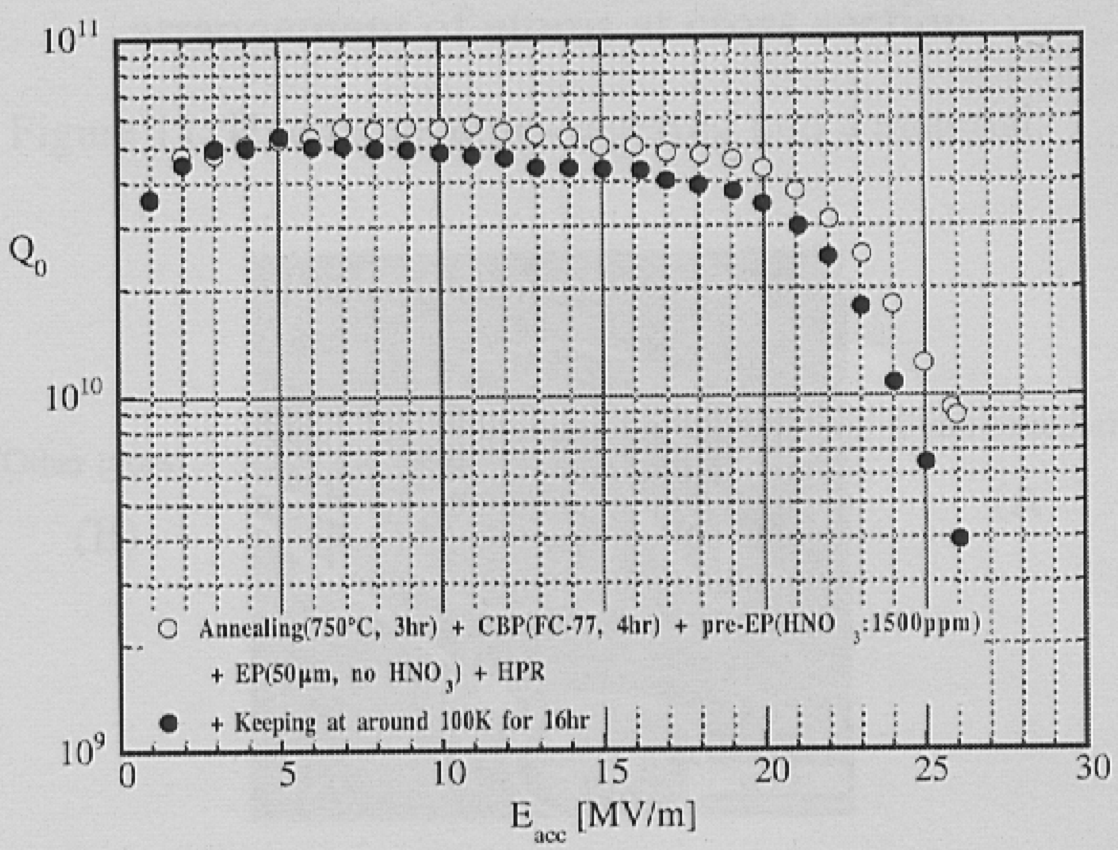


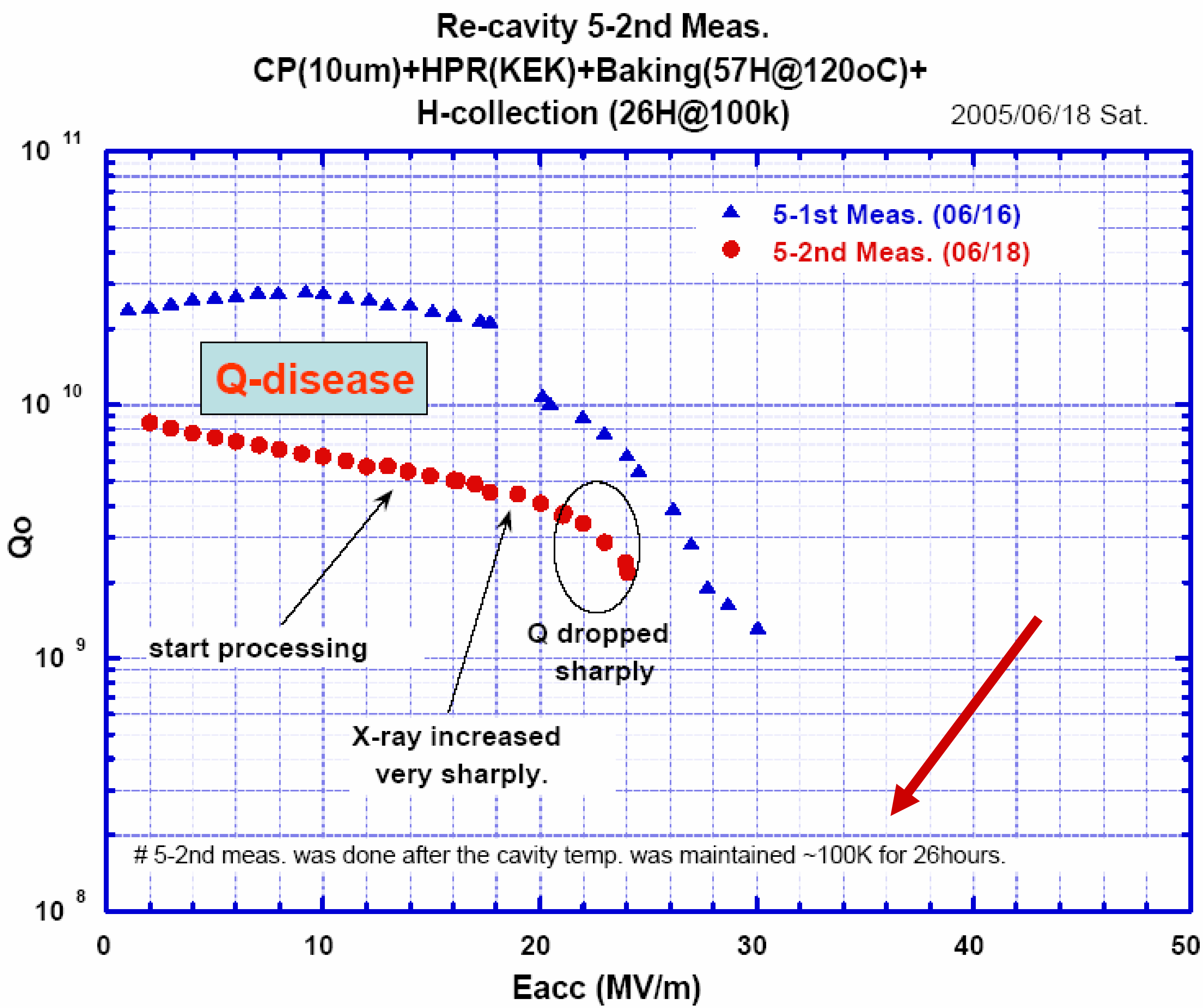
Figure 8: No hydrogen Q-disease resulted for combination of H-free CBP and oxidizer added EP

Failure report in EP system at KEK/Nomura

SMTF meeting

5 October 2005

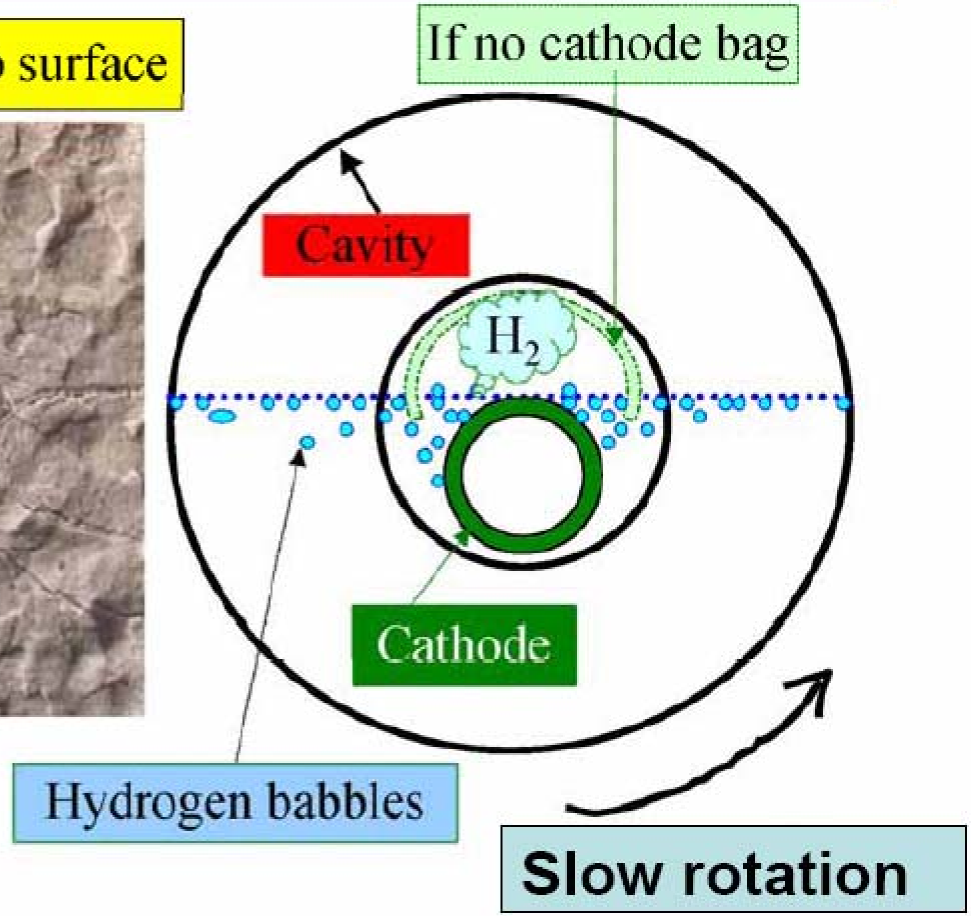
Takayuki SAEKI (KEK)



Re-cavity 5-2nd Meas.
CP(10um)+HPR(KEK)+Baking(57H@120oC)+
H-collection (26H@100k)
2005/06/18 Sat.
5-1st Meas. (06/16)
5-2nd Meas. (06/18)
Q-disease
start processing
X-ray increased
very sharply.
Q dropped
sharply
5-2nd meas. was done after the cavity temp. was maintained ~100K for 26hours.
Qo
10 11
10 10
10 9
10 8
0
10
20
30
40
50
Eacc (MV/m)

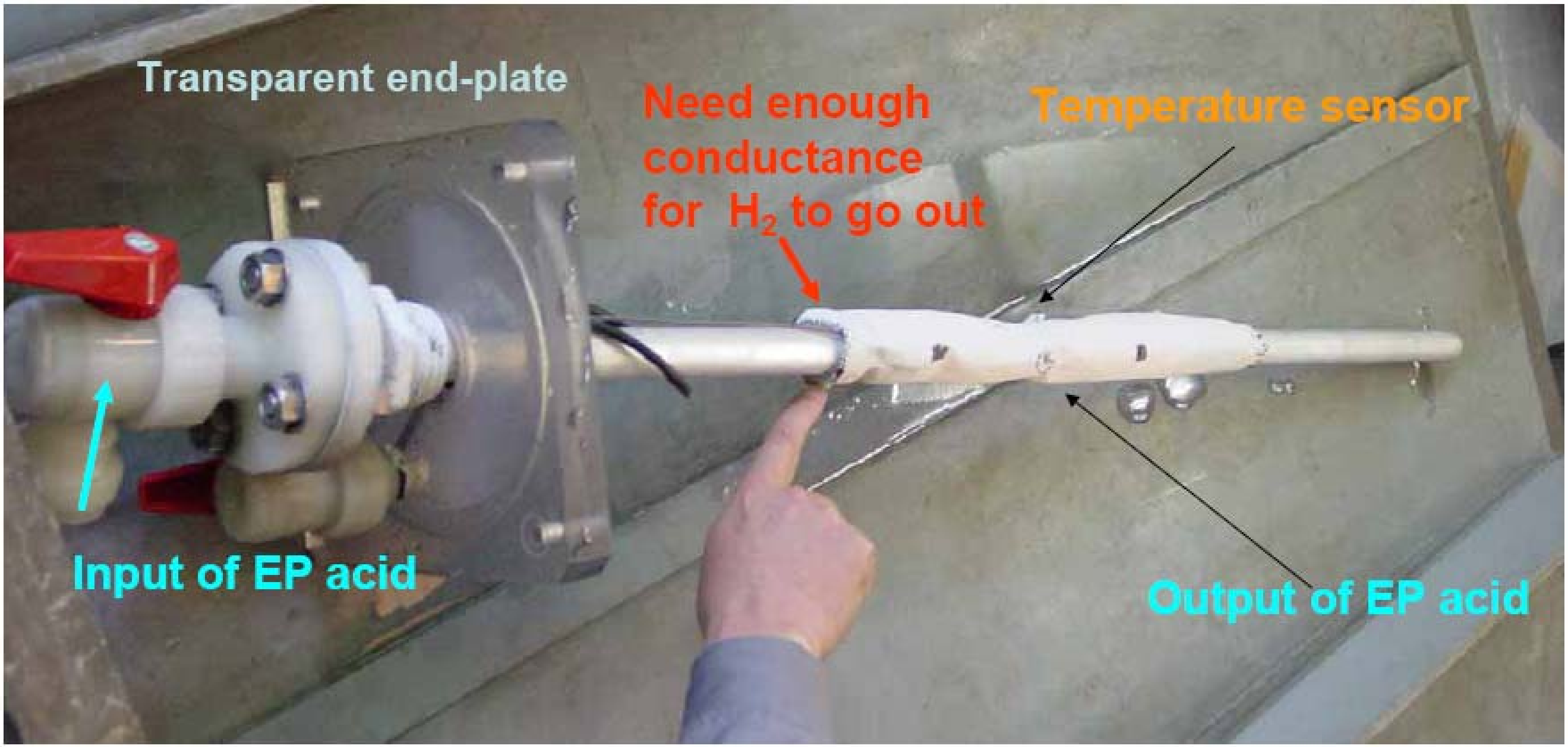
27.July06

Cathode Bag



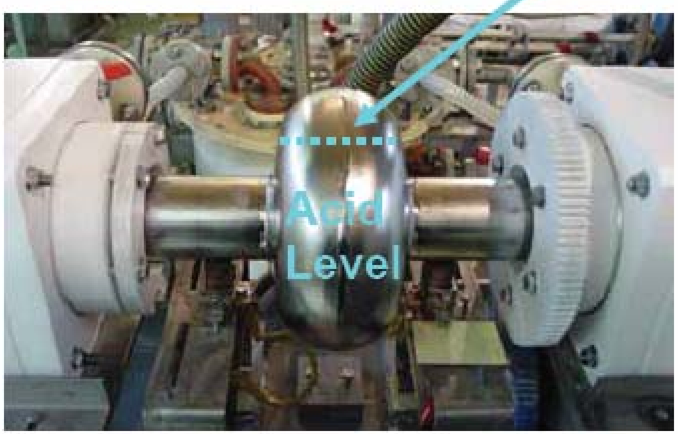
Cathode bag was not setup properly by operator
=> Hydrogen Q-disease

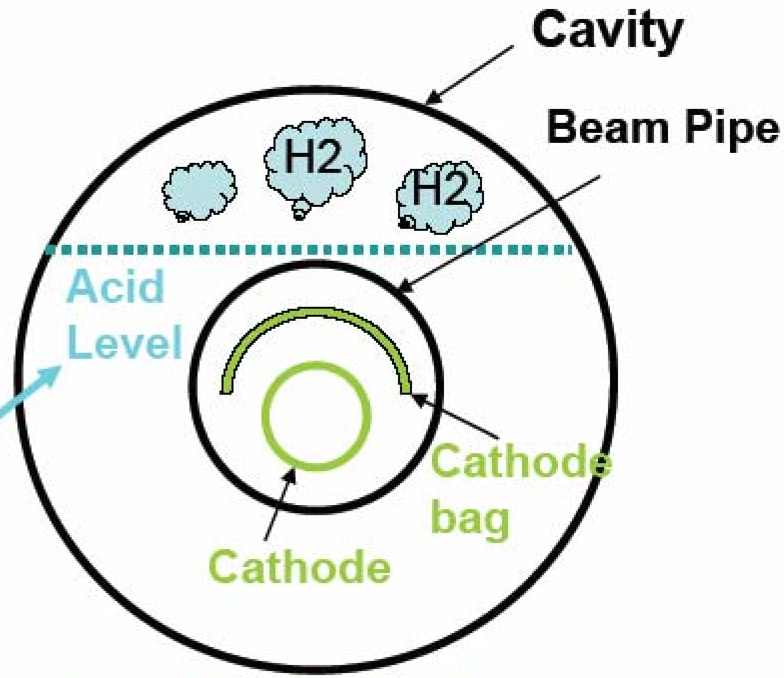
Cathode and cathode bag



EP acid level control failure

EP acid output valves for level control

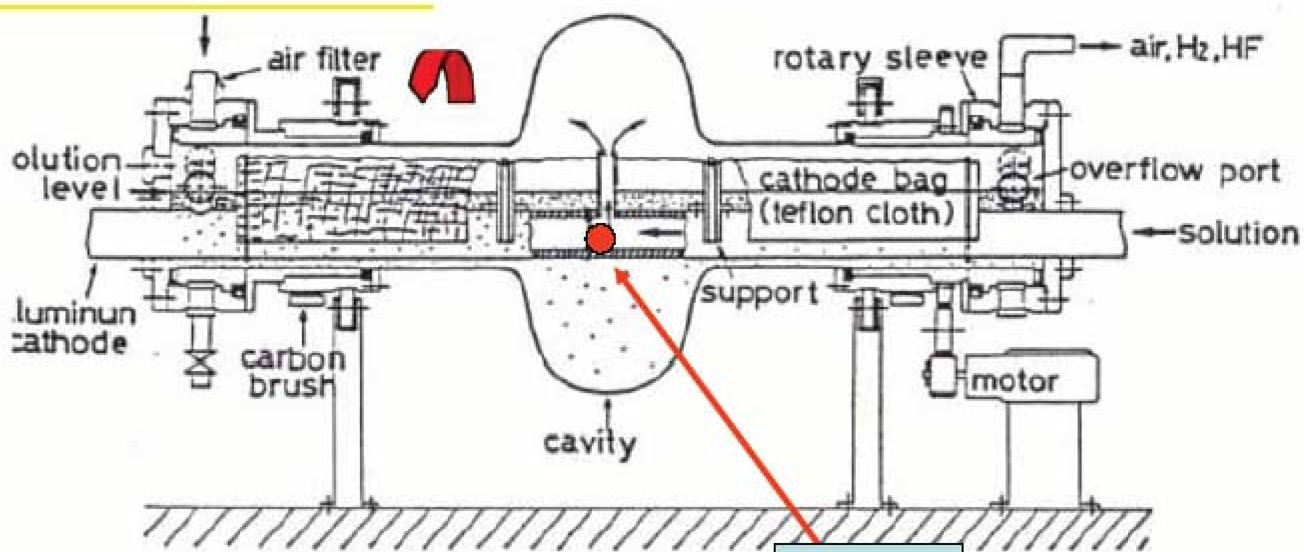


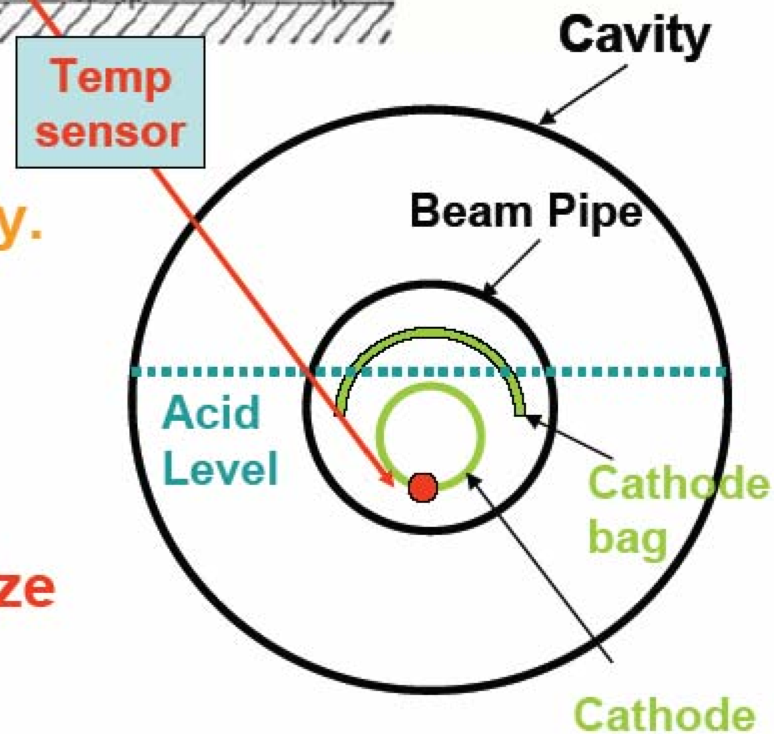


EP acid output valve was not properly controlled.

↓

Hydrogen Q-disease





EP acid temperature monitor & control were not done properly.

Related parameters:

Voltage, Current, EP acid flow, Reservoir tank temperature.

⇒Operator forgot how to optimize these parameter-set.

H disease: Areas for R&D

- Continue H disease tests on 9-cells
- Establish H disease tests on 1-cells
  - So far 5 tests, all no H disease
  - All are treated at Henkel company
    - They use constant current (DESY)
    - They mix the acid by themselves
- Communicate with other laboratories
  - Convince colleagues about need of H-test
- Start sample measurements (H content) after various treatments
  - Detailed program needs to be defined

H disease: Areas for R&D, cont.

- Stable EP parameters
  - Identify missing parameter for arbitrary appearance of H-disease
  - QA on EP chemistry
  - Control of all (?) relevant process parameter
  - H venting in multi-cell EP
  - H contamination after stop of EP / start of rinsing
- Is High RRR Nb more sensitive to H disease?

Alternative approach

- Heat treatment around 800°C will definitely clean Nb from Hydrogen
- EP has the danger of H contamination
- Therefore a low risk procedure could be:
  - EP of cavities to reach smooth surface
  - Heat treatment at 800°C
  - Only slight BCP for last cleaning, several um will not deteriorate the EP surface properties
  - HP rinse

Conclusion

- 5 out of 29 + 8 Q-tests uncovered H- disease
- But “dangerous” temperature range might vary; in our tests we might have missed Q disease which will show up in slow linac cool down
- These 5 cases belong to 4 different cavities
- In these 5 cases a new or additional EP treatment was applied
- In 4 out of these 5 cases the additional cryo-losses are not acceptable (and 24 MV/m might not be in reach)
- Correlation ? The acid container #17 was used for EP in 2+1/2 treatments; two other acid container for the two other treatments
- After 800°C heat treatment the Nb is cleaned from H contamination. Substitution of EP by BCP as final light cleaning will substantially reduce the risk of H disease.

Kenji`s Comments

From the study on Higuchiユs PhD, I understood several things:

1) Mechanical polishing (Tumbling) dopes hydrogen, if it uses a >>> liquid contained hydrogen like water. >>>

2) EDM dopes hydrogen, which comes from oil or water used EDM. >>>

3) When once hydrogen is doped in those process, afterwards material >>> removal like BCP or EP cannot eliminate the hydrogen. >>>

4) Annealing can only remove the hydrogen. >>>

5) Even annealed, when the surface damaged layer still is remained >>> it will pick up hydrogen during EP. >>>

6) Hydrogen is picked up through grain boundary channels. So >>> concerning is gain boundaries.