CERN/EF/RF 81-7
9 November 1981

ADDITIONAL RESULTS ON A SUPERCONDUCTING 4-CELL CAVITY AT 500 MHz

Ph. Bernard, G. Cavallari, E. Chiaveri, E. Haebel, H. Lengeler,
J.M. Maugain, V. Picciarelli*, J. Tückmantel and W. Weingarten**
CERN, Geneva, Switzerland

H. Piel
University of Wuppertal, Wuppertal, Germany

ABSTRACT

Measurements with a superconducting 4-cell cavity at 500 MHz were continued. With a simple H_2O-rinsing after fabrication the Q exceeded 10^9. Helium ion sputtering reduced the e^- loading, and allowed the maximum field to be increased from 2.0 to 2.8 MV/m. No field limitations different from those observed in a one-cell cavity were found.

(*) Scientific Associate from University of Bari, Italy.

(**) Fellow from University of Wuppertal, West Germany.

0416G/WW/ed

1. INTRODUCTION

At the end of 1980 the 500 MHz 4-cell cavity was measured for the first time [1]. The experiments described in this report are a continuation, and the data were taken with the temperature mapping system [2] and the support for tuning to the design frequency and field flatness in operation. Up to May 1981 three further experimental runs were performed and this report will give the results of the r.f.-measurements. Tuning the cavity to field flatness and frequency is described in separate reports [3,4]. In May 1981 the experiments on the 4-cell cavity were stopped in order to study in more detail its field limiting mechanisms. For this a 500 MHz one-cell cavity is used, to permit easier and faster experimentation. The results will be published in a subsequent report [5].

2. CAVITY FABRICATION AND TREATMENT

The cavity is fabricated out of cross-rolled, 2 mm thick Nb sheet material (Kawecki reactor grade niobium, purity 99.8%, Ta-contamination < 1000 ppm, grain size 40 μm) by spinning on a lathe and by applying one intermediate annealing of 1 h in a vacuum furnace at 1050°C and $\sim 10^{-5}$ mbar. After the final spinning tolerances of about 2/10 mm were obtained. Prior to welding a few material checks [2] and a chemical polishing (etching solution 33% HF, 33% HNO_3, 33% H_3PO_4) of 100 μm were applied. Parts were joined by electron beam welding. This consisted of tack welding from the outside, nearly penetrating welding from the outside and a cosmetic welding with a slightly defocused beam from the inside. In the spirit of investigating simple surface preparation methods the cavity was only degreased after welding, rinsed by 2 x 100 ℓ dustfree distilled water, then dried in a dustfree room while in a horizontal position and connected to a cryostat and its vacuum system under dustfree conditions. No bakeout was applied before cooldown. After the first two experimental runs the cavity was chemically polished (18 μm), rinsed in distilled water, ultrasonically agitated in distilled H_2O + H_2O_2, finally rinsed in distilled dustfree H_2O and dried as described before.

3. EXPERIMENTAL

In general the aim of the RF measurements was to discover unexpected features particular to a multicell cavity compared to a one-cell cavity.

The RF parameters of an ideally tuned 4-cell cavity were obtained by SUPERFISH [6] and are listed in table 1. All the experimental runs performed up to now are summarized in table 2. The following treatments were applied, after the fabrication of the cavity had been finished:

- only H_2O-rinsing,
- Chemically Polishing (CP, standard treatment 18 μm [2]),
- "RF processing" [2],
- Helium ion sputtering ("helium processing") [7].

All measurements were done in a magnetically unshielded cryostat with the cavity in a vertical position. The magnetic field at the cavity position was 0.5 Gauss. Three characteristic field values were measured: (a) the maximum accelerating field without e^- loading, (b) the accelerating field at which the losses due to e^- loading alone are half the losses of a cavity with $Q = 10^9$(*), (c) the maximum accelerating field. In addition the e^- current picked up by a current probe in the upper beam tube was measured.

The two in situ processing techniques applied were "RF processing" and Helium ion sputtering. "RF processing" is the operation of the cavity at the highest field. During Helium ion sputtering the cavity is operated in a pure helium gas atmosphere of $p < 5 \times 10^{-5}$ mbar measured at the warm part of the vacuum system. A gas breakdown was observed at about $E_{acc} \approx 2.5$ MV/m for higher pressures. This technique was applied to superconducting cavities for the first time at Stanford [7] and gave excellent results. Experimental results obtained in different one-cell cavities at CERN are discussed in [5], where the experimental procedure is described in more detail.

(*) $Q = 10^9$ is considered to be the design value for a cavity operating in a storage ring.

4. RESULTS AND DISCUSSION

The maximum Q value, which was obtained at 4.2 K, was 1.7×10^9 after a water-rinsing without CP. This did not improve after chemical polishing. In a one-cell cavity measured in the same cryostat without magnetic shielding we never exceeded a Q value of 1.8×10^9 after water-rinsing or after CP, too. This Q-value can be attributed only to frozen-in magnetic flux [5]. Thus we conclude that the Q value is not greatly affected by the more complicated preparation procedure of a multicell cavity. In addition, there is no significant difference in Q value for a cavity that has been only water rinsed after fabrication and the cavity after CP. This suggests that water rinsing alone of the finished cavity is no worse than CP. Before welding, however, a CP of the half shells is essential.

As to the "in situ" processing methods the results were the following. Whereas RF processing at E_{acc} = 2.1 MV/m for two days did not yield a significant reduction of e^- loading, helium ion sputtering, which was applied three times in this cavity, improved its performance. The first one was applied for 6 h at the maximum attainable field and reduced the e^- current at 2 MV/m from 4 nA to 0.1 nA. The maximum accelerating field increased from 2.15 MV/m to 2.8 MV/m (fig. 1). The He gas was pumped out and the cavity was kept cold for 4 days after which it showed no increase of e^- loading. This helium ion sputtering was not performed to the end because of radiation protection requirements. The cavity was then chemically polished and the radiation protection of the system was improved. Helium ion sputtering again proved to be very effective to reduce the e^- loading by more than two orders of magnitude so that it was no longer the reason for the field limitation. The field was limited by a thermal instability of the type described in [2]. The temperature map of this 4-cell structure with the lossy region in the bottom part of the upper cell is shown in figs 3 and 4.

An attempt was made to reduce the resistivity of this lossy area by an extensive helium ion sputtering (experiment 4). The losses were slightly reduced and the maximum field was slightly increased, but the results were not conclusive.

In some tests, the e^- loading during the first field increase of the cavity was moderate. But after some minutes, bursts of radiation associated with breakdowns were observed, after which the e^- loading increased. The x-ray intensity at the cryostat cover was 20 mr/h at 1.9 MV/m and was 200 mr/h at the viewing port.

It is planned to remove the loss region by a mechanical method described in [5] in order to reach field levels in excess of 3 MV/m which is the design value for the operation of such a structure in a storage ring.

Acknowledgements

We would like to express our appreciation of the competence of the technicians of our group. We thank the EF workshop and cryogenic group for their help and in particular M. Firth for a critical reading of the manuscript.

REFERENCES

[1] Ph. Bernard et al., CERN/EF/RF 81-2, Int. note (1981).

[2] Ph. Bernard et al., Nucl. Instr. Meth. 190 (1981) 257.

[3] E. Haebel and J. Tückmantel, CERN/EF/RF 81-5, Int. note (1981).

[4] Ph. Bernard et al., CERN/EF/RF 81-8, Int. Note (1981).

[5] Ph. Bernard et al., CERN/EF/RF 82-1, Int. Note (1982).

[6] K. Halbach and R.F. Holsinger, Part. Acc. 7 (1976) 213.

[7] H.A. Schwettmann, J.P. Turneaure and R.F. Waites, Journal Appl. Phys. 45 (1974) 914.

TABLE 1

Some Computed Parameters[(a)]

$E_{acc}[MV/m]$	$= 1.96 \times 10^{-5} \sqrt{P_c[W]Q_0}$
E_p/E_{acc}	$= 2.34$
H_p/E_{acc}	$= 36.5$ [Gauss/MV/m]
$2\,\frac{f\pi - f\pi/4}{f\pi + f\pi/4}$	$= 0.92\%$
G	$= 266[\Omega]$
r/Q	$= \frac{E^2_{acc}}{\omega W/2\lambda} = 462[\frac{\Omega}{m}]$

E_{acc} is defined for a particle with $\beta = 1$

$$E_{acc} = \frac{1}{2\lambda} \int_{\ell_{tot}} E(z)e^{ikz}dz$$

ℓ_{tot} = total length of cavity including beam tubes

P_c = dissipated power, Q_0 = unloaded Q, λ = free space wavelength

G = geometry factor, W = stored energy

(a) These results were obtained by SUPERFISH. The electron-beam welding caused a deformation of the irises decreasing the iris diameter by ∿ 2 mm and the iris thickness by ∿ 3 mm. The total length of the cavity changed from 150 cm to 148.8 cm. The SUPERFISH calculations take these changes into account. The field flatness is affected only slightly by these deformations.

TABLE 2

Experimental Results of the 500 MHz 4-cell Cavity

No.	Treatment	Low field $Q[10^9]$ (4.2 K)	E_{acc} [MV/m] with no e^-	E_{acc} [MV/m] $Q(e^-) = 2 \times 10^9$ (*)	E_{acc} [MV/m] Maximum	Limitation	I_e [nA] (2MV/m)	Comments
1	H_2O rinsing	1.7	1.7	2.3	2.8	e^- bursts	-	First field increase; quenches associated with radiation bursts
		1.0	1.4	2.0	2.4	e^-	-	After the occurrence of quenches
2	Exposing to dustfree N_2 for two weeks	1.4	-	2.5	> 2.5	e^- bursts	-	First field increase
		1.2	1.4	2.0	2.0	e^-	10	Afterwards; light-emitting spot
	RF processing for 2 days at E_{acc} = 2.1 MV/m	1.3	1.4	2.1	2.1	e^-	4	
	He processing at maximum field for 6 h	(**) 1.5	2.1	2.8	3.0	e^-	0.1	No degradation after 4 days
3	CP (18 μm) H_2O rinsing	1.5	1.9	> 2.5	2.5	e^- bursts	.2 (**)	first field increase
		1.5	1.5	2.1	2.2	e^-	1.2	
	He processing for 17 h at moderate e^- loading (no HOM excitation)	1.3	2.0	> 2.5	2.5	Quench	< 0.1	Dissipative spot at quench location probably an e^- source
4	He processing for 60 h as before	1.6	2.3	> 2.6	2.6	Quench	(**) 1.4×10^{-3}	No significant field increase by He processing

(*) This is the accelerating field for which the losses due to e^- loading contribute to one half of the losses of a cavity with $Q = 10^9$.

(**) Extrapolated.

FIGURE CAPTIONS

Fig. 1 $Q(E_{acc})$ for a field limitation by e^- loading.

Fig. 2 $Q(E_{acc})$ for a field limitation by a "lossy" spot.

Fig. 3 Three dimensional temperature map with "lossy" spots in the upper and lower cells. The one in the upper cell induces the quench.

Fig. 4 Magnification of the temperature map of fig. 3 for the upper cell.

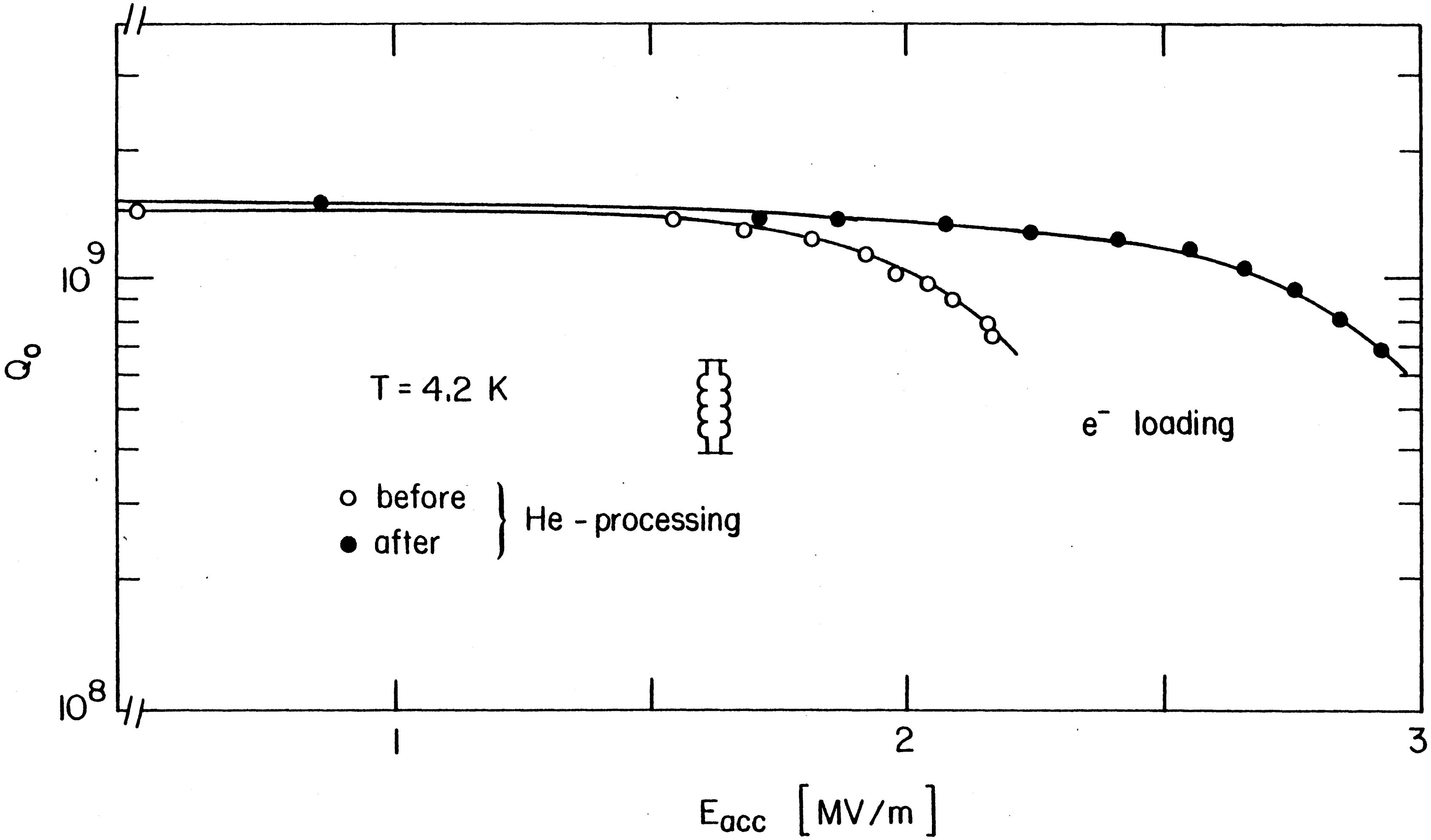
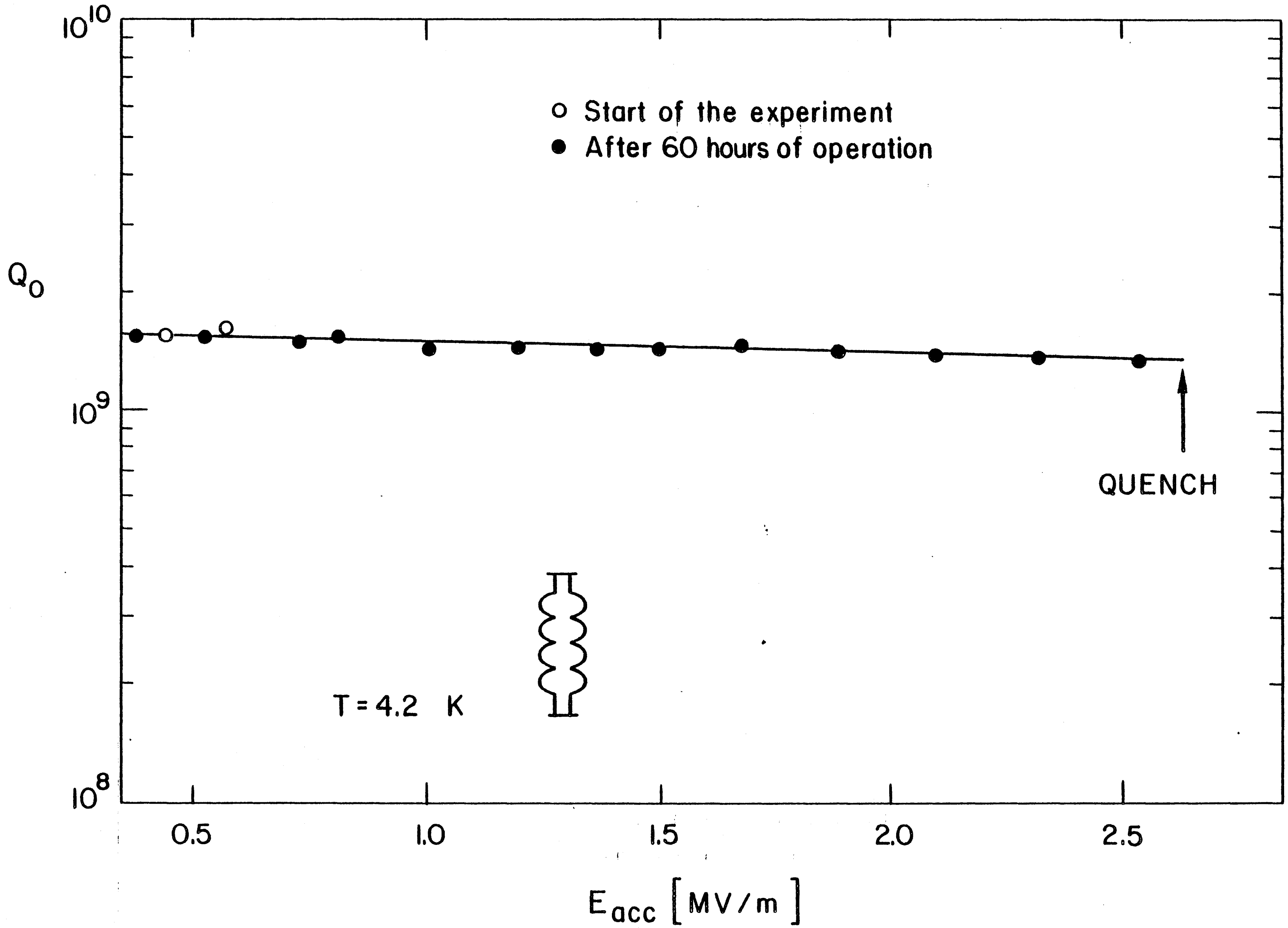

Q_o
10^9
10^8
T = 4.2 K
o before
● after
He - processing
e^- loading
1
2
3
E_{acc} [MV/m]

Fig. 1



10^{10}
10^{9}
10^{8}
Q_0
○ Start of the experiment
● After 60 hours of operation
QUENCH
T = 4.2 K
0.5
1.0
1.5
2.0
2.5
E_{acc} [MV/m]

Fig. 2

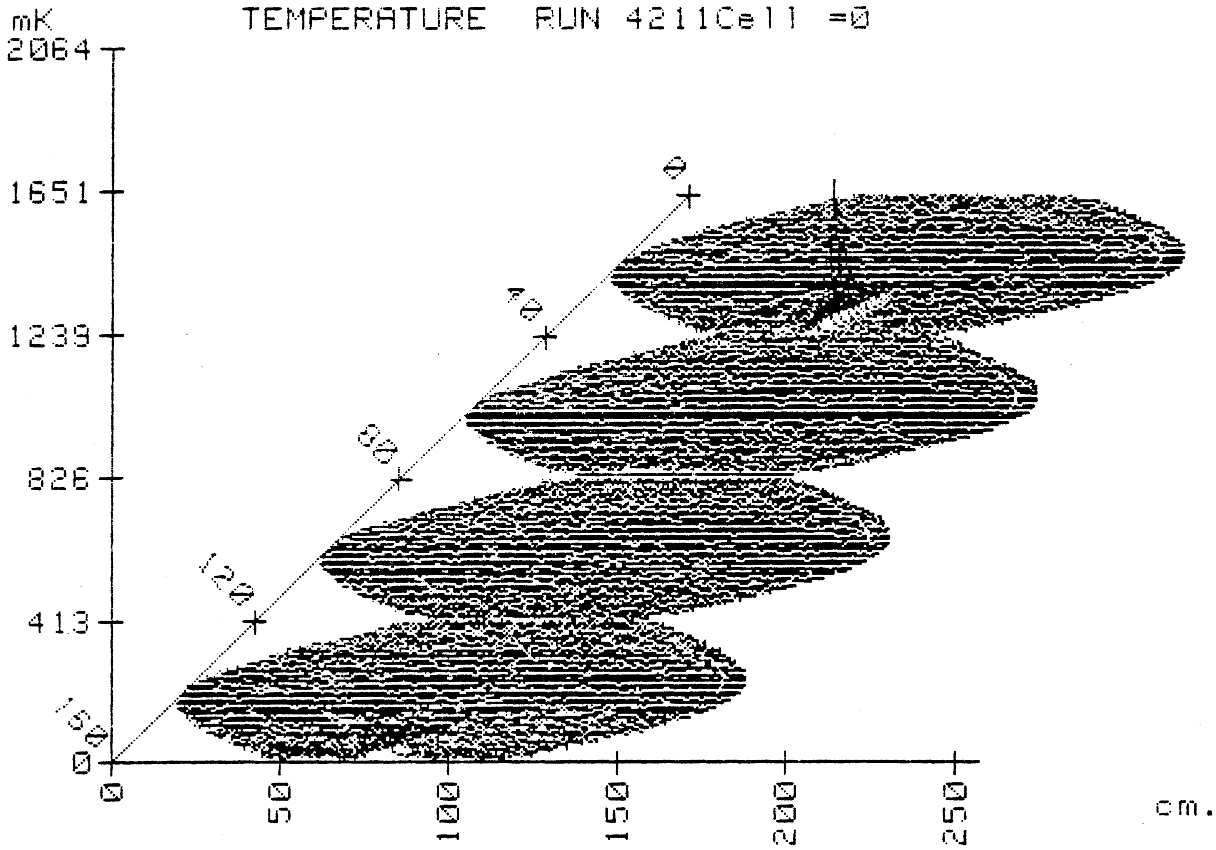

mK
TEMPERATURE RUN 4211Cell =0
2064
1651
1239
826
413
0
0
40
80
120
160
0
50
100
150
200
250
cm.

Fig. 3

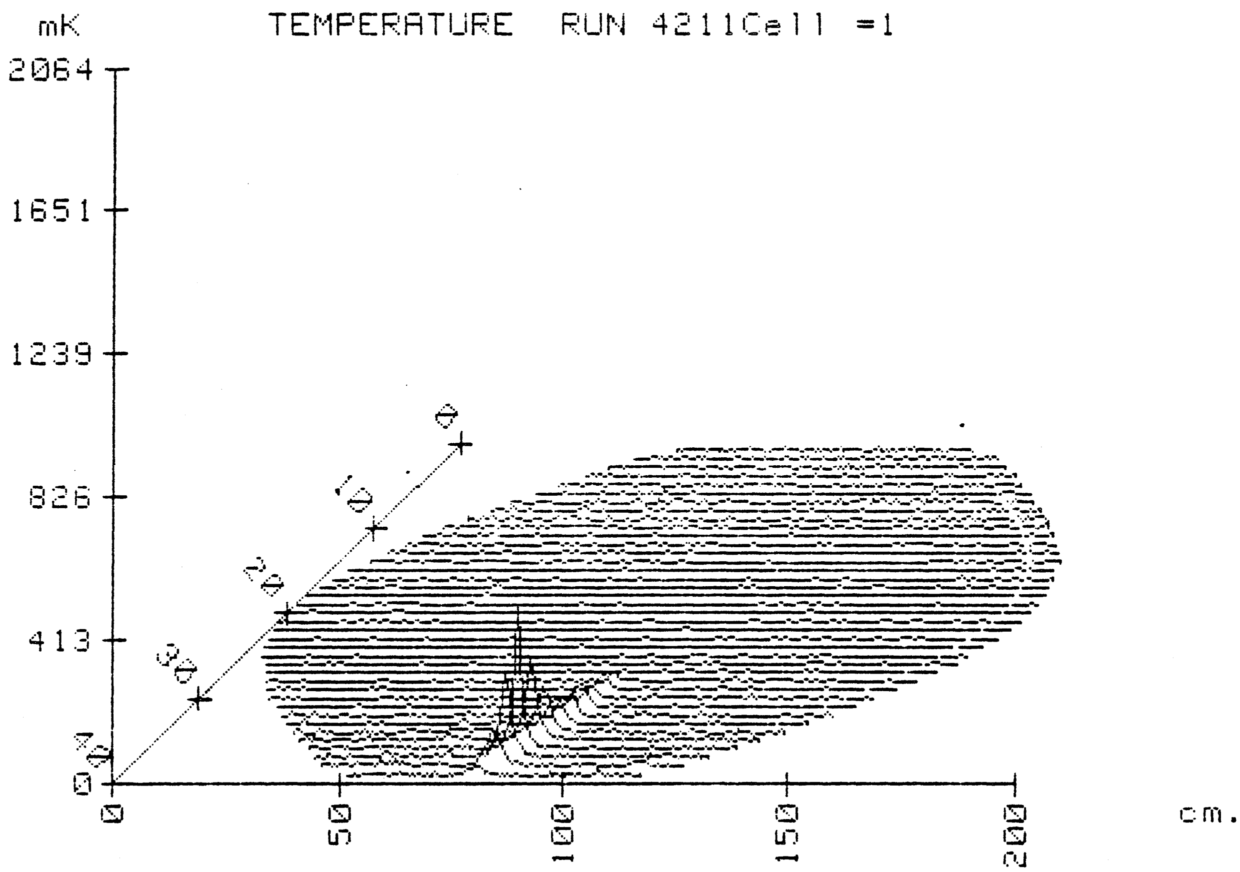

mK
TEMPERATURE RUN 4211Cell =1
2064
1651
1239
826
413
0
0
10
20
30
40
0
50
100
150
200
cm.

Fig. 4