INTERNATIONAL INTERCOMPARISON OF FIXED POINTS
BY MEANS OF SEALED CELLS
(13.81 K to 90.686 K)

(1978 - 1984)

Final Report of the Pilot Laboratory

by

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FINAL REPORT

on the

INTERNATIONAL INTERCOMPARISON OF FIXED POINTS BY MEANS OF SEALED CELLS

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Editor

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I N D E X

I. FOREWORD

This is the Final Report of the International Intercomparison of Fixed Points by Means of Sealed Cells, which has been held under the auspices of the Comité Consultatif de Thermométrie (CCT) between 1978 and 1984.

Forty sealed cells, realizing the triple point of seven different substances, defining both primary fixed points of the IPTS-68 and secondary fixed points in the temperature range from 14 K to 90 K, were supplied by nine Laboratories. They were measured in eleven National Laboratories around the world, against the fixed points realized in these Laboratories (both in open cryostats or in other sealed cells).
Some 150 independent series of data were originated, from almost 300 melting experiments, representing some 2300 equilibrium temperature values.

This work involved a large staff of experts in every Laboratory. The role of IMGC, after the initial proposition of the Intercomparison and apart from its own measurements, has been first to work out a comparison scheme tailored on the requests of each participating Laboratory, secondly to co-ordinate the circulation of the cells between Laboratories in the whole world, and finally to collect, compile and digest the measurement data obtained in the Laboratories, write and edit the present Report.

This could be done also through three Meetings of the participating Laboratories held on the day before CCT Meetings in 1980, 1982 and 1984.

II. INTRODUCTION

The calibration of platinum resistance thermometers of specified quality (SPRT) on the International Practical Temperature Scale (IPTS) in the cryogenic region consists of the measurement of their resistance values at a certain number of reference temperatures, corresponding to the boiling and triple points of substances that are gaseous at room temperature. Although the Scale is based on thermodynamic states uniquely defined and on platinum of a specified quality, interlaboratory comparisons are necessary to check the degree of uniformity internationally achieved in the realization of the Temperature Scale.

In fact, the practical implementation of both temperature fixed points and the interpolating instrument may perceivably affect the physical property being measured; with PRTs it brings about a dispersion of the W versus T characteristic, which affects the uniqueness of the Scale definition between fixed point temperatures; with fixed points, it produces different temperature values for the same physical thermodynamic state in different measurements.

Several international intercomparisons have been promoted to control the uniformity of IPTS realizations in different laboratories[1.4]. An intercomparison requires travelling standards: only SPRTs, calibrated on laboratory realizations of the IPTS (LAB-IPTS), were available for this purpose in the past, although they are very delicate instruments liable to instability when transported.

In the last 10-year period, extensive studies were made on the realization of fixed points in transportable sealed cells, down to solid hydrogen temperatures (see below for references). Since the beginning, the cells made at IMGC and INM have been compared with conventional realizations at BIPM (1975)[65], NRC (1976)[66.67] and NPL (1975-78)[52], and this immediately demonstrated the superior results that could be obtained transporting the cells[66.52], with respect to the use of travelling thermometers[65.52], as pointed out in Ref.66. Consequently, in 1978 IMGC proposed to undertake under the auspices of the Comité Consultatif de Thermométrie (CCT) an intercomparison of fixed-point realizations in National Laboratories by using fixed points in small sealed cells, instead of capsule PRTs, as travelling standards. This was decided in the 12th Meeting of the CCT in June 1978 [5]. Since these devices are both strong and stable in time, one set of them (one cell for each substance) would have been sufficient for the comparison (only triple points and solid-to-solid transitions could be studied in sealed cells). However, as it was quite a recent device, it was preferred to circulate more than one cell for each substance, in order to check also for the quality of the standards used.

The definition of the goals of the intercomparison required an extensive discussion (see Section III.3); as a result, it was decided that this exercise should generate information in three main areas:

a) Intercomparison of different models of sealed cells.

b) Intercomparison of candidate substances for reference points.

c) Relationship between the LAB-IPTS-68 at the reference temperatures considered in the intercomparison.

III. INTERCOMPARISON CONFIGURATION

1. Standards used in the intercomparison: sealed cells and gases

The travelling standards used to compare the fixed point realizations of the Laboratories were sealed-cell devices, in which a sample of a gaseous substance is permanently enclosed in order to provide a permanent realization of its triple point (and of the solid-to-solid transitions, if any: this possibility has not been used).

As sealed cells from many of the participant Laboratories were available at the time where the comparison started in 1978 (and more became available later), cells from nine of them were circulated between Laboratories. The physical appearance of each different cell model taking part in this exercise is shown in Fig. III.1.

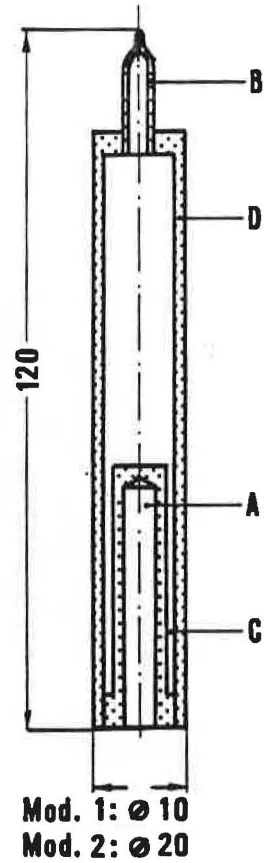
Five different gases were initially selected to be sealed into the cells: argon, oxygen, e-hydrogen, methane and neon; two more were added subsequently: nitrogen and e-deuterium. Table III.1 gives the set of 41 cells and 7 gases involved in the studies. The following references should be consulted for information about cell fabrication and performances: ASMW[55], BIPM[6], IMGC[7,8], INM[9,10], NBS[11,68], NIM[18], NRLM[12]. Cell ageing after sealing ranged from few months (at the beginning of the circulation) to more than eight years (at the end).

2. Participating Laboratories

Eleven Laboratories took part in the Intercomparison at different times and with different involvements.

Table III.2 lists the dates when the measurements were made by each Laboratory: some relevant measurements made before 1979 are also included; 151 independent sets of measurements are included, corresponding to each circulating cell being measured by an average of 4-5 Laboratories. Some 300 meltings were performed during these studies.

Since the cells are stable devices, a regular pattern was not required for the circulation scheme. However, the circulation plan was designed so as to send at least two models of cells for each of the substances and at the same time. The circulation started at the beginning of 1979 and was completed by the beginning of 1984. Although a variety of unexpected events has randomly disturbed the regularity of the circulation pattern (involving 31 of the devices and 11 countries in



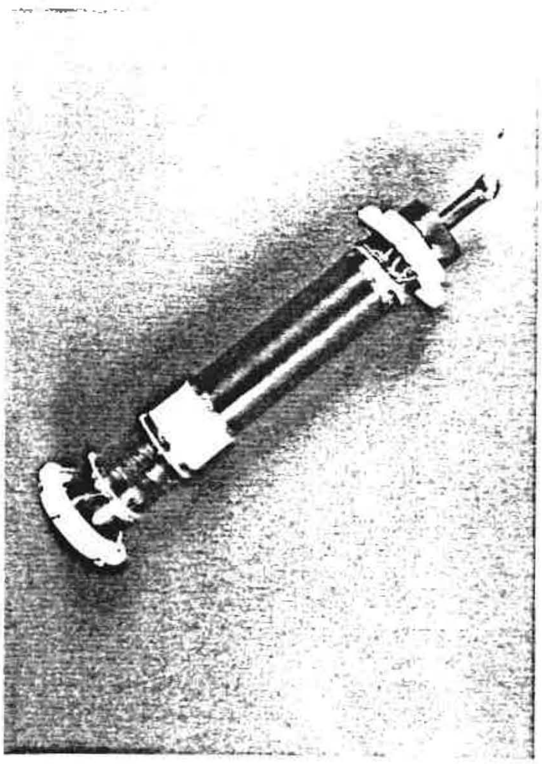


Fig. III.1 a - A S M W models 1 and 2

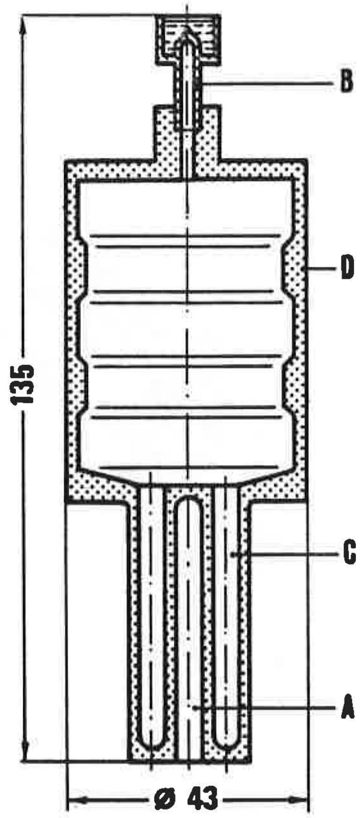
Cell parts: A: body (copper); B: block for one thermometer (copper); C: "pinch-off" tube (copper).

Cell assembling: silver brazing.

Cell volume: mod.1 2.5 cm^3
mod.2 5 cm^3

Volume for condensed sample (surrounding the block): mod.1 0.6 cm^3
mod.2 2 cm^3

Filling method: argon, cryogenic condensation;
neon, high pressure at 78 K.



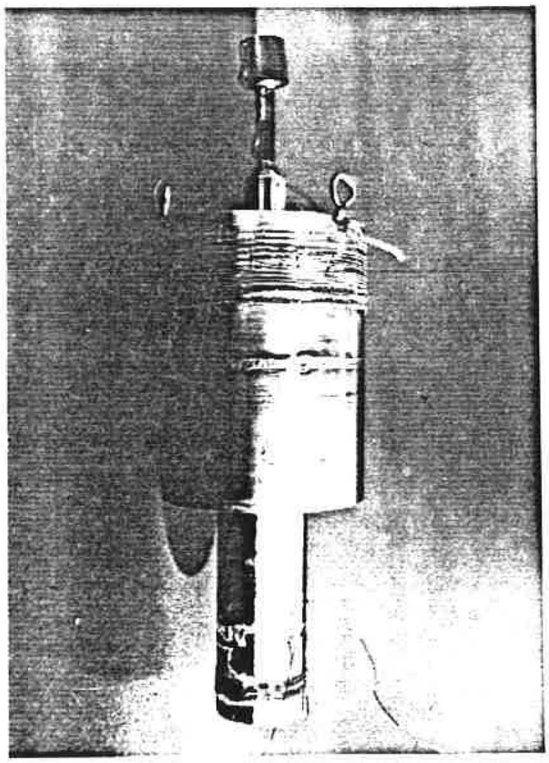


Fig. III.1 b - B I P M

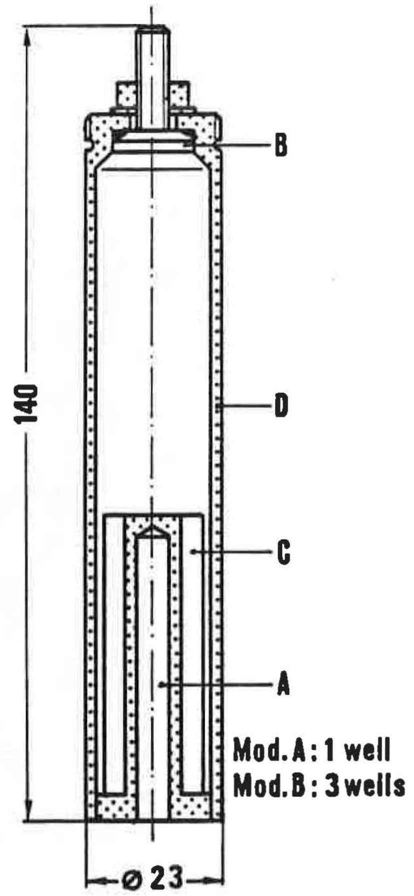
Cell parts: A: well for one thermometer; B:"pinch-off" tube (copper); C: sample wells (6); D: body (stainless steel).

Cell assembling: arc welding, except for the "pinch-off" tube, which is silver brazed.

Cell volume: 74 cm^3

Volume for condensed sample: (in the wells): 9 cm^3

Filling method: cryogenic condensation.



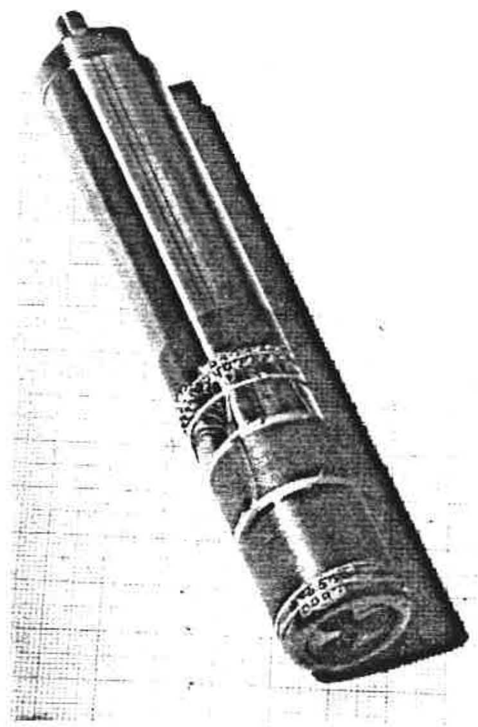


Fig. III.1 c - <u>I M G C</u> models A and B

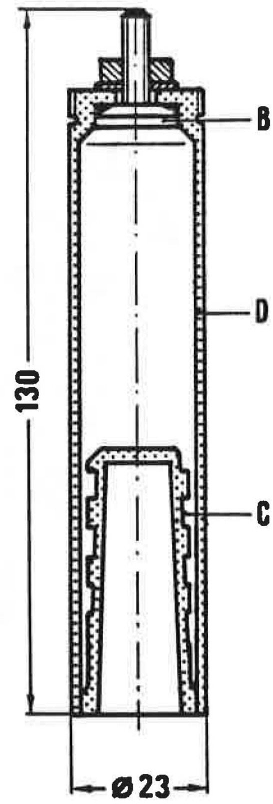
<u>Cell parts:</u> A: well for one (mod.A) or three (mod.B) thermometers; B: indium seal; C: thermometer block with vertical fins (copper); D: body (stainless steel).

<u>Cell assembling:</u> arc welding.

<u>Cell volume:</u> mod.A 33 cm^3
mod.B 22 cm^3

<u>Volume for condensed sample</u> (surrounding the block): mod.A 5 cm^3
mod.B 4 cm^3

<u>Filling method:</u> cryogenic condensation.



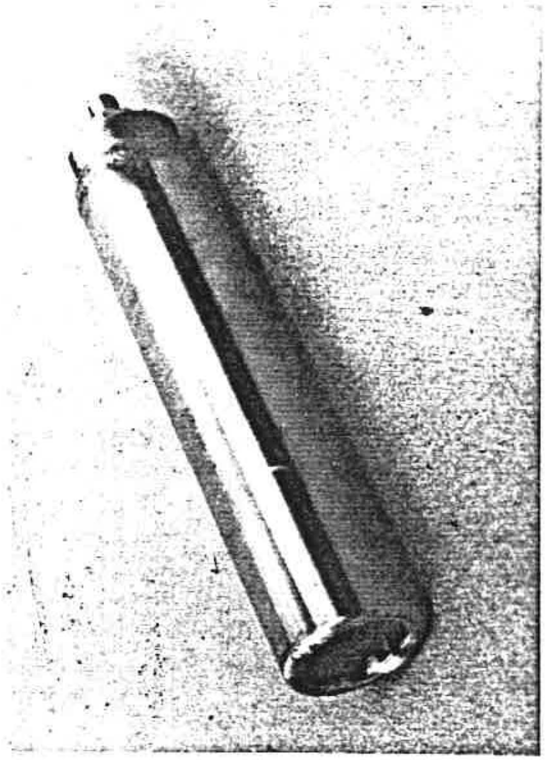


Fig. III.1 d - <u>I M G C</u> model C

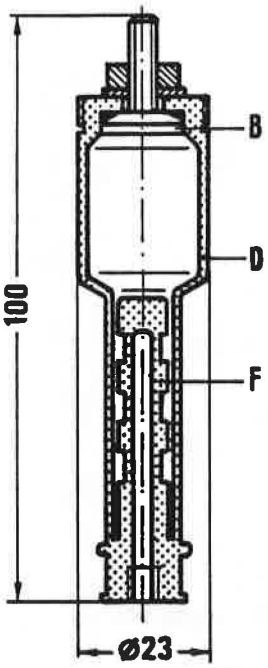
<u>Cell parts</u>: A: large conical well for thermometer adaptor; B: indium seal; C: thermometer block with helical thread (copper); D: body (stainless steel).

<u>Cell assembling</u>: arc welding.

<u>Cell volume</u>: 20 cm^3

<u>Volume for condensed sample</u> (surrounding the block): 2.5 cm^3

<u>Filling method</u>: cryogenic condensation.



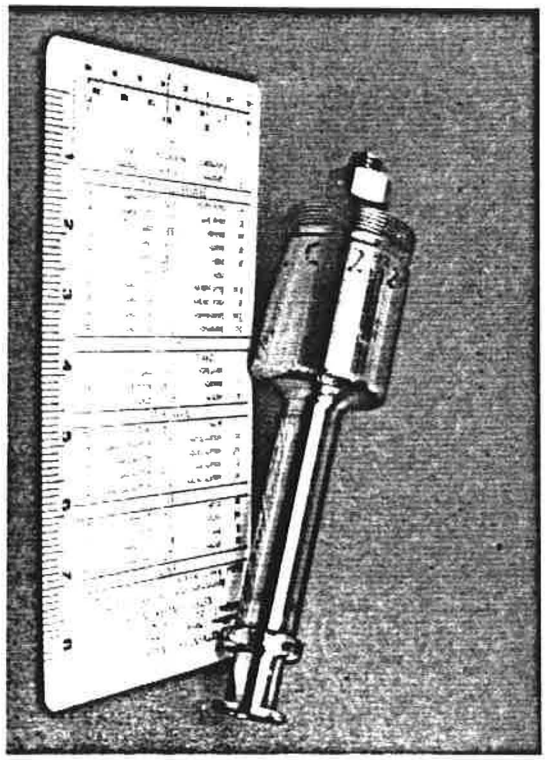


Fig. III.1 e - I M G C model M

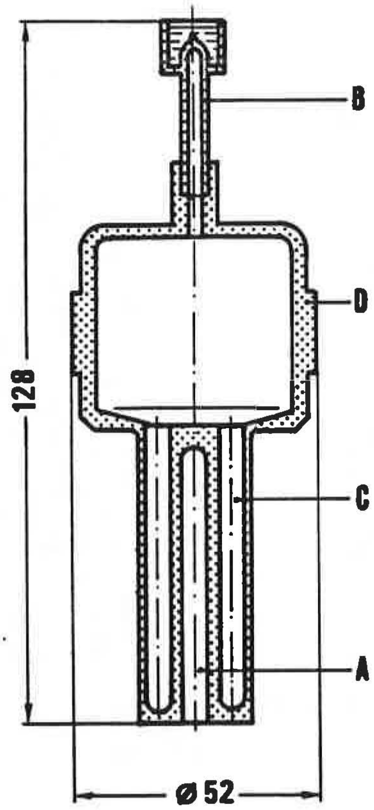
Cell parts: B: indium seal; D: body (stainless steel); F:body (copper with horizontal fins) to transfer interface temperature to the external thermometer block (not shown).

Cell assembling: arc welding.

Cell volume: 8 cm^3

Volume for condensed sample (surrounding the copper body): 1 cm^3

Filling method: cryogenic condensation.



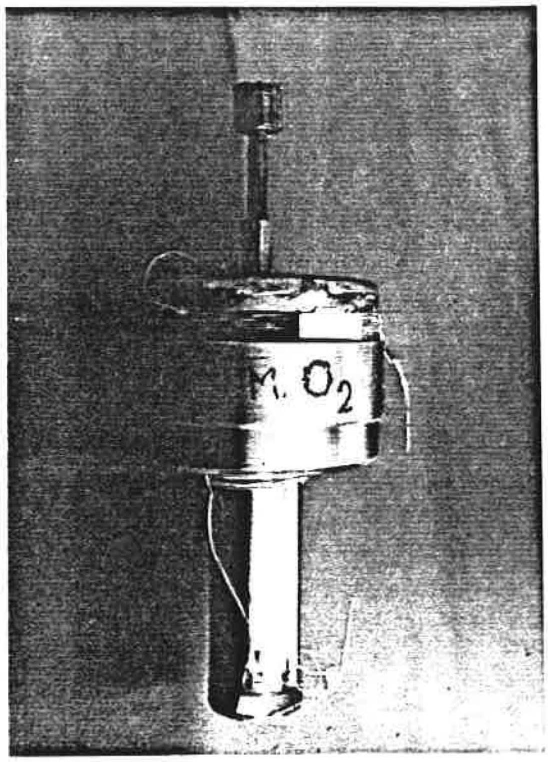


Fig. III.1 f - I N M model A

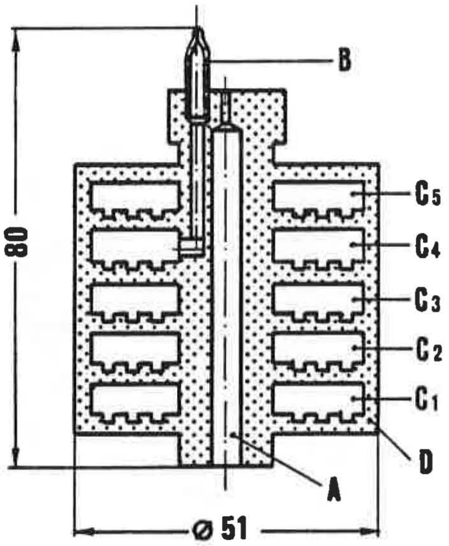
Cell parts: A: well for one thermometer; B:"pinch-off" tube (copper); C: sample wells (6); D: body (stainless steel).

Cell assembling: arc welding, except for the "pinch-off" tube, which is silver brazed.

Cell volume: 60 cm^3

Volume for condensed sample (in the wells): 9 cm^3

Filling method: cryogenic condensation.



INM mod. BCM

Fig. III.1 g - I N M model BCM (Multicomponent cell)

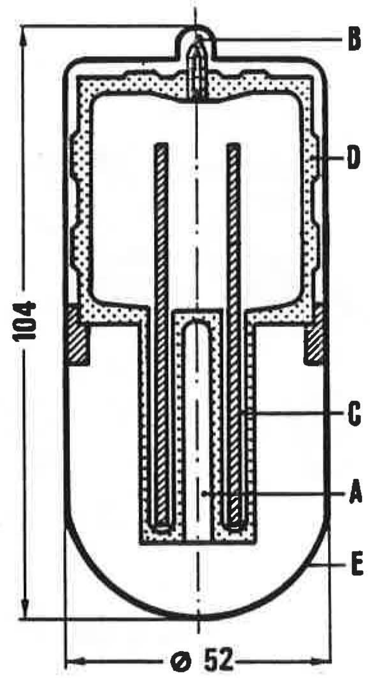
Cell parts: A: well for one thermometer; B: body (stainless steel); C: "pinch-off" tube (copper: one for each chamber); D: sample chambers with heat exchanger.

Cell assmbling: arc welding, except for the "pinch-off" tubes, which are silver brazed.

Cell volume (each chamber): 7.5 cm^3

Volume for condensed sample (in the thread): 0.9 cm^3

Filling method: high pressure, room temperature.



NBS (Ar)

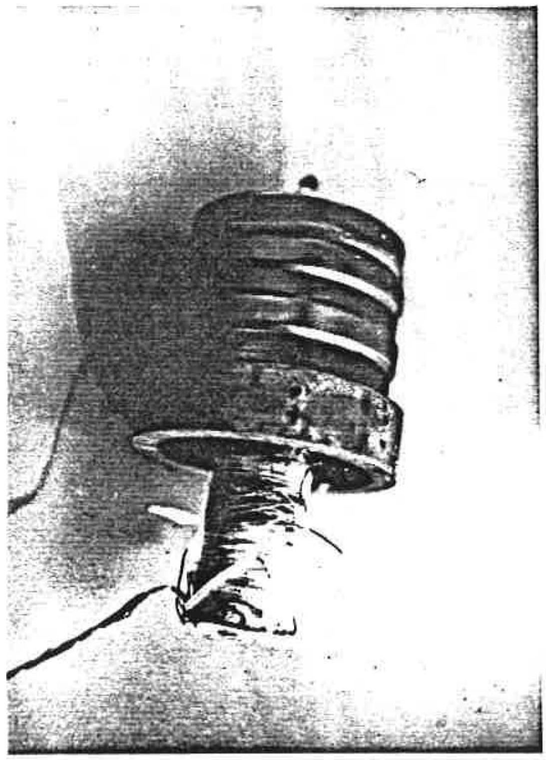


Fig. III.1 h <u>N B S</u> model M1

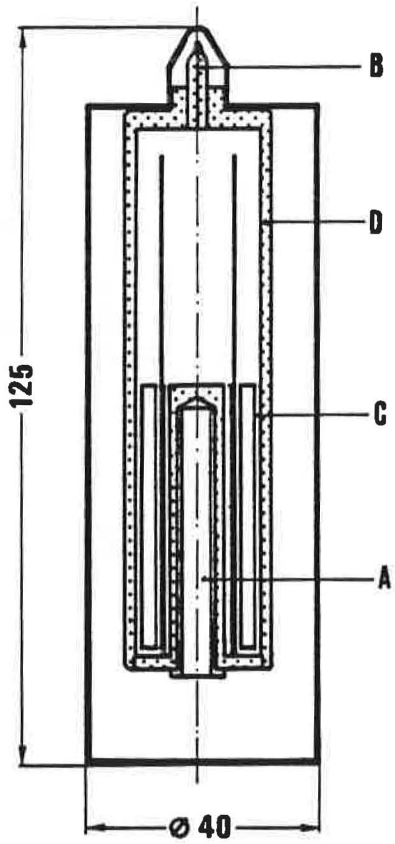
<u>Cell parts:</u> A: large well for one thermometer; B: "pinch-off" tube (stainless steel); C: sample chamber; D: body (stainless steel); E: isothermal thin shell (copper).

<u>Cell assembling:</u> arc welding.

<u>Cell volume:</u> 50 cm^3

<u>Volume for condensed sample</u> (surrounding the well): 4 cm^3

<u>Filling method:</u> high pressure, room temperature.



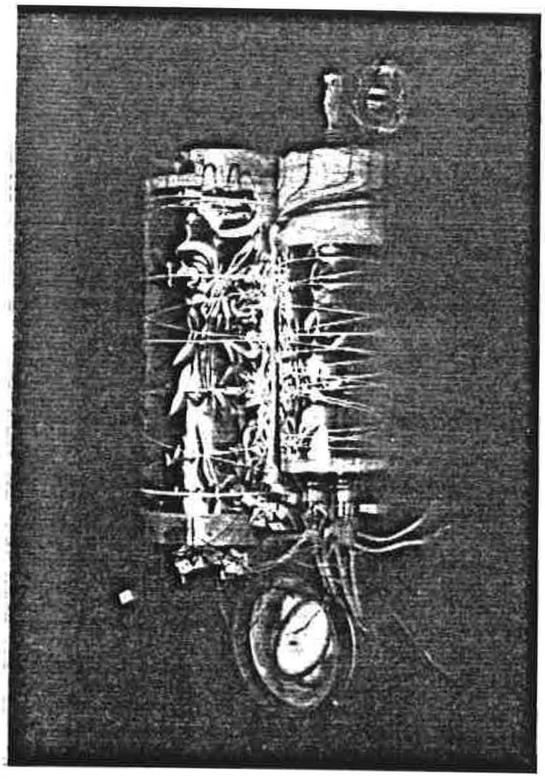


Fig. III.1 i - N B S model M2

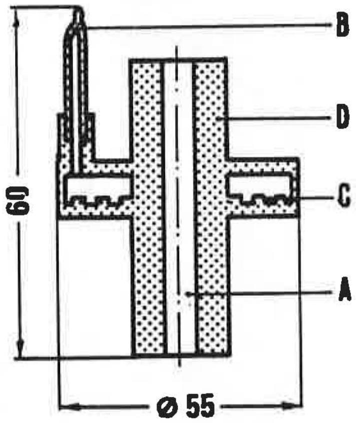
Cell parts: A: large well for one thermometer; B: "pinch-off" tube (stainless steel); C: sample chamber; D: body (stainless steel); E: isothermal thin shell (copper).

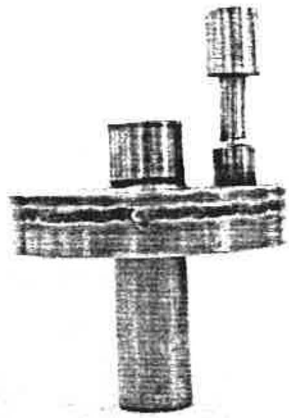
Cell assembling: arc welding.

Cell volume: n°2-1: 50 cm^3; n° 2-3: 16 cm^3

Volume for condensed sample (surrounding the well): 2 cm^3

Filling method: cryogenic condensation.





NIM mod. BC-INM

Fig. III.1 j - N I M model BC(INM)

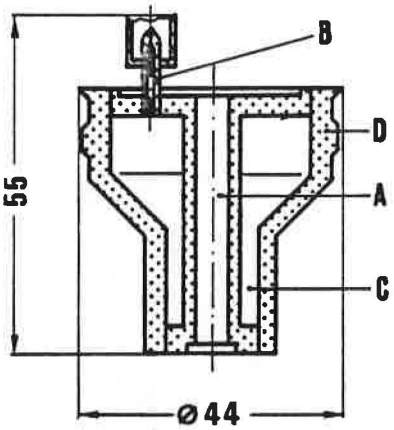
Cell parts: A: well for one thermometer; B:"pinch-off" tube (copper); C: heat exchanger; D: body (stainless steel).

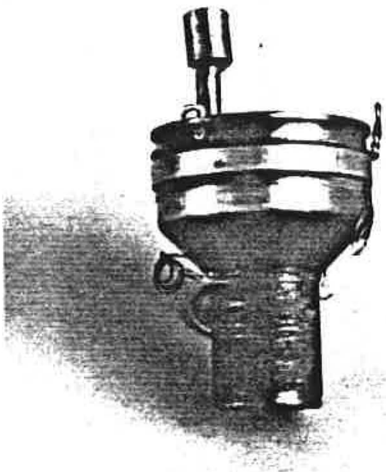
Cell assembling: arc welding, except for the "pinch-off" tube, which is silver brazed.

Cell volume: 15 cm^3

Volume for condensed sample (in the thread): 0.9 cm^3

Filling method: high pressure, room temperature.





NIM

Fig. III.1 k - N I M model 1

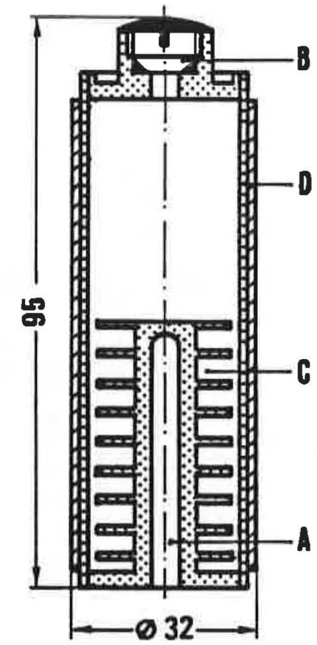
Cell parts: A: large well for one thermometer (copper); B:"pinch-off" tube (copper); C: body (copper).

Cell assembling: silver brazing.

Cell volume: 7.5 cm^3

Volume for condensed sample (surrounding the well): 1 cm^3

Filling method: high pressure, room temperature.



NRC

Fig. III.1 1 - N R C

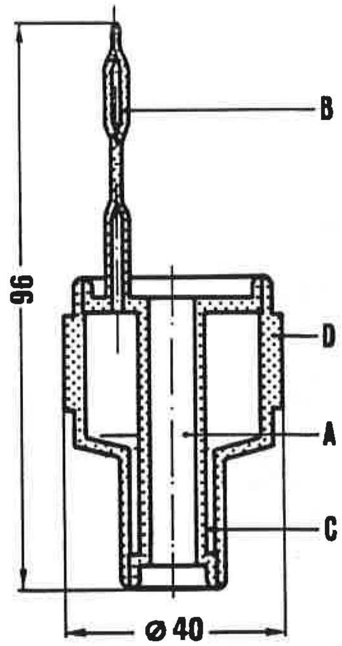
Cell parts: A: well for one thermometer; B: indium seal; C: thermometer block (copper) with horizontal thin baffles (15 copper disks, 0.5 mm spacing); D: body (copper, with external stainless steel jacket). Hydrogen cell: all stainless steel.

Cell assembling: arc welding and silver brazing.

Cell volume: 35 cm^3

Volume for condensed sample (between the baffles): 5 cm^3

Filling method: high pressure, room temperature.



NRLM

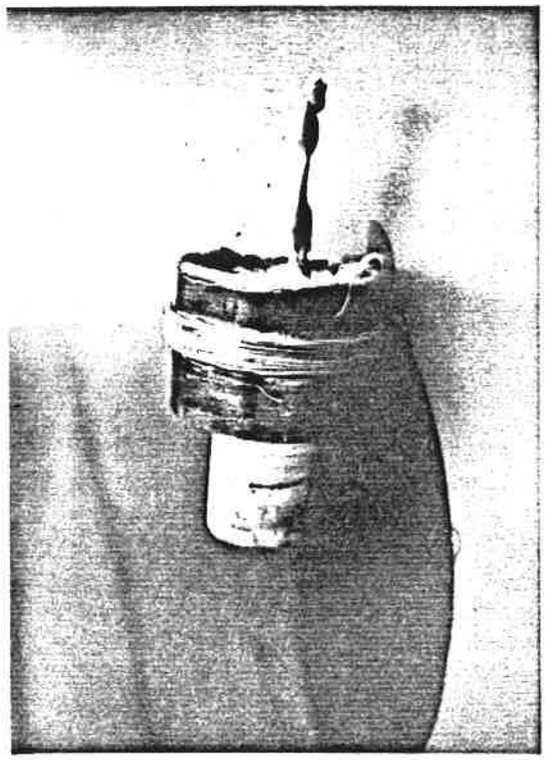


Fig. III.1 m - N R L M

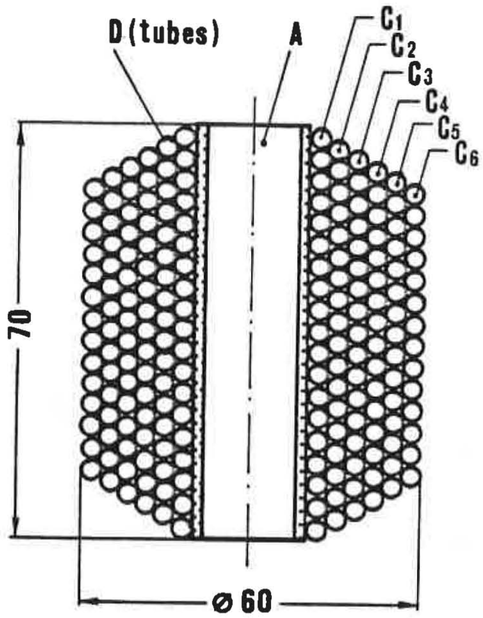
Cell parts: A: large well for one thermometer (copper); B:"pinch-off" tube (copper); C: body (copper).

Cell assembling: silver brazing.

Cell volume: 15 cm^3

Volume for condensed sample (around the well): 0.9 cm^3

Filling method: (supposed) Ar, O_2, CH_4, cryogenic condensation; H_2, Ne high pressure, room temperature.



PRMI

Fig. III.1 n - P R M I Multicomponent cell

Cell parts: A: thermometer well (copper tube); B_{1to6}: sample chambers (copper coil).

Cell assembling: silver brazing.

Cell volume (each chamber): 20 cm^3

Volume for condensed sample: non definable.

Filling method:

Table III.1 : Sealed cells involved in the intercomparison

Substances sealed in the cells

Laboratories supplying the cells	ARGON °83.798 K	OXYGEN °54.361 K	HYDROGEN °13.81 K	METHANE ^90.7 K	NITROGEN ^63.1 K	NEON ^24.6 K	e-DEUTERIUM ^18.7 K
ASMW	4Ar(May 81)					1Ne (Nov 81)	
BIPM	3Ar(Feb 77)*			7CH4(Sep 77)			
IMGC	1Ar(Jul 75) 2Ar(May 78)	102(Sep 76) 802(Nov 78)	1H2(Aug 80) 2H2(Jan 83)*	2CH4(Aug 76) 12CH4(Apr79)	2N2(Feb 80)	1Ne(Jun 77) 3Ne(Feb 79)	1eD2(Nov 80)
INM	1Ar(Sep 75) XXI(Dec 78) BCM4(Jan 82)	802(Feb 76) BCM4(Jan 82)			BCM4(Jan 82)	BCM4(Jan 82)	
NBS	M1Ar(Feb 78)	M2-102(Feb83)* M2-202(Jul83)*					
NIM	113(Dec 80)*	PP11(Aug81)* PP07(Jul81)*					
NRC	10Ar(May 79) 14Ar(May 79)	1502(Jun 79)	23H2(Aug 79)	18CH4(Aug79)	33N2(Jul 82)	12Ne(Jun 79)	31eD2(Dec81)*
NRLM	7803(Jun 78)	7802(Jun78)* 7801(Jun78)	7801(Jun 78)			Ne01(Jul 78) Ne02(Jul 78)	
PRMI	MC(Dec 78)*	MC(Dec 78)*	MC(Dec 78)*			MC(Dec 78)*	

* cell not circulated; reference cell; °IPTS-68 value; ^approximate value.

Table III.2 — CELLS available from:

Laboratories		ASMW	BIPM	IMGC	INM	NBS	NIM	NRC	NRLM	PRMI
ASMW	Ar	Jun 81		Nov 79					Nov 80	
	O2			Feb 80				Feb 81		
	H2			Mar 81					Dec 80	
	CH4			Dec 79						
	Ne	Dec 82		Mar 81				Jan 81		
BIPM	Ar		Feb 80	Dec 79	Nov 79	Feb 80		Feb-Mar 80	Nov-Dec 79	
	CH4		Feb-Apr 80	Apr 80				Jan-Feb 80		
IMGC	Ar	Oct 82		Sep75-May80				Apr 80	Sep 80	
	O2			Sep76-Nov81				Sep 80	Nov 80	
	H2			Oct80-Jun83				Oct 80	Mar 79	
	CH4			Aug76-Oct81				Jul 80		
	N2			Aug 80				Jun 83		
	Ne	May 83		Jun77-Dec81				Oct 80	Sep 80	
	D2			Dec 80						
INM	Ar			Apr 80	Apr80-Feb82	Apr 80		Apr 80	Apr 80	
	O2			Oct 80	May80-Feb82			May 80	May 80	
	N2			Sep 83	Feb 82					
	Ne			Sep 83	Mar 82					
NBS	Ar			Aug 79		Feb-Mar 79		Feb 81	Jul 81	
	O2			Mar 84		Mar-Oct 83				
NIM	Ar			Feb 81	Aug 81		Aug 81	Aug 81		
	O2			Feb 81	Aug 81		Jul 81			
	CH4			Mar 81						
NML	Ar			May 79	May 79			Nov 79	Jul 79	
	O2			Nov 78	Sep 79			Nov 79		
	H2							Feb 83	Oct 79	
	Ne			Dec 82				Dec 79		
NPL	Ar			Jan 78				Nov 81		
	O2			Feb 78				Nov 81		
	H2							Feb 80	May 79	
	CH4			Apr 78						
	N2			Nov 80						
	Ne			Jan 80				Feb 80	May79-Feb80	
	D2			Nov 81						
NRC	Ar			Dec 76	Dec76-Jul82	Aug 79		Jun79-Jul80	May 79	
	O2			Dec76-Oct79	Jun76-Jul82			Jun 79	Oct 79	
	H2							Sep 79	Jun 80	
	CH4		Aug 79	Dec76-Aug79				Aug 79		
	N2			Nov 81	Jul 82			Jul 82		
	Ne			Jun 79	Jul 82			Sep79-Feb82	Oct 79	
	D2			Nov 81				Dec 81		
NRLM	Ar			Nov 81		May 82			Oct78-Nov81	
	O2			Nov 81					Oct78-Nov81	
	H2								Jul78-Nov81	
	CH4			Nov 81						
	Ne			Nov 81					Aug78-Nov81	
PRMI	Ar			Dec 81						Nov 81
	O2			Dec 81						Nov 81
	H2			Dec 81						Nov 81
	CH4			Dec 81						
	Ne			Dec 81						Nov 81

the whole world), loss of substantial information could almost entirely be avoided, at the expense of an increase in the total time initially planned for the exercise.

The stability of each cell was controlled by the originating Laboratory at the end of the circulation.

3. Purposes of the intercomparison

The meaning of the direct comparison of fixed points made possible by the sealed cell devices has been subject of extensive discussion among the Laboratories involved.

At the beginning, the intercomparison had been proposed only to complement the intercomparison of National IPTS-68 realizations, performed at NPL since 1975, where calibrated SPRTs were used as travelling standards. As these standards are delicate instruments liable to instability in transportation, the use of transportable fixed points, insensitive to normal transportation, should have permitted a comparison of national fixed-point realizations with higher reliability (± 0.1 mK).

Subsequently, the availability of many models of cells in 1978, suggested to extend the comparison to the realization of fixed points in different types of cells.

As a result of the discussion, the comparison was set to provide information in the following areas:

a) Intercomparison of different cell models.

This exercise comprised direct comparison of the devices received by each Laboratory. This comparison does not involve either Scale realization or the quality of the thermometer used, except its short-term stability, since the same thermometer must be used with all cells. This rule was strictly followed, with only few exceptions.
The aim is to understand if these devices are suitable for accurate realization of fixed points, and how much the results on each single cell are dependent on the ancillary equipment.

b) Intercomparison of candidate substances for reference points.

The gases included in this exercise are all the substances with triple-point temperature lower than 90 K. They were already previously studied in some of the participating Laboratories. However the use of common devices for all the Laboratories made it possible to study the quality of each substance as a candidate for a reference temperature in a more uniform way. In fact, the merits of a candidate-substance do not only consist of a flat and reproducible melting plateau, but also on the possibility of a realization which should be simple, reliable and largely insensitive to the quality of the thermal equipment and to the details of the experimental method used.

c) Relationship between LAB-IPTS-68s at reference temperatures.

The intercomparison makes it possible first, to measure the systematic differences between the LAB-IPTS-68 realizations and the reference travelling standards at three definition temperatures; secondly, to assign a temperature value to four secondary fixed points. This latter goal involves the use of the National Scales; hence, some precautions must be taken to limit the influence of the scale non-uniqueness.

IV. EXPERIMENTAL CONDITIONS

1. Measurement equipment

To carry out the measurements, the Laboratories used their routine equipment for the realization of the IPTS-68. The following references should be consulted for more information on each Laboratory realization:

A S M W (26) - The cells are suspended in an adiabatic cryostat by means of plastic wires or a rod. Shield is controlled to less than 5 mK to the cell temperature. Residual heat leak corresponds to a drift of the cell temperature less than 5 mK/h.
Resistance measurements are made with a R-348 dc potentiometer, with a temperature-equivalent resolution of about 0.1 mK at Ar, 0.3 mK at Ne and 0.4 mK at H_2 triple point.

B I P M (6,14) - The cells are suspended in an adiabatic cryostat by means of a plastic rod. The shield is controlled so that the residual heat exchange (positive or negative) corresponds to a temperature drift of the cell of few millikelvins per hour.
Resistance measurements are made with a dc Kusters Comparator bridge, with a temperature-equivalent resolution of 0.01 mK at Ar and CH_4 triple points.

I M G C (8) - Two adiabatic cryostats have been used for the work respectively below and above 54 K; the one used for higher temperatures is a much simplified one. The cells are suspended by means of a plastic rod. Thermal drift rates (always positive) generally do not exceed 10 mK/h.
Resistance measurements are made with a dc Kusters Comparator bridge, with a temperature-equivalent resolution of 0.01 mK above 50 K, decreasing to 0.15 mK at 14 K. All plateaux are continuously recorded on paper.

I N M (15,10) - An adiabatic calorimeter with one isothermal shield has been used, regulated to the same temperature of the cell by means of a differential thermocouple; he cell is suspended with nylon threads. The typical thermal drift rate is less than 1 mK/h.
Resistance measurements are made with a dc Kusters Comparator bridge, connected to an automatic data acquisition system. This system calculates the response time of the cell using a statistical criterion that always leads to larger values than the adopted criterion of recovery of temperature within 0.1 mK (see later on).

N B S (17) - An adiabatic calorimeter built for specific heat measurements has been used. The cells were enclosed in an auxiliary copper shell suspended inside the shield with plastic threads, so that the residual temperature drift rate is of the order of 1 mK/h.
Resistance measurements are made with a dc Kusters Comparator bridge, with a temperature-equivalent resolution of 0.01 mK.

N I M (18,53) - Two cryostats have been used for the work below and above 84 K; both are of the adiabatic type, but that used at the higher temperature is a much simplified one. The cells are suspended by means of plastic wires or rod. Shield is controlled to closer than 10 mK to the cell temperature. Residual heat leak corresponds to a drift of the cell temperature of less than 10 mK/h.
Resistance measurements are made with a dc Kusters Comparator bridge with a temperature-equivalent resolution of 0.01 K above 50 K.

N M L (19) - The cells are suspended from the shield of a flow adiabatic cryostat with a low-conductance thermal path made of stainless steel. Residual thermal drift rate was kept below 2 mK/h.
Resistance measurements are made with a dc Kusters Comparator bridge, or with an automatic data acquisition system with a temperature-equivalent resolution of 0.01 mK.

N P L (3) - The adiabiatic cryostat of the 1975 intercomparison has been used, where residual thermal drift rates less than 1 mK/h were generally obtained.
Resistance measurements are made with a dc Kusters Comparator bridge.

N R C (20) - An adiabatic cryostat has been used with residual thermal drift rate lower than 1 mK/h.
Resistance measurements are made with a dc Kusters Comparator bridge; before 1979 a Mueller G4 bridge has been used.

N R L M (21) - An adiabatic calorimeter has been used, with the temperature of the isothermal shield controlled so as to be the same as that of the sample cell, using a differential thermocouple. The residual thermal drift rate is of the order of a few millikelvins per hour.
Resistance measurements are made with a dc Kusters Comparator bridge with a temperature-equivalent resolution of 0.02 mK.

P R M I (22) - An adiabatic calorimeter has been used with two adiabatic shields. The outer one is controlled through a differential thermocouple. The inner one is regulated in an absolute way with a resistance thermometer or,relative to the cell, with another differential thermocouple. The residual heat leak is less than 0.1 mW at 14 K and 3 mW at 90 K. IMGC cells were suspended by means of a thin-walled stainless-steel tube; the PRMI cell is held by three needle points away from a further shield. Thermal drift rates do not exceed 5 mK/h.
Resistance measurements are made with a potentiometer R-348, calibrated with a precision of ± 3 ppm. The resistance standards are certified to be accurate within ± 1 ppm. Temperature resolution is never worse than 0.1 mK.

Each Laboratory used SPRTs of their own for the measurements. As a rule, the same thermometer was always used in each Laboratory, at least for all the cells containing the same substance. Each Laboratory was also asked to use the thermometers which had taken part in the 1975 NPL intercomparison, in order to establish a relationship between the previous and the present exercise (see section VII.2). These rules have been followed, except in a few cases, which will be listed later on.

2. Cell measurement method

Some Laboratories supplied a reference procedure for the use of their cells as, at the beginning of the exercise, it was thought that the method of using the cells might sensibly affect cell performances and results. This was eventually proved not to be the case.

The cells were measured with methods differing in many details but one: the calorimetric method of heating the cell in discrete amounts and waiting for temperature re-equilibration , under adiabatic conditions, was always followed.

The differences in method concerned mainly:
rate of cooling to freeze the sample; temperature distribution in the cell during cool-down, owing to different cryostat geometries; minimum temperature allowed in the solidified sample; stabilization time before melting; heating rate to warm the sample to the melting temperature; residual heat exchange; temperature drift-rate value considered as the limit during re-equilibration, for definition of the equilibrium conditions.

A uniform criterion was used in order to evaluate the triple-point temperature: the experimental equilibrium temperature values at different melted fractions F were plotted as temperature (actually resistance) versus 1/F and the extrapolated temperature value at 1/F=1 was defined as the triple-point temperature.

3. Measurement accuracy

It is necessary to make a distinction between the part of the Intercomparison which involves the definition of temperature values and that where only differences between resistance values are required.

3.1 Accuracy in cell intercomparison

This concerns the comparison of the different cell models for each substance (section VII.1), where it is only necessary to define a resistance value at 1/F=1 for each melting and to compare it with the corresponding values of other melting plateaux.

In this case, uncertainty derives from the following sources:

a) reproducibility of measurements in each laboratory. It was obtained from direct assessment of the Laboratory or from reproducibility of data from several melting plateaux made with the same cell;

b) fitting of the melting plateau curve. The plateaux were all made by intermittent melting; therefore each plateau consists of a number of experimental equilibrium temperatures obtained at different liquid-to-solid ratios F. By plotting these values versus 1/F one obtains the usual melting plot which shows a negative slope. The temperature values at the definition value F=1 must be obtained usually by extrapolation from lower F values and the difficulty in defining a smooth curve through the experimental points may limit the precision of the triple-point temperature value assigned to that plateau.

c) thermometer calibration. In a few cases, where the cells were measured with different thermometers (or with the same thermometer over a large time interval during which the R(0°C) value could have changed), additional uncertainty derives from thermometer calibration.

It must be pointed out that, owing the small number of measurements generally involved, a curve through the experimental points on a plateau could not be easily fitted mathematically. Therefore, the uncertainties associated with each difference between cells are entirely related to the scatter range of the values available for this analysis, or to source a). However, the resulting figure was set at a value never less than ± 0.1 mK. Considering that the difference values come from a pair of independent measurements of comparable precision, the uncertainty associated with these differences will be 1.41 times larger than that of the single measurement.

The uncertainty values for these differences can be summarized as follows for each Laboratory:

A S M W : values assigned by the Laboratory (1 σ): ± 0.15 mK above 54 K; ± 0.25 mK at 25 K; ± 0.5 mK at 14 K.

B I P M : essentially limited by the "definability" of the melting plateau: ± 0.3 mK.

I M G C : values assigned by the Laboratory on the basis of the internal consistency of a large number of measurements on melting plateaux: ± 0.15 mK, except with methane (± 0.2 mK) and hydrogen (± 0.3 mK).

I N M : value assigned: ± 0.15 mK.

N B S : value assigned: ± 0.15 mK. The measurements show a better reproducibility.

N I M : limited by the "definability" of the melting plateau: ± 0.4 mK

N M L : value assigned: ± 0.15 mK.

N P L : value assigned: ± 0.15 mK, in consideration of the accuracy figure reported in Ref.3.

N R C : value assigned : ± 0.15 mK, in consideration of the accuracy figures stated in most of the published studies on the same substances.

N R L M : value assigned : ± 0.15 mK.

P R M I : value assigned by the Laboratory: ± 0.3 mK.

The figures given above still apply to the comparison of the sealed cells against the conventional realizations of both definition and secondary fixed points in each Laboratory, provided again that the same thermometer is used for all the measurements.

3.2 Accuracy in assigning temperature values

When temperature values are to be stated, the whole Scale realization in each Laboratory is involved (as in goal c), Sections VI.2 and VII.2). Hence, the accuracy associated with these temperature values depends not only on the uncertainty figures given above, but also on the contributions introduced by the Scale definition itself.

The latter are twofold: i) systematic errors in the definition fixed points; ii) scale non-uniqueness between fixed points. For temperatures above 54 K, this intercomparison included a check of item i). However, most of the national IPTS-68 realizations are still obtained by using the condensation point of oxygen instead of the triple point of argon, and it is known that the two realizations are not unique within ± 0.1 mK between 80 K and 90 K (see later for methane).

The non-uniqueness of the IPTS-68 between fixed points is known to be considerably larger than ± 0.1 mK; for this reason, the temperature value assigned to each non-definition fixed point sensibly depends on the thermometer used and there is no way to by-pass the problem. It can only be limited by using a single thermometer for all the measurements or by using a "virtual" unique thermometer. The first solution would have implied shipping one thermometer with the cells: as it was completely unpractical, this solution has been discarded. On the contrary, it was decided to take advantage of the exercise made at NPL in the previous intercomparison, when thermometers from all the laboratories participating in the present exercise were compared at several temperatures in the range 14 K to 273 K. With them it was possible to cancel out the effect of Scale non-uniqueness, and that group could be virtually considered as a single thermometer, available to all the Laboratories and not needing further transportation. The level of uniqueness was stated at NPL to be ± 0.1 mK in 1975 [3]; however, the present traceability to those measurements has been lowered in the years by the degree of stability of each thermometer with time.

Appendix I summarizes the data of the thermometers used in the measurements of cells in different Laboratories. Relevant comments about the quality of the thermometers are given here for the individual Laboratories.

A S M W : thermometer 217990, 217997 and 207278. All these thermometers were measured at NPL in 1975; R(0°C) values drifted since then by -140, -30 and +80 μΩ, but original W values are assumed to be still retained. However, below 30 K some disagreement seems to occur between 217990 and 217997, up to 1 mK level.

B I P M : thermometer 226321 and 226322. This Laboratory did not take part in the NPL exercise but, later, NPL calibrated both thermometers and stated that this calibration can be traced to the intercomparison within ± 0.1 mK [23]. Both thermometers showed some R(0°C) changes after that calibration: from BIPM and NPL calibrations, thermometer 226322 showed a R(0°C) difference of + 150 μΩ in the period 1976-1980. BIPM is supplying R(0°C) values during the intercomparison time, ranging randomly by about 80 μΩ with thermometer 226322 and steadily increasing by about + 200 μΩ with thermometer 226321.

I M G C : thermometer PL01-6, PL02-6 and 45. The IMGC thermometer 838, of the NPL group, was very unstable after return to IMGC. Therefore IMGC used the three PRMI thermometers of the NPL group, which had been available since 1978. Thermometer PL01-6 showed, shortly after arrival at IMGC, a R(0°C) instability equivalent to about a 1 mK change, while the other two remained stable within 0.2 mK; after this R(0°C) change of thermometer PL01-6 and the previous change of thermometer PL02-6 reported to have occurred at NPL, PRMI calibrations of PL01-6 and PL02-6 agreed very well below 54 K, differing from that of thermometer 45 by about 1 mK, while above 60 K, thermometer PL02-6 disagreed by about 1 mK with respect to the other two[24]. On the other hand, NPL calibration of thermometer

PL01-6 seemed to have suffered from the R(0°C) change, below 30 K. In addition, thermometer 45 showed a very large overheating, as it was also observed at NPL, which limits its reliability. In conclusion, traceability to NPL measurements in certainly worse than the required ± 0.1 mK level.

I N M : thermometer 232788 and 1812283. The former was used for many of the measurements. The relationship with thermometer 1812283 of the NPL group was supplied at Ar and O_2 triple-point temperatures. However, R(0°C) for the latter thermometer was observed to change with time, by + 280 μΩ between 1975 and 1979, recovering back by - 100 μΩ in 1982. These facts certainly lower the traceability to NPL measurements.

N B S : thermometer 1774095. It was used for all the measurements. The relationship to NBS thermometer 1812282 of the NPL group was supplied at the triple points of argon (0.2 ± 0.1 mK) and oxygen (0.1 ± 0.1 mK). Both thermometers are reported to have been stable within ± 0.1 mK for years.

N I M : thermometer 7709, 7703 and 188640. The last-mentioned thermometer holds a NIM-IPTS-68 calibration above 54 K. Relationship to NPL measurements could be obtained only for thermometer 7709, through a comparison performed in 1982 with thermometer 1812283.

N M L : thermometer 1731676. This thermometer was used for all the measurements and belongs to the NPL group. It is reported to have been stable within ± 0.1 mK.

N P L : thermometer 1728839. This thermometer is the "master" of the NPL group and it is reported to have been stable within ± 0.1 mK.

N R C : thermometer 1521389 and 1872179. The latter has been used only for the last measurements and it is reported to agree with the former within ± 0.1 mK at 63 K and ± 0.25 mK at 18 K. Changes in calibration of the former (up to 300 μΩ of R(0°C) since 1976) have been traced back. None of these thermometers belongs to the NPL group but the relationship with NRC thermometer 1158062 of the NPL group is provided at the relevant reference temperatures. NRC also pointed out that the systematic differences found at NPL between thermometers 1158062 and 1158066 were not confirmed by measurements made at NRC before and after the NPL comparison, although both were perfectly stable in time[25]. These facts lower the traceability to NPL measurements.

N R L M : thermometer 7681 (1981). No reference to thermometers used in 1978 was possible. Neither thermometer 6601 nor 6803 of the NPL group could be used. Thermometer 7681 was compared with NPL-IPTS-68 in 1982; traceability is stated to be ± 0.3 mK.

P R M I : thermometer 1842381. Since PRMI thermometers of the NPL group were at IMGC at the time of the intercomparison, PRMI used a thermometer calibrated at ASMW against thermometer 217997 of the NPL group, with a stated accuracy of ± 0.5 mK. However, W(100°C) has only been estimated[26]: at IMGC this value has been set, in the calibration table, to 1.39270, using Seifert's criterion[54]. These facts lower the traceability to NPL measurements; scale non-uniqueness is also involved for the secondary-point temperature calculations. At PRMI thermometers 8, 14 and 17 were also used: results on cell differences will use a mean value from the four thermometers.

A detailed discussion on the resulting estimated accuracy of temperature values is given in Section VII.2.

4. LAB-IPTS-68 realizations (status during the intercomparison)

A S M W : The Scale is maintained above 84 K, using the triple point of argon realized in a conventional way. In the future, sealed cells will be used for the Scale definition.

B I P M : The Scale is maintained above 84 K, using the triple point of argon in a sealed cell.

I M G C : The Scale is maintained above 54 K, using the triple point of argon and sealed-cell realizations of the fixed points. Below 54 K triple points are available in sealed cells.

I N M : The Scale is maintained above 54 K, using the triple point of argon and sealed-cell realizations of the fixed points. Below 54 K triple points are available in sealed cells.

N B S : The Scale is defined over the whole range by a group of standard thermometers. The Scale is NBS-1955 adjusted according to its relationship to IPTS-68 prescribed by the CCT [64].

N I M : The Scale is maintained above 54 K with an accuracy of 1 to 3 mK. The condensation point of oxygen is used. In the future sealed-cell realizations will be used.

N M L : The Scale is maintained over the whole range on a set of standard thermometers, calibrated on recent conventional realizations of the fixed points. The condensation point of oxygen is used.

N P L : The Scale is maintained over the whole range on a set of standard thermometers, calibrated on recent conventional realizations of the fixed points. The condensation point of oxygen is used.

N R C : The Scale is maintained over the whole range on a set of standard thermometers, calibrated on recent conventional and sealed-cell realizations of fixed points. The condensation point of oxygen is used. A set of fixed points in sealed cells (triple points) is also available.

N R L M : The Scale NRLM-80 is defined by a set of calibrated thermometers. The condensation point of oxygen is used. A set of fixed points in sealed cells (triple points) is also available.

P R M I : The Scale is maintained over the whole range on a set of standard thermometers, calibrated on recent conventional realizations of the fixed points. The condensation point of oxygen is used. For some triple points a sealed-cell realization is also available.

V. RESULTS ON CELL INTERCOMPARISON

Some 300 meltings (with 2300 equilibrium temperatures) have been originated by the 11 Laboratories, each Laboratory having measured several cells for each substance, each cell having been measured by several Laboratories and each substance having been sealed in several cells.

This Section will supply the whole original data, so that everyone may have access to them as they were available to the Editor and will be able to make his own calculations and speculations.

However, it was decided not to present merely a collection of the graphs and tables provided by the Laboratories, especially as they were originally not given in a uniform way.

Consequently, data on cell intercomparison have been organized in two different ways:

The first consists of a series of 57 data sheets wherein the 151 sets of independent data originated by the Laboratories are collected. There is one sheet for each of the 40 cells (one for each substance, in the case of the multicomponent cells), with an additional sheet in the case when there are more than five Laboratories having measured the cell. Each sheet contains a drawing of the cell and a Table with the physical and filling characteristics. Then, data of a typical melting plateau from each Laboratory (selected, when more then one was available) are given in the form W versus the melted fraction F: the W(100%) value at F=1 is taken as the definition value for the triple-point measurements of that Laboratory on that cell and substance, and it is used in the subsequent analysis of results. Sometimes, W(100%) does not come from extrapolation of all the experimental points, since there was evidence of steady overheating of the liquid phase or of anomalous reversal of slope for high melted fractions; this evidence comes only from analysis of the plot of the melting plateau as W versus 1/F, or from comparison of different meltings.

Therefore, a second representation of the data is given which is complementary to the former. Each data sheet is followed by a plot of all the meltings made with that cell by all the Laboratories. Plots are given as differences to the definition W(100%) value, so that systematic differences between Laboratories are cancelled out. These plots present the variability in the shape of meltings, which represents one of the limiting reasons for accuracy in the determination of the triple-point temperature.

The data sheets contain also some ancillary data on thermal behaviour of the equipment and cell (which will be defined later on and discussed in Section VII.1.2.b-c) and collect some information useful for calculations, such as R(0°C) of the thermometer used and the corresponding temperature values in the LAB and NPL Scales, which will be examined in Section VI.

The data sheets (and associated plots) are grouped for each gas, giving realizations of the definition points of the IPTS-68 first, then of secondary points, for decreasing temperatures. The cells for each substance are presented in the alphabetical order of the Laboratories.

Definition of parameters in the data sheets

Cell drawing: The drawing is intended only to show the design geometry of the cell, with its overall dimensions.

Sealing date: indicates the ageing of the sample in the cell; the gas could have been bottled by the manufacturer in the cylinder used by the Laboratory significantly earlier.

Cell total mass: is the mass of the filled cell: when no wires are permanently glued on the body, it is reproducible within 1 mg and can be used to check for leaks with time, by weighing.

Sample mass: is the mass of the sealed sample;with some kind of sealed cells, it is possible to obtain this value very accurately by difference of the weights of the filled and empty cell.

Impurity analysis: Nominal purity means purity specification given by the manufacturer's catalogue; most of the reported analyses are actually batch analyses, not specific to the bottle used.

Enthalpy of melting: is the value calculated from the mass of the sample and literature data on enthalpy of melting.

Thermometer: is the thermometer actually inserted in the cell for the measurements; the R(0°C) value indicated is the actual value at the time of the measurements and has been used in order to obtain W values.

Typical melting plateau: This has been selected from the meltings reported by each Laboratory (when more than one). The number of points has been sometimes limited to eleven for practical reasons.

Temperature values: They are included in the sheets in order to complete the collection of data received from the Laboratories. For definition of their meaning see Section VI.

Average drift: is the average value of thermal drift observed by the thermometer inserted in the cell when the cell is left unheated just before and after melting. It is determined by the residual heat exchange of the cell with the cryostat: this heat flows through the cell all the time during the melting.

Recovery time: is defined here as the time required for the temperature of the cell (as measured by the thermometer) to recover within 0.1 mK its equilibrium value, after a heating cycle. Since overheating depends on the heating power, recovery time slightly depends on it, especially for small values (fast cells). Part of the reason for the quite large variability observed for this parameter is the lack of uniqueness in the interpretation of this parameter in different laboratories.

Overheating: indicates the rise in temperature during the heating periods, as observed by the thermometer. Since it is strongly dependent on the melted fraction (it increases with the melted fraction), the value at F = 50% is considered and it is referred to the heating power, as it depends on that too.

Enthalpy of melting (end of the sheet): refers to the value actually obtained by the Laboratories during the melting experiments.

GRAPHS

Temperature differences: For each of the melting plateaux the plots show the difference between the temperature of each equilibrium point and the value at 1/F = 1; this value corresponds to the W(100%) value given in the sheets. Therefore, systematic differences between Laboratories are cancelled out.

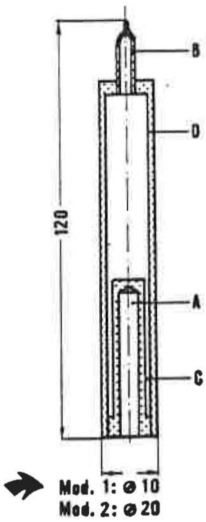
Symbols: One symbol has been used for each Laboratory: it is a letter taken from its acronym and it is used rotated to distinguish between different meltings made by the same Laboratory: W (ASMW); B (BIPM); G (IMGC); N (INM); S (NBS); M (NIM); L (NML); P (NPL); R (NRLM); C (NRC); V (PRMI).

DATA SHEETS FOR THE CELLS

Definition points:
1. argon
2. oxygen
3. e-hydrogen

Secondary points:
1. methane
2. nitrogen
3. neon
4. e-deuterium

C E L L T Y P E: 4 AR ASMW



Manufacturer: ASMW

Sealing date: May 1981

cell total mass: 80 g

sample mass: 0.014 mol

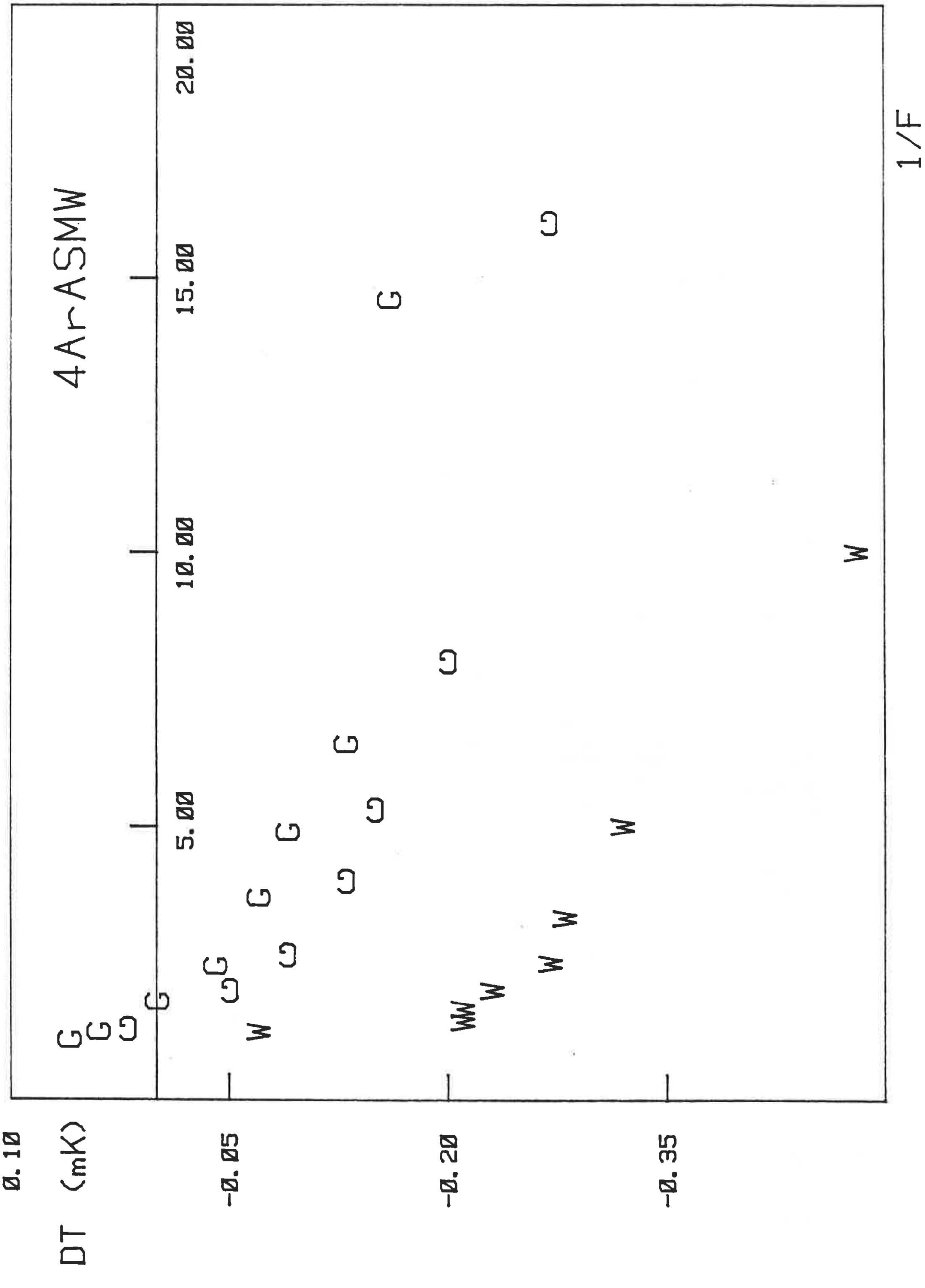
Filling gas type: R 50 Technische Gase

impurity analysis: < 10 ppm

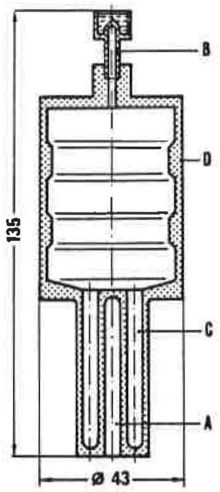
Enthalpy of melting: 16.5 J

Measurements at	Resistance Ratio (W)			
LABORATORY	ASMW		IMGC	
Date	Jun 81		Oct 82	
thermometer N°	217278		PL01-6	
Ro (ohm)	25.346860		25.271140	
Typical melting plateau	10%	2237	6 %	2654
	20%	2308	12%	2689
	30%	2324	19%	2709
	40%	2328	25%	2719
	50%	2348	38%	2733
	60%	2356	50%	2749
	70%	2356	77%	2780
melted fraction F	80%	2415		
W(100%)	0.21602447		0.21602772	
T (K) LAB	83.79758		83.79806	
T (K) NPL	83.79731		83.79729	
average drift (mK/h)	<3		5	
recovery time to 0.1mK (min)	1-3		1-3	
overheating at 50% (mK/mW)	0.26		1	
enthalpy of melting (J)	16.5		15	

Notes:


4ArASMW
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 3 AR BIPM



Manufacturer: BIPM

Sealing date: Feb 1977

cell total mass: 315 g

sample mass: 0.18 mol

Filling gas type: Air Liquide

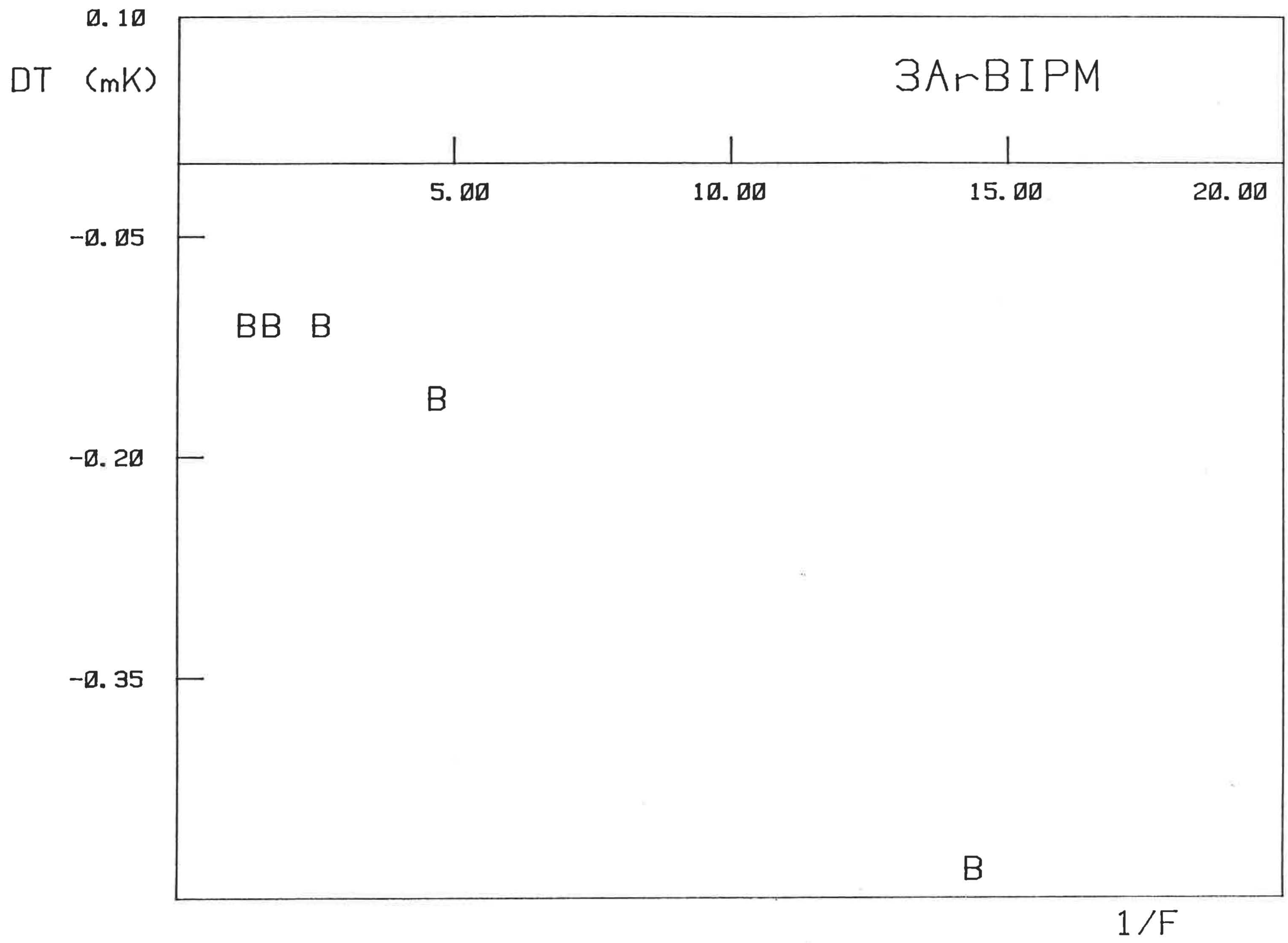
impurity analysis: nom. 99.9995%
nitrogen 3 vppm
oxygen <1
methane <0.5

Enthalpy of melting: 240 J

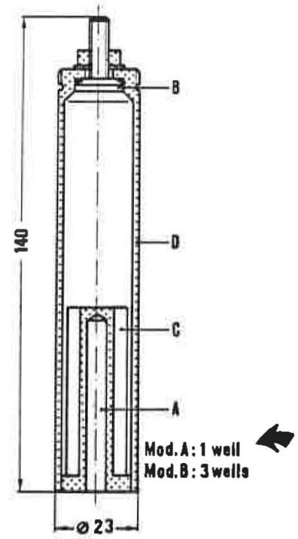
Resistance Ratio (W)

Measurements at	
LABORATORY	BIPM
Date	Feb 80
thermometer N°	226321
Ro (ohm)	25.369110
Typical melting plateau	6.7% 3714 21% 3852 38% 3872 62% 3872 80% 3872
melted fraction F	
W(100%)	0.21603920
T (K) LAB	ref
T (K) NPL	83.79670
average drift (mK/h)	-1.5
recovery time to 0.1mK (min)	2-100
overheating at 50% (mK/mW)	0.3
enthalpy of melting (J)	241

Notes:


0.10
DT (mK)
3ArBIPM
5.00
10.00
15.00
20.00
-0.05
-0.20
-0.35
BB B
B
B
1/F

C E L L   T Y P E: 1 AR IMGC



Manufacturer: IMGC

Sealing date: Jul 1975

cell total mass: 190 g

sample mass: 0.17 mol

Filling gas type: SIO-Air Liquide

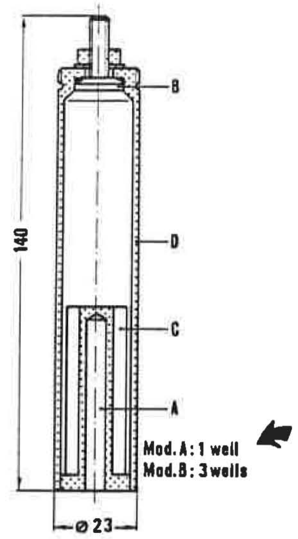
impurity analysis:	nom. 99.9997%	
nitrogen	a) 1.85 ;	b) 2.8 vppm
oxygen	0.95	0.5
carb.dioxide	<0.5	none
hydrocarbons		none

Enthalpy of melting: 195 J

Measurements at	Resistance Ratio (W)				
LABORATORY	ASMW	IMGC	NIM	NPL	NRC
Date	Nov 79	Sep 75-May 80	Feb 81	Jan 78	Dec 76
thermometer N°	217990	PL01-6	188640	1728839	1521389
Ro (ohm)	24.186290	25.271140	24.164330	25.559570	25.523332
	5.5% 0770	6 % 2528	12% 0312	4 % 0063	11% 7823
	9.5% 0810	10% 2551	23% 0346	6 % 0083	40% 7921
Typical	19% 0865	15% 2579	35 0321	23% 0171	80% 7960
melting	27% 0880	18% 2595	46% 1099*	29% 0183	92% 8003
plateau	37% 0880	23% 2603	58% 1182*	38% 0182	
	50% 0875	27% 2634	70% 1463*	46% 0187	
	63% 0880	32% 2662	81% 1641*	55% 0175	
melted	76% 0880	36% 2682		59% 0184	
fraction	91% 0890	44% 2694	* not used	64% 0196	
F		53% 2702		74% 0175	
		62% 6710		87% 0196	
W(100%)	0.21600890	0.21602745	0.21650500 (1)	0.21610195	0.21597964
T (K) LAB	83.79770	ref	83.79960	83.79690	83.79776
NPL	83.79745	83.79723		83.79690	83.79666
average drift (mK/h)	2	2	5		
recovery time (min)	2-10	2-3	2-25	<15	
overheating at 50% (mK/mW)	0.05	0.04	0.8		
enthalpy of melting (J)	197	195	190		

Notes: (1) 0.21652080 using all data (NIM).

C E L L T Y P E: 1 AR IMGC



Manufacturer: IMGC

Sealing date: Jul 1975

cell total mass: 190 g

sample mass: 0.17 mol

Filling gas type: SIO-Air Liquide

impurity analysis: nom. 99.9997%

nitrogen	a) 1.85	; b) 2.8 vppm
oxygen	0.95	0.5
carb.dioxide	<0.5	none
hydrocarbons		none

Enthalpy of melting: 195 J

Measurements at — Resistance Ratio (W)

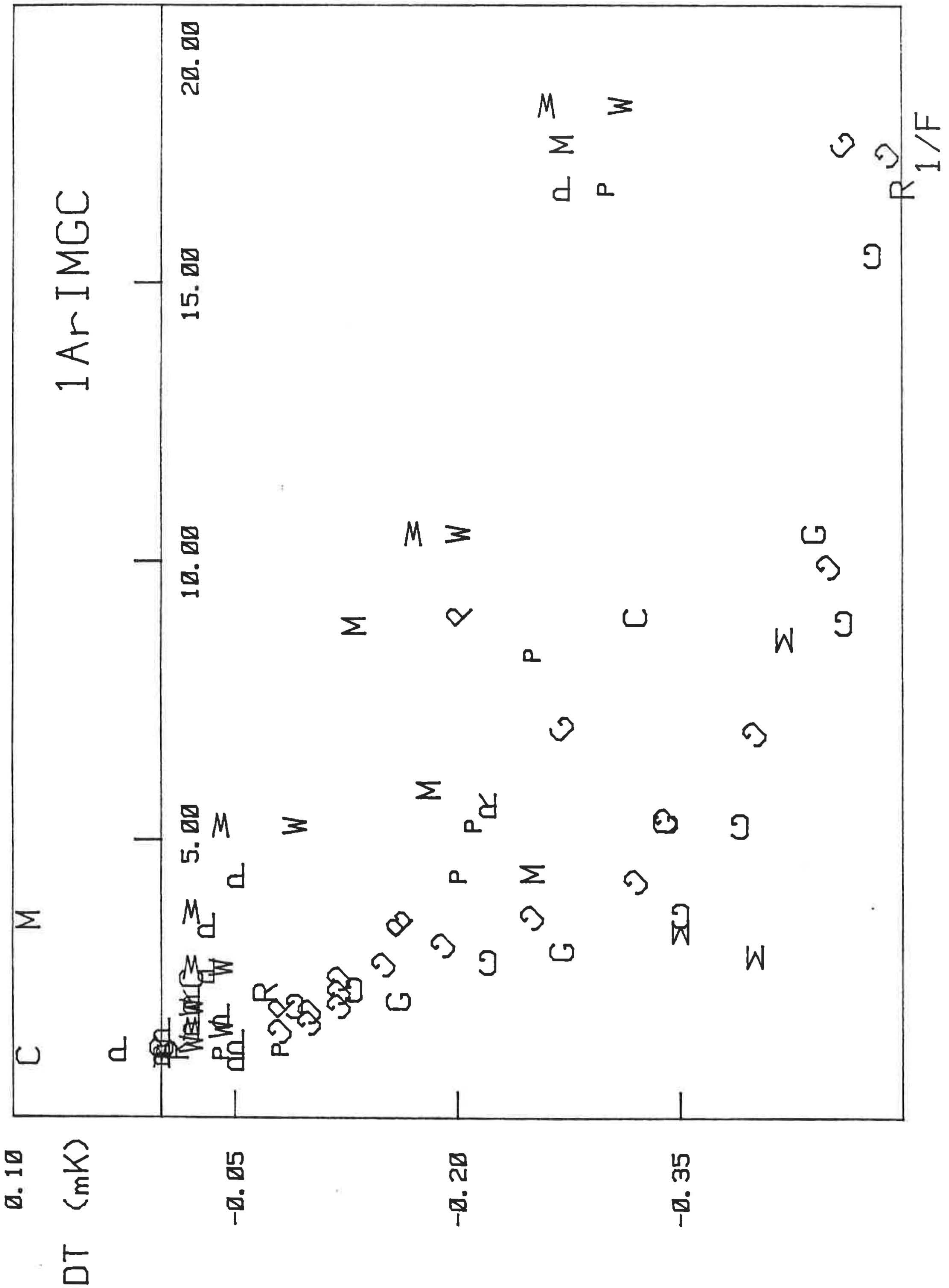
LABORATORY	NRLM
Date	Nov 81
thermometer N°	7681
Ro (ohm)	25.363254

Typical melting plateau

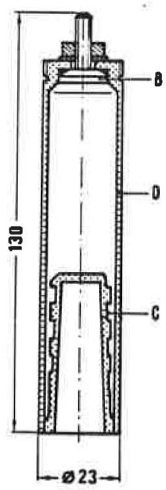
melted fraction F	
6 %	1174
18%	1290
44%	1362
48%	1380
79%	1384
83%	1386

W(100%)	0.21611388
T (K) LAB	83.79878
T (K) NPL	83.79828
average drift (mK/h)	2.5
recovery time to 0.1mK (min)	3-8
overheating at 50% (mK/mW)	
enthalpy of melting (J)	202

Notes:


1Ar-IMGC
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00
1/F

C E L L T Y P E: 2 AR IMGC



Manufacturer: IMGC

Sealing date: May 1978

cell total mass: 167.419 g (1)

sample mass: 0.08915 mol (1)

Filling gas type: SIO-Air Liquide

impurity analysis: nom. 99.9997%

	a)	b)
nitrogen	1.9 ;	2.4 vppm
oxygen	1.0	0.2
carb.dioxide	<0.5	none
hydrocarbons	none	

Enthalpy of melting: 106 J

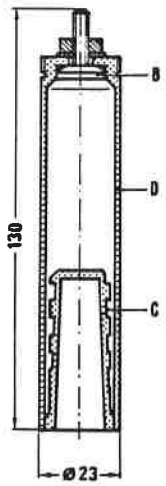
Measurements at — Resistance Ratio (W)

LABORATORY	BIPM		IMGC		INM		NBS		NML	
Date	Dec 79		May 78-May 80		Apr 80		Aug 79		May 79	
thermometer N°	226321		PL01-6		232788		1774095		1731676	
Ro (ohm)	25.369005		25.271140		25.087300		25.560840		25.522800	
	7 %	3685	8 %	2607	10%	3297	13%	4819	2.5%	0126
	26%	3863	12%	2627	20%	3333	28%	4883	12%	0149
Typical	48%	3882	20%	2647	30%	3349	44%	4918	19%	0152
melting	67%	3969	29%	2663	40%	3361	60%	4931	22%	0162
plateau	90%	3980	36%	2679	50%	3369	75%	4946	27%	0170
			50%	2702	60%	3381	91%	4980	44%	0192
			59%	2710	70%	3401			65%	0198
melted			74%	2734	80%	3429			80%	0198
fraction F					90%	3461			95%	0198
W(100%)	0.21603980		0.21602738		0.21603380		0.21604960		0.21610195	
T (K) LAB	83.79814		83.79798		83.79805		83.80030		83.79670	
T (K) NPL	83.79680		83.79722		83.79732		83.79700		83.79698	

	BIPM	IMGC	INM	NBS	NML
average drift (mK/h)	1	10			
recovery time to 0.1mK (min)	15	5	60	40-60	
overheating at 50% (mK/mW)	5 (2)	0.02	24 (2)		
enthalpy of melting (J)	115	104		106	

Notes: (1) this cell was returned to IMGC without sealing nut in May 1980, with no apparent contamination of the sample.
(2) cell heated from inside the block.

C E L L   T Y P E: 2 AR IMGC



Manufacturer: IMGC

Sealing date: May 1978

cell total mass: 167.419 g (1)

sample mass: 0.08915 mol (1)

Filling gas type: SIO-Air Liquide

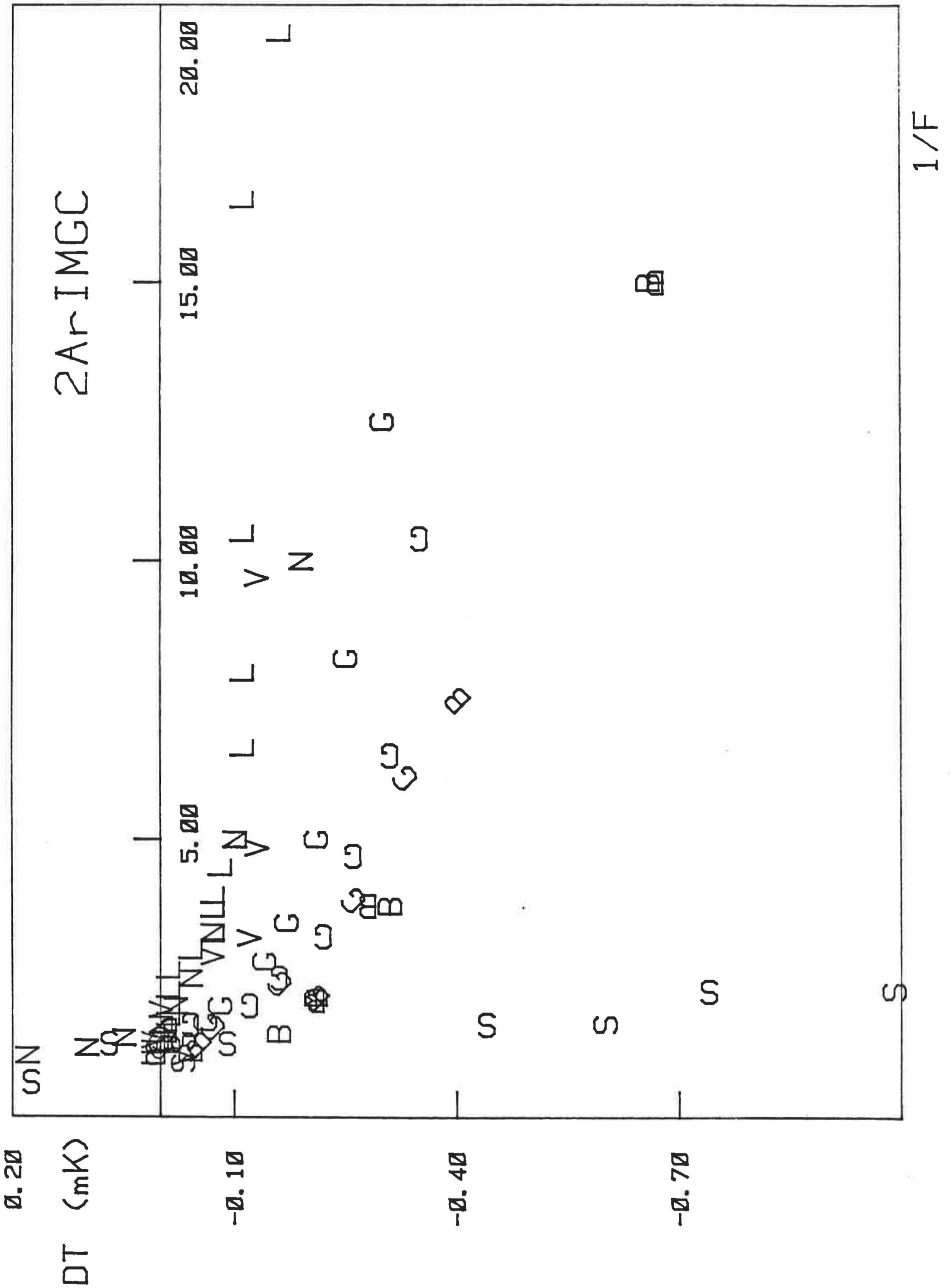
impurity analysis: nom. 99.9997%

oxygen	a) 1.9	b) 2.4
nitrogen	1.0	0.2
carb.dioxide	<0.5	none
hydrocarbons	none	

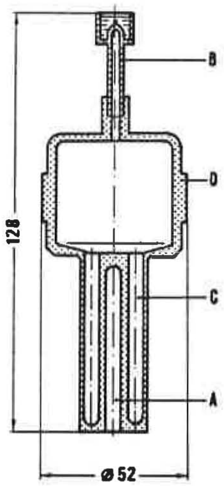
Enthalpy of melting: 106 J

Measurements at	Resistance Ratio (W)	
LABORATORY	PRMI	
Date	Dec 81	
thermometer N°	1842381	
Ro (ohm)	25.544950	
Typical melting plateau / melted fraction F	10%	9262
	21%	9264
	31%	9269
	41%	9292
	52%	9321
	72%	9325
	93%	9308
W(100%)	0.21589320	
T (K) LAB		
T (K) NPL	83.79693 (2)	
average drift (mK/h)	<1	
recovery time to 0.1mK (min)	20	
overheating at 50% (mK/mW)	0.06	
enthalpy of melting (J)	98.8	

Notes: (1) this cell was returned to IMGC without sealing nut in May 80, with no apparent contamination of the sample.
(2) through ASMW thermometer.


2ArIMGC
1/F
DT (mK)
0.20
-0.10
-0.40
-0.70
5.00
10.00
15.00
20.00

C E L L T Y P E: 1 AR INM



Manufacturer: INM

Sealing date: Sep 1975

cell total mass: 265 g

sample mass: 0.268 mol

Filling gas type: Air Liquide

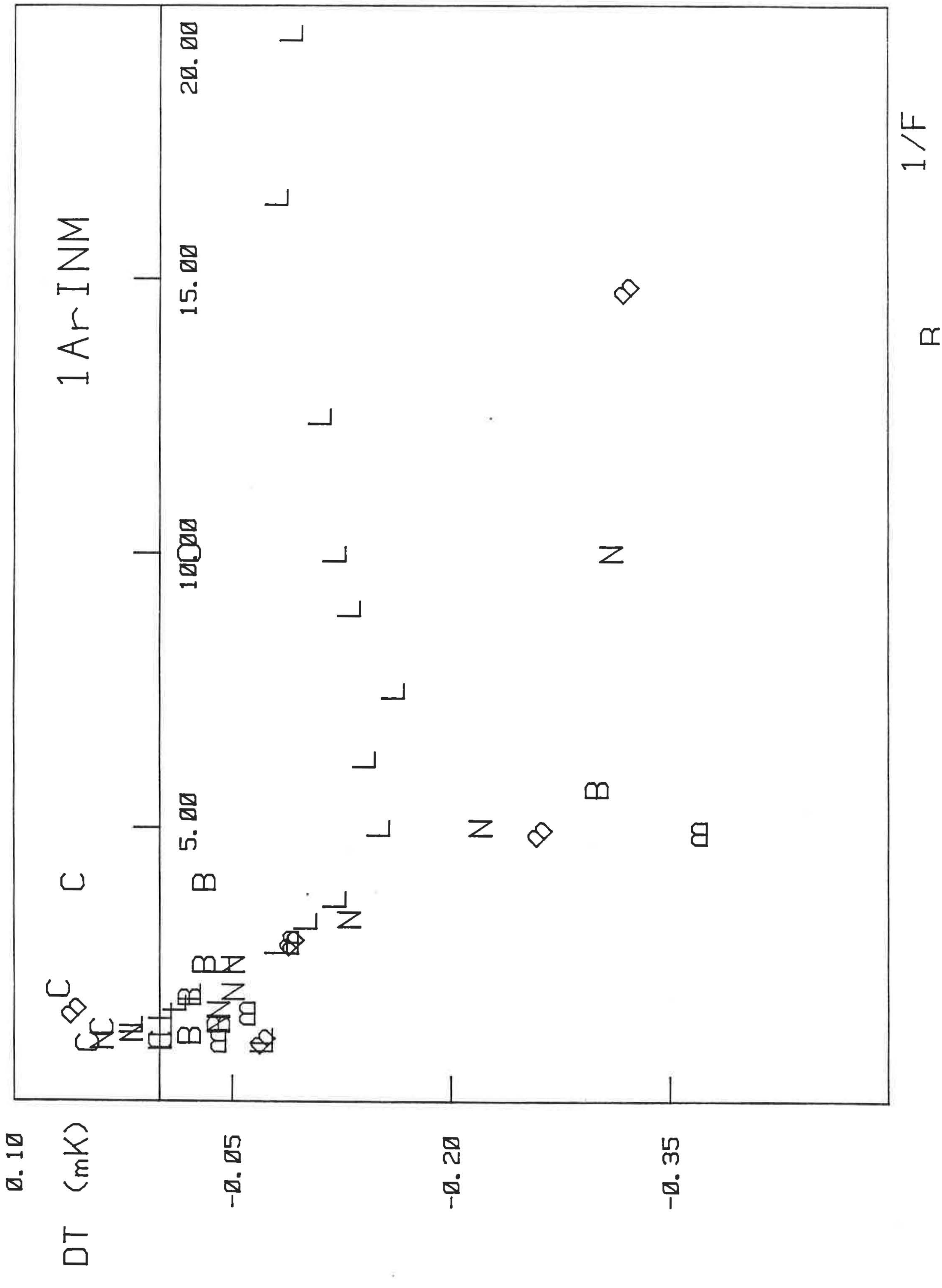
impurity analysis: nom. 99.9995%
oxygen <1 vppm
nitrogen 3
hydrocarbons <0.5
carbon oxide <0.5

Enthalpy of melting: 276 J

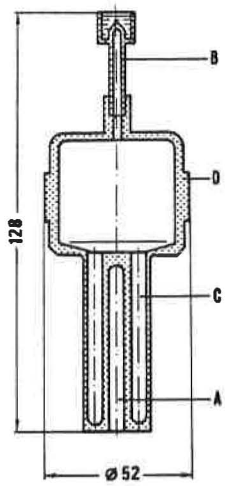
Measurements at — Resistance Ratio (W)

LABORATORY	BIPM		INM		NML		NRC	
Date	Nov 79		Apr 80		May 79		Dec 76	
thermometer N°	226321		232788		1731676		1521389	
Ro (ohm)	25.368966		25.087300		25.522800		25.523332	
Typical melting plateau	7 %	3450	10%	3341	5 %	0329	3 %	7940
	20%	3837	20%	3345	10%	0317	10%	7979
	34%	3955	30%	3349	16%	0305	25%	7979
	67%	3971	40%	3353	30%	0321	49%	7991
	90%	3979	50%	3353	40%	0344	74%	8042
			60%	3353	50%	0364	89%	8026
			70%	3353	65%	0372	94%	8050
melted fraction F			80%	3365	75%	0364		
			90%	3373	85%	0337		
W(100%)	0.21603990		0.21603355		0.21610340		0.21598038	
T (K) LAB	83.79817		ref		83.79710		83.79793	
NPL	83.79690		83.79727		83.797362		83.79683	
average drift (mK/h)	<1		<2					
recovery time to 0.1mK (min)	22		10-20					
overheating at 50% (mK/mW)	1.8		2.7					
enthalpy of melting (J)	162		276				301	

Notes:


1Ar-INM
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00
1/F
R

C E L L T Y P E: XXI AR INM



Manufacturer: INM

Sealing date: Dec 1978

cell total mass: 284.36 g

sample mass: 0.130 mol

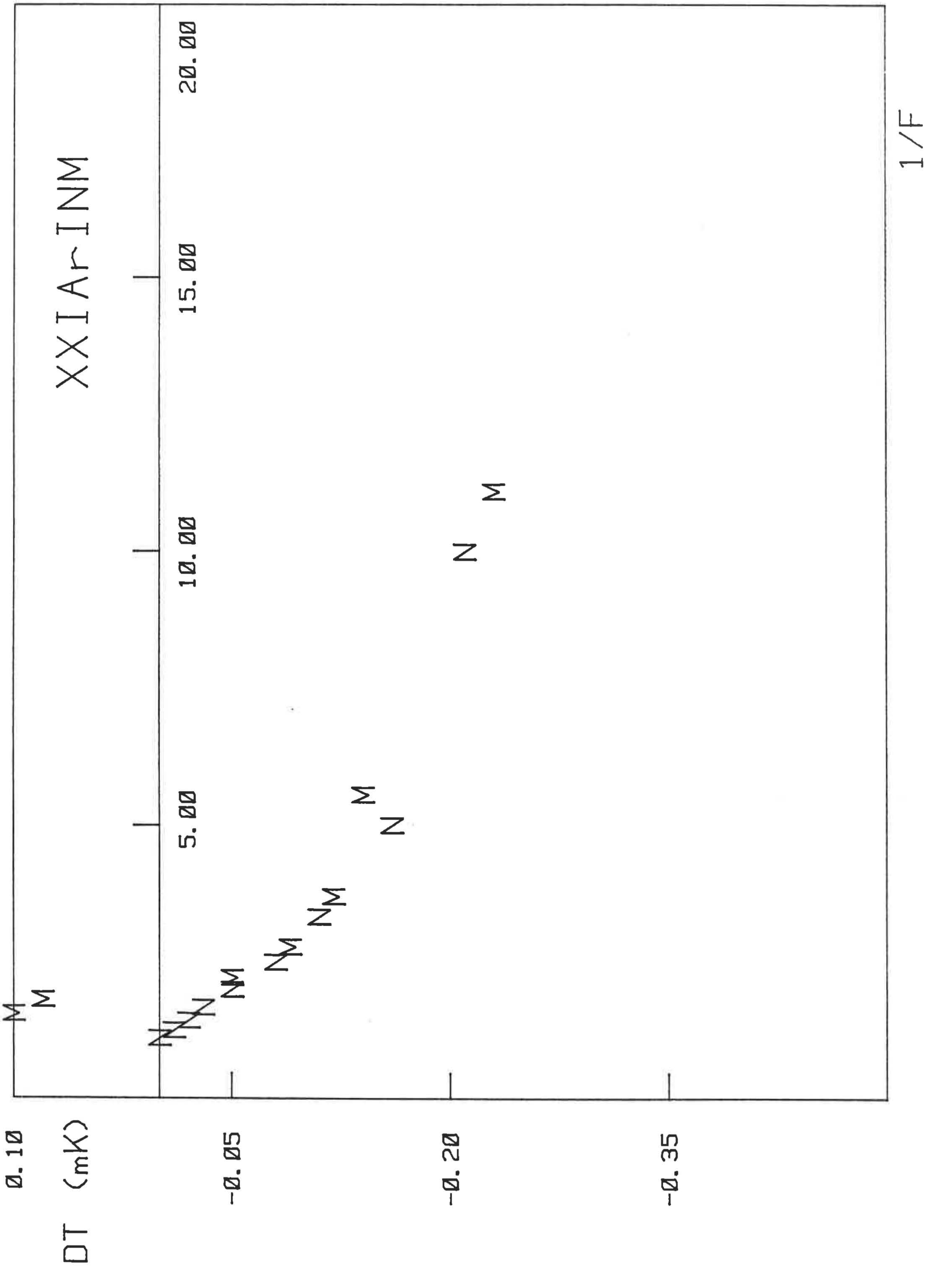
Filling gas type:

impurity analysis:
oxygen <1 vppm
nitrogen <3
methane <0.5
carbon oxide <0.5

Enthalpy of melting: 160 J

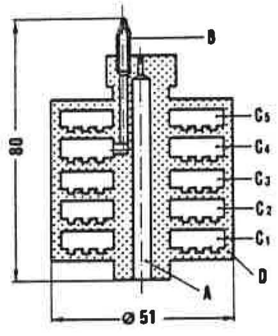
Measurements at	Resistance Ratio (W)			
LABORATORY	INM		NIM	
Date	Jan 79		Aug 81	
thermometer N°	1812283		7703	
Ro (ohm)	25.494778		24.899378	
	0 %	6234	9 %	4668
	10%	6253	18%	4701
Typical	20%	6273	27%	4709
melting	30%	6297	36%	4721
plateau	40%	6309	45%	4737
	50%	6321	55%	4798
	60%	6329	64%	4821
melted	70%	6333	73%	4829
fraction	80%	6340	82%	4841
F	90%	6344	91%	4845
W(100%)	0.21596344		0.21614760	
T (K) LAB	83.79802			
NPL	83.79729			
average drift (mK/h)	<2		<10	
recovery time to 0.1mK (min)	6		1-3	
overheating at 50% (mK/mW)			0.2	
enthalpy of melting (J)	160		120	

Notes:



XXIAr-INM
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: BCM4 INM (Ar)



INM mod. BCM

Manufacturer: INM
Multicomponent cell
(argon,oxygen,neon,nitrogen)

Sealing date: Jan 1982

cell total mass: 369.83 g

sample mass: 0.0218 mol

Filling gas type:

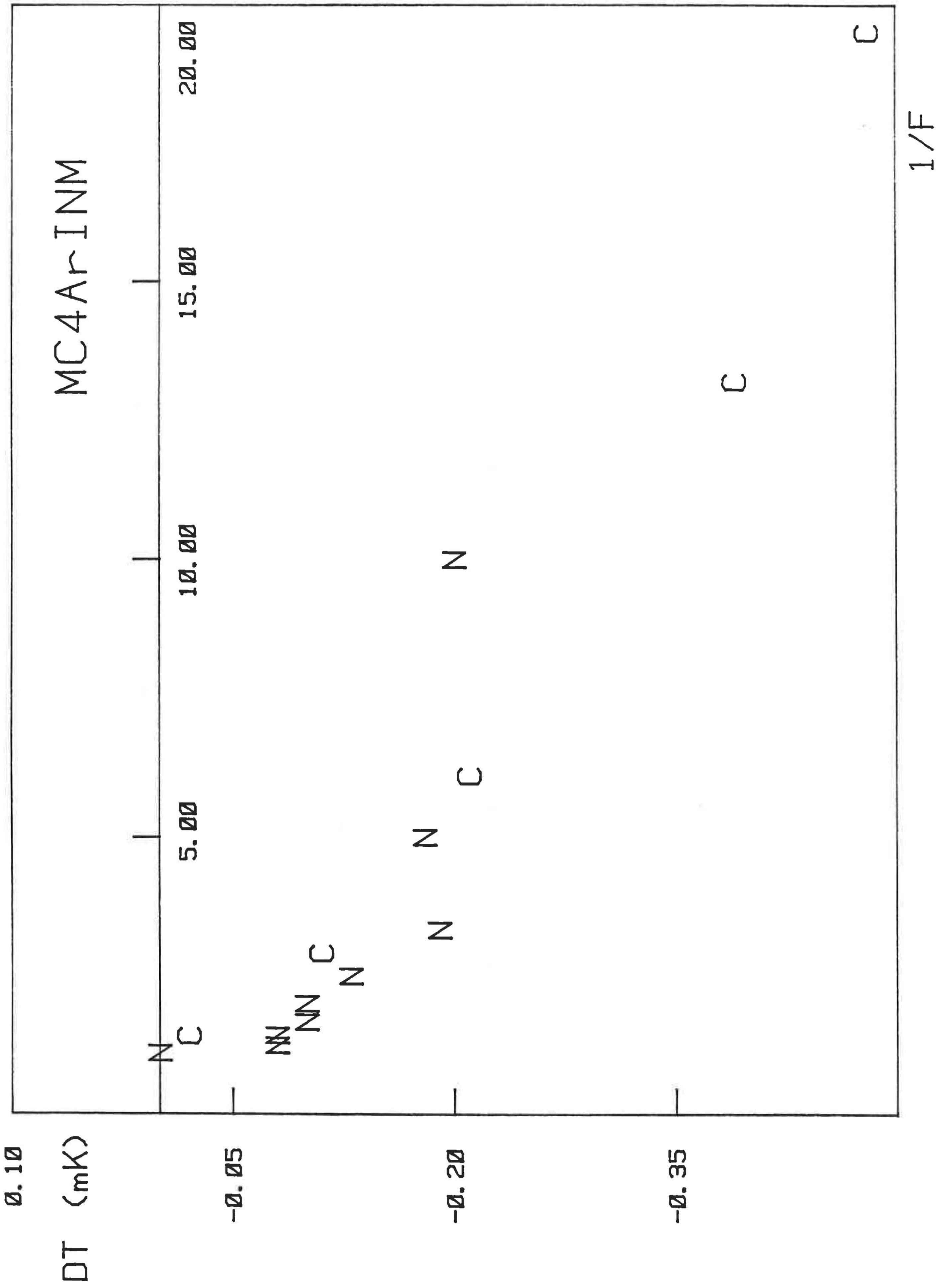
impurity analysis:

oxygen	0.2 vppm
nitrogen	0.5
methane	0.1
water	0.5

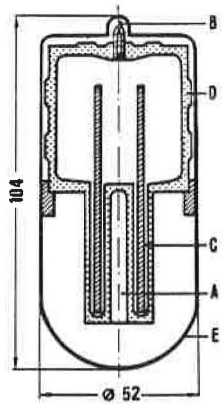
Enthalpy of melting: 25.7 J

Measurements at	Resistance Ratio (W)			
LABORATORY	INM		NRC	
Date	Feb 82		Jul 82	
thermometer N°	1812283		1521389	
Ro (ohm)	25.494713		25.523332	
Typical melting plateau	0 %	6258	3.1%	7867
	10%	6316	7.6%	7907
	20%	6328	16%	7987
	30%	6324	34%	8027
	40%	6348	70%	8067
	50%	6360		
melted fraction F	60%	6360		
	70%	6369		
	80%	6369		
	90%	6405		
W(100%)	0.21596405		0.21598077	
T (K) LAB	83.79816		83.79802	
T (K) NPL	83.79743		83.79695	
average drift (mK/h)	3			
recovery time to 0.1mK (min)	8.5		30	
overheating at 50% (mK/mW)				
enthalpy of melting (J)	25.7		26.8	

Notes:


MC4Ar-INM
1/F
5.00
10.00
15.00
20.00
DT (mK)
0.10
-0.05
-0.20
-0.35

C E L L T Y P E: M1 AR NBS



NBS (Ar)

Manufacturer: NBS

Sealing date: Feb 1978

cell total mass: 357 g

sample mass: 0.21 mol

Filling gas type:

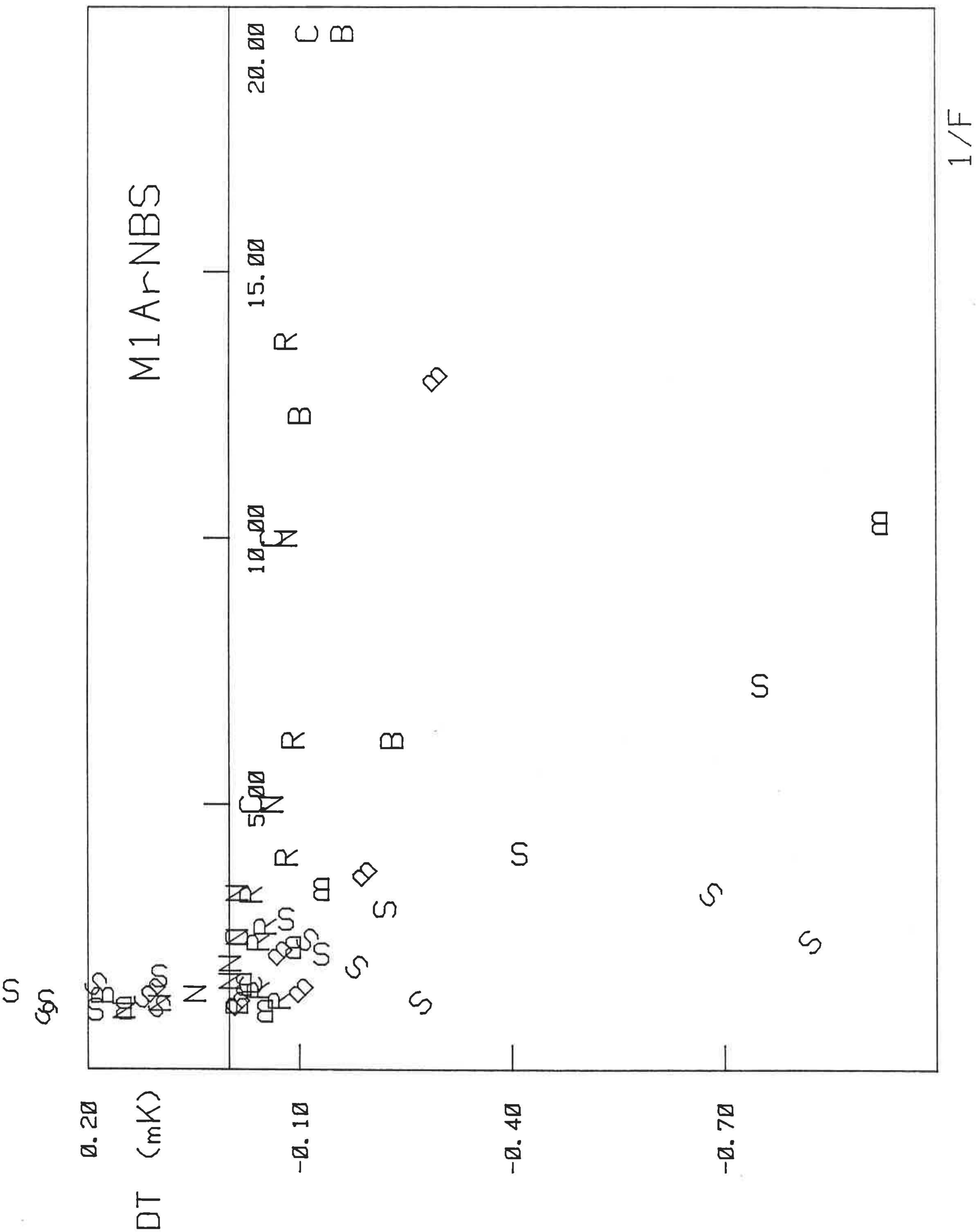
impurity analysis: nom. 99.9999%

Enthalpy of melting: 250 J

Measurements at — Resistance Ratio (W)

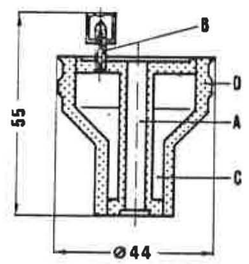
LABORATORY	BIPM		INM		NBS		NRC		NRLM	
Date	Feb 80		Apr 80		Feb 79		Aug 79		May 82	
thermometer N°	226321		232788		1774095		1521389		1781356	
Ro (ohm)	25.369062		25.087300		25.560840		25.523332		25.525818	
Typical melting plateau	8 %	3952	10%	3361	3.1%	4908	5 %	7912	7.3%	9594
	27%	3991	20%	3369	14%	4924	10%	7936	16%	9661
	45%	4039	30%	3393	24%	4939	20%	7947	25%	9665
	67%	4031	40%	3393	35%	4953	41%	7959	30%	9688
	90%	4070	50%	3393	46%	4951	60%	7947	37%	9676
			60%	3393	57%	4961			42%	9684
			70%	3417	67%	4971			67%	9665
melted fraction F			80%	3445	78%	4968			77%	9696
			90%	3461	89%	4965				
W(100%)	0.21604070		0.21603395		0.21604965		0.21597961		0.21599700	
T (K) LAB	83.79834		83.79809		83.80032		83.79775		83.79885	
T (K) NPL	83.79700		83.79736		83.79700		83.79665		83.79835	
average drift (mK/h)	0.4								0.1	
recovery time to 0.1mK (min)	30		1-6						30-180	
overheating at 50% (mK/mW)	1		0.1							
enthalpy of melting (J)	222				250		255		253	

Notes:


M1Ar-NBS
1/F
5.00
10.00
15.00
20.00
DT (mK)
0.20
-0.10
-0.40
-0.70

C E L L T Y P E: 113 AR NIM

International Intercomparison
CCT: 1979-1983



NIM

Manufacturer: NIM

Sealing date: Dec 1980

cell total mass: 193 g

sample mass: 0.06 mol

Filling gas type:

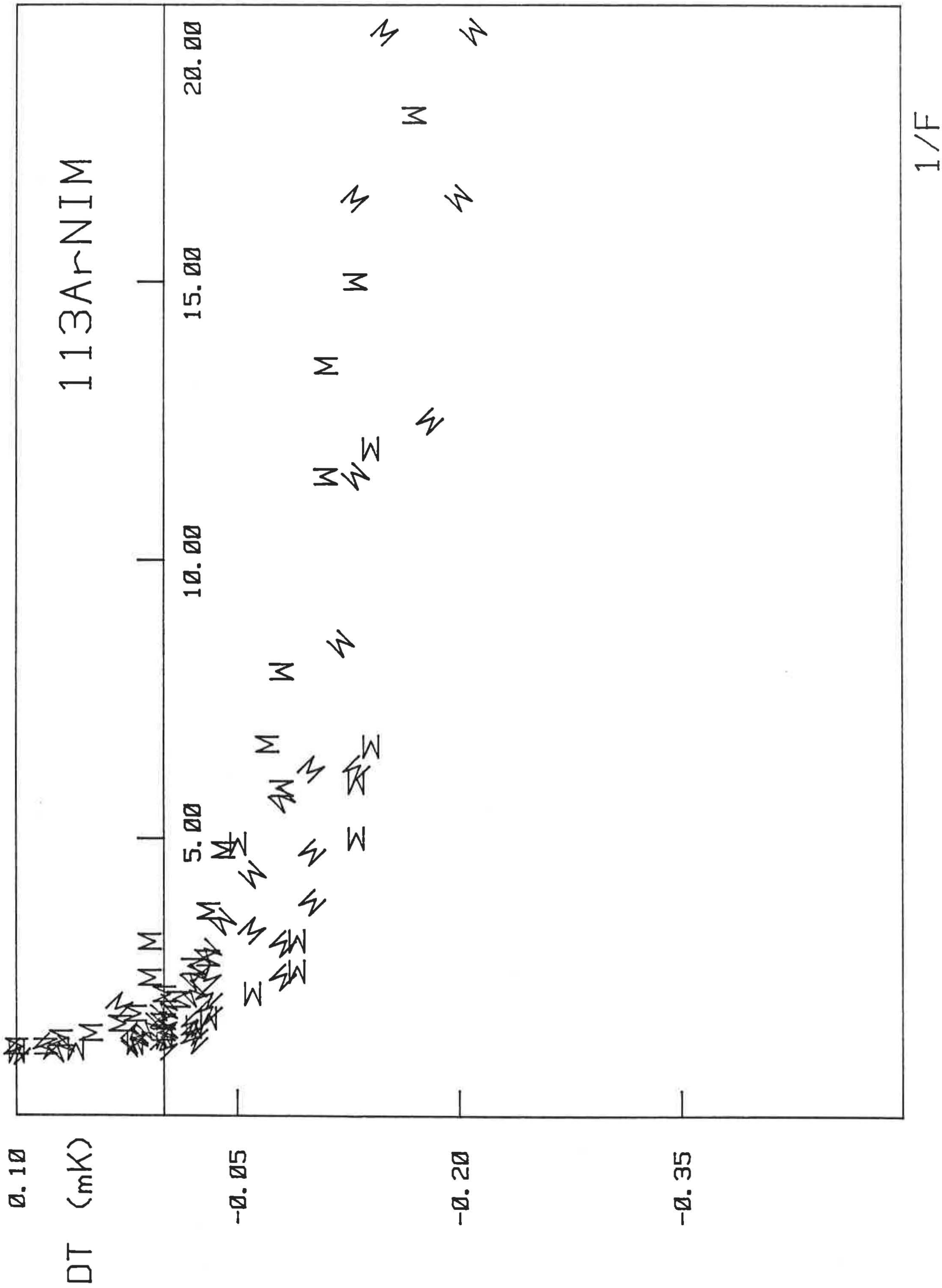
impurity analysis:
nitrogen 4 vppm
oxygen 1
carb.diox.<1
hydrocarb.<1 ; hydrogen <1

Enthalpy of melting: 57 J

Measurements at — Resistance Ratio (W)

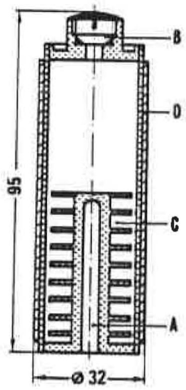
LABORATORY	NIM	
Date	Aug 81	
thermometer N°	7703	
Ro (ohm)	24.899378	
Typical melting plateau — melted fraction F	5%	4661
	10%	4685
	19%	4705
	30%	4721
	48%	4737
	60%	4745
	71%	4753
	82%	4757
	88%	4761
W(100%)	0.21614755	
T (K) LAB		
NPL		
average drift (mK/h)	<10	
recovery time to 0.1mK (min)	1-3	
overheating at 50% (mK/mW)	0.15	
enthalpy of melting (J)	57	

Notes:


113Ar-NIM
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L   T Y P E: 10 AR NRC

Manufacturer: NRC



NRC

Sealing date: May 1979

cell total mass: 200 g

sample mass: 0.05943 mol

Filling gas type: Matheson

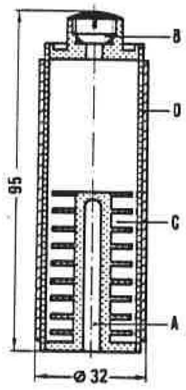
impurity analysis: research grade

Enthalpy of melting: 70 J

Measurements at	Resistance Ratio (W)									
LABORATORY	BIPM		IMGC		INM		NBS		NML	
Date	Mar 80		Apr 80		Apr 80		Feb 81		Nov 79	
thermometer N°	226321		PL01-6		232788		1774095		1731676	
Ro (ohm)	25.369098		25.271140		25.087300		25.560840		25.522800	
	4.5%	3850	10%	2745	10%	3218	6.5%	4868	5 %	0246
	14%	3992	15%	2773	20%	3301	18%	4926	10%	0297
Typical	24%	4044	19%	2785	30%	3313	32%	4935	15%	0321
melting	90%	3969	24%	2793	40%	3317	50%	4952	20%	0323
plateau			27%	2795	50%	3321	58%	4955	30%	0340
			31%	2797	60%	3325	72%	4954	40%	0344
			42%	2793	70%	3329	85%	4955	50%	0352
melted			55%	2795	80%	3337	98%	4953	70%	0359
fraction			62%	2797	90%	3345			75%	0376
F			85%	2808					80%	0399
W(100%)	0.21604000		0.21602805		0.21603335		0.21604955		0.21610370	
T (K) LAB	83.79818		83.79814		83.79795		83.80028		83.79717	
NPL	83.79690		83.79736		83.79722		83.79696		83.79739	
average drift (mK/h)	0.4		1							
recovery time to 0.1mK (min)	1		1-2		0.5-5					
overheating at 50% (mK/mW)	0.13		0.35		0.25					
enthalpy of melting (J)	81		65				70			

Notes:

C E L L T Y P E: 10 AR NRC



NRC

Manufacturer: NRC

Sealing date: May 1979

cell total mass: 200 g

sample mass: 0.05943 mol

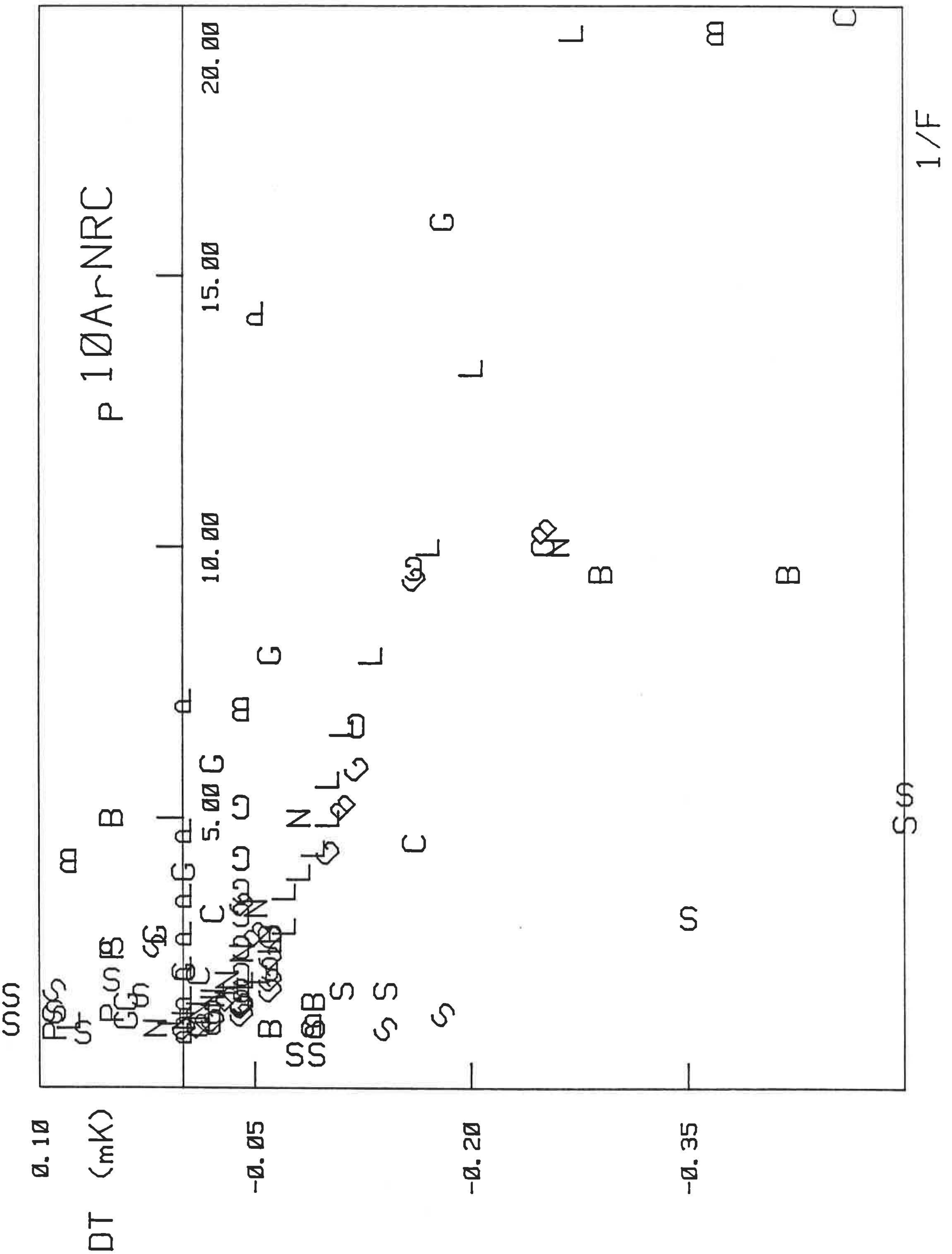
Filling gas type: Matheson

impurity analysis: research grade

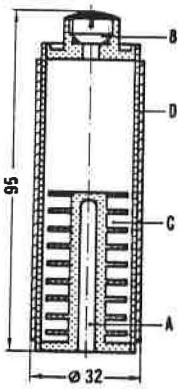
Enthalpy of melting: 70 J

Measurements at	Resistance Ratio (W)			
LABORATORY	NPL		NRC	
Date	Nov 81		Jun 79	
thermometer N°	1728839		1521389	
Ro (ohm)	25.559570		25.523332	
	7 %	0190	5 %	7779
	14%	0210	10%	7873
Typical	21%	0210	22%	7912
melting	28	0208	31%	7947
plateau	35%	0210	48%	7959
	45%	0210	74%	7959
	60%	0210	90%	7959
melted	76%	0210		
fraction	97%	0210		
F				
W(100%)	0.21610210		0.21597959	
T (K) LAB	83.79695		83.79775	
NPL	83.79695		83.79665	
average drift (mK/h)	0.3		6	
recovery time to 0.1mK (min)	5			
overheating at 50% (mK/mW)				
enthalpy of melting (J)			70	

Notes:


P 10Ar-NRC
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 14 AR NRC



NRC

<u>Manufacturer:</u> NRC

<u>Sealing date:</u> May 1979

cell total mass: 228 g

sample mass:

<u>Filling gas type:</u> Matheson

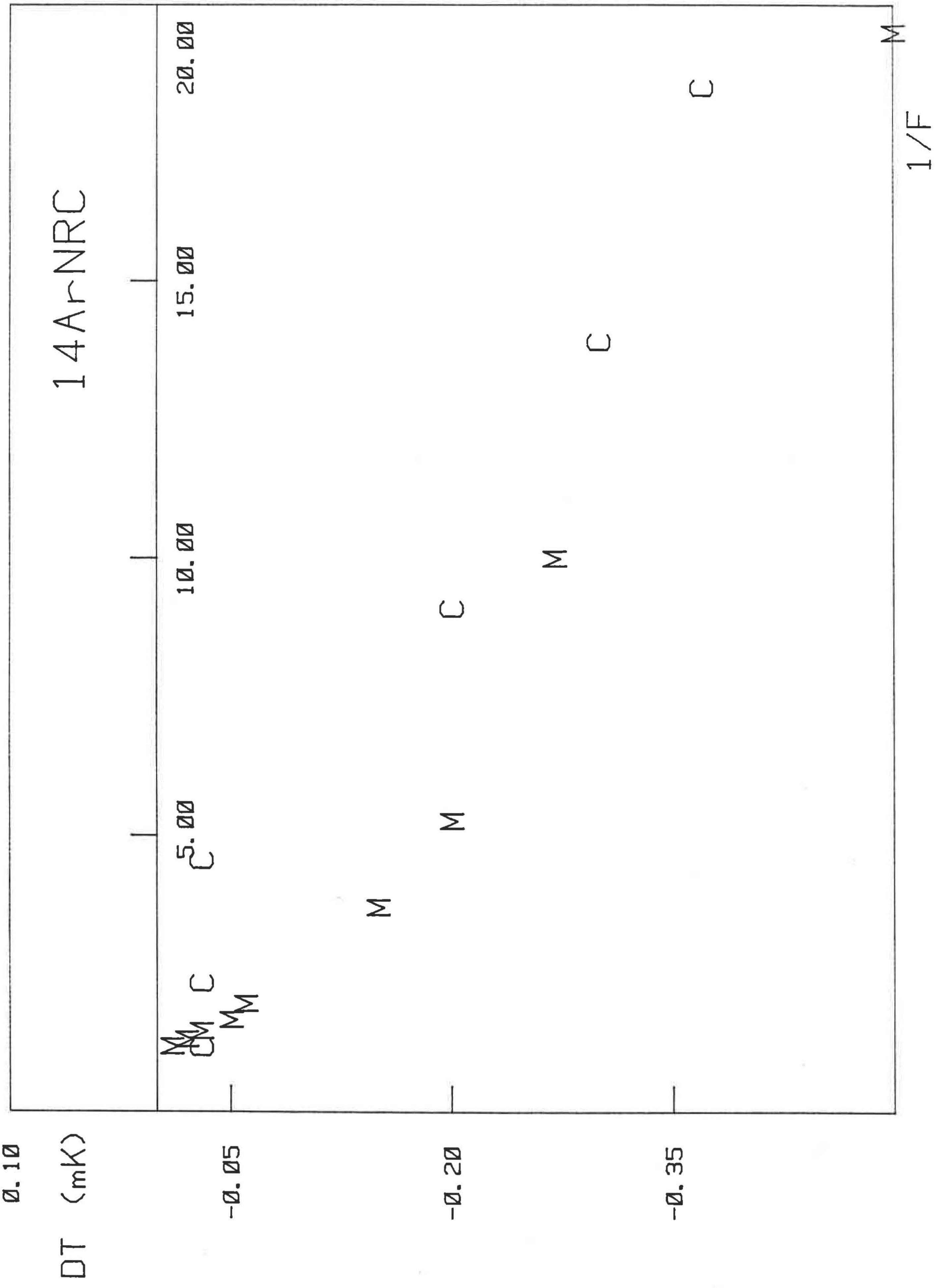
impurity analysis: research grade

<u>Enthalpy of melting:</u> 72 J

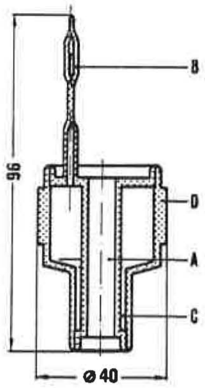
Measurements at — Resistance Ratio (W)

LABORATORY	NIM		NRC	
Date	Aug 81		Jul 80	
thermometer N°	7703		1521389	
Ro (ohm)	24.899378		25.523332	
Typical melting plateau	5 %	4617	2.7%	7751
	10%	4713	3.6%	7786
	19%	4738	5.4%	7822
	27%	4758	7.2%	7849
	51%	4797	11%	7896
	60%	4801	22%	7970
	68%	4809	43%	7970
melted fraction F	76%	4814	86%	7970
	84%	4814		
W(100%)	0.21614820		0.21597970	
T (K) LAB			83.79775	
T (K) NPL			83.79665	
average drift (mK/h)	<10			
recovery time to 0.1mK (min)	1-2		<16	
overheating at 50% (mK/mW)	0.3			
enthalpy of melting (J)	63		71.5	

Notes:


14Ar-NRC
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 7801 AR NRLM



NRLM

Manufacturer: NRLM

Sealing date: Jun 1978

cell total mass: 170 g

sample mass: 0.063 mol

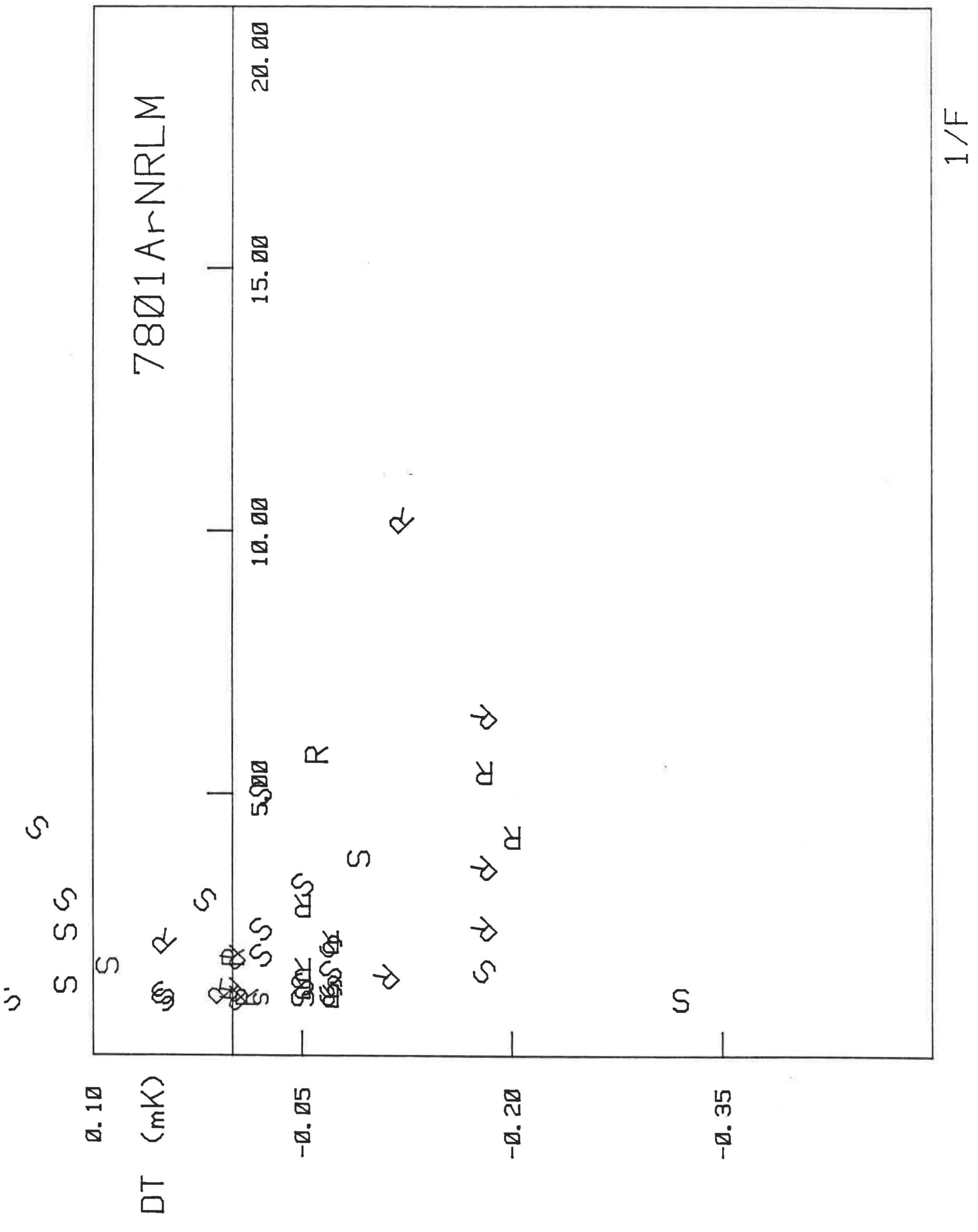
Filling gas type:

impurity analysis: tot. 0.8 ppm

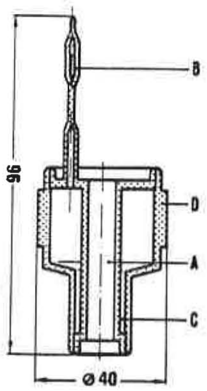
Enthalpy of melting: 74.6 J

Measurements at	Resistance Ratio (W)			
LABORATORY	NBS		NRLM	
Date	Jul 81		Jul 78	
thermometer N°	1774095		(1)	
Ro (ohm)	25.560840			
Typical melting plateau	5.6%	4829	16%	6210
	20%	4959	28%	6210
	31%	4958	41%	6220
	41%	4959	54%	6280
	52%	4952	67%	6240
	63%	4957	81%	6280
	74%	4958	93%	6280
melted fraction F	84%	4962		
	95%	4967		
W(100%)	0.21604960		0.21606270	
T (K) LAB	83.80030			
T (K) NPL	83.79698			
average drift (mK/h)				
recovery time to 0.1mK (min)				
overheating at 50% (mK/mW)				
enthalpy of melting (J)	75		74.6	

Notes: (1) 1978 data are reported only for record.


7801Ar-NRLM
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.000
10.00
15.00
20.00

C E L L T Y P E: 7803 AR NRLM



NRLM

Manufacturer: NRLM

Sealing date: Jun 1978

cell total mass: 170 g

sample mass: 0.06 mol

Filling gas type:

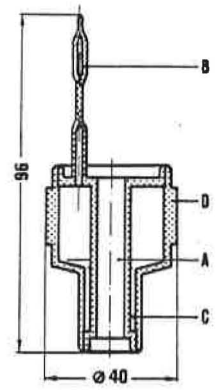
impurity analysis: tot. 0.8 ppm

Enthalpy of melting: 67 J

Measurements at	Resistance Ratio (W)									
LABORATORY	ASMW		BIPM		IMGC		INM		NML	
Date	Nov 80		Dec 79		Sep 80		Apr 80		Jul 79	
thermometer N°	217997		226321		PL01-6		232788		1731676	
Ro (ohm)	25.418540		25.368956		25.271140		25.087300		25.522800	
Typical melting plateau	10%	0210	9 %	3893	5 %	2690	10%	3297	5 %	0325
	30%	0281	27%	3900	8 %	2725	20%	3313	10%	0333
	50%	0320	45%	3963	12%	2757	30%	3329	15%	0356
	70%	0352	67%	4023	17%	2773	40%	3361	20%	0364
	80%	0352	90%	3987	21%	2785	50%	3389	30%	0395
	90%	0332			25%	2797	60%	3389	40%	0431
	95%	0360			31%	2801	70%	3389	50%	0446
melted fraction F	98%	0340			45%	2824	80%	3389	65%	0454
					67%	2836	90%	3401	75%	0474
									90%	0501
W(100%)	0.21600360		0.21604000		0.21602825		0.21603400		0.21610510	
T (K) LAB	83.79760		83.79818		83.79817		83.79811		83.79730	
T (K) NPL	83.79735		83.79690		83.79739		83.79738		83.79760	
average drift (mK/h)	2.5		1		5					
recovery time to 0.1mK (min)			2		1		2-23			
overheating at 50% (mK/mW)	0.4		0.6		0.1-0.5		0.8			
enthalpy of melting (J)	55.4		63		60					

Notes:

C E L L T Y P E: 7803 AR NRLM



NRLM

Manufacturer: NRLM

Sealing date: Jun 1978

cell total mass: 170 g

sample mass: 0.06 mol

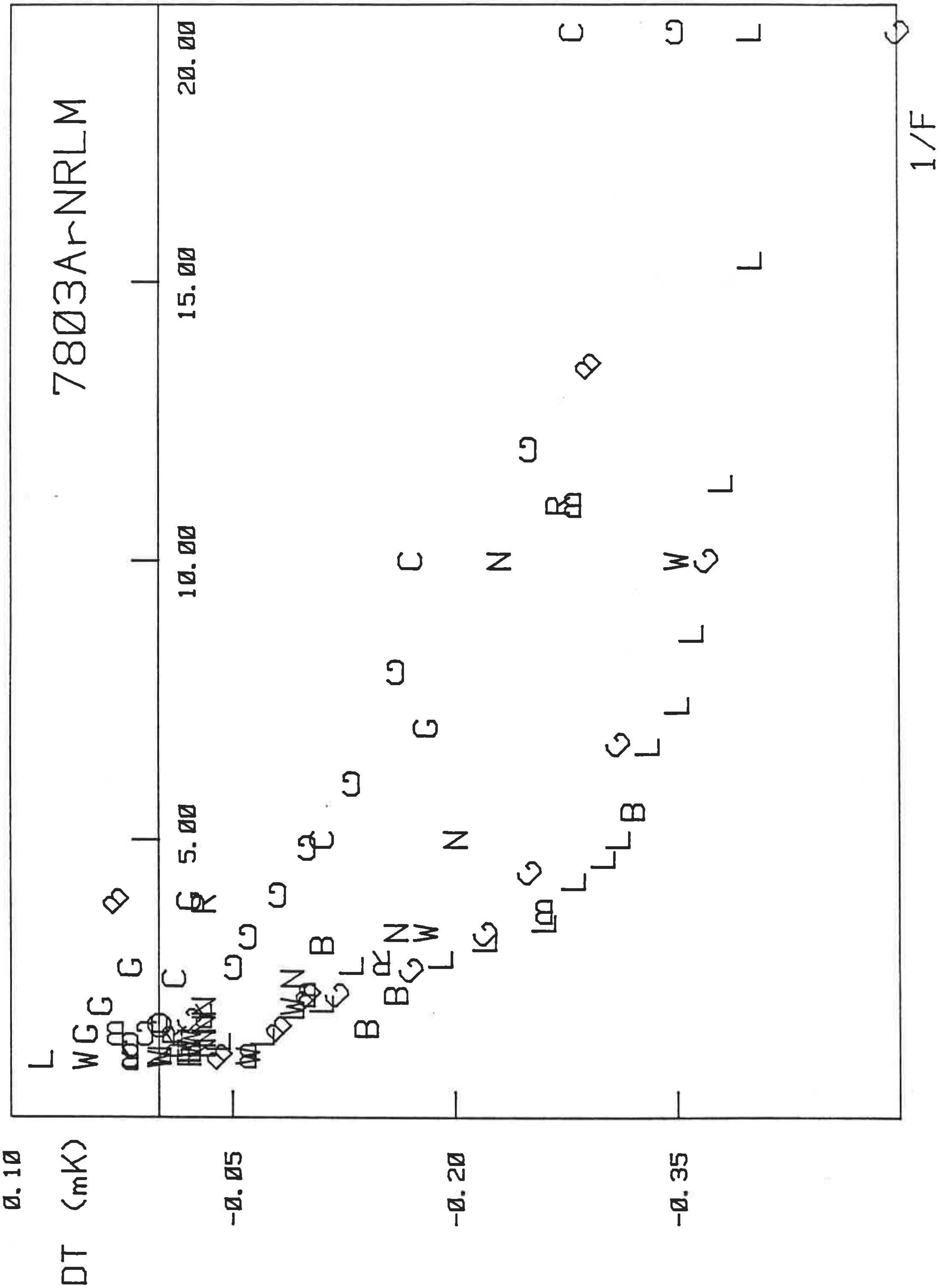
Filling gas type:

impurity analysis: tot. 0.8 ppm

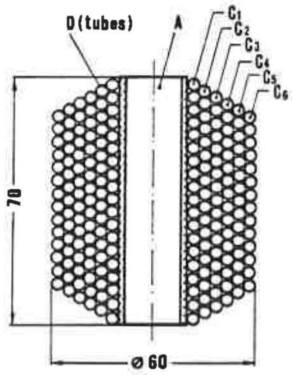
Enthalpy of melting: 67 J

Measurements at	Resistance Ratio (W)					
LABORATORY	NRC		NRLM		NRLM	
Date	May 79		Oct 78		Nov 81	
thermometer N°	1521389		(1)		7681	
Ro (ohm)	25.523332				25.362937	
Typical melting plateau	5 %	7838	9 %	6170	9.8%	1305
	10%	7885	27%	6230	17%	1354
	20%	7912	36%	6220	46%	1377
	40%	7959	56%	6280	53%	1379
	60%	7959	68%	6290	82%	1359
	80%	7955	77%	6300	89%	1377
melted fraction F			91%	6270		
			94%	6310		
W(100%)	0.21597961		0.21606280		0.21611377	
T (K) LAB	83.79775				83.79875	
T (K) NPL	83.79665				83.79825	
average drift (mK/h)						
recovery time to 0.1mK (min)	8					
overheating at 50% (mK/mW)						
enthalpy of melting (J)	64		66.7			

Notes: (1) 1978 data are reported only for record.


7803Ar-NRLM
DT (mK)
0.10
-0.05
-0.20
-0.35
1/F
5.00
10.00
15.00
20.00

C E L L T Y P E: PRMI (Ar)



PRMI

Manufacturer: PRMI
Multicomponent cell
(argon,oxygen,neon,hydrogen)

Sealing date: Dec 1978

cell total mass:

sample mass:

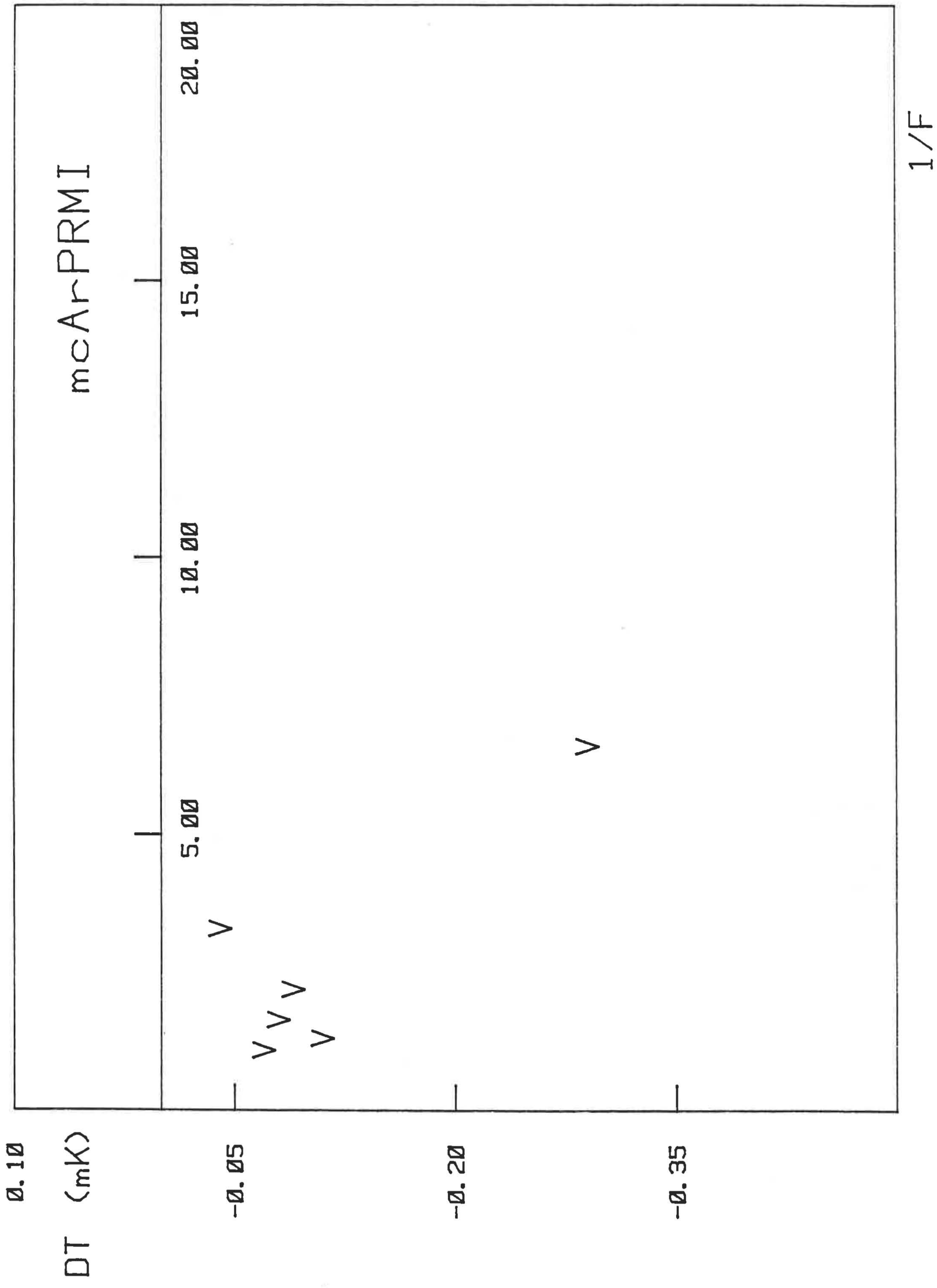
Filling gas type:

impurity analysis:
nitrogen <10 vppm
oxygen < 2
carb.dioxi.< 3

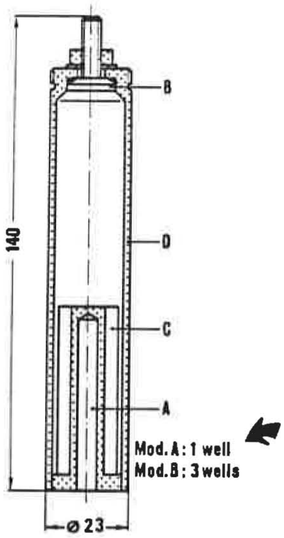
Enthalpy of melting: 102.5 J

Measurements at	Resistance Ratio (W)	
LABORATORY	PRMI	
Date	Nov 81	
thermometer N°	1842381	
Ro (ohm)	25.544950	
Typical melting plateau	15%	9169
	30%	9277
	45%	9254
	61%	9258
	76%	9248
	91%	9263
melted fraction F		
W(100%)	0.21589295	
T (K) LAB		
NPL	83.79672 (1)	
average drift (mK/h)	1	
recovery time to 0.1mK (min)	15	
overheating at 50% (mK/mW)	0.09	
enthalpy of melting (J)	102.5	

Notes: (1) through ASMW thermometer.


mcAr-PRMI
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00
1/F

C E L L T Y P E: 1 02 IMGC



Manufacturer: IMGC

Sealing date: Sep 1976

cell total mass: 190 g

sample mass: 0.22 mol

Filling gas type: SIO-Air Liquide

impurity analysis: nom. 99.998%
nitrogen 8 vppm
argon <10
krypton+xenon <1

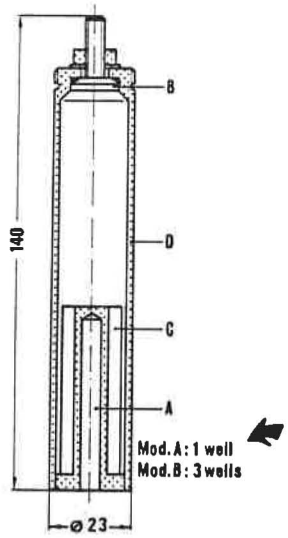
Enthalpy of melting: 96 J

Measurements at / Resistance Ratio (W)

LABORATORY	ASMW		IMGC		NIM		NPL		NRC	
Date	Feb 80		Sep 76-Nov 81		Feb 81		Feb 78		Dec 76	
thermometer N°	217997		PL01-6		7709		1728839		1521389	
Ro (ohm)	25.418580		25.271140		25.352963		25.559570		25.523332	
Typical melting plateau	12%	7380	7 %	1655	5 %	3116	17%	6389	8 %	4526
	30%	7860	10%	1675	10%	3155	18%	6393	16%	4734
	48%	7840	12%	1698	15%	3175	28%	6387	46%	4746
	72%	7850	17%	1717	20%	3274	48%	6377	77%	4746
	90%	7790	20%	1730	30%	3274	59%	6378	96%	4757
			30%	1750	40%	3273	77%	6380		
			45%	1754	51%	3286	88%	6382		
melted fraction F			65%	1758	71%	3290				
W(100%)	0.09187880		0.09191770		0.09183293		0.09196382		0.09184746	
T (K) LAB	54.36090		ref		54.36360		54.36072		54.36108	
T (K) NPL	54.36093		54.36132		54.36125		54.36072		54.36091	
average drift (mK/h)			5		3					
recovery time to 0.1mK (min)	2-12		1-10		2-5		<5			
overheating at 50% (mK/mW)	0.35		0.3		0.7					
enthalpy of melting (J)	96		105		91					

Notes:

C E L L   T Y P E: 1 02 IMGC



Manufacturer: IMGC

Sealing date: Sep 1976

cell total mass: 190 g

sample mass: 0.22 mol

Filling gas type: SIO-Air Liquide

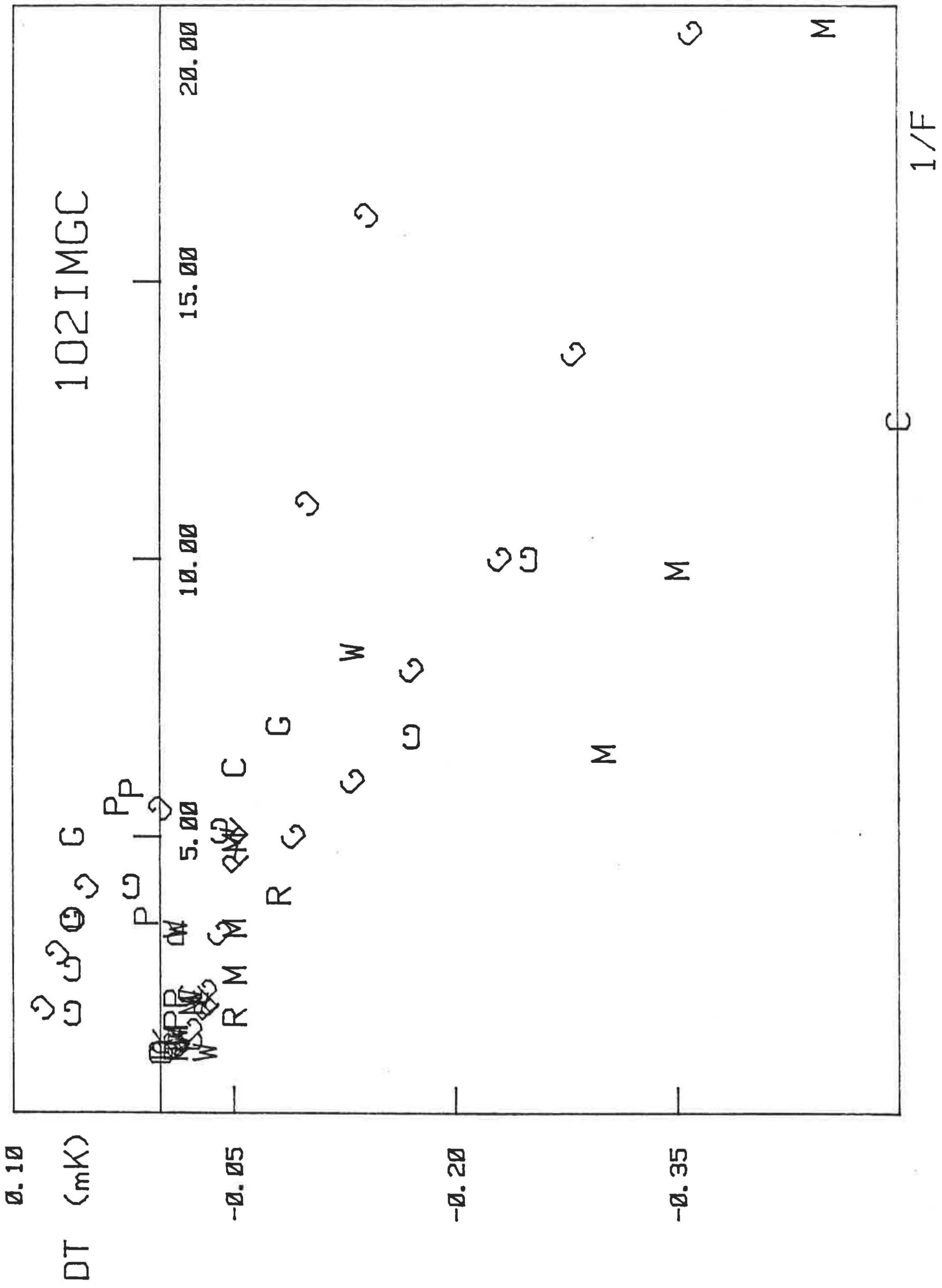
impurity analysis: nom. 99.998%
nitrogen 8 vppm
argon <10
krypton+xenon <1

Enthalpy of melting: 96 J

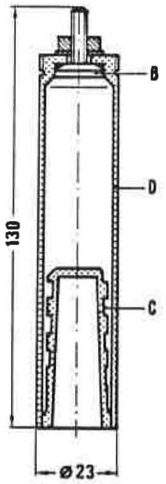
Measurements at — Resistance Ratio (W)

LABORATORY	NRLM
Date	Nov 81
thermometer N°	7681
Ro (ohm)	25.363060
Typical melting plateau	22% 1188 25% 1179 52% 1196 57% 1191 82% 1205 89% 1206
melted fraction F	
W(100%)	0.09201210
T (K) LAB	54.36160
T (K) NPL	54.36170
average drift (mK/h)	1.6
recovery time to 0.1mK (min)	1-8
overheating at 50% (mK/mW)	
enthalpy of melting (J)	95.5

Notes:


102IMGC
DT (mK)
0.10
-0.05
-0.20
-0.35
1/F
5.00
10.00
15.00
20.00

C E L L   T Y P E: 8 02 IMGC



Manufacturer: IMGC

Sealing date: Nov 1978

cell total mass: 168.316 g

sample mass: 0.10610 mol

Filling gas type: SIO-Air Liquide

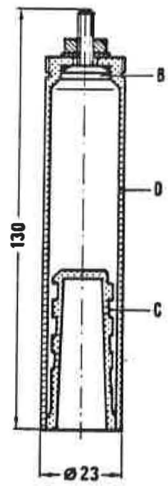
impurity analysis: nom. 99.998%
nitrogen 1.8 vppm
argon 3.0
methane 0.7

Enthalpy of melting: 47 J

Measurements at	Resistance Ratio (W)									
LABORATORY	IMGC		INM		NBS		NML		NRC	
Date	Nov 78-May 81		Oct 80		Mar 84		Nov 78		Oct 79	
thermometer N°	PL01-6		232788		1812282		1731676		1521389	
Ro (ohm)	25.271140		25.087300		25.510280		25.522800		25.523332	
	11%	1900	10%	3329	16%	4154	5 %	6561	4.5%	4756
	18%	1914	20%	3353	40%	4196	10%	6573	5%	4840
Typical	24%	1924	30%	3369	63%	4189	17%	6581	8 %	4820
melting	32%	1932	40%	3369	87%	4194	25%	6593	10%	4847
plateau	63%	1952	50%	3369			30%	6597	18%	4851
			60%	3369			37%	6601	20%	4867
			70%	3405			50%	6605	36%	4890
melted			80%	3400			60%	6613	40%	4902
fraction			90%	3400			80%	6585	71%	4910
F							95%	6581	90%	4918
W(100%)	0.09191956		0.09193405		0.09184211		0.09196593		0.09184920	
T (K) LAB	54.36148		54.36163		54.36196		54.36143		54.36153	
NPL	54.36180		54.36194		54.36149		54.36133		54.36136	
average drift (mK/h)	2									
recovery time to 0.1mK (min)	2-10		5-10							
overheating at 50% (mK/mW)	0.02		0.09							
enthalpy of melting (J)	46								48	

Notes:

Manufacturer: IMGC



Sealing date: Nov 1978

cell total mass: 168.316 g

sample mass: 0.10610 mol

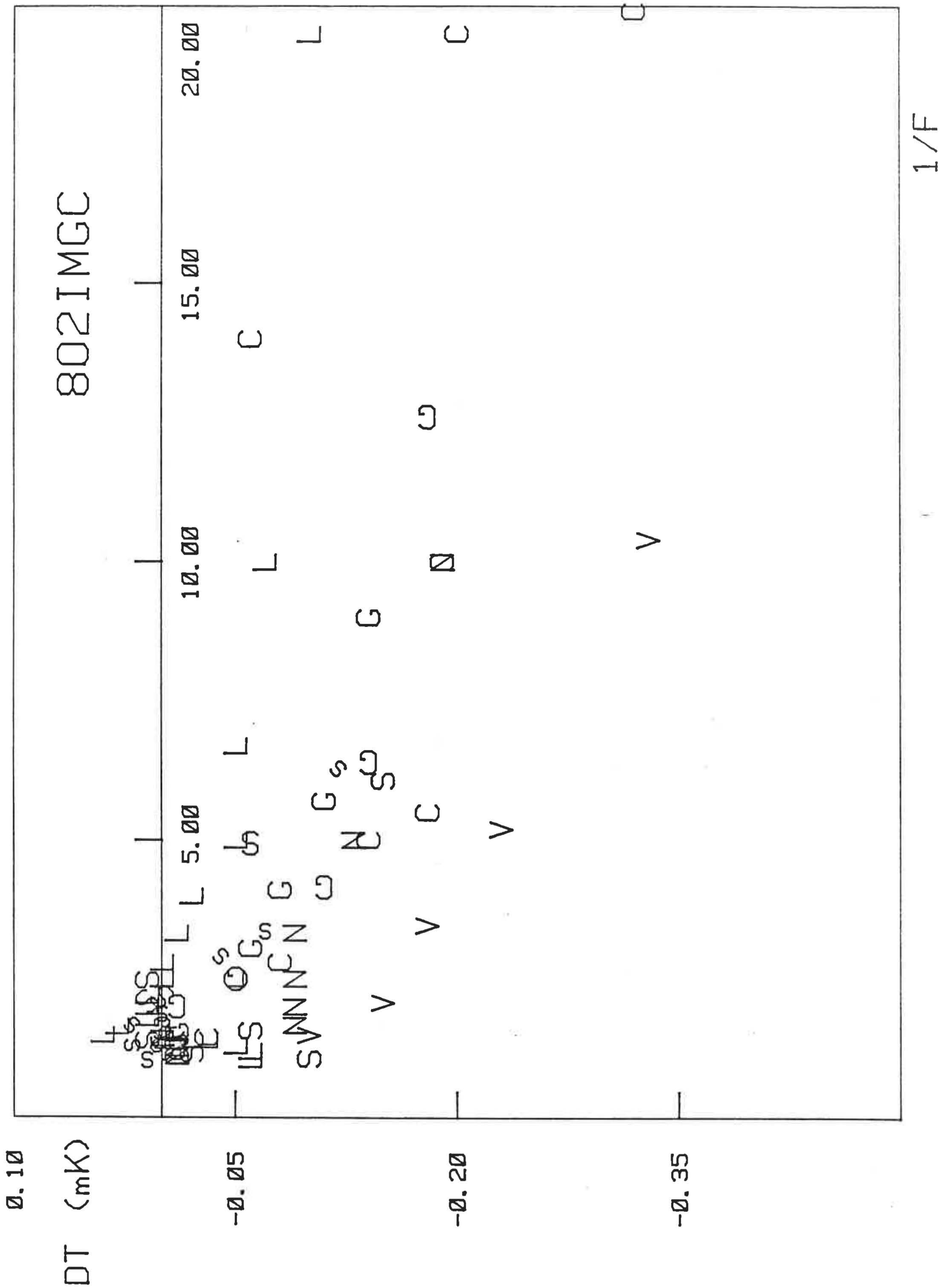
Filling gas type: SIO-Air Liquide

impurity analysis: nom. 99.998%
nitrogen 1.8 vppm
argon 3.0
methane 0.7

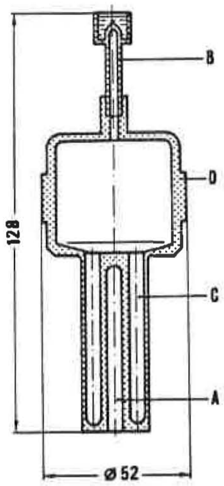
Enthalpy of melting: 47 J

Measurements at	Resistance Ratio (W)	
LABORATORY	PRMI	
Date	Dec 81	
thermometer N°	1842381	
Ro (ohm)	25.544950	
Typical melting plateau / melted fraction F	10%	4690
	19%	4730
	29%	4750
	39%	4840
	48%	4760
	67%	4780
W(100%)	0.09174820	
T (K) LAB		
NPL	54.36059	
average drift (mK/h)	3	
recovery time to 0.1mK (min)	20	
overheating at 50% (mK/mW)	0.01	
enthalpy of melting (J)	46.3	

Notes:


8021MGC
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L   T Y P E: 8 02 INM



Manufacturer: INM

Sealing date: Feb 76

cell total mass: 265 g

sample mass: 0.279 mol

Filling gas type: Air Liquide

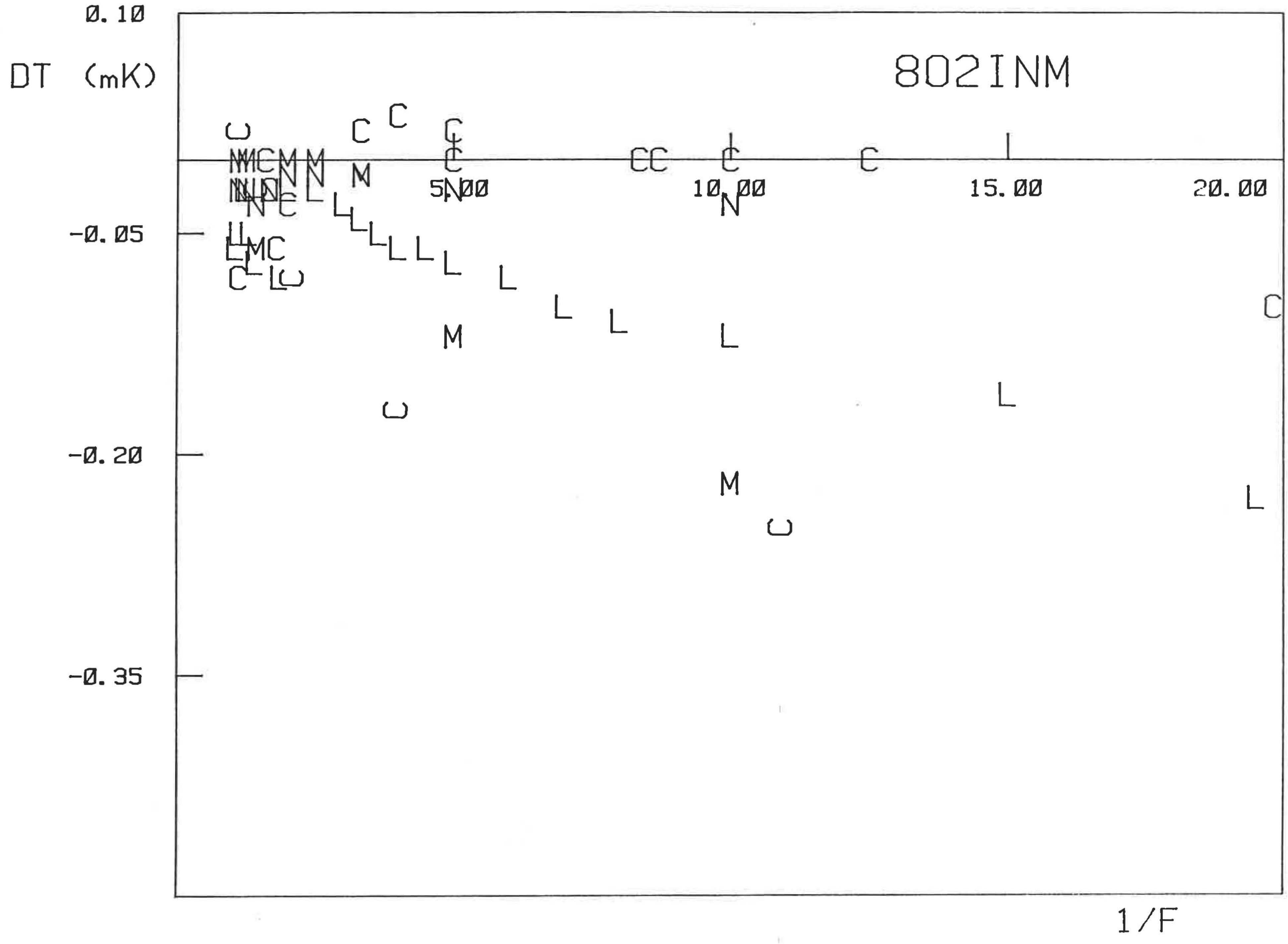
impurity analysis: nom. 99.998%
nitrogen 5 vppm
argon 12
krypton 3

Enthalpy of melting: 124 J

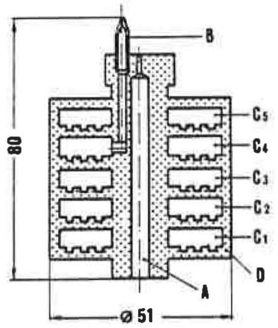
Measurements at — Resistance Ratio (W)

LABORATORY	INM		NIM		NML		NRC		NRC	
Date	May 80-Feb 82		Aug 81		Sep 79		Jun 76		Nov 79	
thermometer N°	232788		7709		1731676		1521389		1521389	
Ro (ohm)	25.087300		25.352963		25.522800		25.523332		25.523332	
	10%	3145	10%	3211	5 %	6413	9.2%	4808	5 %	4695
	20%	3149	20%	3250	10%	6456	25%	4840	10%	4730
Typical	30%	3153	30%	3293	15%	6464	48%	4875	12%	4734
melting	40%	3153	40%	3297	20%	6475	72%	4901	20%	4742
plateau	50%	3153	50%	3297	30%	6487	92%	4914	25%	4746
	60%	3149	60%	3274	40%	6495			30%	4738
	70%	3145	70%	3297	50%	6499			50%	4722
melted	80%	3149	80%	3297	60%	6464			56%	4710
fraction	90%	3149	90%	3297	70%	6482			60%	4726
F					80%	6498			62%	4734
					90%	6484			90%	4702
W(100%)	0.09193155		0.09183300		0.09196500		0.09184906		0.09184734	
T (K) LAB	ref		54.36360 (1)		54.36112		54.36149		54.36105	
T (K) NPL	54.36131		54.36127		54.36102		54.36132		54.36088	
average drift (mK/h)	1.5		10							
recovery time to 0.1mK (min)	2-14		1-4							
overheating at 50% (mK/mW)			0.03		5.8					
enthalpy of melting (J)	124								120	

Notes: (1) through thermometer 1812283 (1982).


802INM
0.10
DT (mK)
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00
1/F

C E L L T Y P E: BCM4 INM (02)



INM mod. BCM

Manufacturer: INM
Multicomponent cell
(argon,oxygen,neon,nitrogen)

Sealing date: Jan 1982

cell total mass: 369.83 g

sample mass: 0.0222 mol

Filling gas type:

impurity analysis:

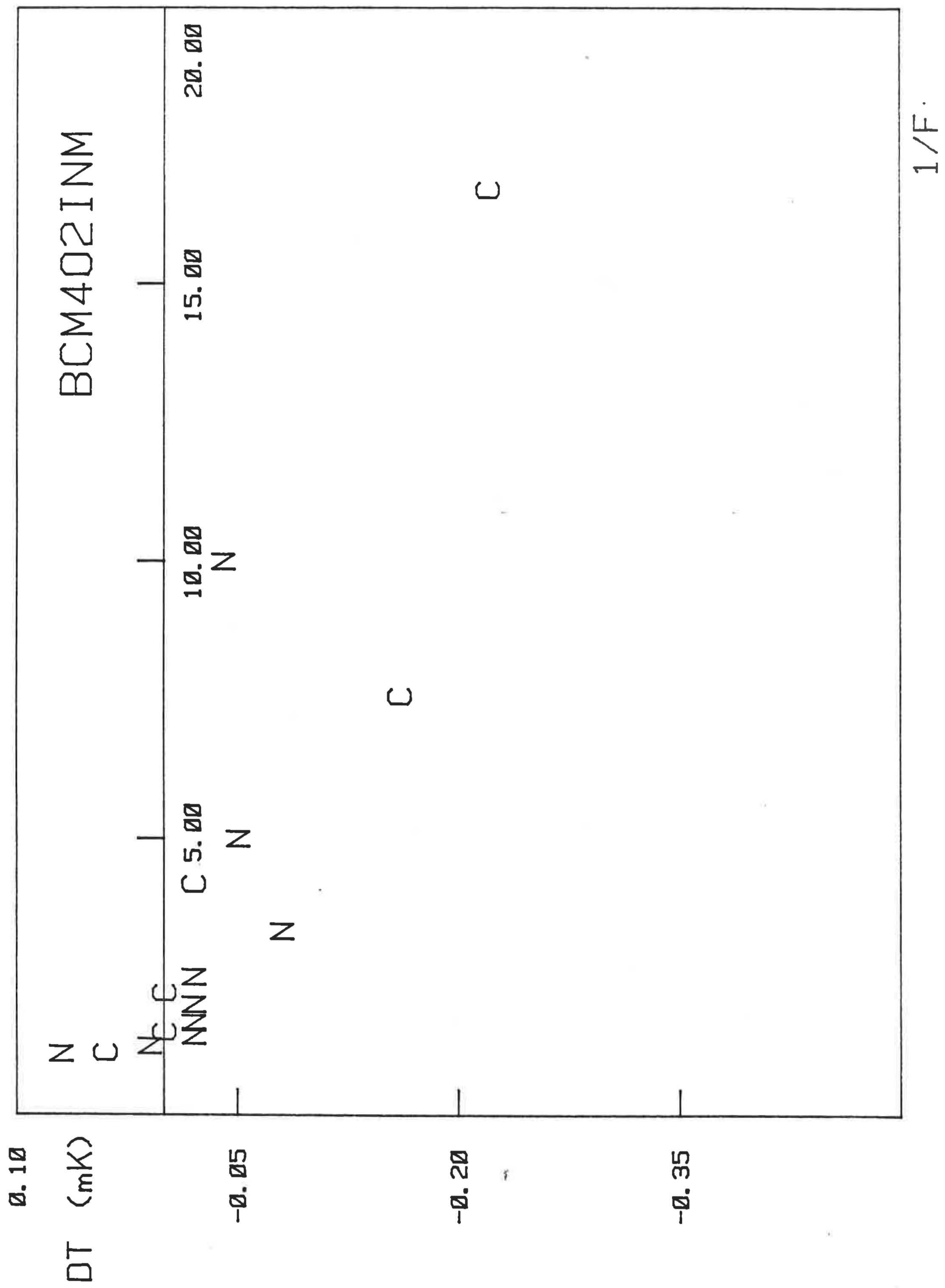
nitrogen	5 vppm;	methane <0.2
argon	12 ;	hydrogen<0.1
krypt.+xenon	3	
carbon diox.	0.2	

Enthalpy of melting: 9 J

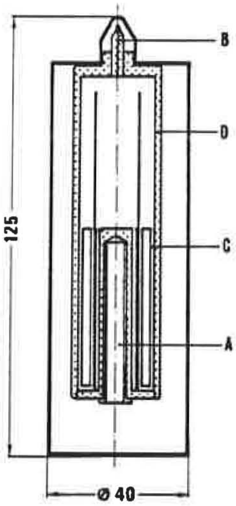
Measurements at — Resistance Ratio (W)

LABORATORY	INM		NRC	
Date	Feb 82		Jul 82	
thermometer N°	1812283		1521389	
Ro (ohm)	25.494713		25.523332	
	0 %	0958	6 %	4652
	10%	1103	14%	4674
Typical	20%	1099	24%	4730
melting	30%	1087	45%	4738
plateau	40%	1111	67%	4738
	50%	1111	88%	4754
	60%	1111		
melted	70%	1111		
fraction	80%	1123		
F	90%	1146		
W(100%)	0.09181120		0.09184740	
T (K) LAB	54.36104		54.36107	
NPL	54.36135		54.36090	
average drift (mK/h)	-12			
recovery time to 0.1mK (min)	6		30	
overheating at 50% (mK/mW)				
enthalpy of melting (J)	9		8.9	

Notes:


BCM4021NM
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L   T Y P E: M2 02 NBS



n.1 1 well
n.3 3 well

Manufacturer: NBS

Sealing date: n.1 Feb 1983
n.3 Jul 1983

cell total mass: 240 g; 190 g

sample mass: 0.08 mol; 0.12 mol

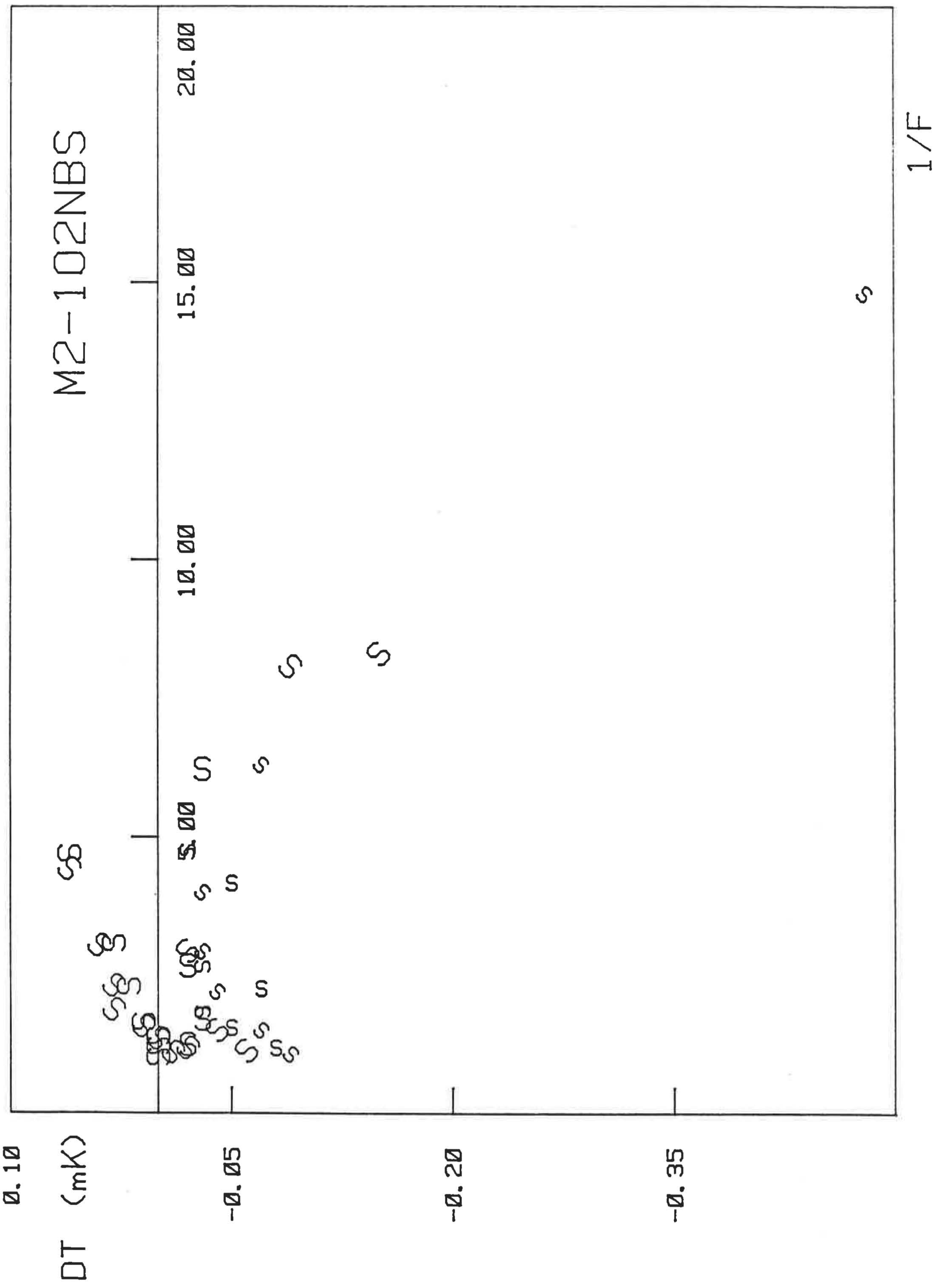
Filling gas type: home-made from decomp. of $KMnO_4$

impurity analysis:

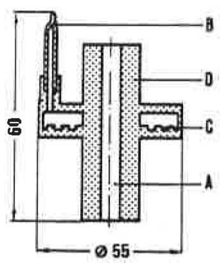
Enthalpy of melting: 35 J; 53 J

Measurements at	Resistance Ratio (W)			
LABORATORY	NBS (n°1)		NBS (n°3)	
Date	Apr 1983		May 1983	
thermometer N°	1774095		1812282	
Ro (ohm)	25.560840		25.570340	
Typical melting plateau	6.7%	1904	2.1%	3631
	16%	2087	12%	3913
	25%	2098	23%	3967
	34%	2099	33%	3963
	45%	2096	43%	3960
	67%	2088	53%	3958
	93%	2074	63%	3953
melted fraction F			73%	3950
			83%	3939
			93%	3943
W(100%)	0.09192112		0.09183948	
T (K) LAB	54.36145		54.36130	
NPL	54.36099		54.36083	
average drift (mK/h)				
recovery time to 0.1mK (min)				
overheating at 50% (mK/mW)				
enthalpy of melting (J)	35		53	

Notes:


M2-102NBS
DT (mK)
0.10
-0.05
-0.20
-0.35
1/F
5.00
10.00
15.00
20.00

C E L L T Y P E: PP07 02 NIM



NIM mod. BC-INM

Manufacturer: NIM

Sealing date: Aug 1981

cell total mass: 156.39 g

sample mass: 0.020 mol

Filling gas type:

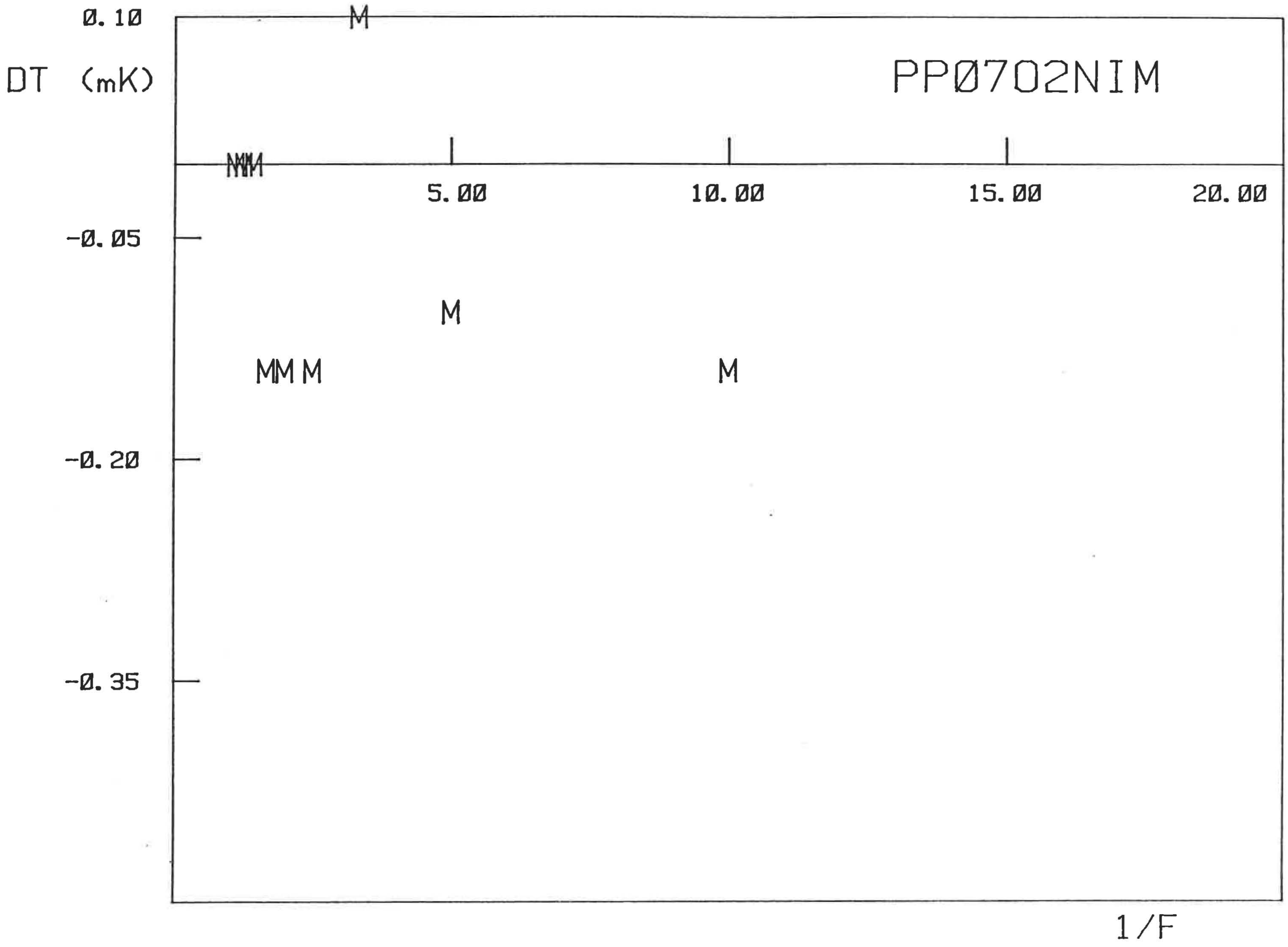
impurity analysis:

nitrogen	3.1 vppm
argon	0.15
carb.diox.<	0.5
methane	0.15

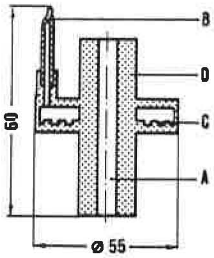
Enthalpy of melting: 9 J

Measurements at	Resistance Ratio (W)	
LABORATORY	NIM	
Date	Aug 81	
thermometer N°	7709	
Ro (ohm)	25.352963	
Typical melting plateau	11%	3234
	22%	3254
	28%	3254
	39%	3254
	50%	3254
	61%	3254
	72%	3293
melted fraction F	83%	3293
	94%	3293
W(100%)	0.09183293	
T (K) LAB		
NPL	54.36125 (1)	
average drift (mK/h)		
recovery time to 0.1mK (min)	1-2.5	
overheating at 50% (mK/mW)	0.04	
enthalpy of melting (J)	9	

Notes: (1) through thermometer 1812283 (1982).


PP0702NIM
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00
1/F

C E L L   T Y P E: PP11 02 NIM



NIM mod. BC-INM

Manufacturer: NIM

Sealing date: Aug 1981

cell total mass: 176.38 g

sample mass: 0.020 mol

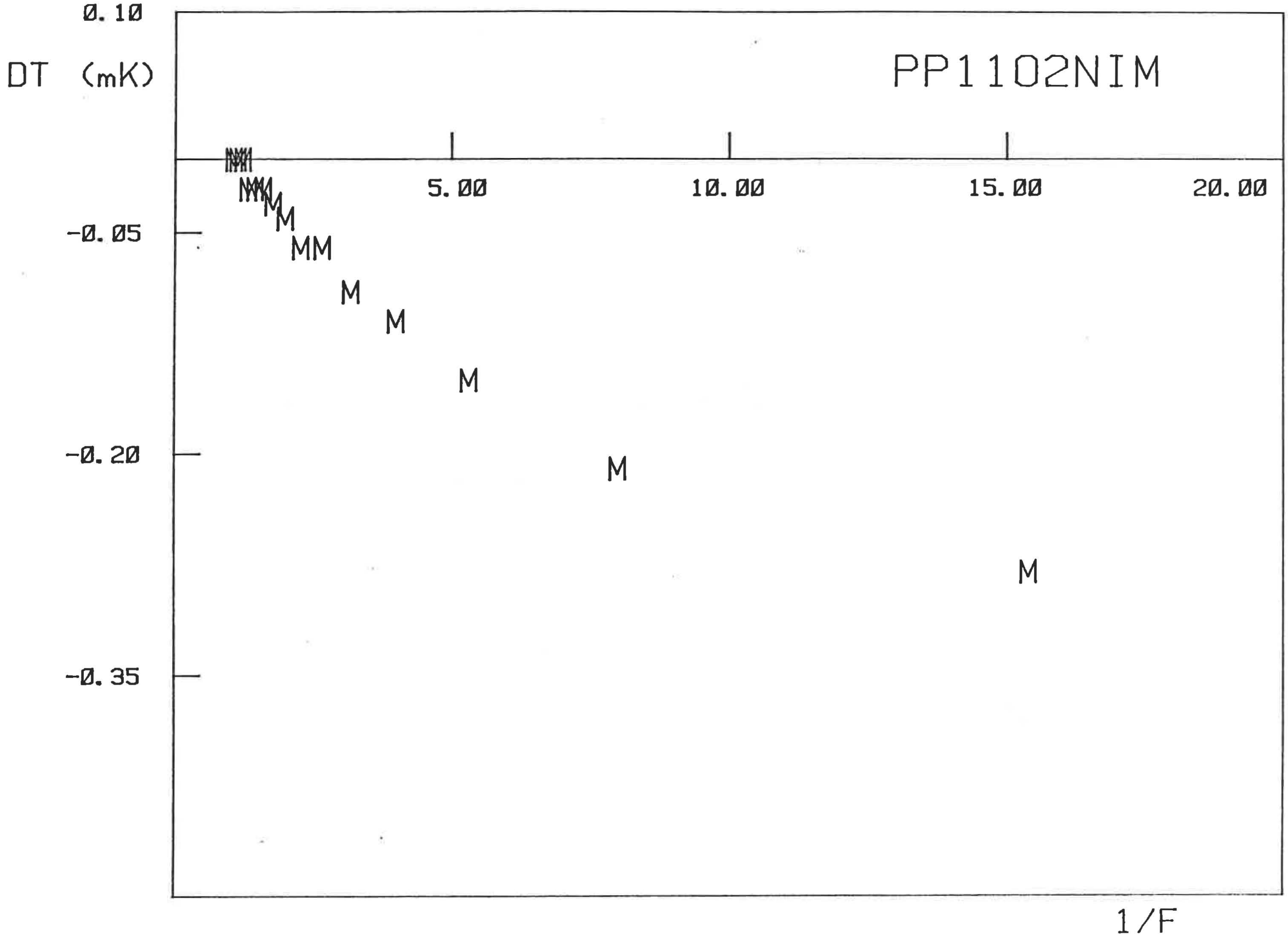
Filling gas type:

impurity analysis: nom. 99.999%
nitrogen 4.2 vppm
argon 0.8
methane 0.83
carb.diox.0.5

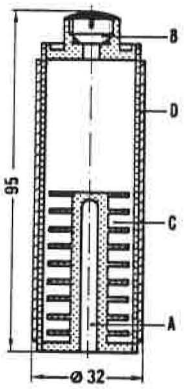
Enthalpy of melting: 9 J

Measurements at	Resistance Ratio (W)
LABORATORY	NIM
Date	Aug 81
thermometer N°	7709
Ro (ohm)	25.352963
Typical melting plateau / melted fraction F	6.2% 3136
	12% 3163
	19% 3187
	25% 3203
	31% 3211
	37% 3222
	44% 3222
	50% 3230
	56% 3234
	69% 3238
	87% 3246
W(100%)	0.09183246
T (K) LAB	
T (K) NPL	54.36113 (1)
average drift (mK/h)	9
recovery time to 0.1mK (min)	1-4
overheating at 50% (mK/mW)	0.03
enthalpy of melting (J)	9

Notes: (1) through thermometer 1812283 (1982).


0.10
DT (mK)
PP1102NIM
5.00
10.00
15.00
20.00
-0.05
-0.20
-0.35
1/F

C E L L   T Y P E: 15 02 NRC



NRC

Manufacturer: NRC

Sealing date: Jun 1979

cell total mass: 202.586 g

sample mass: 0.063 mol

Filling gas type: Matheson

impurity analysis:

Enthalpy of melting: 28 J

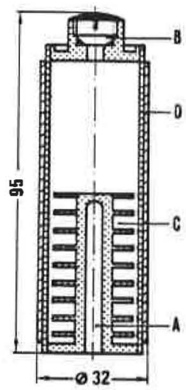
Measurements at — Resistance Ratio (W)

LABORATORY	ASMW		IMGC		INM		NML		NPL	
Date	Feb 81		Sep 80		May 80		Jun 79		Nov 81	
thermometer N°	217997		PL01-6		232788		1731676		1728839	
Ro (ohm)	25.418540		25.271140		25.087300		25.522800		25.559570	
	8 %	7849	8 %	1786	10%	3157	5 %	6424	5 %	6420
	16%	7912	15%	1809	20%	3169	15%	6448	10%	6424
Typical	24%	7888	20%	1821	30%	3161	20%	6452	18%	6430
melting	42%	7912	26%	1837	40%	3165	25%	6456	25%	6440
plateau	58%	7919	32%	1849	50%	3173	30%	6460	35%	6440
	75%	7880	42%	1861	60%	3165	40%	6460	50%	6442
			50%	1884	70%	3153	60%	6460	65%	6444
melted			60%	1896	80%	3149	80%	6460	80%	6450
fraction F					90%	3138	95%	6460	95%	6460
W(100%)	0.09187939		0.09191885		0.09193165		0.09196460		0.09196444	
T (K) LAB	54.36107		54.36148		54.36103		54.36102		54.36088	
T (K) NPL	54.36110		54.36167		54.36134		54.36092		54.36088	
average drift (mK/h)	2		5							
recovery time to 0.1mK (min)	0.5-4		1		2-3				2	
overheating at 50% (mK/mW)	0.7		0.5							
enthalpy of melting (J)	27.8		21							

Notes:

C E L L T Y P E: 15 02 NRC

Manufacturer: NRC



NRC

Sealing date: Jun 1979

cell total mass: 202.586 g

sample mass: 0.063 mol

Filling gas type: Matheson

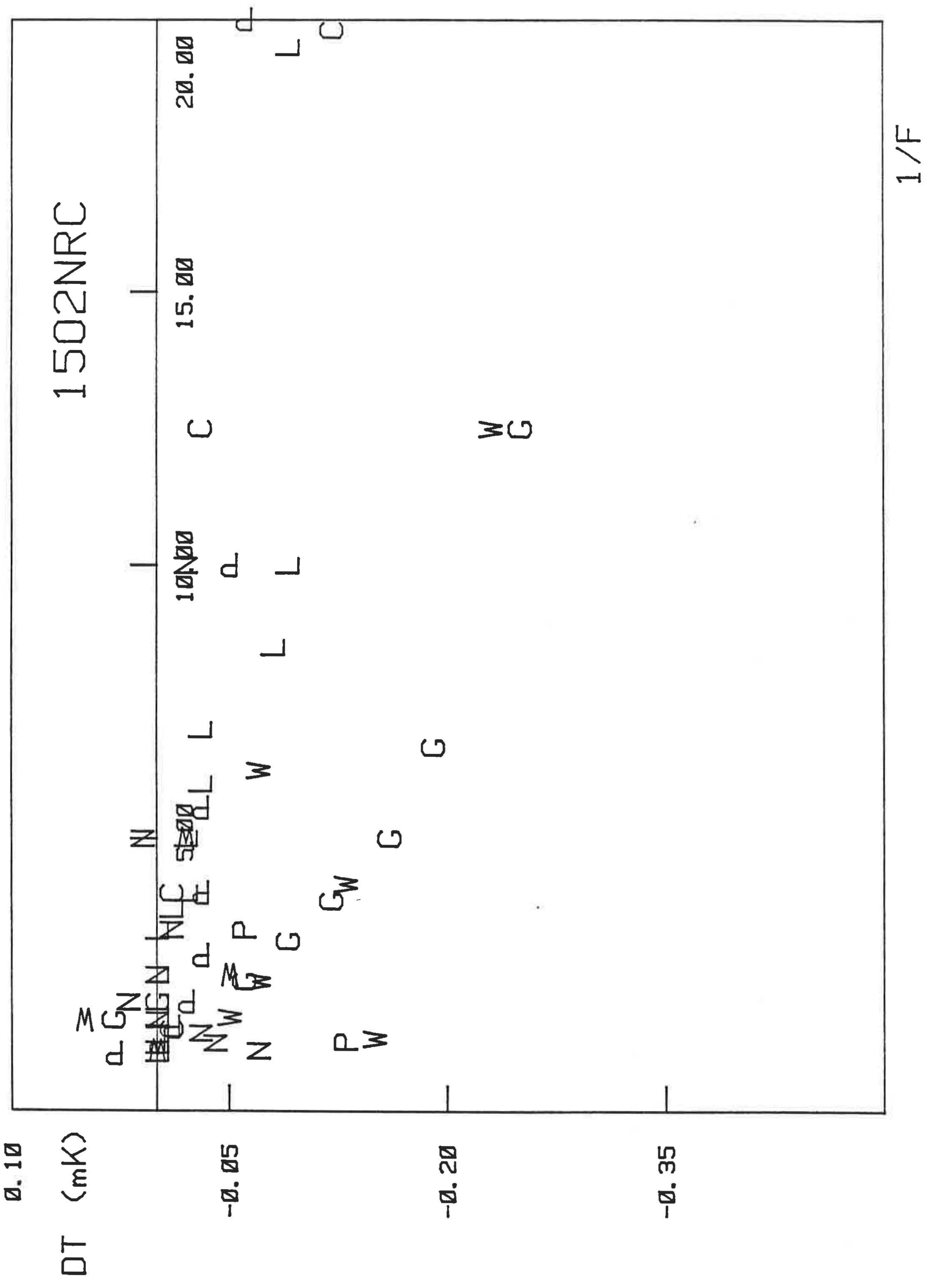
impurity analysis: research grade

Enthalpy of melting: 28 J

Resistance Ratio (W)

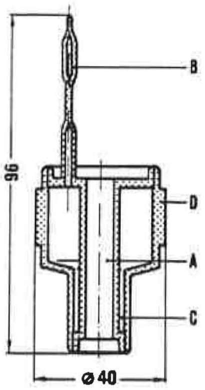
Measurements at	
LABORATORY	NRC
Date	Jun 79
thermometer N°	1521389
Ro (ohm)	25.523332
Typical melting plateau	4 % 4729 8 % 4764 25% 4772 67% 4772
melted fraction F	
W(100%)	0.09184772
T (K) LAB	54.36116
T (K) NPL	54.36099
average drift (mK/h)	
recovery time to 0.1mK (min)	10
overheating at 50% (mK/mW)	
enthalpy of melting (J)	27

Notes:


1502NRC
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

CELL TYPE: 7801 02 NRLM

International
Intercomparison
CCT: 1979-1983



NRLM

Manufacturer: NRLM

Sealing date: Jun 1978

cell total mass: 170 g

sample mass: 0.06 mol

Filling gas type:

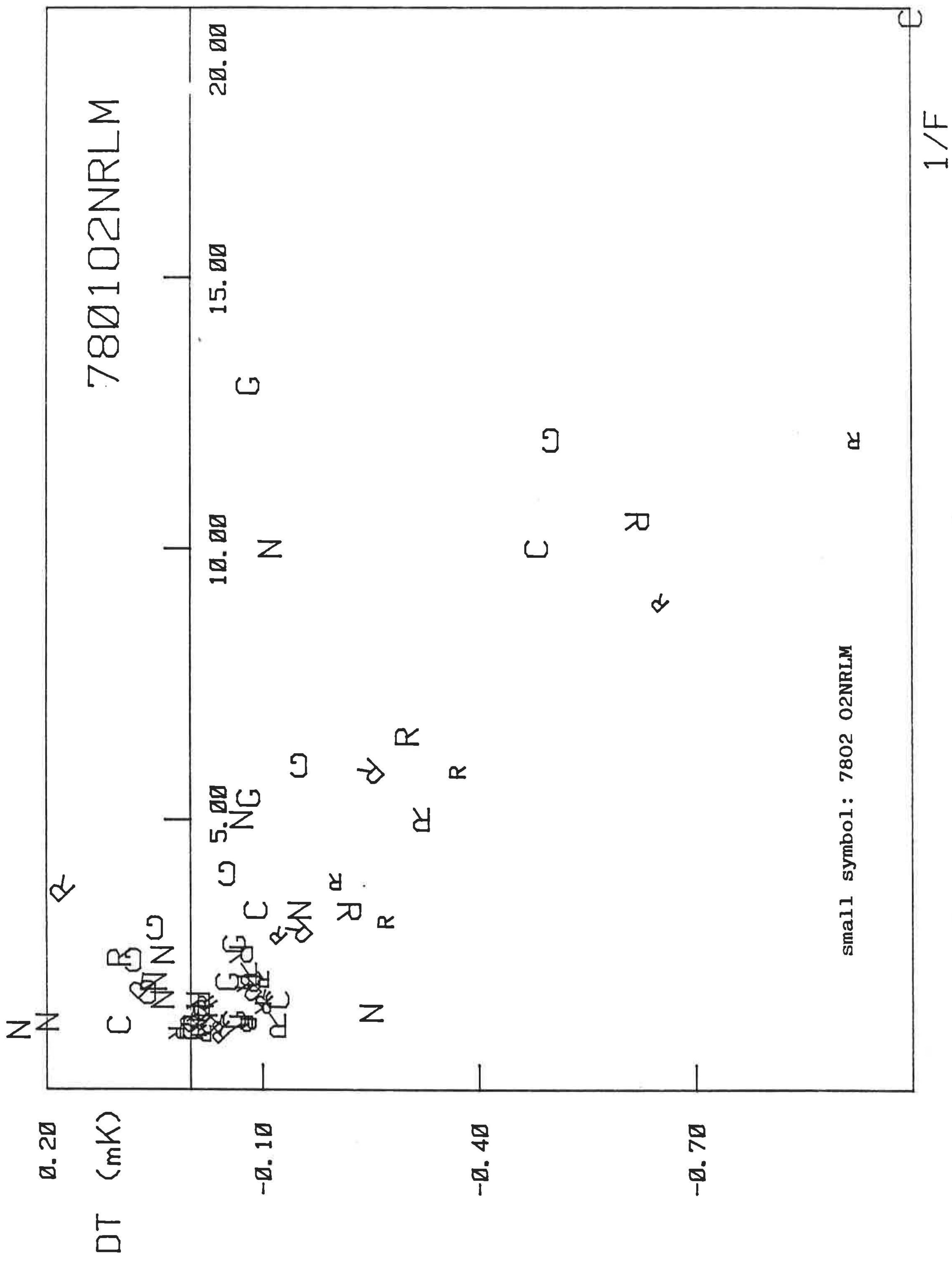
impurity analysis: nom. 99.99%

Enthalpy of melting: 28 J

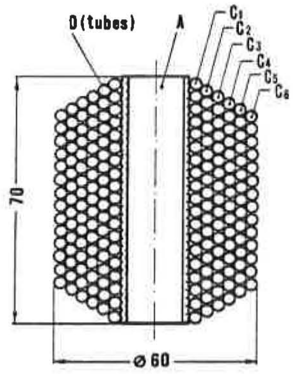
Measurements at — Resistance Ratio (W)

LABORATORY	IMGC	INM	NRC	NRLM (cell 7802)	NRLM
Date	Nov 80	May 80	Oct 79	Oct 78	Nov 81
thermometer N°	PL01-6	232788	1521389	(1)	7681
Ro (ohm)	25.271140	25.087300	25.523332		25.362928
	8 % 2351	10% 4050	5 % 4930	8 % 6415	1.7% 1276
	17% 2498	20% 4066	10% 5165	11% 6515	15% 1592
Typical	25% 2545	30% 4034	30% 5321	18% 6630	27% 1789
melting	33% 2581	40% 4110	60% 5306	26% 6705	41% 1750
plateau	42% 2513	50% 4114	83% 5400	35% 6740	52% 1746
	54% 2585	60% 4110		49% 6740	66% 1700
	67% 2573	70% 3995		59% 6735	77% 1718
melted	90% 2561	80% 4174		67% 6745	92% 1710
fraction		90% 4190		72% 6735	
F				91% 6775	
W(100%)	0.09192560	0.09194095	0.09185354	0.09196770	0.09201750
T (K) LAB	54.36300	54.36337	54.36264		54.3631
T (K) NPL	54.36335	54.36368	54.36247		54.3632
average drift (mK/h)	20				1.5
recovery time to 0.1mK (min)	2	2-4			2-8
overheating at 50% (mK/mW)	0.4				
enthalpy of melting (J)	20			28.1	20.7

Notes: (1) 1978 data reported only for record.


780102NRLM
DT (mK)
0.20
-0.10
-0.40
-0.70
5.00
10.00
15.00
20.00
1/F
small symbol: 7802 02NRLM

C E L L T Y P E: PRMI (02)



PRMI

Manufacturer: PRMI
Multicomponent cell
(argon,oxygen,neon,hydrogen)

Sealing date: Dec 1978

cell total mass:

sample mass:

Filling gas type: home-made from decomp. of $KClO_4$

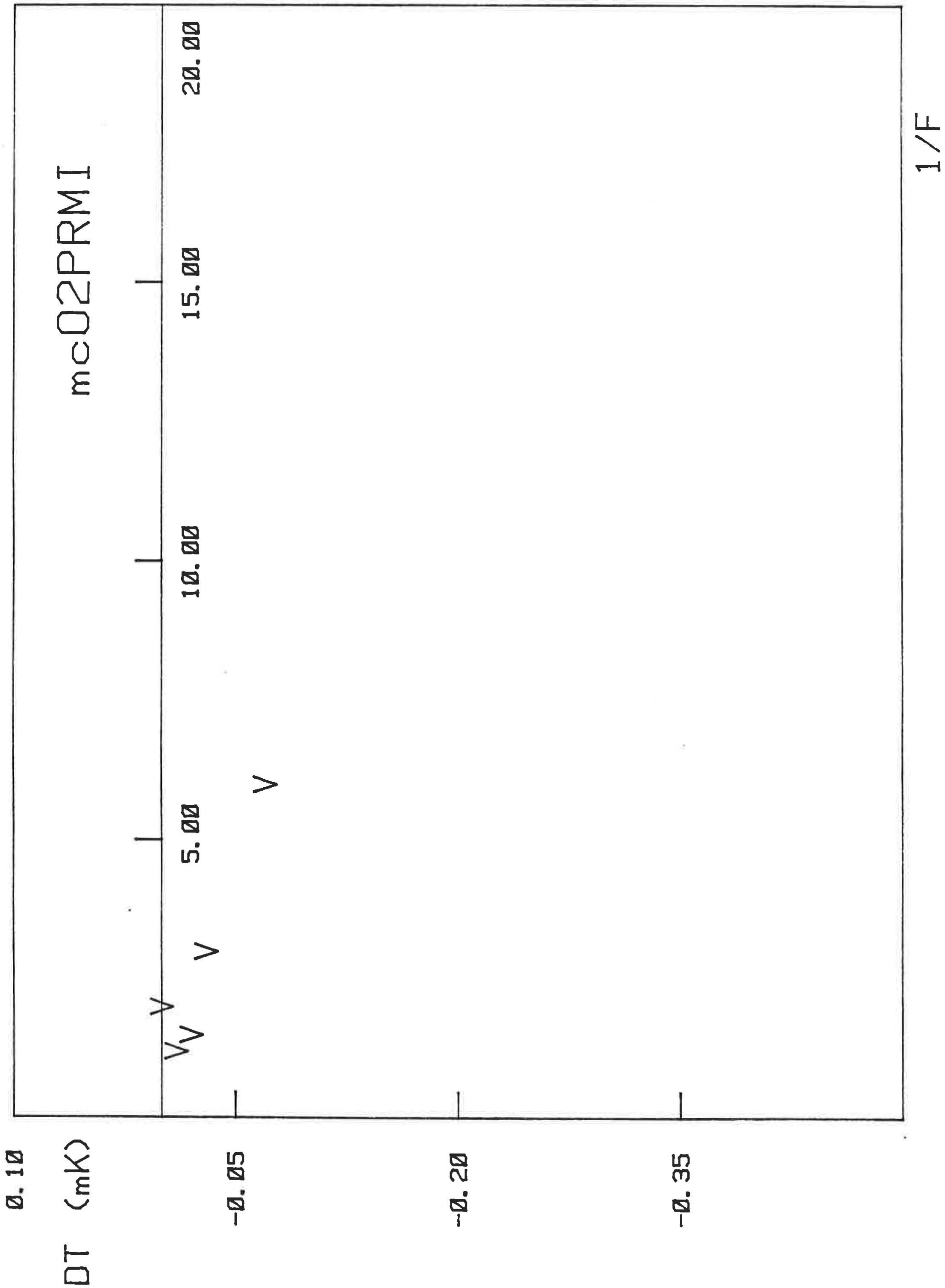
impurity analysis:

Enthalpy of melting: 32.5 J

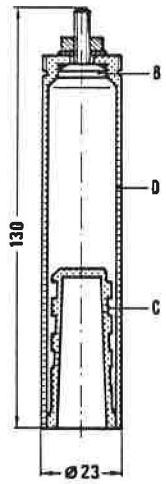
Resistance Ratio (W)

Measurements at	
LABORATORY	PRMI
Date	Nov 81
thermometer N°	1842381
Ro (ohm)	25.544950
Typical melting plateau	17% 4520 33% 4680 50% 4780 67% 4690 83% 4710
melted fraction F	
W(100%)	0.09174780
T (K) LAB	
NPL	54.36049
average drift (mK/h)	-3
recovery time to 0.1mK (min)	20
overheating at 50% (mK/mW)	0.15
enthalpy of melting (J)	32.5

Notes:


mcO2PRMI
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 1 H2 IMGC



Manufacturer: IMGC

Sealing date: Aug 1980

cell total mass: 164.422 g (with 1.000 g catalyst)
sample mass: 0.11 mol

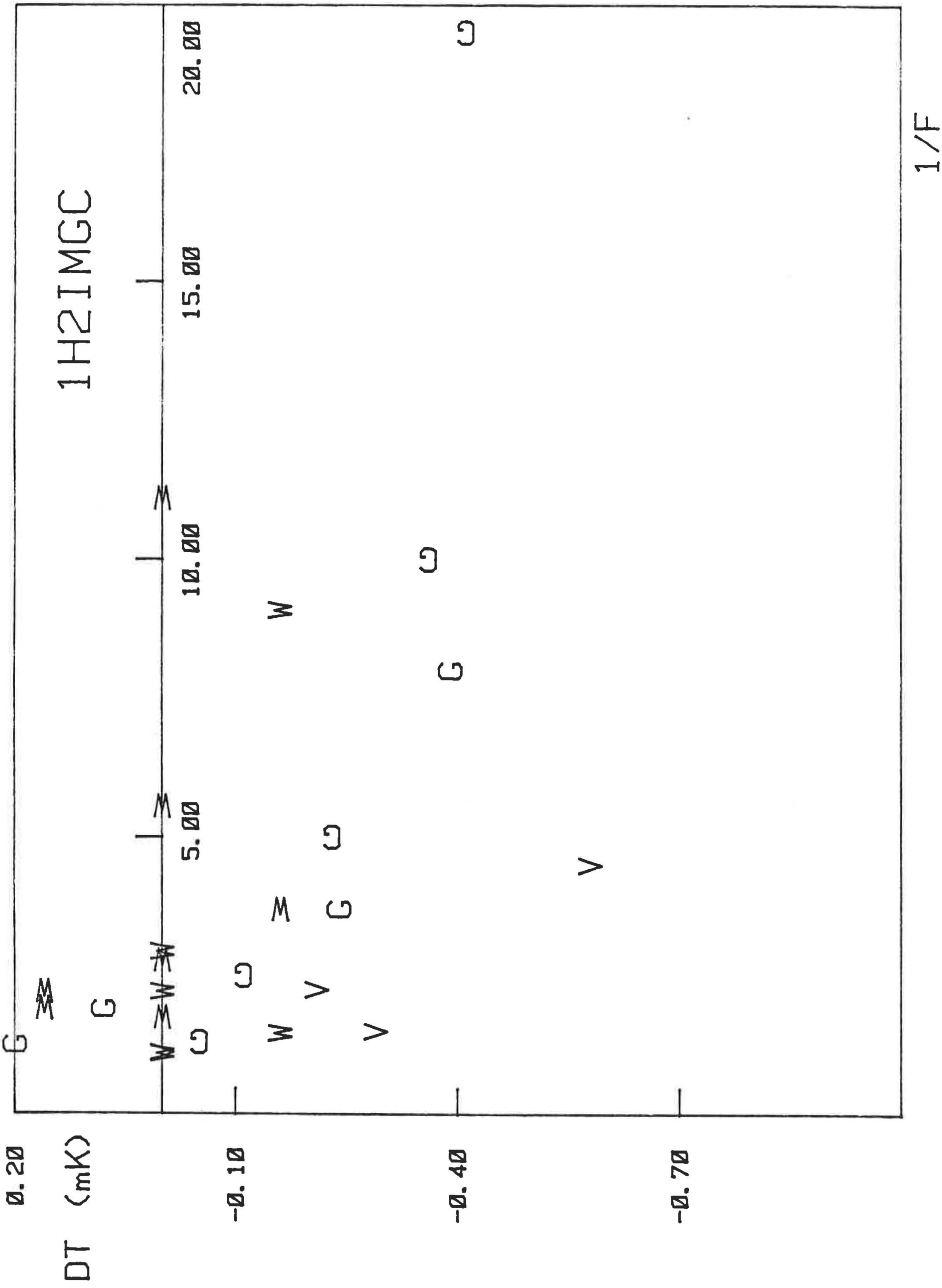
Filling gas type: Precision Gas Products

impurity analysis: nom. 99.9999%

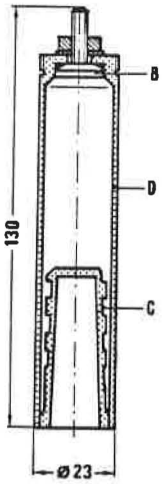
Enthalpy of melting: 13 J

Measurements at	Resistance Ratio (W)		
LABORATORY	ASMW	IMGC	PRMI
Date	Mar 81	Aug 80	Dec 81
thermometer N°	207278	PL01-6	1842381
Ro (ohm)	25.346860	25.271140	25.544950
Typical melting plateau / melted fraction F	9 % 4358	5 % 0983	22% 8814
	18% 5358	10% 0985	44% 8823
	27% 5354	20% 0988	67% 8821
	36% 5358	40% 0991	89% 8828
	45% 5362	75% 0992	
	52% 5362		
	57% 5358		
	91% 5358		
W(100%)	0.001353580	0.001409930	0.001188280
T (K) LAB		ref	
T (K) NPL	13.81109	13.81567 (2)	13.81030
average drift (mK/h)	4	5	<1
recovery time to 0.1mK (min)	1-3	1	10
overheating at 50% (mK/mW)	1.5	1	0.2
enthalpy of melting (J)	14.9	13.2	3.7 (1)

Notes: (1) the cell began to leak at PRMI.
(2) with PL02-6 T(NPL)= 13.81070 K.


1H2IMGC
1/F
DT (mK)
0.20
-0.10
-0.40
-0.70
5.00
10.00
15.00
20.00

C E L L T Y P E: 2 H2 IMGC



Manufacturer: IMGC

Sealing date: Jan 1983

cell total mass: 163.343 g

sample mass: 0.055 mol

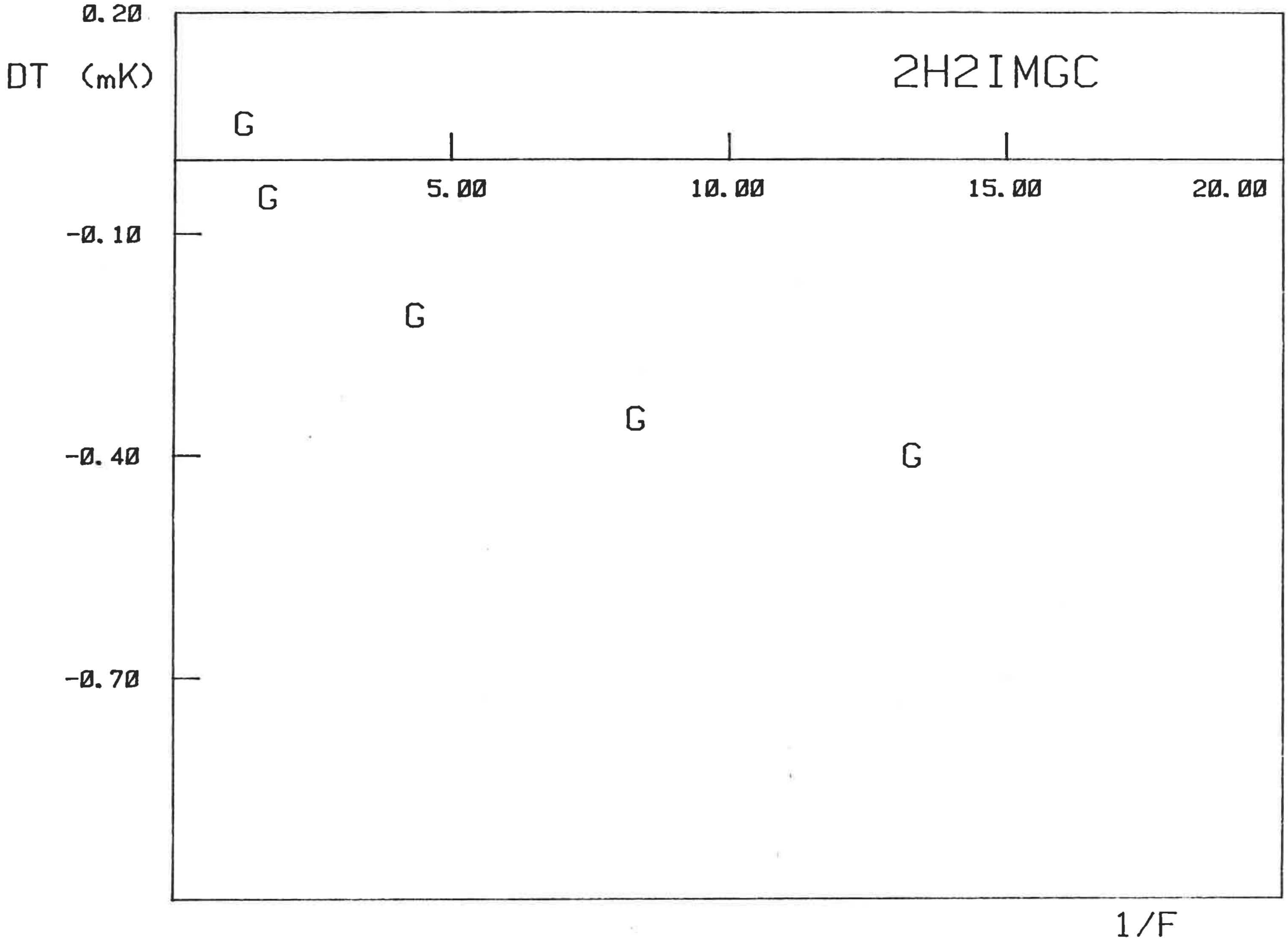
Filling gas type: Precision Gas Products

impurity analysis: nom. 99.9999%

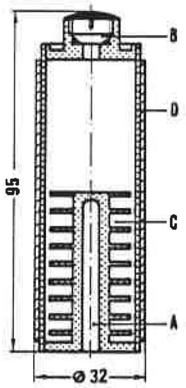
Enthalpy of melting: 6.5 J

Measurements at	Resistance Ratio (W)	
LABORATORY	IMGC	
Date	Jun 83	
thermometer N°	PL01-6	
Ro (ohm)	25.271140	
Typical melting plateau	7.5%	09822
	12%	09836
	23%	09869
	59%	09910
	80%	09934
melted fraction F		
W(100%)	0.001409922	
T (K) LAB	13.80997	
T (K) NPL	13.81564	
average drift (mK/h)	<10	
recovery time to 0.1mK (min)	1	
overheating at 50% (mK/mW)	10	
enthalpy of melting (J)	5.9	

Notes:


0.20
DT (mK)
2H2IMGC
5.00
10.00
15.00
20.00
-0.10
-0.40
-0.70
1/F

C E L L   T Y P E: 23 H2 NRC



NRC

Manufacturer: NRC

Sealing date: Aug 1979

cell total mass: 127.808 g

sample mass: 0.04556 mol

Filling gas type:

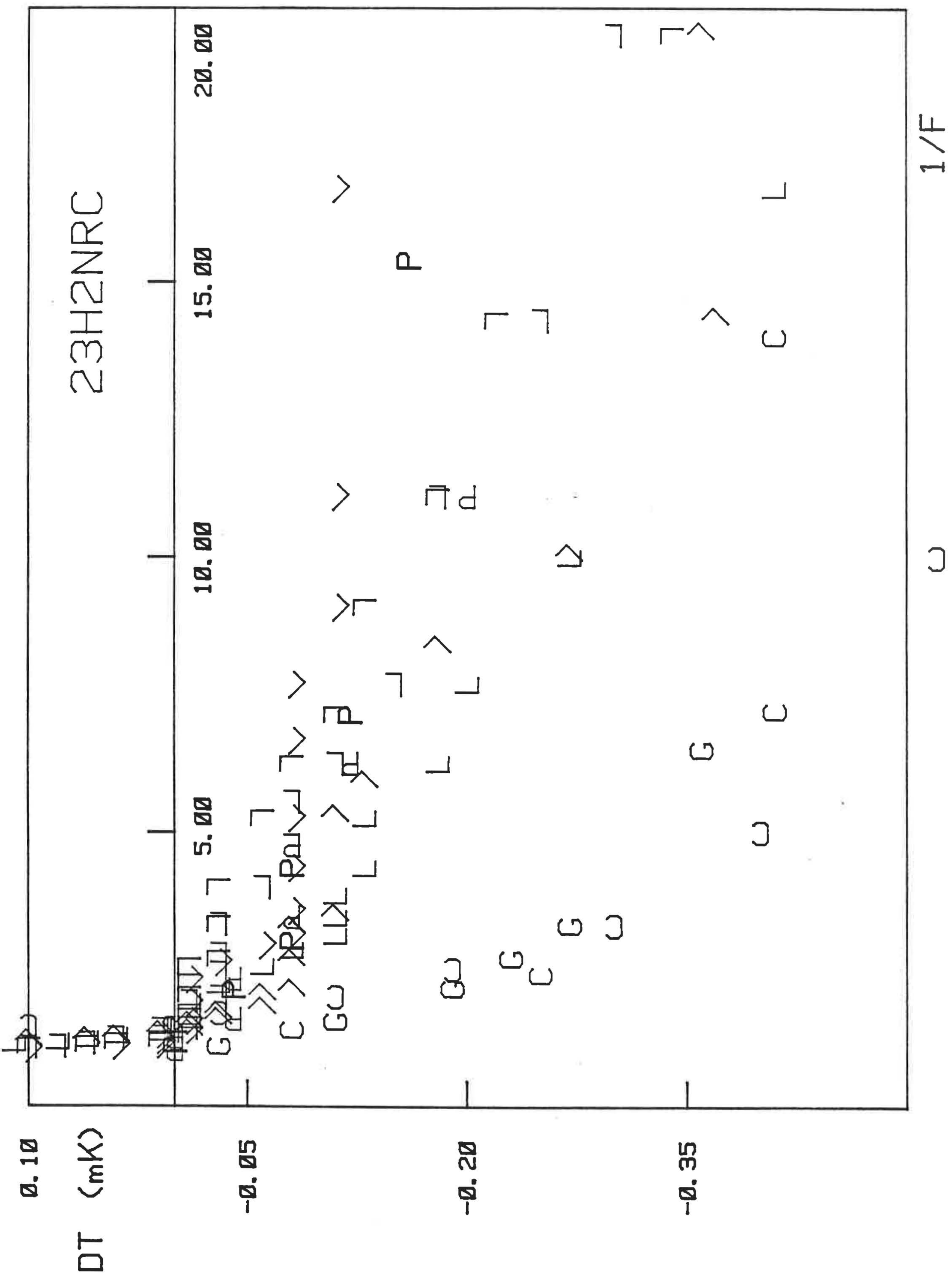
impurity analysis:

Enthalpy of melting: 5.33 J

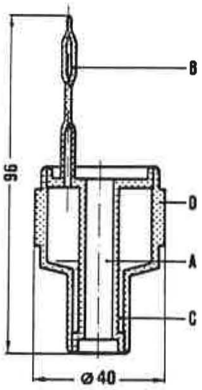
Measurements at — Resistance Ratio (W)

LABORATORY	IMGC		NML		NPL		NRC	
Date	Oct 80		Feb 83		Feb 80		Sep 79	
thermometer N°	PL01-6		1731676		1728839		1521389	
Ro (ohm)	25.271140		25.522800		25.559570		25.523332	
Typical melting plateau	15%	0983	5 %	0022	7 %	5059	4 %	1490
	30%	0985	7 %	0034	14%	5060	7 %	1650
	37%	0986	9 %	0051	23%	5061	14%	1650
	45%	0987	13%	0057	33%	5061	42%	1690
	62%	0989	16%	0069	47%	5062	71%	1730
	90%	0991	25%	0081	67%	5063		
			36%	0086	88%	5063		
melted fraction F			50%	0086				
			61%	0092				
			71%	0098				
			86%	0110				
W(100%)	0.001409917		0.001350095		0.001350630		0.001301750	
T (K) LAB	13.80995		13.80962		13.81008		13.80881	
T (K) NPL	13.81562		13.80993		13.81008		13.80927	
average drift (mK/h)	5				0.3			
recovery time to 0.1mK (min)	10				1			
overheating at 50% (mK/mW)	1.5							
enthalpy of melting (J)	4.2						5.0	

Notes:


23H2NRC
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 7801 H2 NRLM



NRLM

Manufacturer: NRLM

Sealing date: Jun 1978

cell total mass: 174 g

sample mass: 0.038 mol

Filling gas type:

impurity analysis: nom. 99.99999%
tot. 0.6 vppm

Enthalpy of melting: 4.42 J

Measurements at — Resistance Ratio (W)

LABORATORY	ASMW	IMGC	NML	NPL	NRC
Date	Dec 80	Mar 79	Oct 79	May 79	Jun 80
thermometer N°	217997	PL01-6	1731676	1728839	1521389
Ro (ohm)	25.418540	25.271140	25.522800	25.559570	25.523332

Typical melting plateau — melted fraction F

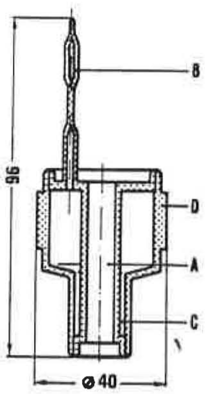
ASMW F	ASMW W	IMGC F	IMGC W	NML F	NML W	NPL F	NPL W	NRC F	NRC W
5 %	1963	5 %	0982	5 %	5004	4 %	5060	11%	1810
10%	1982	10%	0987	10%	5006	6 %	5061	14%	1850
22%	1986	20%	0987	20%	5006	9 %	5061	28%	1850
30%	1982	30%	0985	30%	5006	19%	5062	55%	1810
50%	1982	50%	0987	40%	5006	41%	5063	69%	1770
57%	1990	65%	0989	50%	5006	45%	5063	83%	1810
70%	1982	75%	0987	60%	5006	51%	5063		
90%	1986			70%	5006	59%	5063		
				80%	5006	87%	5063		
				95%	5006				

	ASMW	IMGC	NML	NPL	NRC
W(100%)	0.001319900	0.001409870	0.001350063	0.001350630	0.001301830
T (K) LAB		13.80975	13.80950	13.81008	13.80914
T (K) NPL	13.81057	13.80542	13.80981	13.81008	13.80960
average drift (mK/h)	4	5			
recovery time to 0.1mK (min)	0.5-3	3	1	1	
overheating at 50% (mK/mW)	0.3	2			
enthalpy of melting (J)	4.3	4.17			4.64

Notes:

C E L L T Y P E: 7801 H2 NRLM

Manufacturer: NRLM



NRLM

Sealing date: Jun 1978

cell total mass: 174 g

sample mass: 0.038 mol

Filling gas type:

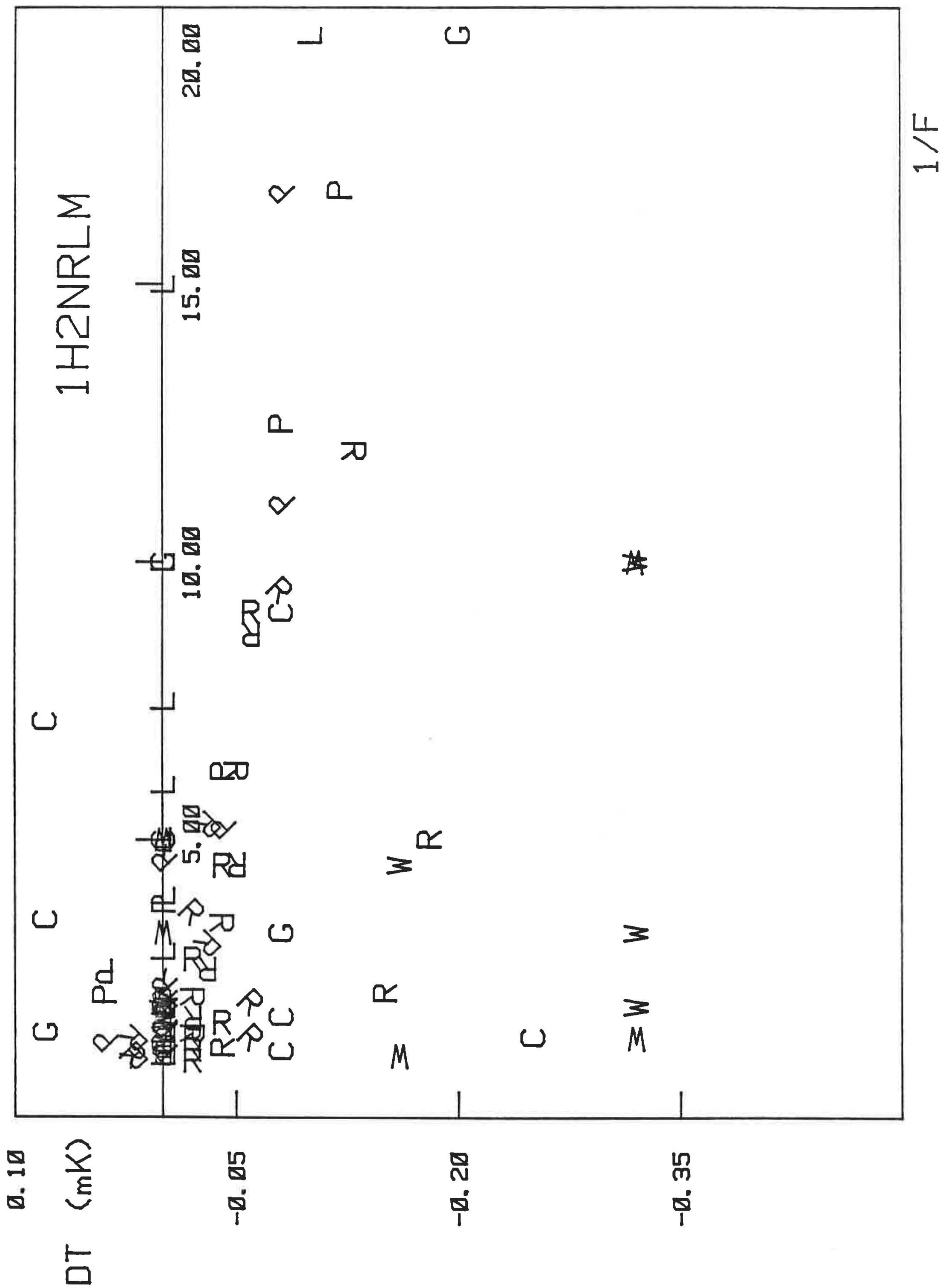
impurity analysis: nom. 99.99999%
tot. 0.6 vppm

Enthalpy of melting: 4.42 J

Measurements at — Resistance Ratio (W)

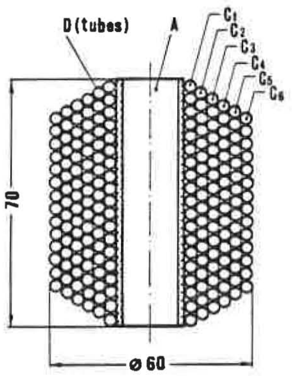
LABORATORY	NRLM		NRLM	
Date	Jul 78		Nov 81	
thermometer N°	(1)		7681	
Ro (ohm)			25.362929	
Typical melting plateau / melted fraction F	8 %	34863	1.7%	398435
	10%	34875	20%	400794
	16%	34882	21%	00784
	28%	34887	41%	00784
	46%	34891	49%	00802
	67%	34891	61%	00783
	78%	34895	79%	00827
	82%	34891	81%	00783
	92%	34898		
W(100%)	0.001334895		0.001400810	
T (K) LAB			13.8115	
NPL			13.8134	
average drift (mK/h)			2.6	
recovery time to 0.1mK (min)				
overheating at 50% (mK/mW)				
enthalpy of melting (J)	4.42		4.37	

Notes: (1) 1978 data reported only for record.


1H2NRLM
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L   T Y P E: PRMI (H2)

International Intercomparison
CCT: 1979-1983



PRMI

Manufacturer: PRMI
Multicomponent cell
(argon,oxygen,neon,hydrogen)

Sealing date: Dec 1978

cell total mass:

sample mass:

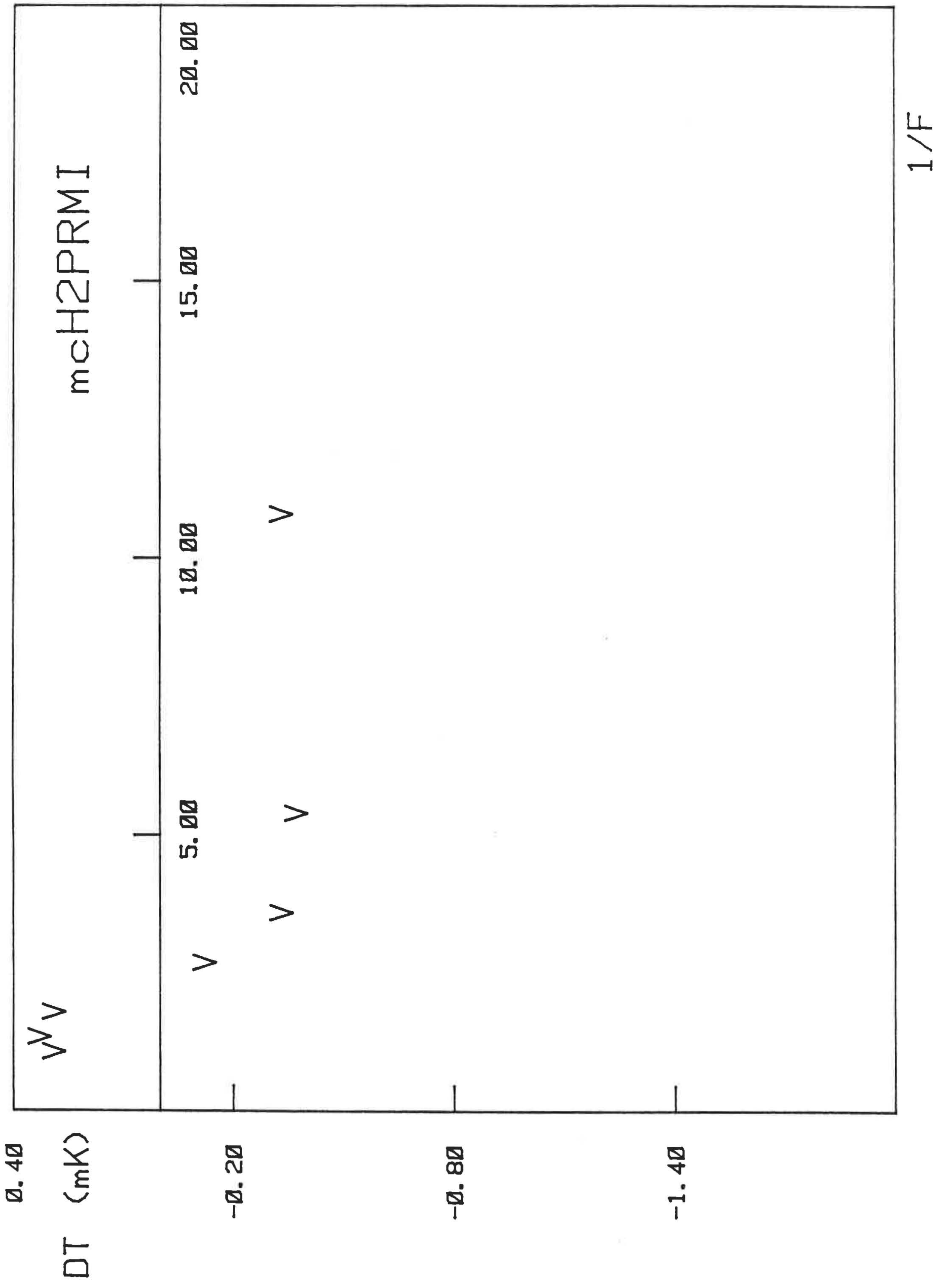
Filling gas type: commercial source purif. through palladium filter

impurity analysis:

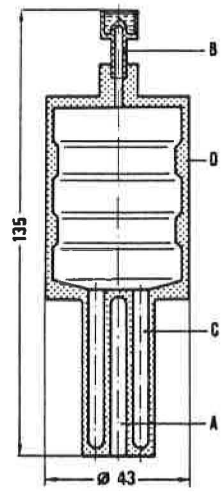
Enthalpy of melting:

Measurements at	Resistance Ratio (W)
LABORATORY	PRMI
Date	Nov 81
thermometer N°	1842381
Ro (ohm)	25.544950
Typical melting plateau / melted fraction F	9 % 8822 19% 8821 28% 8822 37% 8827 56% 8837 74% 8838 93% 8837
W(100%)	0.00118830
T (K) LAB	
T (K) NPL	13.81033
average drift (mK/h)	2
recovery time to 0.1mK (min)	10
overheating at 50% (mK/mW)	0.6
enthalpy of melting (J)	

Notes:


mcH2PRMI
1/F
DT (mK)
0.40
-0.20
-0.80
-1.40
5.00
10.00
15.00
20.00

C E L L   T Y P E: 7 CH4 BIPM



Manufacturer: BIPM

Sealing date: Sep 1977

cell total mass: 230 g

sample mass: 0.15 mol

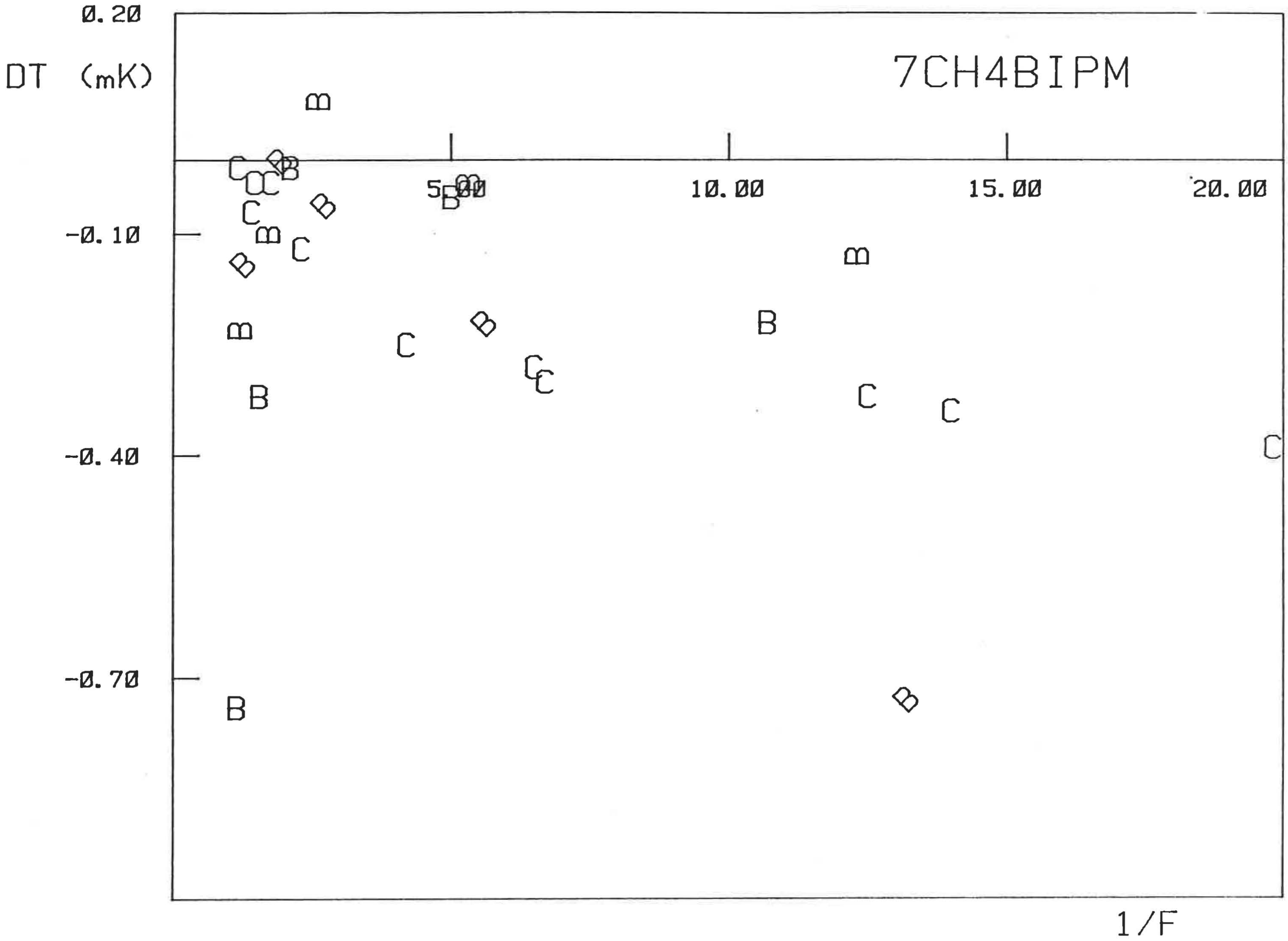
Filling gas type: Air Liquide

impurity analysis: nom. 99.9995%
nitrogen 2 vppm
oxygen 0.5
carb.diox. 0.1
hydrogen <0.1; hydroc. <0.1

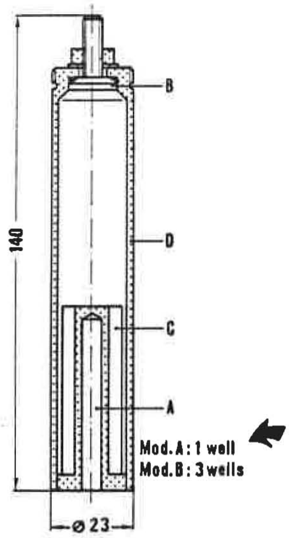
Enthalpy of melting: 140 J

Measurements at	Resistance Ratio (W)			
LABORATORY	BIPM		NRC	
Date	Apr 80		Aug 79	
thermometer N°	226321		1521389	
Ro (ohm)	25.369150		25.523332	
Typical melting plateau	9 %	3847	4 %	7934
	20%	3934	8 %	7954
	50%	3946	15%	7973
			24%	7993
			44%	8051
			58%	8091
			70%	8091
melted fraction F			73%	8071
			88%	8101
W(100%)	0.24593950 (1)		0.24588103	
T (K) LAB	90.68661		90.68539	
T (K) NPL	90.68402		90.68464	
average drift (mK/h)	<3			
recovery time to 0.1mK (min)	30-40		20	
overheating at 50% (mK/mW)	0.3			
enthalpy of melting (J)	143			

Notes: (1) in oct 77/nov 78 the same cell and thermometer gave
W(100%)= 0.2459363 ≙ T(LAB)= 90.68586 K: no explanation available.


7CH4BIPM
DT (mK)
0.20
-0.10
-0.40
-0.70
5.00
10.00
15.00
20.00
1/F

C E L L   T Y P E: 2 CH4 IMGC



Manufacturer: IMGC

Sealing date: Aug 1976

cell total mass: 195 g

sample mass: 0.23 mol

Filling gas type: Matheson

impurity analysis: nom. 99.995%

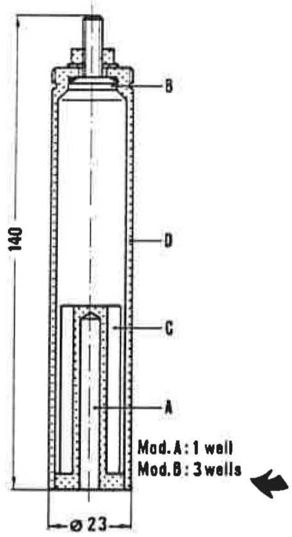
Enthalpy of melting: 220 J

Measurements at — Resistance Ratio (W)

LABORATORY	ASMW		IMGC		NIM		NPL		NRC	
Date	Dec 79		Aug 76		Mar 81		Apr 78		Dec 76	
thermometer N°	217990		PL01-6		188640		1728839		1521389	
Ro (ohm)	24.186290		25.271140		24.164330		25.559570		25.523332	
	10%	8901	5 %	0740	7 %	3716	9 %	59850	5.4%	5662
	22%	8982	7.5%	1000	14%	3794	16%	9900	11%	6504
Typical	40%	9013	10%	1240	20%	3799	22%	9930	15%	6782
melting	58%	9023	25%	1780	27%	3827	31%	9940	16%	6813
plateau	60%	9016	42%	2000	41%	3839	41%	9960	26%	7182
	76%	9024	62%	2140	55%	3858	53%	9970	33%	7244
	82%	9031			68%	3868	87%	9990	44%	7464
melted	89%	9026							65%	7624
fraction F									78%	7664
W(100%)	0.24590300		0.24592185		0.24638710		0.24600010		0.24587703	
T (K) LAB	90.68350		90.68518		90.68370		90.68372		90.68447	
T (K) NPL	90.68350		90.68386				90.68372		90.68373	
average drift (mK/h)	2		10							
recovery time to 0.1mK (min)	5-20		40-20				15			
overheating at 50% (mK/mW)	0.3		0.04							
enthalpy of melting (J)	224.5		215						215	

Notes:

C E L L T Y P E: 2 CH_4 IMGC



Manufacturer: IMGC

Sealing date: Aug 1976

cell total mass: 195 g

sample mass: 0.23 mol

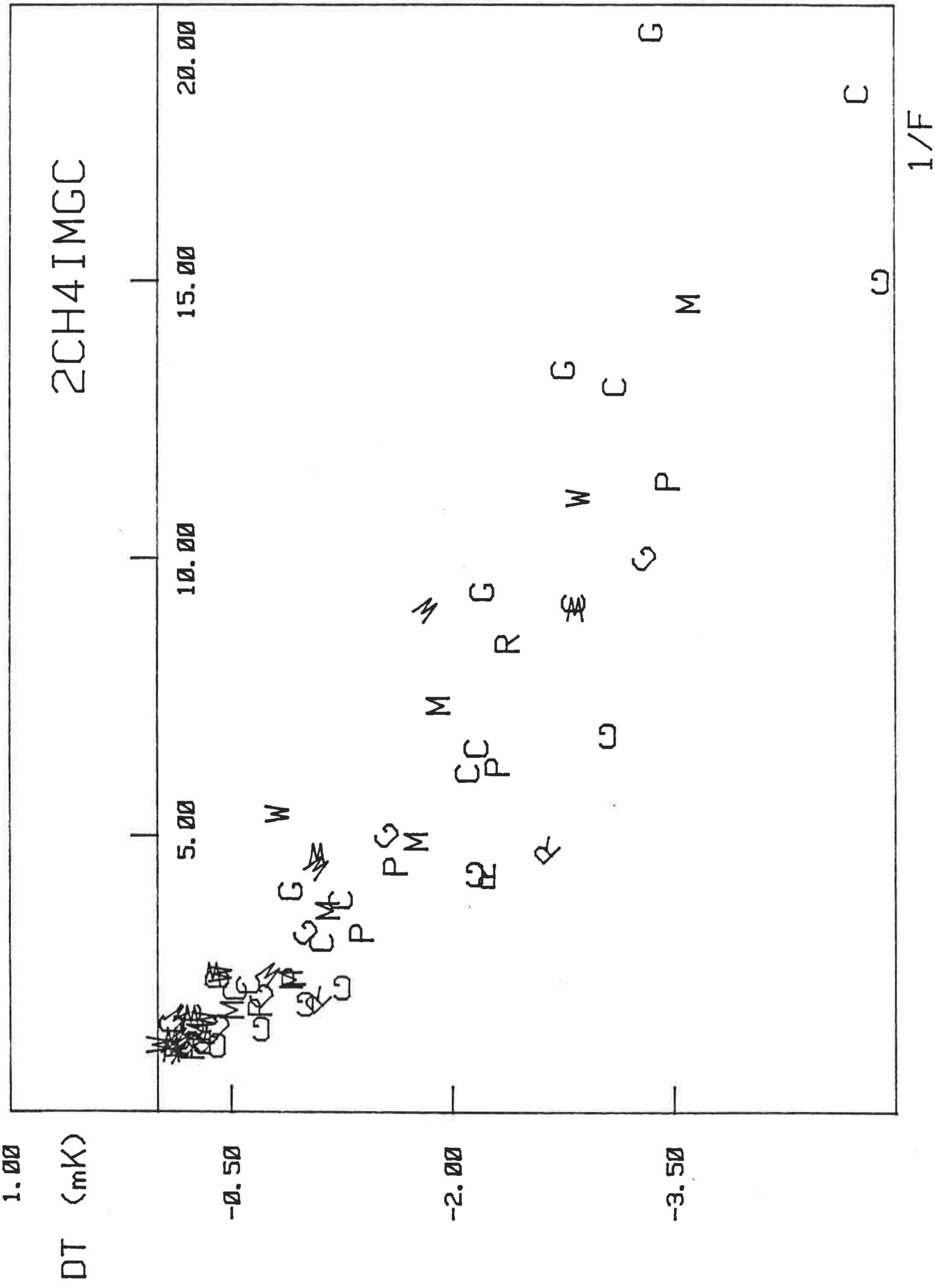
Filling gas type: Matheson

impurity analysis: nom. 99.995%

Enthalpy of melting: 220 J

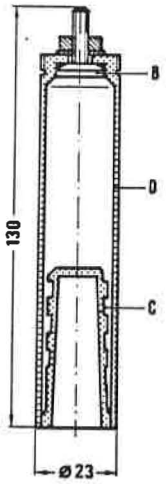
Measurements at	Resistance Ratio (W)
LABORATORY	NRLM
Date	Nov 81
thermometer N°	7681
Ro (ohm)	25.363524
Typical melting plateau / melted fraction F	19% 599131 21% 9252 23% 9406 49% 9930 77% 600263 79% 0241 87% 0112
W(100%)	0.24600250
T (K) LAB	90.68811
T (K) NPL	90.68798
average drift (mK/h)	4
recovery time to 0.1mK (min)	10-40
overheating at 50% (mK/mW)	
enthalpy of melting (J)	218

Notes:



2CH4IMGC
1/F
5.00
10.00
15.00
20.00
DT (mK)
1.00
-0.50
-2.00
-3.50

C E L L T Y P E: 12 CH4 IMGC



Manufacturer: IMGC

Sealing date: Apr 1979

cell total mass: 165.573 g

sample mass: 0.11489 mol

Filling gas type: Matheson

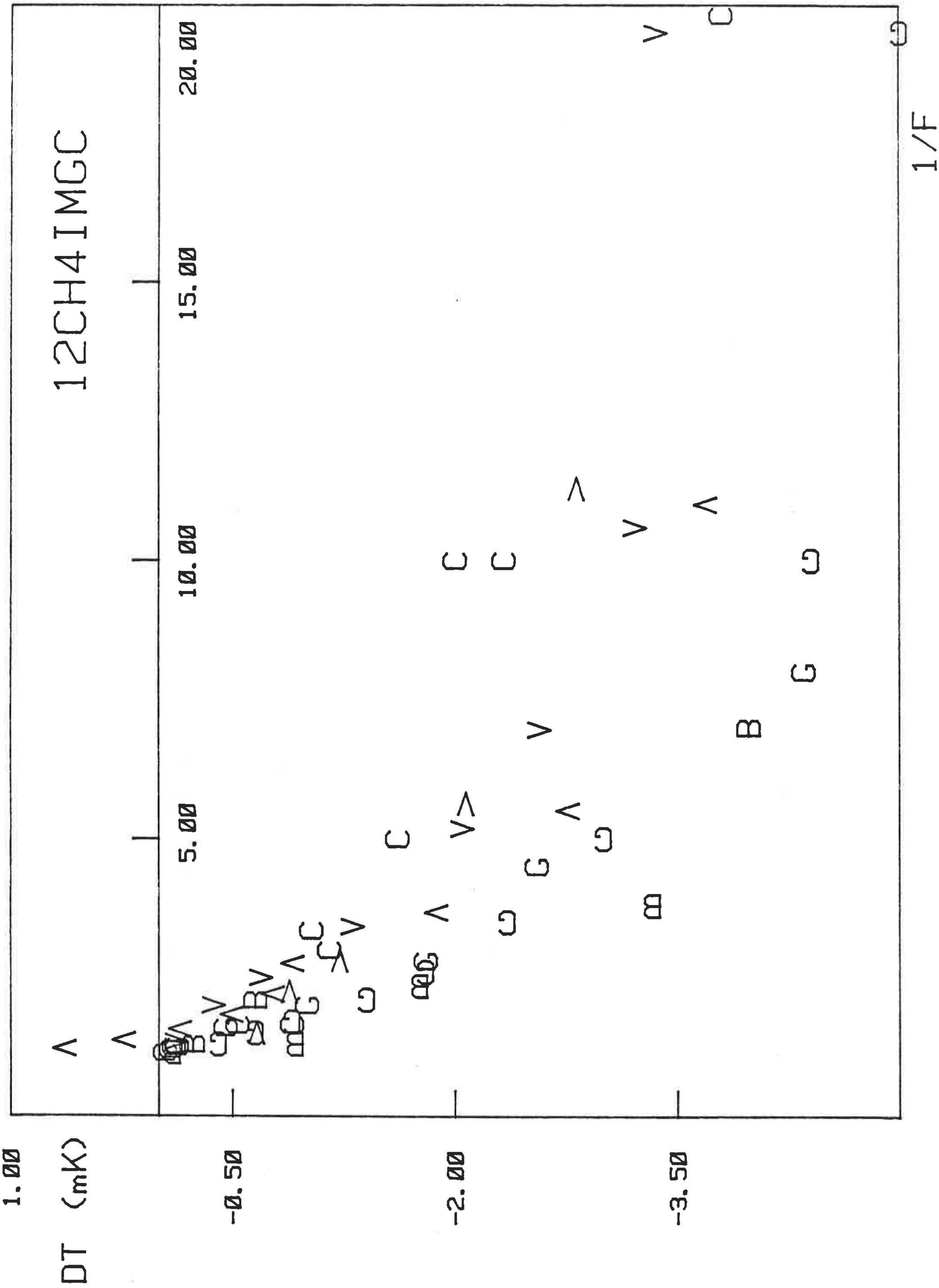
impurity analysis: nom. 99.995%
oxygen+argon 0.25 vppm
carbon dioxide 0.1
nitrogen 2.3

Enthalpy of melting: 108 J

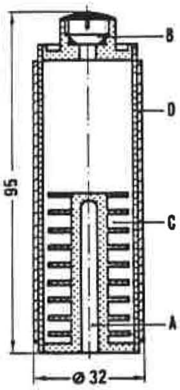
Measurements at — Resistance Ratio (W)

LABORATORY	BIPM		IMGC		NRC		PRMI	
Date	Mar 80		Apr 79-Oct 81		Aug 79		Dec 81	
thermometer N°	226321		PL01-6		1521389		1842381	
Ro (ohm)	25.369150		25.271140		25.523332		25.544950	
Typical melting plateau, melted fraction F	14%	1880	5 %	89927	2.5%	5897	5 %	7941
	48%	3300	10%	90422	10%	6739	9 %	8003
	77%	3450	20%	0877	20%	7052	14%	8283
			29%	1154	30%	7307	19%	8509
			38%	1392	60%	7621	29%	8829
			48%	1550	80%	7699	40%	9099
			59%	1787	85%	7738	50%	9241
			67%	1905			74%	9349
			77%	1985				
W(100%)	0.24593500		0.24592120		0.24587753		0.24579400	
T (K) LAB	90.68554		90.68503		90.68459			
T (K) NPL	90.68298		90.68371		90.68384		90.67968	
average drift (mK/h)	-2.6		10				<1	
recovery time to 0.1mK (min)	30		20		30		90	
overheating at 50% (mK/mW)	5 (1)		0.02				0.3	
enthalpy of melting (J)	76		107		105		117	

Notes: (1) cell heated from inside the block.



12CH4IMGC
DT (mK)
1/F
1.00
-0.50
-2.00
-3.50
5.00
10.00
15.00
20.00



NRC

Manufacturer: NRC

Sealing date: Aug 1979

cell total mass: 197.291 g

sample mass:

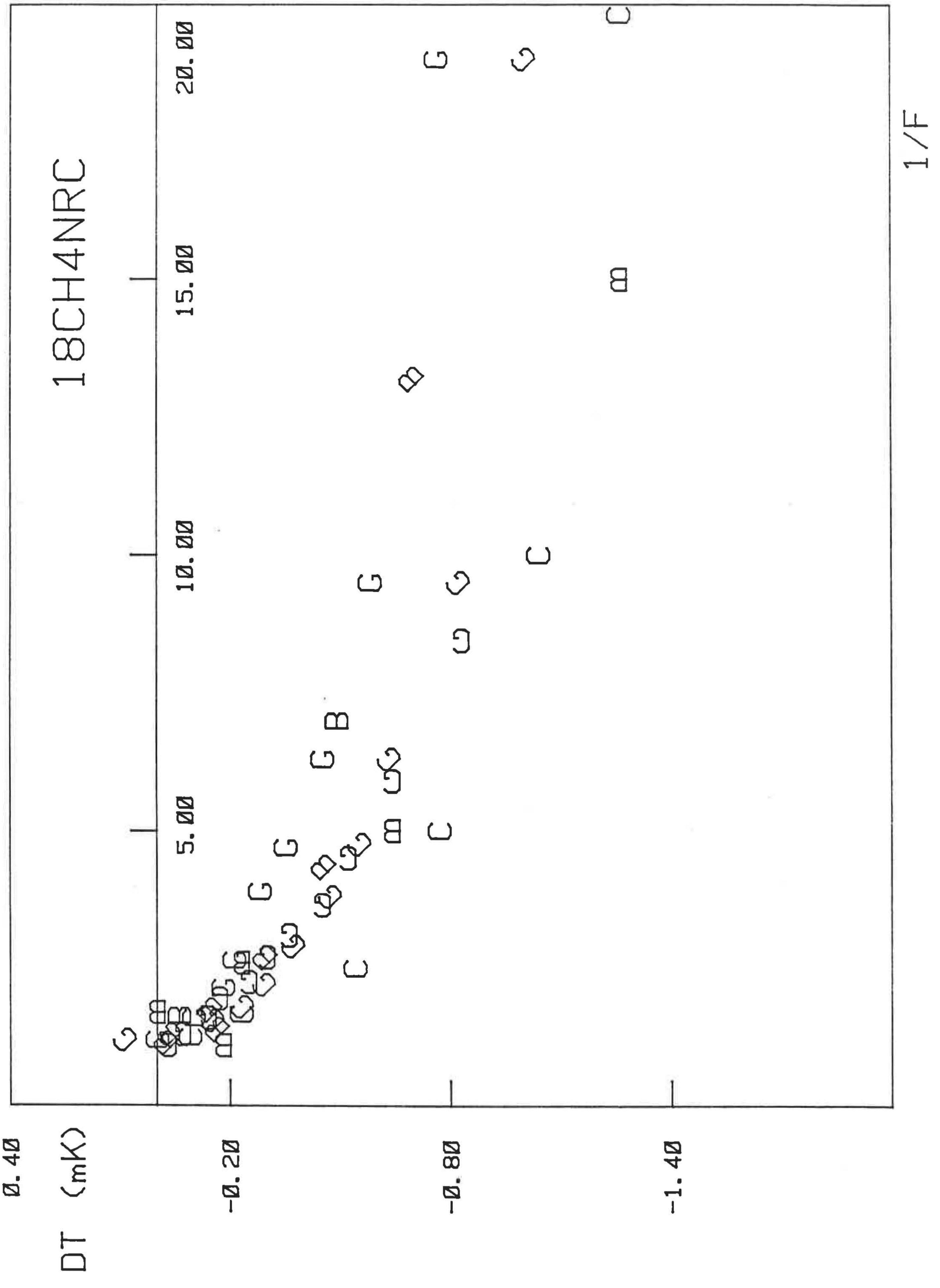
Filling gas type: commercial source purified at NRC

impurity analysis:

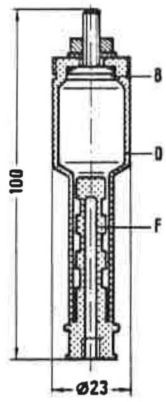
Enthalpy of melting: 60 J

Measurements at	Resistance Ratio (W)		
LABORATORY	BIPM	IMGC	NRC
Date	Feb 80	Jul 80	Aug 79
thermometer N°	226321	PL01-6	1521389
Ro (ohm)	25.369088	25.271140	25.523332
Typical melting plateau melted fraction F	7 % 2977 20% 3245 38% 3415 59% 3513 90% 3434	12% 1922 17% 2005 22% 2056 27% 2092 32% 2124 38% 2151 45% 2175 53% 2207 62% 2223 80% 2254 90% 2261	2.5% 7229 5 % 7425 10% 7523 20% 7640 40% 7738 60% 7875 80% 7933
W(100%)	0.24593430 (1)	0.24592280	0.24587955
T (K) LAB	90.68566	90.68540	90.68505
T (K) NPL	90.68310	90.68408	90.68430
average drift (mK/h)	-6	5	
recovery time to 0.1mK (min)	5	5-10	30
overheating at 50% (mK/mW)	0.12	0.2	
enthalpy of melting (J)	84	51	60

Notes: (1) suggested BIPM value: 0.2459354.


18CH4NRC
1/F
DT (mK)
0.40
-0.20
-0.80
-1.40
5.00
10.00
15.00
20.00

C E L L T Y P E: 2 N2 IMGC



Manufacturer: IMGC

Sealing date: Feb 1980

cell total mass: 78.429 g

sample mass: 0.03596 mol

Filling gas type: Matheson

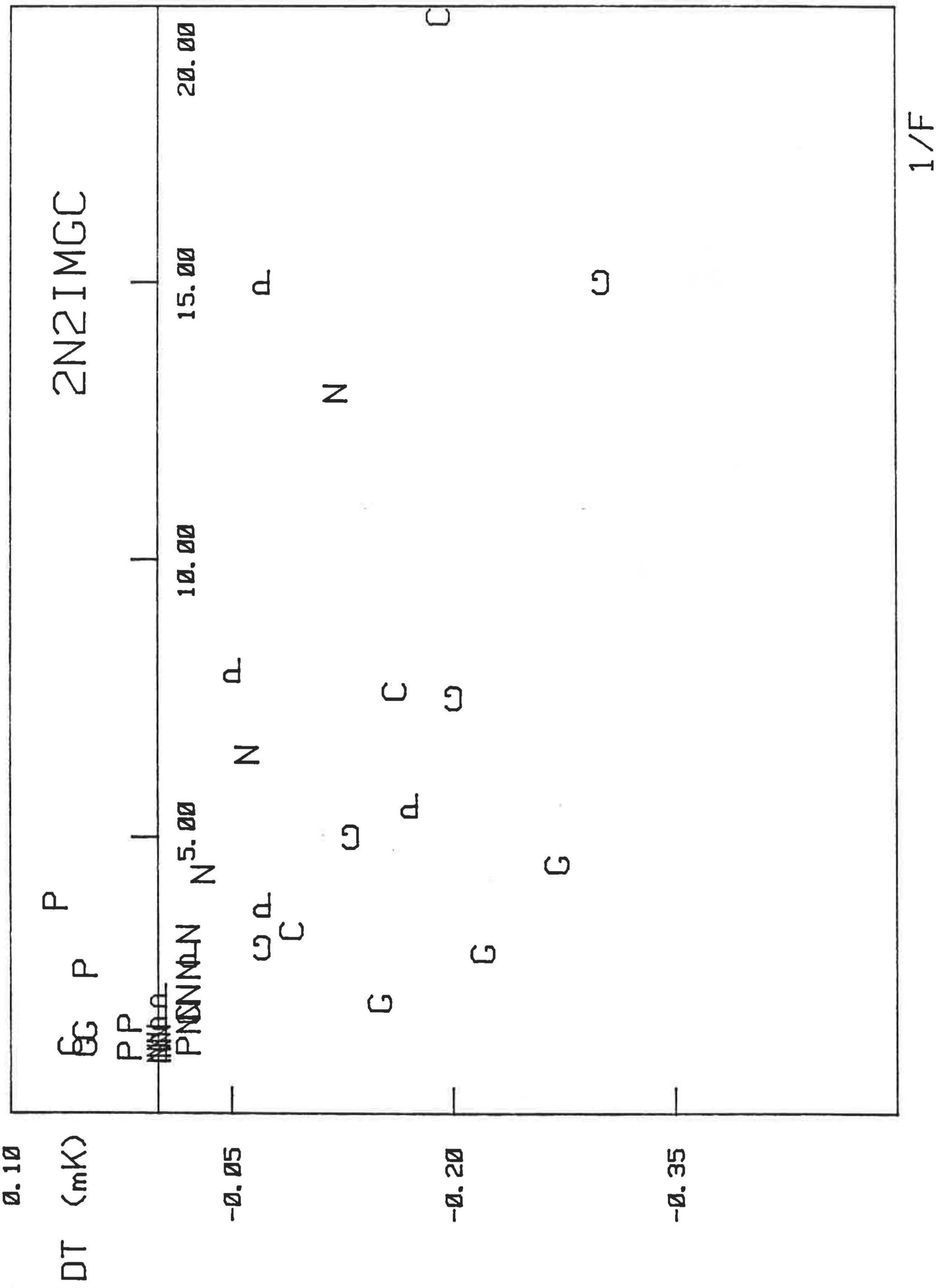
impurity analysis: nom. 99.9995%
oxygen+argon 1.6 vppm

Enthalpy of melting: 25.9 J

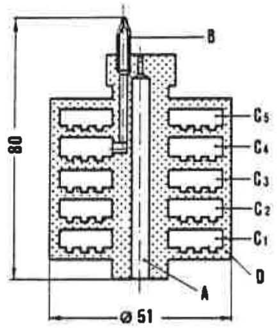
Measurements at — Resistance Ratio (W)

LABORATORY	IMGC		INM		NPL		NRC	
Date	Aug 80		Sep 83		Nov 80		Nov 81	
thermometer N°	45		1812283		1728839		1872179	
Ro (ohm)	25.679410		25.494711		25.559570		25.582650	
Typical melting plateau: melted fraction F	7 %	8549	7.7%	1753	7 %	6650	0.5%	3356
	13%	8587	15%	1780	12%	6660	1.1%	3759
	20%	8617	23%	1792	18%	6610	4.5%	3793
	33%	8636	31%	1796	27%	6650	13%	3805
			38%	1796	35%	6670	30%	3832
			46%	1796	47%	6680	56%	3856
			54%	1796	58%	6680	82%	3879
			62%	1796	70%	6680		
			69%	1804	88%	6680		
			91%	1804				
W(100%)	0.12758665		0.12741804		0.12756680		0.12743810	
T (K) LAB	63.14627		63.14596		63.14611		63.14637	
T (K) NPL	63.14626		63.14671		63.14611		63.14562	
average drift (mK/h)	2		-1.5 to +3		0.3			
recovery time to 0.1mK (min)	10		30		10		20	
overheating at 50% (mK/mW)	0.1							
enthalpy of melting (J)	23							

Notes:


2N2IMGC
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: BCM4 INM (N2)



INM mod. BCM

Manufacturer: INM
Multicomponent cell
(argon,oxygen,neon,nitrogen)

Sealing date: Jan 1982

cell total mass: 369.83 g

sample mass: 0.0218 mol

Filling gas type:

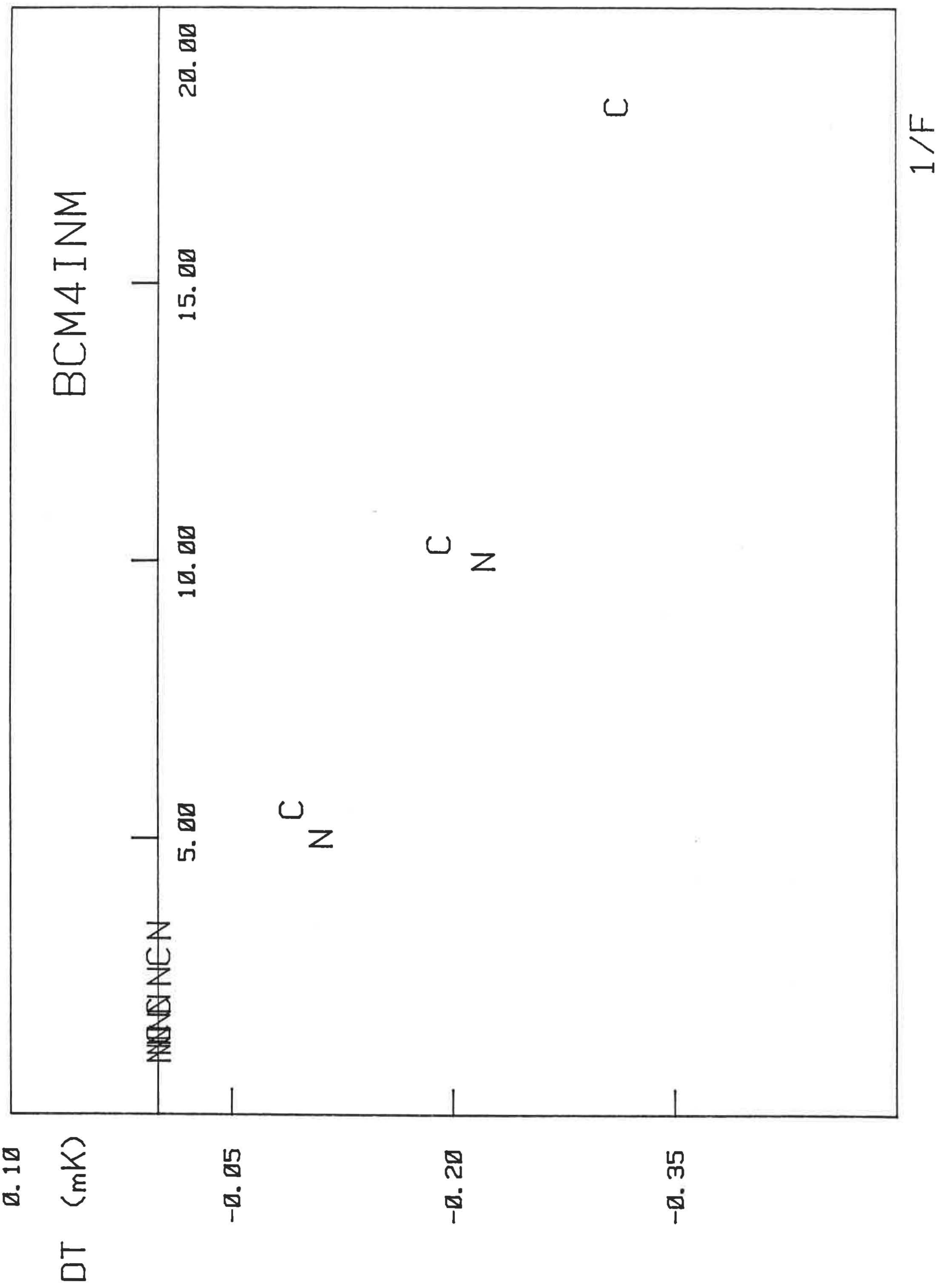
impurity analysis:
oxygen 5 vppm
carbon ox. 5
carb.diox. 10

Enthalpy of melting: 13 J

Measurements at — Resistance Ratio (W)

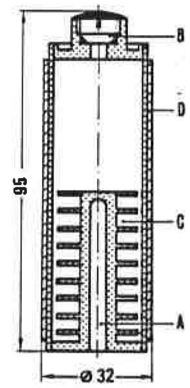
LABORATORY	INM		NRC	
Date	Feb 82		Jul 82	
thermometer N°	1812283		1872179	
Ro (ohm)	25.494713		25.582657	
	0 %	1480	5.5%	3665
	10%	1637	9.7%	3715
Typical	20%	1684	18%	3754
melting	30%	1731	35%	3793
plateau	40%	1731	52%	3793
	50%	1731	68%	3793
	60%	1731		
melted	70%	1731		
fraction	80%	1731		
F	90%	1731		
W(100%)	0.12741731		0.12743793	
T (K) LAB	63.14579		63.14633	
NPL	63.14654		63.14558	
average drift (mK/h)	-12 to 3			
recovery time to 0.1mK (min)	10		30	
overheating at 50% (mK/mW)				
enthalpy of melting (J)	13			

Notes:


BCM41NM
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 33 N2 NRC

Manufacturer: NRC



NRC

Sealing date: Jul 82

cell total mass: 205.100 g

sample mass: 0.05236 mol

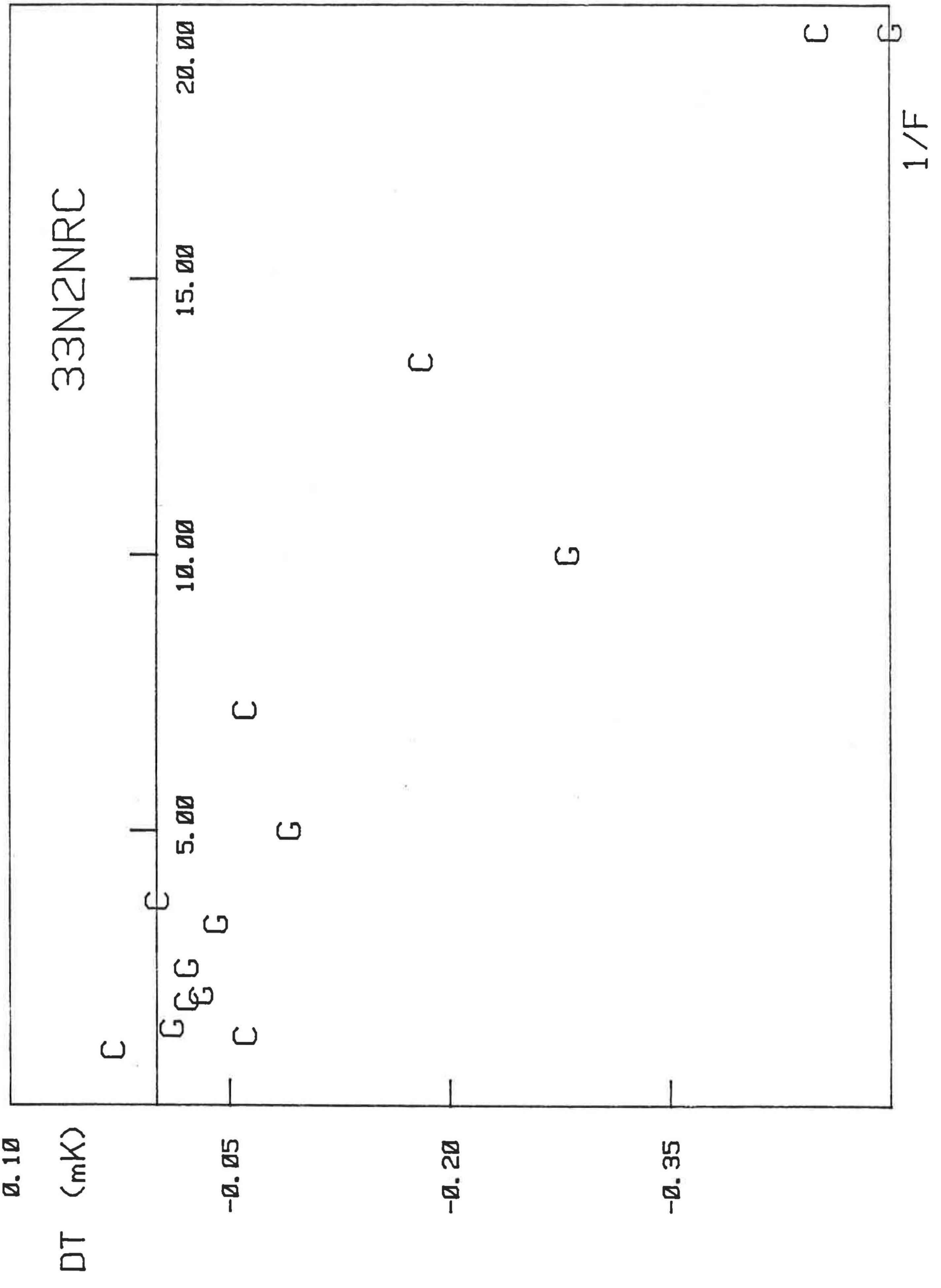
Filling gas type: MG Scientific Gases

impurity analysis: research grade

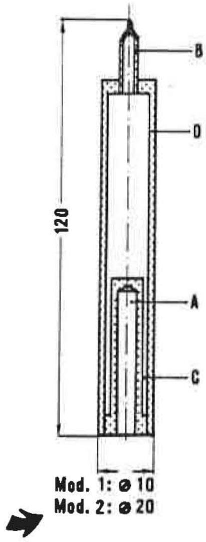
Enthalpy of melting: 37.4 J

Measurements at	Resistance Ratio (W)			
LABORATORY	IMGC		NRC	
Date	Jun 83		Jul 82	
thermometer N°	45		1872179	
Ro (ohm)	25.679410		25.582651	
	5%	8430	2.6%	3430
	10%	8528	4.2%	3555
Typical melting plateau	20%	8603	7.4%	3664
	30%	8622	14%	3715
	40%	8630	27%	3738
	50%	8626	53%	3731
	70%	8632	79%	3715
melted fraction F			99%	3754
W(100%)	0.12758642		0.12743740	
T (K) LAB	63.14622		63.14620	
T (K) NPL	63.14621		63.14545	
average drift (mK/h)	2			
recovery time to 0.1mK (min)	1		13	
overheating at 50% (mK/mW)	0.02			
enthalpy of melting (J)	37.2		37.4	

Notes:


33N2NRC
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L   T Y P E :   1 NE ASMW



Manufacturer: ASMW

Sealing date: Nov 1981

cell total mass: 105 g

sample mass: 0.0375 mol

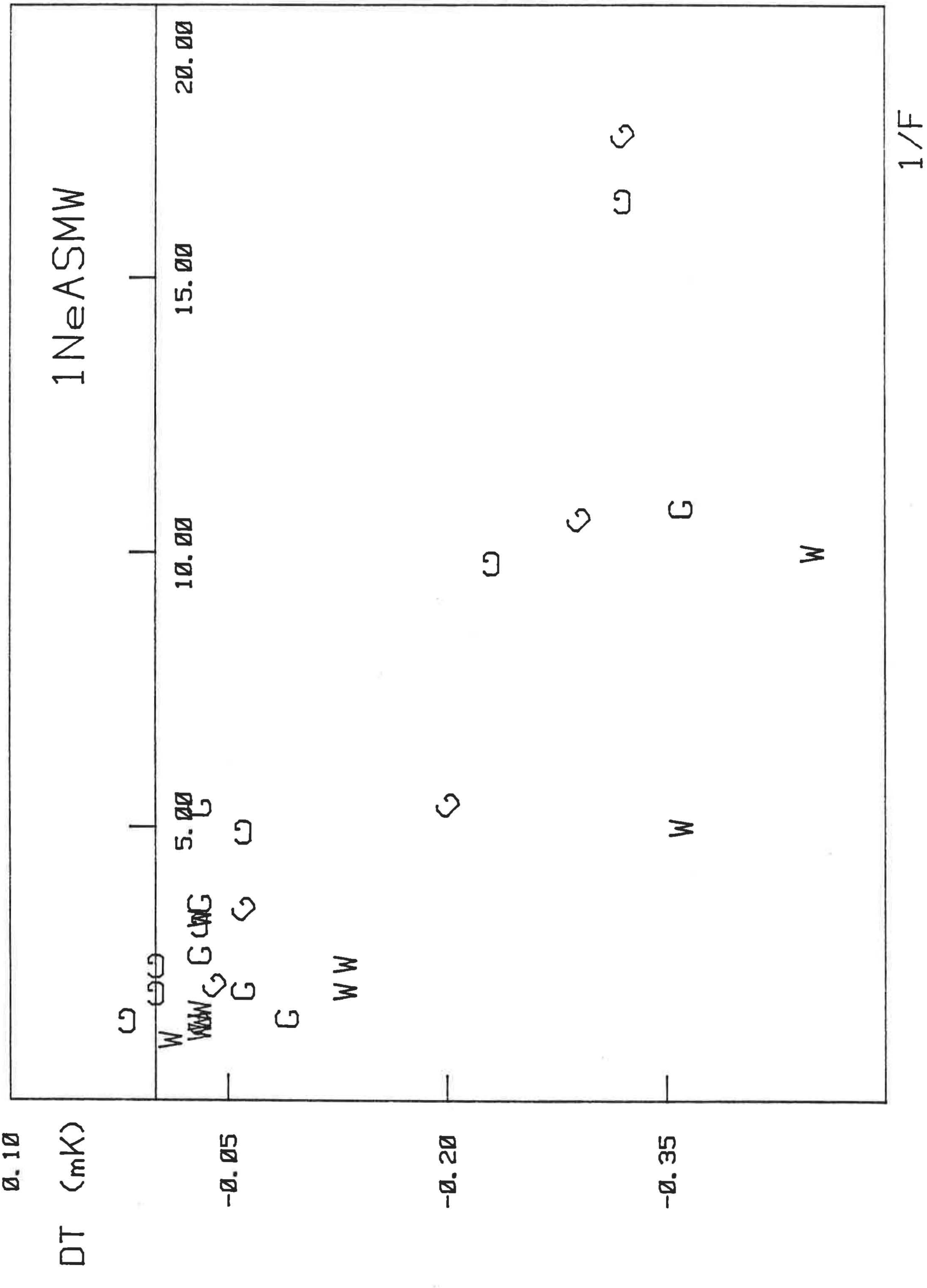
Filling gas type: Linde AG type R5.0

impurity analysis: nom. 99.999%

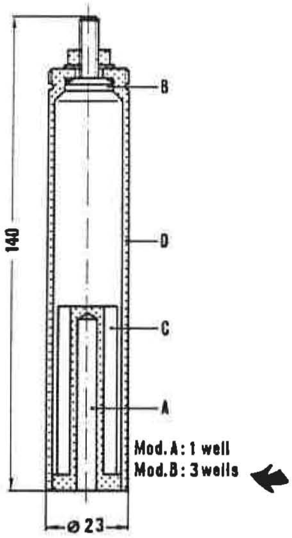
Enthalpy of melting: 12.2 J

Measurements at	Resistance Ratio (W)			
LABORATORY	ASMW		IMGC	
Date	Dec 82		May 83	
thermometer N°	207278		PL01-6	
Ro (ohm)	25.346860		25.271140	
Typical melting plateau	10%	3317	6.1%	8061
	20%	3329	10%	8069
	30%	3369	20%	8089
	40%	3357	31%	8093
	50%	3357	41%	8097
	60%	3369	53%	8097
	70%	3369	69%	8099
melted fraction F	80%	3369		
	90%	3373		
W(100%)	0.00863370		0.00868097	
T (K) LAB / NPL	24.56312 (1)		24.56308	
average drift (mK/h)	5		2	
recovery time to 0.1mK (min)	1		1	
overheating at 50% (mK/mW)	0.55		0.7	
enthalpy of melting (J)	12.2		11.8	

Notes: (1) in Ref.55: T(NPL) = 24.5627 K.


1NeASMW
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00
1/F

C E L L T Y P E: 1 NE IMGC



Manufacturer: IMGC

Sealing date: Jun 1977

cell total mass: 200 g

sample mass: 0.32 mol

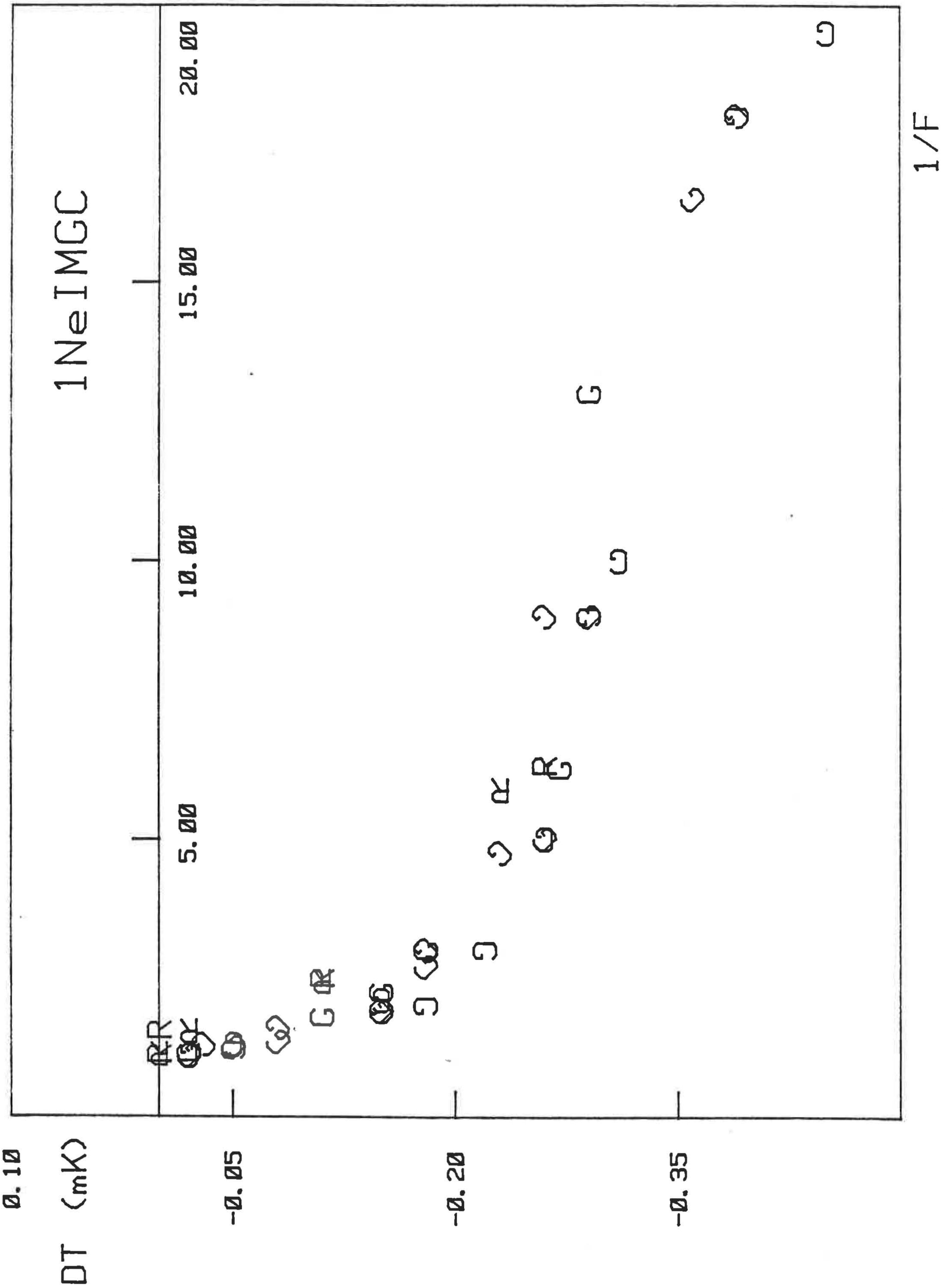
Filling gas type: Matheson

impurity analysis: nom. 99.995%
hydrogen 25 vppm
nitrogen 11.3
oxygen+argon 2.7

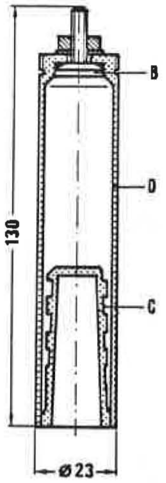
Enthalpy of melting: 106 J

Measurements at	Resistance Ratio (W)			
LABORATORY	IMGC		NRLM	
Date	Jun 77-Dec 81		Nov 81	
thermometer N°	PL01-6		7681	
Ro (ohm)	25.271140		25.362939	
Typical melting plateau	11%	8026	16%	30288
	20%	8030	17%	30345
	30%	8040	40%	30475
	50%	8044	41%	30495
	70%	8052	64%	30607
	80%	8054	65%	30600
			87%	30608
melted fraction F			89%	30633
W(100%)	0.008680620		0.008730630	
T (K) LAB	ref		24.5615	
T (K) NPL	24.56281 (1)		24.5622	
average drift (mK/h)	10		1.6	
recovery time to 0.1mK (min)	1		3-9	
overheating at 50% (mK/mW)	0.1			
enthalpy of melting (J)	106		104.8	

Notes: (1) with PL02-6 T(NPL) = 24.5617 K.


1NeIMGC
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 3 NE IMGC



Manufacturer: IMGC

Sealing date: Feb 1979

cell total mass: 165.449 g

sample mass: 0.11128 mol

Filling gas type: Matheson

impurity analysis: nom. 99.995%

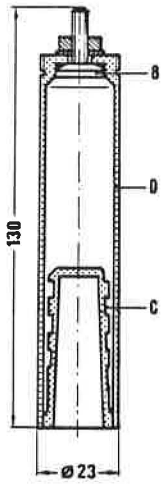
	a)	b)
hydrogen	-	<25
nitrogen	5.5	6.3
oxygen+argon	2.5	6.3

Enthalpy of melting: 37 J

Measurements at	Resistance Ratio (W)				
LABORATORY	ASMW	IMGC	INM	NML	NPL
Date	Mar 81	Feb 79-Dec 81	Sep 83	Dec 82	Jan 80
thermometer N°	207278	PL01-6	1812283	1731676	1728839
Ro (ohm)	25.346860	25.271140	25.494711	25.522800	25.559570
	8 % 3239	10% 8048	14% 8468	5 % 4581	6 % 4510
	21% 3266	12% 8050	28% 8471	7 % 4585	12% 4524
Typical	33% 3254	17% 8052	42% 8476	10% 4588	20% 4536
melting	50% 3262	20% 8054	56% 8492	15% 4592	29% 4543
plateau	70% 3270	33% 8056	70% 8495	20% 4594	40% 4545
		48% 8058	84% 8508	24% 4596	52% 4548
		67% 8058		32% 4600	67% 4550
melted		80% 8060		41% 4605	
fraction				51% 4607	
F				80% 4607	
				95% 4613	
W(100%)	0.008632780	0.008680620	0.008484935	0.008646070	0.008645500
T (K) LAB				24.56250	24.56163
T (K) NPL	24.56236	24.56281	24.56195	24.56190	24.56163
average drift (mK/h)	3.5	15			0.3
recovery time to 0.1mK (min)	1-5	1-5	12	1	2
overheating at 50% (mK/mW)	0.15	0.18		0.02	
enthalpy of melting (J)	36.3	35.7		37.5	

Notes:

C E L L T Y P E: 3 NE IMGC



Manufacturer: IMGC

Sealing date: Feb 1979

cell total mass: 165.449 g

sample mass: 0.11128 mol

Filling gas type: Matheson

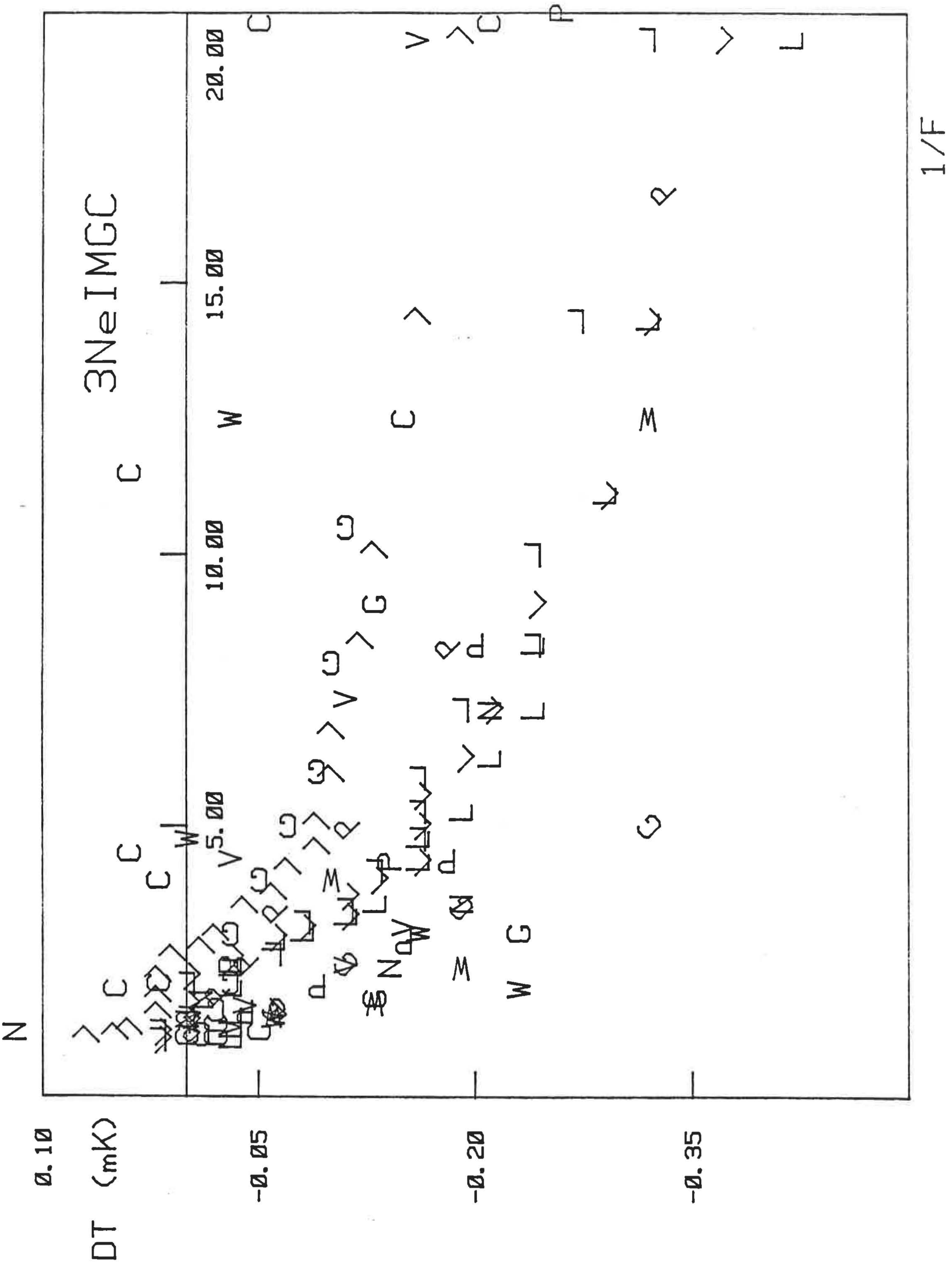
impurity analysis: nom. 99.995%

hydrogen	a) -	b) <25 vppm
nitrogen	5.5	6.3
oxygen+argon	2.5	6.3

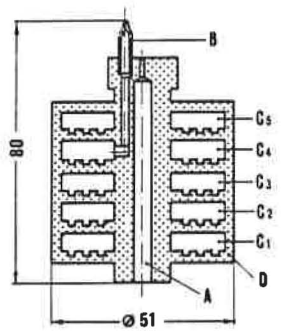
Enthalpy of melting: 37 J

Measurements at	Resistance Ratio (W)			
LABORATORY	NRC		PRMI	
Date	Jun 79		Dec 81	
thermometer N°	1521389		1842381	
Ro (ohm)	25.523332		25.544950	
	2 %	7282	5 %	5735
	4 %	7302	14%	5741
Typical melting plateau	9 %	7314	23%	5751
	25%	7314	32%	5737
	50%	7310	41%	5742
	75%	7306	59%	5750
	82%	7302	77%	5759
melted fraction F	90%	7306		
W(100%)	0.008573080		0.008457550	
T (K) LAB	24.56346			
NPL	24.56125		24.56187	
average drift (mK/h)			<1	
recovery time to 0.1mK (min)			20	
overheating at 50% (mK/mW)			0.02	
enthalpy of melting (J)				

Notes:


3NeIMGC
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: BCM4 INM (Ne)



INM mod. BCM

Manufacturer: INM
Multicomponent cell
(argon,oxygen,neon,nitrogen)

Sealing date: Jan 1982

cell total mass: 369.83 g

sample mass: 0.0262 mol

Filling gas type:

impurity analysis:

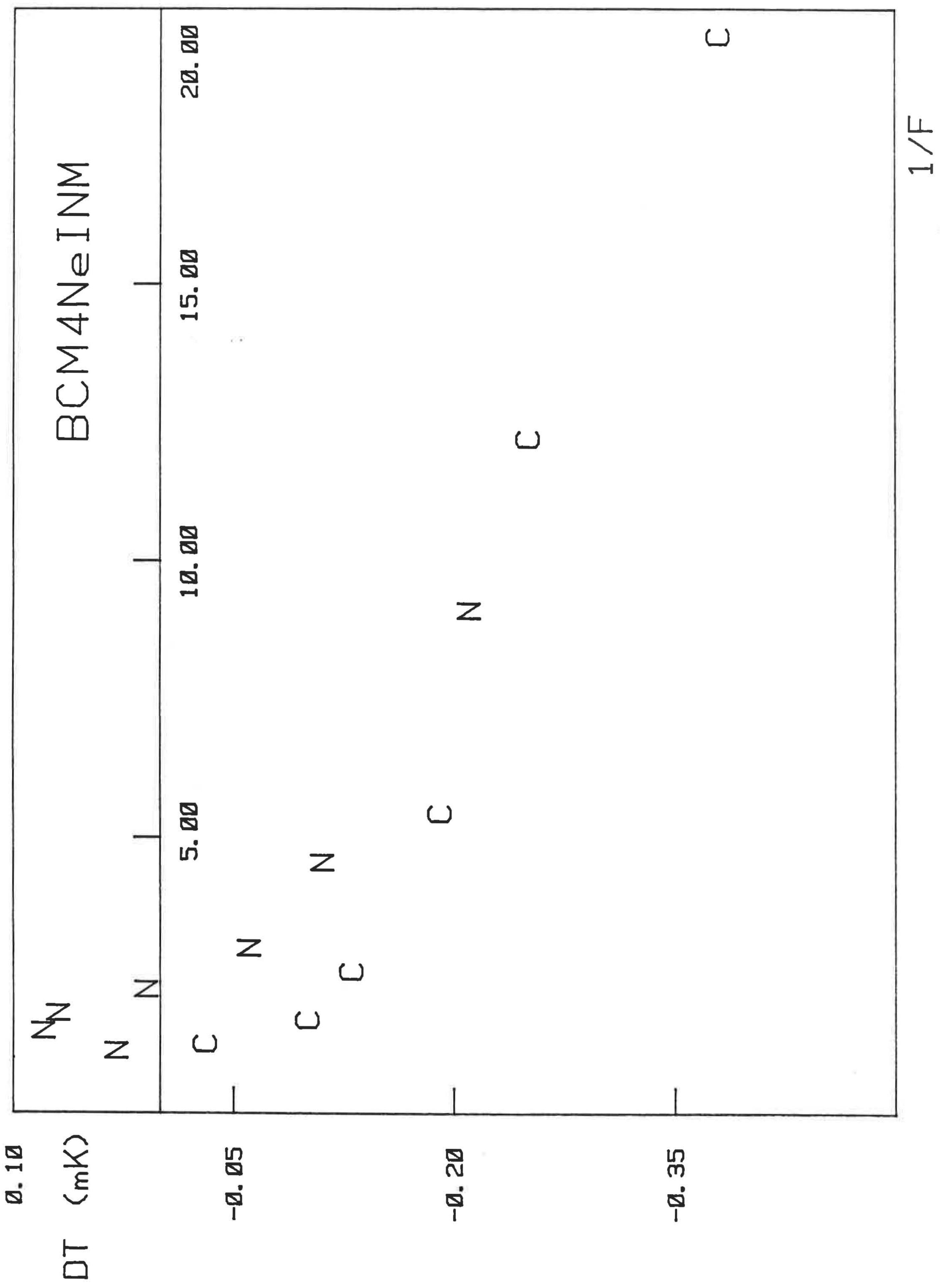
nitrogen	15	vppm
oxygen	3	
helium	80	
hydrogen	3	

Enthalpy of melting: 9.1 J

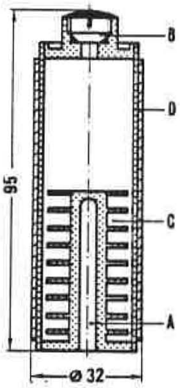
Measurements at — Resistance Ratio (W)

LABORATORY	INM		NRC	
Date	Jan 82		Jul 82	
thermometer N°	1812283		1872179	
Ro (ohm)	25.494713		25.582650	
Typical melting plateau	0 %	8470	4.1%	1655
	11%	8466	8.2%	1811
	22%	8479	18%	1890
	33%	8485	39%	1968
	44%	8493	59%	2007
	55%	8501	80%	2085
	66%	8503		
melted fraction F	77%	8513		
	88%	8495		
W(100%)	0.008484920		0.008552124	
T (K) LAB			24.56336	
T (K) NPL	24.56194		24.56115	
average drift (mK/h)	-5			
recovery time to 0.1mK (min)	6		18	
overheating at 50% (mK/mW)				
enthalpy of melting (J)	9.1			

Notes:


BCM4NeINM
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 12 NE NRC



NRC

Manufacturer: NRC

Sealing date: Jun 1979

cell total mass: 206.507 g

sample mass: 0.051 mol

Filling gas type:

impurity analysis:

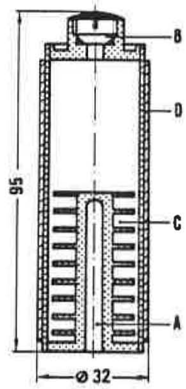
Enthalpy of melting: 17 J

Measurements at — Resistance Ratio (W)

LABORATORY	ASMW		IMGC		NML		NPL		NRC	
Date	Jan 81		Oct 80		Dec 79		Feb 80		Sep 79	
thermometer N°	217997		PL01-6		1731676		1728839		1521389	
Ro (ohm)	25.418540		25.271140		25.522800		25.559570		25.523050	
Typical melting plateau	9 %	1198	5 %	7990	5 %	4516	5 %	4502	5 %	7274
	18%	1210	10%	8003	10%	4518	9 %	4512	10%	7282
	27%	1222	19%	8029	20%	4524	15%	4518	30%	7298
	45%	1230	29%	8027	30%	4535	22%	4521	60%	7302
	58%	1230	40%	8029	40%	4537	29%	4524	90%	7302
	76%	1222	50%	8027	50%	4535	43%	4522		
			70%	8029	60%	4537	59%	4520		
melted fraction F			90%	8027	80%	4547	73%	4522		
							86%	4522		
							97%	4523		
W(100%)	0.008612220		0.008680300		0.008645370		0.008645220		0.008573030	
T (K) LAB					24.56287		24.56141		24.56342	
T (K) NPL	24.56234		24.56255		24.56166		24.56141		24.56121	
average drift (mK/h)	3.5		15				0.3			
recovery time to 0.1mK (min)	1-5		2				1			
overheating at 50% (mK/mW)	0.02		0.05							
enthalpy of melting (J)	17.2		15.5						17	

Notes:

C E L L T Y P E: 12 NE NRC



NRC

Manufacturer: NRC

Sealing date: Jun 1979

cell total mass: 206.507 g

sample mass: 0.051 mol

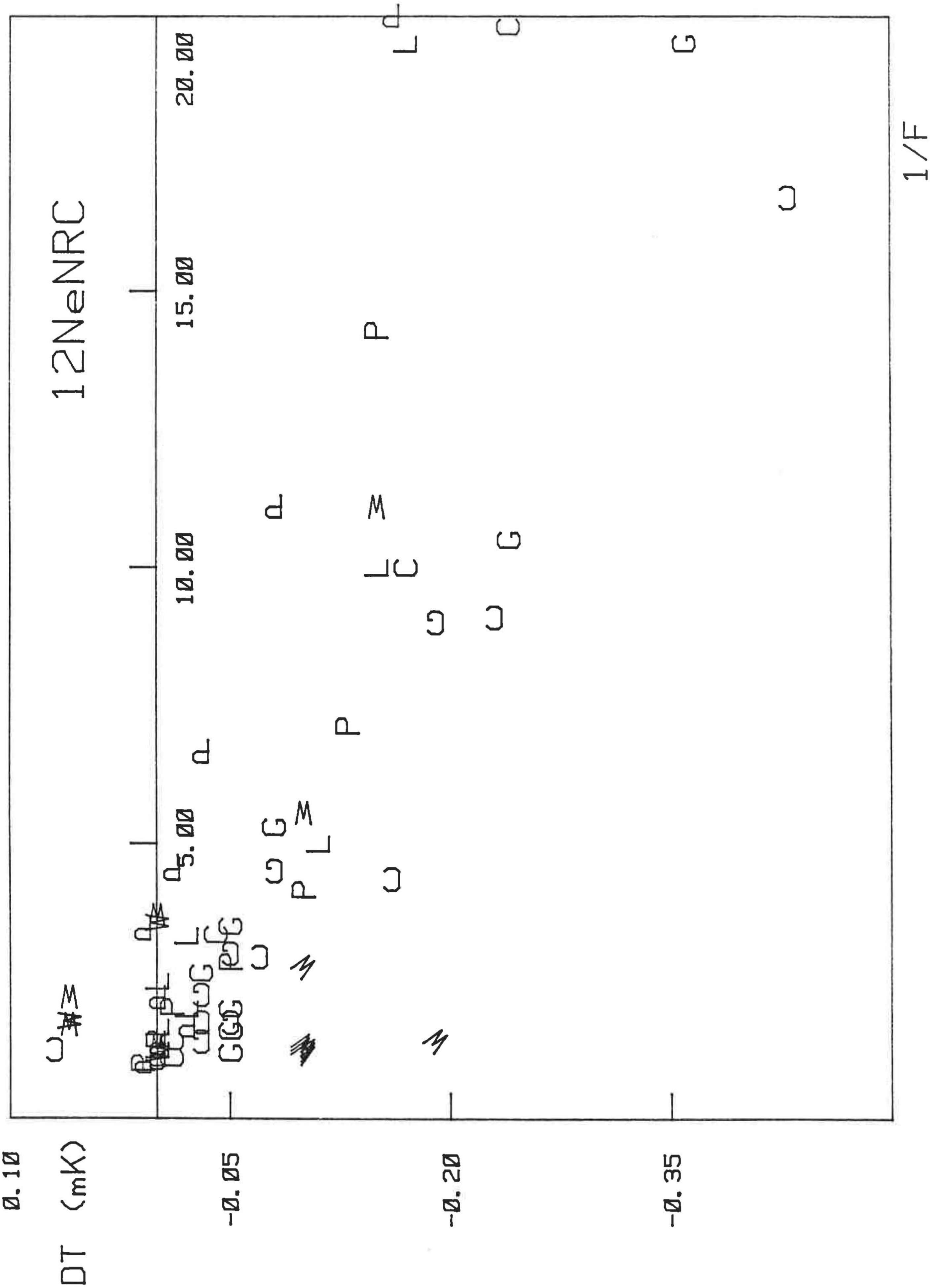
Filling gas type:

impurity analysis:

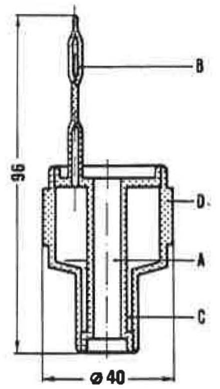
Enthalpy of melting: 17 J

Measurements at	Resistance Ratio (W)	
LABORATORY	NRC	
Date	Feb 82	
thermometer N°	1872179	
Ro (ohm)	25.582651	
Typical melting plateau	6%	1303
	11%	1538
	23%	1616
	34%	1733
	57%	1772
	80%	1890
melted fraction F		
W(100%)	0.008551811	
T (K) LAB	24.56311	
T (K) NPL	24.56090	
average drift (mK/h)		
recovery time to 0.1mK (min)		
overheating at 50% (mK/mW)		
enthalpy of melting (J)		

Notes:


12NeNRC
1/F
5.00
10.00
15.00
20.00
DT (mK)
0.10
-0.05
-0.20
-0.35

C E L L T Y P E: 1 NE NRLM



NRLM

Manufacturer: NRLM

Sealing date: Jul 1978

cell total mass: 170 g

sample mass: 0.050 mol

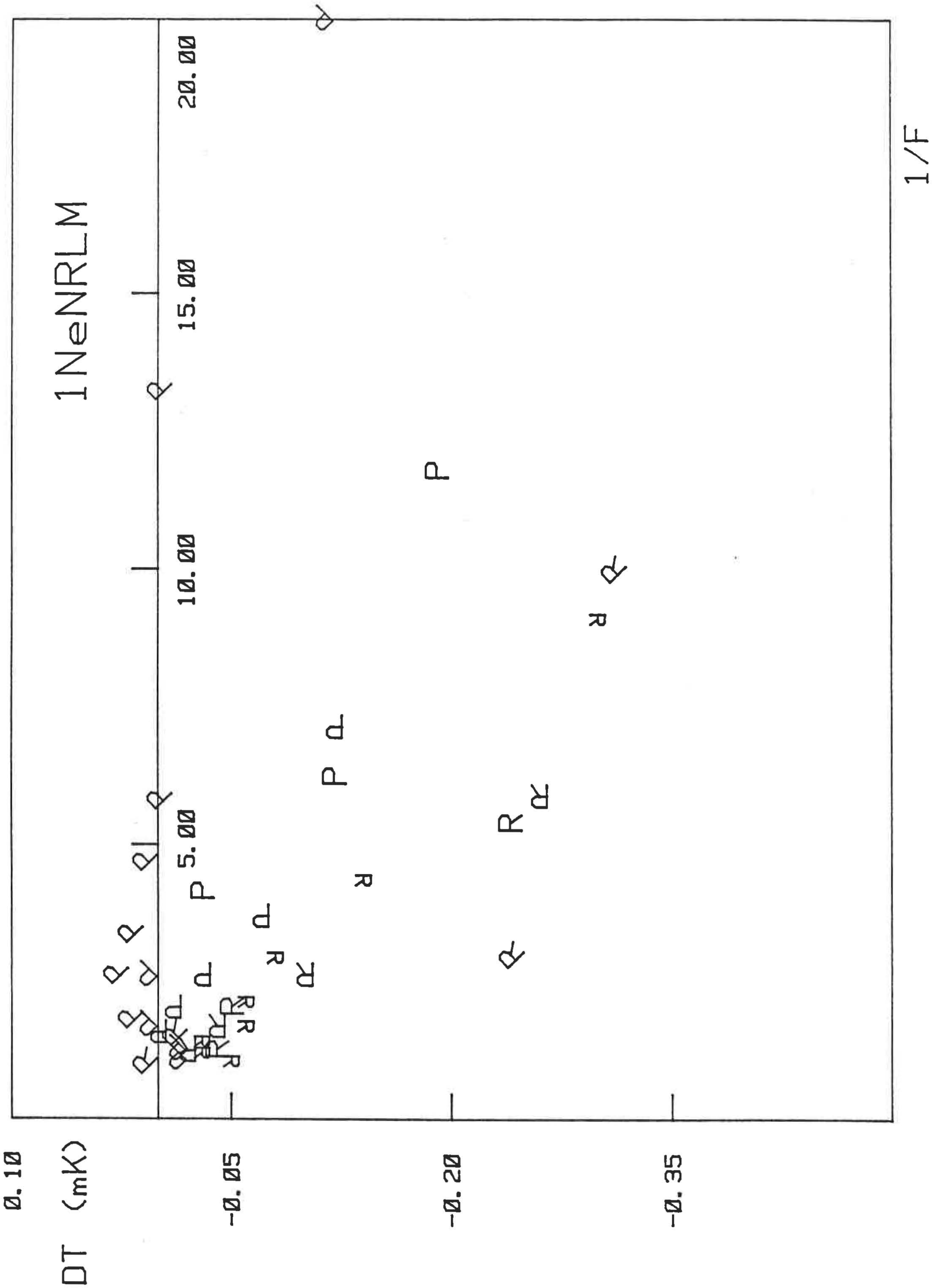
Filling gas type:

impurity analysis: nom. 99.99%
tot. 2.5 vppm

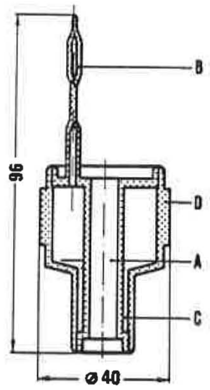
Enthalpy of melting: 16.7 J

Measurements at	Resistance Ratio (W)		
LABORATORY	NPL (1)		NRLM
Date	May 79		Sep 78
thermometer N°	1728839		(2)
Ro (ohm)	25.559570		
Typical melting plateau	8 %	4529	
	14%	4537	
	27%	4543	
	38%	4548	
	49%	4550	
	63%	4552	
	78%	4551	
melted fraction F	90%	4551	
W(100%)	0.008645520		
T (K) LAB	24.56165		24.56305
T (K) NPL	24.56165		
average drift (mK/h)	1		
recovery time to 0.1mK (min)	2		
overheating at 50% (mK/mW)			
enthalpy of melting (J)			16.7

Notes: (1) the cell lost the gas after the measurements at NPL.
(2) 1978 data reported only for record.


1NeNRLM
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: 2 NE NRLM



NRLM

Manufacturer: NRLM

Sealing date: Jul 1978

cell total mass: 168 g

sample mass: 0.052 mol

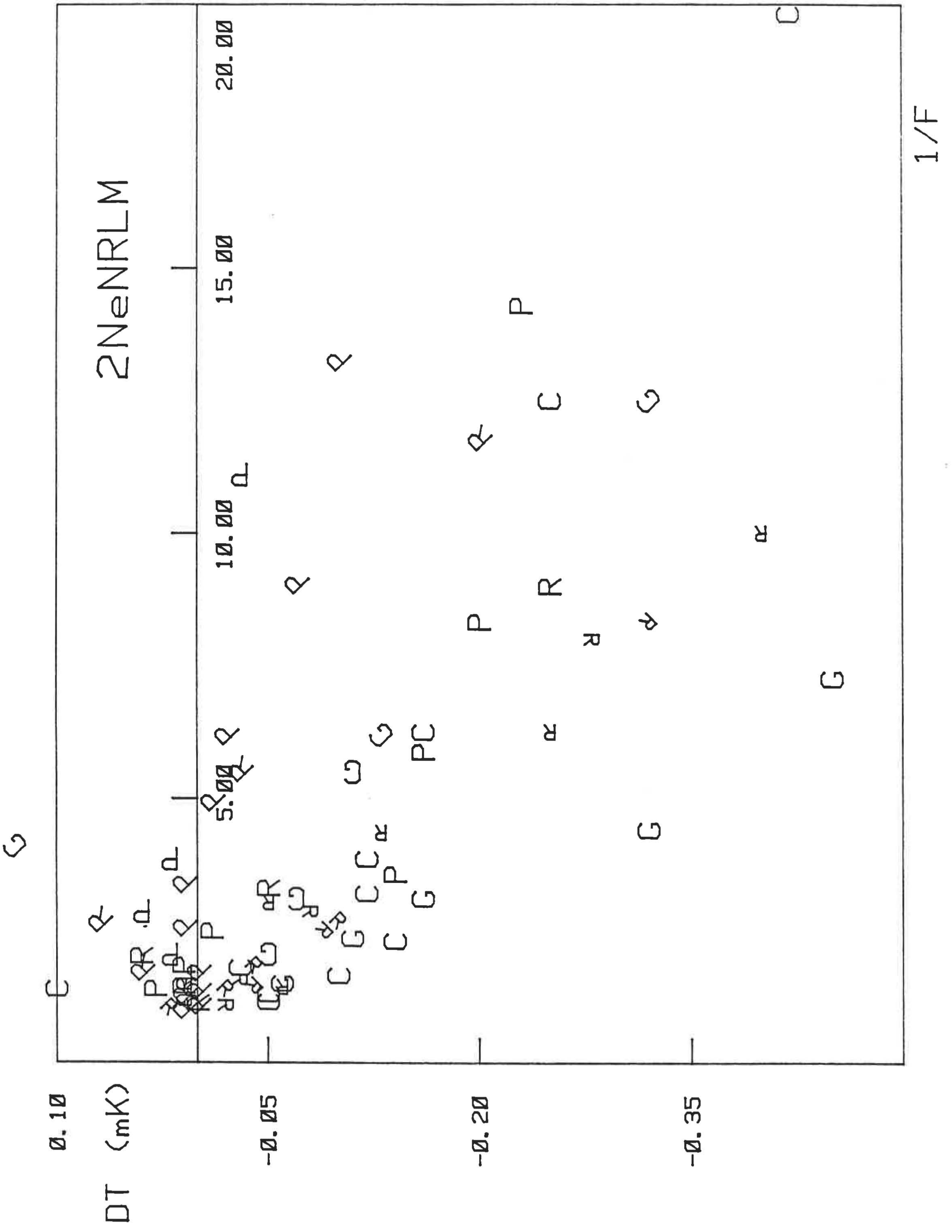
Filling gas type:

impurity analysis: nom. 99.99%
tot. 2.5 vppm

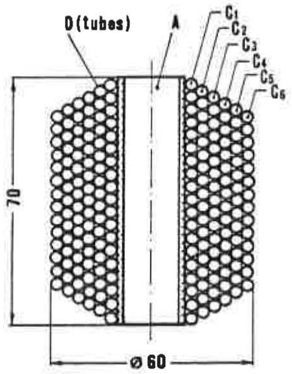
Enthalpy of melting: 17.5 J

Measurements at	Resistance Ratio (W)				
LABORATORY	IMGC	NPL	NRC	NRLM	NRLM
Date	Sep 80	Feb 80	Sep 79	Nov 81	Aug 78
thermometer N°	PL01-6	1728839	1521389	7681	(1)
Ro (ohm)	25.271140	25.559570	25.523332	25.362925	
	9 % 8000	7 % 4548	4 % 7278	8.5% 30204	
	14% 8010	11% 4552	8 % 7298	11% 30133	
Typical melting plateau	22% 8026	16% 4558	16% 7310	18% 30421	
	32% 8046	20% 4559	26% 7314	30% 30381	
	43% 8052	29% 4562	31% 7314	37% 30539	
	68% 8058	38% 4562	43% 7314	49% 30500	
		56% 4559	55% 7325	56% 30500	
melted fraction F		70% 4558	60% 7318	68% 30460	
		87% 4557	70% 7333	75% 30460	
			77% 7325	87% 30444	
			88% 7325	93% 30460	
W(100%)	0.008680640	0.008645600	0.008573290	0.0087305000	
T (K) LAB		24.56172	24.56363	24.5614	24.56307
T (K) NPL	24.56283	24.56172	24.56142	24.5621	
average drift (mK/h)	15	0.3		2.3	
recovery time to 0.1mK (min)	1-5	2		1.4-3	
overheating at 50% (mK/mW)	0.8				
enthalpy of melting (J)	17		19	20.1	

Notes: (1) 1978 data reported only for record.


2NeNRLM
DT (mK)
1/F
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

C E L L T Y P E: PRMI (Ne)



PRMI

Manufacturer: PRMI
Multicomponent cell
(argon,oxygen,neon,hydrogen)

Sealing date: Dec 1978

cell total mass:

sample mass:

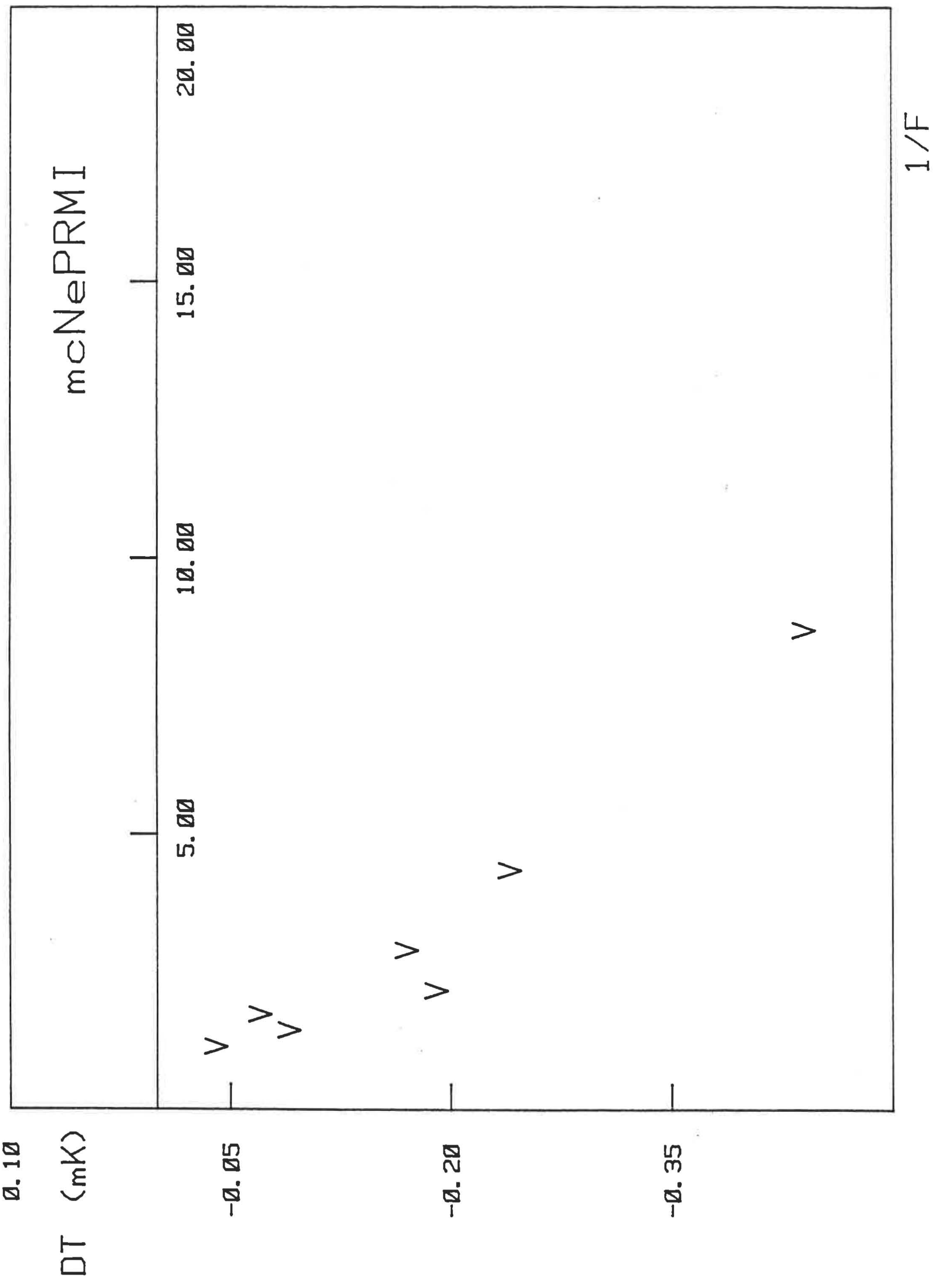
Filling gas type:

impurity analysis:
nitrogen 16 vppm
oxygen 3
carb.dioxi.<0.7
hydrog.,helium none

Enthalpy of melting:

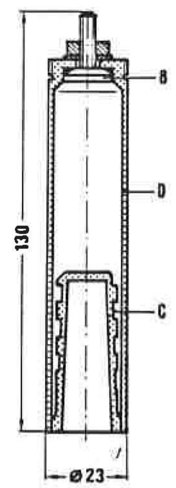
Measurements at	Resistance Ratio (W)
LABORATORY	PRMI
Date	Nov 81
thermometer N°	1842381
Ro (ohm)	25.544950
Typical melting plateau / melted fraction F	11% 5717 23% 5741 34% 5750 46% 5748 57% 5763 69% 5762 87% 5789
W(100%)	0.00845771
T (K) LAB	
T (K) NPL	24.56200
average drift (mK/h)	-1.5
recovery time to 0.1mK (min)	10
overheating at 50% (mK/mW)	0.07
enthalpy of melting (J)	

Notes:


mcNePRMI
1/F
DT (mK)
0.10
-0.05
-0.20
-0.35
5.00
10.00
15.00
20.00

CELL TYPE: 1 eD2 IMGC

International
Intercomparison
CCT: 1979-1983



Manufacturer: IMGC

Sealing date: Nov 80

cell total mass: 169.195 g
(incl. 1.5 g catalyst)
sample mass: 0.013 mol

Filling gas type: C.E.A.

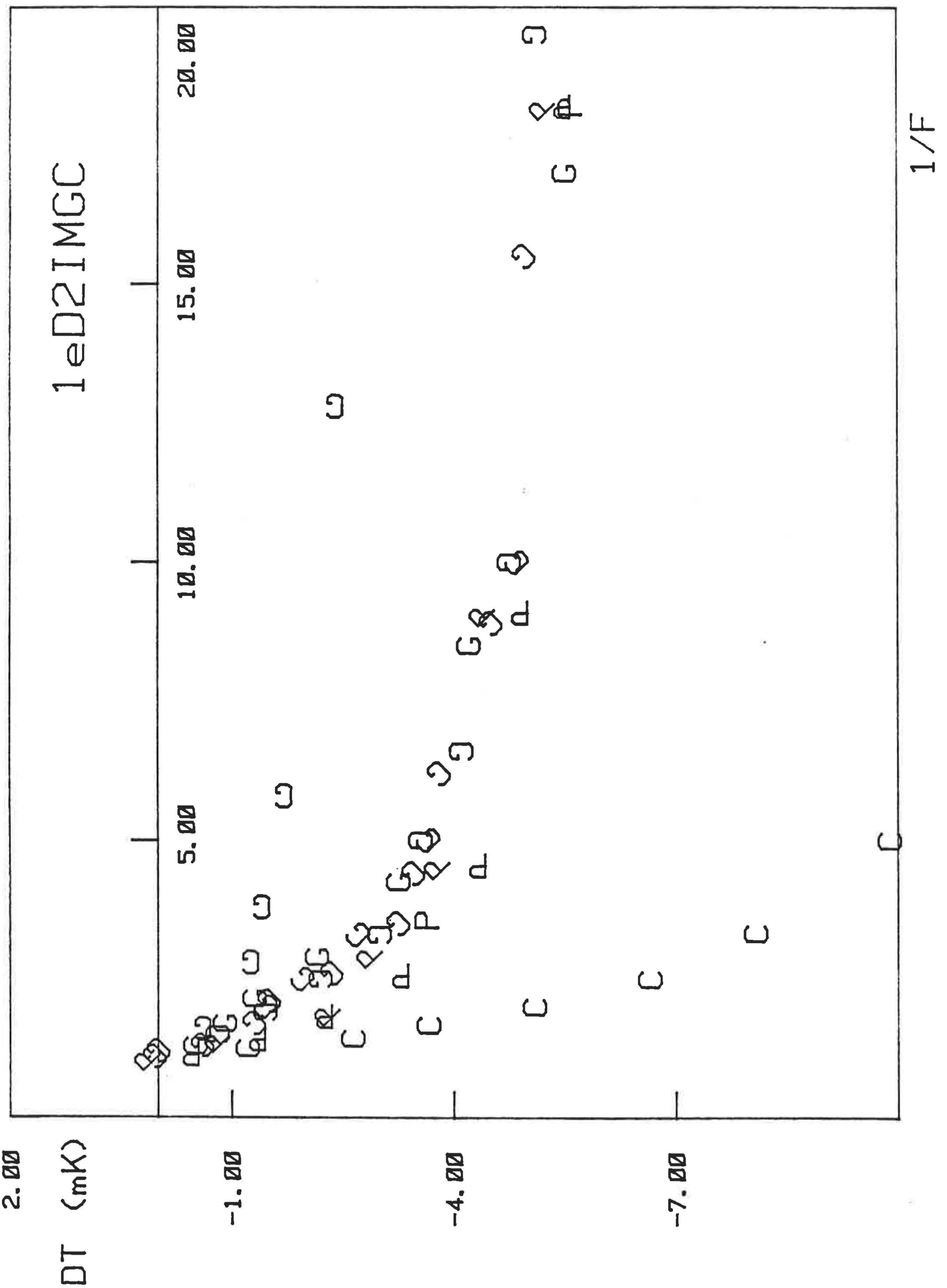
impurity analysis: nom. 99.86%

Enthalpy of melting: 20.5 J

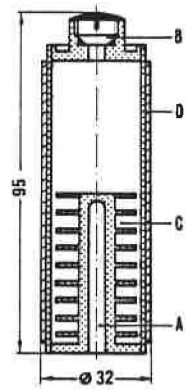
Measurements at — Resistance Ratio (W)

LABORATORY	IMGC		NPL		NRC	
Date	Dec 80		Jan 82		Nov 81	
thermometer N°	PL01-6		1728839		1872179	
Ro (ohm)	25.271140		25.559570		25.582651	
	6.5%	8208	5.5%	2965	5 %	3520
	11%	8235	11%	2999	20%	3704
Typical	16%	8295	22%	3033	30%	3813
melting	23%	8331	39%	3095	40%	3899
plateau	28%	8358	55%	3156	50%	3993
	39%	8390	71%	3210	60%	4079
	48%	8429	88%	3264	70%	4141
melted	59%	8469			80%	4227
fraction	90%	8520				
F						
W(100%)	0.00338515		0.00333290		0.00324300	
T (K) LAB			18.6753		18.6764	
NPL	18.6778		18.6753		18.6777	
average drift (mK/h)	5				bad thermal control	
recovery time to 0.1mK (min)	5					
overheating at 50% (mK/mW)	0.3					
enthalpy of melting (J)	20.5				20.8	

Notes:


1eD2IMGC
1/F
DT (mK)
2.00
-1.00
-4.00
-7.00
5.00
10.00
15.00
20.00

C E L L   T Y P E :   31 eD2 NRC



NRC

Manufacturer: NRC

Sealing date: Dec 1981

cell total mass: 204.954 g

sample mass: 0.0484 mol

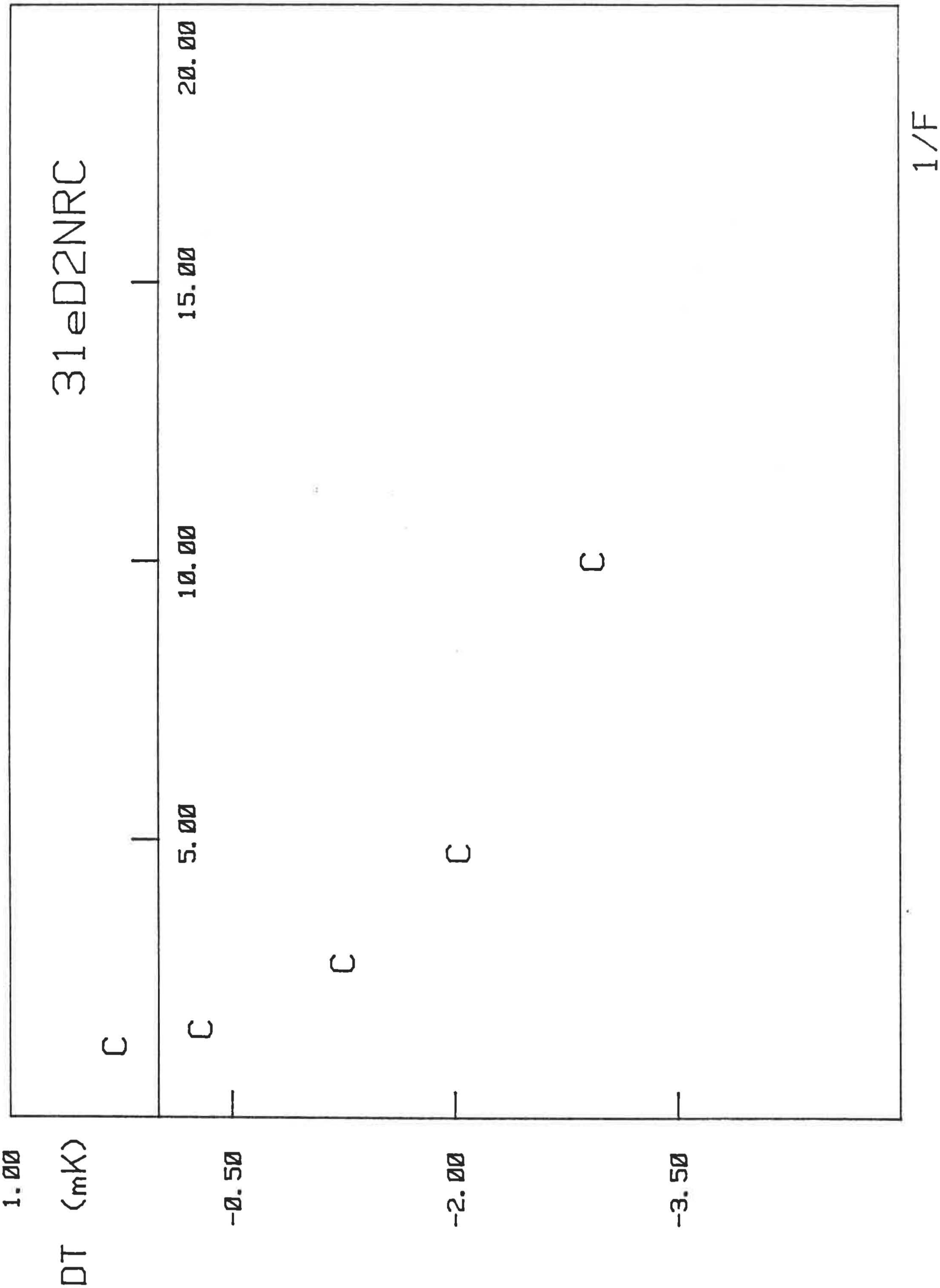
Filling gas type: Monsanto

impurity analysis: nom. 99.6%

Enthalpy of melting: 4.9 J

Measurements at	Resistance Ratio (W)	
LABORATORY	NRC	
Date	Dec 81	
thermometer N°	1872179	
Ro (ohm)	25.582651	
Typical melting plateau	5.2%	3043
	10%	3203
	21%	3258
	36%	3305
	63%	3363
	78%	3398
melted fraction F		
W(100%)	0.00323380	
T (K) LAB	18.6610	
T (K) NPL	18.6623	
average drift (mK/h)		
recovery time to 0.1mK (min)		
overheating at 50% (mK/mW)		
enthalpy of melting (J)	4.9 J	

Notes:


31eD2NRC
DT (mK)
1.00
-0.50
-2.00
-3.50
5.00
10.00
15.00
20.00
1/F

VI. RESULTS ON SCALE REALIZATIONS

This section collects the temperature data that could be obtained from the measurements made during the Intercomparison. These data are also contained in the data sheets of the preceeding Section.

In this Section, they are grouped in three sets of Tables (VI.1.x, VI.2.x and VI.3.x); each set contains seven Tables, one for each of the three definition points (a., b. and c.) and one for each of the secondary fixed points (d. to g.).

Tables VI.1.x collect the W(100%) values used in order to calculate the temperature values (and the temperature differences of Section VII, Tables VII.1.x).

Tables VI.2.x collect the temperature values, calculated on the National realizations of the IPTS-68 (LAB-IPTS-68), when available (see information about these realizations at p.13-14).

Tables VI.3.x collect the temperature values, calculated with calibrations on NPL-IPTS-68, when available on the thermometers used by the Laboratories.

Captions of the Tables

Tables VI.1.x: W(100%) values

Thermometer: in the first row the reference thermometers are indicated, to which the underlined W values pertain. In the subsequent lines, the thermometers actually used in the measurements at the Laboratories are indicated (when different from the reference thermometer): the corresponding W values are reported in a subsequent line below the reference W values in the Table. Underlining of the thermometers indicates that a NPL calibration is available.

W values: - underlined (reference) values refer to the reference thermometers.
- not-underlined values refer to the other indicated thermometers; in this case, the reference value is calculated from the former, using the calibration tables of both the reference (1) and non-reference (2) thermometers, at the temperature indicated by thermometer (2).
- some Laboratories have not measured the reference cell , but another IMGC cell. In this case, the reference value for the reference cell has been calculated from the difference between the two cells, as measured at IMGC. With hydrogen, the PRMI value for the NRLM cell has been obtained through IMGC cell.

Tables VI.2.x: T(LAB-IPTS-68) values

Thermometers: only the thermometers used for temperature calculation are indicated. They are underlined when a NPL calibration is also available.

Temperature values: (ref.) indicates that this cell has been considered as the reference realization for the Laboratory. In a few cases, two independent determinations of the same Laboratory, made at different times, are available for the same cell.

Tables VI.3.x: T(NPL-IPTS-68) values

Thermometer: only thermometers with NPL calibrations are indicated. The calibration may be one of two types: a) calibration made at NPL during the International Intercomparison of thermometers in 1975 (underlined; referred as "international group"); b) calibration made subsequently either at NPL (e.g. the BIPM thermometer) or by comparison with other thermometers calibrated at NPL (e.g. the NRLM and PRMI thermometers . For the latter the comparison, and calibration table, has been done at the argon triple point, instead of at the NPL calibration point (normal condensation of oxygen)).
At NBS and NRC, the reference thermometer of Tables VI.1 and VI.2 (here indicated in second line), has a known relationship with the thermometers of the "international group" reported in the first line.

Temperature values: owing to thermometer instability, in a few cases temperature values obtained at the same Laboratory with different calibrated thermometers are reported, when differences between them greatly exceeded IPTS-68 non-uniqueness.

Table VI.1.a : Results of the intercomparison between sealed cells filled with: A R G O N
(Reference cell: 1 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217997 217990 (217278)	226321	PL01-6	232788 1812283	1774095	7703 188640	1731676	1728839	1521389	7681 1781356	1842381
Cells:					Resistance ratio at F=100%						
4 ASMW	0.21600349 (0.21602447)		0.21602772								
3 BIPM		0.21603920									
1 IMGC	0.21600380 0.21600890	0.21603987	0.21602745	0.21603387	0.21604967	0.21614787 0.21650500	0.21610202	0.21610195	0.21597964	0.21611388	0.21589327
2 IMGC		0.21603980	0.21602738	0.21603380	0.21604960		0.21610195				0.21589320
1 INM		0.21603990		0.21603355			0.21610340		0.21598038		
XXI INM				0.21603360 0.21596344		0.21614760					
BCM4 INM				0.21603421 0.21596405					0.21598077		
M1 NBS		0.21604070		0.21603395	0.21604965				0.21597961	0.21611416 0.21599700	
113 NIM						0.21614755					
10 NRC		0.21604000	0.21602805	0.21603335	0.21604955		0.21610370	0.21610210	0.21597959		
14 NRC						0.21614820			0.21597970		
7801 NRLM					0.21604960						
7803 NRLM	0.21600360	0.21604000	0.21602825	0.21603400			0.21610510		0.21597961	0.21611377	
Ar PRMI											0.21589295

Table VI.2.a : Results of measurements on sealed cells filled with: A R G O N

	ASMW°	BIPM°	IMGC°	INM°	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217997	226321	PL01-6	1812283	1774095	7703	1731676	1728839	1521389	7681	1842381
Cells:					Temperature in LAB-IPTS-68 (K)						
4 ASMW	83.79758		83.79806								
3 BIPM		83.798 §									
1 IMGC	83.79770		83.798 §			83.79960		83.79690	83.79776	83.79878	
2 IMGC		83.79814	83.79798	83.79805	83.80030		83.79670				
1 INM		83.79817		83.798 §			83.79710		83.79793		
XXI INM				83.79802							
BCM4 INM				83.79816					83.79802		
M1 NBS		83.79834		83.79809	83.80032				83.79775	83.79885	
113 NIM											
10 NRC		83.79818	83.79814	83.79795	83.80028		83.79717	83.79695	83.79775		
14 NRC									83.79775		
7801 NRLM					83.80030						
7803 NRLM	83.79760	83.79818	83.79817	83.79811			83.79730		83.79775	83.79875	
Ar PRMI											

°) Laboratories using argon triple point in the IPTS-68 definition. §) exact by definition (reference cell).

Table VI.3.a : Results of measurements on sealed cells filled with: A R G O N

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer: (°)	217997	226321	PL01-6	1812283	1812282 1774095		1731676	1728839	1158062 1521389	7681	1842381
Cells:					Temperature in NPL-IPTS-68 (K)						
4 ASMW	83.79731		83.79729								
3 BIPM		83.79670									
1 IMGC	83.79745		83.79723					83.79690	83.79666	83.79828	
2 IMGC		83.79680	83.79722	83.79732	83.79700		83.79698				83.79693
1 INM		83.79690		83.79727			83.79732		83.79683		
XXI INM				83.79729							
BCM4 INM				83.79743					83.79695		
M1 NBS		83.79700		83.79736	83.79700				83.79665	83.79835	
113 NIM											
10 NRC		83.79690	83.79736	83.79722	83.79696		83.79739	83.79695	83.79665		
14 NRC									83.79665		
7801 NRLM					83.79698						
7803 NRLM	83.79735	83.79690	83.79739	83.79738			83.79760		83.79665	83.79825	
Ar PRMI											83.79672

°) underlining indicates thermometers of the "international group".

Table VI.1.b : Results of the intercomparison between sealed cells filled with: O X Y G E N
(Reference cell: 1 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217997		PL01-6	1812283 232788	1812282	7709	1731676	1728839	1521389	7681	1842381
Cells:					Resistance ratio at F=100%						
1 IMGC	0.09187880		0.09191770	0.09181177 0.09193219	0.09184025	0.09183293	0.09196407	0.09196382	0.09184746	0.09201210	0.09174634
8 IMGC §			0.09191956	0.09193405	0.09184211		0.09196593		0.09184920		0.09174820
8 INM				0.09181113 0.09193155		0.09183300	0.09196500		0.01984906 0.09184734		
BCM4 INM				0.09181120					0.09184740		
M2 NBS					0.09183952*						
PP07 NIM						0.09183293					
PP11 NIM						0.09183246					
15 NRC	0.09187939		0.09191885	0.09181123 0.09193165			0.09196460	0.09196444	0.09184772		
7801 NRLM			0.09192560	0.09182053 0.09194095					0.09185354	0.09201750	
02 PRMI											0.09174780

*) mean of two cells. §) Cell actually measured at INM,NBS, NML and PRMI instead of the reference cell, whose values are calculated.

Table VI.2.b : Results of measurements on sealed cells filled with: O X Y G E N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217997		PL01-6	1812283	1812282 1774095	7709	1731676	1728839	1521389	7681	1842381
Cells:					Temperature in LAB-IPTS-68 (K)						
1 IMGC	54.36090		ref.			54.36360		54.36072	54.36108	54.36160	
8 IMGC			54.36148	54.36163	54.36190		54.36143		54.36153		
8 INM				ref.		54.36360	54.36112		54.36149 54.36105		
BCM4 INM				54.36104					54.36107		
M2 NBS					54.36131 * 54.36145 *						
PP07 NIM											
PP11 NIM											
15 NRC	54.36107		54.36148	54.36103			54.36102	54.36088	54.36116		
7801 NRLM			54.36300	54.36337					54.36264	54.36310	
02 PRMI											

*) mean of two cells.

Table VI.3.b : Results of measurements on sealed cells filled with: O X Y G E N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer: (°)	217997		PL01-6	1812283	1812282 1774095	7709	1731676	1728839	1158062 1521389	7681	1842381
Cells:					Temperature in NPL-IPTS-68 (K)						
1 IMGC	54.36093		54.36132			54.36125		54.36072	54.36091	54.36167	
8 IMGC			54.36180	54.36194	54.36144		54.36133		54.36136		54.36059
8 INM				54.36131		54.36127	54.36102		54.36132 54.36088		
BCM4 INM				54.36135					54.36090		
M2 NBS					54.36085 54.36099 *						
PP07 NIM						54.36125					
PP11 NIM						54.36113					
15 NRC	54.36110		54.36167	54.36134			54.36092	54.36088	54.36099		
7801 NRLM			54.36335	54.36368					54.36247	54.36320	
O2 PRMI											54.36049

°) underlining indicates thermometers of the "international group". *) this value would be 54.36087 K if the 1976 (NPL-NBS) comparison is used. The mean difference (NPL-NBS)= +0.58 mK for the three PRTs of the "international group".

Table VI.1.c : Results of the intercomparison between sealed cells filled with: e - H Y D R O G E N
(Reference cell: 7801 NRLM)

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217997 207278		PL01-6				1731676	1728839	1521389	7681	1842381
Cells:					Resistance ratio at F=100%						
1 IMGC	0.00132003 0.00135358		0.00140993								0.00118828
2 IMGC			0.001409922								
23 NRC			0.001409917				0.00135009	0.00135063	0.00130175		
7801 NRLM	0.00131990		0.00140987				0.00135006	0.00135063	0.00130183	0.00140081	0.00118822
H2 PRMI											0.00118830

Table VI.2.c : Results of measurements on sealed cells filled with: e - H Y D R O G E N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217997		PL01-6				1731676	1728839	1521389	7681	1842381
Cells:					Temperature in LAB-IPTS-68 (K)						
1 IMGC			13.81 §								
2 IMGC			13.80997								
23 NRC			13.80995				13.80962	13.81008	13.80810		
7801 NRLM			13.80975				13.80950	13.81008	13.80914	13.81150	
H2 PRMI											

§) exact by definition (reference cell).

Table VI.3.c : Results of measurements on sealed cells filled with: e - H Y D R O G E N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer: (°)	217997 (207278)		PL01-6 (PL02-6)				1731676	1728839	1158062 1521389	7681	1842381
Cells:					Temperature in NPL-IPTS-68 (K)						
1 IMGC	(13.81109)		13.81567 (13.81070)								13.81030
2 IMGC			13.81564 (13.81067)								
23 NRC			13.81562 (13.81065)				13.80993	13.81008	13.80927		
7801 NRLM	13.81057		13.81542 (13.81045)				13.80981	13.81008	13.80960	13.81340	
mc PRMI											13.81033

°) underlining indicates thermometers of the "international group".

Table VI.1.d : Results of the intercomparison between sealed cells filled with: M E T H A N E
(Reference cell: 2 IMGC)

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217990	226321	PL01-6			188640		1728839	1521389	7681	1842381
Cells:					Resistance ratio at F=100%						
7 BIPM		0.24593950							0.24588103		
2 IMGC	0.24590300	0.24593565	0.24592185			0.24638710		0.24600010	0.24587703	0.24600250	0.24579465
12 IMGC		0.24593500	0.24592120						0.24587753		0.24579400
18 NRC		0.24593430	0.24592280						0.24587955		

Table VI.2.d : Results of measurements on sealed cells filled with: M E T H A N E

	ASMW°	BIPM°	IMGC°	INM°	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217990	226321	PL01-6			188640		1728839	1521389	7681	1842381
Cells:					Temperature in LAB-IPTS-68 (K)						
7 BIPM		90.68661							90.68539		
		(1978) 90.68586									
2 IMGC	90.68350		90.68518			90.68370		90.68372	90.68447	90.68811	
12 IMGC		90.68554	90.68503						90.68459		
18 NRC		90.68566	90.68540						90.68505		

°) Laboratories using the argon triple point in the IPTS-68 definition.

Table VI.3.d : Results of measurements on sealed cells filled with: M E T H A N E

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer: (°)	217990	226321	PL01-6					1728839	1158062 1521389	7681	1842381
Cells:					Temperature in NPL-IPTS-68 (K)						
7 BIPM		90.68402							90.68464		
	(1978)	(90.68325)									
2 IMGC	90.68350		90.68386					90.68372	90.68373	90.68798	
12 IMGC		90.68298	90.68371						90.68384		90.67968
18 NRC		90.68310	90.68408						90.68430		

°) underlining indicates thermometers of the "international group".

Table VI.1.e : Results of the intercomparison between sealed cells filled with: N I T R O G E N
(Reference cell: 2 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:			45	1812283				1728839	1872179		
Cells:					Resistance ratio at F=100%						
2 IMGC			0.12758665	0.12741804				0.12756680	0.12743810		
BCM4 INM				0.12741731					0.12743793		
33 NRC			0.12758642						0.12743740		

Table VI.2.e : Results of measurements on sealed cells filled with: N I T R O G E N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:			45	1812283				1728839	1872179		
Cells:					Temperature in LAB-IPTS-68 (K)						
2 IMGC			63.14627	63.14596				63.14611	63.14637		
BCM4 INM				63.14579					63.14633		
33 NRC			63.14622						63.14620		

Table VI.3.e : Results of measurements on sealed cells filled with: N I T R O G E N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:			45	1812283				1728839	1158062 1872179		
Cells:					Temperature in NPL-IPTS-68 (K)						
2 IMGC			63.14626	63.14671				63.14611	63.14562		
BCM4 INM				63.14654					63.14558		
33 NRC			63.14621						63.14545		

°) underlining indicates thermometers of the "international group".

Table VI.1.f : Results of the intercomparison between sealed cells filled with: N E O N
(Reference cell: 3 IMGC)

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217997 207278		PL01-6	1812283			1731676	1728839	1521389 1872179	7681	1842381
Cells:					Resistance ratio at F=100%						
1 ASMW	0.00861321 0.00863370		0.00868097								
1 IMGC			0.00868062							0.00873063	
3 IMGC	0.00861229 0.00863278		0.00868062	0.00848493			0.00864607	0.00864550	0.00857308	0.00873063	0.00845755
BCM4 INM				0.00848492					0.00857334 0.00855212		
12 NRC	0.00861222		0.00868030				0.00864537	0.00864522	0.00857303 0.00855181		
1 NRLM								0.00864552			
2 NRLM			0.00868064					0.00864560	0.00857329	0.00873050	
Ne PRMI											0.00845771

Table VI.2.f : Results of measurements on sealed cells filled with: N E O N

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217997		PL01-6	1812283			1731676	1728839	1521389 1872179	7681 other(1978)	1842381
Cells:					Temperature in LAB-IPTS-68 (K)						
1 ASMW											
1 IMGC			ref.							24.56150	
3 IMGC			same T				24.56250	24.56163	24.56346		
BCM4 INM									24.56336		
12 NRC							24.56225	24.56141	24.56342 24.56311		
1 NRLM								24.56165		--- 24.56305	
2 NRLM								24.56172	24.56363	24.56140 24.56307	
Ne PRMI											

Table VI.3.f : Results of measurements on sealed cells filled with: N E O N

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer: (°)	217997 (207278)		PL01-6 (PL02-6)	1812283			1731676	1728839	1158062 1521389	7681	1842381
Cells:					Temperature in NPL-IPTS 68 (K)						
1 ASMW	(24.56312) 24.5627 §		24.56308 (24.5620)								
1 IMGC			24.56281 (24.5617)							24.56220	
3 IMGC	24.56236		24.56281 (24.5617)	24.56195			24.56190	24.56163	24.56125		24.56187
BCM4 INM				24.56194					24.56115		
12 NRC	24.56234		24.56255 (24.5615)				24.56165	24.56141	24.56121 24.56090		
1 NRLM								24.56165			
2 NRLM			24.56283 (24.5617)					24.56172	24.56142	24.56210	
Ne PRMI											24.56200

§) in Ref.55. °) Underlining indicates thermometers of the "international group".

Table VI.1.g : Results of the intercomparison between sealed cells filled with: e - D E U T E R I U M
(Reference cell: 1 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:			PL01-6					1728839	1872179		
Cells:					Resistance ratio at F=100%						
1 IMGC			0.00338515					0.00333290	0.00324300		
31 NRC									0.00323380		

Table VI.2.g : Results of measurements on sealed cells filled with: e - DEUTERIUM

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:			PL01-6					1728839	1872179		
Cells:					Temperature in LAB-IPTS-68 (K)						
1 IMGC			ref.					18.6753	18.6764		
31 NRC									18.6610		

Table VI.3.g : Results of measurements on sealed cells filled with: e - D E U T E R I U M

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:			PL01-6 (PL02-6)					1728839	1158062		
Cells:					Temperature in NPL-IPTS-68 (K)						
1 IMGC			18.6778 (18.6763)					18.6753	18.6777		
31 NRC									18.6623		

°) Underlining indicates thermometers of the "international group".

VII. DISCUSSION OF RESULTS

1. On cell intercomparison

This part of the Intercomparison fulfilled goals a) and b) of Section III.3. We shall examine the results by considering, in turn, three separate features:

1) differences between fixed-point realizations in different cells;

2) measurability of the sealed-cell devices;

3) merits of the different gases as candidate substances for temperature reference points.

1.1 Differences between fixed-point realizations in different cells

These differences can be obtained directly from the W values in Tables VI.1. They are shown as temperature differences in Tables VII.1.x for the three definition points and for the four secondary fixed points. These calculations do not involve errors related to scale realization or thermometer calibration, provided that the same thermometer is used. Therefore, some small increase in the uncertainty levels, indicated in Section IV.3.1 for the comparison measurements, may occur in the cases indicated in Tables VI.1, where additional calculations were needed, when thermometers or cells different from the reference ones have been actually used.

However, the usual representation of these differences as a single value with associated uncertainty limits can be misleading, because all the values in the uncertainty interval are, in most cases, equally probable, since most of the uncertainty comes from what has been called in Section III "definability" of the triple point temperature, due to the shape of the melting plateau.

The single difference values in Tables VII.1.x came only from the need of representing a "typical" plateau in a Table of the data sheets, but the analysis of the data and their statistical significance should be performed on the whole uncertainty interval, seen as an "indeterminacy" of the assignable temperature value.

Therefore, Figs. VII.1.x have been drawn, which represent such intervals, centred on the value given in Tables VII.1.x and as wide as defined in Section III.3.1.

From these figures the overall distribution of the deviations shown in Figs. VII.2.x has been obtained, summing up the number of cells found at each deviation value (taken in 0.01 mK steps); from these figures the mean value has been defined as the deviation value dividing the area into two equal parts, and the standard deviation as the deviation limit which contains 66.7% of the total area of the pattern.

Let us now examine the gases separately.

A R G O N (Table VII.1.a; Figs. VII.1.a and VII.2.a)

This gas has been the pivot of the intercomparison and, in fact, it has been measured by all the participating Laboratories; 14 cells have been involved and some 48 measurements resulted, leading to 36 values of differences between them.

The cell chosen as a reference is shown to well represent the average temperature value reproduced by all the cells; actually, no systematic differences are evident for any cell.

However, some asymmetry is equally evident, as all the outliers reproduced a higher temperature value. Of the 6 difference values higher than σ, the three obtained at NML have actually been discarded in Fig. VII.2.a: the analysis of temperature data (Section VII.2) shows that the high values are not due to an anomalously low value for the measurement on the reference cell, but to high temperature values obtained with INM, NRC and NRLM cells.

The standard deviation of the resulting distribution is ± 0.15 mK, not significantly different from the uncertainty limit of most Laboratories and from the weighted combined uncertainty of all the participating Laboratories (± 0.21 mK).

O X Y G E N (Table VII.1.b; Figs. VII.1.b and VII.2.b)

This gas, which exhibits one of the flattest and more reproducible melting plateaux (using the same sample), is generally considered as a very good definition point for the IPTS. However, in the past years evidence has grown in several Laboratories of difficulties in its realization, resulting essentially from systematic differences between samples that could not be predicted from the certification of the gas purity or from thermal analysis (see Section VII.1.3).

Two of the cells involved in the Intercomparison showed definite systematic deviations: 8 IMGC, which was known to deviate from the reference cell by + 0.48 ± 0.15 mK[8], and 7801 NRLM, which was found to have an average deviation of + 1.8 mK (with its companion 7802 NRLM, measured only at NRLM). The rise in systematic deviation resulted in a rise of the measurement scatter for the latter. For cell 8 IMGC, this was not evident. In fact, in addition to the fact that reproducibility of the deviation from 1 IMGC was found to be ± 0.15 mK at IMGC, no systematic difference appears between the two sets of measurements: the ones made at ASMW, IMGC, NIM, NPL using cell 1 IMGC as a reference, and the ones made at INM, NBS, NML, NRC, PRMI using reference cell 8 IMGC.

The two cells 1 IMGC and 7801 NRLM have been excluded from consideration in Fig. VII.2.b; nevertheless, the resulting standard deviation of the distribution is ± 0.23 mK, considerably larger than that found with argon.

e - H Y D R O G E N (Table VII.1.c; Figs. VII.1.c and VII.2.c)

With this gas, the NRLM cell was selected as a reference since it has circulated in all the Laboratories, except PRMI. The number of measurements for this definition point of IPTS-68 is much more limited than with argon and oxygen but some interesting features of the results can be pointed out.

First of all, the reference cell appears to deviate systematically from the others: in fact, all the differences in Table VII.1.c, except for the NRC measurement on its cell, are positive. From Fig. VII.2.c a mean deviation value + 0.31 mK is obtained.

There is also a large standard deviation (± 0.30 mK), which is certainly related to the larger uncertainty limit given by most Laboratories. The weighted combined uncertainty is now ± 0.29 mK.

M E T H A N E (Table VII.1.d; Fig. VII.1.d)

This substance has been included in the Intercomparison since its triple-point temperature value is very close to that of the condensation point of oxygen. The intercomparison of the four cells available showed some difficulties. First, the IMGC cells showed a melting range larger than the others; cell 2 IMGC was used as a reference, since it has been circulated around all the Laboratories (four of them actually measured only this cell, therefore only temperature data are available in these cases). However, some increase in the resulting uncertainty can be due to this fact, since it has been shown[56] that the spread of values with different melting ranges is larger at $1/F=1$ than at $1/F=0$ and that the values themselves are systematically lower. This may be also a reason for the fact that most of the differences are positive.

Another problem arose with the BIPM cell, which was found to present quite a high temperature value: this was apparently due to a shift of the triple-point temperature of the cell, observed at BIPM since 1978 (Table VII.1.d; also the companion cell 6 BIPM is reported to have suffered the same drift). This instability has been the only one reported for a cell taking part in this exercise, but some instability in the realization of the triple point of methane in sealed cells had been previously reported by NRLM[41], and explained by spin conversion.

For these reasons, Fig. VII.2.d has not been drawn; when no problems are evident, differences between cells could be limited within about ± 0.3 mK.

N I T R O G E N (Table VII.1.e; Fig. VII.1.e)

This substance was introduced into the exercise at a very late stage, so that only three cells were involved, with a limited circulation. For this reason Fig. VII.2.e has not been drawn.

However, the results available are very good. This fixed point appeared to be easily achieved and showed quite a limited melting range; the difference values in Table VII.1.e are small, so that an uncertainty limit of about ± 0.15 mK can be stated, similar to that of argon.

N E O N (Table VII.1.f; Figs. VII.1.f and VII.2.f)

The neon triple-point temperature is quite close to that of the normal boiling point and can therefore be considered for substitution for the latter in the Scale definition, but some problems can, in principle, arise from normal neon being an isotopic mixture.

A comprehensive batch of cells has been available, filled with gas of different manufacturers from all the continents of the world. The difference values are collected in Table VII.1.f; there is evidence from Table VI.3.f that the correct value of the difference for the ASMW cell measured by the same Laboratory is the lower one.

Figure VII.2.f shows no deviation from the reference cell and a small standard deviation (± 0.20 mK).

However, the figures reveal small systematic differences between some of the cells. The mean deviation for each cell is given in Fig. VII.1.f: the extreme values are + 0.30 ± 0.04 mK for the ASMW cell and - 0.20 ± 0.15 mK for the NRC cell. Therefore, the distribution of Fig. VII.2.f is biased by these systematic differences, which broaden it to some extent, though they are of low statistical significance. For each cell, a standard deviation of ± 0.15 mK could be probably more appropriate.

e - D E U T E R I U M (Table VII.1.g)

Its temperature value is situated very usefully in between those of the hydrogen and neon triple points, so that it could be considered for a Scale definition. It has been included in this exercise in a very late stage and only two cells were available.

For this reason and because large differences have been found (see Table VI.2.g and VI.3.g) the discussion will be postponed to Section VII.2.

Table VII.1.a: Results of the intercomparison between sealed cells filled with: A R G O N
(Reference cell: 1 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217997 217990 (207278)	226321	PL01-6	232788 1812283	1774095	7703 188640	1731676	1728839	1521389	7681 1781356	1842381
Cells:				Temperature differences: cell(LAB)-cell(ref) (mK)							
4 ASMW	-0.07		+0.06								
3 BIPM		-0.15									
1 IMGC	ref.	ref.*	ref.	ref.*	ref.*	ref.	ref.*	ref.	ref.	ref.	ref.*
2 IMGC			-0.02								
1 INM		+0.07		-0.07			+0.32		+0.17		
XXI INM				-0.06		-0.06 (assumed)					
BCM4 INM				+0.08					+0.26		
M1 NBS		+0.19		+0.02	-0.00				-0.01	+0.07	
113 NIM						-0.07					
10 NRC		+0.03	+0.14	-0.12	-0.03		+0.39	+0.03	-0.01		
14 NRC						+0.08			-0.01		
7801 NRLM					-0.02					-0.03	
7803 NRLM	-0.05	+0.03	+0.18	+0.04			+0.71		-0.01	-0.03	
mc PRMI											-0.08
										(mean)	-0.02

* through cell 2 IMGC.

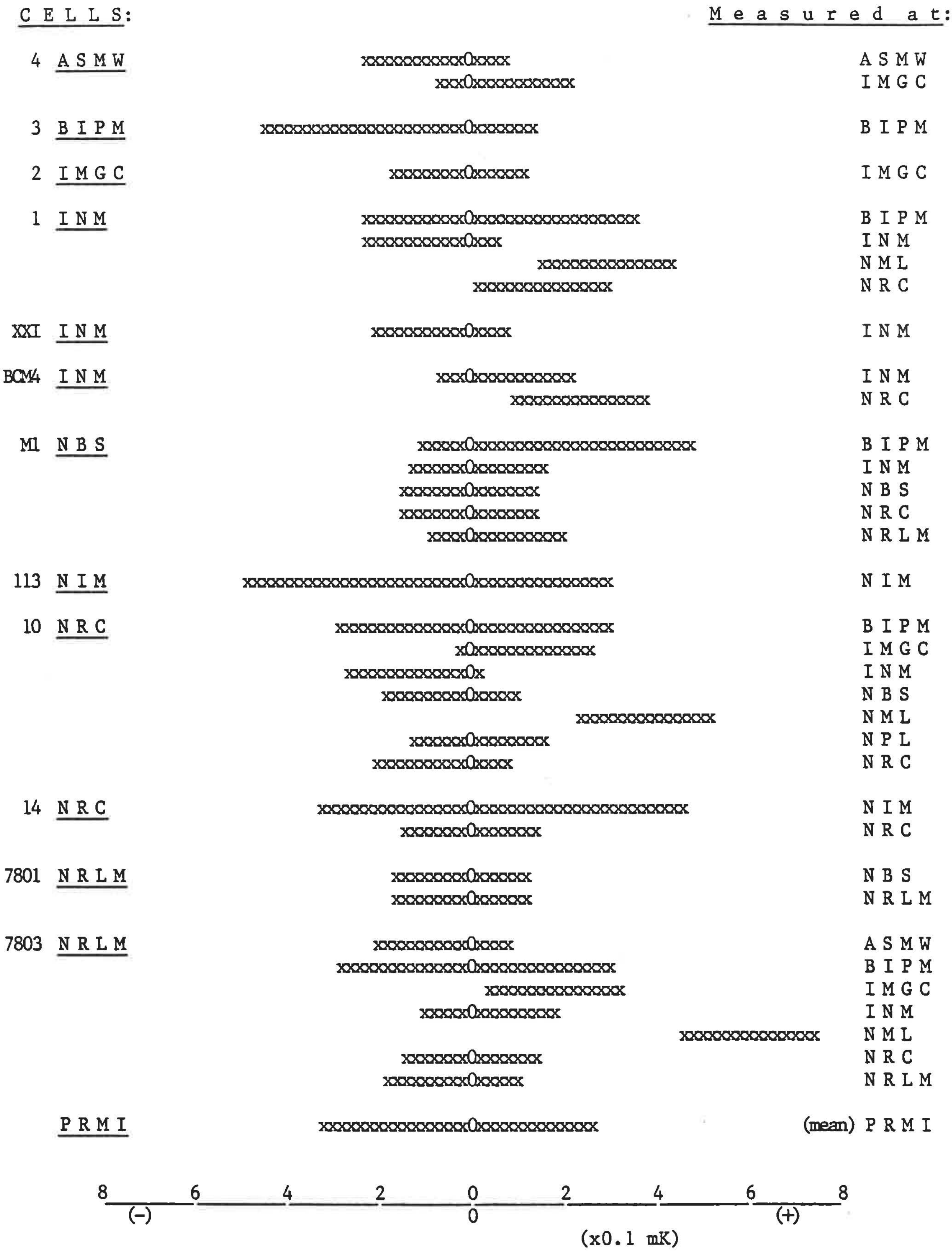
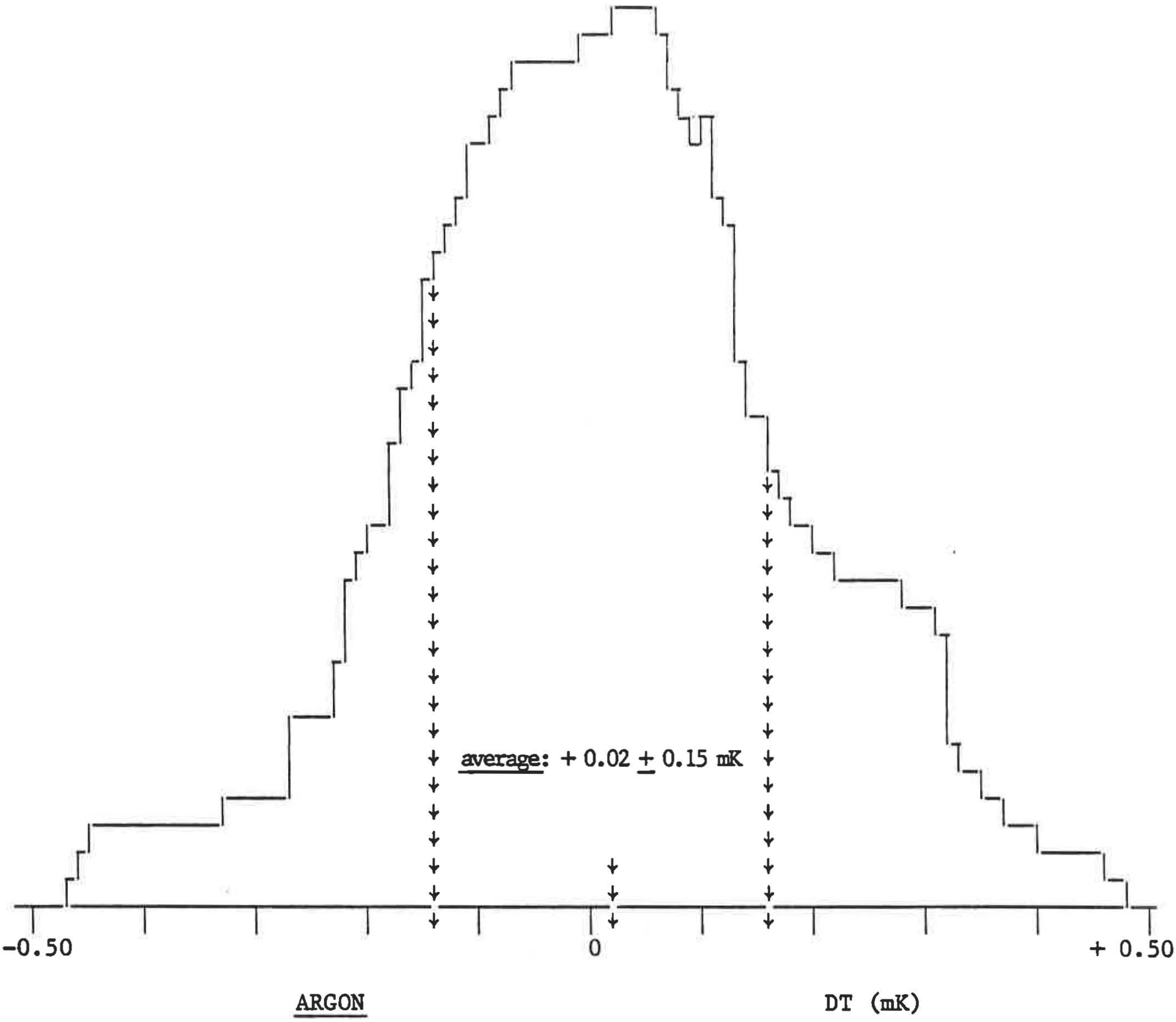


Fig. VII.1.a: Differences between cells filled with A R G O N and the reference cell 1 IMGC.



Distribution of mean difference
values of Table VII.1.a:

```
                    (0)
X X   XX XXXX XXX XXX    X XXX     X
      XX XXX   X  XX
      X  XX    X
      XX  X
```

Fig. VII.2.a: Distribution of the differences between cells filled with A R G O N and reference cell 1 IMGC.

Table VII.1.b: Results of the intercomparison between sealed cells filled with: O X Y G E N
(Reference cell: 1 IMGC)

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217997		PL01-6	1812283 232788	1812282	7709	1731676	1728839	1521389	7681	1842381
Cells:				Temperature differences: cell(LAB)-cell(ref) (mK)							
1 IMGC	ref.		ref.	ref.*	ref.*	ref.	ref.*	ref.	ref.*	ref.	ref.
8 IMGC			+0.48						+0.45		
8 INM				-0.15		+0.02	+0.24		-0.03		
BCM4 INM				-0.14					-0.01		
NBS					...						
PP07 NIM						-0.01					
PP11 NIM						-0.12					
15 NRC	+0.15		+0.29	-0.12			+0.14	+0.16	+0.08		
7801 NRLM			+2.02	+2.23					+1.56	+1.40	
mc PRMI											+0.39 (mean) +0.09

* through cell 8 IMGC.

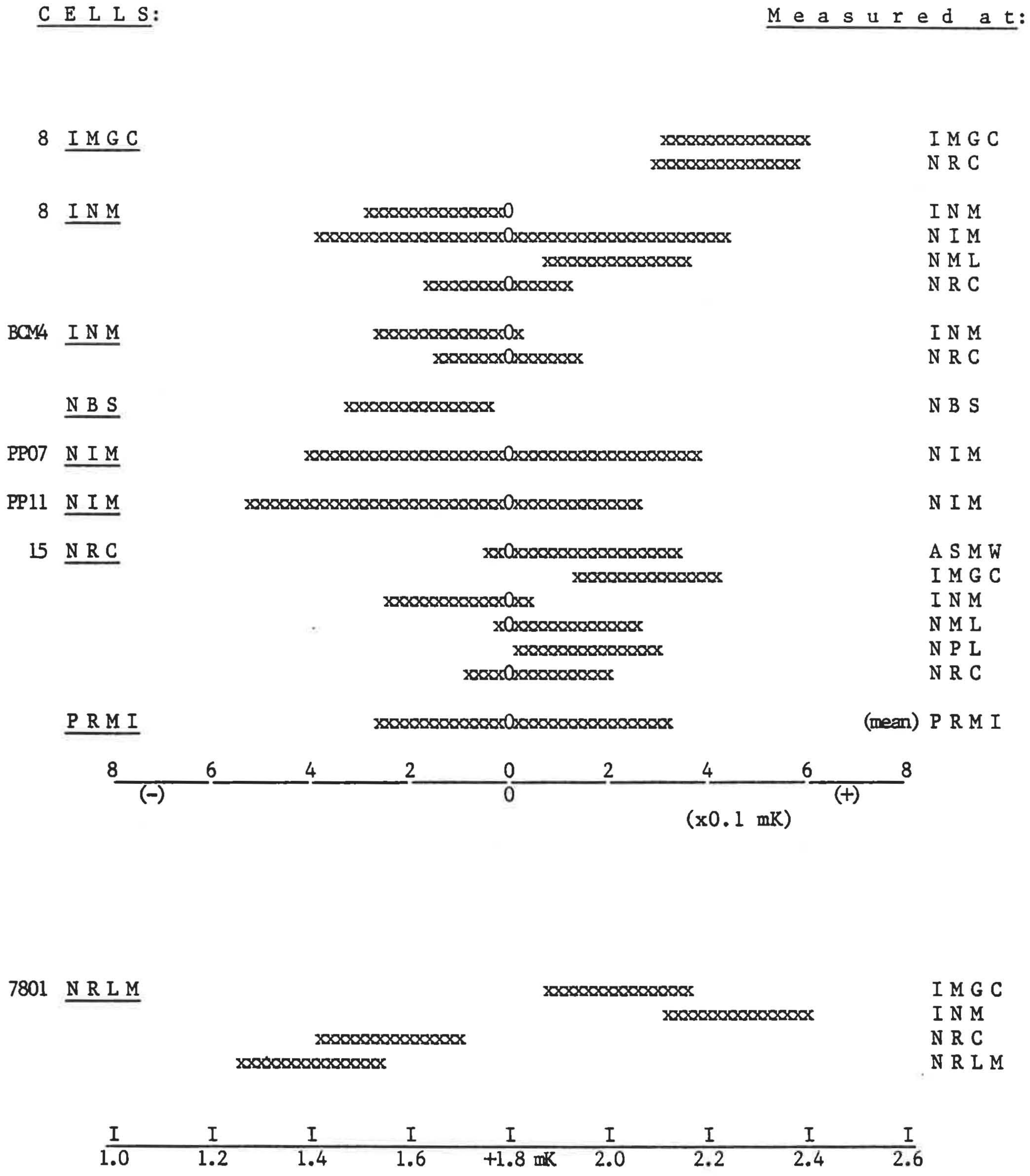
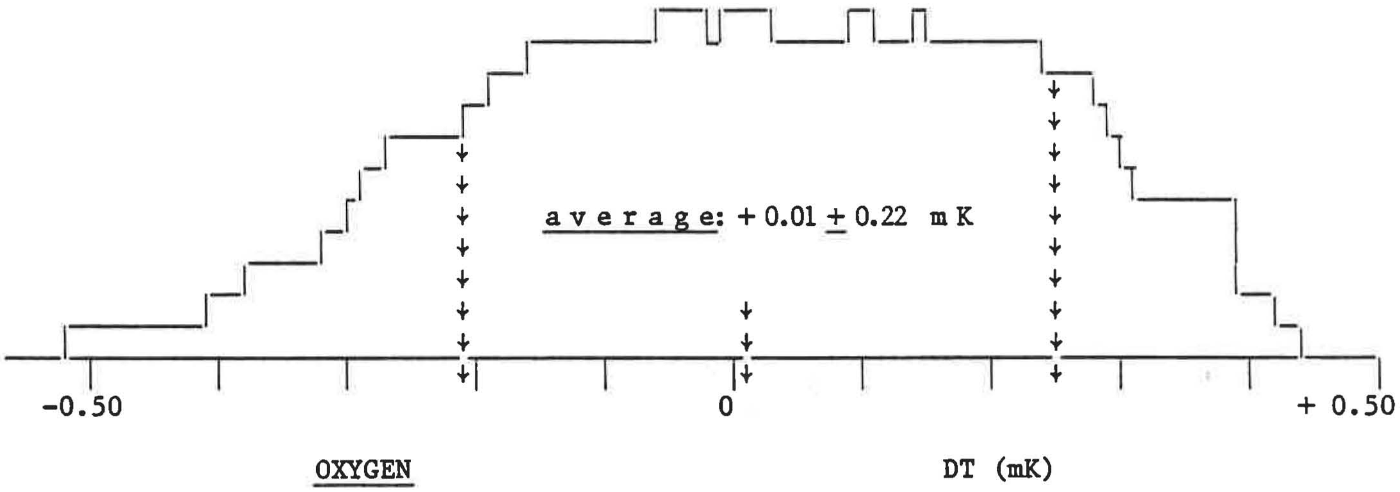


Fig. VII.1.b: Differences between cells filled with O X Y G E N and the reference cell 1 IMGC.



Distribution of mean difference
values of Table VII.1.b: (0)

X XXXX XX X XX XXX X X
X X

Fig. VII.2.b: Distribution of the differences between cells filled with O X Y G E N and reference cell 1 IMGC.

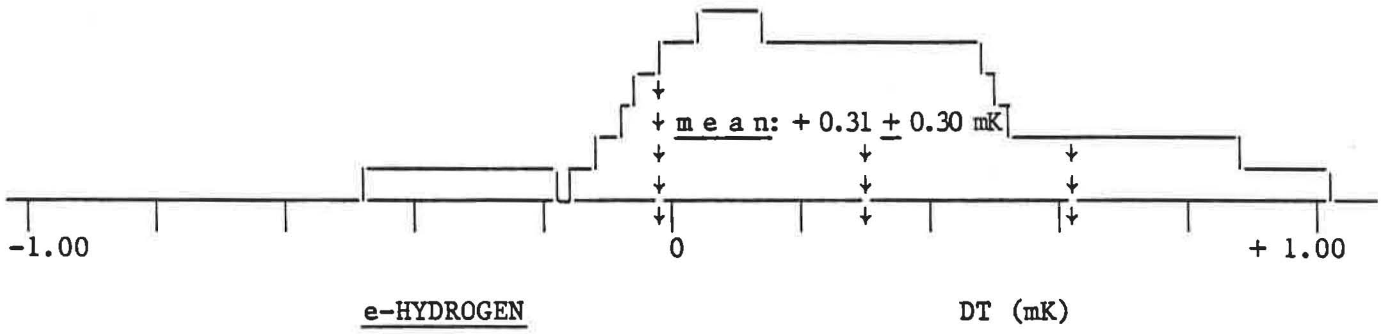
Table VII.1.c: Results of the intercomparison between sealed cells filled with: e - H Y D R O G E N
(Reference cell: 7801 NRLM)

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:	217997 207278		PL01-6				1731676	1728839	1521389	7681	1842381
Cells:				Temperature differences: cell(LAB)-cell(ref) (mK)							
1 IMGC	+0.52*		+0.24								+0.24 (assumed)
2 IMGC			+0.21								
23 NRC			+0.19				+0.13	0.00	-0.33		
7801 NRLM	ref.		ref.				ref.	ref.	ref.		ref.
mc PRMI											+0.34 (mean) +0.57

* difference of NPL temperature values of thermometers 217997 and 207278: there is a possible error (see Neon, Table VII.1.f).

```
C E L L S:                                                   M e a s u r e d  a t:

1 I M G C                  xxxxxxxxxxxxxxxxxxxxxxxxx          A S M W
                        x0xxxxxxxxxxxxx                      I M G C

2 I M G C              xx0xxxxxxxxxxxx                      I M G C

23 N R C              xxx0xxxxxxxxxxx                      I M G C
                        x0xxxxxx                             N M L
                      xxx0xxx                               N P L
              xxxxxxxx                                      N R C

  P R M I                        xxxxxxxxxxxxxxx      (mean) P R M I

    16_____12______8______4______0______4______8______12_____16
     (-)                         0                       (+)
                                         (x0.1 mK)
```

Fig. VII.1.c: Differences between cells filled with e - H Y D R O G E N and the reference cell 7801 NRLM.



Distribution of mean difference values of Table VII.1.c: (0)

X X X XX X X X

Fig. VII.2.c: Distribution of the differences between cells filled with e - H Y D R O G E N and reference cell 7801 NRLM.

Table VII.1.d: Results of the intercomparison between sealed cells filled with: M E T H A N E
(Reference cell: 2 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217990	226321	PL01-6			188640		1728839	1521389	7681	1842381
Cells:	Temperature differences: cell(LAB)-cell(ref) (mK)										
7 BIPM		+0.89							+0.91		
(1978)		+0.14									
2 IMGC	ref.	ref.*	ref.			ref.		ref.	ref.	ref.	ref.
12 IMGC			-0.15						+0.11		
18 NRC		-0.31	+0.22						+0.57		

* through cell 12 IMGC.

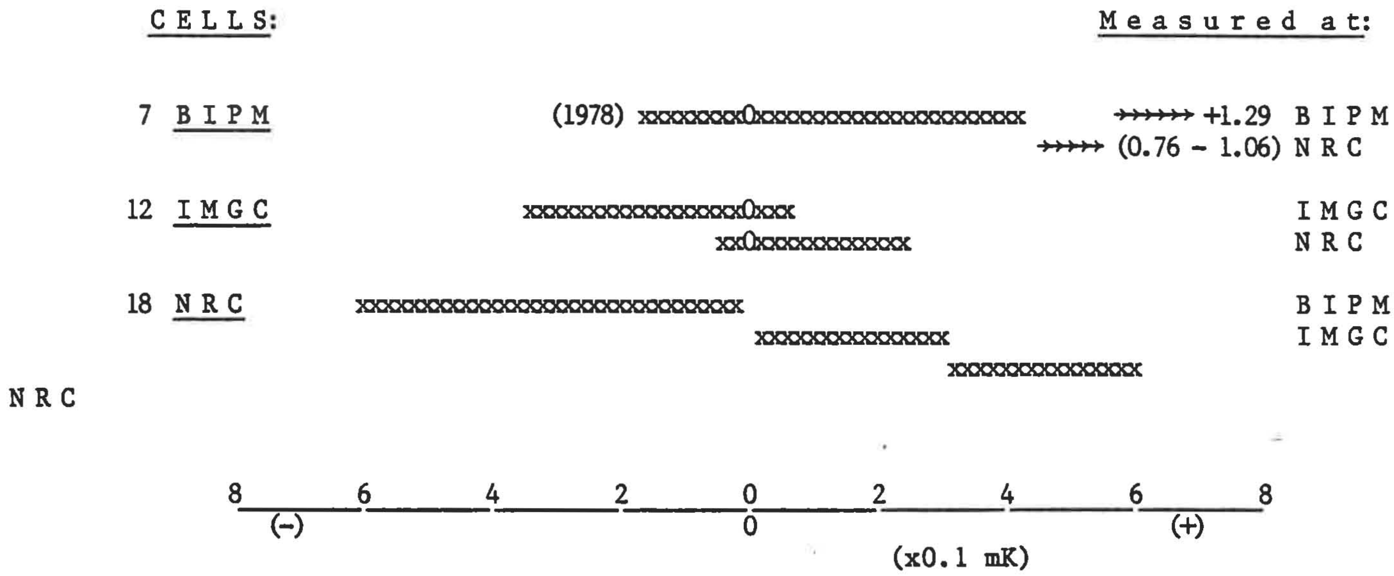


Fig. VII.1.d: Differences between cells filled with METHANE and the reference cell 2 IMGC.

Table VII.1.e: Results of the intercomparison between sealed cells filled with: N I T R O G E N
(Reference cell: 2 IMGC)

	A S M W	B I P M	I M G C	I N M	N B S	N I M	N M L	N P L	N R C	N R L M	P R M I
Thermometer:			45	1812283				1728839	1872179		
Cells:				**Temperature differences:** cell(LAB)-cell(ref) (mK)							
2 IMGC			ref.	ref.				ref.	ref.		
BCM4 INM				-0.17					-0.04		
33 NRC			-0.06						-0.17		

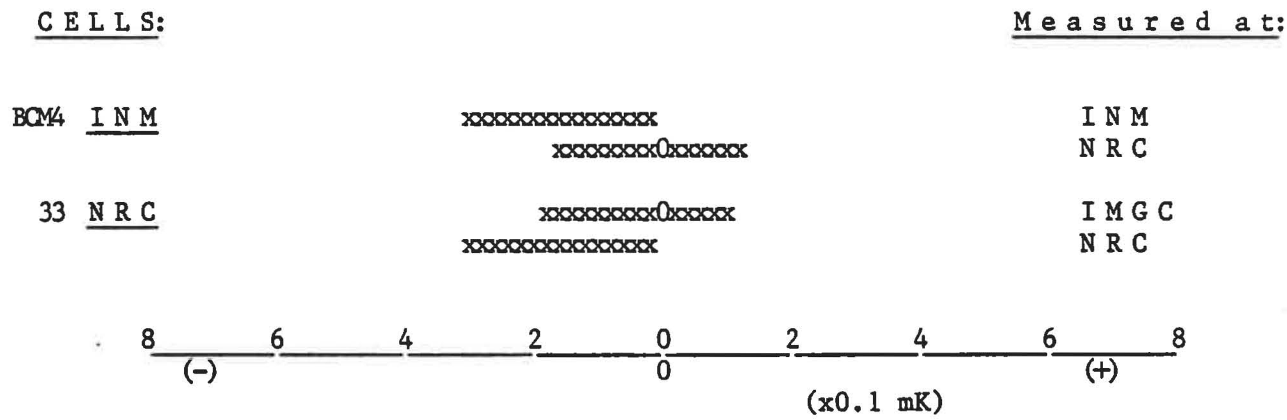


Fig. VII.1.e: Differences between cells filled with N I T R O G E N and the reference cell 2 IMGC.

Table VII.1.f: Results of the intercomparison between sealed cells filled with: N E O N
(Reference cell: 3 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:	217997 207278		PL01-6	1812283			1731676	1728839	1521389 1872179	7681	1842381
Cells:	Temperature differences: cell(LAB)-cell(ref) (mK)										
1 ASMW	+0.74 +0.34 §		+0.26								
1 IMGC			0.00								
3 IMGC	ref.		ref.	ref.			ref.	ref.	ref.	ref.*	ref.
BCM4 INM				-0.03					-0.10		
12 NRC	-0.06		-0.27				-0.25	-0.24	-0.04 -0.35		
1 NRLM								+0.03		-0.13	
2 NRLM			+0.03					+0.08	+0.17	-0.11	
mc PRMI											+0.13 (mean) +0.06

* through cell 1 IMGC. §) with thermometer 207278 (see Table VI.3.f).

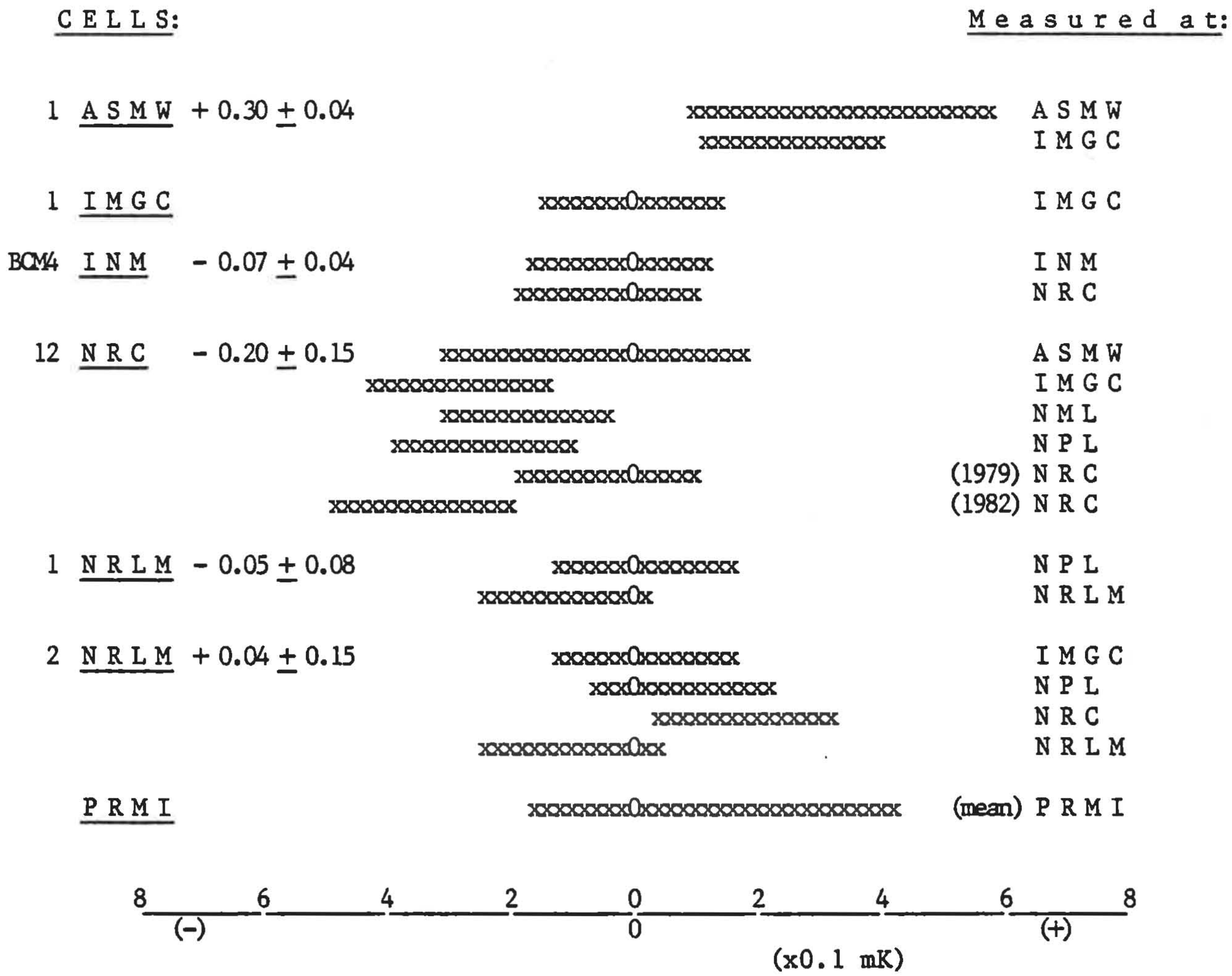
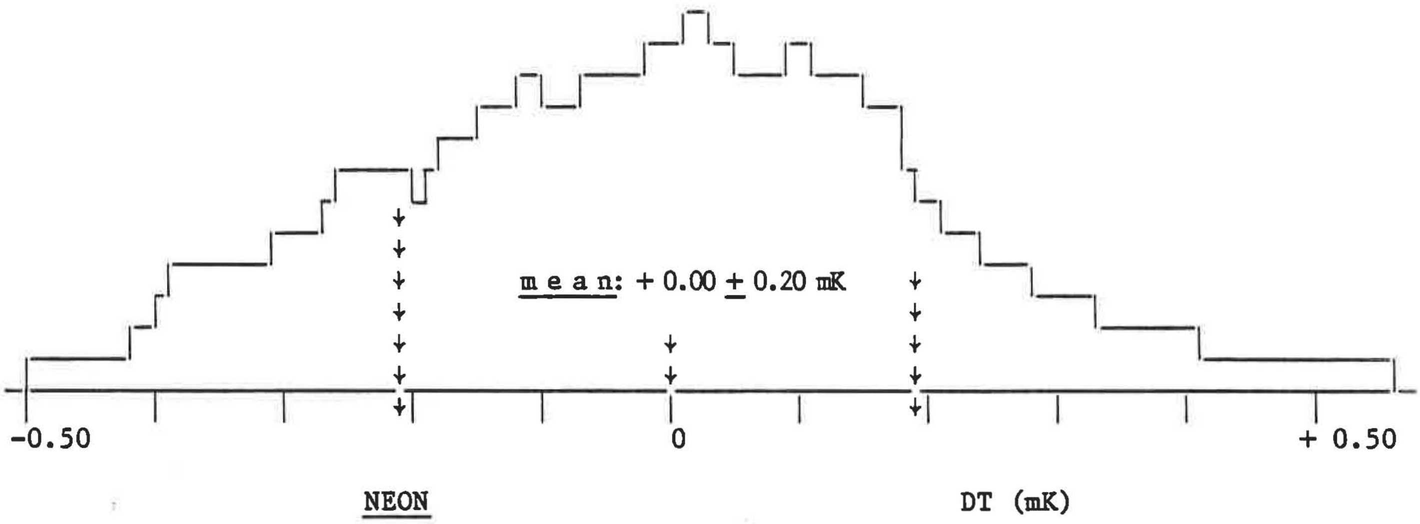


Fig. VII.1.f: Differences between cells filled with N E O N. and the reference cell 3 IMGC.



Distribution of mean difference values of Table VII.1.f: (0)

X X X X X X XX X X X X X X X
X

Fig. VII.2.f: Distribution of the differences between cells filled with N E O N and reference cell 3 IMGC.

Table VII.1.g: Results of the intercomparison between sealed cells filled with: e - D E U T E R I U M
(Reference cell: 1 IMGC)

	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
Thermometer:			PL01-6					1728839	1872179		
Cells:	Temperature differences: cell(LAB)-cell(ref) (mK)										
1 IMGC			ref.					ref.	ref.		
31 NRC									-15.4		

1.2 Measurability of the sealed-cell devices.

The Intercomparison permitted one to study the realization of the same thermodynamic state in cells of different design, as has been shown so far, but also to check the performance of the same cell when measured by different users. This is important, since a measurement with a sealed cell should no longer be considered an "experiment" but a test, the performance of a device instead of the running of an experimental apparatus.

For the former statement to be true, the results of the measurements should not depend critically on details of the test: this quality is called here "measurability", that is, the disposition of a cell to reproduce the same temperature value of the fixed point when used in as wide a variety of situations as possible (or convenient).

The Intercomparison tested this quality, both by confronting different cell designs and by using different cryostats and measurement procedures.

Sixteen models of cells were considered, showing quite different geometries and using copper and stainless steel for the fabrication in many possible combinations. The weight of the devices varied over the range 80-370 g, sealing a sample of mass ranging from 0.02 to 0.3 mol. Ageing of the sample in the cell after sealing ranged from one month to eight years.

The apparatuses used for the measurements were all vacuum adiabatic calorimeters, since this was mandatory, but the design was extremely varied; both flow and bath cryostats were included, with one or two isothermal shields. The cells were suspended in the experimental chamber either with nylon threads or with plastic or stainless steel fittings. The overall quality of the thermal equipment ranged from purposedly simple experiments (e.g. ASMW, IMGC above 54 K) to extremely careful calorimetry (e.g. NBS). Some experiments were computer assisted (INM, NML). Usually, the apparatuses used for testing these devices have been the same as are used in the Laboratories to reproduce or transfer LAB-IPTS-68, so that this exercise allowed also a test of the traceability of temperature measurements between Laboratories.

The answer to the question whether the results were affected or not by this variety of experimental conditions and cell design is evident from the preceeding Chapter. As can be seen particularly from Figs. VII.1.x, in most cases the mean value is within (or not significantly outside) the uncertainty limits of the differences measured by each Laboratory (strip boundaries), which indicates a small probability for experimental circumstances to produce systematic errors exceeding the limit of $\pm \sigma$ (as a matter of fact, almost all the difference values shown in Tables VII.1.x, and reported at the bottom of Figs. VII.2.x, are within these limits). This seems to be the actual limit of uniformity in temperature measurements at these fixed points around the world, which is about twice or three times larger, depending on the substance, than the reproducibility limit for most Laboratories, which is close to $\pm$ 0.1 mK.

Within these limits, cell design did not appear to have any systematic influence on the quality of the results. This means that no better or worse reproducibility for the differences from the reference cell could have been obtained with different cell models. Consequently it is possible to state that every model tested was equally good in reproducing the correct value for the thermodynamic state temperature (of course, differences due to sample contamination are not under consideration here).

Nevertheless, not every model allowed one to obtain this result with the same ease or, sometimes, with the same confidence. There are three the main parameters which allow one to check the quality of the cell performance in a melting experiment:

a) melting range;
b) overheating when heating the cell;
c) recovery time to equilibrium after overheating.

The values obtained during each experiment of the Intercomparison are recorded in the data sheets of Section V. Let us consider them separately.

a) melting range - from a thermodynamic point of view, this is defined only by sample purity and, consequently, it should be as reproducible as the value of the triple-point temperature. The shape of the melting plateau, too, should be quite similar (though not necessarily a straight line) for samples of comparable purity of the same substance. This has not been observed during the Intercomparison. The Figures associated with the data sheets of Section V show all the melting plateaux obtained in different Laboratories: it is evident that the same cell can produce curves of quite different shapes. That applies to all cell models, no one showing sensible reduction of the dispersion: large differences of the melting range for different cells are not due to cell design but to the purity of the sample.

Therefore, it is impossible, as a rule, to correlate the melting behaviour with parameters such as the materials of the cell body or the geometry of the sample interface. Speculations have been attempted in many Laboratories to guess about the distribution of the liquid-solid interface in the cell during melting, which depends on the distribution of the impurities, on the thermal map both during heating and at equilibrium and on the internal geometry of the cell. However, except when melting behaviour is dominated by relevant sample contamination (cells 2 CH4 IMGC, 12 CH4 IMGC, 1 eD2 IMGC, 33 NRC; 7801 02 NRLM is a special case that will be examined in the next Chapter), the melting pattern appears to depend completely on the thermal conditions of the experiment, which essentially means non-adiabaticity for the environment or not a true-equilibrium state for the sample. Since the sensitivity of a cell design to these conditions can be qualitatively related to an overheating factor and to the thermal reponse time, the discussion of this point is postponed to the following sections.

b) overheating factor - When the sample of condensed substance enclosed in the cell is crossed by a heat flux a temperature-gradient distribution develops and the thermometer, which is thermally linked to the sample, indicates an overall change of the temperature value. In addition, gradients will develop also in the cell body. Therefore, when the cell is heated with a heater mounted on the cell body, in order to melt the sample, an increase of temperature is observed and when heating is stopped, the temperature recovers to a lower value (which is supposed to be an equilibrium one). For this reason a melting plateau must be made by steps and not with the continuous heating method, if maximum accuracy is the aim. The overheating of the cell for heating at constant rate is known to always rise with the melted fraction: this is explained by an increase of overheating in the liquid phase, since there is experimental evidence that the solid phase tends to be shielded by the liquid one.

The size of the overheating produced by the cell heater for a given heating power fully depends on the details of each model design. Since it is essentially the same as that produced by any kind of heat exchange of the cell with its surroundings, no matter how imposed, the smallest is the temperature change measured by the thermometer, the best should the thermal behaviour of the cell be considered, because the least will be the sensitivity of the cell behaviour to heat exchanges with the surroundings. Although a study of the overheating behaviour versus heating power is possible for each of the cell models, this specific measurement has only been made recently for the ASMW cell[55]; in a few other cases the whole overheating profile (what one could define as the "overheated plateau") has been reported. During the Intercomparison only a few Laboratories supplied the overheating profile (ASMW, BIPM, IMGC, NPL (few)), so that it has not been included in this Report, but only a single point has been selected to represent the sensitivity of each cell to overheating. An overheating factor has been defined at F=50%, referred to the unit power P (in mW); this is not exactly true if overheating is not proportional to P. It must be pointed out that the sensitivity of the cell to freezing is different, but it is generally agreed that heat leaks should be kept positive to avoid the risk of condensation of substance in parts of the cell sufficiently decoupled from the thermometer to produce a lowering of temperature due to evaporation (though this effect in a sealed cell is much less dramatic than in a conventional apparatus).

The reason for selecting the point at F=50% can be better explained with Fig. VII.3. Melting begins with no overheating if a proper procedure has been followed for solidification of the sample and the subsequent warm up, so that the beginning of melting has been reached slowly. Then, if P is such that the energy supplied per minute is of the order of a hundredth of the total enthalpy of sample melting, overheating increases to quickly reach an almost steady value, only slowly increasing with the melted fraction. Eventually, past 60% to more than 90% of total melted fraction, depending on cell model and on substance, it increases again rapidly. In several cases it is so high, close to the end of melting, that it is difficult to locate the very end of the plateau, resulting in an uncertainty of few percent on the total length of melting. The selection of F=50% for the definition of typical overheating brings into consideration the steady portion of the "overheated plateau", after the initial transient and before the variable final portion.

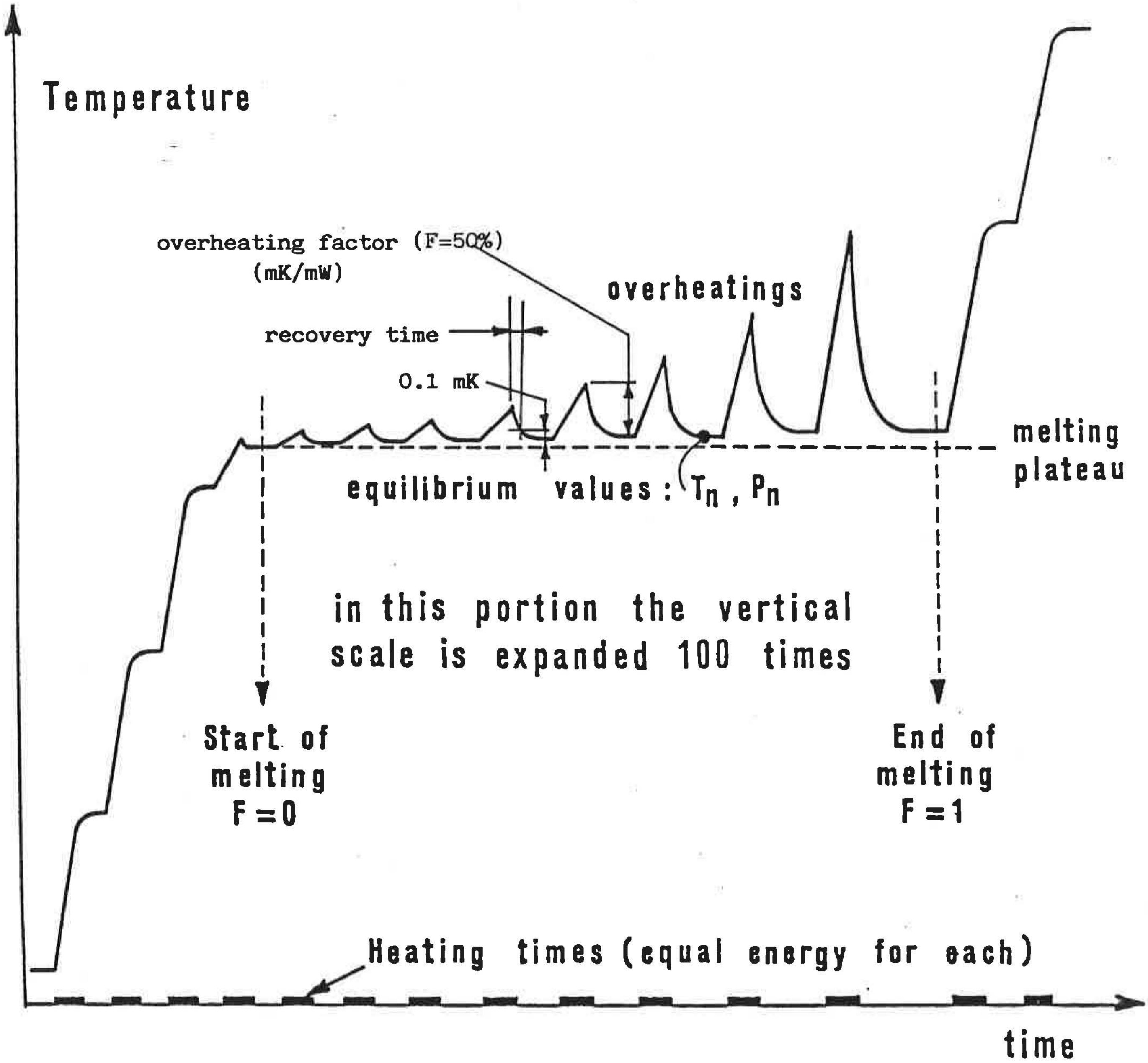


Fig.VII.3: Definitions of overheating factor and recovery time.

It is possible now to discuss the statement at the end of point a). In fact, the shape of the "overheated plateau" shows the evolution of the sensitivity of the cell to an external heat flux, and consequently the shape of the equilibrium plateau can be considered as the limit of the former for very small heat flux. As a matter of fact, also the equilibrium plateaux often show a curvature upward, sharply increasing above F=50-90% (particularly evidenced in the 1/F plot), which corresponds to the sharp increase of overheating. This correlation is easily explained by a loosening of the thermal coupling between thermometer and solid-liquid interface. The temperature of the cell (as indicated by the thermometer) becames more and more influenced by the residual heat exchange with the cryostat; therefore, after heating, the sample does not return to equilibrium but to a steady state, corresponding to a temperature higher than the equilibrium one (for heat intake). This error may be different from model to model and be relevant beginning from different F values.

The extent of non-adiabaticity during each experiment has been controlled in two ways. The first, by asking the Laboratories to report the temperature drift observed just before beginning and after completion of melting: therefore, from the heat capacity of the cell (approximately calculable from its total mass) the residual heat leak could be calculated. Since the two drift rates were in general quite close together, only the average value is reported in the data sheets.The second control is through the measured value of the enthalpy of melting. This parameter is a constant of each cell: therefore the deviations from the calculated value (or assumed value, when the mass of the sample must be assumed) are due only to lack of adiabaticity of the calorimeter. The data sheets often show large discrepancies, up to about 30%, in these values, indicating bad thermal control: most of the wrong values are too small, which means large heat inflow.

The overheating factor varies widely from cell to cell, in the range 0.04-0.3 mK/mW for CH_4 (but 5 mK/mW at BIPM, where the cell heater has been mounted on the thermometer block of cell 12 IMGC, instead of externally on the body), 0.02-3 mK/mW for Ar (but 5 and 24 mK/mW respectively at BIPM and INM, for the same reason, on cell 2 IMGC), 0.01-0.1 mK/mW for N_2, 0.01-6 mK/mW for O_2, 0.02-0.7 mK/mW for Ne and 0.2-10 mK/mW for H_2. Moreover, large differences (up to more than one order of magnitude) were found for this parameter when the same cell was measured in different Laboratories.

In conclusion, although the collection of these secondary parameters was incomplete, a picture arises from the data sheets of a quality of thermal control that is very different from experiment to experiment, and often less effective than expected.

The discussion on overheating does not fully help in explaining the large variability observed in the melting-onset temperature. The Intercomparison was unable to provide any enlightenment on this point, which seems to be related, for a given sample, to the possibility of gradients inside the sample depending on its thermal history (freezing and warming rates, stabilization times, annealing), or to the distribution of impurities in it.

c) recovery time - The return of the cell to equilibrium after each heating pulse proceeds exponentially, but two time constants are involved: a shorter one related to the cell body and a longer one due to the sample, whose thermal diffusivity is always low. For this reason, and because not all the Laboratories recorded (on chart or by computer) the whole pattern of the plateaux, it was preferred not to define recovery time by means of a time constant, but in a simple and uniform operational way: as the recovery of temperature to within 0.1 mK of the value considered as the equilibrium one by each Laboratory (Fig. VII.3). A much tighter limit could have been selected (e.g. 0.02 mK), since many of the cells are fast and show small overheating, but this was not possible in every case. On the other hand, for the purposes of the Intercomparison, recovery within the uncertainty limit and expressed in minutes was a sufficient goal. Nevertheless, there has been some lack of uniformity in the Laboratory reports in applying the criterion, especially concerning the definition of equilibrium temperature. This is particularly evident in the case of INM, whose statistical criterion always led to larger values.

The values of recovery time are recorded in the data sheets: when two figures are given, the first refers to small melted fractions (when overheating is small), the second to very high melted fractions (where overheating is high). Recovery time was generally observed to increase up to one order of magnitude from beginning to the very end of melting (but it remains almost stable at the smaller value for most of plateau).

Several data sheets show also a dramatic variety of values obtained in different Laboratories for the same cell, up to more than two orders of magnitude, quite outside the possible spread due to different interpretations of the definition. As a matter of fact, the thermal coupling of the cell with the cryostat, pointed out in b), also affects thermal recovery time.

Screening the results from these artifacts, the Intercomparison has shown that recovery time depends for each cell model on the substance, and for each substance on cell design. Among the substances investigated here, methane is the slowest, followed by nitrogen and argon; re-equilibration is quite fast in oxygen, neon and hydrogen. Among the cell models, considering the average behaviour, the all-copper cells (e.g. NRC, NRLM) seem to have the faster response, while the massive NBS argon cell was the slowest. However, differences are smaller than the systematic differences between Laboratories. As a rule, at 54 K or less, after 10 minutes the temperature can be considered to be at equilibrium well within the uncertainty limits, while one should wait twice as long as that for argon and nitrogen (and methane, when the purity is such that the melting range is within 1 mK; when it is around 5 mK, 30-40 minutes are required).

There are two reasons why it is important for cells to have a reasonably fast thermal recovery. The first is the opportunity to limit the time required to perform a full melting, since this limits non-adiabaticity errors: the effect of a slow cell is worse than proportional to the time constant, since these cells necessarily show also high overheating factors, slow recovery being a symptom of bad thermal coupling with the whole sample. The second is to have more reliably true equilibrium states: in fact, a slow cell can average fluctuating residual heat exchanges with the surroundings and stabilize itself in a steady overheated state instead of in the true equilibrium state.

1.3 Gases as candidate substances for reference points.

The Intercomparison also collected useful information about the merits of the different substances for their use in the realization of temperature reference points. All these gases have already been studied in several Laboratories, and, on the other hand, there is a very limited choice of fixed points below 100 K. However, the Intercomparison allowed one for the first time to study the same sample of gas in different Laboratories, for a better understanding of how much the measured properties could be influenced by the Laboratory equipment and procedures (as in a round-robin test); and different samples in different cells, which is important to check for differences in gases produced by different manufacturers in the world (particularly for neon). Only the influence of the cell model on the measured properties could not be resolved in this exercise, as the same model of cell was never filled with gases of different countries (but this has already been done during other studies in some Laboratories). Of course, no check of the effect of impurities was possible, the devices being sealed, but it was possible, on the other hand, to test the quality of research-grade gases (though the Laboratories generally circulated devices known to work properly).

A R G O N

No problems were found in reproducing very accurately the triple-point temperature of this gas. The melting range was always a few tenths of a millikelvin and the reponse time of the devices quite fast, allowing one to perform a full melting in few hours. This gas is therefore extremely good and reliable for realizing a reference point of a temperature Scale.

O X Y G E N

The Intercomparison has confirmed the systematic differences between cells which are possible with this gas, already observed at IMGC[8], INM[13], NBS[13], NIM[13] and NRC[36], where differences higher than a millikelvin have been found.

The effect consists in a rise of the triple-point temperature with no apparent change in melting range (or recovery time), so that the systematic errors cannot be detected otherwise than by comparison of the device with a certified cell. It has been observed that this error never occurred with oxygen home-made by decomposition of $KClO_4$ or $KMnO_4$ (NBS, NRC); no data are available yet about the behaviour of commercial research-grade oxygen obtained by electrolysis of water versus that obtained by distillation of air (most common).

In particular, two of the cells taking part in the Intercomparison suffered from a systematic deviation: 8 IMGC which was higher by + 0.48 mK and 7801 NRLM which was higher by 1.8 mK.

The problem is puzzling, since there has been so far no experimental evidence of the reason for these systematic errors. The only known phenomenon that could cause a rise in the triple-point temperature of that kind is contamination with argon (see Ref.36 and references in Ref.52). It forms with oxygen a mixture showing a peritectic around 10% Ar in O_2 at a temperature 0.2 K higher than that of pure oxygen. The initial slope of the mixture diagram is such that 100 ppm of argon are necessary to raise the triple-point temperature by 1.5 mK, and there is no separation of the liquidus and solidus lines, leaving the melting range unaffected. Unfortunately, there is not a single confirmation, so far, of such a contamination with argon for the samples used in the Laboratories[8,13] all the analyses, batch or especially made on the bottles used for filling the cells, gave argon contamination never exceeding 10 ppm (see also data sheets).

Consequently, this gas still requires careful analysis for further use in a temperature Scale: the problem needs to be eliminated or a reliable procedure must be found to avoid these systematic errors. Actually, there is not even experimental evidence at present, but only a high probability of occurrence, that the lower value reproduced by most of the cells is the right one to assign to the triple-point temperature of pure oxygen.

The other characteristics of melting are extremely good: melting range is very narrow and recovery to equilibrium very fast.

e - H Y D R O G E N

The main problem in assessing the quality of this gas does not come from the limited number of measurements during the Intercomparison but from the broadening of the uncertainty limits for many of the measurements, which can be due to increasing difficulties both in resistance measurements (1 μΩ corresponds to about 0.15-0.20 mK) and in thermal control. As a matter of fact, the very narrow melting range and the very fast recovery to equilibrium are the prerequisites of a very good fixed point, but it has been impossible to compare the cells and to check reproducibility at a convenient accuracy level. Therefore, it is quite possible that this fixed point reproduces better than could be inferred from Fig. VII.2.c.

No problems have been found with the catalyst contained in the cells. It must be pointed out that the mass of the sample cannot be known accurately if cryogenic condensation is used to fill the cell, since the catalyst is losing weight in the activation process.

M E T H A N E

This substance confirmed that it may be good for the realization of a fixed point but this is not certain at present. In fact, as happens with oxygen, there is not enough expertise at present to avoid systematic errors. In this case, unstable temperature values have been found, although limited to two Laboratories (BIPM[13] and NRLM[41]): the cells involved were completely different in design, the first being all made of stainless steel, the second all of copper. Also, large melting-range differences have been found with gases of the same nominal purity (confirmed by specific analyses, for some of them); gas with better nominal purity gave even worse results both at IMGC and BIPM[13]. Finally, there is some evidence that the geometry of the cell can be an influence parameter for that.

Considering also the slower recovery time of this gas, the superior performance of the nearby argon triple point leaves very little interest in considering this fixed point as a candidate definition-point of a temperature Scale.

N I T R O G E N

Contrary to the considerations with methane, the limited number of measurements made with this substance were sufficient to reveal the very high quality of this fixed point, which appears to be very much the same as that of argon. Probably, more work should be done to ascertain the influence of impurities (especially argon) on sample-to-sample reproducibility of the triple-point temperature.

N E O N

Quite a lot of interest was focused on this substance, since it was expected to show problems connected with isotopic composition and distillation during melting[6]. The measurements made during the Intercomparison on a comprehensive set of cells showed a melting plateau and a thermal behaviour of very high quality, so that a reproducibility of the same level as argon cells should be expected for each device. However, there has been evidence, though not conclusive, that some systematic differences between cells may occur: a scatter of the mean values of the cells close to half a millikelvin has been found (Fig. VII.1.f). Again, as with oxygen and methane, one must conclude that, although these results could represent an extreme situation, a reliable assessment of the accuracy of the realization of this fixed point must include, at present, a statement that differences up to 0.5 mK can be found from cell to cell, probably due to differences in isotopic composition of the gas. If a better accuracy is aimed at, each new device should be compared with certified cells.

However, the correlation between these differences and the isotopic composition has not been demonstrated so far; consequently, it is impossible, at present, even to guess which one of the cells taking part in the Intercomparison most closely approaches the realization of the triple point of neon of natural composition (as defined by IPTS-68).

e - D E U T E R I U M

An evaluation of this substance was attempted in the Intercomparison on the only two cells available. In contrast to all other gases considered here, the purity of the samples has been very poor (nominal purity 99.86% for the IMGC and 99.6% for the NRC cell). Measurements on the IMGC cell, made in three Laboratories, demonstrated that it is possible to obtain an agreement compatible with the quality of the cell (melting range of about 5 mK): the temperature values (Tables VI.2.g and VII.3.g) actually show an agreement limited to about 2 mK, due to thermometer calibration problems at IMGC and NRC.

On the other hand, the difference between the two cells is very large (-15 mK): it is large also compared with another recent (conventional) realization at NML: +15 mK[50]. In addition, the differences between the triple-point temperature of normal and equilibrium deuterium were widely different, being 18 mK, 51 mK and 51 mK at NML, IMGC and NRC respectively. Recent discussions with specialists of deuterium production and handling seem to indicate that the problem consists of a contamination with HD[16], and that this is almost unavoidable. The only hope of avoiding it resides in a very special fabrication of the cell and in a direct filling at the production plant, where HD contamination is known to be limited (before any handling) to a few tens of parts per million.

2. On Scale realizations

The results discussed in this Chapter should in no way be confused with those of the former Chapter. In fact, the former results do not depend on assigned temperature values, except in the limited number of cases where they were obtained indirectly, involving some calculations indicated earlier.

Although it was not necessary for cell intercomparison, Laboratories were asked to use calibrated thermometers for the measurements, since some additional useful information can be obtained, and in order to fulfill goal c) of the Intercomparison (see Sect.III.3 and IV.3.2). First of all, for Laboratories where the Scale is not based on sealed-cell realizations of the fixed points it is possible to obtain a relationship between the cells and the conventional realizations (or LAB-IPTS-68 for a specified thermometer, when secondary points are not realized). Secondly, it is possible to obtain a relationship between these measurements and the exercise at NPL in 1975 when thermometers belonging to what has been called here "international group" were used. Finally, it is possible to relate the measurements on some cells to the others, even in the (few) cases where only one cell of a substance was measured by a Laboratory.

Tables VI.2.x and VI.3.x collect the same information on temperature values as are in the data sheets of Section V, for LAB-IPTS-68 and NPL-IPTS-68 respectively, and for all cells. They show a dispersion of values which depends both on differences between cells, already analyzed in Tables VII.1.x, and on differences due to the thermometers or to Scale realizations. If the latter contributions to total uncertainty were small, the set of results would present the same dispersion of values in Tables VI.2-3 and in Tables VII.1.x. This was not the case, as one will see later for each substance.

In addition to the inaccuracy of the thermometer calibrations and to differences between National Scales, with secondary fixed points there is also a contribution due to IPTS-68 non-uniqueness. For the thermometers of the "international group" the amount of this contribution is known, since they were not only calibrated at NPL but also compared to the "master" thermometer 1728839 in the whole temperature range. Since many of the Laboratories used them, it is possible for most of the temperature data of Tables VI.3.x to apply the non-uniqueness correction and obtain the temperature values on NPL-IPTS-68(1728839). They are reported in Tables VII.2.a,d,e,f for the secondary fixed points, excluding e-deuterium and including argon, which was a secondary point of the NPL exercise. Non-uniqueness corrections are reported in Appendix I (data from Ref.3).

In the following chapter, the analysis of the temperature values for all the cells will be made on the basis of the three sets of data, collected in Tables VI.2.x, VI.3.x and VII.2.x. From each of these Tables a mean temperature value can be obtained for the whole set of cells and a standard deviation calculated. Table VII.3 allows a compact comparison of these data, which can be compared also with the dispersion of the differences between cells obtained from Figs. VII.2.x: the latter figure represents the width of the dispersion histogram at 2/3 of the total area. The last column of the Table allows one to compare the former experimental uncertainties of the intercomparison with the limit represented by the Laboratory-weighted total uncertainty, that is, the mean square of the uncertainties defined in Sect.IV.3.1, weighted according to the number of measurements done by each Laboratory.

Finally, a collection of data on IPTS-68 National realizations will be done in the second chapter. In this case, only one cell value for each substance is needed: the reference cell has been used, since it generally represents well the average value (Figs. VII.2.x).

2.1 On the temperature values of the cells.

Let us consider the substances separately.

A R G O N

Systematic differences of more than 1 mK are visible between LAB-IPTS-68 values. Some are certainly related to Scale realizations, as the well-known case of NBS, others could be due only to the thermometer actually used (NRLM, NIM). It must be noticed that temperature values for BIPM, IMGC and INM are relative to a Laboratory reference cell, which is supposed to reproduce T = 83.798 K exactly (actually, these Laboratories use the argon triple point for IPTS-68 definition). The mean temperature value and standard deviation reported in Table VII.4 are calculated excluding NBS values.

Concerning NPL-IPTS-68 values with the Laboratory thermometers, Table VI.3.a shows a rather good agreement (± 0.27 mK) among these old (circa 1975) calibrations. Only the newer calibration of n°7681 (NRLM) shows quite an anomalous value, which has been excluded from the calculated values reported in Table VII.3. After the non-uniqueness corrections are applied (Table VII.2.a), the standard deviation (± 0.27 mK) does not improve and remains higher than the cell-comparison uncertainty (± 0.15 mK) and the total uncertainty (± 0.21 mK) (Table VII.4).

O X Y G E N

With oxygen, the systematic differences in LAB-IPTS-68 values of Table VI.2.b come only from cell differences, except for the NIM measurements. The values in Table VII.4 have been obtained excluding both NIM values and deviating cells (8 IMGC and 7801 NRLM). The same calculation has been performed in Table VI.3.b on NPL-IPTS-68 values, discarding only the values of the deviating cells.

The standard deviation is worse (± 0.29 mK) than with argon (of course there are no uniqueness corrections here) and significantly worse than the cell-comparison dispersion (± 0.23 mK) and total uncertainty (± 0.21 mK).

e - H Y D R O G E N

Among the few values available on LAB-IPTS-68, it must be noticed that the IMGC ones are relative to the 1H2IMGC cell, chosen to represent the definition value T = 13.81 K. Concerning NPL-IPTS-68 values, there is evidence of the large calibration drift of thermometer n°PL01-6, which has been discarded from the calculations, together with the NRLM value.

Still, the standard deviation is worse (± 0.49 mK) than the cell-comparison dispersion (± 0.31 mK) and the total uncertainty (± 0.29 mK) (again no non-uniqueness corrections to apply).

M E T H A N E

Large systematic deviations are evident between Laboratories in LAB-IPTS-68 (Table VI.2.d). They generally reflect the systematic differences at the argon triple point[56,63], and the fact that the two definitions of IPTS-68, using argon triple-point or oxygen condensation-point, give rise to a systematic difference ($T(Ar)-T(O_2)$) at the methane triple point, amounting in this Intercomparison to 0.7 ± 0.7 mK (where NRLM values were again discarded).

In fact, values are better reproduced using NPL-IPTS-68, as shown in Table VI.3.d. After NRLM and PRMI values are discarded, standard deviation settles to a lower value (± 0.48 mK), and to a still better value after non-uniqueness corrections are applied(± 0.35 mK) (Table VII.2.d). The last value is practically coincident with the results of cell comparison (± 0.3 mK) and the total uncertainty level (± 0.25 mK). However, cell 7 BIPM had also to be excluded, since it was found to be unstable (Table VII.1.d).

N I T R O G E N

Results with nitrogen suffer from being only a small number. This results in a random pattern for changes of standard deviation values in Table VII.3. In fact, the very good agreement between LAB-IPTS-68 values (Table VI.2.e) and the poor one for NPL-IPTS-68 values (Table VI.3.e) are quite contradictory; the latter improves only a little when applying the non-uniqueness corrections (Table VII.2.e). Consequently, the quality of temperature measurements (± 0.35 mK) turns out to be much worse than the agreement between cells (± 0.15 mK) and compared with the total uncertainty (± 0.15 mK).

N E O N

From Sect.VII.1 it is known that some systematic differences may exist between cells. This results, of course, in some spread also for the temperature values. However, a spread much larger than justified by that may be observed between LAB-IPTS-68 values in Table VI.2.f (± 0.86 mK), though only four Laboratories are involved. It may be mainly attributed to differences between the National realizations, because the NPL-IPTS-68 values of Table VI.3.f, though extended to many more Laboratories, give a better agreement (± 0.41 mK, excluding n°PL01-6), with no change after the non-uniqueness corrections are applied

(± 0.41 mK); this value is still quite a bit higher than the dispersion of cell-comparison measurements (± 0.20 mK) and the total uncertainty (± 0.25 mK) .

e - D E U T E R I U M

As pointed out in Sect.VII.1.3, the quality of the two cells available was much worse than for the others, the gas being quite impure. No evaluation was possible in Sect.VII.1.1; here some considerations come from the measured temperature values.

The IMGC cell was measured in three Laboratories: the agreement between measurements was about 2 mK. This is much worse than the published reproducibility figure (± 0.3 mK)[48,49], but is compatible with the difficulties found at NPL and NRC in obtaining a good shape for the melting plateau and with the differences in calibration of the thermometers (e.g. see hydrogen, Table VI.3.c). By the way, it is much better than the systematic difference found with respect to the NRC cell (15 mK): a possible reason for that is given in Sect.VII.1.3.

Table VII.2.a : Results of measurements on sealed cells filled with: A R G O N

Temperature in NPL-IPTS-68 (K) (thermometer: 1728839)

Cells:	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
4 ASMW	83.79758		83.79746								
3 BIPM											
1 IMGC	83.79772		83.79740					83.79690	83.79685		
2 IMGC			83.79739	83.79742	83.79719		83.79705				
1 INM				83.79737			83.79730		83.79702		
XXI INM				83.79739							
BCM4 INM				83.79753					83.79714		
M1 NBS				83.79746	83.79719				83.79684		
113 NIM											
10 NRC			83.79753	83.79732	83.79715		83.79737	83.79695	83.79684		
14 NRC									83.79684		
7801 NRLM					83.79717						
7803 NRLM	83.79762		83.79756	83.79748			83.79758		83.79684		
mc PRMI											

T_{mean} = 83.79723 K, σ = 0.27 mK.

Table VII.2.d : Results of measurements on sealed cells filled with: M E T H A N E

Temperature in NPL-IPTS-68 (K) (thermometer: 1728839)

Cells:	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
7 BIPM									90.68462°		
2 IMGC	90.68348		90.68385					90.68372	90.68372		
12 IMGC			90.68370						90.68383		
18 NRC			90.68407						90.68429		

Excluding °): T_{mean} = 90.68392 K , σ = 0.35 mK.

Table VII.2.e : Results of measurements on sealed cells filled with: N I T R O G E N

Temperature in NPL-IPTS-68 (K) (thermometer: 1728839)

Cells:	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC	NRLM	PRMI
2 IMGC			63.14629	63.14686				63.14611	63.14599		
BCM4 INM				63.14669					63.14593		
33 NRC			63.14624						63.14590		

T_{mean} = 63.14625 K , σ = 0.35 mK.

Table VII.2.f : Results of measurements on sealed cells filled with: N E O N

Temperature in NPL-IPTS 68 (K)
(thermometer: 1728839)

Cells:	ASMW	BIPM	IMGC	INM	NBS	NIM	NML	NPL	NRC (*)	NRLM	PRMI
1 ASMW	24.56298°		24.56292° 24.56185								
1 IMGC			24.56284° 24.56155								
3 IMGC	24.56213		24.56284° 24.56155	24.56208			24.56191	24.56163	24.56105		
BCM4 INM				24.56207					24.56095		
12 NRC	24.56211		24.56258° 24.56135				24.56166	24.56141	24.56101 24.56070		
1 NRLM								24.56165			
2 NRLM			24.56286° 24.56155					24.56172	24.56122		
mc PRMI											

* through 1521389. σ_{tot} = 0.55 mK. Excluding °): T_{mean} = 24.56156 K , σ = 0.41 mK.

Table VII.3: Uncertainties in the International Intercomparison. (mK)

	(1)	(2)	(3)	(4)	(5)
	On temperature values			On cell Inter-comparison	Laboratory weighted total uncertainty
Substance	LAB-IPTS-68 σ	NPL-IPTS-68 lab.therm. σ	NPL-IPTS-68 1728839 σ		
Argon	83.79793 K	83.79707 K	83.79727 K		
	± 0.59	± 0.27	± 0.27	± 0.15	± 0.21
Oxygen	54.36113 K	54.36109 K	54.36109 K		
	± 0.24	± 0.29	± 0.29	± 0.23	± 0.21
e-Hydrogen	13.80977 K	13.81025 K	13.81025 K		
	± 0.85	± 0.49	± 0.49	± 0.31	± 0.29
Methane	90.68485 K	90.68372 K	90.68392 K		
	± 0.79	± 0.48	± 0.35	∿ ± 0.3	± 0.25
	90.68517 K (Ar)* ± 0.79				
	90.68449 K (O_2)* ± 0.68				
Nitrogen	63.14625 K	63.14606 K	63.14625 K		
	± 0.20	± 0.45	± 0.35	∿ ± 0.15	± 0.15
Neon	24.56248 K	24.56176 K	24.56156 K		
	± 0.86	± 0.41	± 0.41	± 0.20	± 0.25

* for laboratories using the two different IPTS-68 definitions.

(1) from Tables VI.2.x
(2) from Tables VI.3.x
(3) from Tables VII.2.x
(4) from Figs. VII.2.x
(5) from Sect. IV.3.1 and Tables VII.1.x

2.2 On differences between Scale realizations

The possibility of making this analysis suffers from some restrictions, due to limitations in the availability of data.

Tables VII.4.x summarize the relevant data. On the left side of each Table, there is a summary of the data available from the literature and information is given about the thermometer(s) used (when available). On the right side, the reference cell of the intercomparison is compared with the Laboratory realization. The NPL-IPTS-68 value (column 1) is reported only as a memo. The LAB-IPTS-68 value measured with the Laboratory thermometer (column 2) is corrected for non-uniqueness, leading to the value for thermometer n°1728839 of column 3. That is made using again the corrections given in Appendix I: the error due to differences of this correction using NPL instead of LAB calibration are supposed to be immaterial. The last column (4) gives, for secondary points, the temperature value for the Laboratory realization, again calculated on LAB-IPTS-68(1728839); unfortunately, some of these data are lacking.

Therefore, the difference between the last two values in a row gives the difference between the same device (the reference cell) and the Laboratory realization of the fixed point and, consequently, the differences between Laboratory fixed-point realizations may be obtained. From column (3), on the other hand, the differences between Scale realizations can be obtained. The two sets of differences are coincident at the definition points of IPTS-68. The absolute temperature values are relative to the reference cell used here and consequently would change slightly if other cells were used in Tables VII.4.x, according to the dispersion shown in Tables VI.2.X. Finally, one has to notice that all the values in columns (1),(2) and (3) are affected by the uncertainty specified in Sect.VI.3.1, and the values in column (4) by the error indicated in the literature.

The two sets of differences are collected, for convenience, in Table VII.6 (differences between LAB-IPTS-68 and NPL-IPTS-68) and Table VII.5 (differences between Laboratory and NPL realizations). With methane and nitrogen, IMGC-IPTS-68 has been used instead as a reference, since NPL realizations of these fixed points are not available.

The analysis of these differences will not be made in this Report.

Table VII.4.a: Summary on Scale realizations

. triple point of. A R G O N

Laboratory	Published realizations: open	Published realizations: cell	Ref.	Reference cell (results of the Intercomparison): (1) NPL lab.thermom.	(2) (IPTS-68) LAB lab.thermom.	(3) LAB 1728839	Laboratory realization (4) LAB 1728839
A S M W		$^{\alpha}$83.7976	26	83.7975	83.7977	83.7977	83.7979
B I P M	definition point		6,14	83.7968	83.7982	§	83.7980*
I M G C	-	defin.	7,8	83.7972	refer.	refer.	83.7980*
I N M	-	defin.	9	83.7973	83.7981	83.7982	83.7980*
N B S	$^{\beta}$83.7996^{+}	$^{\gamma}$83.8001	27	83.7970	83.8003	83.8005	
N I M		83.7996	18		83.7996	§	§
N M L	$^{\delta}$83.7974	-	28	83.7970	83.7967	83.7968	83.7976
N P L	$^{\varepsilon}$83.7971	-	29	83.7969	83.7969	83.7969	83.7971
N R C	$^{\eta}$83.7973	-	30	83.7967	83.7978	83.7981	83.7975
N R L M	-			83.7983	83.7988	§	§
P R M I	$^{\kappa}$83.7975		32,33	83.7960			
Other National Laboratories							
K O L	-	-					
P T B	$^{\lambda}$83.7972	-	42				83.7977

Thermometers used and Notes: *) definition value. §) not available.
+) low-purity sample.

$^{\alpha}$ n° 207278 (NPL-IPTS-68); $^{\beta,\gamma}$ n°1774095 (NBS-IPTS-68); $^{\delta}$ n°1654278 (NML-IPTS-68); $^{\varepsilon}$ n°1728839 (NPL-IPTS-68); $^{\eta}$ n°1521389 (NRC-IPTS-68); $^{\kappa}$ average of n°874, 876 and F (PRMI-IPTS-68); $^{\lambda}$ n° 188682 (PTB-IPTS-68; thermom. n°188682 belongs to the "international group": T_{NPL} = 83.7976 K).

Table VII.4.b: Summary on Scale realizations

triple point of: O X Y G E N

Laboratory	Published realizations: open	Published realizations: cell	Ref.	Reference cell (results of the Intercomparison) (1) NPL lab.thermom.	(2) (IPTS-68) LAB	(3) LAB 1728839	Laboratory realization (4) LAB 1728839
A S M W	defin.			54.3609	54.3609	54.3609	54.3610*
B I P M	-	-					
I M G C	-	defin.	8,52	54.3613	refer.	refer.	54.3610*
I N M	-	defin.		54.3615	54.3612	54.3612	54.3610*
N B S	defin.			+54.3609	54.3614	54.3614	54.3610*
N I M		α54.3636	62	54.3612	54.3636	§	54.3610*
N M L	defin.	-	34	54.3608	54.3609	54.3609	54.3610*
N P L	defin.	-	35	54.3607	54.3607	54.3607	54.3610*
N R C	defin.		36	54.3608	54.3611	54.3611	54.3610*
N R L M	defin.			54.3617	54.3616	§	54.3610*
P R M I	defin.			54.3606			54.3610*
Other National Laboratories							
K O L	defin.	-	46,58				
P T B	defin.	-					

Thermometers used and Notes: *) definition value. §) not available.
+) using NPL comparison data.

α n°7709 (NIM-IPTS-68).

Table VII.4.c: Summary on Scale realizations

triple point of: e - H Y D R O G E N

Laboratory	Published realizations: open	Published realizations: cell	Ref.	Reference cell (results of the Intercomparison) (1) NPL lab.thermom.	(2) (IPTS-68) LAB 1728839	(3) (IPTS-68) LAB 1728839	Laboratory realization (4) LAB 1728839
A S M W	-	-		13.8106			
B I P M							
I M G C	-	$^{\alpha}$defin.	8,49	13.8105	13.8097	13.8097	13.8100*
I N M							
N B S	defin.	-					
N I M							
N M L	defin.	-	37	13.8098	13.8095	13.8095	13.8100*
N P L	defin.	-	38	13.8101	13.8101	13.8101	13.8100*
N R C	defin.	-	39	13.8110	13.8106	13.8106	13.8100*
N R L M				13.8134	13.8115		13.8100*
P R M I	defin.		40	13.8103			13.8100*
Other National Laboratories							
K O L							
P T B							

Thermometers used and Notes: *) definition value.

$^{\alpha}$ n° 1722205, PL01-6 and PL02-6; using the NBS, NPL and PRMI-IPTS-68 calibrations, values for $T(H_2)$ of 13.8082 K, 13.8108 K and 13.8167 K respectively have been obtained.

Table VII.4.d: Summary on Scale realizations

triple point of: M E T H A N E

Laboratory	Published realizations		Ref.	Reference cell (results of the Intercomparison)			Laboratory realization
				(1)	(2)	(3)	(4)
					(IPTS-68)		
	open	cell		NPL lab.thermom.	LAB	LAB 1728839	LAB 1728839
A S M W	-	-		90.6835	90.6835	90.6836	-
B I P M	$^{\alpha}$90.6858	$^{\alpha}$90.6854	6,14	90.6847	90.6857	§	§
I M G C	-	$^{\beta}$90.6856	8,56	90.6839	90.6855	90.6856	90.6856
I N M	-	-					
N B S	-	-					
N I M	-	-			90.6837		-
N M L	-	-					
N P L	-	-		90.6821	90.6821	90.6821	-
N R C	-			90.6841	90.6849	90.6850	
N R L M	-	$^{\gamma}$90.685	41	90.6880	90.6881	§	§
P R M I	-	-		90.6797			-
Other National Laboratories							
K O L	-	-					
P T B	$^{\delta}$90.6846	-	42				90.6851

Thermometers used and Notes: §) not available.

$^{\alpha}$ n°226321 (BIPM-IPTS-68); $^{\beta}$average of n°646, 838, 1754792, 1722205, 45, 1761201, PL01-6, PL02-6 (IMGC-IPTS-68); $^{\gamma}$ not specified; $^{\delta}$ n° 188682 (PTB-IPTS-68(O_2); using Ar the the Scale definition: T = 90.6854 K; thermom. n°188682 belongs to the "international group": T_{NPL}= 90.6851 K).

Table VII.4.e: Summary on Scale realizations

triple point of: N I T R O G E N

Laboratory	Published realizations: open	Published realizations: cell	Ref.	Reference cell (results of the Intercomparison) (1) NPL lab.thermom.	(2) (IPTS-68) LAB lab.thermom.	(3) (IPTS-68) LAB 1728839	Laboratory realization (4) LAB 1728839
A S M W							
B I P M							
I M G C	-	α63.1458	8,60	63.1463	63.1463	63.1463	63.1463
I N M	-			63.1467	63.1460	63.1461	63.1459
N B S							
N I M							
N M L	β63.1459	-	28				
N P L	-	-		63.1461	62.1461	63.1461	-
N R C	γ63.1464	-	47	63.1456	63.1464	63.1460	63.1467
N R L M							
P R M I							
Other National Laboratories							
K O L	δ63.148	-	61				
P T B	-	-					

Thermometers used and Notes:

α average of n°1722205, 45 (IMGC-IPTS-68); β n°459 (NML-IPTS-68);
γ n°1521389 (NRC-IPTS-68); δ not specified.

Table VII.4.f: Summary on Scale realizations

triple point of: N E O N

Laboratory	Published realizations: open	Published realizations: cell	Ref.	Reference cell (results of the Intercomparison) (1) NPL lab.thermom.	(2) (IPTS-68) LAB lab.thermom.	(3) LAB 1728839	Laboratory realization (4) LAB 1728839
A S M W	-	α 24.5627	55	24.5621	-	-	-
B I P M							
I M G C	-	β 24.562	8,56 57	24.5625 24.5616	-	-	-
I N M	-			24.5619	-	-	-
N B S	γ 24.5611	-	43				
N I M							
N M L	δ 24.5631 ε 24.5623	-	28 59	24.5619	24.5625	24.5625	24.5623
N P L	η 24.5619	-	29	24.5616	24.5616	24.5616	24.5619
N R C	θ 24.5620	-	44	24.5617	24.5640	24.5628	24.5618
N R L M	-	μ 24.5630		24.5622	24.5615	§	§
P R M I	κ 24.5627		32,33	24.5619			
Other National Laboratories							
K O L	λ 24.5618	-	46,58				
P T B							

Thermometers used and Notes: §) not available.

α n° 207278 (NPL-IPTS-68); β average of n°1722205, 1761201, PL01-6, PL02-6, 45 (platinum calibrated on NBS, NPL, PRMI-IPTS-68) and n°2551, 2863 (germanium calibrated on XAC'); γ n°1692598 (NBS-IPTS-68 from NBS-55; 0.9 mK lower on NPL-IPTS-68); δ n°459 (NML-IPTS-68); ε n°1731676 (NML-IPTS-68); η n°1728839 (NPL-IPTS-68); θ n° 1521389 (NRC-IPTS-68); κ average of n°874, 876, F (PRMI-IPTS-68); λ average of n°164956(B2) and T4 calibrated on KOL-IPTS-68; μ not specified.

Table VII.4.g: Summary on Scale realizations

Laboratory	Published realizations: open	Published realizations: cell	Ref.	Reference cell (results of the Intercomparison): (1) NPL lab.thermom.	(2) (IPTS-68) LAB	(3) (IPTS-68) LAB 1728839	Laboratory realization: (4) LAB 1728839
	triple point of: e - D E U T E R I U M						
A S M W							
B I P M							
I M G C	-	$^{\alpha}$18.678	8,49	18.6778 18.6763	-	-	-
I N M							
N B S							
N I M							
N M L	$^{\beta}$18.6909	-	50				
N P L				18.6753	18.6753	18.6753	-
N R C	-	$^{\gamma}$18.662	51	18.6786	18.6773	18.6778	18.6620
N R L M							
P R M I							
	triple point of: n - D E U T E R I U M						
I M G C	-	$^{\delta}$18.729	48,49				
N M L	$^{\beta}$18.709	-	50				
N R C	-	$^{\gamma}$18.712	51				

Thermometers used and Notes:

$^{\alpha}$ average of n°1722205, PL01-6, PL02-6 calibrated on NBS, NPL, PRMI-IPTS-68. $^{\beta}$ n° 373 (NML-IPTS-68); $^{\gamma}$ n°1872179 (NRC-IPTS-68); $^{\delta}$ same as $^{\alpha}$ plus n°1761201 and n°45.

Table VII.5: Differences between national fixed-point realizations.
(NPL(or IMGC) - LAB, mK)

Laboratory	Ar	O_2	e-H_2	CH_4	N_2	Ne
A S M W	+0.02	-0.2				
B I P M°						
I M G C°	(+0.0) *	-0.3	+0.4	(+0.0)*	(+0.0)*	
I N M°	-0.2	-0.5			+0.2	
N B S		-0.7				
N I M						
N M L	+0.8	-0.2	+0.6			-0.5
N P L	+0.2	(+0.3)*	(-0.1)*			(+0.3)*
N R C	-0.5	-0.4	-0.5		-0.7	-1.3
N R L M						
P R M I						

* (ref.Lab.) - (ref.cell); °) Argon is used for IPTS-68 definition.

Table VII.6: Differences between REF-IPTS-68 and LAB-IPTS-68.
(reference thermometer: 1728839; mK)

Laboratory	Ar	O_2	e-H_2	CH_4	N_2	Ne
A S M W	-0.8	-0.2		+2.0		
B I P M°						
I M G C°	-1.1	-0.3	+0.4	REF.	REF.	
		-0.2 §				
I N M°	-1.3	-0.5			-0.2	
N B S	-3.6	-0.7				
		+0.5 §				
N I M						
N M L	+0.1	-0.2	+0.6			-0.9
		+0.1 §	-0.3 §			
N P L	REF.	REF.	REF.	-3.5	+0.2	REF.
N R C	-1.1	-0.4	-0.5	+0.6	+0.3	-1.2
		+0.2+0.7 §	+2.5 §			
N R L M						
P R M I						
		+0.1-0.3 §	+1.1 §			

§ NPL-IPTS-68 - LAB-IPTS-68 differences measured at NPL in 1975 (Ref.3)

VIII. CONCLUSIONS

Most of the goals of the International Intercomparison have been fulfilled during the five years of circulation of cells. Only the comparison of the National Scale realizations at the fixed-point temperatures suffered from some lack of results. This was generally due to a fact that may be considered also as a result of this exercise: when thermometer calibrations were involved in the calculations, i.e. when one was dealing with temperature values, data generally showed a larger dispersion of values.

This is equivalent to stating that this intercomparison of fixed points in sealed devices allowed one to check for uniformity of realization of these fixed points among laboratories, with an accuracy better than was possible with thermometers; or, at least, that the reliability in assessing the accuracy level of fixed-point intercomparison was higher.

As a matter of fact, the agreement found between the values obtained when comparing the participating cells was much better than it was possible to conclude from literature data, based on LAB-IPTS-68. On the other hand, the level of inaccuracy was found to be between ± 0.15 and ± 0.3 mK, higher than the one (± 0.1 mK) which was anticipated. This may be due either to the actual state of the art in thermal experiments in the laboratories, or to the present limit of measurability of the sealed-cell devices.

Apart from the few cases of inaccuracy ascertained for some cells, values of differences between cells up to about 0.5 mK were occasionally found. This limit is higher than most of the melting ranges observed for the samples enclosed in the cells: in addition, quite large differences from laboratory to laboratory have been observed in the shape of the melting plateau. These facts seem to indicate that there is a real lack of control of the thermal process at a ± 0.1 mK level. A better knowledge and control of the behaviour of the sample inside the cell seems to be necessary to reach a reproducibility level of the order of few tens of microkelvins, needed to limit the total inaccuracy to within ± 0.1 mK. Some of the results of this exercise seem to indicate that it is not an impossible goal, since for most of the substances the melting range could be limited well within 0.5 mK. On the other hand, there was also evidence of some increase in the spread of values for lower temperatures, especially in the range where platinum resistance thermometers exhibit decreasing sensitivity: this could be due to increasing practical difficulties, more in the measurement process with the experimental apparatus than in the control of the thermal process in the cell.

However, the present agreement between the realizations of the fixed points that is shown in the figures and tables may be already considered adequate for the uniqueness requirements of an improved future IPTS. It has been proved that it can be obtained using the technique of small transportable sealed cells, whose design turned out to be largely non-critical.

The temperature of the thermodynamic state reproduced by each of the cells will be accurately conserved and reproduced for many years to come (no tendency to change has been observed so far), allowing immediate availability for realization to any new Scale definition, provided only that it uses triple points exclusively, and that a suitable value is assigned to each temperature reproduced by them.

ACRONYMS OF THE LABORATORIES

A S M W = Amt für Standardisierung Messwesen und Warenprüfung, G.D.R.

B I P M = Bureau International des Poids et Mesures, Sèvres.

I M G C = Istituto di Metrologia "G.Colonnetti", Italy.

I N M = Institut National de Métrologie, France.

K O L = Kamerling Onnes Laboratorium, The Netherlands.

N B S = National Bureau of Standards, U.S.A.

N I M = National Institute of Metrology, China.

N M L = National Measurements Laboratory, Australia.

N P L = National Physical Laboratory, U.K.

N R C = National Research Council, Canada.

N R L M = National Research Laboratory of Metrology, Japan.

P T B = Physikalisch-Technische Bundesanstalt, F.R.G.

P R M I = Physicotechnical and Radiotechnical Measurement Institute, U.S.S.R.

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APPENDIX I

Non-uniqueness corrections for thermometers
of the "international" group
(after Compton & Ward, Ref.3)[23]

$T_{1728839} - T_x$ (mK)

Thermometer	Argon 83.798 K	Methane 90.6855 K	Nitrogen 63.1462 K	Neon 24.5622 K
217997	+ 0.27	- 0.02	+ 0.49	- 0.23
207278	+ 0.33	- 0.03	+ 0.58	- 0.14
PL01-6	+ 0.17	- 0.01	+ 0.47	- 0.16
PL02-6	+ 0.24	- 0.01	+ 0.51	- 0.15
45	- 0.15	+ 0.01	+ 0.03	- 0.08
1812283	+ 0.10	- 0.01	+ 0.15	+ 0.13
1812282	+ 0.19	- 0.02	+ 0.19	+ 0.19
1731676	+ 0.07	- 0.01	+ 0.06	+ 0.01
1158062	+ 0.19	- 0.02	+ 0.35	- 0.20

APPENDIX II: Calibration data of thermometers.

Thermometer:	ASMW 207278	ASMW 217997	ASMW 217990	BIPM 226322	BIPM 226322	BIPM 226321	BIPM 226321	IMGC PL01-6	IMGC PL01-6
(calibration:)	(NPL)	(NPL)	(NPL)	(NPL)	(BIPM)	(NPL)	(BIPM)	(NPL)	(IMGC)
Fixed point (K)					(ohm)				
373.15	35.298875	35.398895	33.682996	34.694699	34.694776	35.329705	35.329733	35.193550	35.193626
273.15	25.346730	25.418300	24.186290	24.913330	24.913392	25.369090	25.369110	25.271030	25.271140
90.188	6.178722	6.195642	6.139226	6.074291	--	6.184647	--	6.160324	--
83.798	--	--	--	--	5.383077	--	5.480737	--	5.459260
54.361	2.329294	2.335410	2.314124	2.290773 (1976)				2.322823	2.322865
27.102	0.307643	0.308040	0.305102					0.307860	
20.28	0.111906	0.111587	0.110502					0.112862	
17.042	0.062608	0.062036	0.061468					0.063771	
13.81	0.034302	0.033546	0.033312					0.035595	0.035630
90.6855	6.233440	6.250517	6.189085	6.128075	6.127892	6.239421	6.239227	6.214877	6.214807
83.798	5.475589	5.490516	5.488947	5.383224	--	5.480956	--	5.459321	--
63.1462	3.231584	3.240213	3.272673	3.177652	--	--	--	3.222258	3.222314
24.5622	0.218808	0.218904	0.219989	--	--	--	--	0.219350	--

APPENDIX II: Calibration data of thermometers.

Thermometer:	IMGC	IMGC	INM	INM	INM	NBS	NBS	NBS	NIM
	45	45	1812283	1812283	232788	1774095	1812282	1812282	7703
(calibration:)	(NPL)	(IMGC)	(NPL)	(INM)	(INM)	(NBS)	(NPL)	(NBS)	(NIM)
Fixed point (K)				(ohm)					
373.15	35.760497	35.760401	35.504765	35.505337			35.526435	35.526518	
273.15	25.679390	25.679381	25.494500	25.494711	24.087300	25.560840	25.510280		24.899378
90.188	6.262076	--	6.213374	--	--	6.231297	6.218080	6.217717	
83.798	--	5.549490	--	5.505919	5.480579	--	--	--	--
54.361	2.362255	2.362190	2.340650	2.340685		2.349529	2.342869	2.342825	
27.102	0.313479	--	0.305813	--	--	0.310304	0.306376	0.306335	
20.28	0.114979	--	0.108619	--	--	0.112833	0.108937	0.108971	
17.042	0.064974	--	0.058992	--	--	0.063049	0.059228	0.059246	
13.81	0.036262	--	0.030629	--	--	0.034498	0.030805	0.030835	
90.6855	6.317517		6.268424	6.268291			6.273159	6.272805	
83.798	5.549724	--	5.505983	--	--		5.510296	5.509901	
63.1462	3.276340		3.248407	3.248509			3.251288	3.251053	
24.5622	0.223397	--	0.216327	--	--		0.216794	0.216734	

APPENDIX II: Calibration data of thermometers.

Thermometer:	NIM	NIM	NPL	NML	NML	NRC	NRC	NRC	NRC
	188640	7709	1728839	1731676	1731676	1521389	1158062	1158062	1872179
(calibration:)	(NIM)	(NIM)	(NPL)	(NPL)	(NML)	(NRC)	(NPL)	(NRC)	(NRC)
Fixed point (K)					(ohm)				
373.15			35.593541	35.542413	35.542413	35.545198	35.467637	35.467457	35.628083
273.15	24.164330	25.352963	25.559570	25.522800	25.522800	25.523332	25.469660	25.469547	25.582651
90.188			6.232672	6.223657	6.223646	6.220654	6.213066	6.212952	6.234894
83.798			--	--	--	--	--	--	--
54.361			2.350583	2.347195	2.347185	2.344245	2.345837	2.345804	2.349500
27.102			0.310722	0.310276	0.310263	0.308205	0.314670	0.314567	0.308485
20.28			0.112961	0.112801	0.112814	0.111212	0.117890	0.117888	0.110721
17.042			0.063120	0.063020	0.063024	0.061615	0.068250	0.068243	0.060859
13.81			0.034521	0.034459	0.034460	0.033232	0.039643	0.039623	0.032318
90.6855			6.287854	6.278764	6.278752	6.275768	6.268040	6.267923	6.290120
83.798			5.523596	5.515606	5.515595	5.512551	5.506668	5.506546	5.525160
63.1462			3.260563	3.255856	3.255844	3.252812	3.252284	3.252204	3.260186
24.5622			0.220997	0.220691	0.220679	0.218775	0.225380	0.225308	0.218749

APPENDIX II: Calibration data of thermometers.

Thermometer:	NRLM 7681	NRLM 7681	NRLM 1781356	PRMI 1842381	PRMI 1842381
(calibration:)	(NPL)	(NRLM)	(NRLM)	(NPL+)	(PRMI)
Fixed point (K)			(ohm)		
373.15				35.576452*	
273.15		25.362925	25.525818	25.544950	
90.188				--	
83.798				5.515116	
54.361				2.343744	
27.102				0.305632	
20.28				0.108293	
17.042				0.058672	
13.81				0.030353	
90.6855				6.279004	
83.798				5.515116	
63.1462				3.253298	
24.5622				0.216070	

* assumed (see text). + triple point of argon used instead of condensation point of oxygen.