Radionuclidic Standardizations by Classical "Isothermal" (*sic*) Microcalorimetry:

Recent and Ongoing Work on ^{32}P, ^{90}Sr, and ^{103}Pd

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Seminar at
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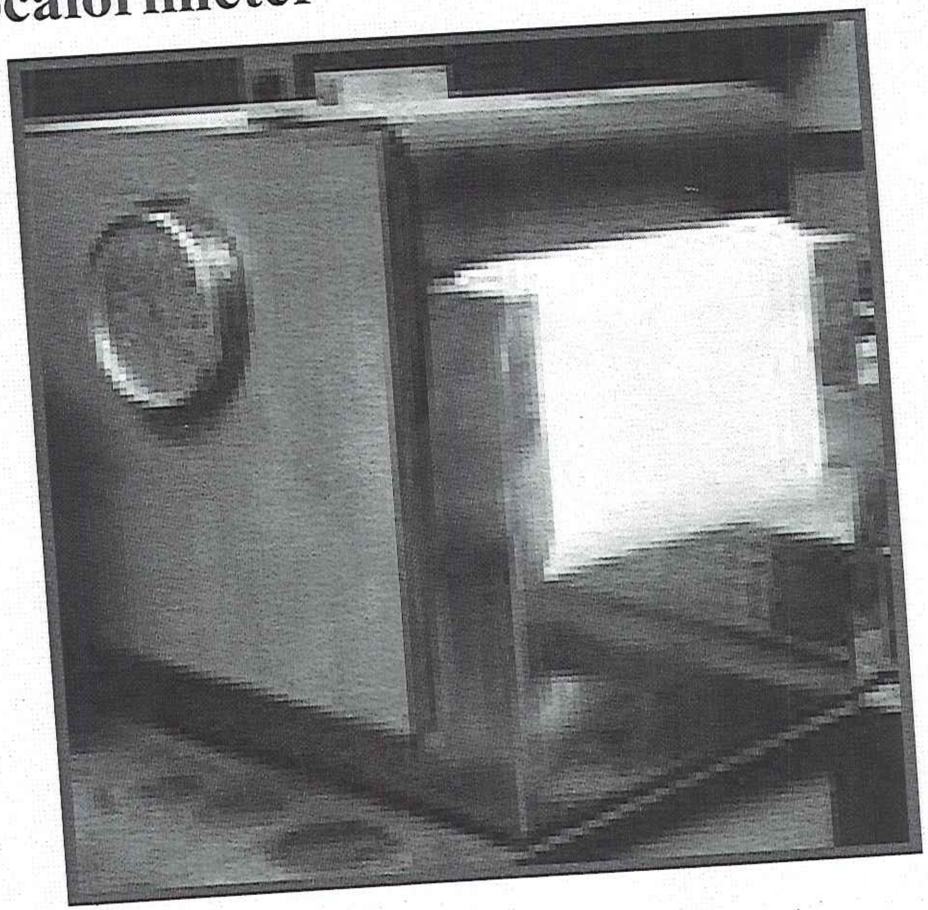
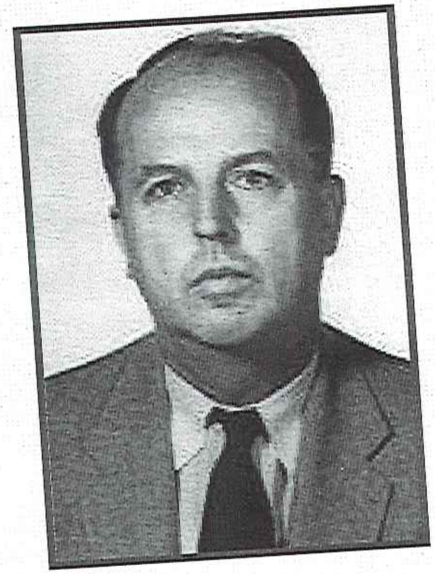
Saclay, France
2 July 2002

This is our laboratory's second foray into measuring radioactivity by calorimetry ...

The NBS twin gold-cup Peltier-effect microcalorimeter



a Callandar-type "radiobalance"



Wilfrid Basil Mann

(1908 - 2001)

Radionuclidic Microcalorimetry at NIST

WHY ?

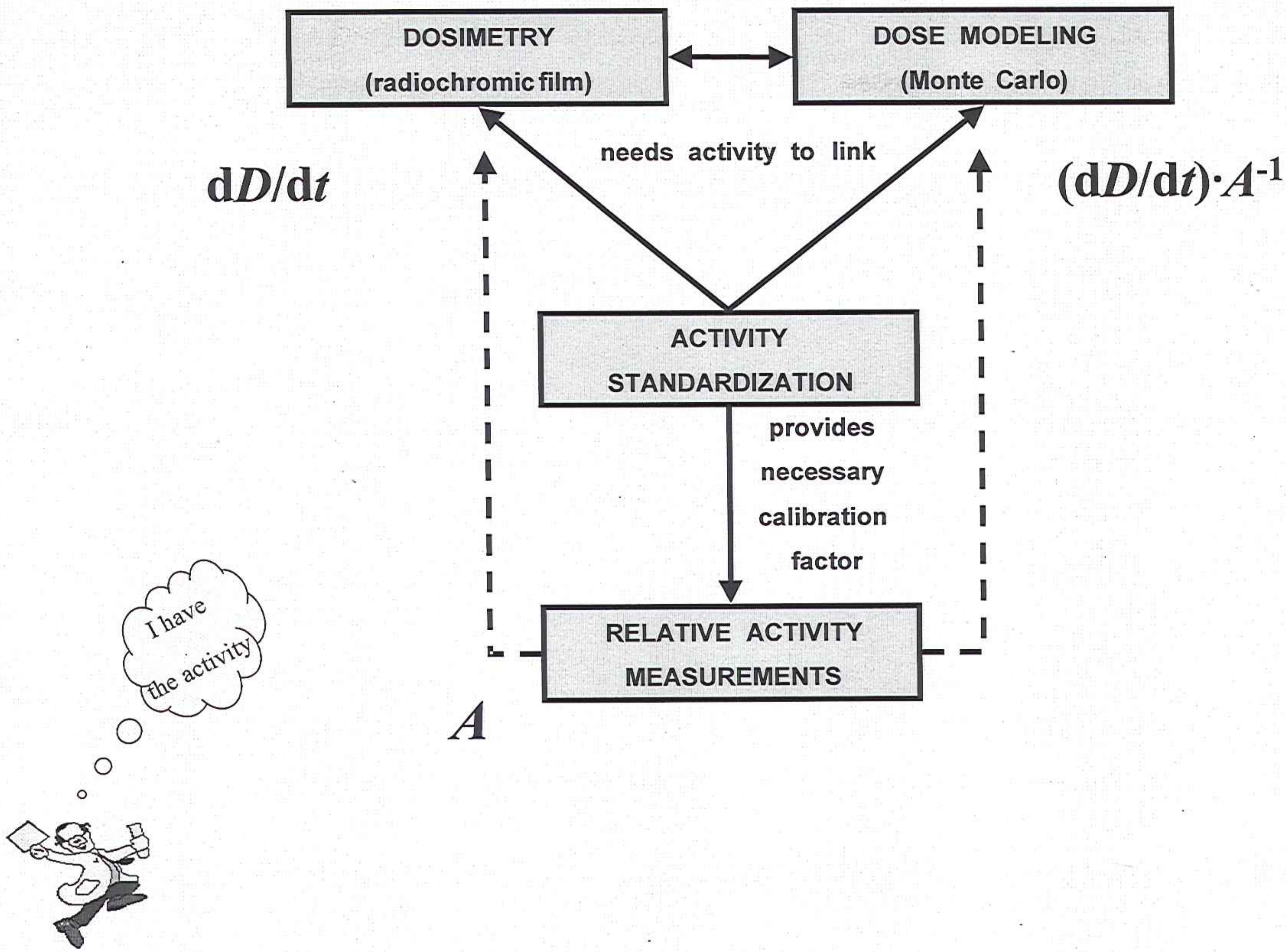
Need to standardize GBq sources

Non-destructive (?)

➡ ***dual-compensated cryogenic (8 K) microcalorimeter***

Appl. Radiat. Isot. 56, 223-230 (2002)

➡ ***dual-cell near-isothermal (heat flow) microcalorimeter (303 K)***


DOSIMETRY
(radiochromic film)
DOSE MODELING
(Monte Carlo)
needs activity to link
dD/dt
(dD/dt)·A-1
ACTIVITY
STANDARDIZATION
provides
necessary
calibration
factor
RELATIVE ACTIVITY
MEASUREMENTS
A
I have
the activity

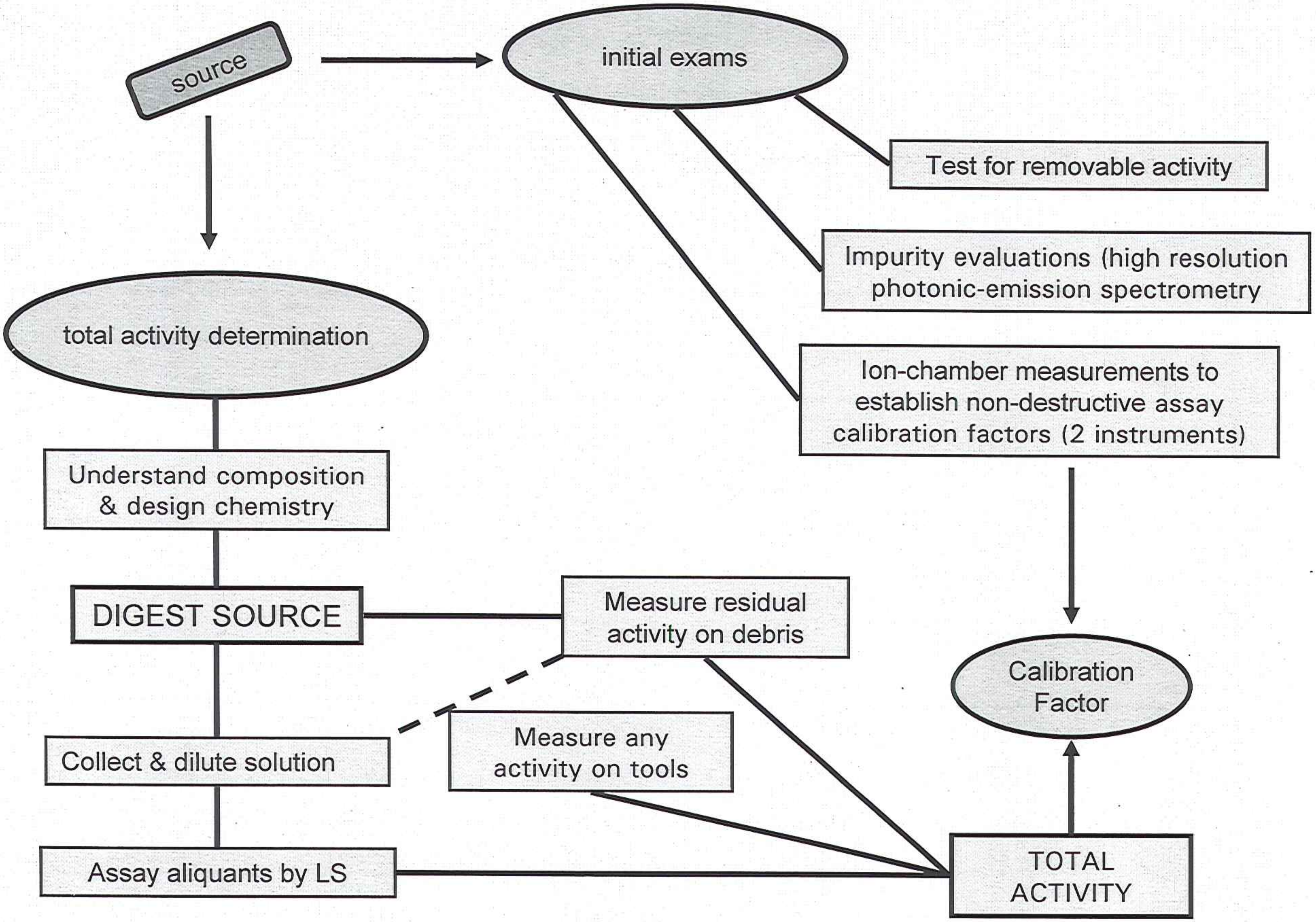
NIST Calibrations of Intravascular Brachytherapy Sources

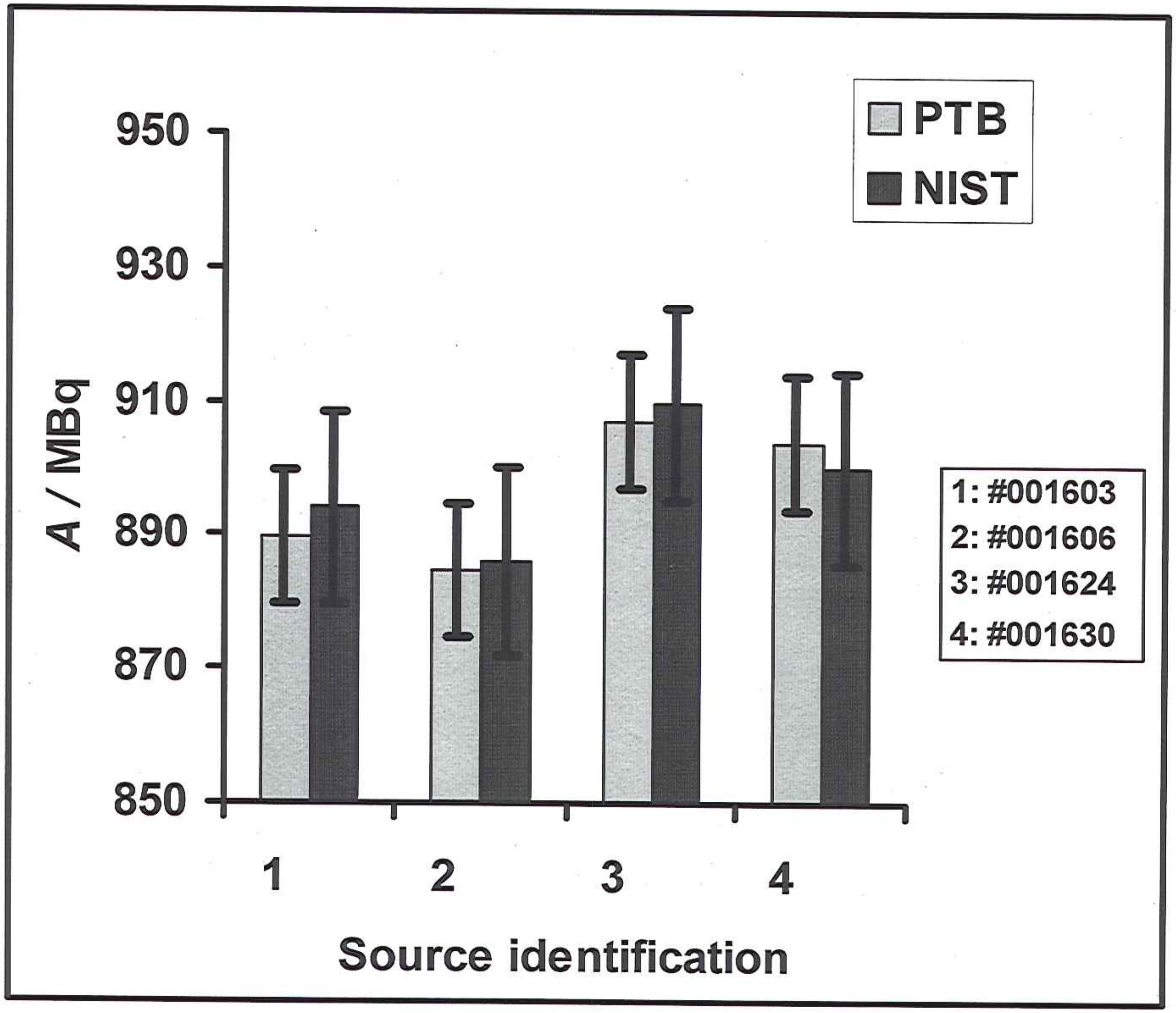
1996 - 2000

Manufacturer/ Collaborator	Guidant	Novoste	Isostent	Radiance	Cedars-Sinai Medical Center	Mallinckrodt	Washington Hospital Center	Interventional Technologies
Nuclide (half-life)	^{32}P (14 d)	^{90}Sr - ^{90}Y (29 a, 64 h)	^{32}P (14 d)	^{32}P (14 d)	^{188}Re (18 h)	^{186}Re (89 h)	^{133}Xe (5 d)	^{99m}Tc (6 h)
Source configuration	Encapsulated seed in long wire	Encapsulated seed for catheter train	Stent	"Hot wall" balloon catheter	Liquid-filled balloon catheter	Liquid-filled balloon catheter	Gas-filled balloon catheter	Liquid-filled perfusion catheter
Source composition	Inert polymeric material	Refractory "ceramic" matrix	Ion-implanted stainless steel	Thin film/inert matrix	^{188}Re-MAG3 solution in saline solution	Proprietary ^{188}Re-labeled compound in saline solution	^{133}Xe gas in CO_2 carrier	Liposome-encapsulated ^{99m}Tc or Ceretec® in saline
Encapsulation	TiNi jacket	Stainless steel	N/A	Double-walled polyethylene balloon	Balloon wall	Balloon wall	Balloon Wall	N/A

Cessna

Zimmerman


source
initial exams
Test for removable activity
Impurity evaluations (high resolution photonic-emission spectrometry
Ion-chamber measurements to establish non-destructive assay calibration factors (2 instruments)
total activity determination
Understand composition & design chemistry
DIGEST SOURCE
Measure residual activity on debris
Calibration Factor
Collect & dilute solution
Measure any activity on tools
Assay aliquants by LS
TOTAL ACTIVITY



PTB
NIST
950
930
910
890
870
850
A / MBq
1: #001603
2: #001606
3: #001624
4: #001630
1
2
3
4
Source identification

Recent calorimetric-based standardizations 2000-2002

- verified extant calibration factors for (i) *Radiance* ^{32}P "hot-wall" angioplasty balloons and (ii) *Novoste* old-style, ceramic-cored, ^{90}Sr - ^{90}Y intravascular seeds

  - performed primary standardization for *Novoste*, new-generation, aluminum-cored ^{90}Sr seeds to establish calibration factors

    - primary standardization for 103Pd (and for calibration of *Theragenics* prostate seeds) is underway

Basic relationship between

Rate of energy (heat) input , or power P,

and

Activity A

is $$dH/dt = P = A\,\hat{E}$$

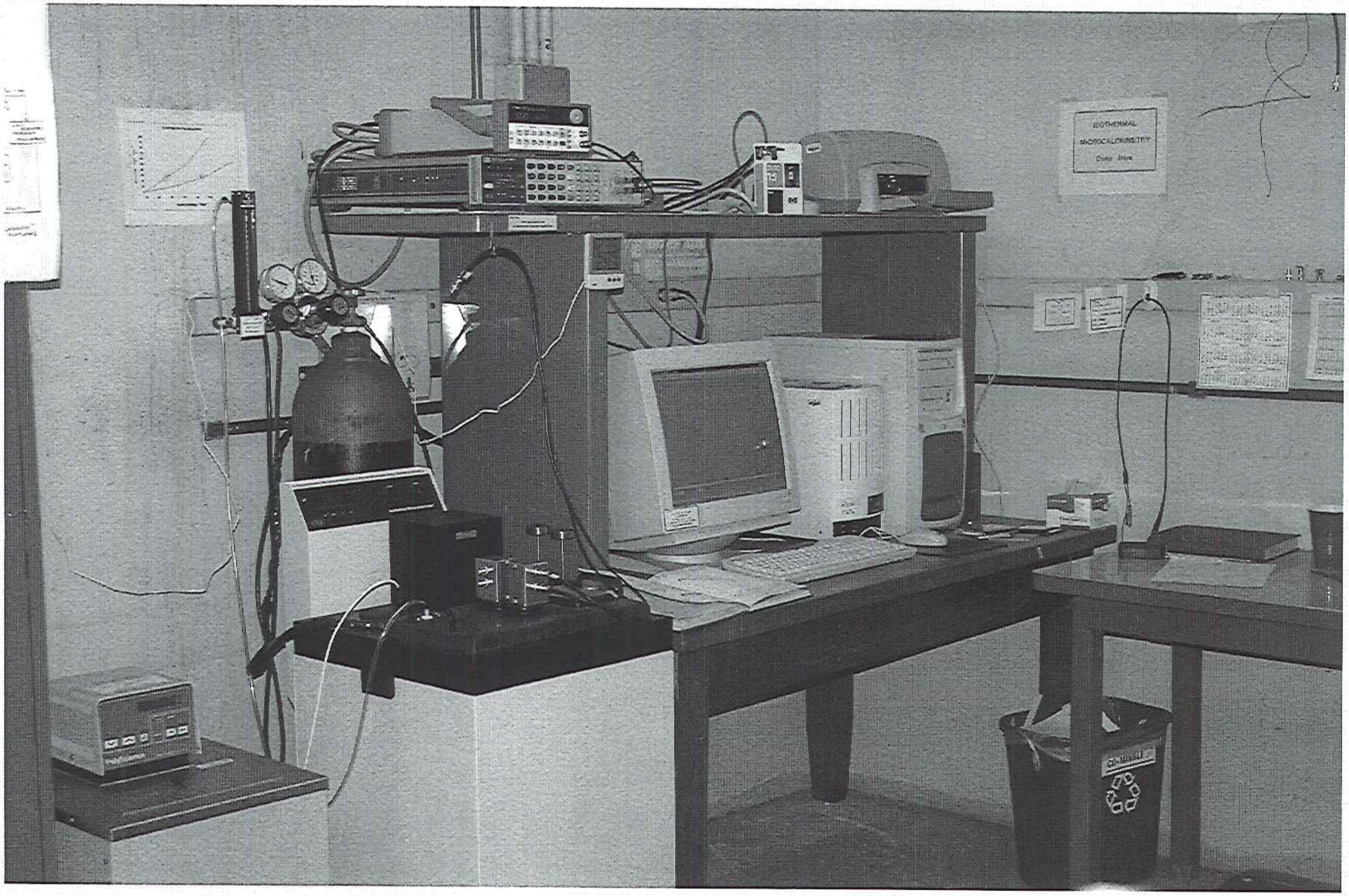
$\hat{E}$ = average energy per decay

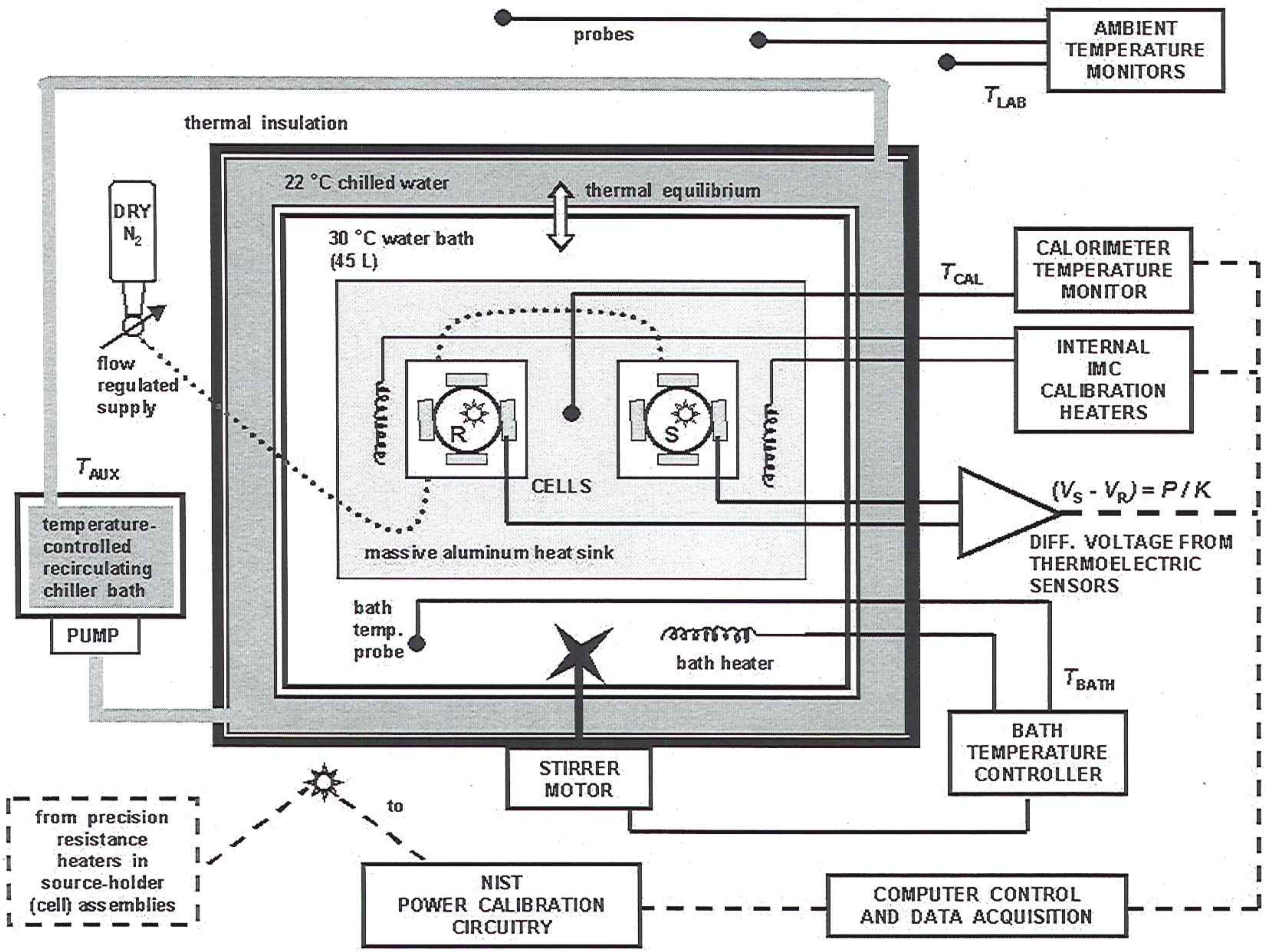
^{3}H / ^{55}Fe	0.9 $\mu W \cdot GBq^{-1}$
^{103}Pd / ^{125}I	9.
^{32}P	111.
^{90}Sr-^{90}Y	181.
^{226}Ra	4338.

Assumes absorb & measure ALL ionizing radiation (no losses)

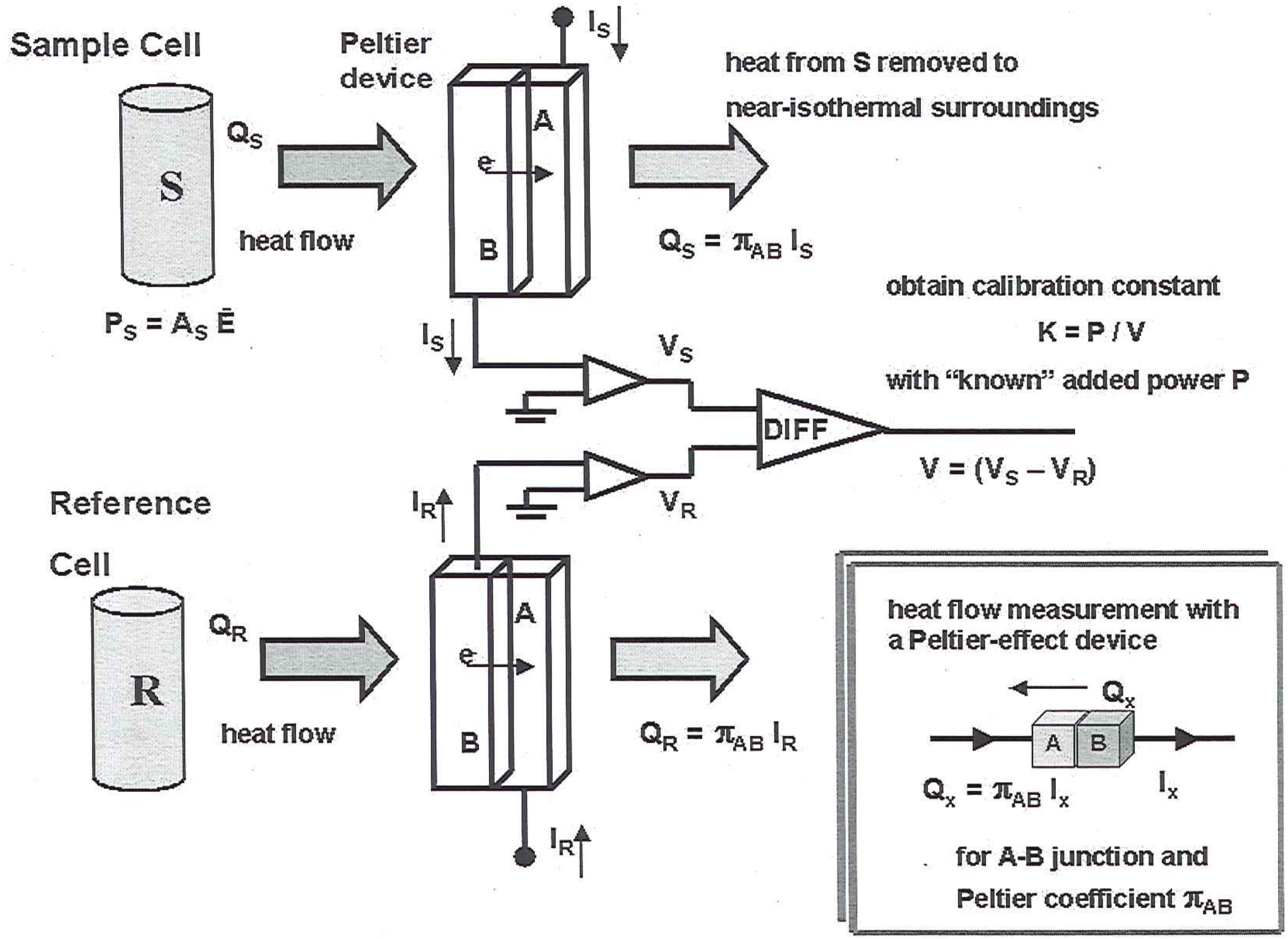
And no "heat defect" effects (I.e., no chemistry)

CSC “Isothermal Microcalorimeter (IMC)”

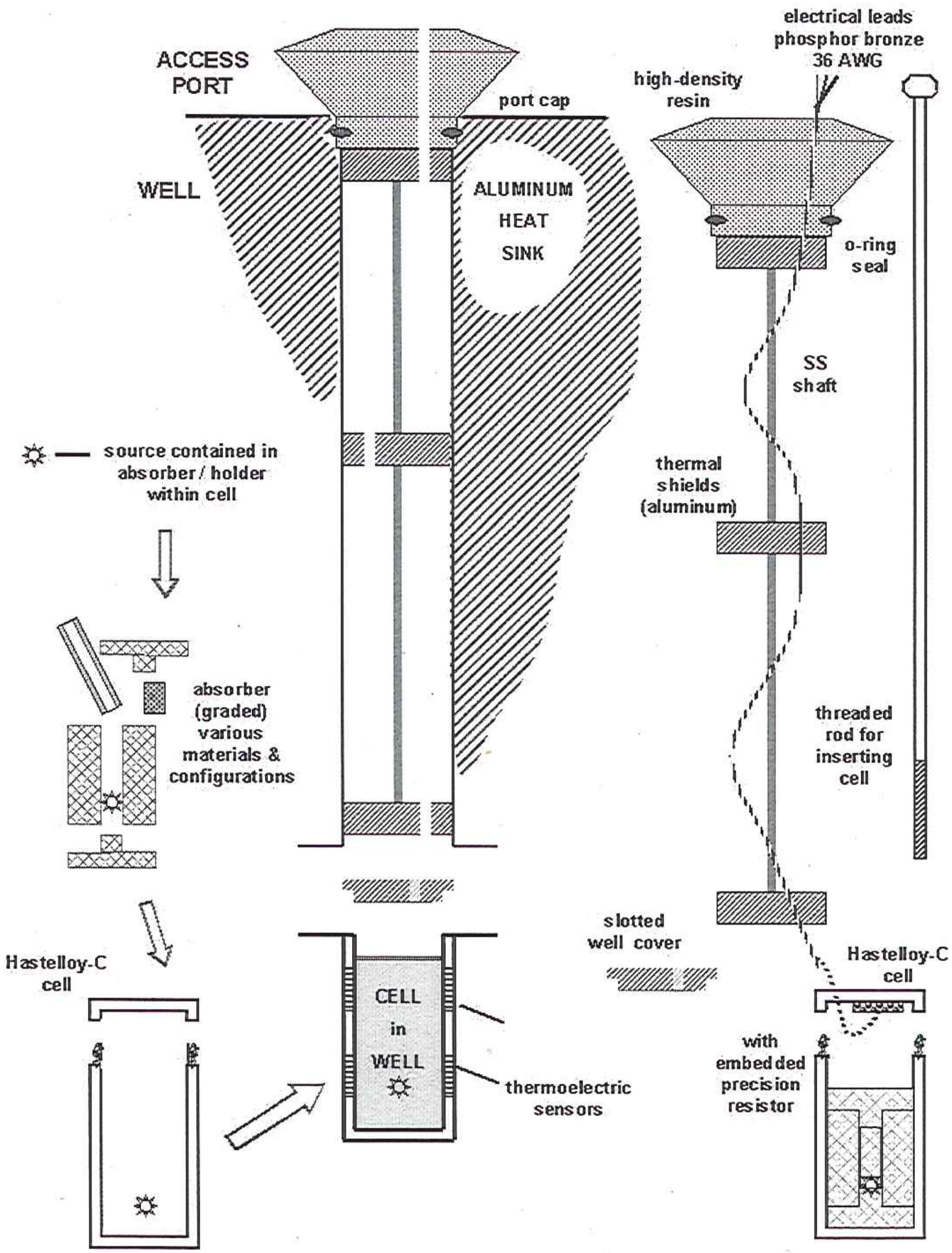




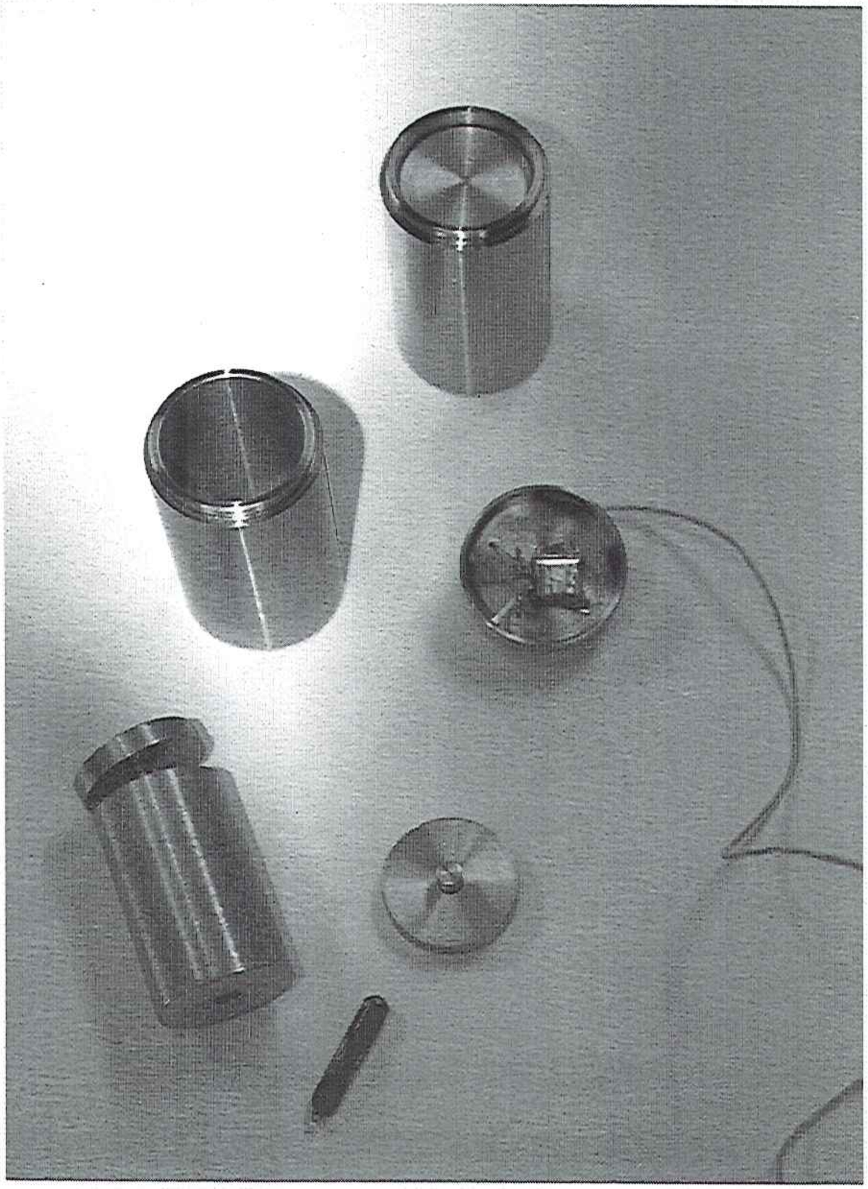
probes
AMBIENT TEMPERATURE MONITORS
T_{LAB}
thermal insulation
22 °C chilled water
thermal equilibrium
DRY N_2
30 °C water bath (45 L)
T_{CAL}
CALORIMETER TEMPERATURE MONITOR
INTERNAL IMC CALIBRATION HEATERS
flow regulated supply
R
S
T_{AUX}
CELLS
$(V_S - V_R) = P/K$
DIFF. VOLTAGE FROM THERMOELECTRIC SENSORS
temperature-controlled recirculating chiller bath
massive aluminum heat sink
PUMP
bath temp. probe
bath heater
T_{BATH}
BATH TEMPERATURE CONTROLLER
STIRRER MOTOR
to
from precision resistance heaters in source-holder (cell) assemblies
NIST POWER CALIBRATION CIRCUITRY
COMPUTER CONTROL AND DATA ACQUISITION

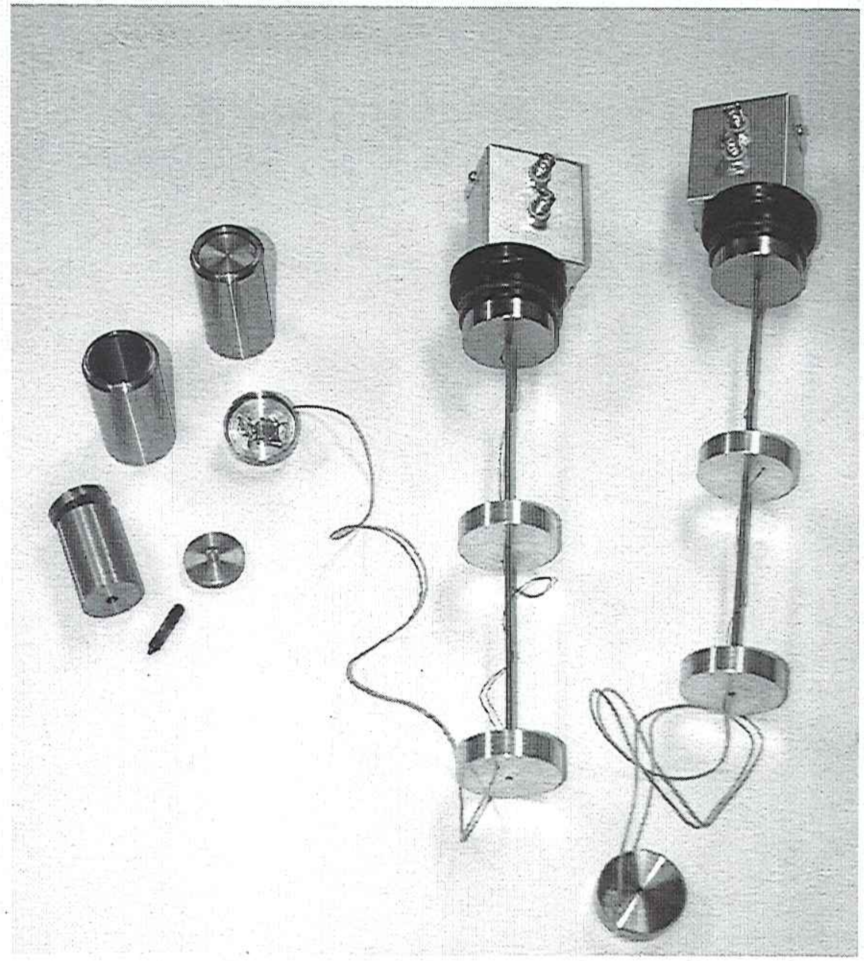


Sample Cell
Peltier device
I_S
heat from S removed to near-isothermal surroundings
Q_S
A
S
e
heat flow
B
$Q_S = \pi_{AB} I_S$
$P_S = A_S \bar{E}$
obtain calibration constant
$K = P / V$
I_S
V_S
with "known" added power P
DIFF
$V = (V_S - V_R)$
Reference Cell
I_R
V_R
Q_R
A
R
e
heat flow
B
$Q_R = \pi_{AB} I_R$
I_R
heat flow measurement with a Peltier-effect device
Q_x
A
B
$Q_x = \pi_{AB} I_x$
I_x
for A-B junction and Peltier coefficient π_{AB}

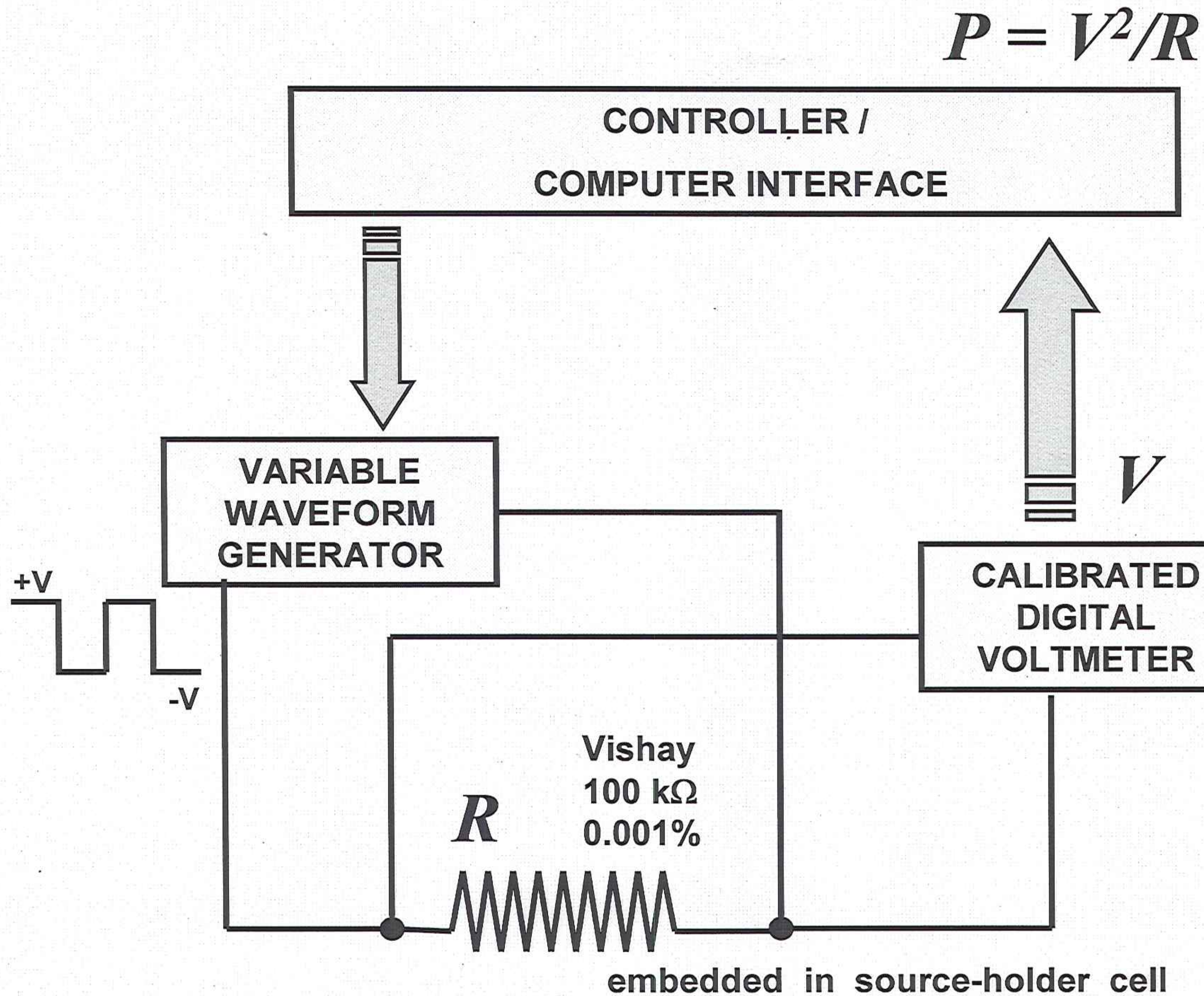


ACCESS PORT
port cap
WELL
ALUMINUM HEAT SINK
high-density resin
electrical leads phosphor bronze 36 AWG
o-ring seal
SS shaft
thermal shields (aluminum)
threaded rod for inserting cell
source contained in absorber / holder within cell
absorber (graded) various materials & configurations
slotted well cover
Hastelloy-C cell
CELL in WELL
thermoelectric sensors
Hastelloy-C cell
with embedded precision resistor

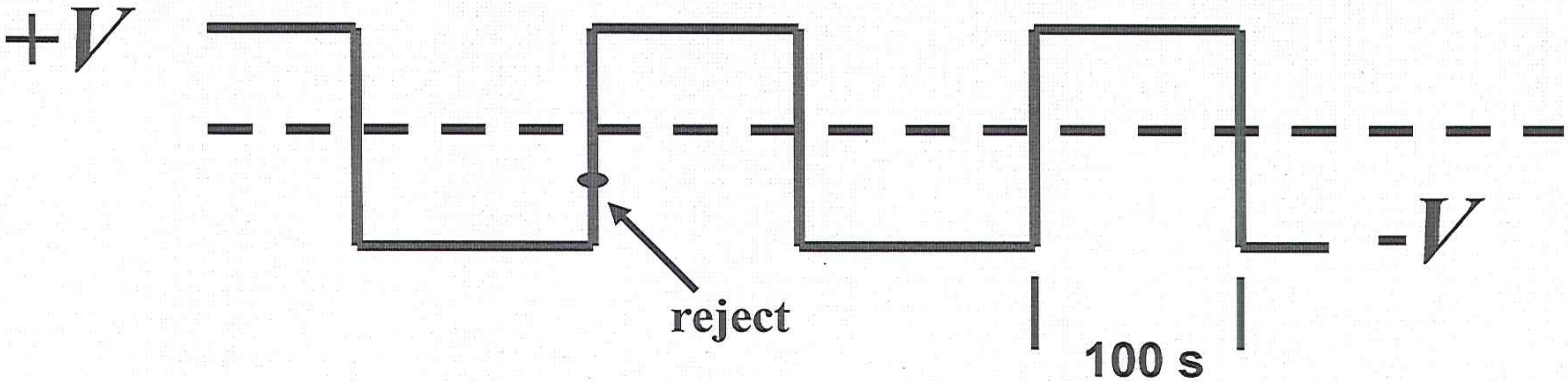




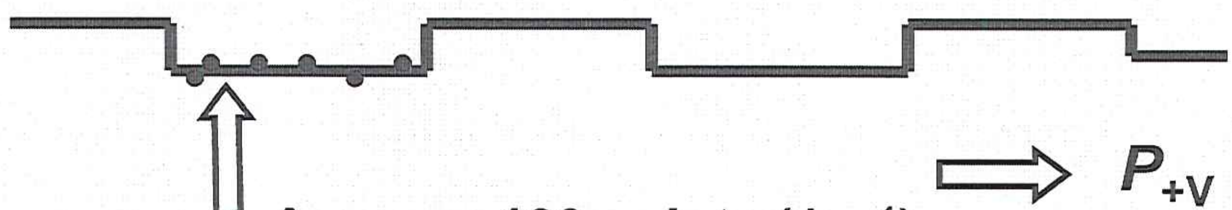
port assemblies -- source (absorbers) holders & cells


$P = V^2/R$
CONTROLLER /
COMPUTER INTERFACE
VARIABLE
WAVEFORM
GENERATOR
+V
-V
V
CALIBRATED
DIGITAL
VOLTMETER
R
Vishay
100 kΩ
0.001%
embedded in source-holder cell

$f = 0.005\ \mathrm{s}^{-1}$ $\qquad |+V| = |-V|$



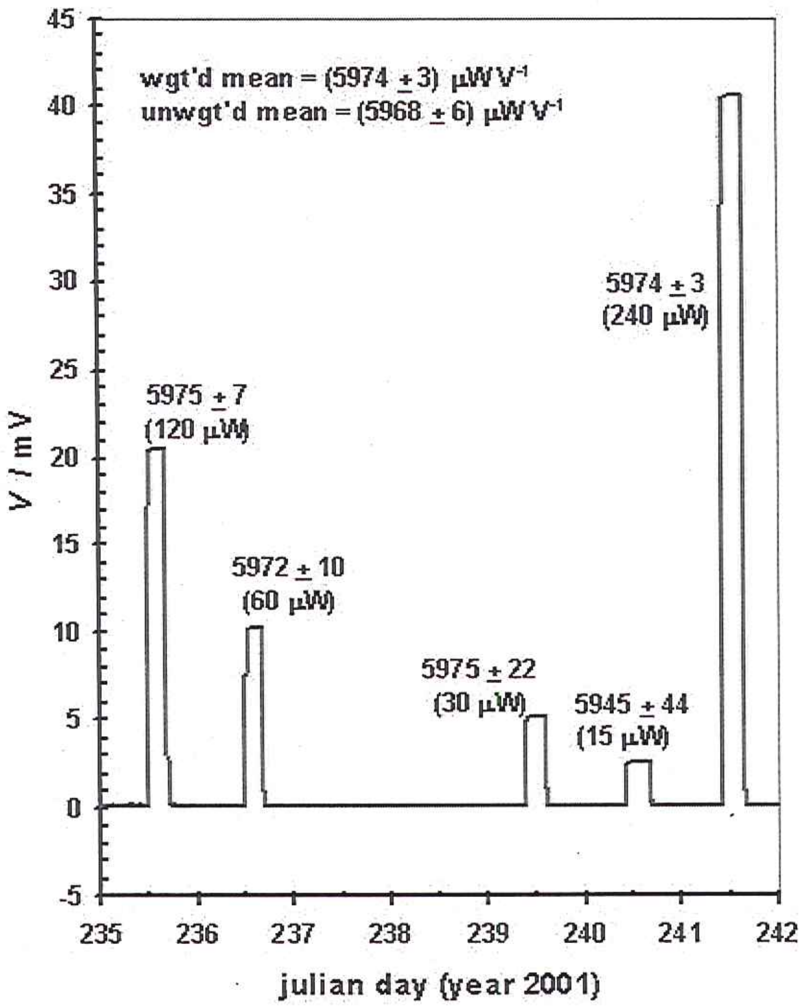
$$P = V^2/R$$



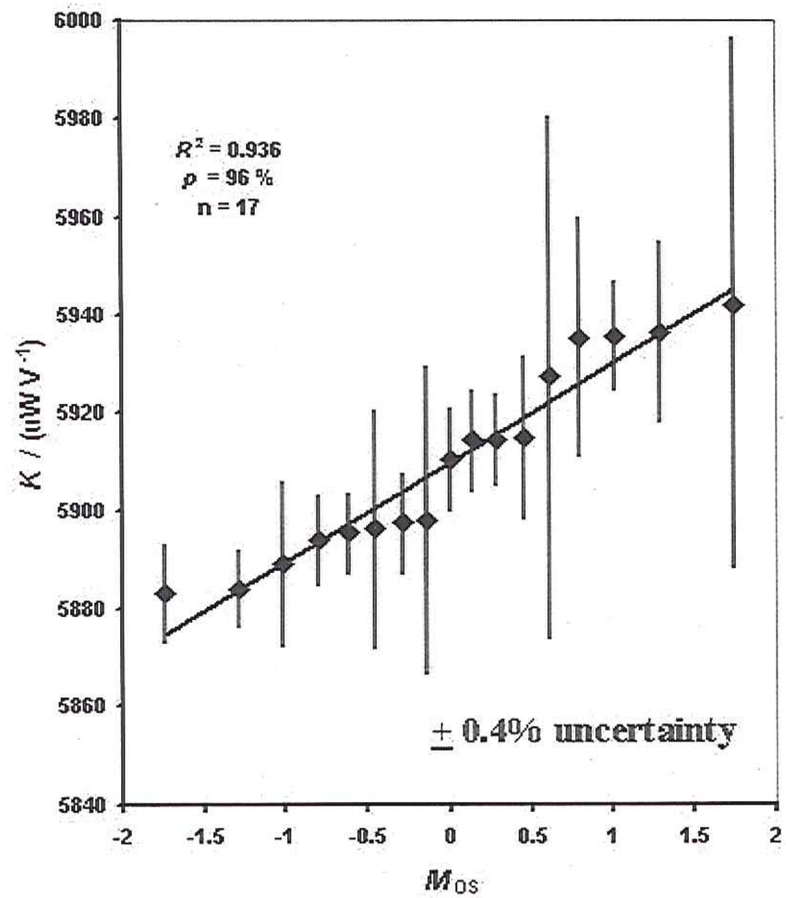
Average 100 points ($1\ \mathrm{s}^{-1}$) $\Rightarrow P_{+V}$ or P_{-V}

$$\text{mean}(P) = 1/2\ \text{mean}(P_{+V}) + 1/2\ \text{mean}(P_{-V})$$

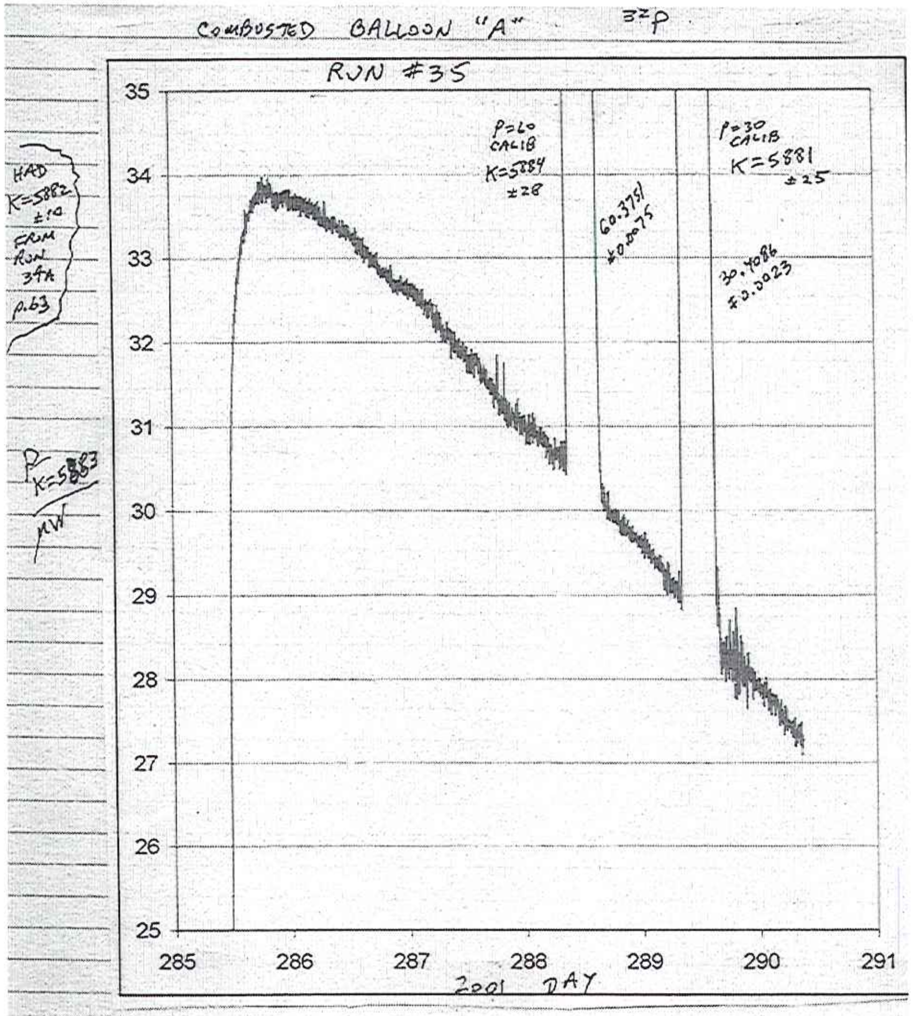
$$\text{var}(P) = 1/2\ \text{var}(P_{+V}) + 1/2\ \text{var}(P_{-V}) + \text{covar}(P_{+V}, P_{-V}) + \text{autocorr}(P_{+V}) + \text{autocorr}(P_{-V})$$



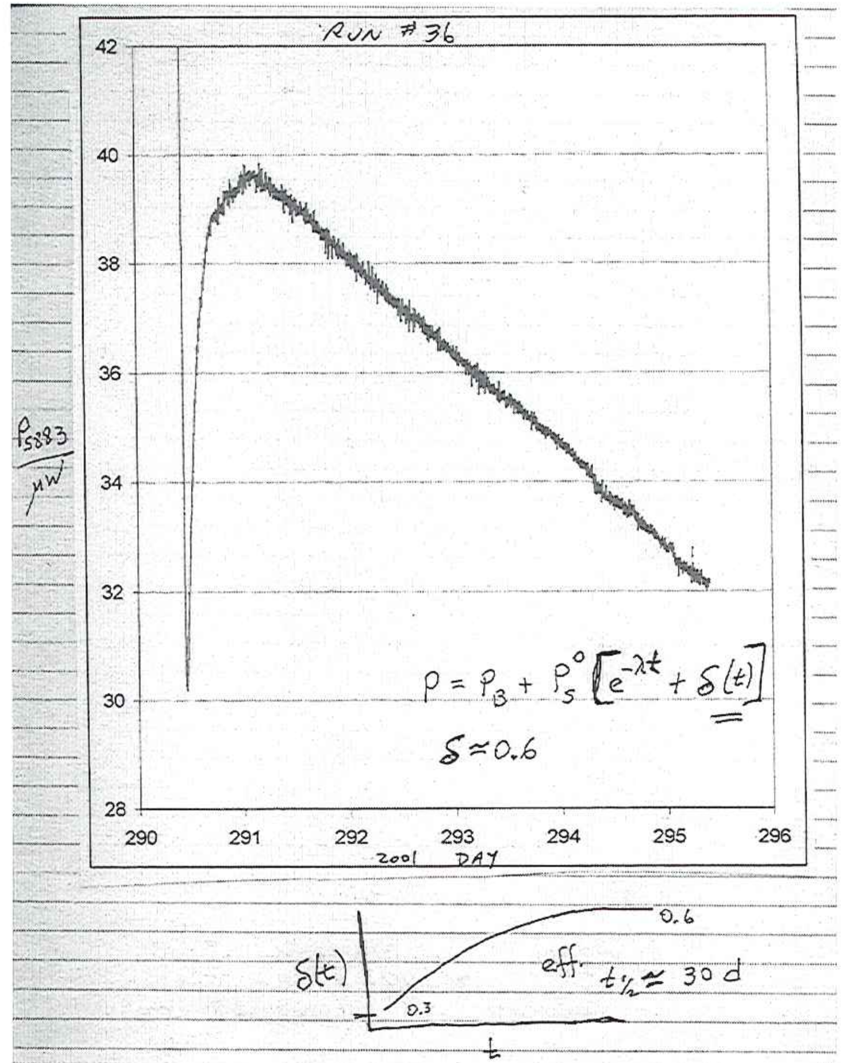
typical calibration data set



Filliben normality test for calibration data (Novoste seeds)



IMC Lab Book II, p.79

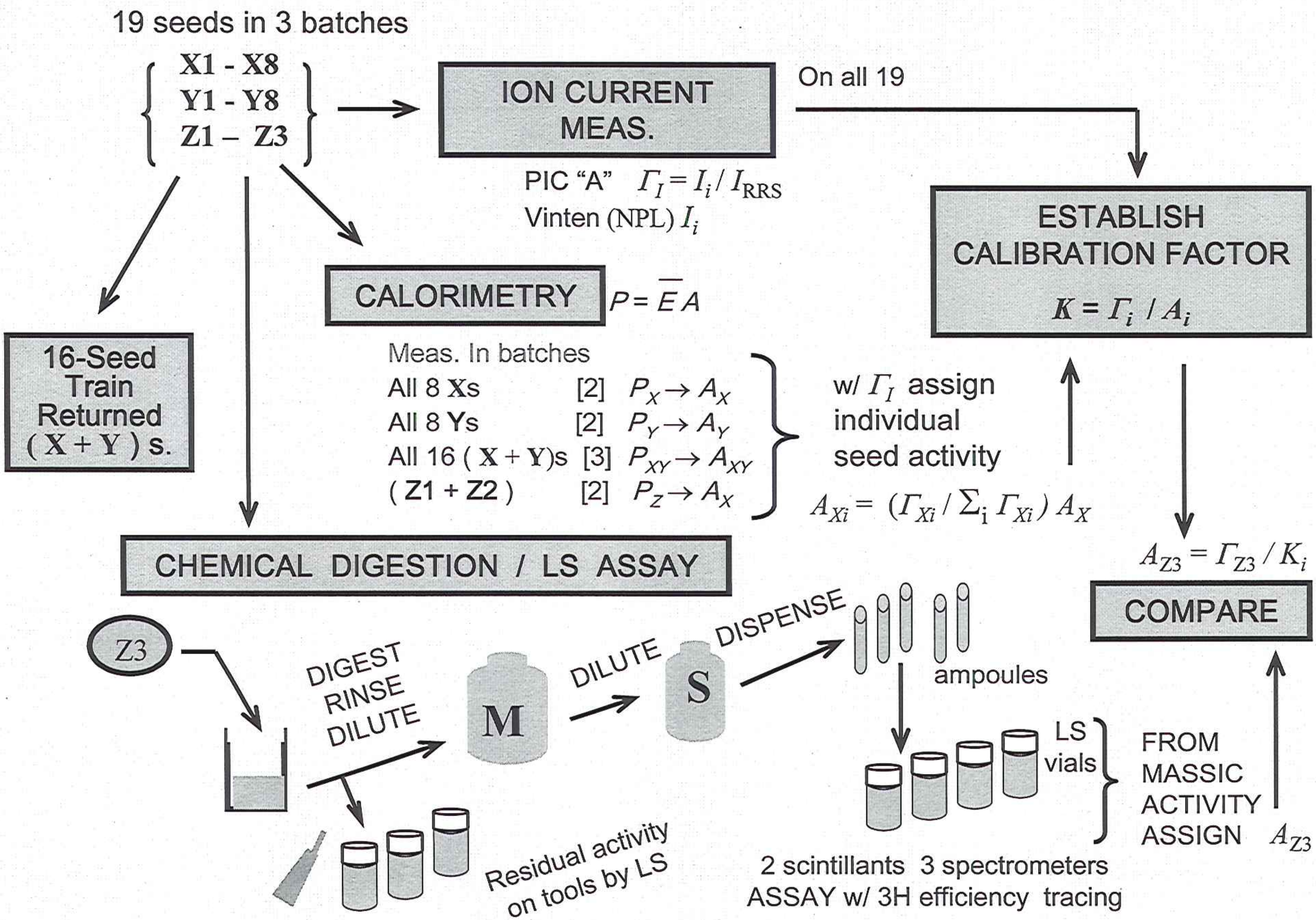


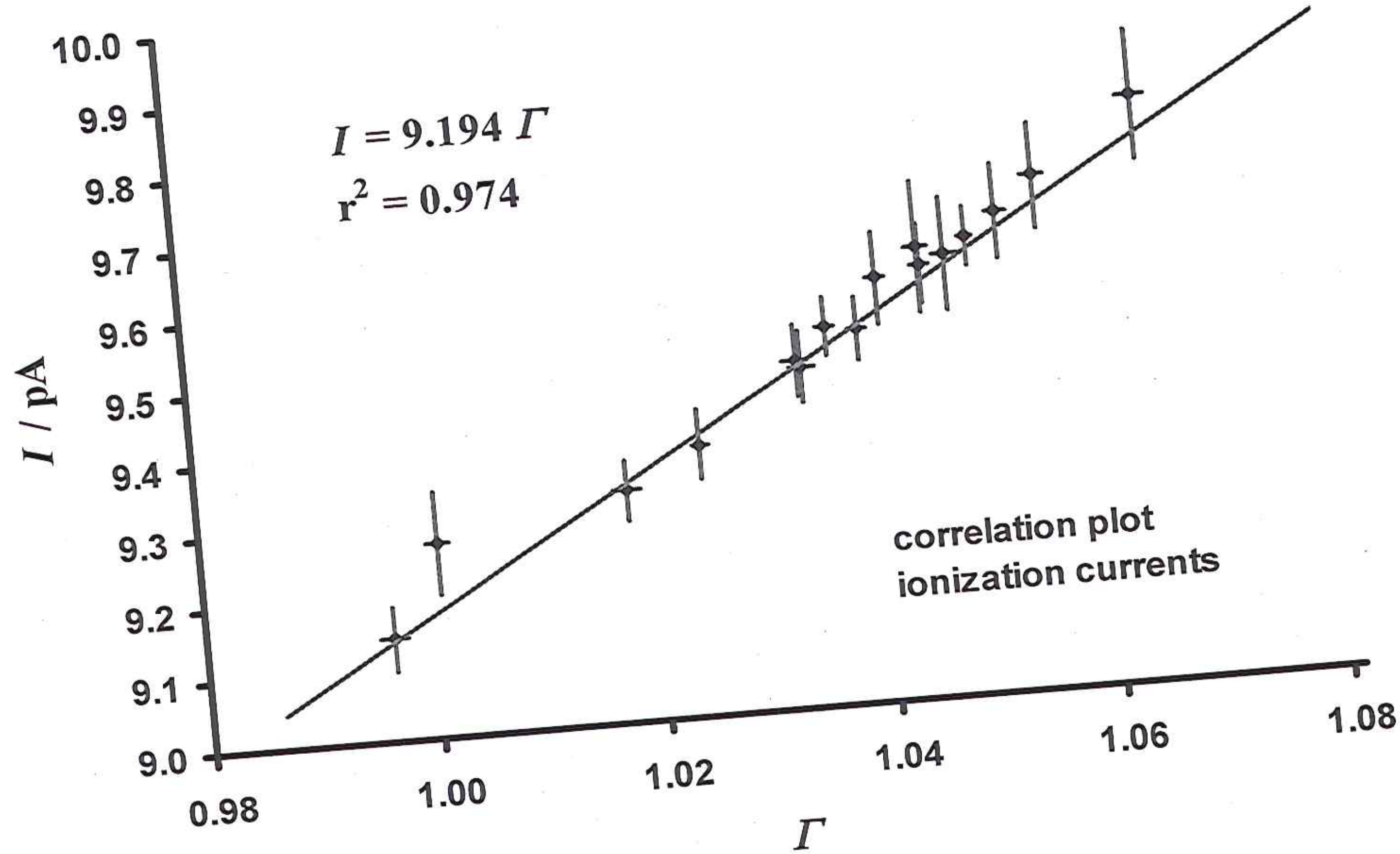
IMC Lab Book II, p.97

combusted ^{32}P balloon "A"

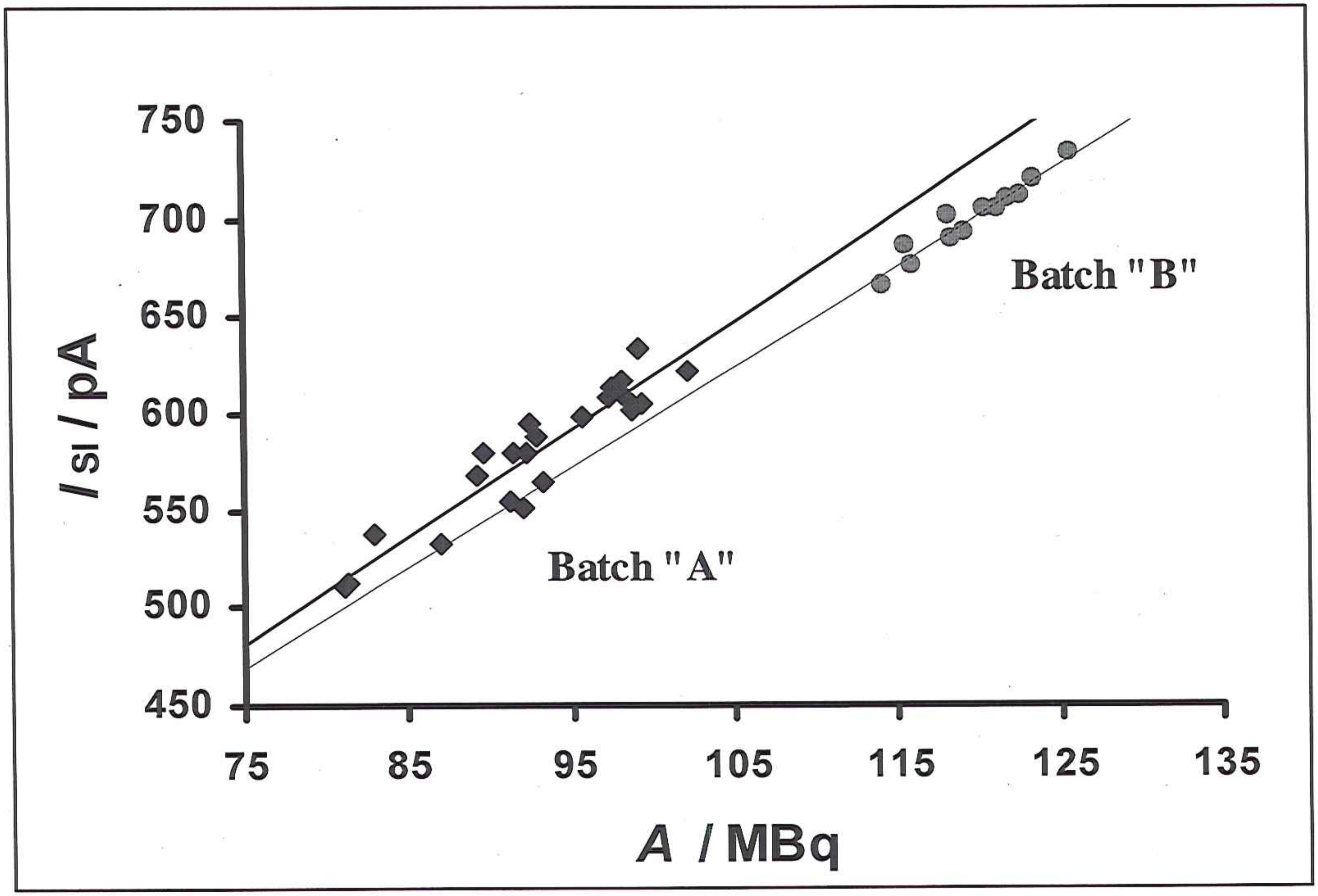
uncombusted ^{32}P balloon "C"

Standardization scheme for Novoste ^{90}Sr new-style seed





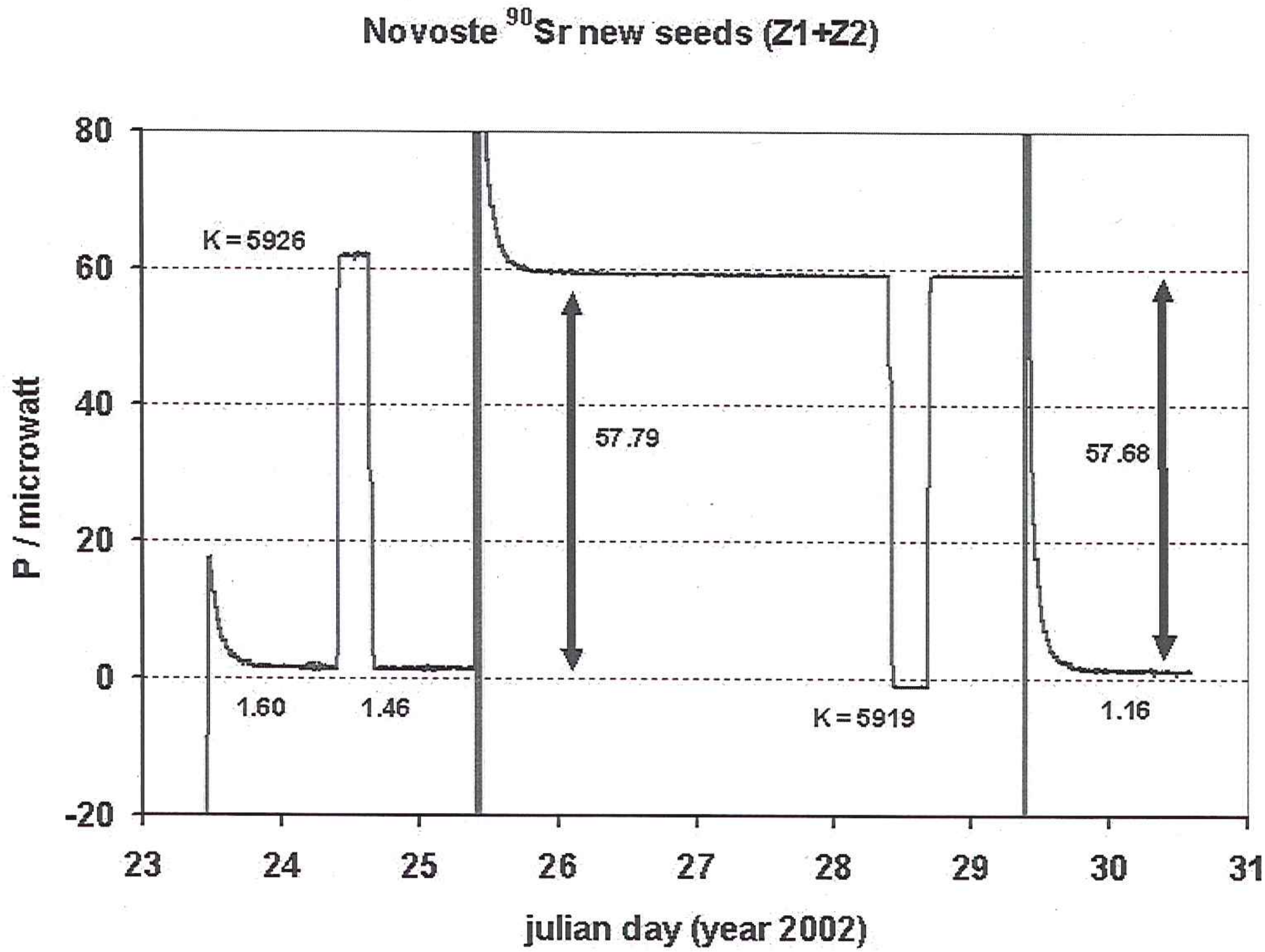
Correlation of Vinten ionization current *I* with the PIC "A" ionization current ratio Γ for the 16-seed batch



750
700
650
600
550
500
450
I_{SI} / pA
75
85
95
105
115
125
135
A / MBq
Batch "A"
Batch "B"

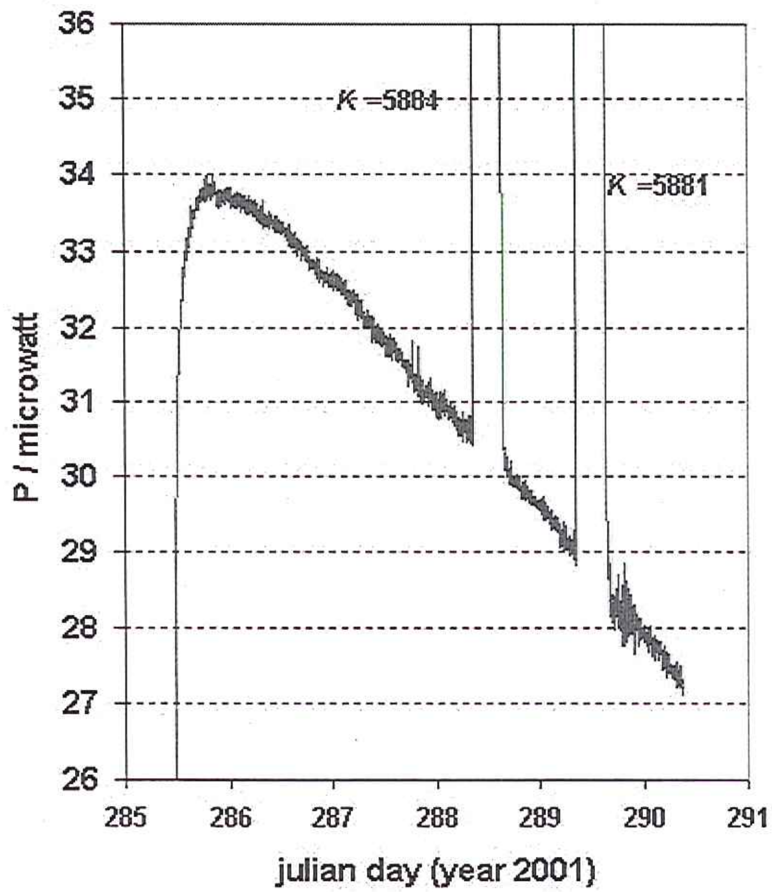
Run59

Bk3p173



Run35
Bk2,p79

Radiance ^{32}P balloon "A" (combusted)

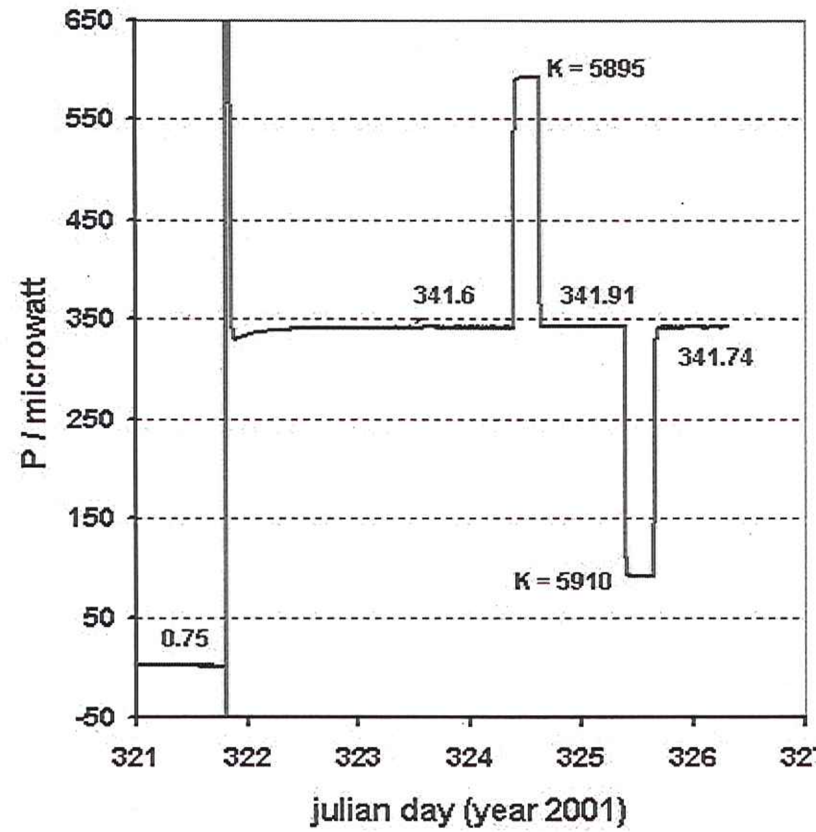


Get P_B and P_0 from "fit"

$$P = P_B + P_0 \exp(-\lambda t)$$

Run43
Bk2,p167

Novoste ^{90}Sr-^{90}Y new seeds (16)



requires baseline P_B measurement

Standardization results

source batch	number in batch	power (micowatt)	equivalent activity (MBq)
all (Xs + Ys)	16	342.70 342.30 344.41	1893.2 1891.0 1902.6
all Xs	8	172,45 172.76	952.7 954.4
all Ys	8	169.84 170.75	938.3 943.3
(Z1 + Z2)	2	57.81 58.27 58.09	319.4 321.9 320.9

From ion current measurements on individual seeds

X1 -X2 ranged from 114.4 MBq to 121.7 MBq
Y1 -Y2 ranged from 113.9 MBq to 119.9 MBq } ± 1.6 % (k = 2)

Z1 -Z3 ranged from 156.3 MBq to 164.3 MBq ± 3 % (k = 2)

Destructive assay (by LS) on Z3 agreed with calorimetry *initially* by - 1.1 % (*now* with n = 5 determinations to 0.4 %)

FINDINGS

Got 1 to 2 % agreement w/ extant IC calibrations for both

Radiance ^{32}P balloons

Novoste ^{90}Sr-^{90}Y seeds (old)

Calibration factors (15 determinations) for Novoste seeds (new)

has s.d.m < 0.1% and 1/2range = 0.5 %

Replicate measurement uncertainty is about 1 % or so

if can get P_B by fit with decay

or if one has sufficient replications to get ΔP

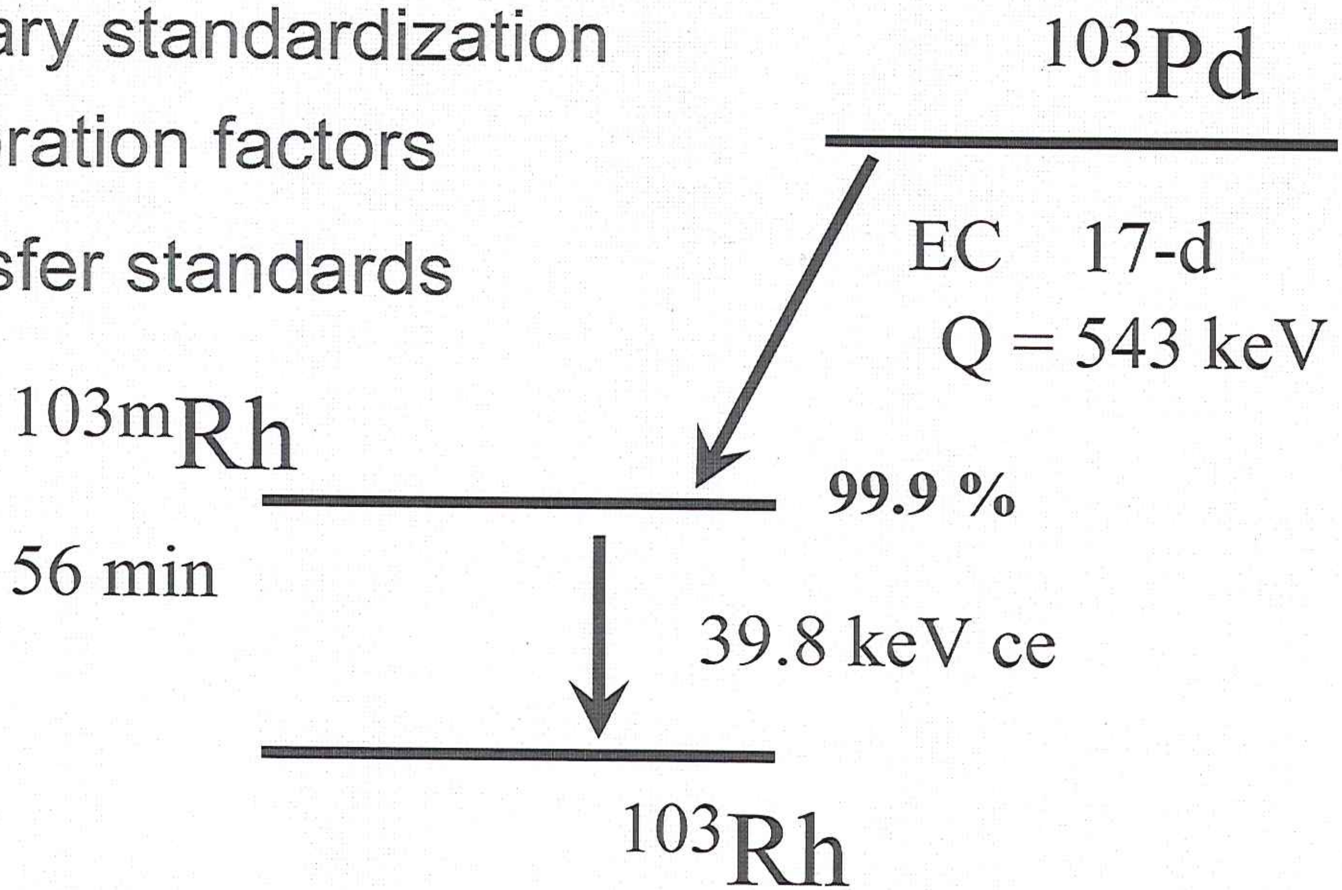
(with little decay)

More conclusions at end ....

need primary standardization

+ calibration factors

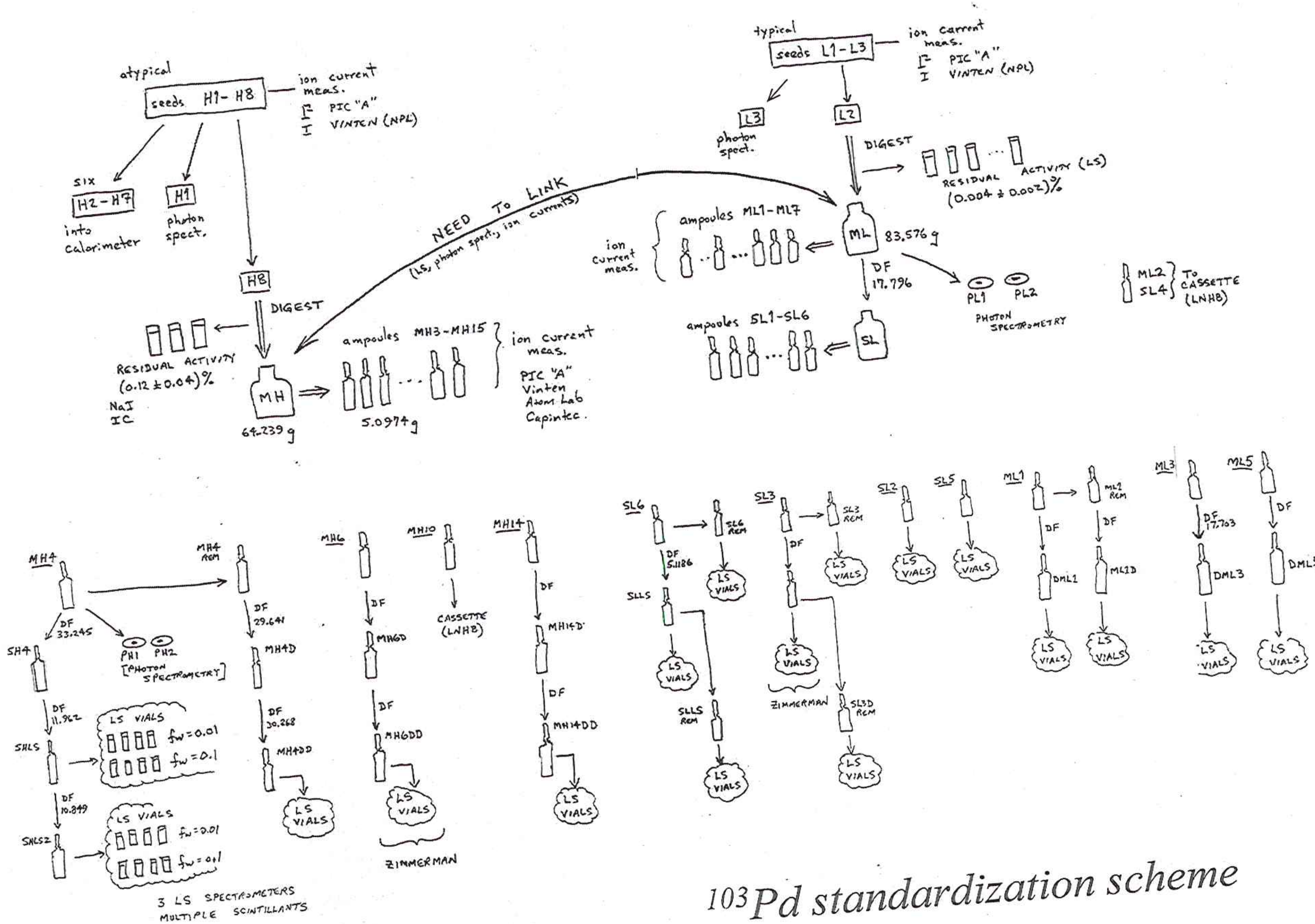
+ transfer standards



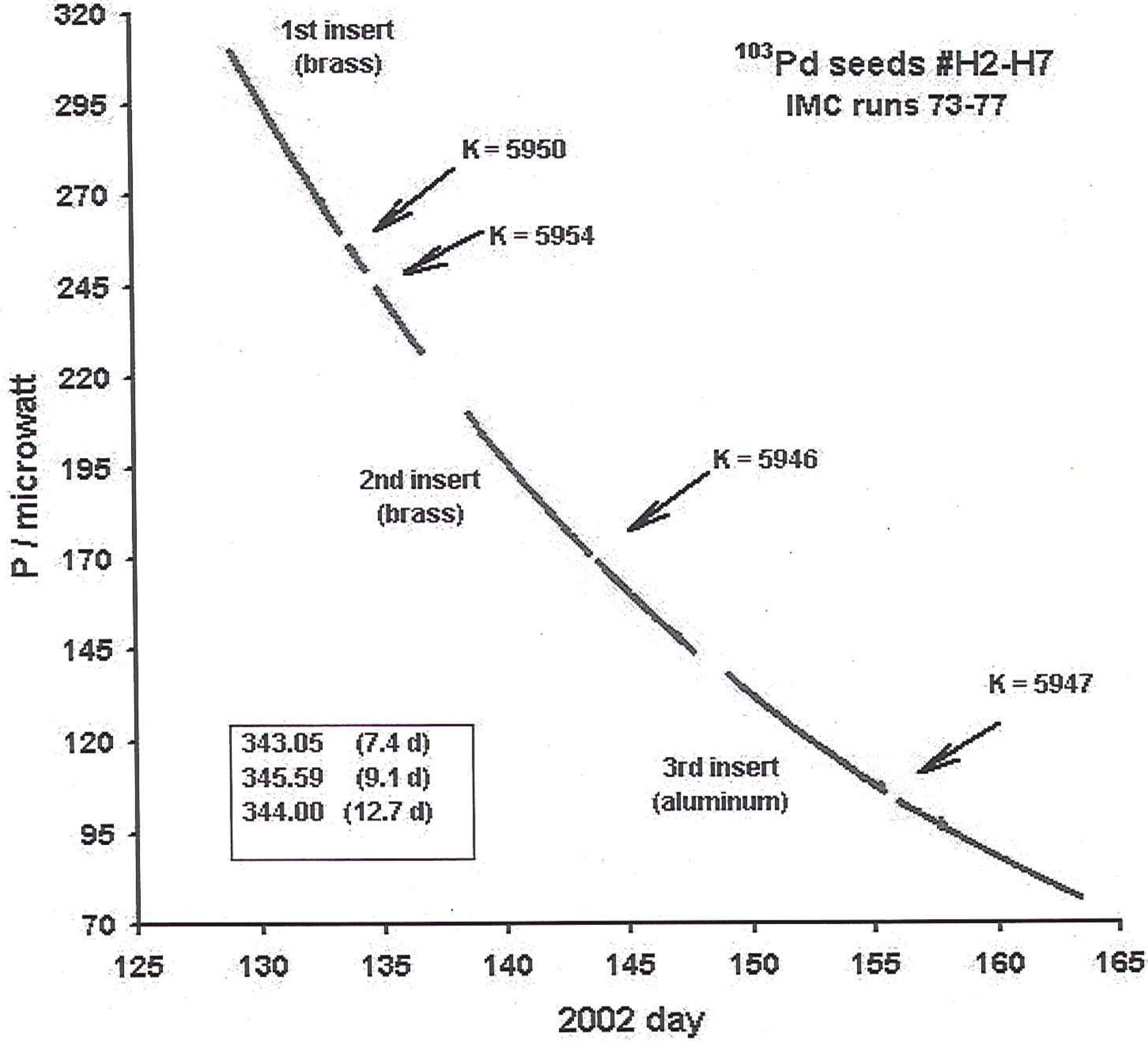
Brachytherapy source

used to treat prostate cancer

candidate for intravascular use



^{103}Pd standardization scheme

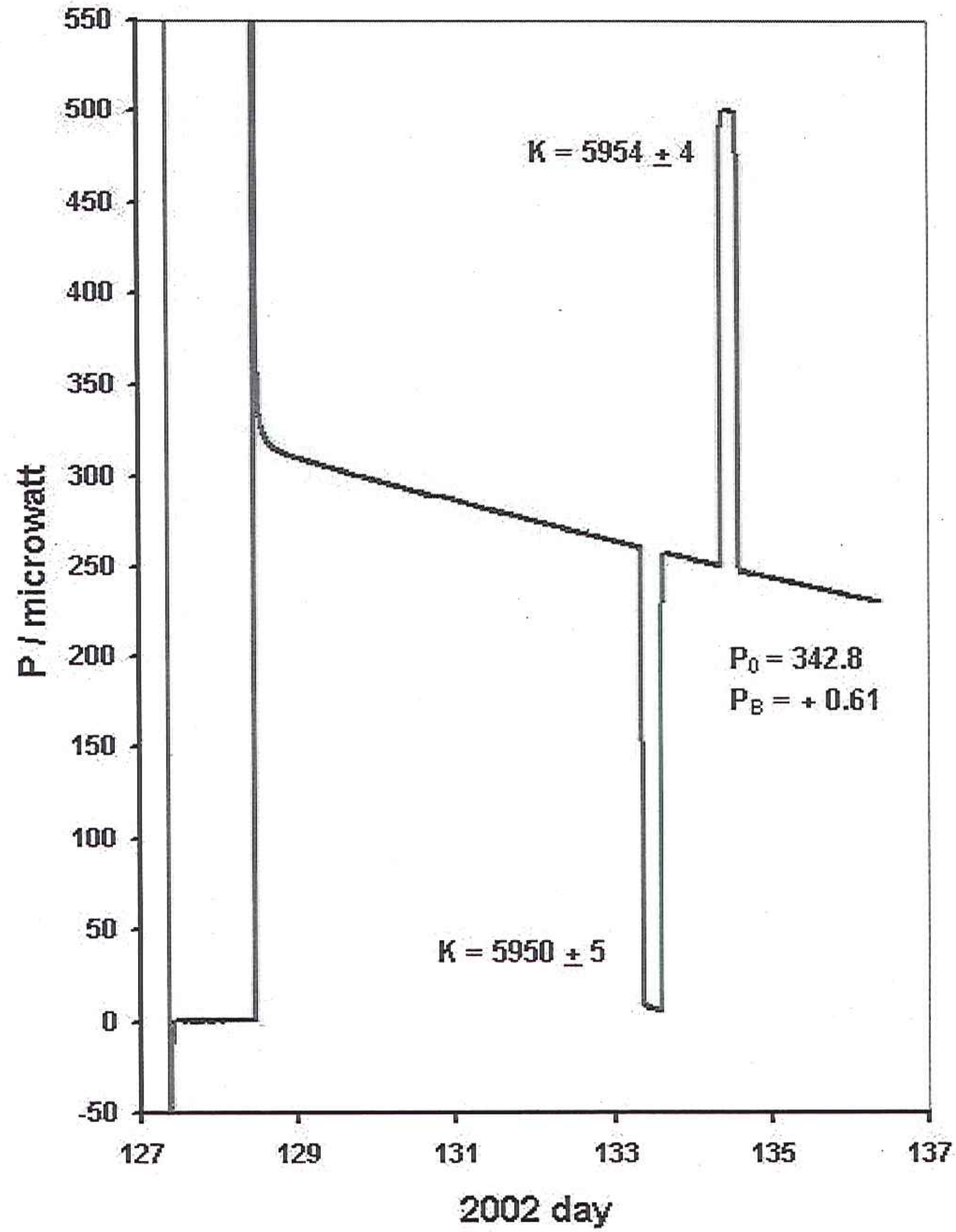


103Pd seeds #H2-H7
IMC runs 73-77
1st insert (brass)
2nd insert (brass)
3rd insert (aluminum)
K = 5950
K = 5954
K = 5946
K = 5947
343.05 (7.4 d)
345.59 (9.1 d)
344.00 (12.7 d)
P / microwatt
2002 day
320
295
270
245
220
195
170
145
120
95
70
125
130
135
140
145
150
155
160
165

Run 73

1st insertion

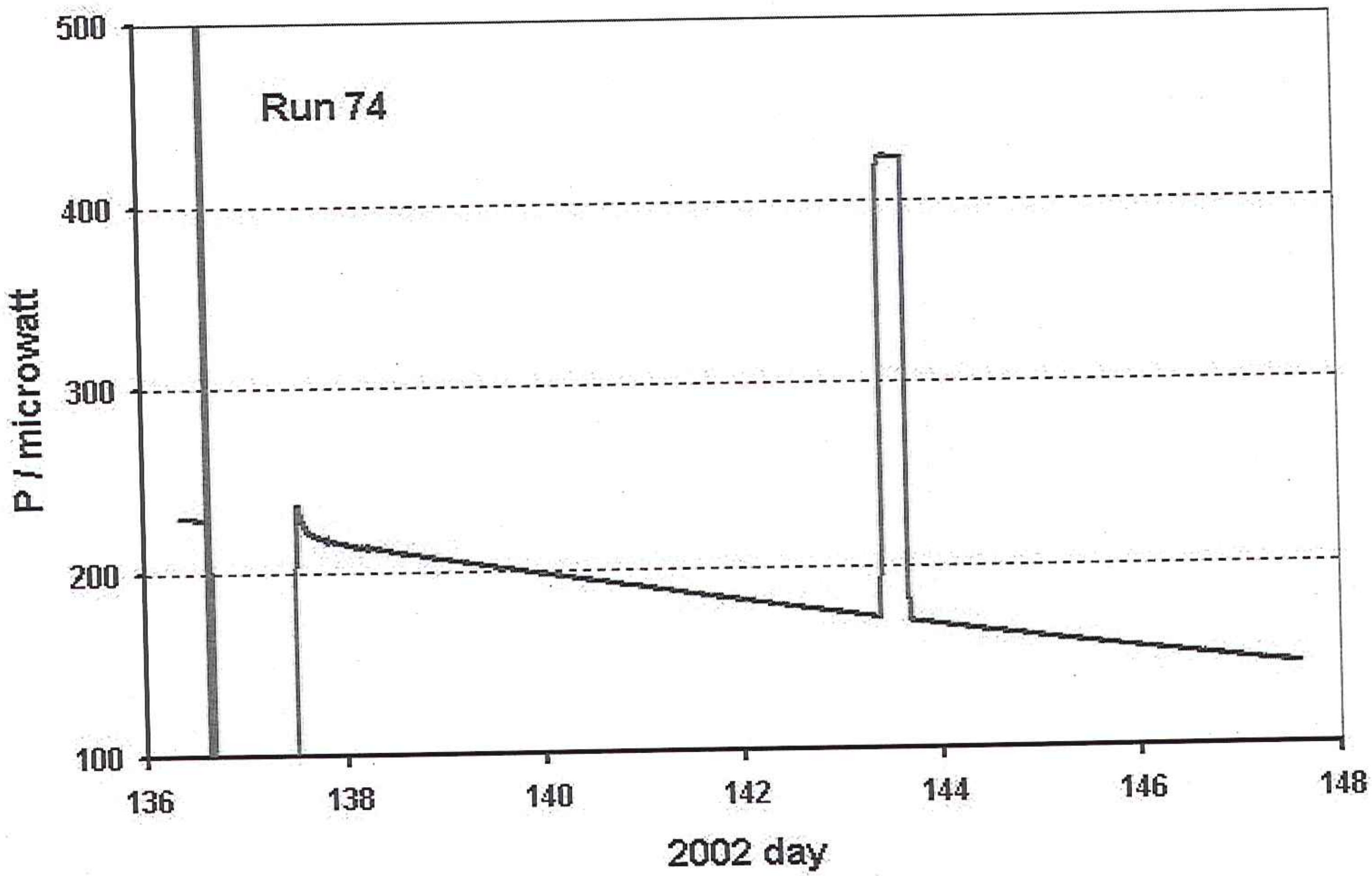
(brass)

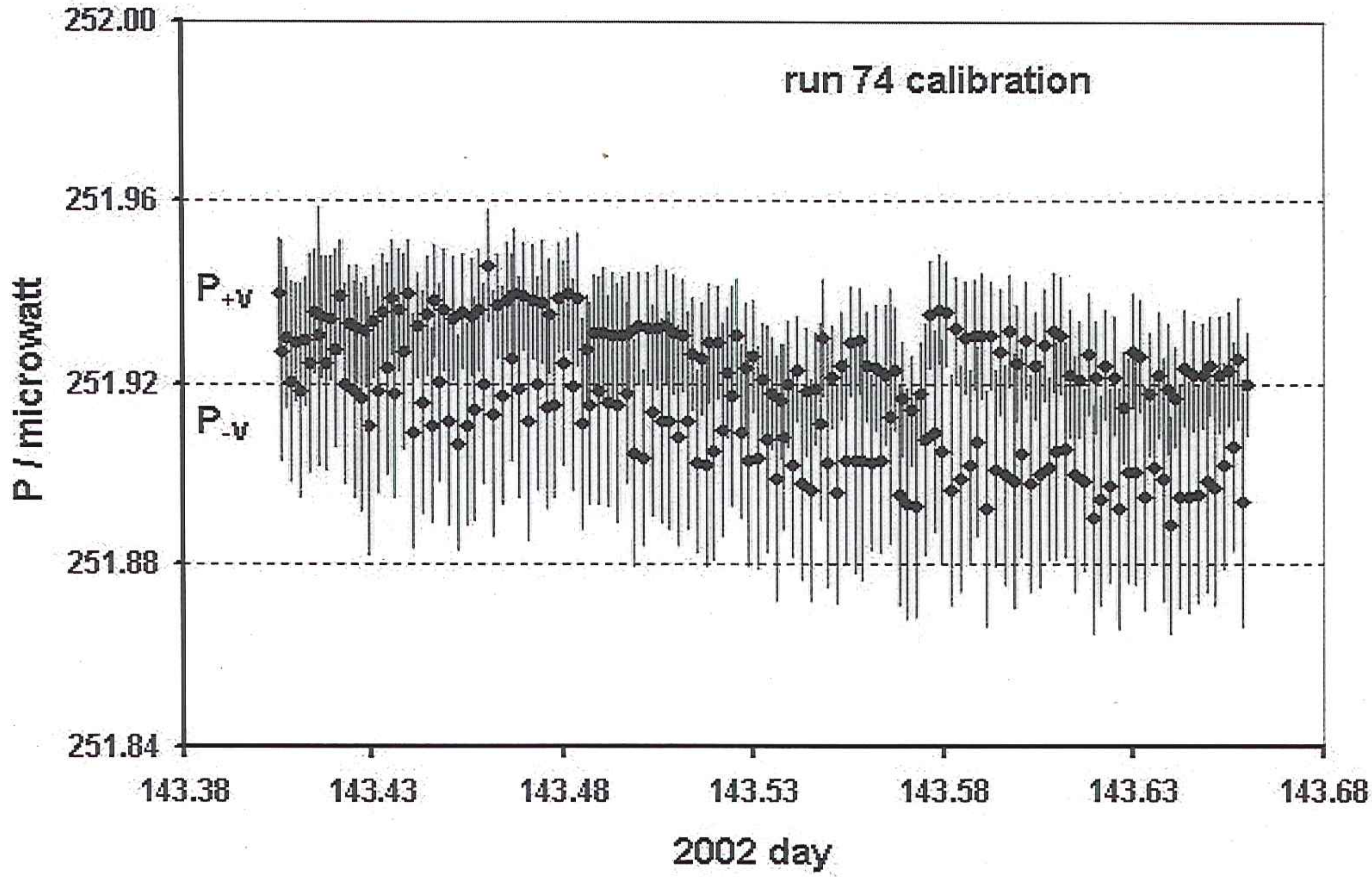


Run 74

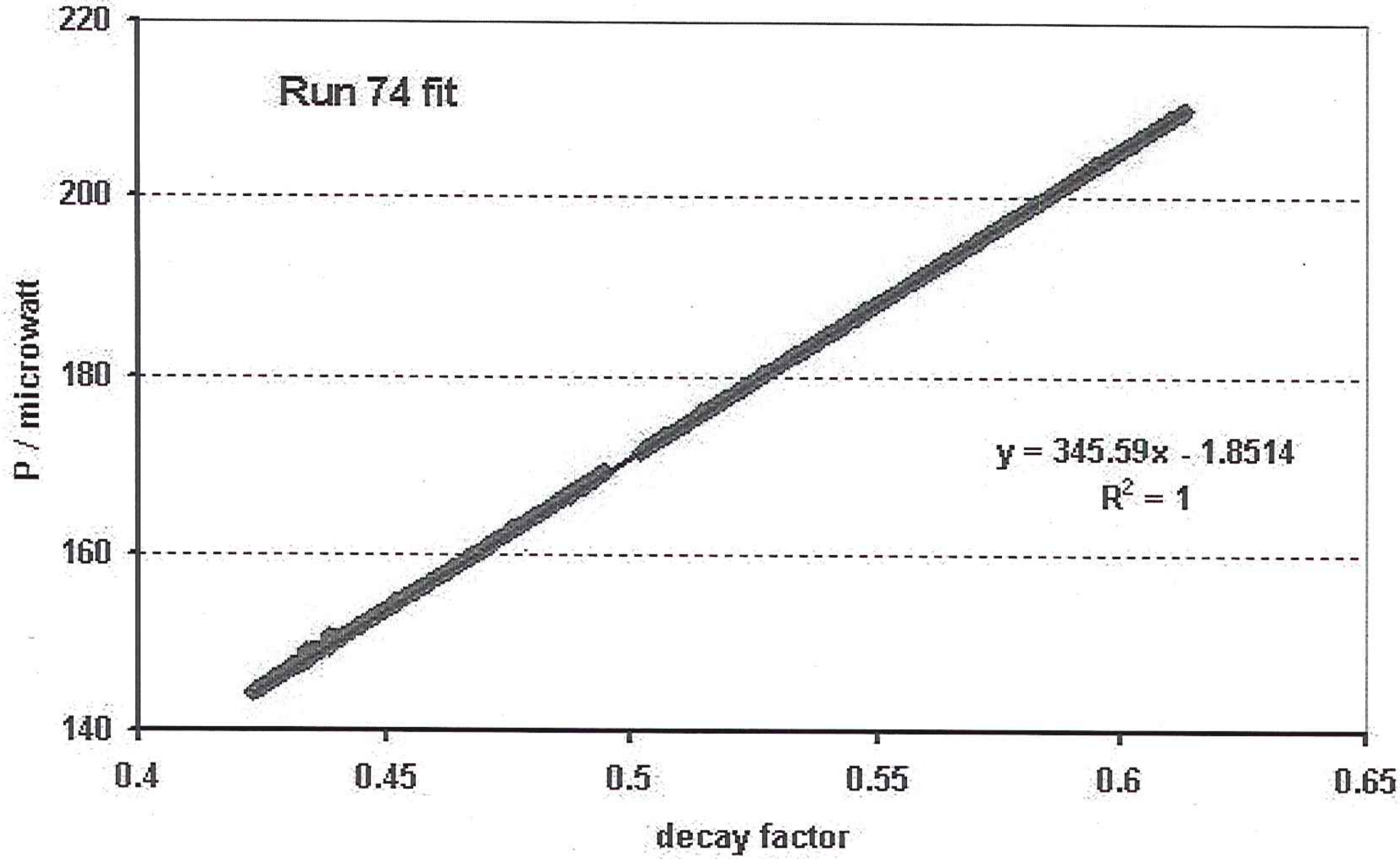
2nd insertion

(brass)

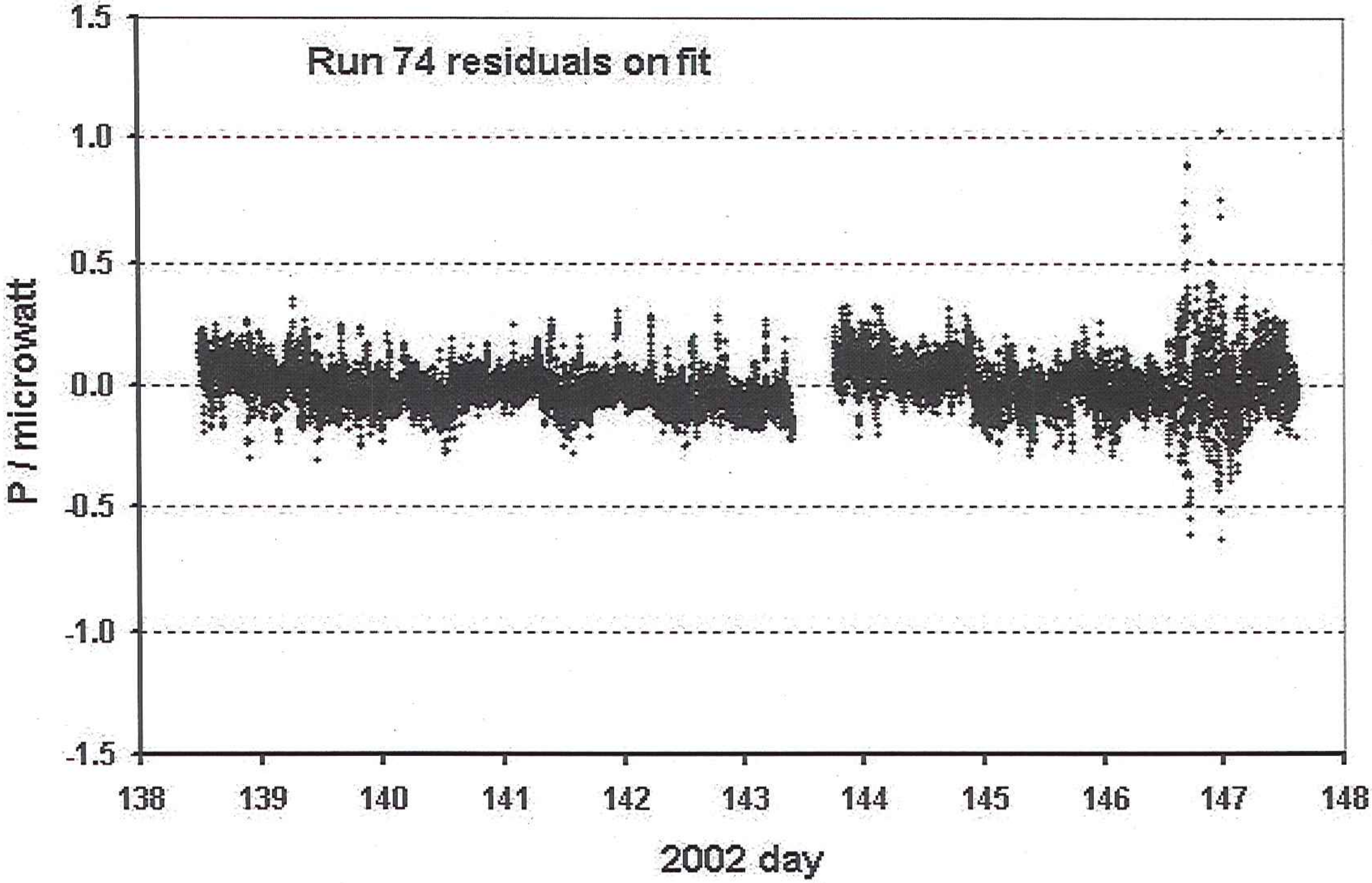


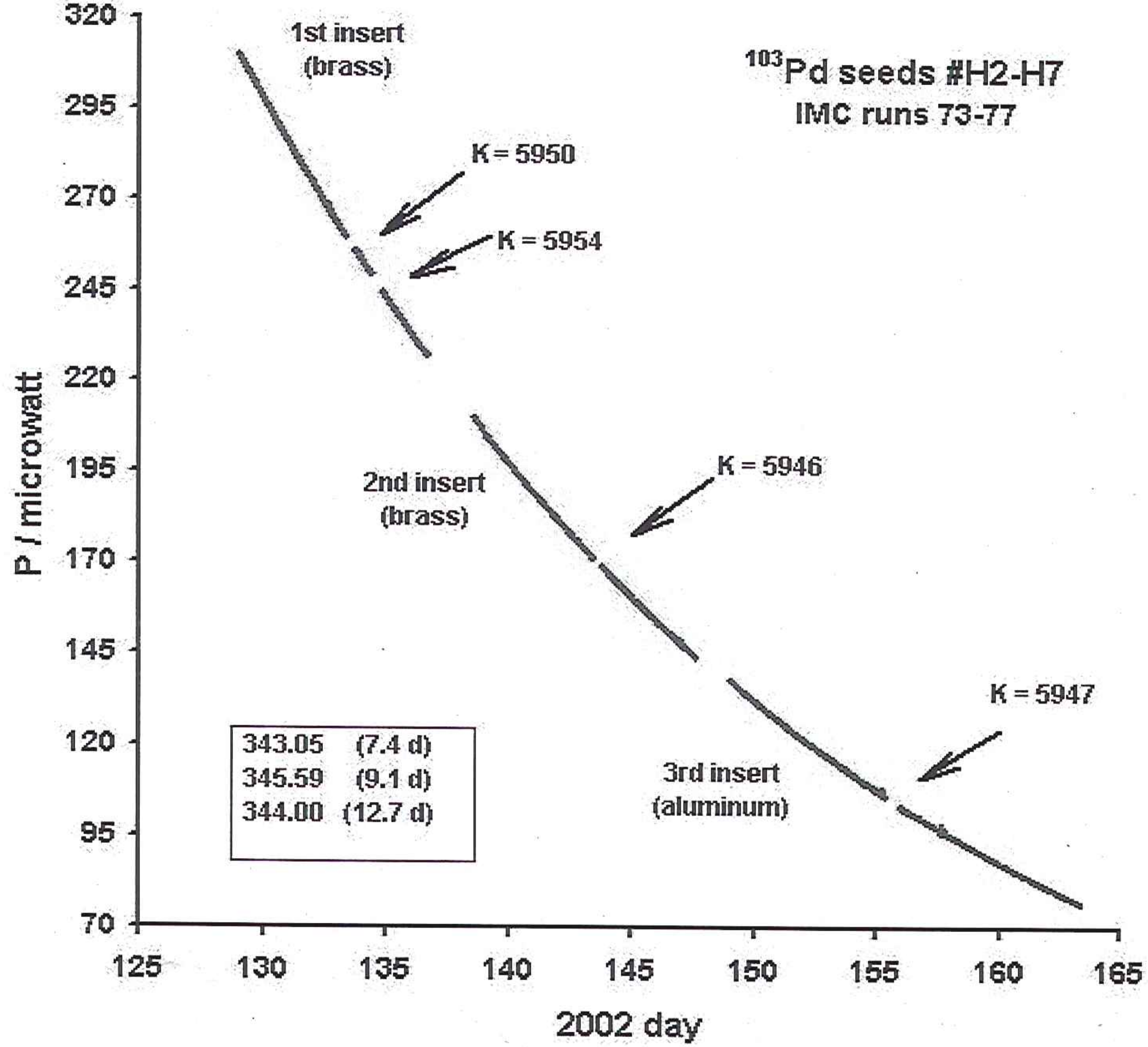


Run 74 calibration

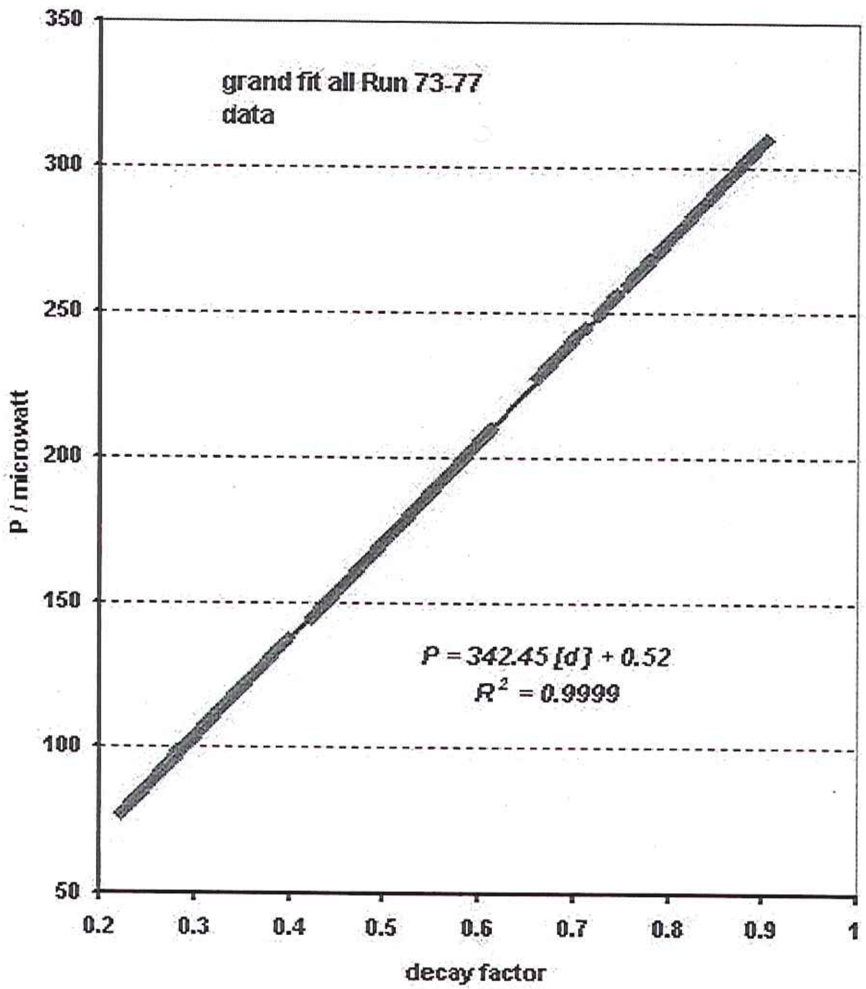

Run 74 fit
220
200
180
160
140
P / microwatt
y = 345.59x - 1.8514
R² = 1
0.4
0.45
0.5
0.55
0.6
0.65
decay factor

Run 74 fit

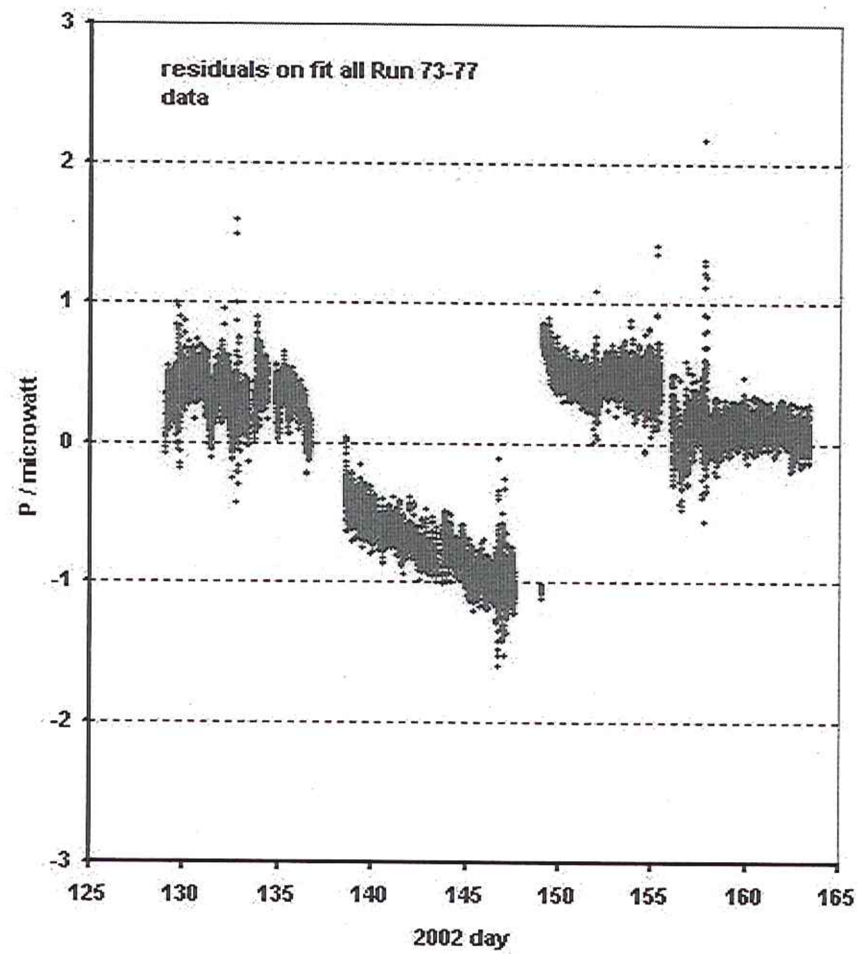

Run 74 residuals on fit
P / microwatt
2002 day
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
138
139
140
141
142
143
144
145
146
147
148



^{103}Pd seeds #H2-H7
IMC runs 73-77
1st insert
(brass)
K = 5950
K = 5954
2nd insert
(brass)
K = 5946
3rd insert
(aluminum)
K = 5947
343.05 (7.4 d)
345.59 (9.1 d)
344.00 (12.7 d)
P / microwatt
2002 day
320
295
270
245
220
195
170
145
120
95
70
125
130
135
140
145
150
155
160
165



grand fit all Run 73-77
data
P = 342.45 [d] + 0.52
R^2 = 0.9999
P / microwatt
decay factor
350
300
250
200
150
100
50
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1



residuals on fit all Run 73-77
data
P / microwatt
2002 day
3
2
1
0
-1
-2
-3
125
130
135
140
145
150
155
160
165

In comparing calorimetric vs. LS standardization of ^{103}Pd…

Consider

… I have not much doubt but that the two standards will be found in very good agreement, but it will be a devil of a mess if they are not.

… I think I can compare two nearly equal standards [to] an accuracy of 1 in 1000. I suppose, however, we shall not worry if the agreement of the two standards is within 1 in 300 or 400.

Ernest Rutherford (University of Manchester)
letter to Bertram Boltwood (Yale University)
18 march 1912

I guess I am supposed to have a conclusion.

So...

- **Calorimetry is SLOW**
  - needs long time to thermally stabilize
  - typically need multiple determinations
  - different / absorbers / Monte Carlo calc. verifications

- **Calorimetry NOT Necessarily Non-Destructive method**

- **NOW, accuracy is in range of $\pm$ 1 or 2 percent**
  - Largely due to baseline instabilities and uncertainties in establishing baselines to get ΔP

- **Power may be measured very accurately**
  - But still need average energy per decay to get Activity