The Abdus Salam International Centre for Theoretical Physics

1833-46

Workshop on Understanding and Evaluating Radioanalytical Measurement Uncertainty

5 - 16 November 2007

Uncertainty in gas proportional counting.

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Counting Uncertainty in Using Gas Proportional Counters

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Main Types of Proportional Counters

1. Gas Flow Proportional

- with window (laboratory alpha-beta counters)
- windowless

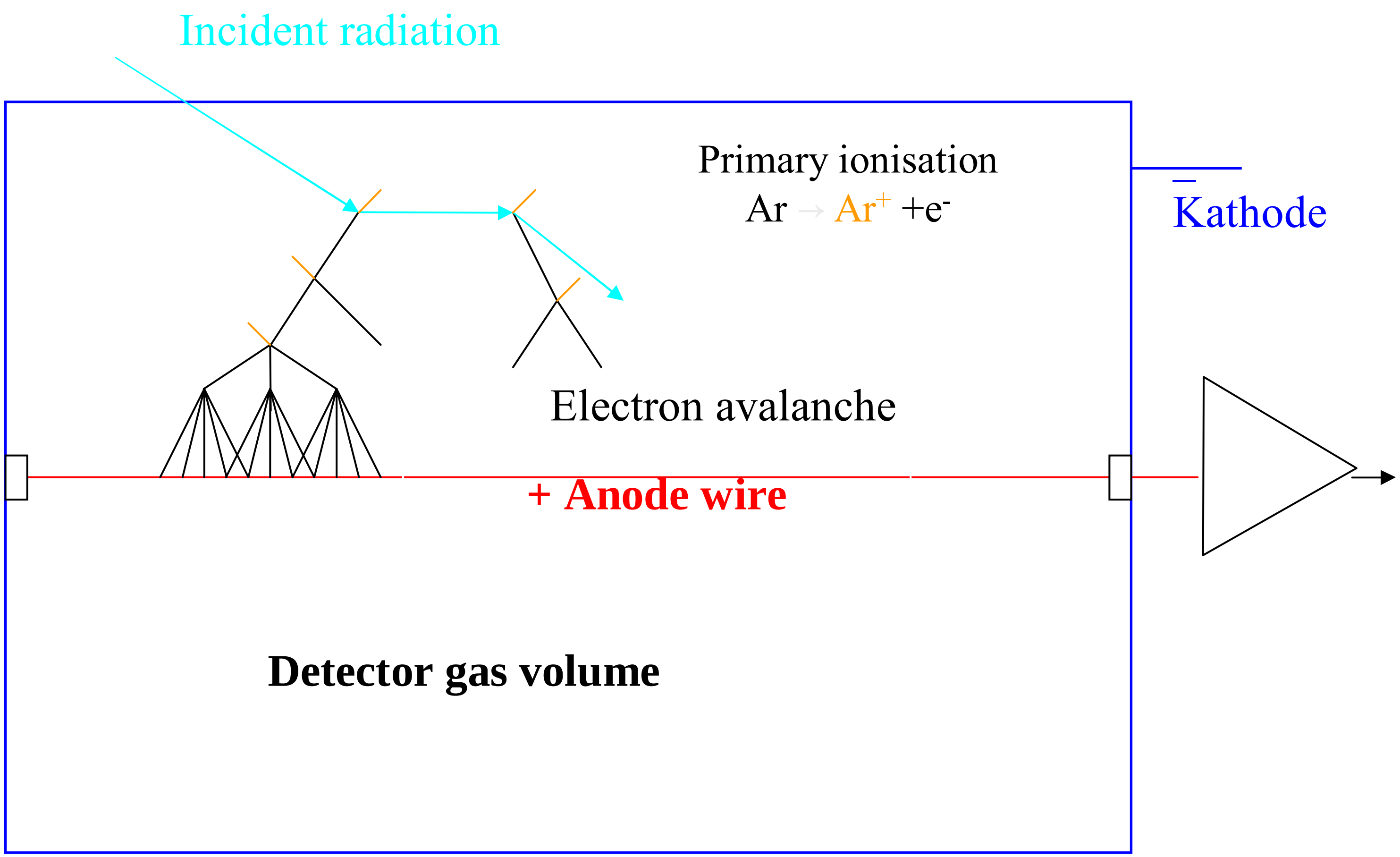
2. Air Proportional (alpha counting only)

3. Sealed proportional (e.g., BF_3, ^3He neutron detectors)

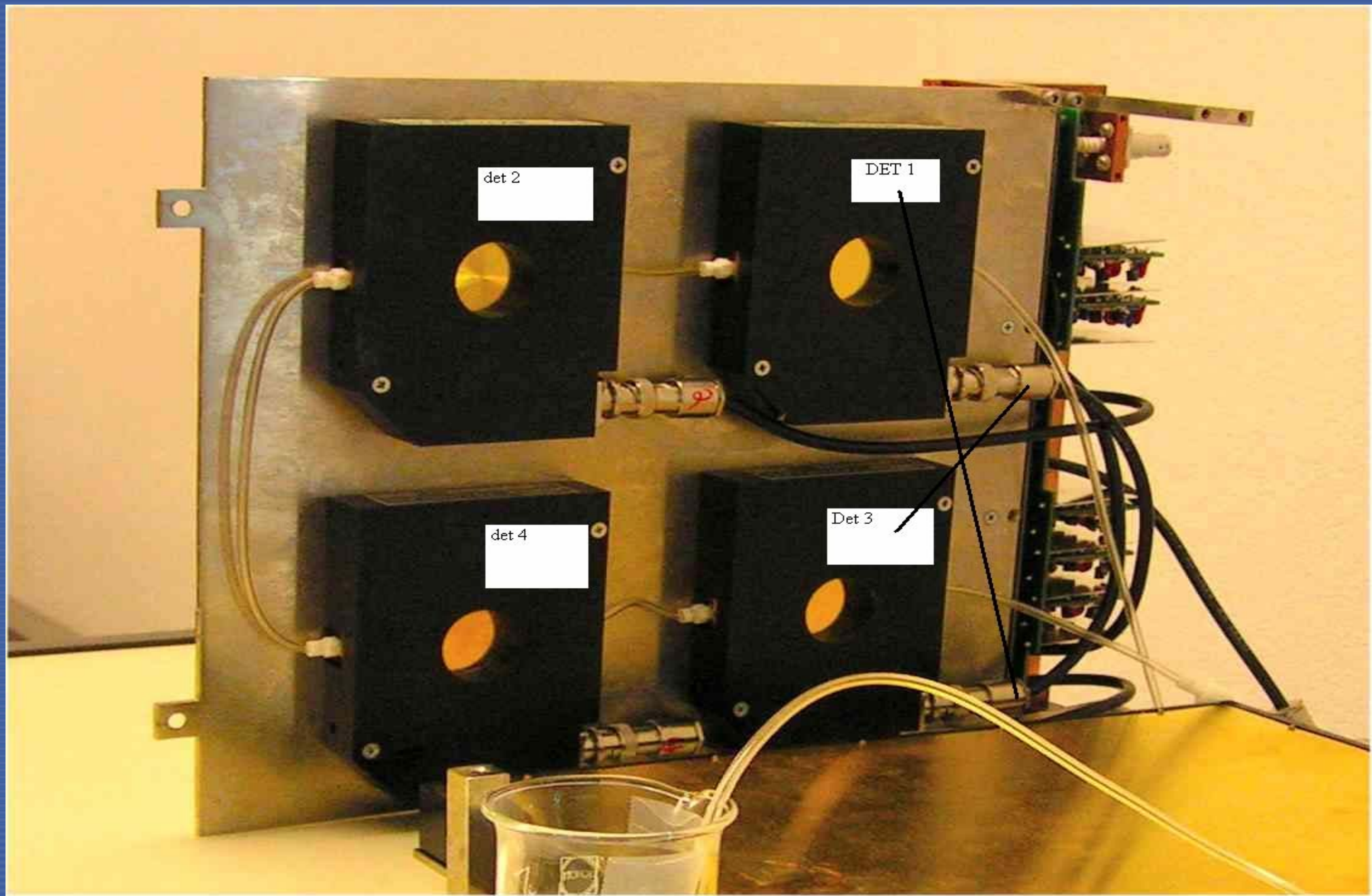
Applications

- Gross alpha and or beta counting
  - Filter
  - Smear (wipe test)
  - Water (residue)
  - Soil,
- Sources from separated alpha or beta emitting radionuclides
  - Sr-90, Y-90 or C-14

Basic Detector Theory



Gas proportional detectors

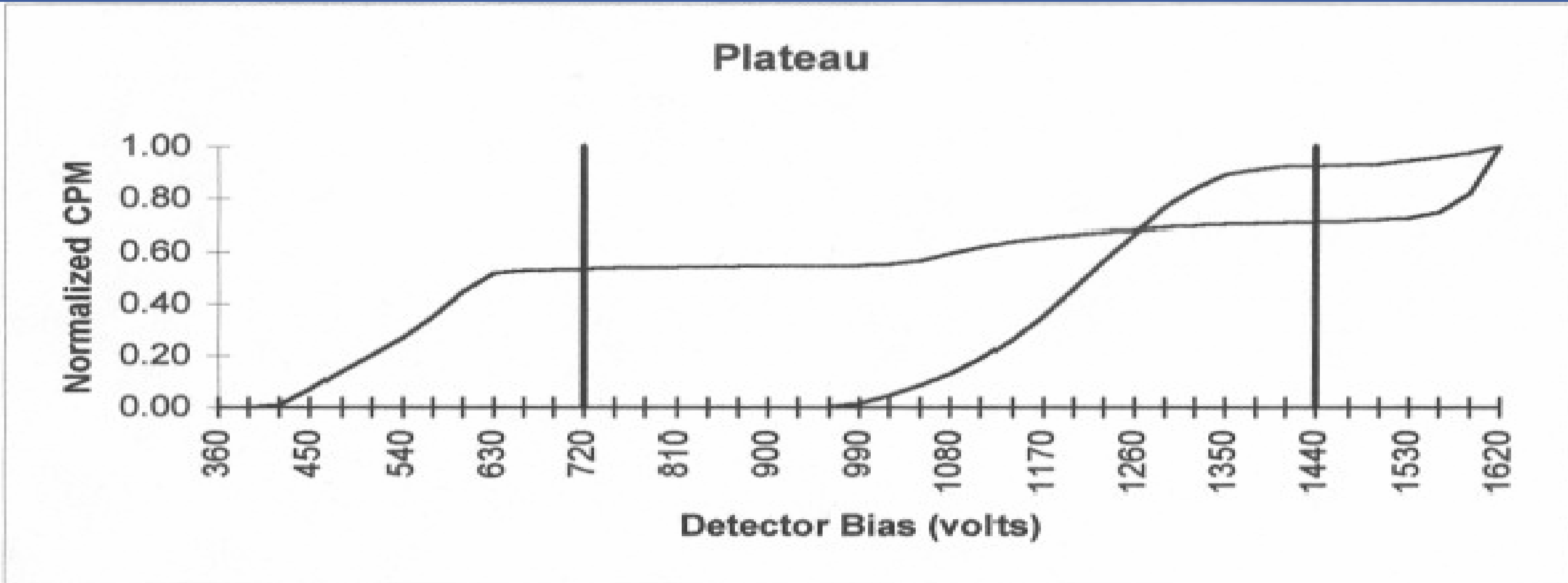


Basic Detector Theory

$$Gain = \frac{N}{n}$$

- Gain
- Number of electrons reaching the anode wire
  ~ U (applied detector voltage bias)
- number of electrons produced by the particle
  ~ Energy of the particle/E_{igas}

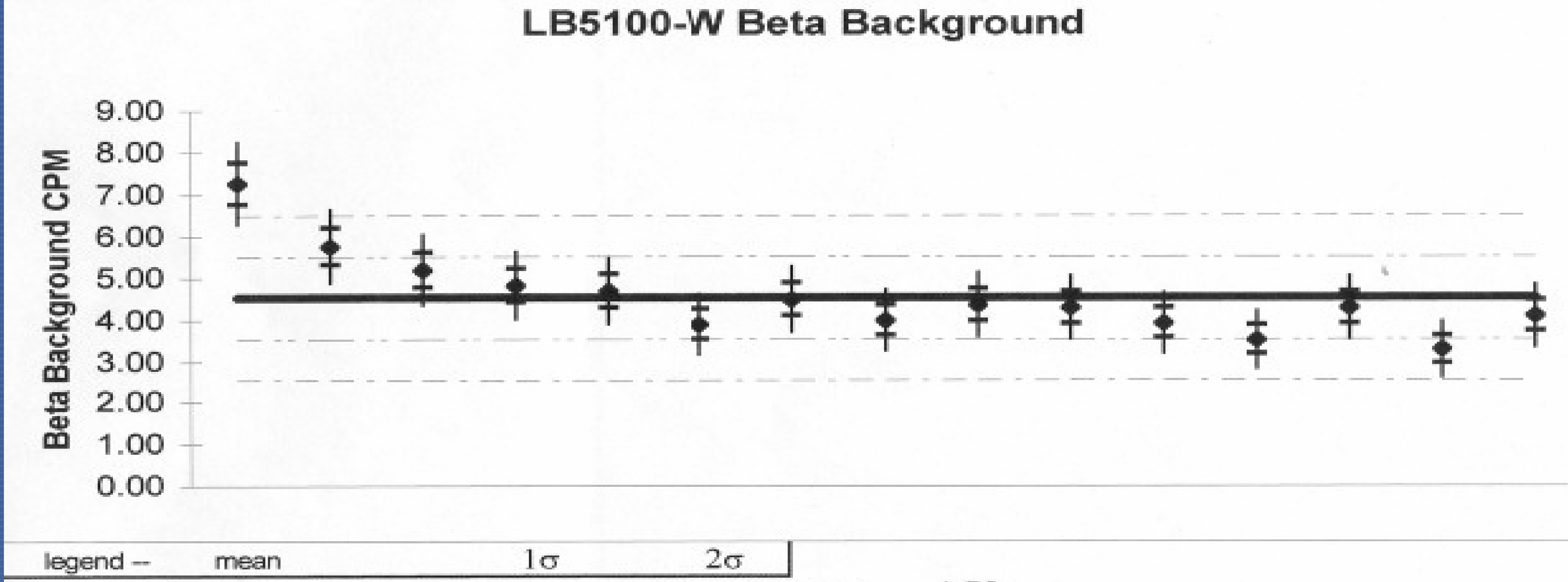
Basic Detector Theory



Optimum alpha & beta simultaneous operating voltage: **1440**
Beta slope per 100 volts at beta voltage: 1.85%
Alpha slope per 100 volts at beta voltage: 1.53%

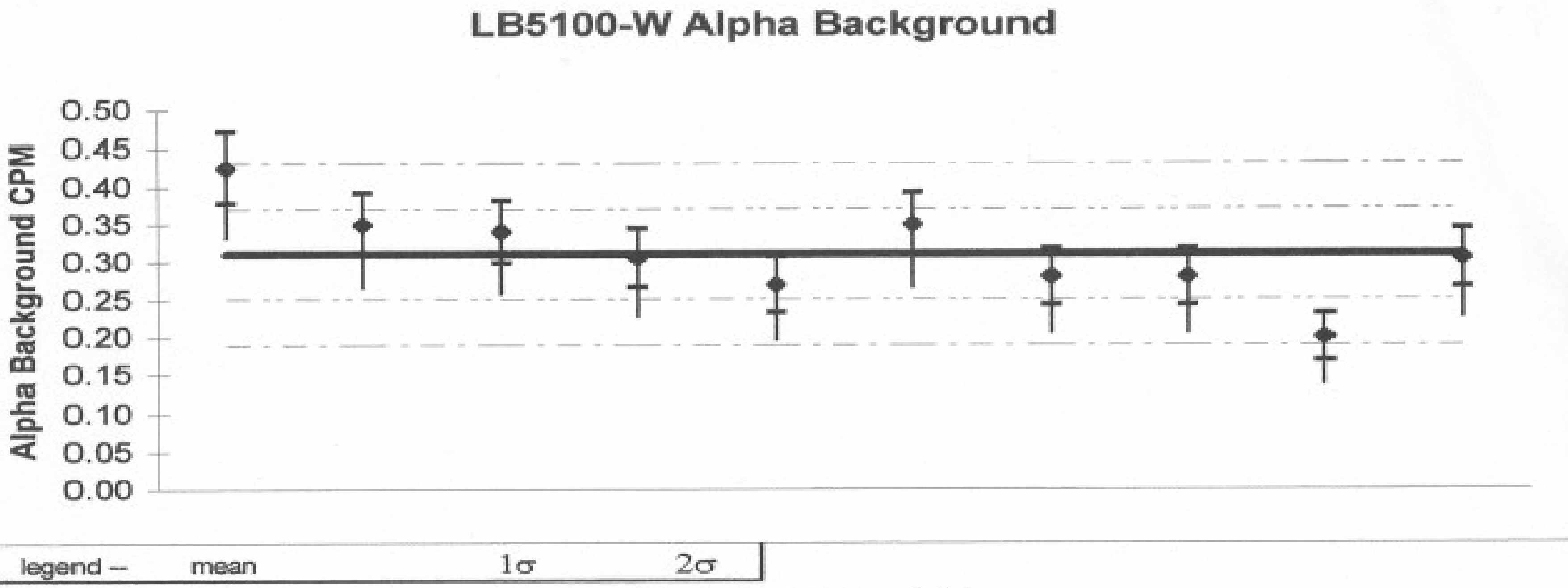
Optimum alpha only operating voltage: **720**
Alpha slope per 100 volts at alpha voltage: 1.82%

Beta background



Mean background:	4.53	
Error for mean background:	0.10	1σ
Actual standard deviation:	0.98	
Predicted standard deviation:	0.39	
Number of individual measurements:	15	
Chi-square:	88.99	
Reduced chi-square:	6.36	

Alpha background



Mean background:	0.31	
Error for mean background:	0.01	1σ
Actual standard deviation:	0.06	
Predicted standard deviation:	0.04	
Number of individual measurements:	10	
Chi-square:	21.17	
Reduced chi-square:	2.35	

Chi Square test for variances – equipment performance

Expected counting uncertainty : $$\sigma_N = \sqrt{N}$$

Calculated standard deviation of n counting: $$s_N = \sqrt{\frac{n * \sum_i^n N_i^2 - (\sum_i^n N_i)^2}{n * (n-1)}}$$

Chi square: $$\chi^2 = \frac{S_N^2}{\sigma_N^2} * (n-1)$$

Hypothesis:
Degree of freedom: n-1

$$H_0 : \sigma_N = s_N ; H_1 : \sigma_N < s_N$$

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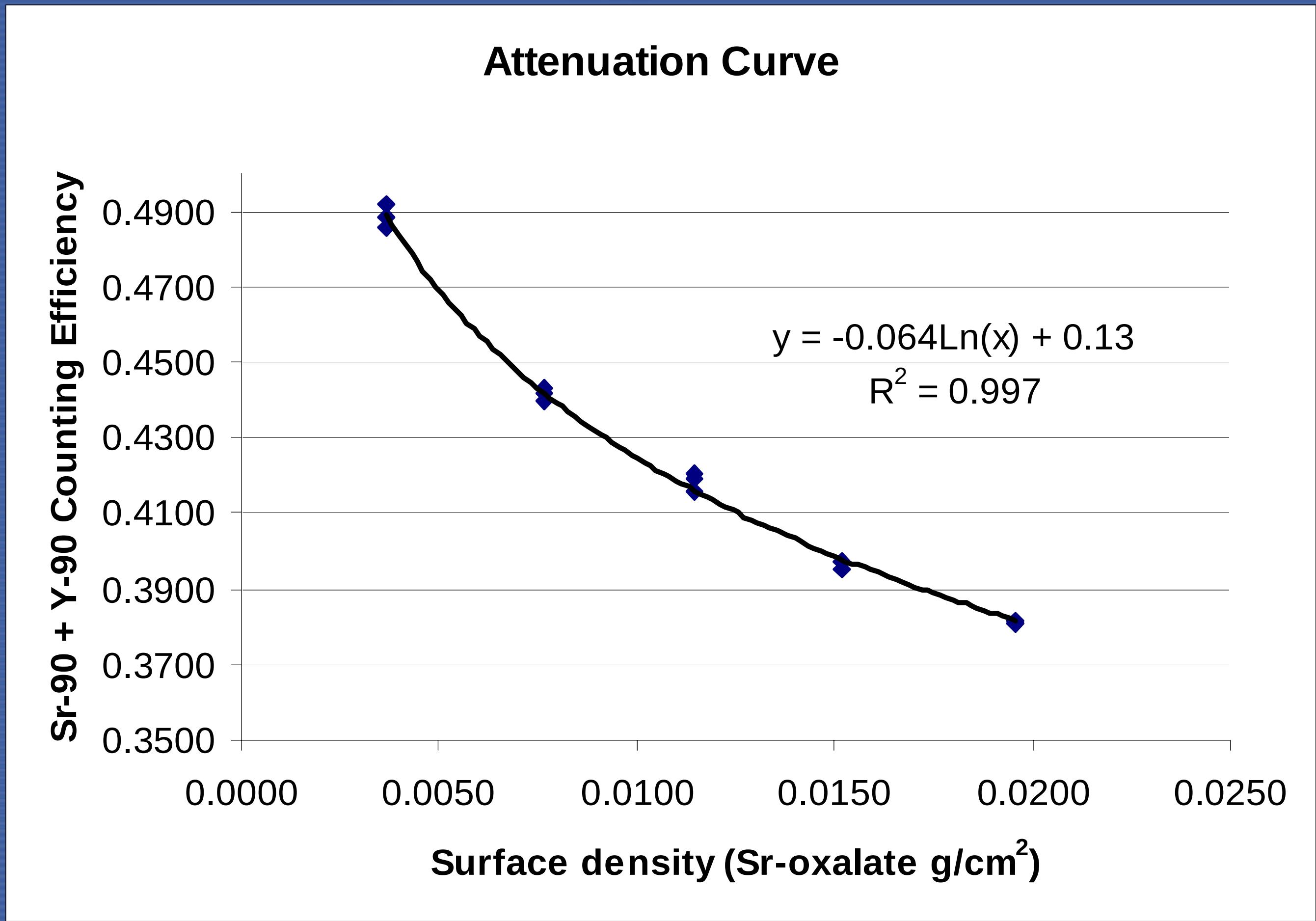
Sources

- Thick source – infinite thickness, saturation layer thickness
  α: 0.02 gcm^{-2} , <3% efficiency, effect of humidity, structure of surface
- Fixed source size
- Variable source thickness
  Mass attenuation curve, Standard addition



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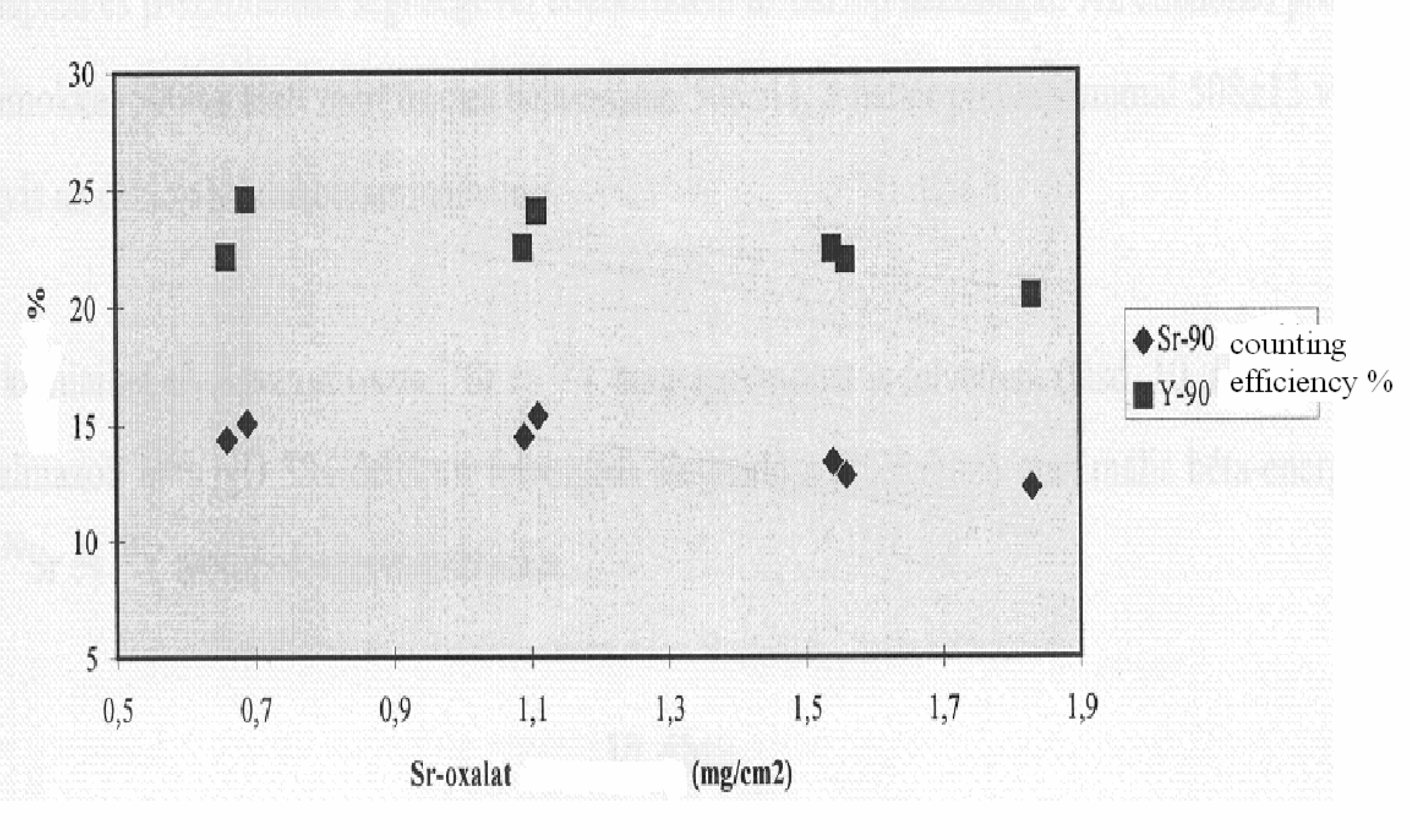
Efficiency – beta energy



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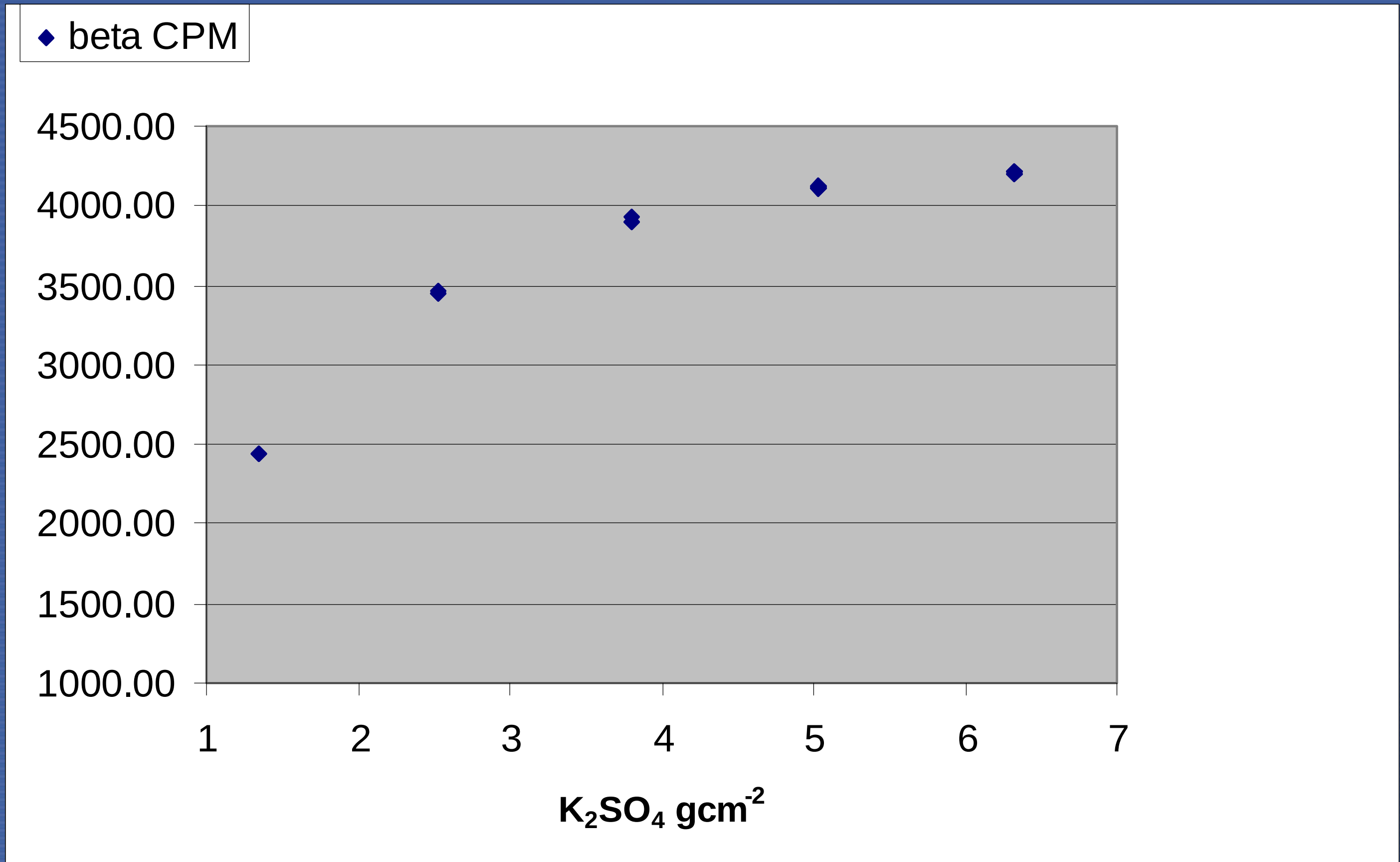
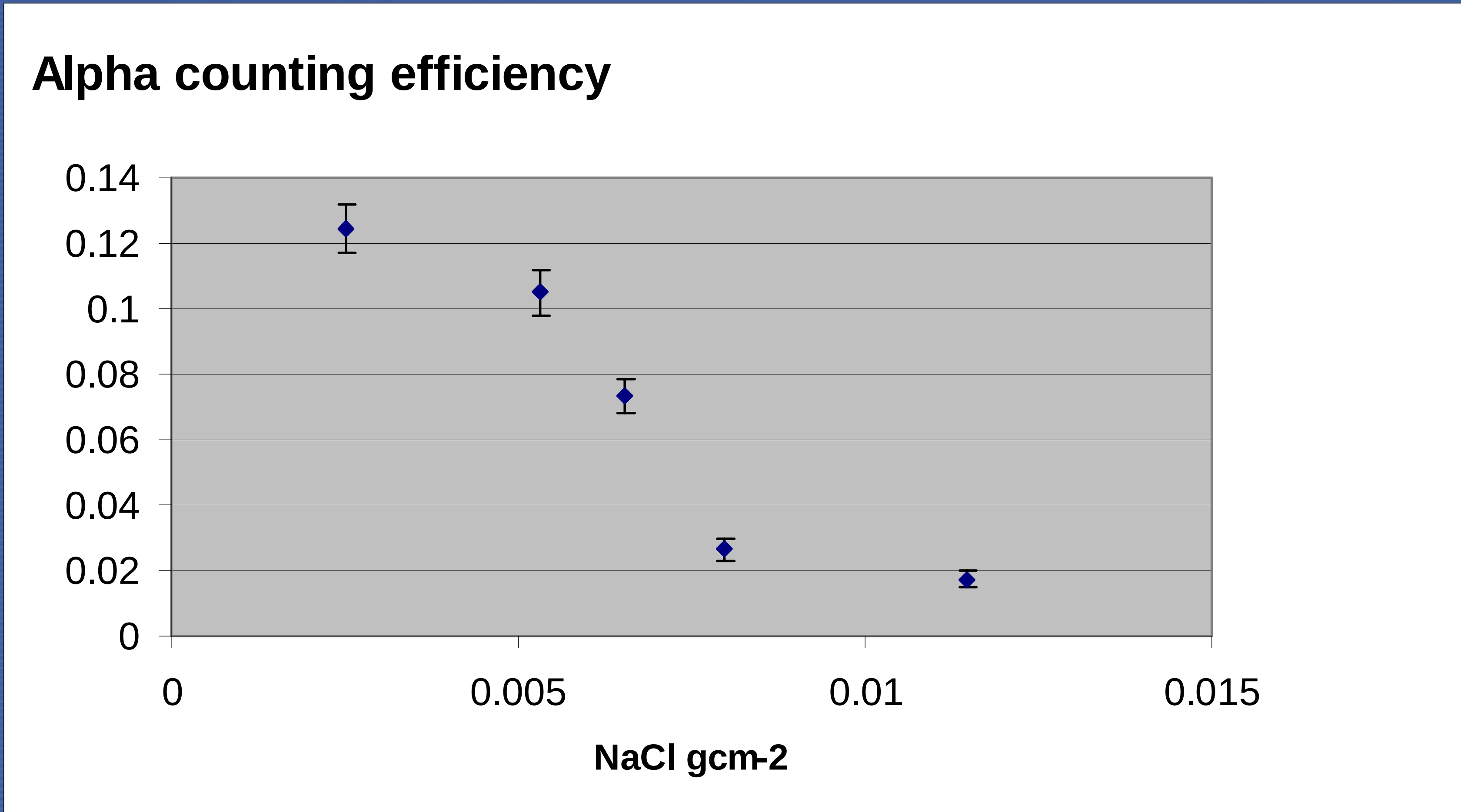
Determination of saturation layer thickness



Alpha attenuation curve



Magnified picture of a ^{210}Po / NaCl source

Calibration

$$\varepsilon = \frac{I_{st} - I_{Bg}}{A_{st} * p_{\beta}}$$

Depends on layer thickness, composition, source/sample distribution on plate

Saturation layer thickness:

$$f_{cal} = \frac{(I_{st} - I_{Bg})}{A_m}$$

A_m Bq/g

Calculation of activity

$$A_{source} = \frac{i_{sample} - i_{BG}}{\varepsilon * p_{\beta}}$$

$$A_{msource} = \frac{i_{sample} - i_{BG}}{f_{cal}} \quad \text{Bq/g}$$

Corrections

- Decay
  - Calibration source/tracer
  - Reporting result to a reference date

$$A = A_o e^{-\lambda * \Delta t}; \lambda = \frac{\ln 2}{t_{1/2}}$$

  - Decay/ingrowth during counting

$$i_0 = i_c * \frac{1 - e^{-\lambda * t_c}}{\lambda * t_c};$$

- Recovery

Crosstalk Spillover

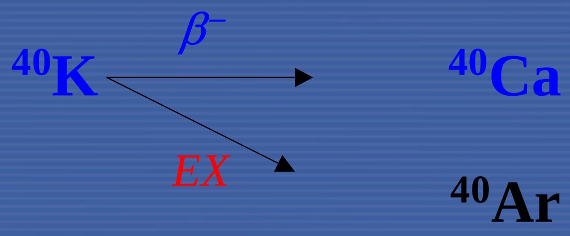
$$X_{\alpha\to\beta} = \frac{i_{\alpha in\beta}}{i_{\alpha in\beta} + i_{\alpha in\alpha}}$$

$$X_{\beta\to\alpha} = \frac{i_{\beta in\alpha}}{i_{\beta in\alpha} + i_{\beta in\beta}}$$

$$i_{\alpha_c} = \frac{i_\alpha - i_\alpha * X_{\beta\to\alpha} - i_\beta * X_{\beta\to\alpha}}{1 - X_{\beta\to\alpha} - X_{\alpha\to\beta}}$$

$$i_{\beta_c} = \frac{i_\beta - i_\beta * X_{\alpha\to\beta} - i_\alpha * X_{\alpha\to\beta}}{1 - X_{\beta\to\alpha} - X_{\alpha\to\beta}}$$

^{40}K



$t_{1/2}$: 1.277E9 Y

$E_{\beta MAX}$: 1.311 MeV (89.3%)

$E\gamma$: 1460.8 keV (10.7%)

Isotopic abundance: 0.000117

A_m: 30.9 Bq/g K

Calculation of uncertainties 1

Approach 1

The combined uncertainties were obtained from the components as using the

$$u_{A\pm B} = \sqrt{u_A^2 + u_B^2}\ ,\quad u_{A*B} = A*B\sqrt{\frac{u_A^2}{A^2} + \frac{u_B^2}{B^2}}\ \text{ and }\ u_{A/B} = \frac{A}{B}\sqrt{\frac{u_A^2}{A^2} + \frac{u_B^2}{B^2}}\ \text{ and}$$

$u_{A_0 * e^{\lambda * t}} = e^{\lambda * t}\sqrt{u_{A_0}^2 + t^2 u_\lambda^2 + \lambda^2 * u_t^2}$, $\lambda = \ln 2/t_{1/2}$, formulae, breaking the used to formulae for calculation of the activity concentration to expressions covered by one of the ones above.

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Calculation of uncertainties 2

Using the partial derivatives method

$SF=(\delta y / \delta x_i)$, $u_y=\Sigma SF_i$^2*ui^2

Analysis and evaluation of uncertainty sources:

Contribution, % : $[(\delta\varepsilon/\delta x_i)^2 . u_{xi}^2 . 100]/u_\varepsilon^2$

Calculation of uncertainties 3

- **using the spreadsheet (Kragten) method**

Quantulus CAL2-05/1										
Table 1 Spreadsheet Method for Uncertainty Calculation in the Efficiency. Calibration of Quantulus for the Determination of ^{210}Pb										
	Parameter x_i	$t_{s,CAL}$	m_{vial}	$m_{vial+carr.sol}$	c_{Pb}	m_{vial}	$m_{vial+standard}$	A_0 ^{210}Pb	$f_{gravimetry}$	m_{filter}
	Unit	min	g	g	g/g	g	g	-	-	g
	Value x_i	60	14.9364	16.03654	0.0274	16.03672	17.1326	12.45	0.70185	0.03654
	u_{xi}	0	0.00010	0.00010	0.000020565	0.00010	0.00010	0.26	0.00041	0.00010
Parameter x_i										
m_{vial}	14.93635		**14.93645**	14.93635	14.93635	14.93635	14.93635	14.93635	14.93635	14.93635
$m_{vial+carr.sol}$	16.03654		16.03654	**16.03664**	16.03654	16.03654	16.03654	16.03654	16.03654	16.03654
c_{Pb}	0.0274		0.0274	0.0274	**0.0274**	0.0274	0.0274	0.0274	0.0274	0.0274
m_{vial}	16.03672		16.03672	16.03672	16.03672	**16.03682**	16.03672	16.03672	16.03672	16.03672
$m_{vial+standard}$	17.13260		17.13260	17.13260	17.13260	17.13260	**17.13270**	17.13260	17.13260	17.13260
A_0 ^{210}Pb	12.4500		12.4500	12.4500	12.4500	12.4500	12.4500	**12.7100**	12.4500	12.4500
$f_{gravimetry}$	0.70185		0.70185	0.70185	0.70185	0.70185	0.70185	0.70185	**0.70226**	0.70185
m_{filter}	0.03654		0.03654	0.03654	0.03654	0.03654	0.03654	0.03654	0.03654	**0.03664**
$m_{filter+Pb(C2O4)}$	0.07377		0.07377	0.07377	0.07377	0.07377	0.07377	0.07377	0.07377	0.07377
I_{ACAL}	349.654		349.654	349.654	349.654	349.654	349.654	349.654	349.654	349.654
I_{ABG}	1.772		1.772	1.772	1.772	1.772	1.772	1.772	1.772	1.772
I_{BCAL}	24.957		24.957	24.957	24.957	24.957	24.957	24.957	24.957	24.957
I_{BBG}	0.703		0.703	0.703	0.703	0.703	0.703	0.703	0.703	0.703
$f_{A/B}$	1.049		1.049	1.049	1.049	1.049	1.049	1.049	1.049	1.049
t	391564800		391564800	391564800	391564800	391564800	391564800	391564800	391564800	391564800
λ ^{210}Pb	9.85E-10		9.85E-10	9.85E-10	9.85E-10	9.85E-10	9.85E-10	9.85E-10	9.85E-10	9.85E-10
ε_{Pb-210}	0.669		0.669	0.669	0.669	0.669	0.669	0.655	0.668	0.671
u_ε Kragten	0.01511									
u_ε parc. Der.	0.01537									
		$\varepsilon_{i,Pb} - \varepsilon_{Pb}$	-6.078E-05	6.078E-05	5.016E-04	6.103E-05	-6.102E-05	-1.368E-02	-3.904E-04	1.801E-03
$\Sigma(\varepsilon_{i,Pb} - \varepsilon_{Pb})^2$	2.283E-04	$(\varepsilon_{i,Pb} - \varepsilon_{Pb})^2$	3.695E-09	3.695E-09	2.516E-07	3.725E-09	3.723E-09	1.871E-04	1.524E-07	3.244E-06
$u_\varepsilon/\varepsilon$, %	2.26	$(\varepsilon_{i,Pb} - \varepsilon_{Pb})^2$	3.69E-09	3.69E-09	2.52E-07	3.72E-09	3.72E-09	1.95E-04	1.53E-07	3.23E-06
	SF by Kragten	$\delta\varepsilon/\delta x_i$	-0.6078	0.6078	24.3888	0.6103	-0.6102	-0.0526	-0.9523	18.0108
	SF by Parc. Deriv.	$\delta\varepsilon/\delta x_i$	-0.608	-0.608	24.389	0.610	-0.6102	-0.0537	-0.9528	17.96244
	Contribution, %	Kragten	1.62E-03	1.62E-03	0.11	1.63E-03	1.63E-03	**81.96**	0.07	1.42
	Contribution, %	parc. Der.	1.56E-03	1.56E-03	0.11	1.58E-03	1.58E-03	82.57	0.06	1.37
	Contribution, % =	$[(\delta\varepsilon/\delta x_i)^2 . u_{xi}^2 . 100]/u_\varepsilon^2$								