Investigation of Uncertainty Sources in the Determination of Alpha Emitting Radionuclides in the UAL

A. Specification

Alpha-spectrometry method is used to identify and determine the activity concentration in Bq/dm^3 of the alpha-emitting radionuclides in urine samples.

Measurement procedure

For alpha-spectrometric measurement the samples have to be processed through different chemical steps (mineralization, pre-concentration, separation and micro-precipitation) to obtain the required thin layer.

The received urine samples are weighted for the volume determination. After beta and gamma measurement the total quantity is used for the alpha analysis. The involved procedures are described in the working instruction from WI-23-UA-08 till WI-23-UA-14.

The determination consists of the following stages:

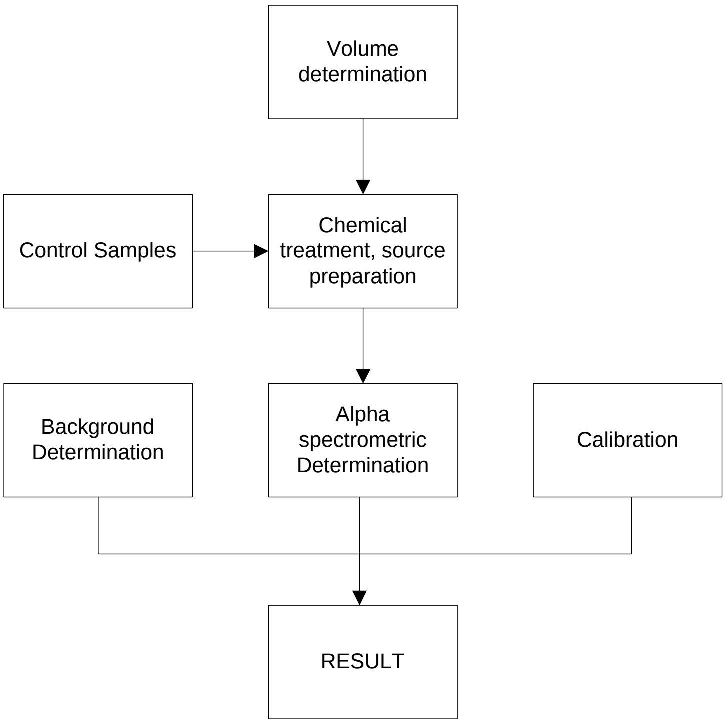


Figure 1: Alpha-spectrometric Analysis

Calculation

The measurand is the nuclide activity concentration in Bq/L, based on the peak at energy, E, is given by:

$$A = \frac{N}{\varepsilon \cdot T_s \cdot Br_E \cdot K \cdot Cr} \text{ [Bq]}$$

$$C_{A_i} = \frac{A}{V} \text{ [Bq/L]}$$

where:

A = Activity for the nuclide in Bq

N = Net Peak Area

ε = Detector efficiency

Br_E = Branching ratio for alpha energy E

Cr = Chemical recovery

C_{Ai} = the activity concentration of this nuclide

V = the volume of the urine sample

K = the decay correction $K = e^{-\frac{\ln 2}{T_{1/2}} \cdot t_e}$ for this nuclide

$T_{1/2}$ = the half-life of this nuclide

t_e = the elapsed time between the start of acquisition and the time of sample collection

B. Identifying and Analysing Uncertainty Sources

The estimation of uncertainties contains the following steps:

- Exploration of all factors influencing the measurement,
- Quantification of the uncertainties connected to each factors by measurement results or by expert judgment if applicable,
- Estimation of the overall uncertainty of the measurement.

Uncertainty Sources

- Net Peak Area
- Detector Efficiency
- Branching Ratio
- Sample Volume
- Chemical Recovery
- Reagent Blank Correction
- Decay Correction
- Measuring time

The different effects and their influences are shown as a cause and effect diagram in Figure 2.

Quantifying the Uncertainty Components

The software analyzes the acquired spectra automatically, reporting the results and its combined counting uncertainties for 95% confidence level.

As the control samples are prepared in the same way like unknown samples, during the chemical recovery correction the internal absorption (attenuation) contribution cancels itself out.

Net Peak Area

Determined by the spectrum evaluation software

Background correction

$$N = G - B$$

where:

G = Gross sum of the counts within the peak region (ROI),

B = background area counts for the peak.

$$B = \left(\frac{n}{2n_1} \right) (B_1 + B_2)$$

The uncertainty in background area counts.

$$u(B) = \frac{n}{2} \sqrt{\left(\frac{B_1}{n_1^2} + \frac{B_2}{n_2^2} \right)}$$

where:

n = number of channels in the ROI,
B_1 = Area of left background region, width n_1 channels,
B_2 = Area of right background region, width n_2 channels.
If the background regions are of equal width ($n_1 = n_2$), the uncertainty in background area counts reduces to:

$$u(B)^2 = \left(\frac{n}{2n_1} \right)^2 (B_1 + B_2)$$

In the spectrometry practice the statistical uncertainty of the net peak area, in connection with the Poisson distribution, is commonly expressed as:

$$u(N) = \sqrt{G + u(B)^2} \qquad (1.a)$$

Subtraction of Peak Environmental Background

$$N = (G - B) - I$$

The environmental background interference peak is calculated as

$$I = \frac{t}{t_B} I_B$$

where:

I = number of count due to the environmental background

t_B = the live time of background spectrum

I_B = the net peak area of the peak in the background

The variance of the background interference can be calculated as:

$$u(I)^2 = \left(\frac{t}{t_B}\right)^2 u(I_B)^2$$

$u(I_B)$ = the uncertainty of the net peak area for the interference peak, it can be calculated by equation (1.a).

In case of the presence of an "interference peak", i.e. a residual area in the ROI due to environmental background radiation or detector contamination, etc. determined by a separate background measurement, the following equation shall be used instead of (1.a):

$$\boxed{u(N) = \sqrt{\left(G + u(B)^2 + u(I)^2\right)}} \qquad (1.b)$$

In practice the presence of interference peaks in the spectrum can be avoided by elimination of contamination of measuring chambers and detectors or cross-contamination of sample.

Non-statistical errors connected with the calculation of net peak area and uncertainty of net peak area

Determined by the spectrum evaluation software

Expert comments:

The calculation of net area and net area uncertainty is also associated with no pure statistical errors, as:

- Set of ROI, i.e. peak width,
- Set of width of background regions,
- Peak fitting.

Detector Efficiency

Determined by the spectrum evaluation software

The efficiency calibration consists of the following steps: collection of spectrum of the calibration standard, evaluation of the spectrum, calculation of alpha peak efficiencies and average.

$$\varepsilon = \frac{N_a}{A_a \cdot t \cdot \gamma_a \cdot K_a}$$

Where:

ε = Detector efficiency

N_a = Net peak area

t = Live time in seconds

A_a = Activity in Bq

γ_a = Branching ratio (generally its value is 1)

K_a = the decay correction factor, $K = e^{-\frac{\ln 2}{T_{1/2}} \cdot t_e}$

t_e = the elapsed time between the start of acquisition and the stated reference time in the certificate

$T_{1/2}$ = the half-life

Uncertainty Sources in the Efficiency Calibration:

- Activity in the reference standard,
- Preparation of calibration standard,
- Peak areas in calibration spectrum,
- Decay correction,
- Fitting of energy-efficiency curve,
- Difference in calibration and measurement geometry,
- Shift of the peak energy.
- Branching ratio

Activity and preparation of the calibration Source

The combined uncertainty of the activity of radionuclides in a reference standard and preparation of the calibration source shall be given in the certificate attached with it. The value of relative uncertainties does not exceed 1-2 percent, generally.

If the reported uncertainty is given with confidence level, it has to be divided by the appropriate percentage point on the normal distribution for the level of confidence given to calculate the standard deviation. Without confidence level, it is normally appropriate to assume a rectangular distribution. The uncertainty should be divided by $3^{1/2}$ to calculate the standard deviation.

Net Peak Area

Determined by the spectrum evaluation software

Expert comments:

The statistical uncertainty of net peak areas of calibration spectrum shall be reduced by use of high activity standards and long measuring time. However, the use of very high activities should also be avoided, because of the possible uncertainty from pile-up in the measuring equipment and contamination. In practice, a dead time up to 3-5 percent is quite acceptable.

The variation of background plays only role in case of interference peaks, when the correction of the peak net area is based on a separate background measurement. Therefore, the frequency of background measurement shall be high enough to exclude the deterministic or systematic uncertainty and the measuring time long enough to reduce the relative statistical uncertainty to less than 5-10 percent.

For the calculation of it the equation (1.a) or (1.b) can be used.

Decay correction

Determined by the spectrum evaluation software

The uncertainty of the decay correction factor is calculated as

$$u(K) = \frac{K \cdot \ln(2) \cdot t_e}{(T_{1/2})^2} \cdot u(T_{1/2})$$

In all cases, if the $u(T_{1/2})$ is not available, it is set to zero.

Fitting of energy-efficiency curve

Determined by the spectrum evaluation software

In Alpha Spectroscopy work, all peaks have the same counting efficiency. The efficiency value is based upon the average of the individual efficiencies.

Difference in calibration and measurement geometry

Determined by expert judgment.

The counting geometry for the calibration sources was prepared by electro deposition. The diameter of the active area is 24.2 mm. The sources in our laboratory are prepared by micro co-precipitation with an active area of 20 mm. The calibration source and the samples are measured at the same position. The counting efficiency may be approximated by the following formula (Hendee 1984):

$$\varepsilon = 0.5 \cdot \left(1 - \frac{h}{\sqrt{h^2 + r^2}}\right) - \frac{3}{16}\left(\frac{ar}{h^2}\right)^2 \left(\frac{h}{\sqrt{h^2 + r^2}}\right)^5$$

Where:

ε = Detector efficiency

a = radius of the disc source

h = distance from the detector

r = detector active radius

	h	a	r	ε	Bias
Calibration	5.0 mm	24.2 mm	13.8 mm	31.82%	
Sample	5.0 mm	20.0 mm	13.8 mm	32.02%	1%

Table 1 – Difference in calibration and counting geometry

The uncertainty of this component is assumed to be 1%

Shift of the peak energy

Determined by expert judgment.

The shift of the peak energy has only minor influence on the efficiency, usually. The low leakage current of the detectors helps minimize peak shift with temperature variation. The uncertainty of the peak shift is negligible.

Combined standard uncertainty for the efficiency calibration

The standard uncertainty u(ε) of the detector efficiency can be calculated as:

$$u(\varepsilon) = \varepsilon \cdot \sqrt{\left(\frac{u(N)}{N}\right)^2 + \left(\frac{u(A)}{A}\right)^2 + \left(\frac{u(\gamma)}{\gamma}\right)^2 + \left(\frac{u(K)}{K}\right)^2}$$

Branching ratio

Determined by the spectrum evaluation software

Expert comments:

There are many nuclide libraries, data sets containing alpha emission probabilities (yields) for radionuclides. The spectrum evaluation software contains also editable nuclide library, usually. There could be no remarkable differences of yields given in different data sources, at least for string peaks of commonly used radionuclides. However, it is worth to mention, that the alpha emission probabilities are given for all energies, which are very closed to each other and cannot bet separated in the spectrum. Generally a 100% branching ratio is assumed for the main energy line. Finally, it can be concluded, that following a careful check of nuclide library of the spectrum evaluation software, the uncertainty associated with the alpha emission probability is usually negligible.

Measuring time

Determined by expert judgment.

Although, the dead time of the ADC is compensated for the measuring equipment (live-time correction) the very high-count rates, resulting dead time higher than about 5-10 percent without pile up rejection shall be avoided. In normal spectrometry practice the count rates are very low usually, therefore the uncertainty of the measuring time is negligible.

Environmental effects

Determined by expert judgment.

The most important environmental factor, which might influence the measurement result, is temperature. However, the change of temperature can cause mainly the change of amplification and leakage current, which results in peak shift. As it was stated above the peak shift has only minor effect on efficiency. Otherwise, the temperature stability of the spectrometers is high enough to ensure that there is no observable peak shift for the temperature range of normal laboratory conditions.

Volume of the Sample

The volume of the sample in the bottle is subject to three major sources of uncertainty:

- The mass of the sample
- m-V calibration of the Balance

Model equation: $V_{sample} = \frac{V_{water}}{m_{water}} \cdot m_{sample}$ [L]

<u>Sample Mass (m_{gross})</u>

The gross mass of the sample is obtained by weighing the urine together with the bottle.

The manufacturer identifies three uncertainty sources for the tare weighing:

- The repeatability
- The readability (digital resolution) of the balance scale
- The contribution due to the uncertainty in the calibration function of the scale (linearity and sensitivity).

Model equation: $m_{sample} = m_{rep} + m_{lin} + m_{read}$ [g]

The uncertainty associated with the mass of the sample is estimated using data from the manufacturer's recommendations.

Repeatability: the standard deviation is quoted as **±0.01 g.** Normal distribution.

Readability : the digital resolution of the balance is **0.01 g.** A rectangular distribution is assumed:

$$\frac{0.01g}{\sqrt{3}} = 0.006g$$

Linearity : the difference from the actual weigh on the scale pan and the reading of the scale is within the limits of **±0.02 g.** A rectangular distribution is assumed.

$$\frac{0.02g}{\sqrt{3}} = 0.012g$$

The three components are combined to give the standard uncertainty u(m_{gross}).

$$u(m_{sample}) = \sqrt{0.01^2 + 0.006^2 + 0.012^2} = 0.017g$$

m-V Calibration of the Balance

To obtain the volume of the sample the balance has to be calibrated.

Water Volume

The volume of the water contained in the volumetric flask, used for the volume measurement, is subject to three major sources of uncertainty:

- The uncertainty in the certified internal volume of the flask.
- Variation in filling the flask to the mark
- The actual temperature differs from the temperature at which the volume of the flask was calibrated

Calibration: The manufacturer quotes a volume for the Grade A volumetric flask of 1000±0.4mL measured a temperature of 20 ^{o}C. A triangular distribution is assumed.

$$\frac{0.4mL}{\sqrt{6}} = 0.163mL$$

Repeatability: The uncertainty due to the variations of filling was estimated from a series of ten fill and weight experiment and gave a standard uncertainty of 0.167mL.

Temperature: According to the manufacturer the volumetric flask has been calibrated at temperature of 20 ^{o}C, whereas the laboratory temperature varies between ±5 ^{o}C. The uncertainty from this effect can be calculated from the estimation of temperature range and the coefficient of volume expansion for water. During the balance calibration the room temperature was 25 ^{o}C.

$$1000mL \cdot \pm 5^{\circ}C \cdot 2.1E-4^{\circ}C^{-1} = 1.05mL$$

The standard uncertainty is calculated using the assumption of a rectangular distribution for the temperature variation:

$$\frac{1.05mL}{\sqrt{3}} = 0.606mL$$

The three contribution are combined to the standard uncertainty u(V) of the water volume.

$$u(V_{water}) = \sqrt{0.163^2 + 0.606^2 + 0.167^2} = 0.649mL$$

Water Mass

The gross mass is obtained by weighing the water together with the bottle.

As the same balance is used the standard uncertainty of the water mass is the same like the standard uncertainty of the sample mass.

$$u(m_{water}) = \sqrt{0.01^2 + 0.006^2 + 0.012^2} = 0.017g$$

The maximum bias (Bρ) due to the difference between urine and water density is 1%.

The bias of the bottle (B_{bottle}) is assumed to be 0.5%

The combine uncertainty for the slope is:

1.

$$u(slope) = slope \cdot \sqrt{\left(\frac{u(V_{water})}{V_{water}}\right)^2 + \left(\frac{u(m_{water})}{m_{water}}\right)^2 + B_\rho{}^2 + B_{bottle}{}^2} =$$

$$= 8.96E-04 \cdot \sqrt{\left(\frac{6.49E-04}{1}\right)^2 + \left(\frac{0.017}{1115.95}\right)^2 + 0.01^2 + 0.005^2} = 1.417E-05 L/g$$

Using the internal counting function of the balance, the program allows automatic conversion of weights into piece counts based on a reference sample weight (1L of Water). The pieces readout is converted to volume in L divided it by the factor of 100. It makes possible the quickly determination of the sample volume in the UAL, avoiding cross contamination.

Calibration data	
x	**y**
0	0.00
1115.95 g	100 pcs

Parameters		Description
m	0.0896	SLOPE(y,x)
b	0.000	INTERCEPT(y,x)
f	0.01	Conversion factor to L

Table 2- Regression Calibration of the Balance

Derived data	
x	y
0.0	0.00
1000.0	0.90
1020.0	0.91
1040.0	0.93
1060.0	0.95
1080.0	0.97
1100.0	0.99
1120.0	1.00
1140.0	1.02
1160.0	1.04
1180.0	1.06
1200.0	1.08

Derived values			
Slope, m	m	8.96E-04	SLOPE(y,x)
Intercept, b	b	8.88E-16	INTERCEPT(y,x)
Observations, n	n	12.000	COUNT(x)
Std error in estimate, S_{yx}	**SYX**	**1.09E-08**	STEYX(y,x)
Average x	XAVG	1008.333	AVERAGE(x)
SSX	SSX	1.15E+06	DEVSQ(x)
t(a,df)	t	2.228	TINV(0.05,n-2)

Table 3 - Regression Line Confidence Interval

2. Combining with the regression standard deviation

$$u(slope,c) = \sqrt{(1.417E-05)^2 + (1.09E-08)^2} = 1.417E-05 L/g$$

The combine uncertainty for the sample volume is:

$$u(V_{sample}) = V_{sample} \cdot \sqrt{\left(\frac{u(m_{sample})}{m_{sample}}\right)^2 + \left(\frac{u(slope,c)}{slope}\right)^2} \; [L]$$

The relative uncertainty of sample weighing is less than 0.1 %. Therefore it can be neglected. The result for the relative standard uncertainty for the sample volume is assumed to be 1.581%.

Chemical Recovery

$$Cr = \frac{A_{ctrl}}{A_e}$$

Where:

A_{ctrl} = Activity of the tracer in the control sample

A_e =- Activity expected for the tracer

Activity of the Tracer in the Control Sample

The uncertainties

- Net Peak Area
- Detector Efficiency
- Branching Ratio
- Decay Correction
- Measuring time

These sources have been above already described.

The evaluation software reports the combined standard uncertainty for the activity of the tracer.

Activity Expected for the Tracer

Uncertainties:

- Certified activity uncertainty
- Dilution of the standard solution
- Dilution for the spiking solution
- Spiking control samples
- Evaporation factor

Certified activity uncertainty

The combined uncertainty of the activity of radionuclides in a reference standard solution shall be given in the certificate attached with it. The value of relative uncertainties does not exceed 1-2 percent, generally.

If the reported uncertainty is given with confidence level, it has to be divided by the appropriate percentage point on the normal distribution for the level of confidence given to calculate the standard deviation. Without confidence level, it is normally appropriate to assume a rectangular distribution. The uncertainty should be divided by $3^{1/2}$ to calculate the standard deviation.

Dilution of the standard solution

The dilution of the standard solution is controlled by weighing in an analytical balance.

The activity concentration of the of the standard solution is calculated as:

$$C_{A1} = \frac{m_0 \cdot C_{A0}}{M_1} \text{ Bq/g}$$

Where:

C_{A1} = Activity concentration of the diluted solution

C_{A0} = Activity concentration of the standard solution (certificate)

m_0 = mass of the standard solution

M_1 = mass of the diluted solution

The manufacturer identifies three uncertainty sources for the tare weighing:

- The repeatability
- The readability (digital resolution) of the balance scale
- The contribution due to the uncertainty in the calibration function of the scale (linearity and sensitivity).

Model equation: $m = m_{rep} + m_{lin} + m_{read}$ [g]

The uncertainty associated with the mass of the solutions is estimated using data from the manufacturer's recommendations for the analytical balance model BP221S.

Repeatability: the standard deviation is quoted as ±**0.0001 g.** Normal distribution.

Readability : the digital resolution of the balance is **0.0001 g.** A rectangular distribution is assumed:

$$\frac{0.0001g}{\sqrt{3}} = 5.77E-05g$$

Linearity : the difference from the actual weigh on the scale pan and the reading of the scale is within the limits of ±**0.0002 g.** A rectangular distribution is assumed.

$$\frac{0.0002g}{\sqrt{3}} = 1.15E-04g$$

These components have to be taken into account twice because of the weight by difference.

The three components are combined to give the standard uncertainty u(m).

$$u(m) = \sqrt{0.0001^2 + 2\cdot(5.77E-05^2) + 2\cdot(1.15E-04^2)} = 2.08E-04g$$

The combined standard uncertainty $u(C_{A1})$ of the activity concentration for the dilution is :

$$u(C_{A1}) = C_{A1} \cdot \sqrt{\left(\frac{u(m)}{m_0}\right)^2 + \left(\frac{u(C_{A0})}{C_{A0}}\right)^2 + \left(\frac{u(m)}{M_1}\right)^2}$$

As the relative standard uncertainty of the solution mass is less or equal to 2.08E-04 these components can be neglected. Therefore the relative standard uncertainty of the activity in the dilution is the same like the certified relative standard uncertainty.

Dilution for the spiking solution

As the spiking solution has low activity concentration, where it is necessary a second dilution is prepared. The dilutions are also controlled by weighing in an analytical balance.

The activity concentration of the of the spiking solution is calculated as:

$$C_{As} = \frac{m_n \cdot C_{A1}}{M_s} \text{ Bq/g}$$

Where:

C_{As} = Activity concentration of the spiking solution

C_{A1} = Activity concentration of the diluted standard solution

m_n = mass taken for the dilution from the diluted standard solution

M_s = mass of the spiking solution

Since the same analytical balance is used, the uncertainty components are the same as described above.

The combined standard uncertainty $u(C_{As})$ of the activity concentration for the spiking solution is :

$$u(C_{As}) = C_{As} \cdot \sqrt{\left(\frac{u(m)}{m_n}\right)^2 + \left(\frac{u(C_{A1})}{C_{A1}}\right)^2 + \left(\frac{u(m)}{M_s}\right)^2}$$

As the relative standard uncertainty of the solution mass is less or equal to 2.08E-04 these components can be neglected. Therefore the relative standard uncertainty of the activity in the dilution for spiking is the same like the relative standard uncertainty in the first dilution, which was recorded previously to be equal to the certified relative standard uncertainty.

$$\frac{u(C_{As})}{C_{As}} = \frac{u(C_{A1})}{C_{A1}} = \frac{u(C_{A0})}{C_{A0}}$$

Spiking control samples

The working instruction WI-23-UA-11 describes the necessary steps for the spiking of the control samples.

The expected activity in the control samples is calculated as:

$$A_e = m_s \cdot C_{As} \cdot F$$

Where:

C_{As} = Activity concentration of the spiking solution

m_s = Mass taken from the spiking solution (generally 1 ml)

F = Evaporation factor

Uncertainty in the Tracer Addition

As the quantity of the tracer is determined by only weighing the difference occurred in the spiking solution and not measuring the real quantity introduced to the control samples an uncertainty is expected. For the quantification of this uncertainty, a study on the bias was performed.
According to the results the bias observed was less than 0.1%, so the progeny uncertainty can be neglected.

Evaporation Factor

An independent evaporation factor is calculated as:

$$F_t = \frac{M_s}{M_{s,t}}$$

Where:
M_s = Mass of the spiking solution
M_{ost} = Mass of the spiking solution at “t” elapsed time since the previous spiking process
F_t = Evaporation factor at “t” time

The standard uncertainty for each independent evaporation factor is:

$$u(F_t) = F_t \cdot \sqrt{\left(\frac{u(m)}{M_s}\right)^2 + \left(\frac{u(m)}{M_{s,t}}\right)^2}$$

The total evaporation is calculated by multiplying all the evaporation factors with each other.

$$F = \prod_{i=0}^{n} F_{t,i}$$

The standard uncertainty for the total evaporation factor is calculated as:

$$u(F) = F \cdot \sqrt{\sum_{i=1}^{n} \left(\frac{u(F_{t,i})}{F_{t,i}}\right)^2}$$

As the main component for the uncertainty in the evaporation factor is the uncertainty of the solution mass and it was determined to be less or equal to 2.08E-04, the relative uncertainty for the evaporation factor is assumed to be less than 0.1%. Therefore this component can be neglected.

The combined uncertainty for the expected activity is

$$u(A_e) = A_e \cdot \sqrt{\left(\frac{u(m)}{m_s}\right)^2 + \left(\frac{u(C_{As})}{C_{As}}\right)^2 + \left(\frac{u(F)}{F}\right)^2}$$

As previously discussed the relative standard uncertainty of the solution mass and the evaporation factor can be neglected. Therefore the relative standard uncertainty of the spiked activity is the same like the certified relative standard uncertainty.

$$\frac{u(A_e)}{A_e} = \frac{u(C_{As})}{C_{As}} = \frac{u(C_{A1})}{C_{A1}} = \frac{u(C_{A0})}{C_{A0}}$$

Combined Uncertainty for the Chemical Recovery

$$u(C_r) = C_r \cdot \sqrt{\left(\frac{u(A_{ctrl})}{A_{ctrl}}\right)^2 + \left(\frac{u(A_e)}{A_e}\right)^2}$$

Calculating the Combined Standard Uncertainty of the Activity-concentration

$$\boxed{u(C_A) = C_A \cdot \sqrt{\left(\frac{u(N)}{N}\right)^2 + \left(\frac{u(\varepsilon)}{\varepsilon}\right)^2 + \left(\frac{u(C_r)}{C_r}\right)^2 + \left(\frac{u(V)}{V}\right)^2}}$$ Bq/L]

The expanded uncertainty is obtained by multiplying the combined standard uncertainty with a coverage factor of 2.

For the determination of the combined standard uncertainty the GUM Workbench will be used.

Spectrum/Nuclide	Evaluation Software Report	Combining Relative Standard Uncertainty	GUM Workbench
05041108\6.cnf/U-234	2.97	4.04	3.9
	Attached	Table 5	Attached

Table 4 – Quantified Uncertainty by different methods

	A	B	C	D	E	F	G
1			Actrl	Ae	Cr	Asample	Vsample [L]
2		Value	2.66E-02	3.41E-02	7.80E-01	9.34E-02	0.50
3		Uncertainty	7.55E-04	3.80E-05	2.22E-02	2.77E-03	7.91E-03
4							
5	Actrl	2.66E-02	2.74E-02	2.66E-02	2.66E-02	2.66E-02	2.66E-02
6	Ae	0.03	0.03	3.42E-02	0.03	0.03	0.03
7	Cr	0.78	0.80	0.78	8.02E-01	0.78	0.78
8	Asample	9.34E-02			9.34E-02	9.62E-02	9.34E-02
9	Vsample [L]	0.50			0.50	0.50	0.51
10							
11							
12	**CA**	**2.40E-01**			2.33E-01	2.47E-01	2.36E-01
13	u(y,xi) [Bq/L]				-6.62E-03	7.11E-03	-3.73E-03
14	u(y)2, u(y,xi)2	1.08E-04			4.38E-05	5.06E-05	1.39E-05
15							
16	**u(CA) [Bq/L]**	**1.04E-02**	4.35%				

Table 5 - Spreadsheet calculation of uncertainty

The values of the parameters are entered in the second row into C2, D2, F2 and G2. The E2 value is calculated from C2 and D2. Their standard uncertainties are in the row bellow (C3-G3). The spreadsheet copies the values from C2-F2 into the second column from B5 to B9. The result (C_A) using B7, B8 and B9 is given in B12. The C5 shows the value of A_{ctrl} from C2 plus its uncertainty given in C3. The result of the calculation using values C5 and C6 is given in C7. The columns D-G follow a similar procedure. The results using E7, E8 and E9 is given in E12. The columns F-G follow a similar procedure. The values shown in row 13 (E13-G13) are the differences of the row (E12-G12) minus the value given in B12. In row 14 (E14-G14) the values of row 13 (E13-G13) are squared and summed to give value shown in B14. B16 gives the combined standard uncertainty, which is the square root of B14. The value shown in C16 is the relative standard uncertainty.

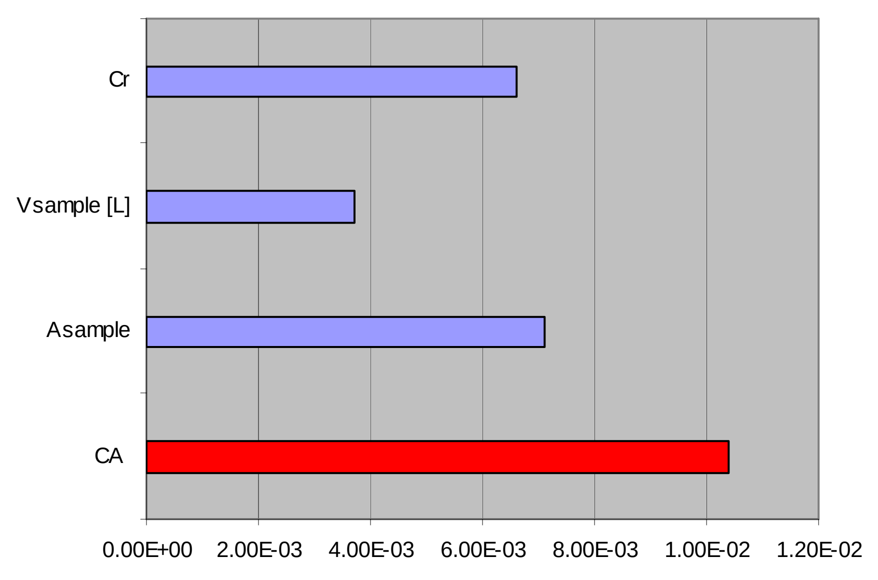
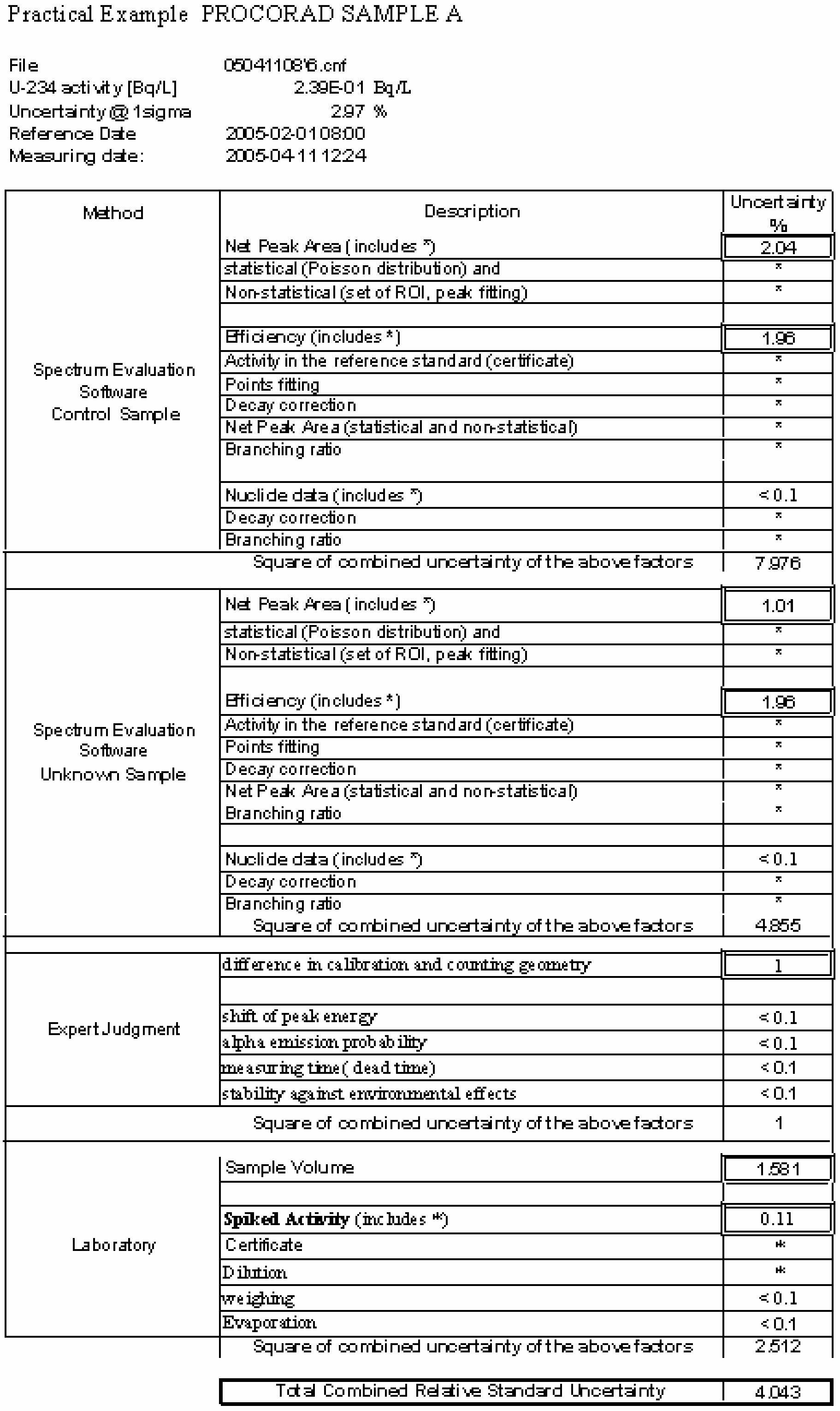


Figure 2 – Uncertainty contributions in Measurement of Activity Concentration



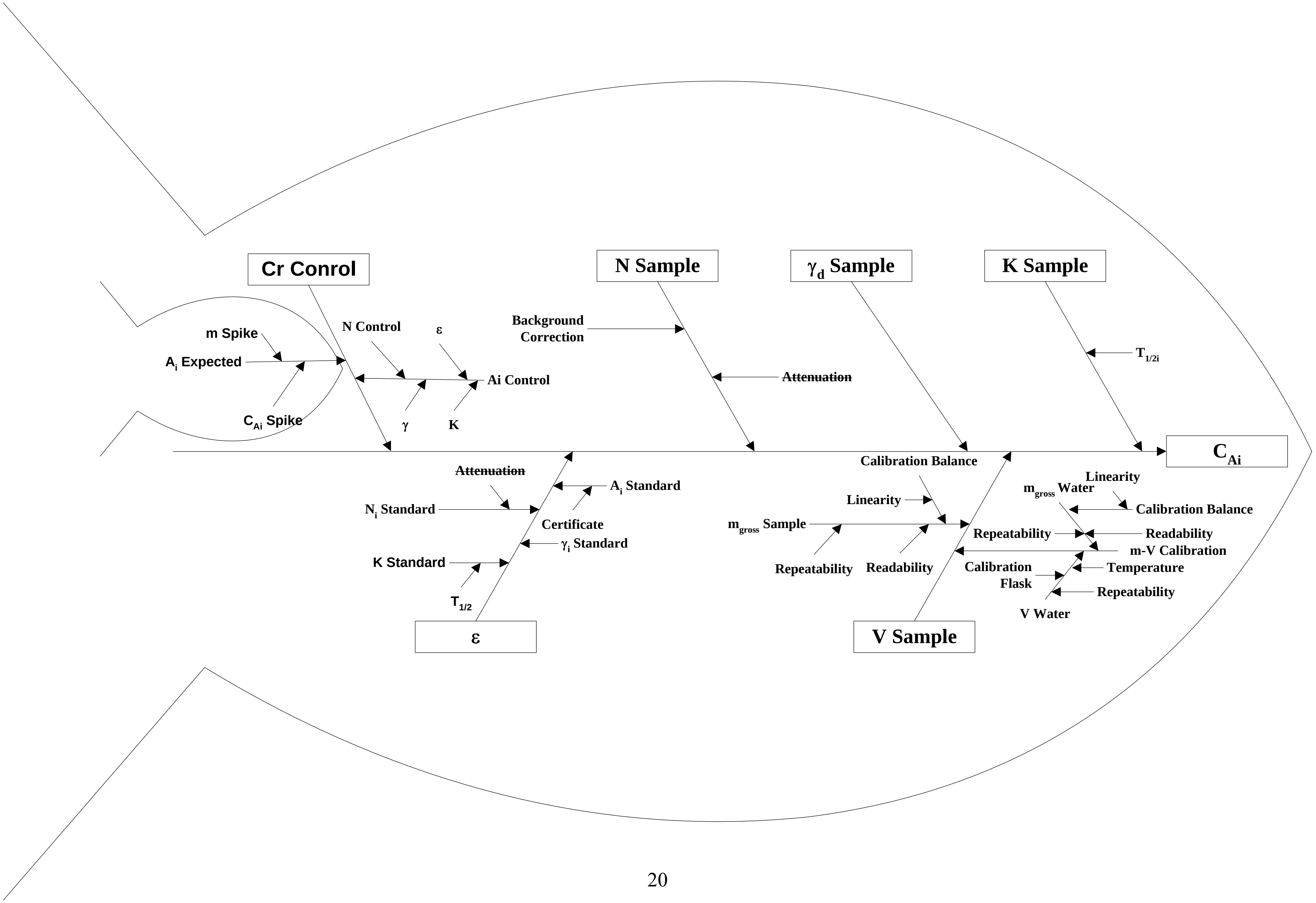
Practical Example PROCORAD SAMPLE A

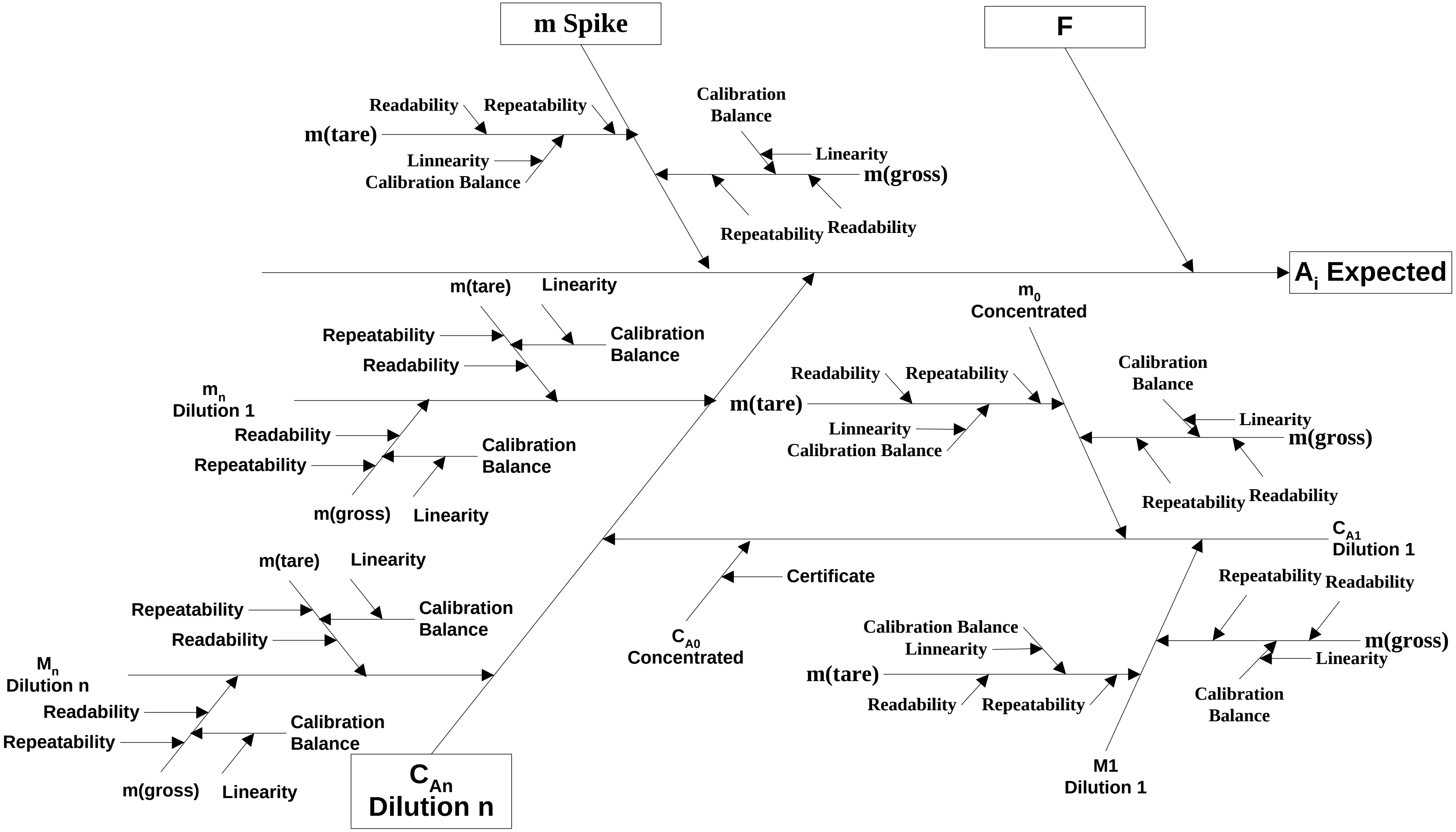
File	05041108'6.cnf
U-234 activity [Bq/L]	2.39E-01 Bq/L
Uncertainty @ 1sigma	2.97 %
Reference Date	2005-02-01 08:00
Measuring date:	2005-04-11 12:24

Method	Description	Uncertainty %
Spectrum Evaluation Software Control Sample	Net Peak Area (includes *)	2.04
	statistical (Poisson distribution) and	*
	Non-statistical (set of ROI, peak fitting)	*
	Efficiency (includes *)	1.96
	Activity in the reference standard (certificate)	*
	Points fitting	*
	Decay correction	*
	Net Peak Area (statistical and non-statistical)	*
	Branching ratio	*
	Nuclide data (includes *)	< 0.1
	Decay correction	*
	Branching ratio	*
	Square of combined uncertainty of the above factors	7.976
Spectrum Evaluation Software Unknown Sample	Net Peak Area (includes *)	1.01
	statistical (Poisson distribution) and	*
	Non-statistical (set of ROI, peak fitting)	*
	Efficiency (includes *)	1.96
	Activity in the reference standard (certificate)	*
	Points fitting	*
	Decay correction	*
	Net Peak Area (statistical and non-statistical) Branching ratio	* *
	Nuclide data (includes *)	< 0.1
	Decay correction	*
	Branching ratio	*
	Square of combined uncertainty of the above factors	4.855
Expert Judgment	difference in calibration and counting geometry	1
	shift of peak energy	< 0.1
	alpha emission probability	< 0.1
	measuring time (dead time)	< 0.1
	stability against environmental effects	< 0.1
	Square of combined uncertainty of the above factors	1
Laboratory	Sample Volume	1.581
	Spiked Activity (includes *)	0.11
	Certificate	*
	Dilution	*
	weighing	< 0.1
	Evaporation	< 0.1
	Square of combined uncertainty of the above factors	2.512
	Total Combined Relative Standard Uncertainty	4.043

Table 5 – Combined Relative Standard Uncertainty for the activity concentration

$$\frac{u(A)}{A} = \sqrt{7.976 + 4.855 + 1 + 2.512} = 4.043\% \text{ at 1 sigma}$$


Cr Conrol
N Sample
γ_d Sample
K Sample
m Spike
A_i Expected
C_{Ai} Spike
N Control
ε
Ai Control
γ
K
Background Correction
~~Attenuation~~
$T_{1/2i}$
C_{Ai}
~~Attenuation~~
N_i Standard
A_i Standard
Certificate
γ_i Standard
K Standard
$T_{1/2}$
ε
Calibration Balance
Linearity
m_{gross} Sample
Repeatability
Readability
Linearity
m_{gross} Water
Calibration Balance
Repeatability
Readability
m-V Calibration
Calibration Flask
Temperature
Repeatability
V Water
V Sample


m Spike
F
Readability
Repeatability
m(tare)
Linnearity
Calibration Balance
Calibration Balance
Linearity
m(gross)
Repeatability
Readability
A_i Expected
m(tare)
Linearity
Repeatability
Calibration Balance
Readability
m_n Dilution 1
Readability
Repeatability
Calibration Balance
m(gross)
Linearity
m_0 Concentrated
Readability
Repeatability
m(tare)
Linnearity
Calibration Balance
Calibration Balance
Linearity
m(gross)
Repeatability
Readability
C_{A1} Dilution 1
m(tare)
Linearity
Repeatability
Calibration Balance
Readability
M_n Dilution n
Readability
Repeatability
Calibration Balance
m(gross)
Linearity
Certificate
C_{A0} Concentrated
Repeatability
Readability
Calibration Balance
Linnearity
m(gross)
m(tare)
Linearity
Readability
Repeatability
Calibration Balance
M1 Dilution 1
C_{An} Dilution n