CCQM-K5 Key Comparison – Determination of pp'-DDE in Fish Oil

Final Report

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March 2001

Introduction

At the meeting of the CCQM held at Sèvres on 10 - 12 February 1999 it was decided to carry out a key comparison based on the determination of pp'-DDE in a fish oil matrix. This followed successful pilot studies on the determination of (pp'-dichlorodiphenyl) dichloroethylene (pp'-DDE) in solvent, (CCQM-P2) [1] and of pp'-DDE in corn oil (CCQM-P4). This compound is one of the major metabolites of the pesticide (pp'-dichlorodiphenyl) trichloroethane (pp'-DDT) and even though the use of pp'-DDT was discontinued many years ago it is extremely persistent and hence of environmental importance. There is much interest in this metabolite, particularly with reference to human fertility studies (it is reported to be ten times more potent in its effect on male fertility than pp'-DDT). Many laboratories worldwide carry out analysis for this compound. A fish oil matrix was selected for the key comparison since measurable levels of pp'-DDE are commonly found in such oils. For the pilot study CCQM-P4 participants used isotope dilution gas- chromatography-mass spectrometry (ID/GC/MS) consequently participants were asked to use ID/GC/MS for this key comparison.

The participants were:

Australia, National Analytical Reference Laboratory (NARL)*
Canada, National Research Council of Canada (NRC)
China, National Research Centre for Certified Reference Materials (NRCCRM)
Germany, Bundesanstalt für Materialforschung und -prüfung (BAM)
Germany, Physikalisch-Technische Bundesanstalt (PTB)
Japan, National Institute of Material and Chemical Research (NIMC)
Korea, Korea Research Institute of Standards and Science (KRISS)
Russia, D. I. Mendeleyev Institute for Metrology of Gosstandart of Russia (VNIIM)
United Kingdom, Laboratory of the Government Chemist (LGC)
USA, National Institute of Standards and Technology (NIST)

* participant did not take part in either of the pilot studies (CCQM-P2, CCQM-P4), consequently this participants results will not be used in the determination of the key comparison reference value (KCRV).

Pilot Studies

A pilot study (CCQM-P2) on the determination of pp'-DDE at two different levels in solvent and organised by LGC was held in 1996 - 1997[1]. Good agreement was obtained between participating NMIs with a majority of them achieving a result within 1% of the reference levels. Following this successful pilot study a further pilot study (CCQM-P4), also organised by LGC, on the determination of pp'-DDE in a corn oil matrix was held in 1998-1999.

For CCQM-P4 participants were provided with two corn oil samples in duplicate each gravimetrically spiked with a pp'-DDE solution in 2,2,4-trimethyl pentane. Concentration levels were 0.07246 ± 0.00053 μg g^{-1} and 4.740 ± 0.034 μg g^{-1}. The lower concentration represented levels found in food such as butter whilst the higher concentration represented levels found in human tissue. Participants were provided with a pp'-DDE calibration solution and a pp'-DDE isotopic analogue (pp'-DDE-$^{13}C_{12}$) solution for spiking purposes. The corn oil matrix is a complex one and a clean-up procedure was necessary prior to analysis. A description of a clean-up method based on the use of gel permeation chromatography (GPC) followed by the use of a silica solid phase extraction cartridge (SPE) was provided to participants. Results were received from eight participants with all using ID/GC/MS. The results showed that at the higher concentration there was good agreement between participants with virtually all achieving a result within 1% of the reference value. At the lower concentration, however, approximately half of the participants achieved a result within 1% of the reference value. This reflected the much lower concentration (by a factor of 65) of the low level solution. It was clear that this concentration is close to the limit of quantification for high accuracy analysis using IDMS (i.e. an accuracy of ±1%). Following discussion of the results amongst participants at the 1999 meeting of the CCQM Organic Working Group the CCQM directed the Organic Working Group to proceed to a key comparison.

Key Comparison

The key comparison involved sending two samples of fish oil to participants for measurement of the pp'-DDE levels. The fish oil material used for this key comparison was a dogfish liver oil (gift from NRC, Canada) and contained a measurable concentration of pp'-DDE. An aliquot of this oil was also gravimetrically spiked with pp'-DDE. This enabled two samples to be sent to participants, Sample A (a natural level of pp'-DDE) and Sample B (a natural level plus fortification with pp'-DDE). Fortification was carried out by gravimetrically adding a solution of pp'-DDE in 2,2,4-trimethylpentane to the fish oil and mixing on a three dimensional rolling shaker for eight hours. No weight loss was observed following mixing which also resulted in the fish oil containing approximately 7% of 2,2,4-trimethylpentane by volume. A homogeneity study was carried out on the gravimetrically spiked material (Sample B) and the resulting variance was not statistically significant at the 95% confidence level. The solvent addition resulted in a dilution of the natural level of the pp'-DDE in the oil by a factor of 0.94909. The difference between the Sample B level and the diluted natural level is 4.580 ± 0.011 μg g^{-1} (standard uncertainty).

A draft protocol was drawn up and circulated to prospective participants and to the Organic Working Group Chairman. Following the incorporation of comments the

protocol was agreed and participation was finalised. Samples were circulated to the participants during October 1999. It was specified in the protocol that the samples could be safely stored at room temperature in the dark.

Participants were responsible for the methods they used (but were requested to use ID/GC/MS at the measurement stage) and for providing their own calibration and isotopic analogue materials. It was suggested that where appropriate participants use the same method that they used for the pilot study on the determination of pp'-DDE in corn oil (CCQM-P4). Participants were supplied with duplicate vials of Samples A and B, each vial containing approximately 20 ml of sample. Participants were required to take two aliquots from each sample vial and analyse each aliquot in each of two instrumental runs (8 determinations in all for each sample). Sample B contained 2,2,4-trimethyl pentane solvent. It was specified that care should be taken to avoid evaporative solvent loss during the sample handling stage and that Sample B should be reported as received with no attempt made to correct for the presence of solvent in Sample B. Participants were requested to report results on an absolute basis (corrected for chemical purity of their calibration standard material) together with the associated overall uncertainty. It was also necessary for participants to submit a full uncertainty budget.

The concentration of pp'-DDE in the samples, in $\mu g\ g^{-1}$, is given by:

$$C_{pp'-DDE} = \frac{R_{SM} \times M_{calib} \times C_{calib} \times M_{spike(sample)}}{R_{CM} \times M_{sample} \times M_{spike(calib)}} \qquad (1)$$

where:

R_{SM}	is the ratio of pp'-DDE/pp'-DDE-$^{13}C_{12}$ observed for the sample solution;
R_{CM}	is the ratio of pp'-DDE/pp'-DDE-$^{13}C_{12}$ observed for the calibration solution;
M_{calib}	is the weight of the calibration solution taken for analysis;
C_{calib}	is the concentration of the calibration solution in $\mu g\ g^{-1}$;
$M_{spike(sample)}$	is the weight of the isotopically labelled spiking solution added to the sample;
$M_{spike(calib)}$	is the weight of the isotopically labelled spiking solution added to the calibration solution;
M_{sample}	is the weight of the sample taken for analysis.

The assumptions made here are (1) there is a negligible amount of the isotopically labelled analogue in the natural sample (2) pp'-DDE-$^{13}C_{12}$ is used as the isotopically labelled analogue and it is of high isotopic purity (it is readily available commercially with an isotopic purity better than 99%).

Results

Dates of study: February 1999 to April 2000.

All of the participants submitted results. Measurements were carried out during February 2000 except for NRC, NIMC and KRISS, whose measurements were carried out in March 2000.

The results are shown in tabular form in Tables 1a and 1b for Samples A and B respectively and graphically in Figures 1 and 2 for Samples A and B respectively. The uncertainty bars in Figures 1 and 2 represent expanded uncertainties. Figures 1 and 2 also show the KCRV together with the upper and lower limits of the 95 % confidence interval (C. I.) of the KCRV as described in Appendix 1. The Tables and Graphs of Equivalence are shown in Appendix 2 as Tables 4a and 4b and Figures 3 and 4 respectively.

Uncertainty budgets for each of the participating NMIs are shown in Appendix 3 (Tables 5 to 14).

Discussion

In general the agreement between participants is good, there is an overall relative standard deviation (RSD) for both sample levels of the order of 2%. This is higher than for the corresponding Pilot Study (CCQM-P4) where the RSD was of the order of 1%. However, for the key comparison participants had to supply their own calibration standards whereas they were supplied from a common source for the pilot study and this is thought to be the main reason for the higher RSD.

It can be seen that the results for both Sample A and Sample B for VNIIM are somewhat high. It is unlikely that this is due to an interfering compound in the fish oil since this apparent bias would not be so apparent in the spiked Sample B. It was thought possible that the purity of this participant's calibration material had been overestimated or that an error has been made in the preparation of the calibration solution. Consequently this participant's calibration solution was measured against that of the Pilot Laboratory to resolve this anomaly. In practice it was not possible for VNIIM to send a sample of their calibration solution to the Pilot Laboratory. Instead, the Pilot Laboratory sent a sample of their calibration solution to VNIIM. Subsequently the VNIIM calibration solution was checked by VNIIM against the Pilot Laboratory calibration solution supplied to them. The results of this check showed that the actual concentration of the VNIIM calibration solution was 6% less (9.309 $\mu g\ g^{-1}$) than the value used (9.893 $\mu g\ g^{-1}$) for the determination of the submitted pp'-DDE results. It was the view of VNIIM that the probable cause of the error was either a personal error when weighing or a faulty balance. Consequently the results of VNIIM will not be used in the determination of the KCRV.

It should be noted that in this key comparison no participant withdrew or changed their results, the only participant to have problems was VNIIM, as detailed above. No requests for follow up bilaterals were received.

The gravimetric spiking of Sample B provides an opportunity to examine the correlation between participant's measurements of Sample A and Sample B. Table 2 shows the fraction of the gravimetric fortification found by each participant (calculated as: (Sample B result - 0.94909 x Sample A result)/4.580). An ideal result would produce a factor = 1. The correlation is good and demonstrates that the overall analytical data is confirmed by the gravimetric spiking to within 0.5%.

With reference to uncertainty, the principal components of the uncertainty budget were set out in the protocol together with guidance on how to estimate them. Major sources of uncertainty were identified as between batch precision for the method as a whole (encompassing ratio measurements for samples and calibration standards) (Type A) and concentration of the calibration standard solution (corrected for purity) (Type B), this was reflected in the uncertainty budgets submitted by participants. Minor sources of uncertainty included balance linearity when carrying out weighing by difference (Type B). Whist the majority of participants included balance linearity uncertainties, their contribution to the overall uncertainty was minimal. It was recognised that not all participants would carry out their measurements in the same manner or use the same type of calibration procedure consequently participants were asked to identify other uncertainty components applicable to their own procedure. There were some differences in the estimation of the contributions to the total uncertainty. For example, one participant added a Type B component to model the risk of a systematic error to be present but not detected. This was not exactly quantifiable but depended on the operators' discretion. Six out of the ten participants followed the guidelines in the protocol, with slight variations in the calculation of the method precision term, such as including a separate estimation of repeatability uncertainty (Type A). The remaining participants did not use the guidelines in the protocol, as their analytical determination did not exactly correspond to the guidelines example. Nevertheless these participants applied the ISO guidelines to their calculations and all participants submitted an uncertainty budget. Overall there were no major differences in uncertainty between participants. The differences that do exist arise essentially from variations in the replicate measurements of the individual participants.

Additional data relating to sample clean-up, measurement and calibration procedures are detailed in Table 3. There does not appear to be a correlation of any of these parameters with uncertainty, in part due to the relatively low number of participants in this comparison.

Conclusions

This key comparison has demonstrated that participating NMIs have the ability to measure pp'-DDE in an oil based matrix with a RSD within 2%. Whist participants in the earlier pilot study (CCQM-P4) achieved a RSD within 1%, participants in this key comparison had to use their own calibration standards rather than have them supplied from a common source, as for CCQM-P4. This is thought to be the main reason for the higher RSD. The compound pp'-DDE is a typical organochlorine pollutant and this key comparison has shown that NMIs have the ability to measure such compounds at levels typically found in the environment. In order to reinforce and broaden this capability a key comparison on the determination of pp'-DDT (CCQM-K21) is currently in progress. The compound pp'-DDT is technically more

challenging than that of pp'-DDE since it can decompose during the measurement procedure. The combination of this key comparison and CCQM-K21 will demonstrate a broad capability of measurement by NMIs for organochlorine compounds in the environment.

Reference

1. Webb, K. S., Carter, D., Barwick, V. J., *Metrologia*, 1999, **36**, 89-99

Acknowledgements

The participation of scientists from BAM (Germany), KRISS (Korea), LGC (United Kingdom), NIMC (Japan), NIST (USA), NRC (Canada), NRCCRM (China), PTB (Germany), VNIIM (Russia) and NARL (Australia) is gratefully acknowledged. Dr J McLaren of NRC (Canada) is thanked for the gift of dogfish liver oil. Dr R L Watters Jr of NIST is gratefully acknowledged for establishing the matrices and graphs of equivalence.

Table 1a. Results: Sample A

Laboratory	**Mean Result** $\mu g\ g^{-1}$	**Std. Uncertainty (u)** $\mu g\ g^{-1}$	**Exp. Uncertainty (U)** $\mu g\ g^{-1}$
BAM	1.498	0.011	0.021
KRISS	1.525	0.006	0.014
LGC	1.554	0.012	0.025
NIMC	1.480	0.007	0.014
NIST	1.500	0.011	0.026
NRC	1.529	0.013	0.026
NRCCRM	1.481	0.008	0.016
PTB	1.535	0.008	0.017
VNIIM	1.606	0.007	0.018
NARL	1.493	0.032	0.064

Overall mean of mean results = 1.513 $\mu g\ g^{-1}$ Std. Deviation of the mean = 0.0095 $\mu g\ g^{-1}$ RSD = 1.8% (excluding NARL and VNIIM)). Degrees of freedom = 7 Coverage factor k = 2.365 Expanded uncertainty U = 0.023 $\mu g\ g^{-1}$

Table 1b. Results: Sample B

Laboratory	**Mean Result** $\mu g\ g^{-1}$	**Std. Uncertainty (u)** $\mu g\ g^{-1}$	**Exp. Uncertainty (U)** $\mu g\ g^{-1}$
BAM	6.090	0.037	0.073
KRISS	6.001	0.012	0.024
LGC	5.989	0.111	0.222
NIMC	5.873	0.038	0.076
NIST	6.046	0.025	0.050
NRC	5.679	0.013	0.026
NRCCRM	6.035	0.022	0.044
PTB	6.037	0.033	0.066
VNIIM	6.301	0.032	0.091
NARL	5.905	0.066	0.131

Overall mean of mean results = 5.969 $\mu g\ g^{-1}$ Std. Deviation of the mean = 0.0471 $\mu g\ g^{-1}$ RSD = 2.2% (excluding NARL and VNIIM) Degrees of freedom = 7 Coverage factor k = 2.365 Expanded uncertainty U = 0.111 $\mu g\ g^{-1}$

Table 2: Correlation between Sample A and Sample B results (Sample B result - 0.94909 x Sample A result)/4.580

Laboratory	Fraction of Gravimetric Fortification
BAM	1.019
KRISS	0.994
LGC	0.985
NARL	0.980
NIMC	0.976
NIST	1.009
NRC	0.923
NRCCRM	1.011
PTB	1.000
VNIIM	1.043

Mean value = 0.994 Std. Deviation = 0.032

Table 3. Instrument types, calibration procedures and measurement parameters for pp'-DDE samples.

Lab.	Clean-Up	Instrument Type	Calibration Method	Quantitation Ions pp'-DDE	Quantitation Ions pp'-DDE-$^{13}C_{12}$	Ion Abundance Ratio, Sample A	Ion Abundance Ratio, Sample B
BAM	Alumina column	Magnetic sector	Graphical	246	258	1.0	1.0
KRISS	GPC + SPE + HPLC	Magnetic sector	Bracketing	318	330	1.0	1.0
LGC	GPC + SPE	Magnetic sector	'Exact Matching'	318	330	1.0	1.0
NARL	GPC + SPE	Magnetic sector	'Exact Matching'	246	258	1.0	1.0
NIMC	GPC + SPE	Quadrupole	'Exact Matching'	318	330	1.0	1.0
NIST	GPC + SPE	Quadrupole	Bracketing	246	258	1.03	0.76
NRC	GPC + SPE	Magnetic sector	Single Point Calib.	Σ246 + 248	Σ258 + 260	1.1 – 1.3	1.1 – 1.2
NRCCRM	GPC + conc. H_2SO_4	Magnetic sector	Bracketing	318	330	1.06	1.0
PTB	GPC	Quadrupole	'Exact Matching'	318	330	0.95	0.95
VNIIM	Conc. H_2SO_4	Quadrupole	Single Point Calib.	318	330	0.9 - 1.0	1.0 - 1.6

Note: GPC = Gel permeation chromatography

SPE = Solid phase extraction

HPLC = High performance liquid chromatography (preparative)

Figure 1 Sample A Results showing Mean and Upper and Lower Limits of the 95% C. I. of the KCRV (NARL and VNIIM excluded)

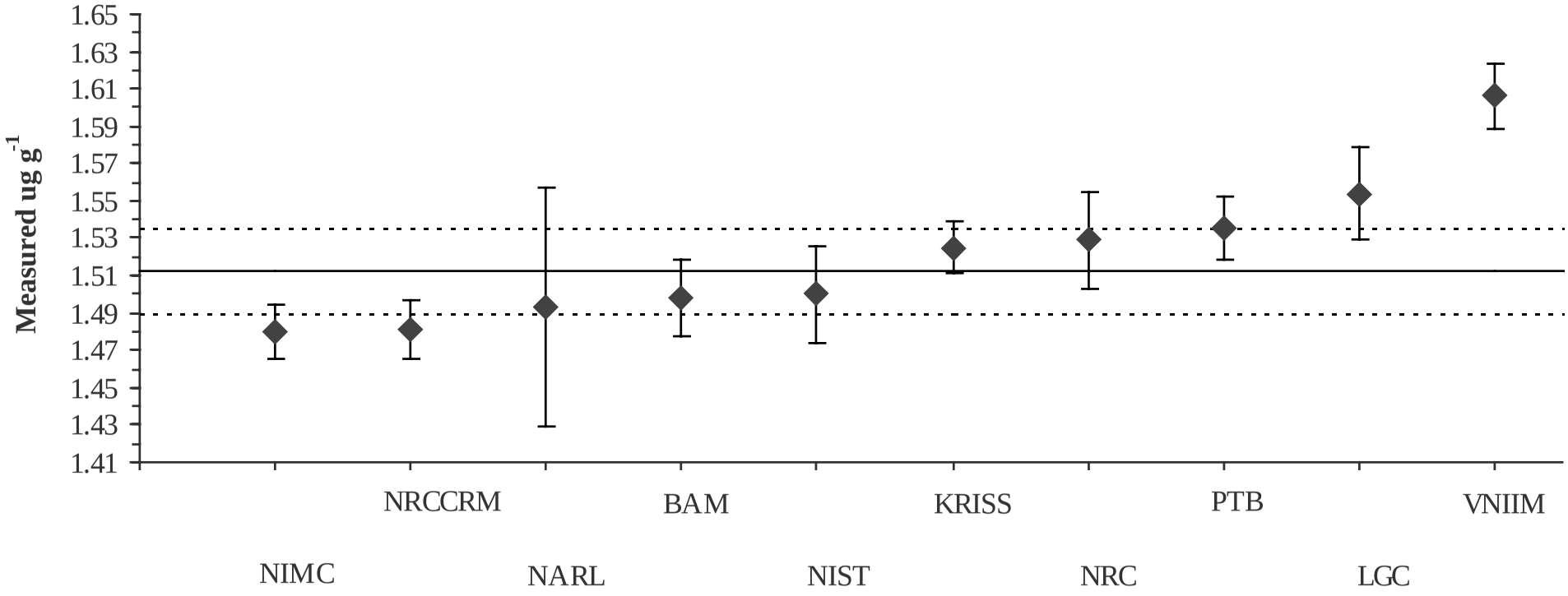
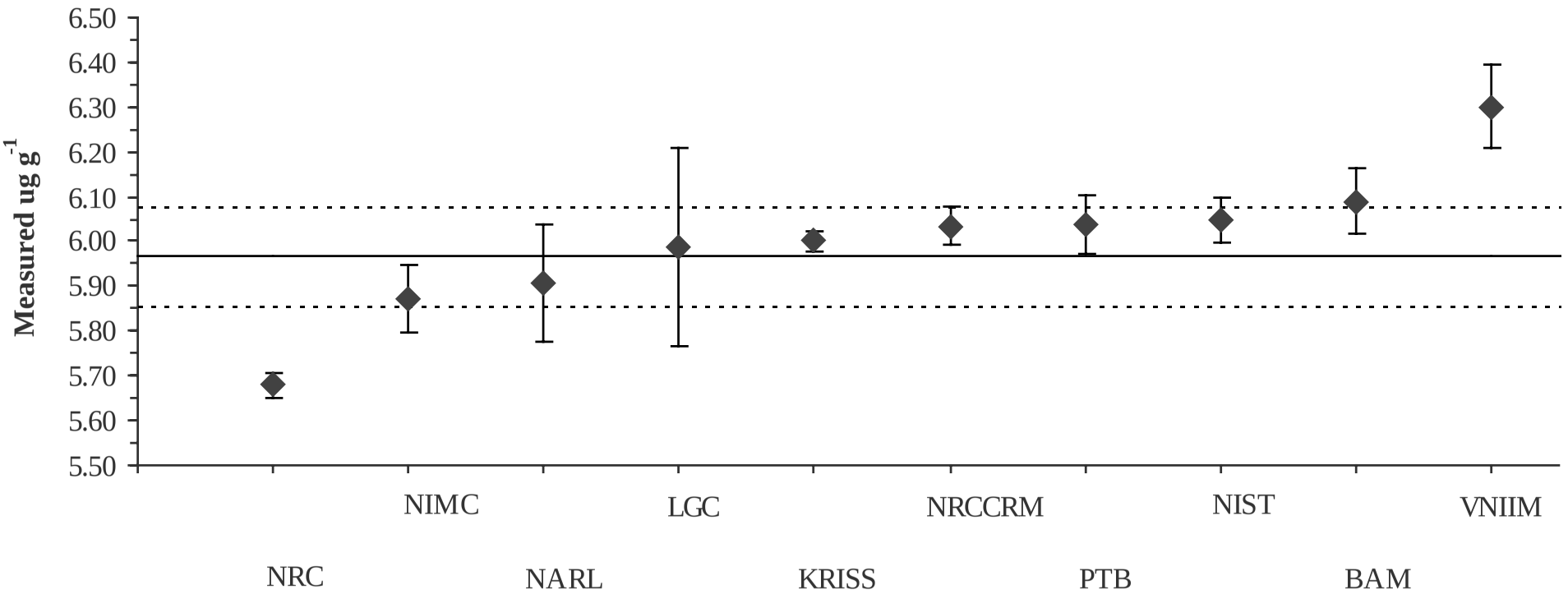


Figure 2 Sample B Results showing Mean and Upper and Lower Limits of the 95% C. I. of the KCRV (NARL and VNIIM excluded)



Appendix 1

Key Comparison Reference Value (KCRV)

It is proposed that the KCRV should be calculated as the mean of the results (excluding NARL and VNIIM) with the standard deviation of the mean taken as the standard uncertainty of the KCRV. This approach was agreed at a meeting of participants held at Sèvres on 3-4 April 2000. The NARL results were not eligible to be included in the calculation of the KCRV since NARL did not take part in either of the relevant pilot studies (CCQM-P2, CCQM-P4). The VNIIM results were excluded from the calculation of the KCRV due to an error in the preparation of their calibration solution resulting in a 6% error in the calculation of their results (see Discussion). The data contains a mix of degrees of freedom, consequently in order to calculate the coverage factor the Satterthwaite approximation is used, resulting in a coverage factor of 2.365 (7 degrees of freedom). For Sample A this calculation yields a KCRV of 1.513 ± 0.023 μg g^{-1} corresponding to a 95% confidence interval of 1.490 μg g^{-1} to 1.536 μg g^{-1}. For Sample B the KCRV would be 5.969 ± 0.111 μg g^{-1} corresponding to a 95% confidence interval of 5.858 μg g^{-1} to 6.080 μg g^{-1}. The Matrices and Graphs of Equivalence are shown in Appendix 2 as Tables 4a and 4b and Figures 3 and 4 respectively.

Appendix 2

Table 4a Matrix of Equivalence for Sample A

Measurand: amount of pp'DDE in fish oil

KCRV 1.513 ± 0.023 μg g^{-1}

	KCRV			BAM		KRISS		LGC		NARL		NIMC		NIST		NRC		NRCCRM		PTB		VNIIM	
	D_i	U_i		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
BAM	**-0.015**	0.029				**-0.027**	0.024	**-0.056**	0.032	**0.005**	0.067	**0.018**	0.025	**-0.002**	0.031	**-0.031**	0.033	**0.017**	0.026	**-0.037**	0.027	**-0.108**	0.026
KRISS	**0.012**	0.025		**0.027**	0.024			**-0.029**	0.028	**0.032**	0.065	**0.045**	0.019	**0.025**	0.027	**-0.004**	0.029	**0.044**	0.020	**-0.010**	0.021	**-0.081**	0.020
LGC	**0.041**	0.032		**0.056**	0.032	**0.029**	0.028			**0.061**	0.068	**0.074**	0.028	**0.054**	0.034	**0.025**	0.036	**0.073**	0.029	**0.019**	0.030	**-0.052**	0.029
NARL	**-0.020**	0.067		**-0.005**	0.067	**-0.032**	0.065	**-0.061**	0.068			**0.013**	0.065	**-0.007**	0.068	**-0.036**	0.069	**0.012**	0.066	**-0.042**	0.066	**-0.113**	0.066
NIMC	**-0.033**	0.025		**-0.018**	0.025	**-0.045**	0.019	**-0.074**	0.028	**-0.013**	0.065			**-0.020**	0.028	**-0.049**	0.029	**-0.001**	0.021	**-0.055**	0.022	**-0.126**	0.021
NIST	**-0.013**	0.031		**0.002**	0.031	**-0.025**	0.027	**-0.054**	0.034	**0.007**	0.068	**0.020**	0.028			**-0.029**	0.035	**0.019**	0.029	**-0.035**	0.029	**-0.106**	0.029
NRC	**0.016**	0.033		**0.031**	0.033	**0.004**	0.029	**-0.025**	0.036	**0.036**	0.069	**0.049**	0.029	**0.029**	0.035			**0.048**	0.030	**-0.006**	0.031	**-0.077**	0.030
NRCCRM	**-0.032**	0.026		**-0.017**	0.026	**-0.044**	0.020	**-0.073**	0.029	**-0.012**	0.066	**0.001**	0.021	**-0.019**	0.029	**-0.048**	0.030			**-0.054**	0.023	**-0.125**	0.022
PTB	**0.022**	0.026		**0.037**	0.027	**0.010**	0.021	**-0.019**	0.030	**0.042**	0.066	**0.055**	0.022	**0.035**	0.029	**0.006**	0.031	**0.054**	0.023			**-0.071**	0.023
VNIIM	**0.093**	0.026		**0.108**	0.026	**0.081**	0.020	**0.052**	0.029	**0.113**	0.066	**0.126**	0.021	**0.106**	0.029	**0.077**	0.030	**0.125**	0.022	**0.071**	0.023		

Table 4b Matrix of Equivalence for Sample B

Measurand: amount of pp'DDE in fish oil

KCRV 5.969 ± 0.111 μg g^{-1}

	KCRV			BAM		KRISS		LGC		NARL		NIMC		NIST		NRC		NRCCRM		PTB		VNIIM	
	D_i	U_i		D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}	D_{ij}	U_{ij}
BAM	**0.121**	0.126				**0.089**	0.077	**0.101**	0.233	**0.185**	0.149	**0.217**	0.105	**0.044**	0.088	**0.411**	0.078	**0.055**	0.085	**0.053**	0.098	**-0.211**	0.104
KRISS	**0.032**	0.115		**-0.089**	0.077			**0.012**	0.223	**0.096**	0.133	**0.128**	0.080	**-0.045**	0.055	**0.322**	0.035	**-0.034**	0.050	**-0.036**	0.070	**-0.300**	0.096
LGC	**0.020**	0.241		**-0.101**	0.233	**-0.012**	0.223			**0.084**	0.256	**0.116**	0.234	**-0.057**	0.227	**0.310**	0.223	**-0.046**	0.226	**-0.048**	0.231	**-0.312**	0.231
NARL	**-0.064**	0.163		**-0.185**	0.149	**-0.096**	0.133	**-0.084**	0.256			**0.032**	0.151	**-0.141**	0.139	**0.226**	0.133	**-0.130**	0.138	**-0.132**	0.146	**-0.396**	0.147
NIMC	**-0.096**	0.127		**-0.217**	0.105	**-0.128**	0.080	**-0.116**	0.234	**-0.032**	0.151			**-0.173**	0.090	**0.194**	0.080	**-0.162**	0.088	**-0.164**	0.100	**-0.428**	0.105
NIST	**0.077**	0.117		**-0.044**	0.088	**0.045**	0.055	**0.057**	0.227	**0.141**	0.139	**0.173**	0.090			**0.367**	0.056	**0.011**	0.066	**0.009**	0.082	**-0.255**	0.093
NRC	**-0.290**	0.113		**-0.411**	0.078	**-0.322**	0.035	**-0.310**	0.223	**-0.226**	0.133	**-0.194**	0.080	**-0.367**	0.056			**-0.356**	0.051	**-0.358**	0.071	**-0.622**	0.097
NRCCRM	**0.066**	0.116		**-0.055**	0.085	**0.034**	0.050	**0.046**	0.226	**0.130**	0.138	**0.162**	0.088	**-0.011**	0.066	**0.356**	0.051			**-0.002**	0.079	**-0.266**	0.092
PTB	**0.068**	0.123		**-0.053**	0.098	**0.036**	0.070	**0.048**	0.231	**0.132**	0.146	**0.164**	0.100	**-0.009**	0.082	**0.358**	0.071	**0.002**	0.079			**-0.264**	0.100
VNIIM	**0.332**	0.127		**0.211**	0.104	**0.300**	0.096	**0.312**	0.231	**0.396**	0.147	**0.428**	0.105	**0.255**	0.093	**0.622**	0.097	**0.266**	0.092	**0.264**	0.100		

Figure 3
Degrees of Equivalence for Sample A

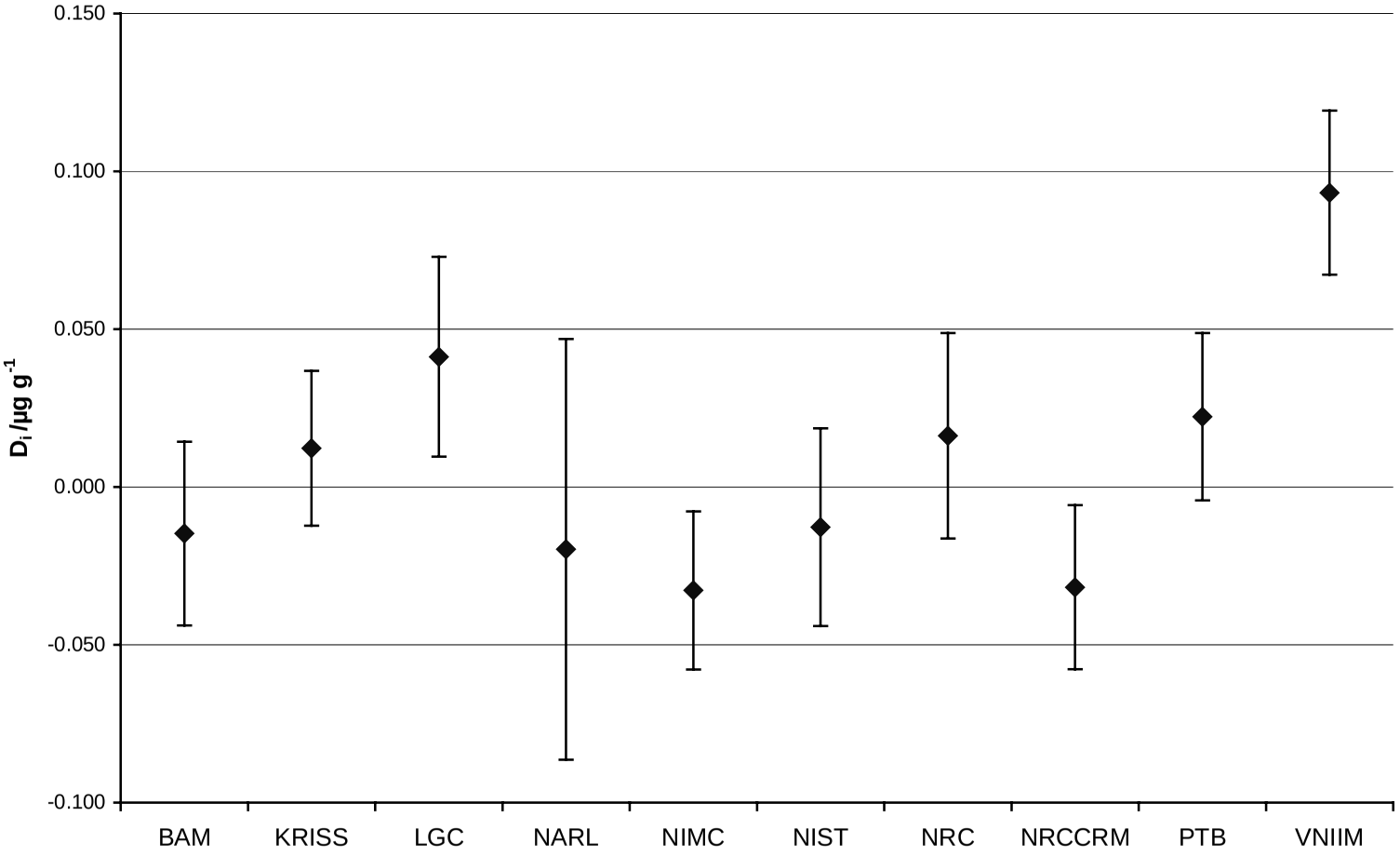
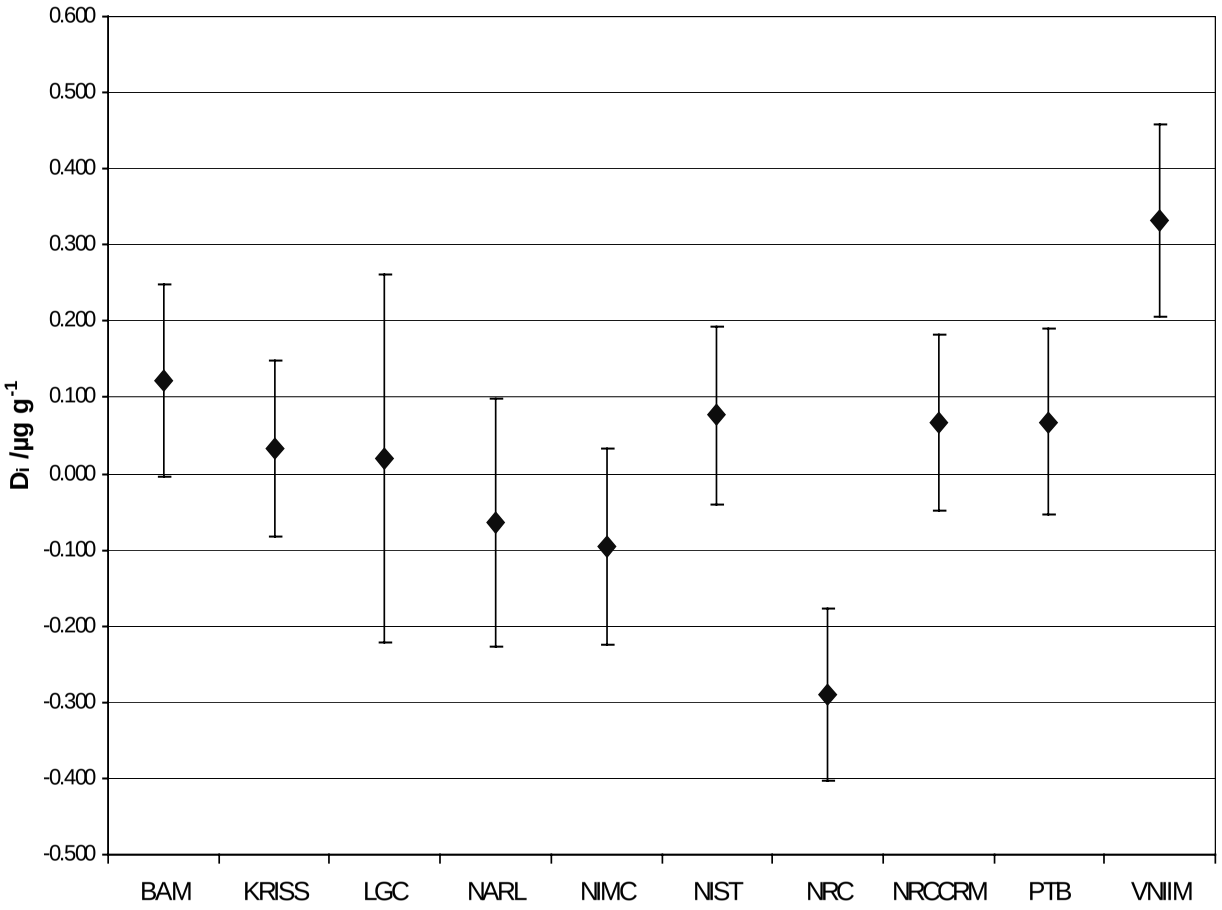


Figure 4
Degrees of Equivalence for Sample B



Appendix 3

Uncertainty Budgets for Participating NMIs

Table 5a BAM – Sample A

Parameter	Uncertainty Type	Expanded Uncertainty μg g^{-1}	Degrees of Freedom
Measured ratio	A	0.015018	3
Mass of sample	A	0.000433	4
Mass of spike	A	0.000324	4
Clean-up stage	B	0.014828	100
Evaporation	B	0.000741	100
Combined expanded uncertainty		0.021	
Coverage factor	2		
Standard uncertainty		0.011	
Mean value of result		1.498	

Table 5b BAM – Sample B

Parameter	Uncertainty Type	Expanded Uncertainty μg g^{-1}	Degrees of Freedom
Measured ratio	A	0.039993	3
Mass of sample	A	0.001976	4
Mass of spike	A	0.00237	4
Clean-up stage	B	0.061379	100
Evaporation	B	0.003069	100
Combined expanded uncertainty		0.073	
Coverage factor	2		
Combined standard uncertainty		0.037	
Mean value of result		6.090	

Table 6a KRISS – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.005	7
Prep. of calibration mixture (1) precision	B	0.00086607	Large
Prep. of calibration mixture (2) precision	B	0.00048875	Large
Ratio calibration mixture (1)	A	0.00084752	5
Ratio calibration mixture (2)	A	0.00059785	5
Ratio sample	A	0.0015247	5
Balance precision	B	0.0000751	Large
Balance precision to include dilution	B	0.0004977	Large
Concentrated standard solution	B	0.0015304	Large
Combined standard uncertainty		0.006	
Coverage factor	2.306		
Combined expanded uncertainty		0.014	
Mean value of result		1.525	

Table 6b KRISS – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.0075	7
Prep. of calibration mixture (1) precision	B	0.0021728	Large
Prep. of calibration mixture (2) precision	B	0.0029846	Large
Ratio calibration mixture (1)	A	0.0025465	5
Ratio calibration mixture (2)	A	0.0034978	5
Ratio sample	A	0.006044	5
Balance precision	B	0.0012596	Large
Balance precision to include dilution	B	0.0021927	Large
Concentrated standard solution	B	0.00603	Large
Combined standard uncertainty		0.012	
Coverage factor	2.039		
Combined expanded uncertainty		0.024	
Mean value of result		6.001	

Table 7a LGC – Sample A

Parameter	Uncertainty Type	Relative Uncertainty	Degrees of Freedom
Method precision	A	0.0056	7
Instrument repeatability	A	0.0026	4
Balance linearity, calibration solution	B	0.00012	Large
Calibration solution concentration	B	0.0024	Large
Balance linearity, sample spike	B	0.00046	Large
Balance linearity, calibration spike	B	0.001	Large
Balance linearity, sample mass	B	0.000034	Large
Combined relative standard uncertainty		0.0067	
Combined standard uncertainty		0.012 μg g^{-1}	
Coverage factor	2		
Combined expanded uncertainty		0.025 μg g^{-1}	
Mean value of result		1.554 μg g^{-1}	

Table 7b LGC – Sample B

Parameter	Uncertainty Type	Relative Uncertainty	Degrees of Freedom
Method precision	A	0.011	7
Instrument repeatability	A	0.0041	4
Balance linearity, calibration solution	B	0.000079	Large
Calibration solution concentration	B	0.0077	Large
Balance linearity, sample spike	B	0.00015	Large
Balance linearity, calibration spike	B	0.00015	Large
Balance linearity, sample mass	B	0.000035	Large
Combined relative standard uncertainty		0.014	
Combined standard uncertainty		0.111 μg g^{-1}	
Coverage factor	2		
Combined expanded uncertainty		0.222 μg g^{-1}	
Mean value of result		5.986 μg g^{-1}	

Table 8a NIMC – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.007	3
Balance linearity, calibration solution	B	0.000499	Large
Calibration solution concentration	B	0.000892	Large
Balance linearity, sample spike	B	0.000557	Large
Balance linearity, calibration spike	B	0.0000481	Large
Balance linearity, sample mass	B	0.0000984	Large
Combined standard uncertainty		0.007	
Coverage factor	2		
Combined expanded uncertainty		0.014	
Mean value of result		1.480	

Table 8b NIMC – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.038	3
Balance linearity, calibration solution	B	0.000198	Large
Calibration solution concentration	B	0.00354	Large
Balance linearity, sample spike	B	0.000812	Large
Balance linearity, calibration spike	B	0.000191	Large
Balance linearity, sample mass	B	0.000574	Large
Combined standard uncertainty		0.038	
Coverage factor	2		
Combined expanded uncertainty		0.076	
Mean value of result		5.873	

Table 9a NIST – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Measurement of samples	A	0.004365	3
Measurement of calibration standards	A	0.009121	4
Concentration of calibration solution	B	0.004495	Infinity
Combined standard uncertainty		0.011	
Coverage factor	2.31		
Combined expanded uncertainty		0.026	
Mean value of result		1.500	

Table 9b NIST – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Measurement of samples	A	0.006740	3
Measurement of calibration standards	A	0.015061	4
Concentration of calibration solution	B	0.018113	Infinity
Combined standard uncertainty		0.025	
Coverage factor	2.06		
Combined expanded uncertainty		0.050	
Mean value of result		6.046	

Table 10a NRC – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.01297	3
Balance linearity, calibration solution	B	0.0000901	Large
Calibration solution concentration	B	0.001787	Large
Balance linearity, sample spike	B	0.0000609	Large
Balance linearity, calibration spike	B	0.0000959	Large
Balance linearity, sample mass	B	0.0000618	Large
Combined standard uncertainty		0.013	
Coverage factor	2		
Combined expanded uncertainty		0.026	
Mean value of result		1.529	

Table 10b NRC – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.0129	3
Balance linearity, calibration solution	B	0.0003428	Large
Calibration solution concentration	B	0.001764	Large
Balance linearity, sample spike	B	0.0003382	Large
Balance linearity, calibration spike	B	0.0003442	Large
Balance linearity, sample mass	B	0.0002982	Large
Combined standard uncertainty		0.013	
Coverage factor	2		
Combined expanded uncertainty		0.026	
Mean value of result		5.679	

Table 11a NRCCRM – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.008	3
Balance linearity, calibration solution	B	0.00013	Large
Calibration solution concentration	B	0.002	Large
Balance linearity, sample spike	B	0.00013	Large
Balance linearity, calibration spike	B	0.00013	Large
Balance linearity, sample mass	B	0.000025	Large
Combined standard uncertainty		0.008	
Coverage factor	2		
Combined expanded uncertainty		0.016	
Mean value of result		1.481	

Table 11b NRCCRM – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.02	3
Balance linearity, calibration solution	B	0.00013	Large
Calibration solution concentration	B	0.009	Large
Balance linearity, sample spike	B	0.00013	Large
Balance linearity, calibration spike	B	0.00013	Large
Balance linearity, sample mass	B	0.000025	Large
Combined standard uncertainty		0.022	
Coverage factor	2		
Combined expanded uncertainty		0.044	
Mean value of result		6.035	

Table 12a PTB - Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.00232	8
Calibration solution concentration	B	0.00308	Infinity
Standard to standard difference in results obtained	A	0.00422	?
Risk of undetected systematic component	B	0.0060	Infinity
Combined standard uncertainty		0.008	
Coverage factor	2		
Combined expanded uncertainty		0.017	
Mean value of result		1.535	

Table 12b PTB - Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.0093	8
Calibration solution concentration	B	0.0121	Infinity
Standard to standard difference in results obtained	A	0.0166	?
Risk of undetected systematic component	B	0.0236	Infinity
Combined standard uncertainty		0.033	
Coverage factor	2		
Combined expanded uncertainty		0.066	
Mean value of result		6.037	

Table 13a VNIIM – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.00609	3
Balance linearity, calibration solution	B	0.00151	Large
Calibration solution concentration	B	0.00268	Large
Balance linearity, sample spike	B	0.00163	Large
Balance linearity, calibration spike	B	0.00155	Large
Balance linearity, sample mass	B	0.00029	Large
Combined standard uncertainty		0.007	
Coverage factor	2.47		
Combined expanded uncertainty		0.018	
Mean value of result		1.606	

Table 13b VNIIM – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.03033	3
Balance linearity, calibration solution	B	0.00212	Large
Calibration solution concentration	B	0.01051	Large
Balance linearity, sample spike	B	0.00179	Large
Balance linearity, calibration spike	B	0.00232	Large
Balance linearity, sample mass	B	0.00117	Large
Combined standard uncertainty		0.032	
Coverage factor	2.82		
Combined expanded uncertainty		0.091	
Mean value of result		6.301	

Table 14a NARL – Sample A

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.032	3
Balance linearity, calibration solution	B	0.00045	Large
Calibration solution concentration	B	0.00868	Large
Balance linearity, sample spike	B	0.00061	Large
Balance linearity, calibration spike	B	0.00060	Large
Balance linearity, sample mass	B	0.00012	Large
Combined standard uncertainty		0.032	
Coverage factor	2		
Combined expanded uncertainty		0.064	
Mean value of result		1.493	

Table 14b NARL – Sample B

Parameter	Uncertainty Type	Standard Uncertainty μg g^{-1}	Degrees of Freedom
Method precision	A	0.064	3
Balance linearity, calibration solution	B	0.00203	Large
Calibration solution concentration	B	0.01374	Large
Balance linearity, sample spike	B	0.00111	Large
Balance linearity, calibration spike	B	0.00111	Large
Balance linearity, sample mass	B	0.00087	Large
Combined standard uncertainty		0.066	
Coverage factor	2		
Combined expanded uncertainty		0.131	
Mean value of result		5.905	