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Certificate

AMIS0634

Certified Reference Material

Copper Concentrate, Kalumbila Minerals, Zambia.

Certificate of Analysis

AMIS

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Summary Statistics

Recommended Concentrations and Limits (at two Standard Deviations) Certified Concentrations

Analyte	Method	Certified (μ) ⁷	(2s) ⁹ \pm	Unit
Cu	4A_MICP ¹	22.60	0.86	%
Co	4A_MICP	1385	124	ppm
Co	FUS ²	1375	64	ppm
Au	Pb Collection ³	0.353	0.15	g/t
LOI	LOI ⁴	15.90	0.39	%
SG	SG ⁵	3.65	0.76	Dimensionless
C	Combustion/LECO ⁶	2.24	0.19	%
S	Combustion/LECO	28.67	1.4	%
Ag	4A_MICP	2	0.8	ppm
Al	4A_MICP	1.25	0.19	%
Al	FUS	1.37	0.052	%
As	4A_MICP	14	3	ppm
Ba	FUS	87	9	ppm
Be	4A_MICP	1	0.3	ppm
Ca	4A_MICP	1796	148	ppm
Cr	FUS	190	28	ppm
Fe	4A_MICP	27.66	1.4	%
Fe	FUS	26.63	1.9	%
Ga	4A_MICP	9	4	ppm
K	4A_MICP	5460	440	ppm
K	FUS	5219	630	ppm
La	4A_MICP	29	5	ppm
Mg	4A_MICP	4413	366	ppm
Mg	FUS	4743	601	ppm
Mn	4A_MICP	124	18	ppm
Mn	FUS	128	21	ppm
Mo	4A_MICP	16	2	ppm
Na	4A_MICP	471	108	ppm
Ni	4A_MICP	367	28	ppm
Ni	FUS	380	36	ppm
P	4A_MICP	262	40	ppm
Pb	4A_MICP	297	24	ppm
Sr	4A_MICP	12	2	ppm
Ti	FUS	815	100	ppm
Tl	4A_MICP	0.6	0.1	ppm
V	4A_MICP	21	7	ppm
Zn	4A_MICP	685	75	ppm
Zn	FUS	675	73	ppm

Major Oxides
Certified Concentrations (at two Standard Deviations)

Analyte	Method	Certified (μ) ⁷	(2s) ⁹ \pm	Unit
Al ₂ O ₃	FUS	2.59	0.10	%
BaO	FUS	0.010	0.001	%
Fe ₂ O ₃	FUS	38.08	2.7	%
MgO	FUS	0.79	0.1	%
K ₂ O	FUS	0.65	0.08	%
MnO	FUS	0.016	0.003	%
TiO ₂	FUS	0.14	0.02	%

1. Certified Concentrations and Uncertainties

AMIS0634 is a new standard material, developed and certified in May 2019. Table 1 gives the certified concentrations, confidence interval, combined and expanded uncertainty for the certified reference material. Table 2 shows the certified major oxides concentrations, two standard deviations, confidence interval, combined and expanded uncertainty.

Table 1. Certified concentrations, two standard deviations, combined and expanded uncertainty.

Analyte	Method	Certified (μ) ⁷	N	n	k	% RSD	(u _c) ⁸	(2s) ⁹ ±	(CI) ¹⁰ 95%	(U) ¹¹ ±	Unit
Cu	4A_MICP ¹	22.60	4	32	3.182	2	0.43	0.86	0.56	1	%
Co	4A_MICP	1385	3	22	4.303	4	62	124	153	266	ppm
Co	FUS ²	1375	3	22	4.303	2	32	64	51	137	ppm
Au	Pb Collection ³	0.353	5	39	2.776	21	0.074	0.15	0.037	0.2	g/t
LOI	LOI ⁴	15.90	3	24	4.303	1	0.19	0.39	0.44	0.8	%
SG	SG ⁵	3.65	5	38	2.776	10	0.38	0.76	0.50	1	Dimensionless
C	Combustion/LECO ⁶	2.24	5	38	2.776	4	0.095	0.19	0.12	0.3	%
S	Combustion/LECO	28.67	6	47	2.571	2	0.68	1.4	0.71	2	%
Ag	4A_MICP	2	3	22	4.303	24	0.4	0.8	1	2	ppm
Al	4A_MICP	1.25	3	23	4.303	7	0.093	0.19	0.22	0.4	%
Al	FUS	1.37	3	24	4.303	2	0.026	0.052	0.048	0.1	%
As	4A_MICP	14	3	24	4.303	11	2	3	3	7	ppm
Ba	FUS	87	2	16	12.706	5	4	9	37	55	ppm
Be	4A_MICP	1	4	31	3.182	14	0.2	0.3	0.2	0.5	ppm
Ca	4A_MICP	1796	4	29	3.182	4	74	148	101	235	ppm
Cr	FUS	190	2	16	12.706	7	14	28	123	178	ppm
Fe	4A_MICP	27.66	3	22	4.303	3	0.71	1.4	1.5	3	%
Fe	FUS	26.63	4	30	3.182	4	0.97	1.9	1.4	3	%
Ga	4A_MICP	9	3	24	4.303	20	2	4	4	8	ppm
K	4A_MICP	5460	3	22	4.303	4	220	440	558	946	ppm
K	FUS	5219	2	16	12.706	6	315	630	2779	4005	ppm
La	4A_MICP	29	3	24	4.303	8	2	5	6	10	ppm
Mg	4A_MICP	4413	3	24	4.303	4	183	366	411	788	ppm
Mg	FUS	4743	4	31	3.182	6	301	601	452	957	ppm
Mn	4A_MICP	124	3	24	4.303	7	9	18	21	38	ppm
Mn	FUS	128	2	16	12.706	8	10	21	76	131	ppm
Mo	4A_MICP	16	4	31	3.182	6	1	2	1	3	ppm
Na	4A_MICP	471	3	24	4.303	11	54	108	125	232	ppm
Ni	4A_MICP	367	4	31	3.182	4	14	28	18	44	ppm
Ni	FUS	380	3	23	4.303	5	18	36	21	78	ppm
P	4A_MICP	262	3	24	4.303	8	20	40	14	86	ppm
Pb	4A_MICP	297	3	24	4.303	4	12	24	26	51	ppm
Sr	4A_MICP	12	4	32	3.182	9	1	2	1	3	ppm
Ti	FUS	815	4	31	3.182	6	50	100	52	159	ppm
Tl	4A_MICP	0.6	2	16	12.706	13	0.07	0.1	0.6	0.9	ppm
V	4A_MICP	21	3	24	4.303	18	4	7	8	16	ppm
Zn	4A_MICP	685	3	24	4.303	5	37	75	89	161	ppm
Zn	FUS	675	3	22	4.303	5	36	73	85	156	ppm

Table 2. Certified major oxides concentrations, two standard deviations, combined and expanded uncertainty.

Analyte	Method	Certified (μ) ⁷	N	n	k	% RSD	(u_c) ⁸	(2s) ⁹ ±	(CI) ¹⁰ 95%	(U) ¹¹ ±	Unit
Al ₂ O ₃	FUS	2.59	3	24	4.303	2	0.049	0.10	0.090	0.2	%
BaO	FUS	0.010	2	16	12.706	5	0.0005	0.001	0.004	0.01	%
Fe ₂ O ₃	FUS	38.08	4	30	3.182	4	1.4	2.7	2.0	4	%
MgO	FUS	0.79	4	31	3.182	6	0.05	0.1	0.07	0.2	%
K ₂ O	FUS	0.65	3	23	4.303	6	0.04	0.08	0.02	0.2	%
MnO	FUS	0.016	2	16	12.706	8	0.001	0.003	0.01	0.02	%
TiO ₂	FUS	0.14	4	31	3.182	6	0.008	0.02	0.009	0.03	%

1. 4A_MICP is a Multi-acid digestion with either ICPOES/ICPMS/AAS finish
2. FUS is Fusion digestion with ICP finish
3. Pb Collection
4. LOI is Loss on Ignition
5. SG is Specific Gravity
6. Combustion/LECO
7. The certified value μ , is an unweighted grand mean of the means of N accepted sets of data from different laboratories and n number of test sample replicates. The certified value is traceable to SI units and is reported on a dry basis.
8. The combined uncertainty of the certified value is the within-laboratory reproducibility standard deviation derived from the analysis of variance of results from N number of laboratories and n number of sample replicates. (u_c)
9. Two standard deviations (2s)
10. Confidence interval at 95% level of confidence.
11. Expanded uncertainty (U) at a confidence level of 95% is determined by multiplication of the combined uncertainty (u_c) with a coverage factor (k) found from N-1 degrees of freedom (see Appendix 7 for t-distribution table). Example: $U = 2.36 \times 0.23 = 0.5\%$

2. Statistical Comparison of Means

A comparison of means for replicate data for the same element concentration determined by different analytical methods is done equating the variances between the two data sets; if the variances are found to be equal (F-test, p -value >0.05), then an equal variance t-test is applied. Should the variances be statistically significant, i.e. $p<0.05$, then an unequal variance t-test is performed. For either t-test, if the obtained p -value ≥ 0.05 , the null hypothesis that the means (certified values) are equal is accepted (Table 3). This gives the analyst confidence in the certified values reported by different analytical methods on the same analyte.

Table 3. The results of a two-sample equal or unequal variance t-test (two-tailed) data sets in which different analytical methods /instrumentation were used.

Method	Certified value	Method	Certified value	F-Test Outcome	p -value (t-test)	t-test Outcome
Cu FUS	22.57 %	Cu 4A_MICP	22.6 %	Equal Variance ($p=0.088$)	0.910	Accept H_0 ; certified values are equal
Co FUS	0.138 %	Co 4A_MICP	0.138 %	Equal Variance ($p=0.101$)	0.819	Accept H_0 ; certified values are equal
Al FUS	1.37 %	Al 4A_MICP	1.25 %	Unequal Variance ($p=0.044$)	0.152	Accept H_0 ; certified values are equal
Fe FUS	26.63 %	Fe 4A_MICP	27.66 %	Equal Variance ($p=0.352$)	0.142	Accept H_0 ; certified values are equal
K FUS	0.522 %	K 4A_MICP	0.546 %	Equal Variance ($p=0.302$)	0.378	Accept H_0 ; certified values are equal
Mg FUS	0.474 %	Mg 4A_MICP	0.441 %	Equal Variance ($p=0.263$)	0.136	Accept H_0 ; certified values are equal
Mn FUS	0.013 %	Mn 4A_MICP	0.012 %	Equal Variance ($p=0.419$)	0.656	Accept H_0 ; certified values are equal
Ni FUS	0.038 %	Ni 4A_MICP	0.037 %	Equal Variance ($p=0.368$)	0.166	Accept H_0 ; certified values are equal
Zn FUS	0.068 %	Zn 4A_MICP	0.068 %	Equal Variance ($p=0.478$)	0.759	Accept H_0 ; certified values are equal

3. Intended Use

AMIS0634 is a matrix matched Certified Reference Material, fit for use as a control sample in routine assay laboratory quality control when inserted within runs of test samples and measured in parallel to test samples. This material can also be used for method development, use as independent calibration verification check standard (i.e. if not used as a calibration standard in an instrument calibration), or for validation of accuracy in a method validation exercise (see Appendix 3). The recommend procedure for the use of this CRM as a control standard in laboratory quality control is to develop a Shewhart chart, where a mean value and corresponding 1, 2 and 3 standard deviations are derived from replicate measurements of the CRM (see Appendix 6). This CRM can also be used to assess inter-laboratory or instrument bias and establish within-laboratory precision and within-laboratory reproducibility. The certified concentrations and expanded uncertainty for this material are property values based on an inter-laboratory measurement campaign and reflect consensus results from the laboratories that took part in the exercise.

4. Abbreviations and Symbols

Abbreviations and symbols used in this document are shown in Table 4.

Table 4. Abbreviations, symbols and descriptions.

Abbreviation/Symbol	Description
Alpha (α)	Significance level (denoted by alpha, ' α ') of 0.05 or 5%
ANOVA	Analysis of variance by statistical means
Bq	The becquerel is the SI derived unit of radioactivity.
BIF	Banded iron formation
CRM	Certified reference material
df	Degrees of freedom, typically, $n-1$, or $N-1$
F_{calc}	Calculated F statistic from ANOVA or Fisher's test
F-critical or F_{crit}	F-critical value from F-distribution table
GOI	Gain on ignition
H_0	Null hypothesis
H_1	Alternate hypothesis
g/t	Grams per tonne
k	Coverage factor, e.g. $k=2$ for 95% level of confidence
LOC	Level of confidence or confidence level
LOD	Limit of detection
LOQ	Limit of quantitation
LOI	Loss on ignition
MS	Mean squares (ANOVA)
MSb	Mean squares between(ANOVA)
MSw	Mean squares within (ANOVA)
N	Number of labs
n	Number of replicates
μ	Property or certified value of a CRM
p	' p -value' a measure of the strength of evidence against H_0
P	Total number of data points in ANOVA
ppm	Parts per million. Equivalent to g/t
RSD	Relative standard deviation usually expressed as % at a 68% LOC
Replicates	Replication is the repetition of an experimental condition so that the variability associated with an analysis can be estimated (ASTM E1847)
s	Standard deviation
s_r	Within laboratory repeatability as derived from ANOVA
s_s	Between laboratory standard deviation as derived from ANOVA
SS	Sum of squares in ANOVA
SST	Total variation in ANOVA
SSB	Between group (laboratory) variance
SSW	Within group (laboratory) variance

Abbreviation/Symbol	Description
2s	Two times standard deviation
SI	Standard International system of units
t_{calc}	Calculated t statistic from a one-sample, two-tailed t-test
t-critical or t_{crit}	t-critical value at given alpha and degrees of freedom
Tonne	A metric ton, is a unit of mass equaling 1000 kilograms
=TINV(5%, <i>df</i>)	MS Excel function for t-critical value at LOC 95% and <i>df</i>
<i>U</i>	Expanded uncertainty at a given k
<i>u</i>	Standard uncertainty at k=1
u_c	Combined standard uncertainty at $k=1$
μm	Micron, is an SI derived unit of length equaling 1×10^{-6} of a meter

5. Uncertified Concentration Values

Appendix 1 gives uncertified concentrations for other elements present in the CRM.

6. Units

All results for major oxides are reported as oxides in percentages. All results for major elements analyses reported in percentages or ppm. Results for Au and the platinum group elements are reported in g/t or ppm. Specific gravity (SG) is the ratio of the density of a substance to the density of a reference substance, *i.e.* equivalently; it is the ratio of the mass of a substance to the mass of a reference substance for the same given volume. Since specific gravity is a ratio of densities its units are therefore dimensionless.

7. Analytical and Physical Methods

A complete list of analytical and physical methods as generic method codes with a brief description of the methods is available on the AMIS web site www.amis.co.za

8. Origin of Material

The material was sourced from the Sentinel Copper Mine owned by Kalumbila Minerals Limited (KML), a First Quantum subsidiary. The Sentinel copper mine is situated on the southern portion of the Trident copper project area. The mine is a stratabound, sediment hosted copper-nickel-cobalt deposit. Sentinel is approximately 150 kilometers west of the town of Solwezi in North Western Province of Zambia.

9. Approximate Mineral and Chemical Composition

The Sentinel copper deposit is a structurally modified sediment hosted copper deposit. Copper mineralisation is hosted within a phyllite package. Copper mineralisation is dominated by chalcopyrite which occurs as fine to coarse disseminations and or veinlets, with extensive zones of pyrite, particularly in the hanging wall, and with pyrrhotite occurring throughout. The copper sulphides are focused in a relatively carbon-rich zone in the center of the phyllite hosted orebody. The host phyllite is very fine grained, with quartz, muscovite, biotite and iron sulphides present.

10. Quantitative Analysis by X-Ray Diffraction

Both natural and synthetic materials have a specific chemistry and atomic arrangement, known as phases. Phases can be identified and quantified using X-ray diffraction (XRD) which produces a plot of the intensity of X-rays scattered at different angles by crystalline phases in a material. Essentially, an X-ray diffraction pattern is the sum of the diffraction patterns produced by each phase. Simply put, an X-ray diffraction pattern is a fingerprint that allows the identification of what is in a target sample material. Knowledge of the mineral phase composition is useful in method development with techniques such as ICP-OES and XRF as potential matrix effects and spectral interferences can be recognised and accounted for. X-ray diffraction is effective in that it allows the identification of different phases of compounds that are identical in chemistry, but have a distinctly different the atoms, e.g. quartz, cristobalite, and glass are all different phases of SiO₂. Where quantitative XRD results do not correspond to results of other analytical techniques, it should be borne in mind that even though the data are quantitative they are meant to be used for indicative purposes in development of other analytical methods. Mineral names may not reflect the actual compositions of minerals identified, but rather the mineral group.

Quantification is determined from the chosen software package: this uses the full-profile Rietveld method of refining the profile of the calculated XRD pattern against the profile of the measured XRD pattern. The total calculated pattern is the sum of the calculated patterns of the individual phases. Results are given as weight % of the total crystalline phases and amorphous content. The amorphous content quantifies the amorphous material and unknown minerals or known minerals for which there is not a suitable crystal structure.

Corrections are incorporated into the process that allows for a more accurate description of the mineral's contribution to the measured pattern and to allow for variation due to atomic substitution, layer disordering, preferred orientation, and other factors that affect the acquisition of the XRD scan.

The limitations of qualitative XRD analysis are as follows:

- The detection of a phase may be dependent on its crystallinity.
- Where there exist multiple phases, overlap of diffracted reflections can occur, thus rendering some ambiguity into the interpretation.
- Overlapping reflections of a major phase can mask the presence of minor or trace phases.
- Some phases cannot be unambiguously identified as they are present in minor or trace amounts.

The limitations of quantitative XRD analysis by a full-profile Rietveld method are as follows:

- The limitations for qualitative XRD analysis apply.
- The method as described is standardless: it relies solely on the published crystallographic data available for each phase. Some data may not exactly describe the phases present.
- Particle size is important with respect to the absorption of the X-rays by the sample.
- Micronising reduces the particle size to that more suitable for quantitative analysis.

The accuracy of the analysis is dependent on sampling and sample preparation in addition to the calculated profiles being exactly representative of the chemistry of the component phases and their crystallinity. Some preferred orientation effects and reflection overlaps may occur which cannot be adequately resolved.

Table 5. Results of XRD analysis.

Phase	Formula	Composite %
Amorphous Content		9
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$	2
Calcium Plagioclase	$(Ca,Na)(Si,Al)_4O_8$	5
Chalcopyrite	$CuFeS_2$	57
Expanding Clay		<1
Illite/Muscovite	$(K,Ca,Na)(Al,Mg,Fe)_2(Si,Al)_4O_{10}(OH)_2$	3
Pyrite	FeS_2	9
Pyrrhotite	$Fe(1-x)S_x$ ($x=0-0.2$)	4
Quartz	SiO_2	11
Siderite	$FeCO_3$	<1
Sphalerite	$(Zn,Fe)S$	1
Total		101%

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11. Health and Safety

The material is a very fine powder coloured dark gray (Corstor 5YR 6/2). Safety precautions for handling fine particulate matter are recommended, such as the use of safety glasses, breathing protection, gloves and a laboratory coat.

12. Method of Preparation

The particle size distribution for this material was shown to have a nominal top size of 54µm (95% passing 54µm). The procedure of preparation in brief is as follows: the material was crushed, dry-milled and air-classified to <54µm. It was then blended in a bi-conical mixer, systematically divided and sealed into 1kg Laboratory Packs. Explorer Packs are then subdivided from the Laboratory Packs as required. Final packaged units were then selected on a random basis and submitted for analysis to an independent laboratory accredited with the ISO17025 standard of general requirements for the competence of testing and calibration laboratories. The results obtained from this laboratory are then evaluated statistically by AMIS for homogeneity.

13. Particle Size Determination

The sample has been analysed using a Malvern Mastersizer 2000. Particles are passed through a focused laser beam that scatter light at an angle inversely proportional to their size. The intensity of light is measured and converted to a volume in particle size distribution. The results for this standard are presented in Table 6.

Table 6. Particle Size Determination by laser diffraction.

Size (µm)	Vol. Under %
<45um	92.3
<63um	94.5
<75um	995.6
<90um	97.0
<100um	97.8
<106um	98.3
<150um	99.97

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14. Handling

The material is packaged in Laboratory Packs and Explorer Packs that must be shaken or otherwise agitated before use. The analyte concentrations are quoted on a dry basis; therefore, the user needs to determine the moisture content to convert any obtained assay values to an air-dry basis (see Appendix 7 for an example calculation).

15. Storage information

The material should be stored in a cool dry place, in such a way that it does not compromise the integrity of the CRM. The material should be stored in conditions which will ensure it does not absorb moisture.

16. Methods of Analysis Requested

The following methods of analysis were requested:

- a) Au-Pb collection finished with either ICP-OES or ICP-MS or AAS or gravimetric
- b) Multi element scan to include all elements and oxides by Peroxide Fusion
- c) Multi element scan to include all elements and oxides by 4 acid digests with any finish
- d) Cu-Acid soluble
- e) LOI and all major oxides with XRF finish (Please specify the temperature for LOI)
- f) SG – gas pycnometer
- g) S and C Combustion/LECO
- h) Moisture

17. Information Requested of Participating Laboratories

The following information was requested of the participating laboratories for the development of this CRM:

- a) State aliquots used for all determinations.
- b) All results for major elements to be reported as oxides in percentages.
- c) All results for multi-element scans and fusion to be reported in ppm.
- d) All results for Au to be reported in ppm.
- e) Report all QC data, to include replicates, blanks and certified reference materials used.
- f) All Round robin samples must be treated the same as routine test samples.
- g) All results must be reported to maximum decimal places i.e. dependent on laboratories capabilities
- h) Please ensure moisture content is determined and calculated. All results should be corrected by the moisture correction factor and this factor should be stated in the laboratory results.
- i) Please use the excel template provided by AMIS. If you require a copy, please email any of the email addresses below. Ensure all uncertainties are added to the results.
- j) Please send excel and PDF of all results.
- k) Ensure correct PPE is used i.e. gloves, dust masks and protective clothing.
- l) Analysis should be done under controlled environmental conditions

18. Certification of Mean and Estimation of Measurement Uncertainty

The samples used in this certification process have been selected in such a way as to represent the entire batch of material and were taken from the final packaged units; therefore, all sources of uncertainty are included in the combined standard uncertainty determination. Initially the data submitted by all the laboratories are subjected to a z-score test, equation [1] to exclude outliers and the remaining data sets examined for their normality in distribution. This is followed by the exclusion of further outliers as defined by the IUPAC Harmonised Protocol of 1995 in which both Cochran and a Grubbs test are applied until all outliers are identified, equations [2] and [3]. A grand mean and standard deviation is re-calculated using all remaining data (Thompson, 2008; Carr, 2011) (see Appendix 2)

19. Two Standard Deviations

AMIS reports two-standard deviations (2s) with all certified values. Two -standard deviations are calculated using the expression:

$$\text{Two standard deviations} = 2 (u_c)$$

Where u_c is the standard combined uncertainty (see Appendix, equation [14]).

20. Confidence Interval

AMIS reports a confidence interval (CI) with all certified values. Confidence interval as used by AMIS is:

$$\text{Confidence Interval (CI)} = \frac{(t_{critical})s}{\sqrt{N}}$$

Where, N is the number of laboratories (accepted laboratory data), $t_{critical}$ is a two-tailed value for $N - 1$ degrees of freedom (df) and s , is the standard deviation of the accepted laboratory means. A two-tailed critical value is found for $N - 1$ degrees of freedom from either a t -distribution table (Appendix 9) or MS Excel as =TINV (5%, df).

21. Expanded Uncertainty

ANOVA gives an estimate of the repeatability and the reproducibility of the data accepted for certification of the candidate reference material (see equations, [15] and [16], in the Appendix). Therefore, random variables (e.g., subsampling, instrument effects, interferences, operators and measurement conditions) that occur during the analysis of the candidate reference material by the various laboratories is considered. This approach does not necessarily quantify each individual source of uncertainty; however, the combined effect of random uncertainties is assessed (Ramsey & Ellison, 2007). A combined standard uncertainty is calculated from equation [14], which when multiplied by the t -critical value for $N-1$ laboratories, gives an *expanded uncertainty* at a 95% level of confidence. The expanded uncertainty is a measure of the doubt around the certified value at a level of 95% confidence. The expanded uncertainty is used in the validation of accuracy (see equation [18]).

22. Confidence Interval and Expanded Uncertainty

A combined standard uncertainty will be greater than a combined CI . This is because ANOVA considers the within-lab repeatability (that is repeatability within each lab group) as well as the repeatability between each lab data set. This attends to random variables that contribute to the measurement of uncertainty, during the analysis of the test sample at the participating laboratories. The within-lab repeatability and the between lab repeatability is combined as the square root of the sum of squares of these two values giving a combined standard uncertainty, at a 68% confidence level. Multiplying the combined standard uncertainty by the t -critical value for $N-1$, gives the expanded uncertainty at 95% level of confidence. It is recommended that the procedure described in Appendix 6, "Using the CRM in Quality Control" be used, in setting the limits of the CRM. Table 7 below shows mean gold values obtained by fire assay lead collection, for nine different laboratories, the confidence interval, two-standard deviations and expanded uncertainty.

Table 7. Example of replicate assay data in which the *CI*, 2s and *U* are shown.

Lab No.	Mean Au (g/t)
1	0.268
2	0.273
3	0.270
4	0.288
5	0.274
6	0.256
7	0.263
8	0.258
9	0.288

<i>CI</i>	0.0088
2s	0.031
<i>U</i>	0.04

23. Participating Laboratories

The laboratories that are accredited with ISO17025 and provided timeous results are:

1. Bureau Veritas Minerals Ultra Trace Pty Ltd
2. ALS Geochemistry Arabia
3. ALS Geochemistry SA
4. ALS Geochemistry Vancouver
5. Intertek Perth
6. Samancor Western Chrome Mine
7. SGS Vancouver (Canada)

24. Accepted Assay Data

Data from the 7 laboratories used for certification are set out in Table 8.

Table 8. Data used to calculate the certified values after removal of outliers.

4A_MICP	4A_MICP	FUS	4A_MICP	4A_MICP	FUS	Pb Collection	LOI	SG	Combustion/LECO	Combustion/LECO
Ag	Al	Al	Cu	Co	Co	Au	LOI	SG	C	S
ppm	ppm	ppm	ppm	ppm	ppm	g/t	%	Dimensionless	ppm	%
2.00	12900	13600	221000	1350	1380	0.23	15.80	3.82	23200	28.30
2.00	12000	13300	228000	1310	1350	0.49	15.90	3.81	23300	28.10
2.00	12700	13500	223000	1340	1300	0.30	16.00	3.81	23400	28.40
2.00	12500	13400	224000	1340	1350	0.48	15.90	3.82	23600	28.10
2.00	12800	13800	226000	1360	1350	0.23	16.00	3.79	23000	28.20
2.00	12900	13600	220000	1320	1380	0.27	16.10	3.81	23400	28.10
2.00	12800	13600	226000	1340	1383	0.29	16.00	3.73	23300	28.30
1.40	12500	13500	228000	1310	1411	0.29	15.90	3.79	23300	28.00
1.20	13200	13800	224000	1390	1375	0.41	16.00	2.88	20700	29.50
1.00	13300	13800	219000	1310	1398	0.43	16.05	3.01	21100	29.50
1.10	13400	13800	223000	1375	1394	0.35	15.95	2.99	20800	30.00
1.10	13300	13900	226000	1350	1390	0.38	15.90	3.10	21000	29.50
1.50	13200	14000	224000	1380	1382	0.37	16.15	2.98	21000	29.50
1.30	13100	14100	224000	1390	1383	0.38	16.10	2.98	20800	29.50
1.80	14100	13800	226000	1380	1380	0.42	16.05	3.73	22400	29.70
1.70	11600	14200	220000	1360	1405	0.44	16.20	3.56	22100	28.80
1.70	11500	13882	220000	1440	1333	0.25	15.77	3.55	21900	28.80
1.60	11700	14037	227000	1465	1343	0.38	15.68	3.52	22300	28.80
1.80	11700	13457	223000	1465	1374	0.39	15.65	3.68	22000	28.90
1.70	11500	13390	226000	1460	1399	0.35	15.68	3.55	22400	29.10
1.90	11400	13710	223000	1455	1408	0.38	15.80	3.51	22100	29.10
1.70	11600	13937	228000	1435	1440	0.38	15.66	3.66	21700	29.00
	11600	13831	230000			0.45	15.74	4.21	22600	29.00
		13661	224000			0.34	15.68	3.98	22700	28.20
			231628			0.37		4.06	22600	28.70
			229565			0.23		4.06	22500	28.20
			230943			0.46		4.19	22800	28.60
			232441			0.22		3.99	22700	28.30
			230912			0.44		4.02	22500	28.10
			233035			0.37		3.96	22600	28.30
			230013			0.24		3.80	23100	28.20
			231151			0.39		3.78	23200	29.16
						0.32		3.82	23500	28.88
						0.35		3.82	23300	29.18
						0.30		3.83	23500	29.09
						0.37		3.82	23300	29.43
						0.41		3.83	22900	29.34
						0.33		3.83	23100	28.97
						0.35				29.32
										27.60
										27.70
										27.60
										28.00
										27.90
										27.90
										27.90
										28.00

Assay Data (Cont.)

FUS	FUS	FUS	FUS	FUS	FUS	FUS
Al ₂ O ₃	BaO	Fe ₂ O ₃	K ₂ O	MgO	MnO	TiO ₂
%	%	%	%	%	%	%
2.57	0.01	38.60	0.65	0.83	0.02	0.13
2.51	0.01	38.60	0.65	0.80	0.02	0.15
2.55	0.01	39.03	0.65	0.81	0.02	0.13
2.53	0.01	39.17	0.66	0.86	0.02	0.15
2.61	0.01	39.75	0.65	0.86	0.02	0.15
2.57	0.01	39.46	0.66	0.83	0.02	0.13
2.57	0.01	39.60	0.65	0.81	0.02	0.15
2.55	0.01	39.03	0.66	0.86	0.02	0.15
2.60	0.01	37.20	0.60	0.76	0.02	0.12
2.60	0.01	37.20	0.60	0.71	0.02	0.13
2.60	0.01	36.70	0.60	0.76	0.01	0.13
2.64	0.01	37.40	0.70	0.74	0.01	0.13
2.65	0.01	37.50	0.70	0.76	0.01	0.13
2.66	0.01	37.60	0.70	0.75	0.02	0.14
2.61	0.01	38.93	0.70	0.75	0.02	0.13
2.68	0.01	38.49	0.70	0.80	0.02	0.14
2.62		38.05	0.66	0.81		0.14
2.65		39.12	0.59	0.81		0.14
2.54		39.31	0.65	0.82		0.14
2.53		39.80	0.63	0.82		0.14
2.59		38.90	0.61	0.82		0.14
2.63		40.24	0.72	0.81		0.14
2.61		36.38	0.65	0.83		0.14
2.58		37.50		0.74		0.14
		35.80		0.77		0.13
		35.90		0.73		0.15
		36.23		0.73		0.14
		37.29		0.75		0.13
		37.07		0.75		0.13
		38.27		0.75		0.13
				0.76		0.15

Assay Data (Cont.)

4A MICP	FUS	4A MICP	4A MICP	FUS	4A MICP	FUS	4A MICP	4A MICP	FUS	4A MICP
As	Ba	Be	Ca	Cr	Fe	Fe	Ga	K	K	La
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
15.00	89.54	1.00	1900	200	267000	270000	6.80	5400	5000	30.20
16.00	89.54	1.00	1900	200	263000	270000	6.80	5200	5000	30.40
16.00	89.54	1.00	1800	200	263000	273000	6.80	5300	5000	30.90
16.00	89.54	1.00	1800	200	275000	274000	7.00	5300	5000	30.90
16.00	89.54	1.10	1800	200	272000	278000	6.80	5300	5000	31.30
15.00	89.54	1.10	1800	200	273000	276000	7.00	5300	5000	32.00
16.00	89.54	1.10	1800	200	271000	277000	7.00	5300	5000	31.10
16.00	89.54	1.10	1700	200	273000	273000	6.80	5300	5000	30.30
12.00	87.00	1.00	1700	174	276000	260000	10.00	5700	5400	30.00
13.00	82.00	1.10	1700	181	283000	260000	10.00	5700	5400	30.00
14.00	83.00	1.20	1700	177	285000	256000	10.00	5800	5300	30.00
14.00	83.00	1.20	1700	184	284000	261000	10.00	5800	5400	30.00
11.00	83.00	1.20	1700	186	281000	262000	10.00	5600	5500	30.00
12.00	85.00	1.20	1700	183	278000	263000	10.00	5700	5500	30.00
16.00	81.00	1.10	1800	177	280100	272300	10.00	5400	5400	30.00
15.00	86.00	1.20	1800	183	276100	269200	10.00	5300	5600	30.00
14.00		1.20	1800		281300	266100	10.00	5400		26.60
16.00		1.20	1900		282000	273600	10.00	5400		26.80
15.00		1.30	1800		278600	275000	10.00	5300		26.40
14.00		1.30	1800		274200	278400	10.00	5400		26.10
14.00		1.30	1900		280400	272100	10.00	5400		26.00
13.00		1.20	1800		278700	281500	10.00	5300		26.10
14.00		1.30	1800			254433	10.00			26.30
13.00		1.30	1900			262317	10.00			27.20
		1.00	1800			250427				
		0.90	1800			251125				
		0.90	1800			253409				
		1.00	1900			260824				
		0.90	1800			259284				
		0.90				267683				
		0.90								

Assay Data (Cont.)

4A_MICP	FUS	4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP
Mg	Mg	Mn	Mn	Mo	Na	Ni	Ni	P
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
4200	5000	130	129	15.50	500	370	340	250
4100	4800	132	129	16.00	500	355	360	250
4200	4900	136	131	15.50	500	350	390	300
4200	5200	130	134	16.00	500	360	370	300
4300	5200	132	144	15.50	500	370	380	300
4300	5000	128	135	16.50	500	360	380	250
4300	4900	130	133	16.50	500	360	370	250
4200	5200	130	133	15.50	500	355	377	250
4400	4560	114	123	15.00	500	360	381	270
4400	4260	114	119	15.00	500	347	384	240
4400	4560	112	115	15.00	500	357	384	260
4500	4440	112	115	14.00	500	361	392	240
4400	4560	113	116	14.00	500	354	389	260
4400	4500	117	122	14.00	500	357	383	270
4600	4500	114	137	14.00	500	353	390	280
4700	4900	120	125	15.00	500	360	368	250
4500	4900	125		15.00	400	360	407	240
4500	4900	122		16.00	400	366	406	250
4500	5000	130		15.00	400	362	350	270
4600	5000	129		16.00	400	370	370	250
4600	5000	125		17.00	400	365	362	260
4600	4900	122		16.00	400	362	388	250
4500	5000	125		14.00	400	383	418	270
4500	4468	127		16.00	500	392		280
	4646			17.00		387		
	4408			17.00		394		
	4418			17.00		372		
	4531			16.00		388		
	4512			16.00		368		
	4552			16.00		372		
	4578			16.00		389		

Assay Data (Cont.)

4A_MICP	4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	FUS
Pb	Sr	Ti	Ti	V	Zn	Zn
ppm	ppm	ppm	ppm	ppm	ppm	ppm
305	11.00	800	0.60	25.00	690	630
308	10.50	900	0.60	25.00	665	690
309	11.00	800	0.60	25.00	670	650
307	11.50	900	0.60	25.00	680	650
316	11.50	900	0.60	25.00	690	680
307	11.50	800	0.60	25.00	670	670
314	11.50	900	0.60	20.00	660	660
309	11.50	900	0.60	25.00	660	680
301	11.00	720	0.50	20.00	658	707
282	12.00	780	0.50	17.00	638	691
296	11.00	780	0.50	20.00	656	719
289	13.00	780	0.50	17.00	661	747
292	12.00	780	0.50	20.00	659	705
295	12.00	840	0.50	20.00	663	714
295	13.00	780	0.50	20.00	661	649
289	13.00	840	0.50	17.00	655	671
297	12.00	800		18.00	750	640
292	12.00	800		19.00	733	635
296	12.00	800		18.00	729	641
287	12.00	800		18.00	728	665
275	12.00	800		18.00	720	636
289	13.00	800		17.00	698	652
290	12.00	800		19.00	728	
293	13.00	800		19.00	712	
	11.20	768				
	11.10	876				
	11.30	837				
	10.20	776				
	10.20	776				
	9.70	779				
	10.00	871				
	10.00					

25. Reported Values

The certified values listed in this certificate fulfil the AMIS statistical criteria (see section 18) regarding agreement for certification and have been independently validated by Allan Fraser.

26. Validation of Accuracy (Trueness)

This CRM can be used to validate accuracy (trueness) as required in method validation as stated in the ISO17025 standard. See Appendix 3 for an example on the validation of accuracy using replicate data derived from the analysis of a CRM.

27. Metrological Traceability

The values quoted herein are based on the consensus values derived from statistical analysis of the data from an inter-laboratory measurement program. Traceability to SI units is via the standards used by the individual laboratories the majority of which are accredited to the ISO17025 general requirements for the competence of testing and calibration laboratories and who have maintained measurement traceability during the analytical process.

28. Period of Validity

The certified values are valid for this product, while still sealed in its original packaging, until notification to the contrary. The stability of the material will be subject to continuous testing for the duration of the inventory. Should product stability become an issue, all customers will be notified and notification to that effect will be placed on the www.amis.co.za website.

29. Minimum Sample Size

Most of the laboratories reporting used a 0.5g sample size for the ICP-OES and a 30g sample size for the fire assay. These are the recommended minimum sample sizes for the use of this material.

30. Availability

This product is available in Laboratory Packs containing 1kg of material and Explorer Packs containing custom weights (from 50 to 250g) of material. The Laboratory Packs are sealed bottles delivered in sealed foil pouches. The Explorer Packs contain material in standard geochem envelopes, nitrogen flushed, and vacuum sealed in foil pouches.

31. Recommended use in Quality Control

Users should set their own limits *i.e.* 1, 2 and 3 standard deviations from an obtained mean value based on at least 10 replicate analyses using this CRM (see Appendix 6 for detail on the use of this CRM in quality control).

32. Legal Notice

This certificate and the reference material described in it have been prepared with due care and attention. However, AMIS, Makhosi Khoza, and Allan Fraser; accept no liability for any decisions or actions taken following the use of the reference material.

Date of Version 000: 18 June 2019

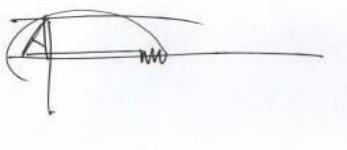
Version: 000

Approving Officer:

African Mineral Standards: _____

Makhosi Khoza (Quality Specialist)

Certifying Officer:

A handwritten signature in black ink, appearing to be 'A. Fraser', written over a horizontal line.

Geochemist: _____

Allan Fraser

M.Sc. (Geology), N.D. (Analytical Chem.),
Pr.Sci.Nat. Pr.Chem.SA

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Appendices

Appendix 1: Uncertified Element Statistics

Uncertified element statistics are shown in **Table 9**.

Table 9. Uncertified element concentrations statistics.

Element	Generic Method	n	Mean	SD	RSD %	Unit
Ag	2A_MICP	8	2.0	0.1	4	ppm
Al	2A_ICPES	8	4587.5	99.1	2	ppm
Al	2A_MICP	8	4637.5	184.7	4	ppm
Al ₂ O ₃	FS_ICPMS	8	2.5	0.01	0.3	%
Al ₂ O ₃	XRF	8	2.6	0.01	1	%
As	2A_MICP	8	18.8	2.1	11	ppm
As	FUS	2	100.0	*	*	ppm
B	4A_MICP	8	35.0	9.3	26	ppm
B	FUS	7	60.4	4.3	7	ppm
Ba	2A_MICP	8	20.0	*	*	ppm
Ba	4A_MICP	23	55.3	37.5	68	ppm
Be	2A_MICP	7	0.6	*	*	ppm
Be	FUS	7	1.0	*	*	ppm
Bi	2A_MICP	6	10.7	1.4	13	ppm
Bi	4A_MICP	20	15.2	1.8	12	ppm
Bi	FUS	8	14.1	0.4	3	ppm
Ca	2A_ICPES	8	1100.0	*	*	ppm
Ca	2A_MICP	8	1150.0	130.9	11	ppm
Ca	FUS	24	1665.6	446.5	27	ppm
CaO	FS_ICPMS	7	0.3	*	*	%
CaO	FUS	24	0.2	0.1	29	%
CaO	XRF	8	0.2	0.01	3	%
Cd	2A_MICP	5	0.6	0.1	17	ppm
Cd	4A_MICP	27	1.2	0.5	39	ppm
Ce	4A_MICP	16	63.1	2.9	5	ppm
Co	2A_ICPES	8	1451.9	29.0	2	ppm
Co	2A_MICP	8	1462.5	51.8	4	ppm
Cr	2A_MICP	8	31.4	0.7	2	ppm
Cr	4A_MICP	24	100.0	25.1	25	ppm
Cr ₂ O ₃	FUS	14	0.02	0.001	6	%
Cs	4A_MICP	15	0.9	0.1	5	ppm
Cs	FUS	8	1.5	0.3	17	ppm
Cu	2A_ICPES	8	217500.0	2138.1	1	ppm
Cu	2A_MICP	8	223875.0	1807.7	1	ppm

Element	Generic Method	n	Mean	SD	RSD %	Unit
Cu	CL	8	26611.3	703.8	3	ppm
Cu	FUS	14	225700.4	3007.2	1	ppm
Cu	SAL	16	5148.1	550.9	11	ppm
Cu	Titration	8	224387.5	223.2	0.1	ppm
Cu	XRF	8	228500.0	534.5	0.2	ppm
Dy	4A_MICP	16	2.8	0.8	29	ppm
Er	4A_MICP	16	1.3	0.7	52	ppm
Eu	4A_MICP	16	0.7	0.04	6	ppm
Fe	2A_ICPES	8	302125.0	5540.4	2	ppm
Fe	2A_MICP	7	251957.1	2416.5	1	ppm
Fe ₂ O ₃	FS_ICPMS	8	37.3	0.1	0.2	%
Fe ₂ O ₃	XRF	8	38.1	0.1	0.1	%
FeO	FUS	8	64.0	0.1	0.2	%
Ga	FUS	8	6.9	0.8	12	ppm
Gd	4A_MICP	16	3.9	0.5	12	ppm
Ge	4A_MICP	3	0.6	0.2	24	ppm
Hf	4A_MICP	16	3.8	0.3	8	ppm
Hg	2A_MICP	8	1.3	0.5	37	ppm
Ho	4A_MICP	16	0.5	0.2	40	ppm
In	4A_MICP	16	4.1	0.1	2	ppm
In	FUS	8	3.8	0.1	3	ppm
K	2A_MICP	8	2237.5	51.8	2	ppm
K ₂ O	XRF	8	0.6	0.002	0.3	%
La	2A_MICP	8	17.5	4.6	26	ppm
Li	4A_MICP	16	9.7	0.8	8	ppm
Li	FUS	8	22.3	7.4	33	ppm
LOI	LOI Additional	8	16.0	0.2	1	%
Lu	4A_MICP	16	0.2	0.1	51	ppm
Mg	2A_ICPES	8	2825.0	46.3	2	ppm
Mg	2A_MICP	8	3150.0	220.4	7	ppm
MgO	FS_ICPMS	7	0.8	*	*	%
MgO	XRF	8	0.9	0.01	1	%
Mn	2A_ICPES	8	87.1	3.5	4	ppm
Mn	2A_MICP	7	100.0	*	*	ppm

* denotes that the results were too similar and SD and RSD% could not be calculated

Table 9 (Continued)

Element	Generic Method	n	Mean	SD	RSD %	Unit
MnO	FS_ICPMS	8	0.02	*	*	%
MnO	XRF	8	0.02	0.01	32	%
Mo	2A_MICP	8	10.0	*	*	ppm
Mo	FUS	8	16.9	0.6	4	ppm
Moisture	Moisture	8	0.3	0.01	4	%
Na	FUS	8	444.0	*	*	ppm
Na ₂ O	FUS	8	0.1	*	*	%
Nb	4A_MICP	16	1.6	0.4	23	ppm
Nb	FUS	7	5.0	*	*	ppm
Nd	4A_MICP	16	26.2	1.1	4	ppm
Ni	2A_ICPES	8	374.9	5.8	2	ppm
Ni	2A_MICP	8	325.0	88.6	27	ppm
P	2A_MICP	8	250.0	7.6	3	ppm
P	FUS	8	201.7	22.6	11	ppm
P ₂ O ₅	FUS	8	0.05	0.01	11	%
P ₂ O ₅	XRF	8	0.1	0.001	2	%
Pb	2A_ICPES	8	307.3	4.1	1	ppm
Pb	2A_MICP	7	300.0	*	*	ppm
Pb	FUS	16	263.7	51.0	19	ppm
Pd	Pb Collection	14	0.2	0.01	3	g/t
Pr	4A_MICP	16	6.8	0.4	5	ppm
Pt	Pb Collection	15	0.3	0.01	5	g/t
Rb	4A_MICP	16	29.7	1.9	6	ppm
Rb	FUS	8	29.5	0.9	3	ppm
Re	4A_MICP	8	0.05	0.01	13	ppm
S	4A_MICP	23	27.8	1.6	6	%
S	FUS	15	28.5	0.5	2	%
S	XRF	7	28.8	*	*	%
Sb	2A_MICP	6	3.2	1.2	37	ppm
Sb	4A_MICP	21	4.2	1.3	32	ppm
Sb	FUS	8	4.8	0.4	8	ppm
Sc	4A_MICP	16	2.5	0.7	28	ppm
Se	2A_MICP	2	300.0	*	*	ppm
Se	4A_MICP	16	10.8	3.1	29	ppm
Si	FUS	16	62250.0	2053.2	3	ppm

Element	Generic Method	n	Mean	SD	RSD %	Unit
SiO ₂	FS_ICPMS	8	12.8	0.05	0.36	%
SiO ₂	FUS	16	13.3	0.5	3	%
SiO ₂	XRF	8	12.9	0.05	0.4	%
Sm	4A_MICP	16	4.9	0.6	13	ppm
Sn	2A_MICP	8	237.5	51.8	22	ppm
Sn	4A_MICP	16	55.5	1.6	3	ppm
Sr	2A_MICP	8	4.6	0.5	11	ppm
Ta	4A_MICP	16	0.4	0.05	11	ppm
Ta	FUS	8	0.9	0.1	8	ppm
Tb	4A_MICP	16	0.5	0.1	21	ppm
Te	2A_MICP	7	228.6	48.8	21	ppm
Te	4A_MICP	16	1.1	0.2	15	ppm
Th	4A_MICP	24	14.8	4.5	31	ppm
Th	FUS	8	11.4	0.1	1	ppm
Ti	2A_MICP	8	100.0	*	*	ppm
Ti	4A_MICP	12	400.0	*	*	ppm
TiO ₂	FS_ICPMS	7	0.1	*	*	%
TiO ₂	XRF	8	0.1	0.00	3	%
Tl	FUS	5	0.5	*	*	ppm
Tm	4A_MICP	15	0.2	0.1	48	ppm
U	2A_MICP	8	10.0	*	*	ppm
U	4A_MICP	18	11.1	0.5	5	ppm
U	FUS	8	11.7	0.3	3	ppm
V	2A_MICP	8	8.0	*	*	ppm
V	FUS	7	24.3	1.8	7	ppm
W	4A_MICP	15	14.0	19.0	136	ppm
W	FUS	6	3.0	1.4	47	ppm
Y	4A_MICP	8	11.2	0.5	4	ppm
Y	FUS	16	26.1	6.7	26	ppm
Yb	4A_MICP	16	1.2	0.7	54	ppm
Zn	2A_ICPES	8	737.3	11.3	2	ppm
Zn	2A_MICP	7	900.0	*	*	ppm
Zr	4A_ICPES	8	143.0	2.2	2	ppm
Zr	4A_MICP	16	142.3	3.7	3	ppm

* denotes that the results were too similar and SD and RSD% could not be calculated

Appendix 2 through 9, prepared by Allan Fraser.

Appendix 2. Certification of Reference Material and Estimation of Measurement Uncertainty

In the establishment of a consensus value for the CRM, outlier tests are carried out followed by performance statistics and the estimation of the measurement uncertainty. In practice, it is highly likely that data generated by multiple laboratories as an inter-laboratory comparison of material for certification, will contain erroneous as well as extreme measurements (outliers). The influence of outliers on summary statistics needs to be minimised by the application of procedures for outlier identification on raw data. The use of z-scoring, Cochran's test for suspect repeatability variances, along with Grubbs test for suspect measurement values allows for the detection of outliers (IUPAC, 1995). Method performance in terms of precision as relative standard deviation is judged by the application of the Horwitz ratio, which gives an indication of whether the observed relative standard deviation at the concentration levels of analyte determined are acceptable (Horwitz & Albert, 2006).

In the absence of an extensive uncertainty budget, measurement uncertainty is estimated from the reproducibility standard deviation from inter-laboratory data and reported as an expanded uncertainty at a level of confidence of 95% (Miller & Miller, 2010).

The steps below give detail on the establishment of a consensus value through the elimination of outliers, method performance and estimation of measurement uncertainty using standard uncertainties and the analysis of variance.

Z-Score

A z-score is calculated using equation [1]:

$$z = \frac{x - x_a}{s_p} \quad [1]$$

Where, x is the result of a submitted sample, x_a is the mean and s_p is the standard deviation of the submitted results from all the participating laboratories. Z-Scores are interpreted as follows:

$|z| \leq 2$ satisfactory performance
 $2 < |z| \leq 3$ questionable performance
 $|z| > 3$ unsatisfactory performance

(Thompson & Lowthian, 2011)

Data with z-scores exceeding two are discarded and are not included for further assessment.

Cochran's Test

The test of Cochran (1950) as shown in equation [2] is applied to any suspect repeatability variances:

$$C_{calc} = \frac{s_{max}^2}{\sum_{i=1}^l s_i^2} \quad [2]$$

Where, C_{calc} , s_{max}^2 and $\sum_{i=1}^l s_i^2$, are the calculated values for Cochran's test, data set with the maximum variance and the sum of the variances of all of the participating, l laboratory datasets. The C_{calc} value is compared with a critical value, C_{crit} at a level of confidence of 95% and an alpha of 0.05% (see Ellison, *et al.*, 2009, Appendix A, Table A.3a, page 209 for a table of critical values for the test of Cochran at LOC 95%).

According to ISO 5725-2 (1999), results from a laboratory with a suspect repeatability variance can be excluded if it is shown by the Cochran test to be an outlier. Therefore, if $C_{calc} > C_{crit}$, the laboratory with the maximum variance is removed. The data found to be excluded should not be $>2/9$, or 22% of the total data.

Grubbs Test

The test of Grubbs (1969) calculates a test statistic, G_{calc} and in the detection of a single outlier, G_1 is found by using

$$G_{1\,calc} = \frac{|Suspect\ value - \bar{x}|}{s} \quad [3]$$

Where, the sample mean and standard deviation, \bar{x} and s , are calculated with the suspect value included. The $G_{1\,calc}$ statistic is compared to a critical value for N measurements. See Ellison, *et al.*, 2009, Appendix A, Table A.2, page 208 for a table of critical values for the test of Cochran at LOC 95%.

Method Performance

The Horwitz function is used to assess the performance of the data under consideration, with respect to precision (Horwitz & Albert, 2006). A calculated %RSD is found using the Horwitz expression

$$\%RSD = \pm 2^{(1-0.5\log C)} \quad [4]$$

where, C is the analyte concentration in percent divided by 100 and \log is the natural logarithm. The observed %RSD is calculated as

$$Observed\ \%RSD = \frac{s}{Mean} \times 100 \quad [5]$$

where s is the standard deviation of n replicates.

The ratio of the observed %RSD and the calculated %RSD gives the Horwitz ratio (HorRat):

$$HorRat = \frac{\%RSD\ Observed}{\%RSD\ Calculated} \quad [6]$$

A HorRat <2 indicates that the method is of adequate precision. Should the HorRat be >2 the overall data are discarded, and the candidate material considered not suitable for certification as the precision is excessive for the concentration of the analyte being determined (Nelsen & Wehling, 2008).

Grand Mean

The grand mean ($\bar{\bar{x}}$) *i.e.* the certified value of a dataset is the total of all the data values divided by the total sample size (n):

$$\bar{\bar{x}} = \sum \frac{x}{n} \quad [7]$$

Certified Value

From ANOVA as per the description in section 18, an 'appropriate precision' as shown in [8] is calculated for sufficient homogeneity (Thompson, 2008):

$$s_r \leq 0.3u_c \quad [8]$$

Where, s_r is the within laboratory repeatability, as determined from [14]. Once [8] is satisfied, a grand mean [7] is calculated and this is taken to be the certified value.

Total Variation (SST)

The total variation (not the variance) comprises the sum of the squares of the differences of each mean with the grand mean.

$$SST = \sum (x - \bar{x})^2 \quad [9]$$

Between Group Variation (SSB)

The *variation* due to the between the laboratories is denoted SSB or Sum of Squares Between laboratories and given by [10]. If the laboratory means are close to each other (and therefore the Grand Mean) SSB will be a small value. There are P samples involved with one datum value for each sample (the sample mean), so there are P-1 degrees of freedom.

$$SSB = \sum n(\bar{x} - \bar{\bar{x}})^2 \quad [10]$$

The *variance* due to the interaction between the laboratories is denoted MSB for Mean Square Between groups and is the SSB divided by its degrees of freedom.

$$MS = \frac{SSB}{n - 1} \quad [11]$$

Within Group Variation (SSW)

The variation due to differences within individual samples is denoted SSW for Sum of Squares Within laboratories. The degrees of freedom are equal to the sum of the individual degrees of freedom for each sample. Since each sample has degrees of freedom (*df*) equal to one less than their sample sizes, and there are *k* samples, the total degrees of freedom is P less than the total sample size: $df = n - P$.

$$SSW = \sum df \cdot s^2 \quad [12]$$

The variance due to the differences within individual samples is denoted MSW for Mean Square Within groups. This is the within group variation divided by its degrees of freedom:

$$MSW = \frac{SSW}{P - n} \quad [13]$$

From equations [9] through [13], the ANOVA table as shown in Table 10 is developed.

Table 10. A single-factor ANOVA table showing key elements. Where P is the total number of groups, or laboratories. P-1 is 1 less than number of laboratories, P (n-1) is the number of data values minus number of groups (equals degrees of freedom for each group added together), and P-1 + P(n-1) is 1 less than the number of data points. MS is the mean squares of between laboratories and within laboratories. After Ellison *et al.*, (2009), Table 6.2, page 61.

Source	Sum of Squares	df	Mean Sum of Squares	F	p	F _{crit}
Between Laboratories	SSB	P-1	MSB=SSB/df	MSB/MSW	=FDIST(x,df,df)	F-table
Within Laboratories	SSW	P(n-1)	MSW=SSW/df	–	–	–
Total	SSB+SSW	P-1 + P(n-1)	–	–	–	–

Combined Standard Uncertainty

The combined standard uncertainty (u_c) represents the effects of random events such as days, instruments, and analysts on the precision of the analytical procedures of all accepted data of the participating laboratories. Using the output from ANOVA, the combined standard uncertainty (u_c) is determined from the square root of the sum of squares of the variances of the within laboratory repeatability, s_r , and the between laboratory precision, s_s :

$$u_c = \sqrt{s_r^2 + s_s^2} \quad [14]$$

Within laboratory repeatability is determined as

$$s_r = \sqrt{MSB} \quad [15]$$

and, the between laboratory precision as

$$s_s = \sqrt{\frac{(MSW - MSB)}{n}} \quad [16]$$

where MSW is the mean squares of the within laboratory variance, MSB is the mean squares for the between laboratories and n in this case, is the number of replicates in a group of the accepted data (Thompson & Lowthian, 2011).

Expanded Uncertainty

The expanded uncertainty (U) at a confidence level of 95% is determined by multiplication of the combined uncertainty (u_c) by a coverage factor (k) found from $N-1$ degrees of freedom (df), where N is the number of laboratory means accepted in the establishment of the certified value. The t-critical value for 5% significance can be found in a t-critical table (see Appendix 9, or from MS Excel as =TINV (5%, df)).

Uncertainty Statement

Typically, an uncertainty statement is presented as follows: Au =0.77±0.04 g/t, where the number following the symbol ± is the numerical value of an expanded uncertainty, $U = ku_c$, with U determined from a combined standard uncertainty multiplied by a coverage factor $k = 2$ or, a t-critical value for $N-1$ accepted laboratories. Since it can be assumed that the possible estimated values of the standard are approximately normally distributed with standard uncertainty, u_c , the certified value of the CRM is believed to lie in the interval defined by U with a level of confidence of approximately 95 %, e.g. a mean value of 0.77±0.04g/t will have intervals of: 0.73≤0.77≤0.81 g/t.

Appendix 3. Example: Comparison of Mean and Certified Value for Validation of Accuracy

According to ERM (2005); Eurolab (2007); Abzalov (2011) and Carr (2011), the validation of accuracy for a given mean and certified value requires the inclusion of the measurement uncertainty of the CRM in a t-test for statistical significance. The classical Student's t-test as shown in [17], does not consider the measurement uncertainty of the CRM. To compensate for this, Eurolab Technical Report No.1/2007 recommends equation [18] for the validation of CRMs with stated measurement uncertainties.

$$t_{calc} = \frac{|\bar{x} - \mu|}{\frac{s}{\sqrt{n}}} \quad [17]$$

$$t_{calc} = \frac{|\bar{x} - \mu|}{\sqrt{(u_{\mu})^2 + \frac{s^2}{n}}} \quad [18]$$

Where, t_{calc} is the calculated t-statistic, \bar{x} the mean of n replicates with a standard deviation of s for a CRM of μ certified value. The standard uncertainty u is the stated expanded uncertainty (U) of the CRM divided by the coverage factor (k) as stated on the certificate of analysis. Note that the $| \quad |$ bars indicate that the absolute value between the mean and the certified value is to be used, *i.e.* ignore the sign.

An example in which [18] is used for validation of accuracy is given below.

Example

A CRM is independently replicated nine times for Al_2O_3 concentration by XRF analysis, *i.e.* 9 individual fused glass beads were prepared. The observed mean and standard deviation of the replicate data are shown with the certified value and expanded uncertainty in Table 11. In validation of accuracy, the hypothesis question is: Is the difference between the observed mean and the certified value statistically significant at a level of confidence of 95%? Alternatively put, is there sufficient evidence to conclude that the data *i.e.* replicates generated, are inaccurate?

The relevant hypotheses are:

Null hypothesis: H_0 : Mean = Certified value of CRM with stated measurement uncertainty. The acceptance of H_0 means that accuracy is demonstrated; *i.e.* insufficient evidence to reject H_0 ;

Alternate hypothesis: H_1 : Mean \neq Certified value of CRM with stated measurement uncertainty. The acceptance of H_1 means that accuracy is not demonstrated, *i.e.* there is sufficient evidence to accept H_1 ;

Table 11. CRM certified value quoted expanded uncertainty U , the coverage factor for the CRM, $k=2.25$ and mean for $n=9$ replicates and corresponding standard deviation for the replicate data.

CRM Certified Value	Expanded % (U)	Coverage Factor (k)	Mean ($n=9$)	n	Standard Deviation (s)
4.62%	0.08%	2.25	4.59%	9	0.01015

The standard uncertainty (u) is found by dividing the expanded uncertainty by the coverage factor:

$$u = \frac{0.08}{2.25} = 0.0356 \%$$

Using the observed mean for the replicate data ($n=9$) obtained for the CRM and substituting into [18]:

$$t_{calc} = \frac{|\bar{x} - \mu|}{\sqrt{0.0356^2 + \frac{0.01015^2}{9}}} = \frac{|4.59 - 4.62|}{\sqrt{0.00126 + 0.00001145}} = 0.84$$

Therefore, $t_{calc} = 0.84$ and $t_{crit}(5\%, 8) = 2.31$ (df is 8, therefore, $t_{crit}=2.31$, see Appendix 9, page 32) which is >0.84 . Similarly, the p -value=0.43 which is >0.05 . This is strong evidence in favour of accepting the null hypothesis that there is no significant statistical difference between the certified value and the observed mean. Therefore, under the conditions that the uncertainty associated with the certified value is known, the accuracy is validated for the CRM tested. If the null hypothesis is accepted that the mean obtained is not statistically different from the certified value, then the principle of traceability has been conformed to.

Appendix 4. Two-standard Deviations

Two-standard deviations are calculated using the expression:

$$\text{Two standard deviations} = 2 (u_c) \quad [19]$$

Where, u_c is the standard combined uncertainty (equation [14]).

Appendix 5. Confidence Interval

Confidence interval is calculated as:

$$\text{Confidence Interval (CI)} = \frac{(t_{critical})s}{\sqrt{N}} \quad [20]$$

Where, N is the number of laboratories (accepted laboratory data), $t_{critical}$ is a two-tailed value for $N - 1$ degrees of freedom (df) and s , is the standard deviation of the accepted laboratory means. A two-tailed critical value is found for $N - 1$ degrees of freedom from either a t -distribution table (Appendix 9) or MS Excel as =TINV (5%, df).

Appendix 6. Using the CRM in Quality Control

QC chart control limits should not be determined by the certified value and stated measurement uncertainty of the certified reference material used. These parameters although “certified” will never be known; it is only the corresponding statistical estimates, *i.e.* standard deviation and the mean calculated from replicated results that are known and these should be used in quality control charts. However, should the laboratory choose to use the certified value as the mean then the quoted $2s$, or CI value for the CRM can be used in the quality control chart.

It is recommended that a Shewhart chart be developed for the use if this CRM is to be used as a control sample in laboratory quality control. A Shewhart chart is a plot of sequential assay results obtained from quality control material such as an AMIS CRM. The warning and control limits are based on the standard deviation obtained from the mean of the replicates of a CRM (Ellison, *et al.*, 2009; Thompson, 2010). The procedure in preparing a Shewhart chart is as follows:

1. Analyse 10 to 15 replicates or more of the AMIS CRM.
2. Apply the Grubbs test for outliers.
3. Determine the mean of the replicates after application of the Grubbs test.
4. Determine the standard deviation, using equation [21], of the replicates following Grubbs test.
5. Calculate the standard deviation, s from:

$$s = \sqrt{\frac{\sum(x_i - \bar{x})^2}{n - 1}} \quad [21]$$

where, x_i is an individual measurement in the data set, \bar{x} is the mean of the data set at $n-1$ degrees of freedom (df) and n is the number of replicates. The sample standard deviation can be found using the MS Excel formula “=stdev.s (number1;)”.

6. Verify accuracy of the mean value using equation [18].
7. Once accuracy is verified, calculate $\pm 2s$ and $\pm 3s$, where s is the standard deviation calculated from [21].
8. Construct the Shewhart control chart around the mean of n replicates.
9. Use $\pm 2s$ as the warning limits.
10. Use $\pm 3s$ as the control limits.
11. It is recommended that if 2 to 3 points are outside the warning limits analyse another sample and if it is then within warning limits, continue. If it is outside the warning limits, stop and troubleshoot.
12. It is recommended that if any point is outside control limits, analyse another portion (sample) of the CRM. If it is within control limits, continue. If it is outside control limits, stop and troubleshoot.
13. For reference purposes, the CRM certified value can be plotted on the Shewhart chart alongside the mean value.

On a regular basis the accuracy of the replicates of the CRM should be assessed in terms of the certified value of the CRM using equation [18].

Appendix 7. Conversion to Air-dry Basis (Prepared by Allan Fraser)

Since AMIS certified analyte values are reported on a dry-basis, the user laboratory is required to dry a portion (accurately weigh out 1.0 grams in duplicate) of the CRM material in air at 105°C in a drying oven to constant mass to determine the moisture content. Use a crucible with a flat inner surface with a surface area not smaller than 10 cm² with the CRM material spread evenly over same; this represents a 0.1 gram spread per cm². In correcting the certified value for moisture content, a moisture correction factor is calculated:

$$\text{Moisture correction factor (MCF)} = \frac{100 - \% \text{Moisture at } 105^{\circ}C}{100} \quad [22]$$

$$\text{Air dry basis concentration} = \text{MCF} \times \text{certified value on a dry basis} \quad [23]$$

Example

The moisture content determined at 105°C on a CRM is 0.500%. The certified analyte concentration for the CRM is 12.62±0.52% (dry basis). Calculating the moisture correction factor using [22] gives:

$$\text{Moisture correction factor} = \frac{100 - 0.500}{100} = 0.995$$

Multiplying the factor of 0.995 by the certified value as stated on the certificate of analysis on a dry basis (as in [23]) gives the analyte concentration on an air-dry basis:

$$0.995 \times 12.62\% = 12.56\%$$

The stated measurement uncertainty also needs to be corrected using [22] and [23], e.g. $0.995 \times 0.52 = 0.51_{(7)}$, rounded to 0.52%. The air-dry basis concentration *i.e.* $12.56 \pm 0.52\%$ is to be used as the certified value with its corresponding measurement of uncertainty.

Appendix 8. Example of Determination of LOD and LOQ in Fire Assay

The limit of detection (LOD) is the minimum detectable quantity of the analyte of interest (Skoog & West, 1985). To determine the LOD in fire assay by lead collection, the minimum mass that an assay microbalance is capable of weighing (m in micrograms, and the original test sample mass, $Mass_{assay}$ in grams) determines the LOD. The smallest prill mass most assay microbalances can measure is $1\mu\text{g}$ or 0.001mg . Even with a microscope it may be difficult to locate and pick up a prill weighing ten times that amount (*i.e.* 0.01mg or $10\mu\text{g}$) and weigh it. If an analyst can weigh a prill of $1\mu\text{g}$ then the LOD becomes $1\mu\text{g}$. However, the concentration factor would be 50 times for a 50-gram assay sample and therefore the LOD in g/t becomes $1\mu\text{g}$ divided by the original mass of the sample in grams taken for fire assay [24]. Therefore, the LOD in fire assay is computed as:

$$LOD = \frac{m (\mu\text{g})}{Mass_{assay} (g)} (\text{g/t}) \quad [24]$$

The limit of quantitation (LOQ), is simply the LOD multiplied by 10 (Long & Winefordner, 1983):

$$LOQ = 10 \cdot \frac{m (\mu\text{g})}{Mass_{assay} (g)} (\text{g/t}) \quad [25]$$

Therefore, with a sample mass of 50g taken for fire assay, the limit of detection would be 0.02g/t . *i.e.* $1\mu\text{g} = 1\text{g/t}$, therefore $1\mu\text{g}/50\text{g} = 0.02\text{g/t}$. If no prill was found, then the LOD result would be $<0.02\text{g/t}$ or "not detected". Using a larger assay sample mass improves the LOD and LOQ (Table 11). Table 13 gives a recommended reporting scheme for LOD and LOQ.

Table 12. Mass of assay sample and corresponding limit of detection and limit of quantitation for an assay microbalance capability of smallest prill mass of $1\mu\text{g}$ or 0.001mg .

Mass Assay Sample (g)	LOD (g/t)	LOQ (g/t)
30	0.03	0.3
50	0.02	0.2
100	0.01	0.1

Table 13. Recommended reporting scheme for LOD and LOQ in fire assay.

Data	Report as
<LOD	Not detected
<LOQ	Detected
$\geq\text{LOQ}$	Report assay result

Appendix 9. T-distribution table

Table 14. T-distribution table for t-critical values (t crit.) for a two-tailed t-test at a 95% level of confidence.

df	Two-tailed	df	Two-tailed
1	12.71	23	2.06
2	4.30	24	2.06
3	3.18	25	2.06
4	2.78	26	2.05
5	2.57	27	2.05
6	2.44	28	2.04
7	2.36	29	2.04
8	2.30	30	2.04
9	2.26	35	2.03
10	2.22	40	2.02
11	2.20	45	2.01
12	2.17	50	2.00
13	2.16	55	2.00
14	2.14	60	2.00
15	2.13	70	1.99
16	2.12	80	1.98
17	2.11	90	1.98
18	2.10	100	1.98
19	2.09	120	1.98
20	2.08	Infinity	1.96
21	2.08		
22	2.07		

End of certificate