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Certificate

AMIS0632

Certified Reference Material

Copper Feeds, 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) ⁸	(2s) ¹⁰ \pm	Unit
Cu	4A_MICP ¹	4117	133	ppm
Cu	FUS ²	4142	173	ppm
Co	4A_MICP	211	17	ppm
Co	FUS	204	23	ppm
Au	Pb Collection ³	0.017	0.0072	g/t
Pd	Pb Collection	0.069	0.0053	g/t
Pt	Pb Collection	0.137	0.0071	g/t
LOI	LOI ⁴	6.36	0.68	%
SG	SG ⁵	2.83	0.49	Dimensionless
C	Combustion/LECO ⁶	3.13	0.12	%
S	Combustion/LECO	1.89	0.10	%
S	4A_MICP	1.90	0.16	%
S	FUS	1.91	0.26	%
Al	4A_MICP	7.39	0.40	%
Al	FUS	7.90	0.30	%
Ba	4A_MICP	555	24	ppm
Be	4A_MICP	3	0.2	ppm
Bi	4A_MICP	1	0.3	ppm
Ca	4A_MICP	3851	298	ppm
Cd	4A_MICP	0.5	0.1	ppm
Ce	4A_MICP	99	19	ppm
Cr	4A_MICP	171	10	ppm
Cr	FUS	199	15	ppm
Cs	4A_MICP	5	0.1	ppm
Fe	4A_MICP	3.32	0.11	%
Fe	FUS	3.32	0.18	%
Ga	4A_MICP	20	0.9	ppm
Hf	4A_MICP	4	0.3	ppm
In	4A_MICP	0.1	0.01	ppm
K	4A_MICP	3.51	0.18	%
K	FUS	3.54	0.45	%
La	4A_MICP	43	9	ppm
Li	4A_MICP	28	1	ppm
Lu	4A_MICP	0.2	0.08	ppm
Mg	4A_MICP	1.79	0.14	%
Mg	FUS	1.82	0.095	%
Mn	4A_MICP	130	10	ppm
Mn	FUS	145	18	ppm
Mo	4A_MICP	11	3	ppm
Na	4A_MICP	2636	177	ppm
Ni	4A_MICP	98	4	ppm
Ni	FUS	99	16	ppm
P	4A_MICP	568	42	ppm
Pb	4A_MICP	119	15	ppm
Rb	4A_MICP	174	21	ppm
Sc	4A_MICP	13	1	ppm
Sn	4A_MICP	3	0.8	ppm
Sr	4A_MICP	37	3	ppm
Ta	4A_MICP	0.5	0.2	ppm
Tb	4A_MICP	0.7	0.05	ppm
Th	4A_MICP	18	5	ppm
Ti	4A_MICP	2328	281	ppm
Ti	FUS	3130	183	ppm
Tl	4A_MICP	0.9	0.07	ppm
U	4A_MICP	10	0.6	ppm
V	4A_MICP	120	7	ppm
Y	FUS	34	6	ppm
Zn	4A_MICP	157	8	ppm
Zn	FUS	150	21	ppm
Zr	4A_MICP	145	15	ppm

Major Oxides
Certified Concentrations (at two Standard Deviations)

Analyte	Method	Certified (μ) ⁸	(2s) ¹⁰ \pm	Unit
Al ₂ O ₃	FUS	14.92	0.57	%
Al ₂ O ₃	XRF ⁷	15.18	0.089	%
Cr ₂ O ₃	FUS	0.029	0.002	%
Fe ₂ O ₃	FUS	4.75	0.26	%
Fe ₂ O ₃	XRF	4.79	0.12	%
K ₂ O	FUS	4.26	0.54	%
K ₂ O	XRF	4.20	0.15	%
MgO	FUS	3.01	0.15	%
MgO	XRF	3.11	0.067	%
MnO	FUS	0.019	0.002	%
Na ₂ O	XRF	0.38	0.05	%
P ₂ O ₅	XRF	0.13	0.02	%
SiO ₂	XRF	63.53	1.0	%
TiO ₂	FUS	0.52	0.03	%
TiO ₂	XRF	0.53	0.02	%

1. Certified Concentrations and Uncertainties

AMIS0632 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) ⁸	N	n	k	% RSD	(u_c) ⁹	(2s) ¹⁰ ±	(CI) ¹¹ 95%	(U) ¹² ±	Unit
Cu	4A_MICP ¹	4117	5	38	2.776	2	66	133	67	184	ppm
Cu	FUS ²	4142	3	23	4.303	2	86	173	108	372	ppm
Co	4A_MICP	211	5	38	2.776	4	9	17	11	24	ppm
Co	FUS	204	3	23	4.303	6	11	23	25	49	ppm
Au	Pb Collection ³	0.017	6	47	2.571	21	0.0036	0.0072	0.003	0.01	g/t
Pd	Pb Collection	0.069	3	22	4.303	4	0.0027	0.0053	0.002	0.01	g/t
Pt	Pb Collection	0.137	3	22	4.303	3	0.0035	0.0071	0.003	0.02	g/t
LOI	LOI ⁴	6.36	4	32	3.182	5	0.34	0.68	0.54	1	%
SG	SG ⁵	2.83	5	38	2.776	9	0.24	0.49	0.32	0.7	Dimensionless
C	Combustion/LECO ⁶	3.13	4	32	3.182	2	0.058	0.12	0.085	0.2	%
S	Combustion/LECO	1.89	5	39	2.776	3	0.050	0.10	0.057	0.1	%
S	4A_MICP	1.90	5	38	2.776	4	0.081	0.16	0.10	0.2	%
S	FUS	1.91	2	15	12.706	7	0.13	0.26	1.0	2	%
Al	4A_MICP	7.39	4	30	3.182	3	0.20	0.40	0.30	0.6	%
Al	FUS	7.90	4	32	3.182	2	0.15	0.30	0.10	0.5	%
Ba	4A_MICP	555	4	31	3.182	2	12	24	17	38	ppm
Be	4A_MICP	3	5	38	2.776	4	0.1	0.2	0.1	0.3	ppm
Bi	4A_MICP	1	3	24	4.303	13	0.1	0.3	0.3	0.6	ppm
Ca	4A_MICP	3851	5	38	2.776	4	149	298	162	414	ppm
Cd	4A_MICP	0.5	4	26	3.182	13	0.07	0.1	0.1	0.2	ppm
Ce	4A_MICP	99	3	24	4.303	9	9	19	23	40	ppm
Cr	4A_MICP	171	4	30	3.182	3	5	10	4	16	ppm
Cr	FUS	199	4	29	3.182	4	8	15	10	24	ppm
Cs	4A_MICP	5	3	23	4.303	1	0.05	0.1	0.06	0.2	ppm
Fe	4A_MICP	3.32	4	30	3.182	2	0.054	0.11	0.057	0.2	%
Fe	FUS	3.32	4	31	3.182	3	0.090	0.18	0.11	0.3	%
Ga	4A_MICP	20	5	38	2.776	2	0.5	0.9	0.5	1	ppm
Hf	4A_MICP	4	3	24	4.303	4	0.2	0.3	0.4	0.7	ppm
In	4A_MICP	0.1	2	15	12.706	6	0.007	0.01	0.06	0.08	ppm
K	4A_MICP	3.51	5	39	2.776	2	0.088	0.18	0.081	0.2	%
K	FUS	3.54	3	24	4.303	6	0.22	0.45	0.53	1	%
La	4A_MICP	43	4	32	3.182	10	4	9	7	14	ppm
Li	4A_MICP	28	3	21	4.303	2	0.6	1	1	3	ppm
Lu	4A_MICP	0.2	3	24	4.303	22	0.04	0.08	0.09	0.2	ppm
Mg	4A_MICP	1.79	4	32	3.182	4	0.072	0.14	0.11	0.2	%
Mg	FUS	1.82	4	32	3.182	3	0.047	0.095	0.048	0.2	%
Mn	4A_MICP	130	5	38	2.776	4	5	10	6	14	ppm
Mn	FUS	145	2	16	12.706	6	9	18	74	112	ppm
Mo	4A_MICP	11	5	40	2.776	12	1	3	1	4	ppm
Na	4A_MICP	2636	5	39	2.776	3	88	177	83	245	ppm
Ni	4A_MICP	98	5	37	2.776	2	2	4	1	6	ppm
Ni	FUS	99	3	22	4.303	8	8	16	15	35	ppm
P	4A_MICP	568	4	28	3.182	4	21	42	36	67	ppm
Pb	4A_MICP	119	4	31	3.182	6	7	15	12	23	ppm
Rb	4A_MICP	174	3	24	4.303	6	11	21	26	46	ppm
Sc	4A_MICP	13	5	40	2.776	4	0.5	1	0.5	1	ppm
Sn	4A_MICP	3	2	16	12.706	14	0.4	0.8	3	5	ppm
Sr	4A_MICP	37	5	37	2.776	4	2	3	2	4	ppm
Ta	4A_MICP	0.5	3	24	4.303	19	0.1	0.2	0.2	0.4	ppm
Tb	4A_MICP	0.7	3	24	4.303	4	0.03	0.05	0.05	0.1	ppm
Th	4A_MICP	18	5	39	2.776	13	2	5	3	6	ppm
Ti	4A_MICP	2328	3	23	4.303	6	141	281	335	605	ppm
Ti	FUS	3130	4	32	3.182	3	92	183	96	291	ppm
Tl	4A_MICP	0.9	3	24	4.303	4	0.03	0.07	0.06	0.1	ppm
U	4A_MICP	10	4	26	3.182	3	0.3	0.6	0.4	1	ppm
V	4A_MICP	120	5	40	2.776	3	4	7	4	10	ppm
Y	FUS	34	2	16	12.706	9	3	6	28	40	ppm
Zn	4A_MICP	157	5	38	2.776	3	4	8	2	11	ppm
Zn	FUS	150	3	22	4.303	7	11	21	21	46	ppm
Zr	4A_MICP	145	3	23	4.303	5	8	15	19	33	ppm

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

Analyte	Method	Certified (μ) ⁸	N	n	k	% RSD	(u_c) ⁹	(2s) ¹⁰ \pm	(CI) ¹¹ 95%	(U) ¹² \pm	Unit
Al ₂ O ₃	FUS	14.92	4	32	3.182	2	0.29	0.57	0.21	0.9	%
Al ₂ O ₃	XRF ⁷	15.18	4	32	3.182	0.3	0.045	0.089	0.058	0.1	%
Cr ₂ O ₃	FUS	0.029	4	29	3.182	4	0.001	0.002	0.001	0.004	%
Fe ₂ O ₃	FUS	4.75	4	31	3.182	3	0.13	0.26	0.16	0.4	%
Fe ₂ O ₃	XRF	4.79	5	37	2.776	1	0.058	0.12	0.077	0.2	%
K ₂ O	FUS	4.26	3	24	4.303	6	0.27	0.54	0.64	1	%
K ₂ O	XRF	4.20	4	32	3.182	2	0.075	0.15	0.12	0.2	%
MgO	FUS	3.01	4	32	3.182	3	0.076	0.15	0.073	0.2	%
MgO	XRF	3.11	5	39	2.776	1	0.034	0.067	0.039	0.09	%
MnO	FUS	0.019	2	16	12.706	6	0.001	0.002	0.01	0.01	%
Na ₂ O	XRF	0.38	5	38	2.776	7	0.03	0.05	0.03	0.08	%
P ₂ O ₅	XRF	0.13	4	32	3.182	7	0.009	0.02	0.02	0.03	%
SiO ₂	XRF	63.53	4	32	3.182	1	0.51	1.0	0.79	2	%
TiO ₂	FUS	0.52	4	32	3.182	3	0.02	0.03	0.02	0.05	%
TiO ₂	XRF	0.53	4	32	3.182	2	0.01	0.02	0.01	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. XRF is X-ray Fluorescence
8. 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.
9. 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)
10. Two standard deviations (2s)
11. Confidence interval at 95% level of confidence.
12. 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 4A_MICP	0.412 %	Cu FUS	0.414 %	Equal Variance ($p=0.43$)	0.524	Accept H_0 ; certified values are equal
Co 4A_MICP	0.021 %	Co FUS	0.02 %	Equal Variance ($p=0.352$)	0.329	Accept H_0 ; certified values are equal
Al 4A_MICP	7.39 %	Al FUS	7.90 %	Equal Variance ($p=0.055$)	0.002	Reject H_0 ; certified values are <i>not</i> equal
Fe 4A_MICP	3.32 %	Fe FUS	3.32 %	Equal Variance ($p=0.153$)	0.903	Accept H_0 ; certified values are equal
K 4A_MICP	3.51 %	K FUS	3.54 %	Unequal Variance ($p=0.026$)	0.848	Accept H_0 ; certified values are equal
Mg 4A_MICP	1.79 %	Mg FUS	1.82 %	Equal Variance ($p=0.113$)	0.548	Accept H_0 ; certified values are equal
Mn 4A_MICP	0.013 %	Mn FUS	0.015 %	Equal Variance ($p=0.143$)	0.02	Reject H_0 ; certified values are <i>not</i> equal
Ni 4A_MICP	0.010 %	Ni FUS	0.010 %	Unequal Variance ($p=0.005$)	0.831	Accept H_0 ; certified values are equal
Ti 4A_MICP	0.233 %	Ti FUS	0.313 %	Equal Variance ($p=0.111$)	0.001	Reject H_0 ; certified values are <i>not</i> equal
Zn 4A_MICP	0.016 %	Zn FUS	0.015 %	Unequal Variance ($p=0.006$)	0.298	Accept H_0 ; certified values are equal
S Combustion/LECO	1.89 %	S 4A_MICP	1.90 %	Equal Variance ($p=0.143$)	0.831	Accept H_0 ; certified values are equal
Al ₂ O ₃ FUS	14.92 %	Al ₂ O ₃ XRF	15.18 %	Unequal Variance ($p=0.033$)	0.030	Reject H_0 ; certified values are <i>not</i> equal
Fe ₂ O ₃ FUS	4.75 %	Fe ₂ O ₃ XRF	4.79 %	Equal Variance ($p=0.197$)	0.454	Accept H_0 ; certified values are equal
MgO FUS	3.01 %	MgO XRF	3.11 %	Equal Variance ($p=0.239$)	0.006	Reject H_0 ; certified values are <i>not</i> equal
SiO ₂ FUS	66.45 %	SiO ₂ XRF	63.53 %	Unequal Variance ($p=0.003$)	0.258	Accept H_0 ; certified values are equal

Table 4. Comparison on mean values obtained from three different analytical methods for the determination of sulphur. A single-factor analysis of variance gives an F-ANOVA p -value of 0.949 and >0.05 , which is strong evidence to accept the null hypothesis that there all three means are equal.

Method	n	Mean % S	Variance
Leco Comb	5	1.89	0.0021
4A_MICP	5	1.90	0.0067
Fus	2	1.91	0.016

3. Intended Use

AMIS0632 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 5.

Table 5. 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, <i>e.g.</i> $k=2$ for 95% level of confidence
LOC	Level of confidence or confidence level
LOD	Limit of detection
LOQ	Limit of quantitation
LOI	Loss on ignition

Abbreviation/Symbol	Description
MS	Mean squares (ANOVA)
MSb	Mean squares between(ANOVA)
MSw	Mean squares within (ANOVA)
<i>N</i>	Number of labs
<i>n</i>	Number of replicates
μ	Property or certified value of a CRM
<i>p</i>	' <i>p</i> -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)
<i>s</i>	Standard deviation
<i>s_r</i>	Within laboratory repeatability as derived from ANOVA
<i>s_s</i>	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
2 <i>s</i>	Two times standard deviation
SI	Standard International system of units
<i>t_{calc}</i>	Calculated t statistic from a one-sample, two-tailed t-test
t-critical or <i>t_{crit}</i>	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 <i>k</i>
<i>u</i>	Standard uncertainty at <i>k</i> =1
<i>u_c</i>	Combined standard uncertainty at <i>k</i> =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 6. Results of XRD analysis.

Phase	Formula	Composite %
Amorphous Content		20
Alunite	$KAl_3(SO_4)_2(OH)_6$	1
Biotite	$K(Mg,Fe)_3AlSi_3O_{10}(F,OH)_2$	4
Chalcopyrite	$CuFeS_2$	1
Graphite	C	3
Illite/muscovite	$(K,Ca,Na)(Al,Mg,Fe)_2(Si,Al)_4O_{10}(OH)_2$	16
Iron	Fe	<1
Lepidolite	$K(Li,Al)_3(Al,Si,Rb)_4O_{10}(F,OH)_2$	17
Pyrite	FeS_2	<1
Pyrrhotite	$Fe(1-x)S_x$ ($x=0-0.2$)	1
Quartz	SiO_2	35
Sodium plagioclase *	$NaAlSi_3O_8$	1
Total		99%

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11. Health and Safety

The material is a very fine powder coloured medium dark gray. 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 7.

Table 7. Particle Size Determination by laser diffraction.

Size (µm)	Vol. Under %
<45um	91.6
<63um	94.3
<75um	95.3
<90um	96.2
<100um	96.7
<106um	96.9
<150um	99.00

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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 digest 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 8 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 8. 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

CI	0.0088
2s	0.031
U	0.04

23. Participating Laboratories

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

1. ALS Geochemistry Arabia
2. ALS Geochemistry SA
3. ALS Geochemistry Vancouver
4. Bureau Veritas Minerals Ultra Trace Pty Ltd
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 9.

Table 9. Data used to calculate the certified values after removal of outliers.

4A_MICP	FUS	4A_MICP	FUS	Pb Collection	Pb Collection	Pb Collection	LOI	SG	Combustion/LECO	Combustion/LECO
Cu	Cu	Co	Co	Au	Pd	Pt	LOI	SG	C	S
ppm	ppm	ppm	ppm	g/t	g/t	g/t	%	Dimensionless	ppm	%
4047	4176	198	218	0.01	0.07	0.14	6.21	2.79	31500	1.89
4055	4320	198	212	0.02	0.08	0.14	6.14	2.81	31700	1.90
3989	4033	200	214	0.01	0.07	0.13	6.15	2.81	31700	1.87
4078	4182	200	221	0.01	0.07	0.14	6.13	2.80	31400	1.83
4008	4064	207	211	0.02	0.07	0.13	6.10	2.78	31400	1.86
4046	4084	209	198	0.02	0.07	0.14	6.07	2.80	31400	1.86
4143	4015	205	201	0.01	0.07	0.14	6.11	2.80	31400	1.85
4174	4141	201	214	0.02	0.07	0.14	6.14	2.77	31500	1.87
4098	4156	212	208	0.02	0.07	0.14	6.38	2.87	31700	1.94
4222	4215	212	210	0.02	0.07	0.14	6.37	2.91	31600	1.92
4170	4126	210	204	0.02	0.07	0.14	6.36	2.91	31600	1.93
4180	4249	214	213	0.03	0.07	0.14	6.40	2.88	31800	1.90
4198	4093	211	206	0.02	0.07	0.14	6.39	2.92	31600	1.90
4234	4207	213	210	0.02	0.07	0.14	6.41	2.89	31800	1.93
4120	4243	215	211	0.03	0.07	0.14	6.41	2.92	31600	1.94
4060	4240	214	210	0.02	0.06	0.13	6.38	2.96	31700	1.91
4080	4020	205	190	0.02	0.07	0.13	6.08	2.59	30900	1.87
4070	4190	205	200	0.02	0.07	0.14	6.10	2.57	31900	1.88
4020	4140	210	200	0.02	0.07	0.14	6.06	2.56	31500	1.86
4150	4000	200	190	0.02	0.07	0.14	6.01	2.56	31900	1.89
4110	4110	200	180	0.02	0.07	0.13	6.09	2.53	31600	1.92
4150	4190	205	200	0.02	0.07	0.14	6.10	2.59	31400	1.90
4150	4110	205	190	0.02			6.17	2.52	31000	1.86
4190		210		0.02			6.16	2.51	31300	1.87
4170		224		0.02			6.78	2.68	30600	1.80
4120		225		0.01			6.82	2.67	30100	1.85
4120		226		0.02			6.79	2.69	30800	1.86
4220		215		0.01			6.79	2.64	30500	1.84
4010		226		0.02			6.84	2.69	30700	1.80
4200		229		0.02			6.84	2.66	30600	1.81
4080		212		0.01			6.91	2.64	30600	1.85
4140		213		0.02			6.88	2.75	30000	1.84
4150		214		0.02				3.26		1.96
4120		214		0.02				3.20		1.90
4120		208		0.02				3.21		1.95
4160		215		0.02				3.21		1.90
4140		214		0.01				3.27		1.95
4120		211		0.01				3.21		1.98
				0.02						1.99
				0.02						
				0.02						
				0.03						
				0.02						
				0.02						
				0.02						
				0.02						
				0.02						
				0.02						

Assay Data (Cont.)

FUS	XRF	FUS	FUS	XRF	FUS	XRF	FUS	XRF	FUS	XRF	XRF	XRF	FUS	XRF
Al ₂ O ₃	Al ₂ O ₃	Cr ₂ O ₃	Fe ₂ O ₃	Fe ₂ O ₃	K ₂ O	K ₂ O	MgO	MgO	MnO	Na ₂ O	P ₂ O ₅	SiO ₂	TiO ₂	TiO ₂
%	%	%	%	%	%	%	%	%	%	%	%	%	%	%
15.57	15.20	0.03	4.82	4.78	4.46	4.21	2.89	3.14	0.02	0.35	0.13	63.10	0.53	0.52
15.15	15.20	0.03	4.53	4.81	4.70	4.21	3.07	3.15	0.02	0.32	0.13	63.60	0.53	0.51
14.91	15.20	0.03	4.65	4.77	4.46	4.23	3.10	3.16	0.02	0.35	0.13	63.10	0.52	0.50
15.17	15.20	0.03	4.70	4.77	4.58	4.21	3.08	3.15	0.02	0.34	0.13	63.50	0.53	0.52
14.83	15.20	0.03	4.50	4.78	4.58	4.21	3.08	3.13	0.02	0.33	0.13	63.80	0.52	0.51
14.66	15.10	0.03	4.62	4.76	4.46	4.21	2.97	3.15	0.02	0.33	0.13	63.30	0.52	0.51
14.83	15.10	0.03	4.56	4.78	4.46	4.18	2.93	3.13	0.02	0.33	0.13	63.10	0.50	0.52
15.44	15.20	0.03	4.66	4.77	4.70	4.20	3.13	3.08	0.02	0.38	0.13	63.20	0.53	0.51
14.85	15.21	0.03	4.73	4.79	4.17	4.24	2.97	3.06	0.02	0.39	0.13	64.00	0.52	0.53
14.83	15.20	0.03	4.63	4.78	4.10	4.26	2.92	3.09	0.02	0.38	0.13	63.89	0.50	0.52
14.61	15.21	0.03	4.68	4.79	4.11	4.26	2.92	3.06	0.02	0.39	0.13	64.07	0.50	0.53
14.95	15.19	0.03	4.83	4.79	4.20	4.25	2.98	3.07	0.02	0.39	0.13	63.90	0.52	0.52
15.06	15.20	0.03	4.90	4.79	4.25	4.23	3.02	3.08	0.02	0.39	0.13	63.94	0.52	0.52
14.70	15.21	0.03	4.76	4.78	4.14	4.23	2.93	3.06	0.02	0.39	0.13	64.01	0.50	0.52
15.17	15.21	0.03	4.85	4.78	4.29	4.22	3.03	3.07	0.02	0.38	0.13	63.99	0.53	0.53
15.30	15.21	0.03	4.82	4.78	4.28	4.21	3.02	3.10	0.02	0.38	0.13	63.91	0.53	0.53
14.70	15.13	0.03	4.85	4.85	3.98	4.26	3.05	3.10		0.37	0.13	63.91	0.53	0.54
15.08	15.17	0.03	4.90	4.86	3.98	4.25	3.12	3.11		0.37	0.13	63.89	0.55	0.53
15.21	15.16	0.03	4.92	4.86	4.22	4.26	3.08	3.09		0.36	0.13	63.93	0.55	0.53
14.78	15.12	0.03	4.86	4.83	4.10	4.25	3.05	3.08		0.37	0.13	63.91	0.53	0.53
14.81	15.12	0.03	4.79	4.84	3.98	4.24	3.03	3.09		0.37	0.13	63.85	0.53	0.53
14.76	15.10	0.03	4.89	4.83	3.98	4.24	3.03	3.08		0.36	0.13	63.84	0.53	0.53
15.04	15.17	0.03	4.85	4.84	4.10	4.25	3.08	3.10		0.38	0.13	63.94	0.53	0.53
15.08	15.13	0.03	4.85	4.83	4.10	4.24	3.10	3.11		0.37	0.13	63.90	0.52	0.53
14.25	15.22	0.03	4.56	4.66		4.08	2.86	3.10		0.38	0.11	62.95	0.50	0.53
14.45	15.23	0.03	4.85	4.70		4.09	2.90	3.12		0.38	0.11	62.99	0.50	0.53
15.15	15.21	0.03	4.68	4.70		4.10	3.08	3.10		0.37	0.11	62.90	0.53	0.53
15.00	15.20	0.03	4.62	4.68		4.07	2.99	3.13		0.38	0.11	62.88	0.52	0.53
14.50	15.21	0.03	4.75	4.72		4.09	2.95	3.13		0.37	0.11	62.84	0.50	0.53
14.75	15.23		4.79	4.85		4.09	2.98	3.11		0.37	0.11	62.98	0.52	0.53
14.95	15.24		4.75	4.85		4.08	3.05	3.13		0.37	0.11	62.93	0.52	0.53
15.00	15.22			4.80		4.10	3.02	3.16		0.42	0.11	62.86	0.52	0.54
				4.85				3.15		0.42				
				4.84				3.13		0.40				
				4.85				3.11		0.40				
				4.85				3.15		0.42				
				4.85				3.15		0.41				
								3.16		0.40				
								3.12						

Assay Data (Cont.)

4A_MICP	FUS	4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	4A_MICP	4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP
S	S	Al	Al	Ba	Be	Bi	Ca	Cd	Ce	Cr	Cr	Cs
%	%	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
1.83	2.00	72700	82400	557	3.00	1.02	3800	0.46	88.50	179	189	5.00
1.87	2.00	73700	80200	557	2.90	1.04	4100	0.45	90.18	179	195	5.00
1.85	2.00	71300	78900	555	2.90	0.97	3900	0.45	87.00	175	182	5.00
1.80	2.00	72600	80300	563	2.90	0.98	4100	0.40	92.08	164	192	5.00
1.86	2.00	72200	78500	572	2.90	0.99	4100	0.43	91.51	168	185	5.00
1.83	2.00	70200	77600	573	3.00	0.98	4000	0.43	93.42	172	186	5.00
1.82	2.00	70500	78500	568	3.00	0.99	3643	0.44	91.06	167	195	5.00
1.83	1.80	73140	81700	537	2.90	1.00	3609	0.41	90.58	172	195	5.00
1.83	1.84	72084	78600	543	2.85	1.10	3621	0.50	96.92	173	213	4.94
1.78	1.78	72693	78500	533	2.93	1.09	3690	0.48	96.52	171	195	5.02
1.78	1.85	73427	77300	541	2.89	1.09	3703	0.49	95.89	170	199	4.93
1.81	1.85	74329	79100	543	3.05	1.04	3724	0.43	97.45	176	207	4.92
1.81	1.80	74703	79700	539	2.83	1.05	3720	0.52	97.13	170	203	5.06
1.80	1.81	74412	77800	546	2.86	1.06	3730	0.46	97.31	172	201	5.02
1.82	1.82	73739	80300	542	2.97	1.07	3800	0.42	97.87	176	210	5.00
1.80		76100	81000	571	2.81	1.11	3800	0.50	98.56	174	209	5.00
1.92		76900	77800	563	3.00	1.30	3800	0.50	107.00	169	200	4.90
1.90		76800	79800	562	3.00	1.30	3800	0.50	109.00	169	200	4.90
1.90		75300	80500	560	2.90	1.30	3700	0.50	110.00	169	200	5.00
1.89		77500	78200	563	2.90	1.20	3800	0.50	107.00	171	200	5.00
1.88		76500	78400	560	3.00	1.30	3800	0.50	110.00	183	200	5.00
1.93		75700	78100	563	3.00	1.30	3900	0.60	107.00	170	200	4.90
1.89		73300	79600	549	3.00	1.20	4000	0.50	110.00	177	200	4.90
1.94		73900	79800	550	3.00	1.20	4000	0.60	109.00	160	200	
1.99		74400	75525	560	2.90		4000	0.60		169	200	
2.03		74000	76585	560	3.00		3900	0.60		168	200	
2.02		72700	80295	560	3.00		3900			170	200	
1.98		73800	79500	540	2.90		4000			173	200	
2.01		73600	76850	560	2.80		3800			163	200	
2.03		72900	78175	560	2.90		4100			169		
1.92			79235	550	2.80		3700					
1.95			79500		2.90		3900					
1.98					2.70		3900					
1.92					2.70		3800					
1.90					2.70		3700					
1.96					2.70		3900					
1.93					2.70		3800					
1.93					2.70		3800					

Assay Data (Cont.)

4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP	FUS
Fe	Fe	Ga	Hf	In	K	K	La	Li	Lu	Mg	Mg	Mn	Mn
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
33900	33700	19.30	4.33	0.12	34500	37000	44.49	28.00	0.14	17700	17400	127	156
33600	31700	19.20	4.33	0.11	36500	39000	44.43	27.00	0.14	18600	18500	125	147
32400	32500	18.70	4.18	0.11	34200	37000	44.27	28.00	0.13	17800	18700	128	153
33600	32900	19.20	4.34	0.11	36100	38000	44.86	27.00	0.14	18100	18600	129	154
33600	31500	19.60	4.33	0.11	35700	38000	45.23	27.00	0.13	17800	18600	128	150
33500	32300	18.80	4.44	0.11	35900	37000	45.12	27.00	0.15	18400	17900	130	145
32800	31900	20.48	4.30	0.11	35800	37000	45.33	28.00	0.14	18400	17700	123	149
33100	32600	19.68	4.21	0.11	33900	39000	45.92	28.30	0.13	18000	18900	124	156
32800	33100	19.80	4.30	0.12	33903	34600	48.90	28.10	0.16	16891	17900	126	141
32600	32400	20.22	4.10	0.12	33714	34000	49.30	28.20	0.15	16670	17600	126	138
32600	32700	19.37	4.23	0.12	33720	34100	48.90	28.00	0.16	16768	17600	125	137
33200	33800	20.11	4.18	0.12	34263	34900	49.00	28.10	0.16	16946	18000	127	139
33300	34300	20.42	4.29	0.12	34528	35300	49.60	28.20	0.17	17070	18200	129	142
33500	33300	19.79	4.24	0.12	34811	34400	48.30	28.00	0.17	17203	17700	131	136
33600	33900	19.40	4.24	0.12	35000	35600	50.10	28.00	0.17	17242	18300	129	140
33300	33700	19.60	4.06		34547	35500	48.20	28.50	0.15	17158	18200	130	144
33500	33900	19.20	4.60		35500	33000	40.00	28.50	0.20	18400	18400	140	
33900	34300	19.20	4.60		35000	33000	40.00	28.50	0.20	18600	18800	136	
33900	34400	19.60	4.60		35200	35000	40.00	27.50	0.22	18500	18600	140	
33000	34000	19.40	4.40		35000	34000	40.00	28.50	0.22	18100	18400	140	
34100	33500	20.00	4.40		34500	33000	40.00	28.50	0.20	18800	18300	136	
33900	34200	19.00	4.40		35000	33000	40.00		0.22	18500	18300	136	
33500	33900	20.00	4.40		34800	34000	40.00		0.20	18500	18600	136	
33100	33900	20.00	4.60		35200	34000	40.00		0.22	19200	18700	132	
33200	31900	20.00			36400		40.00			17600	17160	130	
32200	33900	20.00			36400	33900	40.00			18300	17400	130	
33300	32700	20.00			36500		40.00			18400	18480	127	
33200	32300	20.00			35300		40.00			17800	17940	138	
32200	33200	20.00			35900		40.00			17700	17700	127	
32700	33500	20.00			35300		40.00			18400	17880	132	
	33200	20.00			36800		40.00			17800	18300	125	
		20.00			33800		40.00			18100	18120	127	
		20.00			35400							129	
		20.00			35500							129	
		20.00			34200							124	
		20.00			34800							129	
		20.00			35500							129	
		20.00			34400							128	
					35100								

Assay Data (Cont.)

4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	4A_MICP	4A_MICP	4A_MICP	4A_MICP
Mo	Na	Ni	Ni	P	Pb	Rb	Sc	Sn	Sr	Ta
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
10.95	2600	99	97	600	108	164	13.20	2.50	36.20	0.45
11.19	2800	99	98	600	111	165	13.20	2.40	37.20	0.46
11.11	2600	97	94	600	108	161	12.60	2.40	36.30	0.38
11.11	2700	99	100	600	110	161	12.70	2.40	37.10	0.37
11.74	2600	100	93	600	109	166	13.00	2.50	37.00	0.50
11.39	2700	100	94	550	107	169	13.30	2.50	37.00	0.40
11.46	2700	98	94	550	107	166	13.00	2.50	37.00	0.40
11.42	2600	99	100	550	122	162	12.80	2.50	35.90	0.53
10.90	2514	97	107	550	121	175	13.70	3.00	35.30	0.57
11.40	2554	96	103	550	121	173	13.20	3.00	35.00	0.56
11.10	2499	96	115	550	123	171	13.40	3.00	35.88	0.62
10.40	2527	98	106	550	123	174	13.10	3.00	35.63	0.57
11.10	2551	96	102	560	122	173	13.10	3.00	35.59	0.58
11.50	2572	99	99	570	122	176	13.20	3.00	36.57	0.53
11.00	2550	99	105	570	124	175	13.50	3.00	35.21	0.56
10.30	2570	99	113	560	122	172	13.30	3.00	35.49	0.55
13.00	2700	100	90	570	124	187	12.00		36.00	0.70
13.50	2700	100	100	560	123	182	12.00		35.50	0.60
13.50	2700	100	80	560	125	183	13.00		35.00	0.60
13.00	2700	100	100	570	123	184	12.00		35.00	0.60
13.00	2700	100	100	550	125	183	12.00		36.00	0.60
13.50	2800	100	100	560	122	188	13.00		35.50	0.60
13.00	2700	100		550	125	184	12.00		35.00	0.60
13.00	2800	97		570	124	190	12.00		35.50	0.60
10.00	2600	102		530	121		13.00		40.00	
11.00	2700	96		570	120		13.00		40.00	
10.00	2700	94		560	126		13.00		39.00	
9.00	2600	97		560	119		13.00		38.00	
12.00	2500	101			125		13.00		39.00	
10.00	2700	100			130		13.00		37.00	
10.00	2500	95			124		13.00		38.00	
11.00	2600	97					13.00		39.00	
11.00	2700	95					13.00		37.00	
10.00	2700	98					13.00		36.00	
10.00	2600	94					13.00		38.00	
12.00	2600	97					13.00		37.00	
9.00	2700	102					12.00		38.00	
10.00	2600						13.00			
11.00	2600						13.00			
10.00							12.00			

Assay Data (Cont.)

4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP	4A_MICP	4A_MICP	FUS	4A_MICP	FUS	4A_MICP
Tb	Th	Ti	Ti	Ti	U	V	Y	Zn	Zn	Zr
ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
0.68	16.40	2168	3200	0.94	9.60	124	31.60	153	160	144
0.67	16.70	2166	3200	0.95	9.37	124	30.80	154	150	144
0.66	16.10	2181	3100	0.91	9.47	122	31.40	158	154	144
0.70	16.70	2147	3200	0.93	9.65	122	31.50	159	154	141
0.69	16.90	2193	3100	0.95	9.59	125	31.70	162	147	145
0.70	17.30	2206	3100	0.95	9.62	122	30.60	159	149	139
0.69	16.80	2176	3000	0.91	9.65	121	31.60	150	141	140
0.68	16.70	2199	3200	0.91	9.57	124	31.30	158	153	142
0.69	17.04	2500	3100	0.96	9.50	121	35.00	151	163	140
0.70	16.85	2500	3000	0.93	9.36	120	36.00	155	152	139
0.70	16.76	2400	3000	0.91	9.20	121	36.00	164	151	139
0.75	17.32	2400	3100	0.94	9.95	121	35.00	155	159	137
0.75	16.66	2500	3100	0.94	9.46	120	36.00	157	168	141
0.72	16.95	2400	3000	0.92	9.22	121	36.00	160	158	143
0.69	16.93	2400	3200	0.90	9.60	122	36.00	155	130	142
0.71	17.30	2300	3200	0.93	9.45	123	36.00	160	130	140
0.70	14.60	2400	3200	0.90	10.20	115		160	150	151
0.72	14.60	2400	3300	0.90	9.70	115		160	140	152
0.74	15.10	2400	3300	0.90	10.20	115		155	140	154
0.72	14.90	2400	3200	0.90	10.00	115		160	150	152
0.74	15.10	2400	3200	0.90	9.90	120		155	150	160
0.72	15.30	2300	3200	0.90	9.80	120		165	140	150
0.70	14.40	2300	3200	0.80	9.80	115		163		159
0.70	14.60		3100	0.90	10.00	115		163		
	20.00		3000		10.00	124		164		
	20.00		3000		10.00	125		158		
	20.00		3180			125		157		
	20.00		3120			121		162		
	20.00		3000			124		149		
	20.00		3120			125		157		
	20.00		3120			120		155		
	20.00		3120			127		152		
	20.00					118		156		
	20.00					118		155		
	20.00					119		156		
	20.00					119		155		
	20.00					116		158		
	20.00					119		152		
	20.00					119				
						117				

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

The majority of 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: 27 May 2019

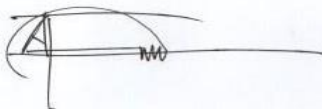
Version: 000

Approving Officer:

African Mineral Standards: _____

Makhosi Khoza (Quality Specialist)

Certifying Officer:



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 10**.

Table 10. Uncertified element concentrations statistics.

Element	Generic Method	n	Mean	SD	RSD %	Unit
Ag	2A_MICP	5	0.2	*	*	ppm
Ag	4A_MICP	15	0.2	0.02	8	ppm
Al	2A_MICP	8	19550.0	671.9	3	ppm
As	2A_MICP	3	2.3	0.6	25	ppm
As	4A_MICP	13	2.1	1.7	82	ppm
As	FUS	6	166.7	51.6	31	ppm
B	4A_MICP	8	225.0	14.1	6	ppm
B	FUS	8	189.6	4.3	2	ppm
Ba	2A_MICP	8	106.3	5.2	5	ppm
Ba	FUS	16	533.6	18.1	3	ppm
BaO	FUS	16	0.1	0.002	3	%
BaO	XRF	16	0.1	0.005	7	%
Be	2A_MICP	8	1.1	0.1	5	ppm
Be	FUS	16	3.0	*	*	ppm
Bi	2A_MICP	5	2.0	*	*	ppm
Bi	FUS	16	1.1	0.1	9	ppm
Ca	2A_MICP	8	2512.5	83.5	3	ppm
Ca	FUS	16	4000.0	*	*	ppm
CaO	FUS	16	0.6	*	*	%
CaO	XRF	29	0.5	0.1	14	%
Cd	2A_MICP	8	0.6	0.05	7	ppm
Cd	FUS	8	0.4	0.1	12	ppm
Ce	FUS	8	89.5	2.1	2	ppm
Co	2A_MICP	8	224.6	7.0	3	ppm
Cr	2A_MICP	8	61.4	2.1	3	ppm
Cr ₂ O ₃	XRF	24	0.03	*	*	%
Cs	FUS	15	4.7	0.2	4	ppm
Cu	2A_MICP	8	4372.5	159.8	4	ppm
Cu	SAL	16	139.4	151.4	109	ppm
Dy	4A_MICP	16	3.2	0.3	8	ppm
Dy	FUS	8	5.7	0.2	4	ppm
Er	4A_MICP	16	1.3	0.2	15	ppm
Er	FUS	8	3.4	0.1	3	ppm
Eu	4A_MICP	15	1.2	0.05	4	ppm
Eu	FUS	8	1.2	0.03	3	ppm
Fe	2A_MICP	8	32600rfg..0	1082.3	3	ppm
FeO	FUS	8	4.9	0.02	0.4	%
Ga	2A_MICP	8	10.0	*	*	ppm
Ga	FUS	16	18.8	0.7	4	ppm
Gd	4A_MICP	16	5.9	0.3	4	ppm
Gd	FUS	8	6.3	0.1	2	ppm
Ge	4A_MICP	8	2.4	0.1	5	ppm
Ge	FUS	16	3.0	*	*	ppm
Hg	2A_MICP	1	1.0	*	*	ppm
Ho	4A_MICP	16	0.5	0.1	13	ppm
Ho	FUS	8	1.2	0.02	2	ppm
In	FUS	5	0.1	0.04	37	ppm
K	2A_MICP	8	11612.5	379.6	3	ppm
La	2A_MICP	8	30.0	*	*	ppm
La	FUS	8	42.7	0.6	1	ppm
Li	FUS	16	40.2	14.4	36	ppm
Lu	FUS	8	0.5	0.03	5	ppm
Mg	2A_MICP	8	14237.5	468.9	3	ppm
Mn	2A_MICP	8	120.6	4.1	3	ppm
MnO	XRF	32	0.02	0.01	30	%
Mo	2A_MICP	8	11.5	0.5	5	ppm
Mo	FUS	16	11.6	0.5	4	ppm
Moisture	Moisture	7	0.2	*	*	%
Na	2A_MICP	8	700.0	*	*	ppm
Nb	4A_MICP	24	6.2	1.7	28	ppm
Nb	FUS	16	10.2	2.4	24	ppm
Nd	4A_MICP	16	41.2	0.7	2	ppm
Nd	FUS	8	39.2	0.7	2	ppm
Ni	2A_MICP	8	104.0	3.1	3	ppm
P	2A_MICP	8	552.5	16.7	3	ppm
P	FUS	8	625.0	46.3	7	ppm
P ₂ O ₅	FUS	8	0.1	0.0	7	%
Pb	2A_MICP	8	127.6	3.4	3	ppm
Pb	FUS	23	114.7	10.8	9	ppm
Pr	4A_MICP	16	10.8	0.4	3	ppm
Pr	FUS	8	10.4	0.2	2	ppm
Rb	FUS	15	168.0	4.9	3	ppm
Re	4A_MICP	7	0.01	0.002	18	ppm
S	2A_MICP	8	2.1	0.1	3	%
Sb	2A_MICP	8	3.0	1.1	36	ppm
Sb	4A_MICP	29	3.9	1.3	34	ppm
Sb	FUS	16	3.1	0.2	5	ppm
Sc	2A_MICP	8	3.0	*	*	ppm
Se	4A_MICP	8	1.2	0.1	11	ppm
Si	FUS	32	311453.6	20357.8	7	ppm
SiO ₂	FUS	32	66.4	4.3	6	%
Sm	4A_MICP	16	7.9	0.6	7	ppm
Sm	FUS	8	7.3	0.2	3	ppm
Sn	FUS	8	7.5	0.5	7	ppm
SO ₃	XRF	16	4.5	0.2	4	%
Sr	2A_MICP	8	11.9	0.6	5	ppm
Sr	FUS	16	41.1	1.1	3	ppm
Ta	FUS	16	1.3	0.2	18	ppm
Tb	FUS	8	0.9	0.0	2	ppm
Te	4A_MICP	8	0.1	0.0	15	ppm
Th	2A_MICP	8	20.0	*	*	ppm
Th	FUS	15	16.1	0.5	3	ppm
Ti	2A_MICP	8	437.5	51.8	12	ppm
TiO	FUS	7	0.6	0.0	1	%
Tl	FUS	16	1.0	0.1	8	ppm
Tm	4A_MICP	16	0.2	0.0	23	ppm
Tm	FUS	8	0.5	0.0	3	ppm
U	2A_MICP	8	10.0	*	*	ppm
U	FUS	16	9.9	0.3	3	ppm
V	2A_MICP	8	33.8	1.2	3	ppm
V	FUS	15	128.5	4.5	3	ppm
V ₂ O ₅	FUS	15	0.02	0.001	3	%
V ₂ O ₅	XRF	8	0.02	0.01	22	%
W	4A_MICP	16	2.4	0.1	4	ppm
Y	4A_MICP	16	10.0	0.8	8	ppm
Yb	4A_MICP	16	1.2	0.5	40	ppm
Yb	FUS	8	3.3	0.1	3	ppm
Zn	2A_MICP	8	160.3	5.1	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 11 is developed.

Table 11. 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 12. 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 12. 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 34) 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 12). Table 14 gives a recommended reporting scheme for LOD and LOQ.

Table 13. 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 14. 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 15. T-distribution table for t-critical values (t crit.) for a two-tailed t-test at a 95% level of confidence.

<i>df</i>	Two-tailed	<i>df</i>	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