

**AMIS0461**

**Certified Reference Material**

**Limestone, South Africa**

***Certificate of Analysis***

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**AMIS**

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## SUMMARY STATISTICS

### *Recommended Concentrations and Limits (at two Standard Deviations)*

#### Major Oxides

#### *Certified Concentrations*

Analyte	Method	<sup>4</sup> Certified( $\mu$ )	<sup>6</sup> Two Standard deviation (2s) $\pm$	Unit
Al <sub>2</sub> O <sub>3</sub>	XRF <sup>1</sup>	0.80	0.11	%
CaO	XRF <sup>1</sup>	48.31	1.67	%
Cr <sub>2</sub> O <sub>3</sub>	XRF <sup>1</sup>	0.378	0.030	%
Fe <sub>2</sub> O <sub>3</sub>	XRF <sup>1</sup>	0.782	0.13	%
K <sub>2</sub> O	XRF <sup>1</sup>	0.03	0.01	%
MgO	XRF <sup>1</sup>	0.833	0.071	%
MnO	XRF <sup>1</sup>	0.05	0.01	%
SiO <sub>2</sub>	XRF <sup>1</sup>	10.1	0.68	%
CCE	ASTM C25 <sup>3</sup>	86.60	1.95	%
LOI	LOI <sup>2</sup>	38.71	0.39	%

#### *Provisional Concentrations*

Analyte	Method	<sup>8</sup> Provisional	<sup>6</sup> Two Standard deviation (2s) $\pm$	Unit
Na <sub>2</sub> O	XRF <sup>1</sup>	0.02	0.01	%
SO <sub>3</sub>	XRF <sup>1</sup>	0.05	0.03	%
TiO <sub>2</sub>	XRF <sup>1</sup>	0.05	0.02	%

# 1. Certified Concentrations and Uncertainties

AMIS0461 is a new standard material, developed and certified in May, 2017. Table 1 gives the certified major oxides concentrations, combined and expanded uncertainty for certified reference material. Table 2 shows the provisional major oxides concentrations, two standard deviations, combined and expanded uncertainty.

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

Analyte	Method	<sup>4</sup> Certified( $\mu$ )	<i>N</i>	<i>n</i>	<i>k</i>	% RSD	<sup>5</sup> Combined uncertainty ( $u_c$ )	<sup>6</sup> Two Standard deviation (2s) $\pm$	<sup>7</sup> Expanded uncertainty ( $U$ ) $\pm$	Unit
Al <sub>2</sub> O <sub>3</sub>	XRF <sup>1</sup>	0.80	14	112	2.16	6.9	0.055	0.11	0.1	%
CaO	XRF <sup>1</sup>	48.31	15	120	2.14	1.7	0.837	1.67	2	%
Cr <sub>2</sub> O <sub>3</sub>	XRF <sup>1</sup>	0.378	7	56	2.45	4.0	0.015	0.030	0.04	%
Fe <sub>2</sub> O <sub>3</sub>	XRF <sup>1</sup>	0.782	15	120	2.14	8.3	0.065	0.13	0.1	%
K <sub>2</sub> O	XRF <sup>1</sup>	0.03	11	84	2.23	18.5	0.006	0.01	0.01	%
MgO	XRF <sup>1</sup>	0.833	12	96	2.20	4.2	0.035	0.07	0.1	%
MnO	XRF <sup>1</sup>	0.05	9	72	2.31	11.0	0.005	0.01	0.01	%
SiO <sub>2</sub>	XRF <sup>1</sup>	10.1	13	104	2.18	3.4	0.34	0.68	0.7	%
CCE	ASTM C25 <sup>3</sup>	86.60	2	16	12.71	1.1	0.976	1.95	12	%
LOI	LOI <sup>2</sup>	38.71	14	112	2.16	0.5	0.194	0.39	0.4	%

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

Analyte	Method	<sup>8</sup> Provisional	<i>N</i>	<i>n</i>	<i>k</i>	% RSD	<sup>5</sup> Combined uncertainty ( $u_c$ )	<sup>6</sup> Two Standard deviation (2s) $\pm$	<sup>7</sup> Expanded uncertainty ( $U$ ) $\pm$	Unit
Na <sub>2</sub> O	XRF <sup>1</sup>	0.02	6	44	2.57	33.1	0.006	0.01	0.02	%
SO <sub>3</sub>	XRF <sup>1</sup>	0.05	5	40	2.78	29.5	0.014	0.03	0.04	%
TiO <sub>2</sub>	XRF <sup>1</sup>	0.05	11	85	2.23	17.4	0.009	0.02	0.02	%

1. XRF is X-ray Fluorescence
2. LOI is Loss on Ignition
3. CCE is Calcium Carbonate Equivalent, ASTM is American Society for Testing and Minerals
4. The certified value  $\mu$ , 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.
5. 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.
6. The two standard deviations (2s) is calculated as for example:  $u_c \times 2 = 0.23 \times 2 = 0.46\%$ . See section 23, page 12 for recommended use in quality control.
7. 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 6 for *t*-distribution table). Example:  $U = 2.36 \times 0.23 = 0.54\%$ .
8. Provisional: the reported provisional concentrations are to be used as indicative values only.

## 2. Intended Use

AMIS0461 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 4). 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 participated in the exercise.

## 3. Abbreviations and Symbols

Abbreviations and symbols used in this document are shown in Table 3.

**Table 3.** Abbreviations, symbols and descriptions.

Abbreviation/Symbol	Description
Alpha ( $\alpha$ )	Significance level (denoted by alpha, ' $\alpha$ ') of 0.05 or 5%
ANOVA	Analysis of variance by statistical means
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
MS	Mean squares (ANOVA)
MSb	Mean squares between(ANOVA)
MSw	Mean squares within (ANOVA)
$N$	Number of labs
$n$	Number of replicates
$\mu$	Property or certified value of a CRM

**Table 3:** Continued

Abbreviation/Symbol	Description
$p$	' $p$ -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
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%, $df$ )	MS Excel function for t-critical value at LOC 95% and $df$
$U$	Expanded uncertainty at a given k
$u$	Standard uncertainty at k=1
$u_c$	Combined standard uncertainty at $k=1$
$\mu\text{m}$	Micron, is an SI derived unit of length equaling $1 \times 10^{-6}$ of a meter

#### **4. Uncertified Concentration Values**

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

#### **5. Units**

All results for major oxides are reported as oxides in percentages.

#### **6. 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](http://www.amis.co.za)

#### **7. Origin of Material**

Limestone is a sedimentary rock composed primarily of calcium carbonate ( $\text{CaCO}_3$ ) in the form of the mineral calcite. It most commonly forms in clear, warm, shallow marine waters. It is usually an organic sedimentary rock that forms from the accumulation of shell, coral, algal, and fecal debris. It can also be a chemical sedimentary rock formed by the precipitation of calcium carbonate from lake or ocean water.

#### **8. Approximate Mineral and Chemical Composition**

Limestone is by definition a rock that contains at least 50% calcium carbonate in the form of calcite by weight. All limestones contain at least a few percent other materials. These can be small particles of quartz, feldspar, clay minerals, pyrite, siderite, and other minerals. It can also contain large nodules of chert, pyrite, or siderite.

#### **9. Health and Safety**

The material is a very fine powder coloured Very light grey (5Y 8/1). Safety precautions for handling fine particulate matter are recommended, such as the use of safety glasses, breathing protection, gloves and a laboratory coat.

#### **10. Method of Preparation**

The particle size distribution for this material was shown to have a nominal top size of  $54\mu\text{m}$  (95% passing  $54\mu\text{m}$ ). The procedure of preparation in brief is as follows: the material was crushed, dry-milled and air-classified to  $<54\mu\text{m}$ . 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 ISO17025:2005 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.

#### **11. 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 in order to convert any obtained assay values to an air-dry basis (see Appendix 5 for an example calculation).



## 12. Methods of Analysis Requested

1. Majors ( $\text{Al}_2\text{O}_3$ ,  $\text{CaO}$ ,  $\text{Cr}_2\text{O}_3$ ,  $\text{Fe}_2\text{O}_3$ ,  $\text{K}_2\text{O}$ ,  $\text{MgO}$ ,  $\text{MnO}$ ,  $\text{Na}_2\text{O}$ ,  $\text{SiO}_2$ ,  $\text{SO}_3$ ,  $\text{TiO}_2$ ,  $\text{P}_2\text{O}_5$ ,  $\text{V}_2\text{O}_5$ , and LOI) XRF
2. Calcium Carbonate Equivalent (CCE) by ASTM C25 Method

## 13. Information Requested of Participating Laboratories

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

1. State aliquots used for all determinations.
2. All results for major elements to be reported as oxides in percentages.
3. Report all QC data, to include replicates, blanks and certified reference materials used.
4. State and provide brief description of analytical techniques used.
5. Send a PDF and excel of the results. (Excel template format was sent to the labs. If you have not received it, please email Melesha and she will send it through)

## 14. 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 possible sources of uncertainty are included in the combined standard uncertainty determination. Initially the data submitted by all of 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 Grubbs tests are applied until all outliers are identified, equations [2], [3], [4] and [5]. A grand mean and standard deviation is re-calculated using all remaining data (Thompson, 2008; Carr, 2011) (see Appendix 2). These data are then subjected to an analysis of variance (ANOVA) as per equations, [10],[11],[12],[13] and [14] in Appendix 2. The mean squares for data within and between laboratories derived from ANOVA are used to compute the within-laboratory reproducibility, or combined standard uncertainty as shown in Appendix 2, equation [15], [16] and [17]. The Horwitz function is applied to assess the performance of the data under consideration with respect to precision as relative standard deviation (equations [6], [7] and [8]). Should the ratio of the observed %RSD and a calculated %RSD be  $<2$ , the observed %RSD is accepted (Horwitz & Albert, 2006). A final certified value is then found by calculating a grand mean of equally weighted individual laboratory means [9] (ISO Guide 35, 2003; Barwick & Pritchard, 2011).

An uncertainty statement on AMIS certificates is typically presented as:

The expanded uncertainty ( $U$ ) is determined by multiplication of the combined uncertainty ( $u_c$ ) with a coverage factor ( $k$ ) found from  $N-1$  degrees of freedom and a t-critical value at a level of confidence of 95% (EURACHEM / CITAC Guide CG 4., (2012), (see Table 8, Appendix 6 for a t-critical table).  $N$  is the number of laboratory means used in the establishment of the certified value. Since the estimated values of the CRM approximate a normal distribution with combined uncertainty,  $u_c$ , the certified value of the CRM is understood to lie in the interval defined by  $U$  with a level of confidence of 95 % (Thompson & Lowthian, 2011).

Appendix 2 gives detail on the principles used for certification of the reported assay values and estimation of measurement uncertainty.

## 15. Participating Laboratories

Twenty one laboratories were each given eight randomly selected packages of the CRM. Eighteen laboratories of the twenty one laboratories submitted results in time for certification.

The 18 laboratories that provided results timeously are:

1. AfriSam (South Africa) (Pty) Ltd Centre of Product Excellence
2. ALS Chemex Laboratory Group Johannesburg SA
3. Antech Zimbabwe
4. ARGETEST
5. Bureau Veritas Minerals Ultra Trace Pty Ltd
6. "Dorfner Anzaplan Analysenzentrum und Anlagenplanungsgesellschaft mbH"
7. Idwala Lime- Danielskull
8. Genalysis Laboratory Services (W Australia P)
9. Intertek Utama Services (Indonesia)
10. SCI-BA Laboratories and Scientific Consulting
11. SGS Mineral Services Lakefield (Canada)
12. SGS South Africa
13. Set Point Laboratories (Isando) SA
14. PPC Rwanda
15. ALS Chemex Laboratory Group Lima (Peru)
16. ALS OMAC (Ireland)
17. UIS
18. SA Lime and Gypsum

## 16. Accepted Assay Data

Data from the 18 laboratories used for certification are set out in Table 4.

**Table 4.** Data used to calculate the certified values after removal of outliers.

XRF Al <sub>2</sub> O <sub>3</sub> %	XRF CaO %	XRF Cr <sub>2</sub> O <sub>3</sub> %	XRF Fe <sub>2</sub> O <sub>3</sub> %	XRF K <sub>2</sub> O %	XRF MgO %	XRF MnO %	XRF Na <sub>2</sub> O %	XRF P <sub>2</sub> O <sub>5</sub> %	XRF SiO <sub>2</sub> %	XRF TiO <sub>2</sub> %	XRF SO <sub>3</sub> %	LOI %
0.78	49.10	0.37	0.81	0.03	0.79	0.05	0.02	0.01	10.13	0.06	0.05	38.63
0.78	48.70	0.36	0.80	0.03	0.79	0.05	0.01	0.01	10.10	0.06	0.05	38.64
0.79	48.40	0.36	0.80	0.03	0.79	0.05	0.02	0.01	10.08	0.05	0.05	38.64
0.79	49.20	0.37	0.81	0.03	0.80	0.05	0.01	0.01	10.17	0.06	0.05	38.62
0.80	49.00	0.38	0.83	0.04	0.80	0.05	0.01	0.01	10.32	0.06	0.05	38.64
0.79	48.80	0.37	0.82	0.03	0.80	0.05	0.02	0.01	10.22	0.06	0.05	38.59
0.79	48.40	0.37	0.81	0.03	0.79	0.05	0.02	0.01	10.14	0.06	0.05	38.67
0.79	48.80	0.37	0.82	0.04	0.80	0.05	0.01	0.01	10.20	0.06	0.05	38.63
0.92	49.65	0.40	0.77	0.04	0.85	0.05	0.01	0.01	9.41	0.06	0.05	38.85
0.92	49.62	0.39	0.78	0.04	0.86	0.05	0.02	0.01	9.37	0.06	0.05	38.84
0.93	49.60	0.39	0.77	0.04	0.86	0.05	0.01	0.01	9.45	0.06	0.04	38.82
0.92	49.61	0.40	0.77	0.03	0.85	0.05	0.02	0.01	9.47	0.06	0.04	38.84
0.92	49.63	0.40	0.78	0.04	0.85	0.05	0.01	0.01	9.36	0.06	0.04	38.82
0.92	49.60	0.39	0.78	0.04	0.85	0.05	0.02	0.01	9.38	0.06	0.04	38.82
0.92	49.65	0.40	0.78	0.03	0.85	0.05	0.02	0.01	9.36	0.06	0.04	38.82
0.92	49.63	0.39	0.78	0.04	0.85	0.05	0.02	0.01	9.36	0.06	0.04	38.82
0.83	48.11	0.35	0.84	0.03	0.88	0.05	0.02	0.01	10.34	0.06	0.06	38.50
0.83	48.23	0.36	0.85	0.03	0.88	0.05	0.02	0.01	10.23	0.06	0.06	38.50
0.83	48.05	0.36	0.84	0.03	0.89	0.05	0.02	0.01	10.30	0.06	0.06	38.50
0.82	48.11	0.35	0.84	0.03	0.88	0.05	0.02	0.01	10.35	0.06	0.06	38.50
0.82	48.14	0.35	0.85	0.03	0.88	0.05	0.03	0.01	10.32	0.06	0.06	38.50
0.82	48.18	0.35	0.85	0.03	0.88	0.05	0.02	0.01	10.29	0.06	0.06	38.50
0.81	48.13	0.36	0.84	0.03	0.87	0.05	0.02	0.01	10.36	0.06	0.06	38.50
0.84	48.09	0.36	0.84	0.03	0.88	0.05	0.02	0.01	10.35	0.06	0.06	38.50
0.80	48.18	0.40	0.80	0.02	0.85	0.05	0.02		10.11	0.06	0.03	38.64
0.81	48.17	0.39	0.80	0.02	0.84	0.05	0.02		10.07	0.06	0.03	38.63
0.81	48.23	0.39	0.81	0.03	0.86	0.05	0.02		10.00	0.06	0.03	38.61
0.80	48.07	0.40	0.81	0.03	0.86	0.05	0.02		10.03	0.07	0.02	38.65
0.81	48.12	0.39	0.80	0.03	0.84	0.05	0.02		10.08	0.06	0.02	38.67
0.81	48.13	0.40	0.80	0.03	0.85	0.06	0.02		10.10	0.06	0.03	38.65
0.81	48.18	0.39	0.81	0.03	0.85	0.05	0.01		10.08	0.06	0.02	38.55
0.80	48.16	0.39	0.80	0.03	0.86	0.06	0.02		10.07	0.06	0.03	38.63
0.72	47.29	0.40	0.66	0.04	0.84	0.04	0.02		10.87	0.04	0.07	38.48
0.75	47.36	0.40	0.66	0.03	0.85	0.05	0.01		10.96	0.04	0.05	38.52
0.746	47.981	0.401	0.646	0.03	0.83	0.04	0.01		10.916	0.037	0.05	38.483
0.739	47.954	0.39	0.65	0.03	0.85	0.04	0.01		10.711	0.04	0.05	38.525
0.704	47.136	0.397	0.639	0.03	0.82	0.04	0.02		10.672	0.037	0.05	38.164
0.689	45.852	0.399	0.63	0.03	0.83	0.04	0.01		10.708	0.035	0.07	38.407
0.689	46.487	0.394	0.636	0.03	0.85	0.04	0.02		10.7	0.036	0.05	38.443
0.732	47.462	0.398	0.642	0.03	0.84	0.04	0.01		10.776	0.04	0.05	38.492
0.86	47.9	0.378	0.79	0.03	0.78	0.053	0.01		10.4	0.04		38.8
0.86	47.9	0.379	0.77	0.03	0.78	0.053	0.02		10.5	0.04		38.86
0.87	47.9	0.377	0.77	0.03	0.79	0.056	0.02		10.5	0.04		38.77
0.86	47.6	0.38	0.78	0.03	0.78	0.055	0.01		10.5	0.04		38.76
0.86	47.9	0.381	0.79	0.02	0.78	0.058	0.01		10.5	0.04		38.75
0.87	47.8	0.382	0.78	0.02	0.77	0.054	0.02		10.5	0.04		38.85
0.86	47.8	0.38	0.76	0.02	0.78	0.057	0.01		10.5	0.06		38.87
0.86	47.8	0.381	0.77	0.02	0.78	0.058	0.02		10.5	0.06		38.75
0.85	47.3	0.37	0.8	0.02	0.83	0.04	0.01		9.64	0.06		38.95
0.85	47.8	0.38	0.8	0.03	0.83	0.04	0.02		9.75	0.06		38.96
0.86	47.9	0.37	0.8	0.02	0.85	0.04	0.02		9.76	0.06		38.96
0.84	47.9	0.37	0.8	0.03	0.86	0.04	0.02		9.83	0.06		38.97
0.85	47.7	0.37	0.79	0.03	0.85	0.04	0.02		9.69	0.06		38.93
0.86	47.7	0.37	0.79	0.031	0.83	0.04	0.02		9.72	0.06		38.97
0.85	47.7	0.37	0.8	0.031	0.84	0.04	0.02		9.78	0.06		38.97
0.86	47.7	0.37	0.8	0.03	0.83	0.04	0.02		9.71	0.06		38.95
0.73	47.49	0.37809	0.76	0.032	0.86	0.05	0.03		10.2	0.06		38.5
0.71	47.25	0.38145	0.77	0.03	0.86	0.05	0.02		10.2	0.06		38.5

## Assay Data (Continued)

XRF Al <sub>2</sub> O <sub>3</sub> %	XRF CaO %	XRF Cr <sub>2</sub> O <sub>3</sub> %	XRF Fe <sub>2</sub> O <sub>3</sub> %	XRF K <sub>2</sub> O %	XRF MgO %	XRF MnO %	XRF Na <sub>2</sub> O %	XRF P <sub>2</sub> O <sub>5</sub> %	XRF SiO <sub>2</sub> %	XRF TiO <sub>2</sub> %	XRF SO <sub>3</sub> %	LOI %
0.76	48.43	0.38	0.74	0.03	0.86	0.05	0.02		10.20	0.07		38.50
0.72	48.27	0.37	0.74	0.03	0.86	0.05	0.02		10.20	0.06		38.50
0.71	48.12	0.38	0.74	0.03	0.87	0.05	0.02		10.10	0.06		38.60
0.73	47.82	0.38	0.73	0.04	0.86	0.05	0.02		10.10	0.06		38.60
0.69	48.21	0.38	0.74	0.04	0.87	0.05	0.02		10.10	0.05		38.60
0.71	48.23	0.38	0.74	0.04	0.87	0.05	0.02		10.10	0.05		38.60
0.79	48.40		0.83	0.03	0.84	0.05	0.02		7.64	0.05		38.50
0.81	48.50		0.82	0.03	0.84	0.05	0.02		7.80	0.05		38.60
0.83	48.20		0.82	0.04	0.84	0.05	0.01		7.56	0.05		38.60
0.81	48.20		0.82	0.04	0.84	0.05	0.02		7.88	0.05		38.50
0.81	47.80		0.80	0.02	0.85	0.05	0.02		7.81	0.05		38.50
0.80	48.50		0.81	0.03	0.84	0.05	0.01		7.73	0.05		38.60
0.82	47.90		0.80	0.03	0.84	0.05	0.01		7.62	0.04		38.50
0.79	48.00		0.83	0.03	0.85	0.05	0.01		7.56	0.05		38.50
0.77	48.15		0.82	0.02	0.77		0.01		10.07	0.05		39.10
0.78	48.00		0.80	0.03	0.76		0.02		10.07	0.05		39.00
0.77	48.04		0.81	0.03	0.78		0.03		10.05	0.05		39.00
0.78	48.25		0.80	0.02	0.77		0.02		10.08	0.05		39.00
0.79	48.36		0.81	0.03	0.75		0.03		10.07	0.05		39.10
0.77	48.20		0.81	0.03	0.77		0.02		10.05	0.05		38.80
0.78	48.19		0.82	0.03	0.77		0.02		10.04	0.05		39.00
0.77	48.12		0.80	0.03	0.77		0.03		10.04	0.05		39.00
0.80	49.96		0.87	0.03	0.85				9.89	0.05		38.77
0.81	49.82		0.89	0.03	0.84				10.05	0.04		38.77
0.80	50.16		0.87	0.03	0.86				9.93	0.05		38.76
0.80	49.74		0.88	0.03	0.86				9.90	0.04		38.79
0.80	49.79		0.89		0.87				10.00	0.05		38.73
0.80	50.02		0.92		0.86				9.96			38.76
0.80	50.07		0.88		0.84				9.87			38.76
0.81	50.09		0.91		0.87				9.80			38.77
0.76	47.77		0.80		0.83				10.16			39.05
0.76	47.79		0.80		0.83				10.19			39.04
0.77	47.81		0.80		0.83				10.15			39.06
0.77	47.81		0.81		0.83				10.19			39.00
0.76	47.84		0.81		0.82				10.17			39.00
0.77	47.76		0.81		0.81				10.12			39.02
0.76	47.85		0.79		0.84				10.11			39.01
0.77	47.88		0.79		0.83				10.13			38.98
0.78	49.50		0.77						10.07			38.63
0.77	49.30		0.84						10.04			38.66
0.77	49.90		0.78						10.00			38.67
0.79	49.40		0.77						9.99			38.66
0.77	49.20		0.85						9.96			38.66
0.78	49.80		0.76						9.93			38.65
0.75	49.40		0.78						10.05			38.67
0.77	49.40		0.75						10.02			38.61
0.79	47.56		0.65									38.64
0.79	47.75		0.65									38.61
0.78	47.63		0.66									38.90
0.78	47.47		0.66									38.64
0.79	47.65		0.65									38.66
0.78	47.46		0.65									38.69
0.82	47.51		0.64									38.69
0.78	47.55		0.64									38.71
	48.30		0.81									
	48.30		0.81									
	48.10		0.77									
	48.00		0.77									
	47.80		0.76									
	47.80		0.76									
	48.20		0.77									
	48.20		0.78									

### 17. Reported Values

The certified values listed in this certificate fulfil the AMIS statistical criteria (see section 14) regarding agreement for certification and have been independently validated by Allan Fraser.

## **18. Validation of Accuracy (Trueness)**

This CRM can be used to validate accuracy (trueness) as required in method validation as stated in the ISO17025:2005 standard, clause 5.4. See Appendix 3 for an example on the validation of accuracy using replicate data derived from the analysis of a CRM.

## **19. 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 ISO17025:2005 general requirements for the competence of testing and calibration laboratories and who have maintained measurement traceability during the analytical process.

## **20. 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](http://www.amis.co.za) website.

## **21. 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.

## **22. 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.

## **23. 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 4 for detail on the use of this CRM in quality control).

## **24. Legal Notice**

This certificate and the reference material described in it have been prepared with due care and attention. However AMIS, a division of Torre Analytical Services (Pty) Ltd, Thivhafuni Matodzi, and Allan Fraser; accept no liability for any decisions or actions taken following the use of the reference material.

04 May 2017

Certifying Officers:

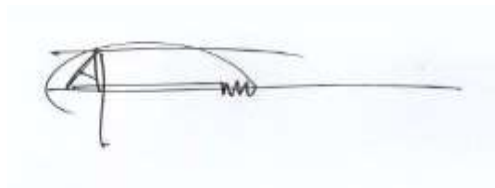
Version: 0.02

Amended: 13 September 2017 Certified CCE, 19 September 2017 Added ASTM C25 (method)

*T. Matodzi*

African Mineral Standards: \_\_\_\_\_

Thivhafuni Matodzi

A handwritten signature in black ink, appearing to read 'A. Fraser', with a stylized flourish at the end.

Geochemist: \_\_\_\_\_

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

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## APPENDICES

### Appendix 1: Uncertified Element Statistics

Uncertified element statistics are shown in Table 5.

**Table 5.** Uncertified element concentrations statistics.

Element	Gen Method	N	Mean	s	RSD %	Unit
BaO	XRF	20	0.02	0.01	40.66	%
Cl	Various methods	24	<100	<0.001	<0.001	ppm
CuO	XRF	8	0.01	<0.001	6.04	%
Fe	XRF	8	4551.00	48.00	1.05	ppm
Mn	XRF	8	396.90	8	1.96	ppm
Mn <sub>2</sub> O <sub>3</sub>	XRF	7	0.08	<0.001	<0.001	%
Mn <sub>3</sub> O <sub>4</sub>	XRF	8	0.06	<0.001	1.96	%
S	Combustion/LECO	15	0.01	<0.001	31.05	%
S	XRF	8	0.02	<0.001	11.08	%
V <sub>2</sub> O <sub>5</sub>	XRF	9	0.01	<0.001	27.44	%
ZrO <sub>2</sub>	XRF	8	0.01	<0.001	5.34	%
P <sub>2</sub> O <sub>5</sub>	XRF	3	0.008	0.002	28.89	%

.....

### Appendix 2. Certification of Reference Material and Estimation of Measurement Uncertainty (Prepared by Allan Fraser)

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 application of z-scoring, Cochran test for suspect repeatability variances, along with Grubbs test as single and paired tests 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 typically 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.



## Outlier Removal

An initial purge of outliers in inter-laboratory analyses of a candidate reference material is done using z-scoring followed by the exclusion of further outliers as defined by the IUPAC Harmonised Protocol of 1995. Here both Cochran and Grubbs tests are applied until all outliers are identified.

### 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 of 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 2 are discarded and are not included for further assessment.

### Cochran 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,  $G$ . 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%. If the data set contains two or more suspect values at either the high end of the dataset or at the low end, or at both ends of the data range, the Grubbs test is adapted to detect such outliers by the calculation of  $G_{2\,calc}$

$$G_{2\text{ calc}} = \frac{|x_n - x_1|}{s} \quad [4]$$

where,  $x_n$  and  $x_1$  are the suspect values that occur at the opposite ends of the dataset.

When there are two suspect values at the at the same end of the dataset two separate standard deviations of all of the data,  $s^*$  is the standard deviation of the data with the two suspect values excluded with  $G_{3\text{ calc}}$  given by:

$$G_{3\text{ calc}} = \frac{(n-3)s^*}{(n-1)s^2} \quad [5]$$

### 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

$$\%RSD = \pm 2^{(1-0.5\log C)} \quad [6]$$

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

$$\text{Observed \%RSD} = \frac{s}{\text{Mean}} \times 100 \quad [7]$$

where  $s$  is the standard deviation of  $n$  replicates.

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

$$\text{HorRat} = \frac{\%RSD\ \text{Observed}}{\%RSD\ \text{Calculated}} \quad [8]$$

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 ( $n$ ):

$$\bar{\bar{x}} = \sum \frac{x}{n} \quad [9]$$

### Certified Value

From ANOVA as per the description in section 14, an 'appropriate precision' as shown in [10] is calculated for sufficient homogeneity (Thompson, 2008):

$$s_r \leq 0.3u_c \quad [10]$$

Where,  $s_r$  is the within laboratory repeatability, as determined from [16]. Once [10] is satisfied, a grand mean [9] 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.

$$SST = \sum (x - \bar{x})^2 \quad [11]$$

### Between Group Variation (SSB)

The *variation* due to the interaction between the laboratories is denoted SSB or Sum of Squares Between laboratories and given by [12]. 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.

$$SSB = \sum n(\bar{x} - \bar{\bar{x}})^2 \quad [12]$$

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.

$$MS = \frac{SSB}{n - 1} \quad [13]$$

### 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:  $df = n - P$ .

$$SSW = \sum df \cdot s^2 \quad [14]$$

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:

$$MSW = \frac{SSW}{P - n} \quad [15]$$

From equations [9] through [15], the ANOVA table as shown in Table 6 is developed.

**Table 6.** 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 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 <sub>crit</sub>
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,  $s_s$ :

$$u_c = \sqrt{s_r^2 + s_s^2} \quad [16]$$

Within laboratory repeatability is determined as

$$s_r = \sqrt{MSB} \quad [17]$$

and, the between laboratory precision as

$$s_s = \sqrt{\frac{(MSW - MSB)}{n}} \quad [18]$$

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 **Error! Reference source not found.**, or from S 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**  
(Prepared by Allan Fraser)

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 [19], does not take into account the measurement uncertainty of the CRM. To compensate for this, Eurolab Technical Report No.1/2007 recommends equation [20] for the validation of CRMs with stated measurement uncertainties.

$$t_{calc} = \frac{|\bar{x} - \mu|}{\frac{s}{\sqrt{n}}} \quad [19]$$

$$t_{calc} = \frac{|\bar{x} - \mu|}{\sqrt{(u_{\mu})^2 + \frac{s^2}{n}}} \quad [20]$$

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  $\mu$  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 [20] 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 7. 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 7.** 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 Uncertainty ( $U$ )	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 [20]:

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

Therefore,  $t_{calc} = 0.84$  and  $t_{crit}(5\%, 8) = 2.31$  ( $df$  is 8, therefore,  $t_{crit}=2.31$ , see Appendix 6, page 23) 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.

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**Appendix 4. Using the CRM in Quality Control**  
(Prepared by Allan Fraser)

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 chose to use the certified value as the mean then the quoted 2s 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;
5. Calculate the standard deviation,  $s$  from:

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

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 [20];
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 warning the limits analyse another sample and if it then within warning limits, continue. If it is outside the warning limits, stop and troubleshoot;
12. It is recommend 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 [20].

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**Appendix 5. 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 cm<sup>2</sup> with the CRM material spread evenly over same; this represents a 0.1 gram spread per cm<sup>2</sup>. In correcting the certified value for moisture content, a moisture correction factor is calculated:

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

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

**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 x 0.52 = 0.51<sub>(7)</sub>, rounded to 0.52%. The air-dry basis concentration *i.e.* 12.56±0.52% is to be used as the certified value with its corresponding measurement of uncertainty.

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**Appendix 6.** T-distribution table

Table 8. 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		

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