WADA Technical Document – TD2019DL

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Written by:	*WADA* Laboratory Expert Group (LabEG)	Approved by:	*WADA* Executive Committee
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DECISION LIMITS FOR THE CONFIRMATORY QUANTIFICATION OF THRESHOLD SUBSTANCES

1. Introduction

This Technical Document shall be applied to the quantitative determination of a Threshold Substance in a *Sample* with particular regard to the Decision Limits (DL) that shall be applied to determine whether the result indicates an *Adverse Analytical Finding (AAF).* It also describes the use of Measurement Uncertainty (MU) information in the establishment of such DL.

A measurement of a Threshold Substance in a *Sample* shall be reported as an *AAF* when the value (expressed as a concentration, ratio or score of measured analytical values) exceeds, with an appropriate level of confidence (95 %), the Threshold value (T) for that *Prohibited Substance* (or ratio or combination of substances or *Markers*) as defined by *WADA*.

This document provides requirements on the following issues:

1. Maximum values of MU;
2. Setting DL for Threshold Substances;
3. Reporting.

Further guidance is provided in Appendix 1, including:

- Estimating MU;
- Development and Validation of quantitative Confirmation Procedures;
- Verification of MU by a Laboratory.

2. Maximum Levels of Measurement Uncertainty

The maximum acceptable combined standard uncertainty (u_{c_Max}) represents the minimum requirement to be met by a Laboratory for the uncertainty of the measurement, estimated at levels close to the Threshold value, when reporting a result for the determination of a Threshold Substance. The u_{c_Max} values are set such that a Laboratory can reasonably expect to work within them when applying quantitative Confirmation Procedures for the determination of Threshold Substances.

In most cases, u_{c_Max} is assigned using data from the combined participant results obtained from relevant rounds of the External Quality Assessment Scheme (EQAS). In cases where a new Threshold Substance is introduced into the *Prohibited List* before EQAS performance data are available, alternative approaches will be used to assign the relevant u_{c_Max}. In this case the assignment of u_{c_Max} must be reviewed and approved by the *WADA* Laboratory Expert Group (LabEG). When data obtained from subsequent EQAS rounds becomes available, the u_{c_Max} may be revised to reflect the actual analytical performance of the Laboratories.

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The results obtained from the *WADA* EQAS indicate that these minimum requirements are conservative. When setting the target values, the degrees of freedom associated with the MU data are assumed to be large.

Laboratories shall estimate the combined standard uncertainty (u_c) for a result at levels close to the T value for each quantitative Confirmation Procedure for Threshold Substances. The estimated u_c shall be not greater than the u_{c_Max} value given in Table 1, which is determined mostly using the method Reproducibility (S_R) estimate obtained from *WADA* EQAS data. As mentioned above, these $u_{c\,Max}$ values are considered to be conservative; therefore, smaller u_c values may be reported by Laboratories.

Various approaches to obtain Fit-for-Purpose estimates of u_c associated with the results from a given measurement procedure are given in Appendix 1.

Table 1

Threshold Substance	Threshold (T)[c]	Max. Combined Standard Uncertainty ($u_{c\,Max}$) at T		Decision Limit (DL)[a, c]
		Absolute [b]	Relative (%)	
Carboxy-THC[d]	**150 ng/mL**[i]	15 ng/mL	10	**1$\overline{8}$0 ng/mL**
Salbutamol[e]	**1.0 µg/mL**[i]	0.10 µg/mL	10	**1.2 µg/mL**
Formoterol[e]	**40 ng/mL**[i]	6.0 ng/mL	15	**5$\overline{0}$ ng/mL**
Morphine[f]	**1.0 µg/mL**[i]	0.15 µg/mL	15	**1.3 µg/mL**
Cathine[g, h]	**5.0 µg/mL**	0.50 µg/mL	10	**6.0 µg/mL**
Ephedrine[g]	**10 µg/mL**	0.50 µg/mL	5.0	**11 µg/mL**
Methylephedrine[g]	**10 µg/mL**	0.50 µg/mL	5.0	**11 µg/mL**
Pseudoephedrine[g]	**150 µg/mL**	7.5 µg/mL	5.0	**1$\overline{7}$0 µg/mL**
Human Chorionic Gonadotrophin (hCG)	**5.0 IU/L**[j, k]	1.0 IU/L[k]	20	**5.0 IU/L**[j, k]
	2.0 IU/L[j, l]	0.40 IU/L[l]	20	**2.0 IU/L**[j, l]

a. DL reported correspond to T plus a guard band *g* of 1.645·$u_{c\,Max}$, rounded up to 2 significant figures*. The guard band corresponds to the expanded MU giving > 95 % coverage interval ($U_{95\%}$) for a result at the Threshold concentration based on a 1-tailed normal distribution.

* The bar placed over the digits in the DL for carboxy-THC, formoterol and pseudoephedrine indicates the last significant figure.

b. $u_{c\,Max}$ is expressed to 2 significant figures.

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c. When the specific gravity (SG)[1] of the *Sample* (SG_{Sample}) is greater than (>) 1.018[2], an adjusted guard band g_{adj} shall be added to the SG-adjusted Threshold (T_{adj}) to determine the DL for an individual test result (DL_{adj})[3].

The SG-adjustment to the T shall be made using the following formula:

$$(1) \quad T_{adj} = \frac{(SG_{Sample\_Max} - 1)}{(1.020 - 1)} \cdot T$$

Where SG_{Sample_Max} is calculated as:

$$(2) \quad SG_{Sample\_Max} = SG_{Sample} + U_{Max\_SG} = SG_{Sample} + 0.002$$

U_{Max_SG} = 0.002 is the maximum allowed expanded uncertainty ($U_{95\%}$, k = 2) for SG determined from the *WADA* EQAS.

The corresponding adjusted DL_{adj} would therefore be:

$$(3) \quad DL_{adj} = T_{adj} + g_{adj} = T_{adj} + 1.645 \cdot u_{cMax(T_{adj})}$$

Where $u_{c\_Max\,(T_{adj})}$ is the absolute u_{c_Max} at T_{adj}, calculated as

$$(4) \quad u_{c\_Max(T_{adj})} = u_{c\_Max\,(\%)} \cdot T_{adj}$$

The formula for DL_{adj} can then be simplified as:

$$(5) \quad \mathbf{DL_{adj}} = \frac{(\mathbf{SG}_{Sample\_\mathbf{Max}} - \mathbf{1})}{(\mathbf{1.020} - \mathbf{1})} \cdot \mathbf{DL}$$

The determined DL_{adj} shall be truncated to the same number of decimal places as the DL, without rounding (*e.g.* a DL_{adj} for morphine of 1.416 shall be expressed as 1.4; a DL_{adj} of 189.35 for pseudoephedrine shall be expressed as 189; a DL_{adj} of 11.8 for ephedrine shall be expressed as 11).

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[1] The Laboratory shall measure the SG_{Sample} in a single Aliquot of the "A" or "B" *Sample* during the Initial Testing Procedures and Confirmation Procedures, as applicable.

The SG value (SG_{Sample}) to be used in applying Equation (2) for the calculation of SG_{Sample_Max} is that measured in the Laboratory with a digital refractometer using a Fit-for-Purpose Analytical Method, which is included within the Laboratory's ISO/IEC 17025 scope of accreditation.

If the digital refractometer reads to four (4) or more decimal places, the SG_{Sample} is the value obtained after rounding the refractometer value up to three (3) decimal places.

[2] The SG_{Sample} cut-off value for adjustment of the DL has been set at 1.018 to account for the lower limit of the 95 % coverage interval, based on a two-tailed normal distribution, of a reference value of SG at 1.020 for normally hydrated individuals (calculated as 1.020 – U_{Max_SG}).

[3] The adjustment of DL for the SG is not needed for "B" *Sample* confirmations of exogenous Threshold Substances, since in those cases "B" *Sample* results shall only confirm the "A" *Sample* identification (in compliance with the TD IDCR) for the *Adverse Analytical Finding* to be valid.

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d. 11-nor-Δ9-tetrahydrocannabinol-9-carboxylic acid.

e. If this exogenous Threshold Substance is detected in conjunction with a prohibited diuretic or other masking agent (as specified in class S5 of the *Prohibited List*), the confirmation of the Threshold Substance requires only the identification of the compound, not its quantification[4]. In such cases, both the exogenous Threshold Substance and the diuretic/masking agent shall be confirmed and reported as *AAF* by the Laboratory (the beta-2 agonist, which is prohibited at all times, *i.e.* both *In- and Out-of-Competition*, shall be reported as an *AAF* if identified **at any concentration** in compliance with the effective TD IDCR [1]).

f. Occasionally, a morphine finding may have resulted from the administration of a permitted substance such as codeine. Therefore, Laboratories shall report an *AAF* for morphine in cases when both of the following conditions are met:

• The total morphine concentration in urine is higher than the DL (after adjustment if SG > 1.018) of 1.3 µg/mL (M_{total} > 1.3 µg/mL), and

• The ratio of total morphine to total codeine (free codeine + codeine-6-glucuronide, expressed as codeine equivalent) concentrations is equal or higher than 2.0 (M_{total}/C_{total} $\geq$ 2.0, expressed rounded down (truncated) to one decimal place), except:

If C_{total} > 5.0 µg/mL (expressed rounded down (truncated) to one decimal place and after correction of the concentration if SG > 1.018), which is indicative of pure codeine intake. In this case, the quantification of morphine is not necessary, and the finding shall be reported as "Negative".

g. If this exogenous Threshold Substance is detected in conjunction with a prohibited diuretic or other masking agent (as specified in class S5 of the *Prohibited List*), the confirmation of the Threshold Substance requires only the identification of the compound, not its quantification[4]. In such cases, the diuretic/masking agent shall be confirmed and reported as *AAF* by the Laboratory. The stimulant, which is prohibited *In-Competition* only, shall be reported as an *AAF* if identified, in compliance with the effective TD IDCR [1], **at an estimated concentration greater than the applicable reporting limit** established in the effective TD MRPL [2].

h. The Laboratory shall report cathine as an *AAF* when found at a urinary concentration greater than the DL. However, if pseudoephedrine is also detected in the *Sample* at concentrations below the DL, the estimated concentration of pseudoephedrine shall also be reported and a comment shall be made in the Test Report on whether the cathine finding may have resulted from the administration of pseudoephedrine. The decision about whether the cathine finding constitutes an Anti-doping Rule Violation shall be made during the results management process.

i. The Threshold concentration is based on total content of the substance, which is defined as the combination of free substance and its glucuroconjugated forms, expressed as substance equivalent *(e.g.* total morphine is based on the combination of free morphine, morphine-3-glucuronide and morphine-6-glucuronide, and expressed as morphine equivalent).

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[4] In cases where a diuretic or masking agent is detected in the *Sample*, the co-presence of an exogenous Threshold Substance shall be considered as an *AAF* (irrespective of the existence or not of an approved *TUE* for the diuretic/masking agent) unless there is an approved *TUE* for the exogenous Threshold Substance itself.

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j. For endogenous Threshold Substances for which the T value has been established based on reference population statistics, the population T already incorporates the uncertainty of the measurements. Therefore, the T constitutes the DL.

k. Applicable when immunoassays are used for quantification of heterodimeric hCG.

l. Applicable when a LC-MS/MS method is used for quantification of heterodimeric hCG.

Specific instructions on the measurement and reporting of hCG findings are provided in the *WADA* Technical Document on Reporting and Management of urinary hCG and LH findings in male *Athletes* [3].

Note: Human Growth Hormone (hGH) is also defined as a Threshold Substance. For the application of the hGH differential immunoassays and/or the hGH Biomarkers Test, the applicable values of u_{c_Max} and the corresponding DLs are specified in the relevant Technical Document [4] or Laboratory Guidelines [5].

The International Standard for Laboratories (ISL) [6] requires that results from quantitative Confirmation Procedures applied to Threshold Substances shall be based on the mean of three independent determinations. The resulting relative standard deviation (RSD, %) shall be consistent with the quantitative Confirmation Procedure method validation data. The MU of the Laboratory's measurement procedure, as estimated from the Analytical Method validation data, shall be such as to ensure an *AAF* non-compliance decision in cases when the mean of the data obtained is above the corresponding DL in Table 1.

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3. Setting Decision Limits for Threshold Substances

Where a T has been established for a *Prohibited Substance*, the DL is the value of the result for that *Prohibited Substance* in a given *Sample* obtained using a validated measurement procedure above which it can be decided that T has been exceeded with a statistical confidence of at least 95 %, and hence that an *AAF* is justified. This is illustrated in Figure 1.
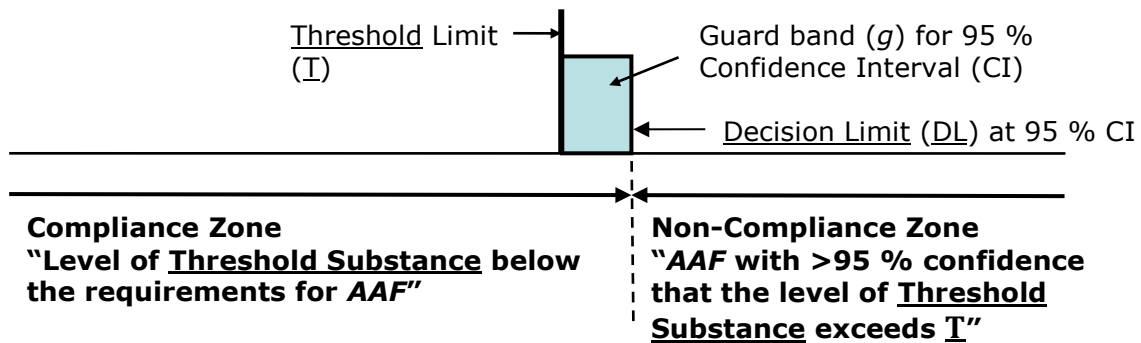

Figure 1: Use of a guard band (*g*) to establish a DL relative to a Threshold limit and to differentiate between compliance and non-compliance zones.

The DL value shall be calculated as the sum of the T value and the guard band (*g*), where *g* is calculated based on the relevant *WADA* maximum acceptable value (unit/mL) of the combined standard uncertainty ($u_{c\,Max}$) given in Table 1, using a coverage factor *k* of 1.645 (95 % coverage range, one-tailed normal distribution).

(6) $DL = T + g$

(7) $g = k \cdot u_{c\,Max}$, with $k = 1.645$

AAF > DL

When a value found in a *Sample* exceeds the T value, but is less than the DL, the Laboratory shall report this result as a Negative Finding and include a recommendation (*e.g.* in the opinion section of the Test Report) for the Result Management Authority to consider this result within its future "target and intelligence" test planning. This result shall not constitute an *AAF* regardless of the value of MU the Laboratory reports for the result.

Note: The compliance decision rule, applicable to assays used for quantification of endogenous Threshold Substances, for which the T have been established on reference population statistics (*e.g.* hCG, hGH differential immunoassays and hGH Biomarkers Method), do not require the inclusion of a guard band since the MU has already been incorporated into the T value.

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4. Reporting

4.1 Test Report

The concentration of a Threshold Substance in a *Sample* shall be reported in *ADAMS* as the mean value from triplicate determinations, rounded **down** (truncated) to the same number of decimal places as the applicable DL, to assess compliance with the DL and as a basis for reporting an *AAF*.

[For example, a finding for formoterol at 52.7 ng/mL shall be reported as "52 ng/mL"; a result for cathine at 7.57 µg/mL shall be reported as "7.5 µg/mL"; a result for ephedrine at 12.2 µg/mL shall be provided as "12 µg/mL"; a result for pseudoephedrine at 173.7 µg/mL shall be given as "173 µg/mL"; a result for morphine at 1.35 µg/mL shall be reported as "1.3 µg/mL" and a concentration for hCG of 7.38 IU/L shall be reported as "7.3 IU/L"].

The minimum requirements for reporting an *AAF* for a Threshold Substance are:
- the result (assigned and reported as stated above);
- a statement that the result exceeds (>) the relevant DL; and
- the relative u_c (%) associated with a result at levels close to the T value as determined during the quantitative Confirmation Procedure method validation.

Provision of the information as described above is sufficient to meet the *WADA* requirements for reporting an *AAF* for a Threshold Substance.

[Reporting example for the Test Report:

The concentration of '*Prohibited Substance* A' in the *Sample*, obtained using the quantitative Confirmation Procedure and stated in accordance with the reporting rules in *WADA* TD DL, is X (units). This exceeds the DL (after adjustment for the SG, if applicable) for A of Y (units). The relative combined standard uncertainty (u_c %) estimated by the Laboratory for a result at the Threshold Z (after adjustment for the SG, if applicable) [units], is '*b*' (%), which does not exceed the relative $u_{c\,Max}$ ('c', %) specified in *WADA* TD DL*.

This result meets the requirements of *WADA* TD DL for an *Adverse Analytical Finding* for the presence of A in the *Sample* at a concentration greater than the Threshold (after adjustment for the SG, if applicable) of Z (units)].

4.2   Laboratory Documentation Package

The source of information for a decision regarding an *AAF* is the measurement result as determined by the Laboratory using its quantitative Confirmation Procedure. This information shall be included in the Laboratory Documentation Package. Reporting a result with the associated expanded MU using a coverage factor (*k*) of 2 is common practice. This provides an expanded MU ($U_{95\%}$) for the result equivalent to the 95 % coverage interval for the value of the Threshold Substance in the *Sample* based on a two-tailed normal distribution.

The Laboratory Documentation Package shall include the following information:
- If an adjustment for SG is necessary, the SG of the *Sample*, the adjusted Threshold and resulting adjusted DL;

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- A statement that the relative u_c (%) for results at the Threshold does not exceed the maximum permissible relative u_{c_Max} (%) in Table 1 of TD DL or applicable Technical Document or Laboratory Guidelines;

- The Laboratory result for the Threshold Substance in the *Sample* (units), as determined and without truncation, with the u_c associated with the result. Generally this is provided by reporting the $U_{95\%}$ (units[5]) determined by the Laboratory based on a two-tailed 95 % coverage interval ($k = 2$) and expressed as $x \pm U_{95\%}$.

[Reporting example for the Laboratory Documentation Package for an *AAF*:

The concentration of *Prohibited Substance* A in the *Sample*, obtained using the quantitative Confirmation Procedure and stated in accordance with the reporting rules in *WADA* TD DL, is X (units). This exceeds the DL (after adjustment for the SG, if applicable) for A of Y (units). The relative combined standard uncertainty (u_c %) estimated by the Laboratory for a result at the Threshold Z (after adjustment for the SG, if applicable) [units], is '*b*' (%), which does not exceed the relative u_{c_Max} ('c', %) specified in *WADA* TD DL.

This result meets the requirements of *WADA* TD DL for an *Adverse Analytical Finding* for the presence of A in the *Sample* at a concentration greater than the Threshold (after adjustment for the SG, if applicable) of Z (units)].

The Laboratory result for A including the associated expanded uncertainty $U_{95\%}$ equivalent to the two-tailed 95 % coverage interval ($k = 2$) is '*d ± e*' (units)].

4.3   Interpretation Examples

4.3.1 Ephedrine is detected in a *Sample* with an SG of 1.018 at a concentration of 12.2 µg/mL using a measurement procedure where the relative u_c is 3.6 % for a result at the Threshold of 10 µg/mL.

The result constitutes an *AAF* since the concentration of ephedrine in the *Sample*, assigned in accordance with the reporting rules established in section 4.1 above, is 12 µg/mL and therefore exceeds the relevant DL for ephedrine of 11 µg/mL. The standard uncertainty u_c of the observed result, corresponding to a relative u_c of 3.6 %, is 0.44 µg/mL. Such cases can be reported as follows:

[Test Report:

The concentration of ephedrine in the *Sample*, obtained using the quantitative Confirmation Procedure and stated in accordance with the reporting rules in *WADA* TD DL, is 12 µg/mL. This exceeds the relevant DL for ephedrine of 11 µg/mL. The relative combined standard uncertainty (u_c %) estimated by the Laboratory for a result at the Threshold (10 µg/mL) is 3.6 %. This result meets the requirements of WADA TD DL for an *Adverse Analytical Finding* for the presence of ephedrine in the *Sample* at a concentration greater than the Threshold of 10 µg/mL].

[Laboratory Documentation Package:

The concentration of ephedrine in the *Sample*, obtained using the quantitative Confirmation Procedure and stated in accordance with the reporting rules in *WADA* TD DL, is 12 µg/mL. This exceeds the relevant DL for ephedrine of 11 µg/mL. The relative

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[5] Expressed to two (2) significant figures.

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combined standard uncertainty (u_c %) estimated by the Laboratory for a result at the Threshold (10 µg/mL) is 3.6 %.

The relative u_c (3.6 %) does not exceed the relative u_{c_Max} (5.0 %) specified in the effective TD DL for concentrations of ephedrine at the Threshold.

The result for ephedrine including the associated expanded uncertainty $U_{95\%}$ equivalent to the two-tailed 95 % coverage interval (k = 2) is 12.2 ± 0.88 µg/mL.

This result meets the requirements of *WADA* TD DL for an *Adverse Analytical Finding* for the presence of ephedrine in the *Sample* at a concentration greater than the Threshold of 10 µg/mL].

4.3.2 Morphine is detected in a *Sample* with a SG of 1.022 at a concentration of 1.47 µg/mL using a measurement procedure where the relative u_c is 14 % for a result at the Threshold of 1.0 µg/mL. The DL$_{adj}$ calculated according to formula (5) is 1.56 µg/mL.

This result does not constitute an *AAF*, since the concentration of morphine in the *Sample*, assigned in accordance with the reporting rules established in section 4.1 above, is 1.4 µg/mL and therefore does not exceed the DL$_{adj}$ for morphine when expressed to one decimal place as 1.5 µg/mL. The standard uncertainty u_c of the observed result, corresponding to a relative u_c of 14 %, is 0.20 µg/mL.

Since the concentration of morphine is greater than the adjusted T value (1.2 µg/mL), but does not exceed the adjusted DL (1.5 µg/mL), the Laboratory shall report this result as a Negative Finding and include a recommendation (*e.g.* in the opinion section of the Test Report) for the Result Management Authority to consider this result within its future "target and intelligence" test planning.

Note: When the result of a *Prohibited Substance* in a *Sample* is moderately in excess of the DL, the expanded uncertainty $U_{95\%}$ (k = 2) for the Laboratory result may extend below the DL. It is important to note that this shall not invalidate an *AAF*. The appropriate statistical comparison of the Laboratory value with the T (not the DL) using a single-tailed distribution (k = 1.645) coverage factor when the u_c of the result is taken into consideration, shows that the result is consistent at greater than 95 % confidence with a level of the *Prohibited Substance* in the *Sample* in excess of the T value.

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APPENDIX 1

1. Estimating Measurement Uncertainty (MU)

The International Vocabulary of Metrology (ISO/IEC Guide 99:2007) [7] formally defines MU as a parameter characterizing the dispersion of quantity values attributed to a measurand.

More simply stated, the combined standard MU of a result [$u_c(y)$] is equivalent to an estimate of the standard deviation (SD) associated with the result (y) obtained for the sample under analysis. Multiplication of $u_c(y)$ by a coverage factor (k) gives the expanded MU (U) associated with result (y). For a given sample, the combination of the result (y) and its associated U specifies a coverage range within which the true value for the sample is expected to be found, at a stated level of coverage. For most doping control purposes, a *value U* corresponding to a 95 % coverage range is the minimum requirement for the reporting of results.

Accreditation to ISO/IEC 17025 [8], as well as compliance with the ISL [6], requires that Laboratories evaluate the MU associated with their results and report the uncertainty where relevant. ISO/IEC 17025 recommends that MU be estimated using an approach consistent with the principles described in the ISO/IEC Guide to the Expression of Uncertainty in Measurement (GUM)[9].

The minimum requirements that shall be applied to any approach to estimate the MU of a quantitative Confirmation Procedure for Threshold Substances are:

- a comprehensive uncertainty evaluation which accounts for all relevant sources of measurement error;

- uncertainties arising from random and systematic effects shall be treated alike, *i.e.* expressed and combined as variances of associated probability distributions;

- evaluation of uncertainty performed by statistical analysis of measurement results (Type A) or by alternative techniques, based on other data / information (Type B), are recognized as equally valid tools; and

- the uncertainties associated with the final results be expressed either as SD (standard uncertainty, u_c) or as a multiple of SD (expanded uncertainty, U) using a specified numerical factor (coverage factor, k).

The examples cited in the GUM concentrate on one method, referred to elsewhere as the "analytical", "modelling" or "bottom-up" approach, for uncertainty evaluation. The basic GUM principles also allow for more global approaches for estimating the sources of MU, generally referred to as "top-down" or "empirical" approaches, using data derived from intra- or inter-laboratory method validation studies, internal quality control procedures or the results of EQAS. These approaches are all potentially compliant with the GUM principles provided the minimum requirements listed above are adequately (but not necessarily exhaustively) addressed and the MU estimate obtained is suitable for the intended purpose of the measurement. Various references are available which give worked

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examples of both the "bottom-up" and "top-down" approaches to MU estimation [10, 11] .

Four separate approaches applicable for the estimation of the combined standard measurement uncertainty $u_c(y)$ associated with an individual result (y) are described in more detail below. They use respectively:

A. a modeling approach based on the principles described in the GUM;

B. "in-house" method validation data combined with quality control data;

C. data derived from collaborative trials;

D. data derived from EQAS.

The strategy used for uncertainty estimation does not have to follow one exclusive model and in practice the combination of data obtained from two or more different approaches can be employed.

All of these approaches are GUM compliant and are considered acceptable. Any of these approaches may be employed by a Laboratory to estimate the MU associated with their measurement results, provided the Laboratory estimate does not exceed the maximum acceptable (target) MU associated with the determination of specific Threshold Substances that have been established by *WADA*. These maximum acceptable MU are conservative estimates derived from EQAS performance data.

A. Modeling approach

In this case, the Laboratory develops a measurement equation or model in which result (y) is a function of independent input parameters $x_1, x_2, x_3....x_n$ that all influence the measurement result.

If the mathematical model is a combination of addition/subtraction and multiplication/addition operations then an appropriate quadratic combination is used to calculate the $u_c(y)$. This approach is also referred to as the "bottom-up" or "GUM" approach.

If the equation is in the form:

$$y = x_1 \pm x_2 .... \pm x_n$$

Then the $u_c(y)$ associated with the result is:

$$u_c(y) = \sqrt{u(x_1)^2 + u(x_2)^2 .... + u(x_n)^2}$$

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If the equation is of the form:

$$y = x_1 * x_2 * x_3 .... * x_n \quad \text{or} \quad y = \frac{x_1}{x_2 * x_3 .... * x}$$

Then the $u_c(y)$ associated with the result is given by:

$$u_c(y) = y * \sqrt{\left(\frac{u(x_1)}{x_1}\right)^2 + \left(\frac{u(x_2)}{x_2}\right)^2 + \left(\frac{u(x_3)}{x_3}\right)^2 .... + \left(\frac{u(x_n)}{x_n}\right)^2}$$

Note: The uncertainty budget derived using this approach indicates the relative magnitude of the various sources of uncertainty but carries the risk of missing a contributing factor which may significantly affect the overall estimate of MU. Nonetheless, it is a valuable means of establishing where the major sources of uncertainty are found in a quantitative Confirmation Procedure and for identifying where efforts should be focused if a reduction is desired in the overall MU of results obtained through use of the quantitative Confirmation Procedure.

B. Intra-laboratory data approach

This approach assumes that the quantitative Confirmation Procedure has undergone intra-Laboratory validation including an estimation of the within-Laboratory Reproducibility (also referred to as the Intermediate Precision or imprecision). It is based on a three component measurement model:

$$y = m + B + e$$

The result (y) is the sum under Reproducibility conditions of the measurement method mean (m), an estimate of method bias (B) and a random error contribution (e) and the $u_c(y)$ associated with the result is given by:

$$u_c(y) = \sqrt{u(m)^2 + u(B)^2 + u(e)^2}$$

The estimate of within-Laboratory Reproducibility or Intermediate Precision of results, usually obtained from intra-Laboratory QC and method validation data, can be expressed as a standard deviation (s_w). It provides a fit-for-purpose estimate of the uncertainty contribution from the $u(m)$ and $u(e)$ terms and the "internally visible" bias components (B_{Int}).

$$(s_w \cong \sqrt{u(m)^2 + u(e)^2 + u(B_{Int})^2}$$

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If *(y)* is the result of a single analysis, the equation for calculating the standard uncertainty associated with the result simplifies to:

$$u_c(y) = \sqrt{s_w^2 + u(B_{Ext})^2}$$

where B_{Ext} is an estimate for bias not accounted for by intra-Laboratory studies.

Where *(y)* is the average of *n* replicate analyses:

$$u_c(y) = \sqrt{\frac{s_w^2}{n} + u(B_{Ext})^2}$$

Note: When appropriately applied this approach, as with the other empirical approaches, is as valid as the modeling approach, and should provide a conservative but pragmatic estimation of MU.

C. Inter-Laboratory method performance data approach

Where a Laboratory has participated in an inter-Laboratory comparison to evaluate a quantitative Confirmation Procedure, or has demonstrated appropriate implementation of a literature method validated using such an approach, the inter-Laboratory SD of the method (s_R) calculated from the results of the comparison can be used as an estimate of the u_c of an individual result obtained using the method:

$$u_c(y) = \frac{s_R}{\sqrt{n}} \quad (y \text{ is the average of } n \text{ replicate analyses})$$

This approach is applicable, in practice, only when the validation study includes a multi-centre, inter-Laboratory trial conducted to a pre-defined experimental protocol.

Note: The major sources of variability can be assessed by inter-laboratory studies and provide estimates of Repeatability standard deviation (s_r), Reproducibility (s_R) and Bias (*b*) of the method (with respect to a known reference value). The Reproducibility can be used as an estimate of the u_c associated with an individual measurement result obtained using this quantitative Confirmation Procedure.

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D. EQAS participation approach

Data obtained from ongoing participation in an EQAS allows, in some cases, for the calculation of a performance characteristic of the ensemble of methods used by participants that can serve, in the absence of a properly constituted inter-Laboratory study, as a conservative estimate of the Reproducibility (s_R) of the quantitative Confirmation Procedure used by an individual Laboratory. It is mostly in the latter sense that the term s_R is used in the current draft. This estimate is only valid when:

- the values reported by participants in the EQAS round (after exclusion of outliers) fall into a normal Gaussian distribution;

- the intra-Laboratory Repeatability (s_r) for the method is smaller than the variation in the participant results;

- uncertainty contributions from instability or heterogeneity of the EQAS sample are negligible;

- the matrices utilised correspond closely to those encountered in routine analytical conditions (*i.e.* "representative" matrices are used to prepare the EQAS materials).

In this case the SD of the participants' results after exclusion of outliers can be used as an estimate of the u_c associated with a result obtained by the method. This value can then be applied as described for the s_R estimate in section 1.C above.

Note: As noted in section 1.C, the Reproducibility (s_R) estimate can be used as a conservative estimate of the u_c associated with a result ($s_R \approx u_c$). Moreover, a Laboratory can, by its participation in the *WADA* EQAS, verify and demonstrate the validity of its chosen approach to estimate the MU (see Section 3).

2. ANALYTICAL METHOD DEVELOPMENT AND VALIDATION

Laboratories must employ a validated quantitative Confirmation Procedure, which when taking into account the MU at the 95 % coverage level (calculated at the T value), assures an *AAF* or *ATF* when the mean measured value exceeds the DL.

When developing the quantitative Confirmation Procedure, before validation, a Laboratory should consider all aspects of the procedure and identify the critical performance characteristics that need to be optimized in order to ensure that the uncertainty of a result obtained using the method is compliant with the criteria set by *WADA*.

Validation is essential for the application of any Analytical Testing Procedure and for accreditation of the Laboratory to ISO/IEC 17025. The performance characteristics established during the validation process of a quantitative Confirmation Procedure can be used as the basis for estimates of the MU associated with the results obtained using the quantitative Confirmation Procedure.

More detailed descriptions of the general principles pertaining to Analytical Method validation are available in various guidance documents [12-15] and will not be

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described in detail. The characteristics listed below (Table 2, Column 1) are provided as an example of the minimum areas extracted from the validation data that should be investigated as part of any quantitative Confirmation Procedure validation process to estimate the u_c. The need to undertake an estimation of the u_c using the ISO component-by-component approach is not necessary if the other forms of data are available and used to estimate the uncertainty. Since the quantitative Confirmation Procedures employed must be validated, the following approach is the preferred option.

Table 2

Analytical Method Characteristic	- Source of Data
Calibration	- 50 % to at least 200 % of the T concentration in calibrators prepared in the same matrix as the *Samples* (at least 5 calibration points across the linear range under investigation and at least four replicates per calibration point are recommended); - 2 individually prepared stock standard solutions and 2 dilution series from each; - Least squares regression analysis of the response versus concentration to calculate the method's regression coefficient over this range.
Repeatability	- At least 10 repeats of a suitable CRM/QC sample(s) or a 'spiked' urine/blood (serum, plasma) of known concentration/ratio/score at or close to the T value. The solutions shall be analyzed by the same analyst and equipment, in the same Laboratory on a short timescale. The SD of the results is the method Repeatability (s_r) at that concentration.
Intermediate Precision	- At least 10 individually prepared test solutions prepared preferably from control urine/blood (serum, plasma) or a CRM or QC sample(s) of concentration/ratio/score that is close to the T value. Analyzed in the same Laboratory on different days using (where possible) different operators and different equipment. The SD of the results is the Intermediate Precision (s_w) estimate for the method at that concentration.
Bias	- Determine the difference or method bias (b) between the mean measured value for test results obtained by analysis of a relevant CRM, QC sample or spiked matrix and the reference values for these samples. - Where information is available from n separate bias determinations calculate the root mean square of the bias (RMS_{bias}). - If the RMS_{bias} is used to estimate the standard u_c of results obtained using the method, a contribution due to the uncertainty associated with the reference values used to establish the method bias shall also be included.

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Robustness	- Estimate the influence of expected variations in analytical conditions and *Sample* parameters (especially variations in matrix).

In cases where the quantitative Confirmation Procedure method validation process is considered to have included the influence effects of all relevant parameters then a Fit-for-Purpose estimate of the $u_c(y)$ for an individual result (y) can usually be obtained by quadratic combination of the Intermediate Precision (s_w) value and the bias uncertainty estimate.

Combined uncertainty	$$u_c = \sqrt{s_w{}^2 + RMS_{bias}{}^2}$$
Expanded uncertainty	$U_{95\%} = k \cdot u_c$, where $k=2$*

* *WADA* has determined that use of a coverage factor of $k=2$ (for a two-tailed distribution) establishing the expanded uncertainty U associated with a result (y) at an approximate coverage level of 95 % is appropriate for anti-doping purposes.

If the procedure is to be applied over a wide concentration range, which is typically not the case for the purposes of anti-doping Analytical Testing, uncertainty of results obtained using the quantitative Confirmation Procedure should be determined at three (3) concentration levels (low, medium and high). For wide concentration ranges it is not unusual to find that the relative uncertainties for individual results decrease as the concentration of the Analyte in the sample increases; however, it is sufficient to focus on the uncertainty associated with the performance of the quantitative Confirmation Procedure at the Threshold concentration to determine an *AAF* for a Threshold Substance.

Having established the expanded uncertainty U associated with results obtained using their quantitative Confirmation Procedure, a Laboratory shall regularly (*i.e.* with every analysis of a Threshold Substance) run a QC sample at a concentration at or near the Threshold concentration (preferably containing the Analyte of interest at or near the T value, if available) and record the values obtained, preferably on a control chart with acceptance limits based on the validation data, to ensure the validity of the values obtained and to follow trends.

A worked example taken from an environmental testing application has been published [16] illustrating how the combination of intra-laboratory validation, quality control data and a bias estimate obtained from regular participation in a EQAS can be used to obtain an estimate of the MU associated with results at defined concentrations.

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3. VERIFICATION OF <u>MEASUREMENT UNCERTAINTY</u>

For some ratios or scores (obtained from the measured concentrations of, for example, two <u>Analytes</u>) a similar approach, as described above, applies but it is necessary to take into account the combined uncertainties of the values obtained for both <u>Analytes</u> when calculating the expanded uncertainty, *U.*

Regardless of the approach employed by a <u>Laboratory</u> to estimate the <u>MU</u> for the results it obtains using a particular quantitative <u>Confirmation Procedure</u>, it is important that this <u>MU</u> estimate be validated and its veracity continuously monitored. This can be accomplished by regular comparison with an appropriate QC sample, preferably a <u>Certified Reference Material</u> (<u>CRM</u>), if available, and/or through evaluation of method performance using <u>EQAS</u> data.

The <u>MU</u> for a particular quantitative <u>Confirmation Procedure</u>, estimated by a <u>Laboratory</u> can also be checked by comparison to data generated from an appropriate <u>EQAS</u> by employing the E_n number.

$$E_n = \frac{x - x_a}{\sqrt{U(x)^2 + U(x_a)^2}}$$

Where x_a is the assigned value for the <u>EQAS</u> study, x is the <u>Laboratory</u> result, and $U(x_a)$ and $U(x)$ are respectively the expanded uncertainties associated with each result. It is considered that when $|E_n|$ is:

- Close to one (1): then the <u>MU</u> is correctly estimated provided it is less than the maximum acceptable <u>MU</u> required by *WADA;*

- Repeatedly less than one (1): then the <u>MU</u> is probably overestimated. This could still be acceptable provided that the reported <u>MU</u> is less than the target <u>MU</u> (maximum uncertainty permitted). Nonetheless, the <u>MU</u> for this particular quantitative <u>Confirmation Procedure</u> should be re-assessed;

- Repeatedly greater than one (1): the <u>MU</u> is probably underestimated and in this case the reason for the high E_n value should be re-assessed. If necessary, steps should be taken to re-evaluate the <u>MU</u>.

Whenever there is a change in the quantitative <u>Confirmation Procedure</u> (extraction step, derivatization conditions, internal standard, etc.) a re-validation of the procedure and a re-assessment of <u>MU</u> of results obtained using the altered procedure is required.

It is necessary to check that the quantitative <u>Confirmation Procedure</u> is still <u>Fit-for-Purpose</u> (*e.g.* the <u>MU</u> estimated by the <u>Laboratory</u> for a particular quantitative <u>Confirmation Procedure</u> is below the maximum acceptable <u>MU</u> given in Table 1 above).

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