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Guidelines on the Calibration of Automatic Gravimetric Filling Instruments
DRAFT CALIBRATION METHOD

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APPENDICES

1 INTRODUCTION

Automatic gravimetric filling instruments (AGFI) [1] are widely used to fill containers with predetermined and virtually constant mass of product from bulk by automatic weighing. There is a growing need for confirmation of their metrological characteristics by calibration, e.g. where required by EN ISO 9001 standard.

2 SCOPE

This document contains guidance for the calibration of automatic gravimetric filling instruments (hereafter called "instrument"), in particular for

1. measurements to be performed,
2. determination of the reference value of mass of the test fills [,
3. calculation of the measuring results,
4. evaluation of the uncertainty of measurement,
5. contents of the calibration certificates.

The guide refers to automatic operation of the instrument.

The object of the calibration is net value of the test fill [1] in relation to the preset value [1], i.e. value, expressed in units of mass, preset by the operator, in order to define the nominal value of the fills. The actual value of the fill will be affected by dynamic effects, rate of operation, the load type and properties, the container properties, local gravity, the load temperature and density, and the temperature and density of the surrounding air.

The uncertainty of measurement depends significantly on properties of the calibrated instrument itself, the control instrument, the characteristics of the test loads, the container, the equipment of the calibrating laboratory. This guideline does not specify lower or upper boundaries for the uncertainty of measurement.

It is up to the calibrating laboratory and the client to agree on the anticipated value of the uncertainty of measurement, which is appropriate in view of the use of the instrument and the cost of the calibration.

While it is not intended to present one or few uniform procedures the use of which would be obligatory, this document gives general guidance for establishing of calibration procedures the results of which may be considered as equivalent within the EURAMET Member Organisations.

Any such procedure must include, for a limited number of the preset values, the determination of the preset value errors and evaluation of the uncertainty of measurement assigned to these errors. The calibration procedure should as closely as possible resemble the weighing operations that are routinely being performed by the user – e.g. production of fills with nominal values and material, which are actually used by client, using the same rate of operation.

The calibration can only deliver a measurement error in comparison to the preset value at the time of calibration and under the conditions of the calibration. Any transfer of this information to other conditions or an extrapolation of the results into the future requires additional succeeding calibrations or a priori information and the respective extrapolation of the uncertainty based on the knowledge about the behaviour of the instrument.

The information presented in this guideline is intended to serve, and should be observed by

1. bodies accrediting laboratories for the calibration of automatic gravimetric filling instruments,
2. laboratories accredited for the calibration of automatic gravimetric filling instruments,
3. manufacturers and other users using calibrated automatic gravimetric filling instruments for measurements relevant for the quality of production subject to QM requirements (e.g. EN ISO 9000 series, EN ISO 10012).

3 TERMINOLOGY AND SYMBOLS

The terminology used in this document is mainly based on existing documents

- OIML R61-1 [1] for terms related to the operation, construction and metrological characterization of automatic catchweighing instruments
- EURAMET Calibration Guide No. 18 [2] for terms related with the static weighing and calibration of control instrument,

Such terms are not explained in this document, but where they first appear, references will be indicated.

Symbols whose meanings are not self-evident, will be explained where they are first used. Those that are used in more than one section are collected in Appendix A.

4 GENERAL ASPECTS OF THE CALIBRATION

4.1 Elements of the calibration

Calibration consists of

1. weighing of the empty containers,
2. applying the material tests to the instrument under specified conditions,
3. weighing of the filled containers,
4. determining the reference value of mass of the test fills,
5. determining the preset value error at dynamic weighing,
6. estimating the uncertainty of measurement to be attributed to the results.

4.1.1 Range of calibration

In agreement with the client, the calibration is performed at individual preset values, and it is only valid for the specified values (with a small bandwidth for mass). It will usually not be possible to calibrate a "range" for such instruments, because of their dynamic behaviour.

The calibration is performed at the rate of operation requested and specified in advance by the client. Normally these conditions are the same as conditions during the actual weighing process.

The calibration it is only valid for these conditions.

4.1.2 Place of calibration

Calibration is performed at the location where the instrument is being installed. The calibration is valid for the place of calibration.

4.1.3 Preconditions, preparations

The calibration should be performed under normal conditions of use (air currents, vibrations, stability of the weighing site etc.) of the instrument. The calibration should not be performed unless

1. the instrument can be readily identified,
2. all functions of the instrument are free from effects of contamination or damage, and functions essential for the calibration operate as intended,
3. presentation of preset values is unambiguous and indications, where given, are easily readable,
4. the instrument shall be operated and fills produced for a time period under normal operating conditions to enable stability.

If agreed with the client, the instrument could be statically adjusted before the calibration. Adjustment should be performed with the means that are normally applied by the client, and following the manufacturer's instructions where available.

Instruments fitted with an automatic zero-setting device or a zero-tracking device [1] should be calibrated with the device operative or not, as used by the client.

The user of the instrument should be asked to ensure that the normal conditions of use prevail during the calibration. In this way disturbing effects such as air currents, vibrations, or inclination of the measuring platform will, so far as is possible, be inherent in the measured values and will therefore be included in the determined uncertainty of measurement.

4.2 Control instrument

A control instrument [1] is used to determine the reference value of mass of the test fills based on weighing of filled and empty containers.

The control instrument may be either separate (a weighing instrument other than the instrument being calibrated) or integral (when a static weighing mode is provided by the instrument being calibrated).

The control instrument should ensure the determination of the reference value of mass of each test fill to accuracy, which is appropriate to the expected uncertainty of calibration of the calibrated instrument.

As a recommendation it can be taken that the control instrument should have a resolution better than the calibrated instrument and, if applicable, ensure the determination of the reference value of mass of each test fill to an accuracy of at least one-third of appropriate tolerances for the calibrated instrument if they are defined by client.

In some cases, it may be necessary to use one control instrument for weighing of filled containers and another for weighing of empty containers.

Details on determination of the reference value of mass of the test fills on the control instrument and corresponding uncertainty are given in Sections 4.6 and 7.1, respectively.

4.3 Containers

The same kind of containers needs to be used during the calibration as they are used during the production process.

4.4 Test fills

The test fills should be made of the type of product, which is normally weighed on the calibrated instrument. For the purpose of calibration, their traceability to the SI unit of mass shall be demonstrated.

The mass of test fills must remain constant throughout the period in which they are used for calibration.

The reference value of mass of the test fills is normally determined at the time and place of calibration of the instrument.

4.4.1 Determination of the reference value of mass of the test fills

The necessary measurements to determine the reference value of mass of the test fills are performed on the control instrument (cf. 4.2). The procedure requires measurements of empty containers (i.e. a tare value) and measurements of filled containers (i.e. a gross value). Recommended approaches for determining the reference value of mass of the test fills are further discussed in Section 4.6.

4.4.2 Standard weights

Standard OIML weights [3] directly applied on the instrument are not used for calibration of the instrument.

The requirements for the standard weights, which are used for calibration of the control instrument are given in [2].

4.4.3 Effects of convection

The test fills may not be at the same temperature as the instrument and its environment, but in general the effect of convenction may be neglected.

At extreme initial temeprature difference ΔT_0 between the test fills and surrounding air, the effect of convection may be reduced to a smaller value ΔT over a time Δt allowing the test fills to reach the temperature of the environment before determing their reference value of mass on the control instrument, i.e. to the extent that the remaining change $\Delta m_{conv}$is negligible in view of the uncertainty of the calibration required by the client. In such a case, it is practically not possible to perform the correction for the convenction effects, therefore the error due to convection intrisically forms part of the preset value error.

4.5 Indications

4.5.1 General

An automatic weighing instrument is capable of performing consecutive weighing cycles without any intervention of an operator [4]. Unlike for non-automatic weighing instrument, the automatic weighing instrument operator is niether capable nor expected to make a correction of the indication under load with the indication at no load.

Furthemore, for the purpose of calibration of automatic gravimetric filling instrument, only the preset value of fill F_p is taken into account.

During calibration tests, the indications of calibrated intrument, if available at all, are not recorded.

4.5.2 Resolution

The preset value of fill F_p is introduced as integer multiple of the scale interval d. This value is considered as a resolution of the instrument.

4.6 Reference value of mass of test fills

To determine the preset value error of an instrument E_P, the reference values of mass of the test fills $m_{ref,i}$ needs to be known. The conventional masses of the test fills are a priori not known, density of filled product ρ_F is normally significantly different from the reference value ρ_c and the air density ρ_a at the time of calibration is normally different from reference air density ρ_0.

Due to effects of air buoyancy and others, which may lead to minor correction terms δm_x, the reference value of mass of the test fill $m_{ref,i}$ further called reference value of mass, is not exactly equal to $m_{cF,i}$, the conventional mass of i-th test fill

$$m_{ref,i} = m_{cF,i} + \delta m_{B,F} + \delta m \dots \quad (4.6\text{-}1)$$

with
$\delta m_{B,F}$ – air buoyancy correction for the test fill (refers to net value of test fill),
δm – further corrections that it may be necessary to apply under special conditions, e.g. correction due to possible drift of the test load or due to convection effects, are not considered hereafter.

The conventional mass of test fill cannot be determined directly, but trough determination of conventional mass of the filled container m_{cB} (gross value) and conventional mass of the empty container m_{cT} (tare value)

$$m_{cF,i} = m_{cB,i} - m_{cT,i} \quad (4.6\text{-}2)$$

Consequently

$$m_{ref,i} = m_{cB,i} - m_{cT,i} + \delta m_{B,F} \quad (4.6\text{-}3)$$

Opposite to calibration of NAWI, density of the test load used at calibration of the AGFI, i.e. the filled product, may significantly differ from the reference density of standard weights ρ_s, i.e. 8000 kg/m^3 [5]. Consequently, air buoyancy corection could be significant. However, the reference value of mass is determined at the time and place of calibration of the AGFI and at the same air density. It will be shown that the density of the filled product and the density of the containers don't need to be known.

m_{ref} could be determined in various ways. Some of these methods are summarised in the table below, with further details given in subsections of Appendix B.

Method of determination of reference value of mass	Time of calibration	Remarks	Appendix
Test fills weighed on the simultaneously calibrated control instrument	Control instrument calibrated at time and place of calibration of AGFI Test load weighed at the time and place of calibration of AGFI	/	B1
Test fills weighed on the previously calibrated control instrument	Control instrument calibrated previously. Test load weighed at the time and place of calibration of AGFI	Control instrument needs to have calibration certificate. Uncertainty of control instrument in use needs to be taken into account.	B2

The air buoyancy correction for the test fill $\delta m_{B,F}$ is affected by air density at the time of calibration of the instrument ρ_a, density of the test fill ρ_F and density of standard weights used for adjustment of the AGFI ρ_s

$$\delta m_{B,F} = -m_{c,F}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_F} - \frac{1}{\rho_s}\right)\right] \quad (4.6\text{-}4)$$

with reference air density $\rho_0 = 1{,}2\ kg/m^3$.

In (4.6-4), $m_{c,F}$ can be replaced, without introducing a significant error, with the nominal mass of the test fill $m_{N,F}$, which equals the preset value of fill F_P

$$\delta m_{B,F} = -m_{N,F}\left[(\rho_a - \rho_0)\left(\frac{1}{\rho_F} - \frac{1}{\rho_s}\right)\right] \qquad (4.6\text{-}5)$$

Appendix B provides complete description of determination of the reference value of mass $m_{ref.i}$, which results from determination of the conventional mass of test fill $m_{cF,i}$ (trough determination $m_{cB,i}$ and $m_{cT,i}$) and the air buoyancy correction for test fill $\delta m_{B,F}$, considering the principle determination of the reference value of mass. Final results of Appendix B subsections are used in Section 7.1.2.

4.7 *Operating parameters*

Type of the test material, rate of operation must be recorded for each case [1].

5 MEASUREMENT METHODS

Tests are normally performed to determine the preset value error at different preset values.

The calibration laboratory deciding on the number of measurements for its routine calibration procedure should consider that, in general, a larger number of measurements tend to reduce the uncertainty of measurement.

Details of the tests performed for an individual calibration may be fixed by agreement of the client and the calibration laboratory, in view of the normal use of the instrument. The parties may also agree on further tests or checks, which may assist in evaluating the performance of the instrument under special conditions of use. Any such agreement should be consistent with the minimum numbers of tests as specified in the following sections.

The general test procedure for the test specified in the following sections shall be as follows:

1) Select the test fills material as specified in Section 4.4 and the preset values of fills as specified in Section 5.2.

2) Weighing of empty containers on the control instrument as specified in Section 5.1.

3) The instrument should be tested in its normal mode of automatic operation. Start the automatic weighing system, including the surrounding equipment, which is normally operational when the instrument is in use.

4) Set the preset value of fills and set the rate of operation agreed with the client. Normally this is the rate of operation used by the client. This may vary depending on the preset value.

5) The number of consecutive test fills depends on the preset value as specified in Section 5.1.

6) Zero shall be set at the start of each test at a given preset value and not readjusted at any time during the test. It has to be allowed that automatic

adjustment of zero, if exists and used by user, is operational during the tests.

7) Enable automatical filling of the specified number of test fills.

8) Weighing of filled containers on the control instrument.

9) Determine the reference value of mass of each test fill as specified in Appendix B.

5.1 Containers tare value

The tare of empty containers, i.e. their mass needs to be determined on the control instrument as a part of the calibration.

Case A:
If the mass difference between individual empty containers is significant in comparison to the expected uncertainty of calibration of the calibrated instrument (e.g. equal or larger then a half of the scale interval value of the preset value device) of the calibrated AGFI, then it is necessary to determine the mass of each empty container, which will be used.

Case B:
If the mass of containers is virtually constant, it is sufficient to determine average mass of empty containers. The average mass of empty containers could be determined by simultaneous weighing of a sample of several empty containers (e.g. 10 or more).

5.2 Test for preset value error and repeatability

The test consists of repeated filling the fills with the same nominal value, and under constant test conditions. The purpose of this test is an evaluation of the accuracy and repeatability of the instrument in selected test points. Each test point is characterized by its own repeatability.

The test is performed with k different preset values F_{pj}, $1 \le j \le k$.

Examples for the preset value target values:

- the minimum nominal value of fills produced on-site Min',
- the largest nominal value of fills produced on-site Max',
- a value equally distributed between *Min′* and *Max′* according to use of the instrument, especially if Min' is less than one third of Max'.

Details about the target preset values need to be agreed with the client to represent usual use of the calibrated instrument.

The minimum number of individual test fills shall be as specified in the following table:

Preset value of the fills, F_p	Minimum number of test fills, n
F_p ≤ 1 kg	60
1 kg < F_p ≤ 10 kg	30
10 kg < F_p ≤ 25 kg	20
25 kg < F_p	10

5.3 Auxiliary measurements

The air temperature in reasonable vicinity to the instrument should be measured, at least once during the calibration.

If it is necessary to prevent excessive convection effects, a limiting value for the temperature difference between the test loads and instrument should be observed, and/or an acclimatisation time that has been executed recorded.

6 MEASUREMENT RESULTS

The procedures and formulae in Sections 6 and 7 provide the basis for the evaluation of the results of the calibration tests and therefore require no further description on a calibration certificate. If the procedures and formulae used deviate from those given in the guide, additional information may need to be provided in the certificate.

6.1 Preset value error

For j-th preset value F_{Pj}, the preset value error E_{Pj} is calculated based on measurement of n test fills as follows

$$E_{Pj} = \frac{1}{n}\sum_{i=1}^{n} m_{ref,ij} - F_{Pj} \qquad (6.1\text{-}1)$$

$\frac{1}{n}\sum_{i=1}^{n} m_{ref,ij}$ being the mean reference value of mass.

For the case when the test fills are weighed on the control instrument calibrated at time and place of calibration of the AGFI (cf. Appendix B1), $m_{ref,ij}$ in (6.1-1) can be modified by introduction of (B1-13)

$$m_{ref} = W'_{CI,B} - W'_{CI,T} + \delta m_{BTot}$$

When the test fills are weighed on the previously calibrated control instrument (cf. Appendix B2), m_{ref} in (6.1-1) can be modified by introduction of (B2-7)

$$m_{ref} = W_{CI,B} - W_{CI,T} + \delta m_{BTot}$$

Further in this section, symbols $W_{CI,B}^{(\prime)}$ and $W_{CI,T}^{(\prime)}$ will be used to represent either $W'_{CI,B}$ and $W'_{CI,T}$ or $W_{CI,B}$ and $W_{CI,T}$.

If according to Case A from Section 5.1 it is necessary to measure each empty container, (6.1-1) is modified, taking into account (B1-13) or (B2-7), to

$$E_{Pj} = \frac{1}{n}\sum_{i=1}^{n}\left(W_{CI,Bij}^{(\prime)} - W_{CI,Tij}^{(\prime)}\right) + \delta m_{BTot,j} - F_{Pj} \qquad (6.1\text{-}2a)$$

If according to Case B from Section 5.1 it is appropriate only to measure a sample of m empty containers, (6.1-1) is modified, taking into account (B1-13) or (B2-7), to

$$E_{Pj} = \frac{1}{n}\sum_{i=1}^{n}\left(W_{CI,Bij}^{(\prime)} - \frac{1}{m}\sum_{z=1}^{m} W_{CI,Tzj}^{(\prime)}\right) + \delta m_{BTot,j} - F_{Pj} \qquad (6.1\text{-}2b)$$

In order to simplify necessary calculations, from (6.1-2a) the apparent mass of a single fill F_{ij} is introduced as

$$F_{ij} = W_{CI,Bij}^{(\prime)} - W_{CI,Tij}^{(\prime)} \qquad (6.1\text{-}3a)$$

and from (6.1-2b) as

$$F_{ij} = W_{CI,Bij}^{(\prime)} - \frac{1}{m}\sum_{z=1}^{m} W_{CI,Tzj}^{(\prime)} \qquad (6.1\text{-}3b)$$

Finally

$$E_{Pj} = \overline{F}_j + \delta m_{BTot} - F_{Pj} \qquad (6.1\text{-}4)$$

where $\overline{F}_j$ is the average apparent mass of fills

$$\overline{F}_j = \frac{1}{n}\sum_{i=1}^{n} F_{ij} \qquad (6.1\text{-}5)$$

6.2 Repeatability

From the n fills F_{ij}, $i = 1, \dots, n$, for a given j-th preset value F_{Pj}, the standard deviation $s(F_j)$ is calculated

$$s(F_j) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}\left(F_{ij} - \overline{F}_j\right)^2} \qquad (6.2\text{-}1)$$

7 UNCERTAINTY OF MEASUREMENT

For the determination of uncertainty, second order terms have been considered negligible, but when first order contributions cancel out, second order contributions should be taken into account (see JCGM 101 [6], 9.3.2.6).

7.1 Standard uncertainty of the preset value error

The basic formula for the calibration is (the same as (6.1-1), only the index j is omitted for the sake of simplicity))

$$E_P = \frac{1}{n}\sum_{i=1}^{n} m_{ref,i} - F_P \qquad (7.1\text{-}1)$$

To account for sources of variability of the preset value error, (7.1-1) is amended by taking into account (6.1-4), (6.1-5) and correction terms δX_{xx} as follows

$$E_P = \frac{1}{n}\sum_{i=1}^{n} F_i + \delta F_{rep} + \delta F_{repT} + \delta m_{BTot} - F_P \qquad (7.1\text{-}2)$$

with standard uncertainty of the preset error

$$u(E_P) = \sqrt{u^2\left(W_{CI,B}^{(\prime)}\right) + u^2\left(W_{CI,T}^{(\prime)}\right) + u^2\left(\delta F_{rep}\right) + u^2\left(\delta F_{repT}\right) + u^2(\delta m_{BTot})} \qquad (7.1\text{-}4)$$

All input quantities are considered to be uncorrelated, therefore covariances are not considered.

The terms are further expanded hereafter.

7.1.1 Standard uncertainty of the weighing result for filled containers (gross)

Taken into account the content of table in Section 4.6 and Appendix B, the following cases are treated in this section:

A. Test load weighed on the simultaneously calibrated control instrument
B. Test load weighed on the previously calibrated control instrument

In general, the uncertainty of weighing result gets larger from procedure A to procedure B.

7.1.1.A Filled container weighed on simultaneusly calibrated control instrument

To account for sources of variability of the weighing result $W'_{CI,B}$, when a control instrument is used, which was calibrated immediately before the weighing took place, (B1-14) is amended by corrections terms δX_{xx} as follows

(7.1.1-1)

$$
\begin{aligned}
W'_{CI,B} = &\left(R_{LCI,B} + \delta R_{digLCI,B} + \delta R_{repCI,B} + \delta R_{eccCI,B} - \left(R_{0CI,B} + \delta R_{0CI,B}\right)\right)\\
&- \left(I_{LCI,B} + \delta I_{digLCI,B} + \delta I_{repCI,B} + \delta I_{eccCI,B} - \left(I_{0CI,B} + \delta I_{dig0CI,B}\right)\right)\\
&+ \left(m_{NCalCI,B} + \delta m_{cCalCI,B} + \delta m_{DCalCI,B} + \delta m_{convCalCI,B}\right)
\end{aligned}
$$

7.1.1.1 $R_{CI,B}$ is the reading of the filled container on the control instrument (cf. also (B1-3)). Its standard uncertainty $u(R_{CI,B})$ should be evaluated according to Section 7.4.1 of [2].

7.1.1.2 $I_{CI,B}$ is indication of the standard weights on the control instrument (cf. also (B1-5)). Its standard uncertainty $u(I_{CI,B})$ should be evaluated according to Section 7.1.1 of [2].

7.1.1.3 $m_{CalCI,B}$ is the reference value of mass of standard weights used for calibration of the control instrument at gross value for the test fills, without taking into account the correction term for air buoyancy. Its standard uncertainty $u(m_{CalCI,B})$ should be evaluated according to Section 7.1.2 of [2], but not taking into account the standard uncertainty of the air buoyancy correction. The standard uncertainty of the air buoyancy correction is treated separately according Section 7.1.5.

7.1.1.4 When the filled containers are weighed on the simultaneulsy calibrated control instrument, the standard uncertainty of the of the weighing result for filled containers is obtained from

$$u^2(W'_{CI,B}) = u^2(R_{CI,B}) + u^2(I_{CI,B}) + u^2(m_{CalCI,B}) \qquad (7.1.1\text{-}2)$$

with the contributions from 7.1.1.1 to 7.1.1.3.

7.1.1.B Filled container weighed on previously calibrated control instrument

7.1.1.5 When a previously calibrated control instrument is used, $W_{CI,B}$ is determined according to Appendix B2. Its standard uncertainty $u(W_{CI,B})$ should be evaluated according to Sections 7.4.5 or 7.5.2 of [2] for the case when errors of the control instrument are accounted by correction or included in a "global" uncertainty $U_{gl}(W_{CI})$, respectively.

According to [2], the standard uncertainty for the weighing result under conditions of the calibration $u(W^*_{CI})$ could be used instead of $u(W_{CI})$ if the control instrument was calibrated right before its use. Similar can be assumed if the control instrument was adjusted right before its use and uncertainty contributions resulting from the opration of the control instrument (as defined in Section 7.4.4 of [2]) are negligable.

The control instruments needs to have the calibration certificate. If the certificate states uncertainty of the instrument in use, this is non-acredited value. On basis of [2] the laboratory needs to independently evaluate uncertainty in use based on actual conditions valid in a period since the last calibration of control instrument.

For a special case, where the control instrument is used, which conforms to [7,8] and where the tolerance specified by the client Tol equals maximum permissible error of the non-automatic weighing instrument mpe_{R76}[7,8], evaluation of the standard global uncertainty is provided in Appendix C.

7.1.2 Standard uncertainty of the weighing result for empty container (tare)

For evaluation of standard uncertainty of the weighing result for empty container $u(W'_{CI,T})$ or $u(W_{CI,T})$, a relevant approach from Section 7.1.1 need to be used, which is in agreement with an applied principle of determination of the weighing result of empy containers from Section 4.6.

If the average mass of containers is determined by simultaneous weighing of a sample of several empty containers, uncertainty is in the first step estimated for the complete sample $u(W_{mT})$, then, in the second step, uncertainty of an individual empty container equals

$$u(W_T) = \frac{1}{m} u(W_{mT}) \qquad (7.1.2\text{-}1)$$

where m is number of empty containers in the sample.

7.1.3 Standard uncertainty of the mean of several fills

δF_{rep} accounts for the repeatability of test fills. The normal distribution is assumed, and the standard uncertainty of the mean of several fills is then

$$u(\delta F_{rep}) = s(F_j)/\sqrt{n} \qquad (7.1.3\text{-}1)$$

where $s(F_j)$ is determined as in 6.2 and n is number of repeated fills.

$s(F_j)$ is determined for each given preset value F_P and it is considered as representative only for the respective preset value.

7.1.4 Standard uncertainty of variability of tare

δF_{repT} accounts for the variability of mass of empty containers. If the mass of containers is virtually constant (cf. Case B in 5.1), i.e. the maximum mass difference between individual containers is smaller than estimated limiting value Δm_T; the rectangular distribution is assumed, and the standard uncertainty of variability of tare is then

$$u(\delta F_{repT}) = \Delta m_T/(2\sqrt{3}) \qquad (7.1.4\text{-}1)$$

δF_{repT} is determined for each given type of container used druging the calibration.

This contribution is not applicable in the case, where tare value of each container is determined and taken into account (cf. Case A in 5.1).

7.1.5 Standard uncertainty of air buoyancy correction

δm_{BTot} is the correction for air buoyancy as introduced in (B.1-12) and (B.2-6).

Where a simple comparison of expected values of δm_{BTot} with the resolution of the preset value device d shows that the air buoyancy correction is small enough, a more elaborate calculation of the correction and its uncertainty component based on actual data may be superfluous. Consequently, no correction is applied, i.e. δm_{BTot}=0. Where conformity of the standard weights used for adjustment of the AGFI and control instrument to OIML R111 [3] is established and if the AGFI is not adjusted before calibration, the standard uncertainty is evaluated as as given in [2]

$$u(\delta m_{BTot}) \approx (0{,}1\,\rho_0 m_{N,F}/\rho_c + mpe/4)/\sqrt{3} \qquad (7.1.5\text{-}1)$$

with $m_{N,F}$ being the nominal mass of the test fill and mpe the maximum permissible error according to [3] of the standard weights corresponding to the nominal mass of the test load. The lowest accuracy class of the standard weights used for adjustment is applicable.

For smaller uncertainties, e.g. if the air buoyancy correction is taken into account according to (B.1-12) or (B.2-6), or the AGFI is adjusted immediately before calibration, the standard uncertainties could be evaluated according to Section 7.1.2.2 of [2].

7.2 Expanded uncertainty at calibration

The expanded uncertainty of the preset value error is

$$U(E_p) = ku(E_p) \tag{7.2-1}$$

The coverage factor $k = 2$ should be chosen such that the expanded uncertainty corresponds to a coverage probability of 95,45 %.

7.3 Standard uncertainty of a weighing result

Chapters 7.3 and 7.4 provide advice how the measurement uncertainty of an instrument could be estimated in normal usage, thereby taking into account the measurement uncertainty at calibration. Where a calibration laboratory offers to its clients such estimates which are based upon information that has not been measured by the laboratory, the estimates must not be presented as part of the calibration certificate. However, it is acceptable to provide such estimates as long as they are clearly separated from the calibration results.

The user of an instrument should be aware of the fact that in normal usage, the situation is different from that at calibration in some if not all of these aspects

1. the weighing process may be different from the procedure at calibration
    a. a mean value of several fills is not obtained,
    b. it is not possible to make corrections to the actual mass value of the fill,
2. the environment (temperature, barometric pressure etc.) may be different,
3. the adjustment may have changed, due to drift or to wear and tear. This effect should therefore be considered in relation to a certain period of time.

To take into account the remaining possible influences on the weighing result W, the correction δF_{inuse}, which represents a correction term due to variability of fill in use, and the correction δF_{instr}, which represents a correction term due to environmental influences, are added to the preset value F_p resulting in the general weighing result

$$W = F_p + \delta F_{inuse} + \delta F_{instr} - E_p \tag{7.3-1}$$

The associated standard uncertainty is

$$u(W) = \sqrt{u^2(\delta F_{inuse}) + u^2(\delta F_{instr}) + u^2(E_p)} \tag{7.3-2}$$

The added terms and the corresponding standard uncertainties are discussed in 7.3.1 and 7.3.2.

Sections 7.3 and 7.4 are meant as advice to the user of the instrument on how to estimate the uncertainty of weighing results obtained under their normal conditions of use. They are not meant to be exhaustive or mandatory.

7.3.1 Standard uncertainty of a variability of fill in use

To account for sources of a variability of the fill, the correction term δF_{inuse} accounts for additional errors (δF_{digPT}, δF_{rep} and δR_0) which may occur in use

$$\partial F_{inuse} = \delta F_{digPT} + \delta F_{rep} + \delta R_0 \tag{7.3.1-1}$$

No corrections are actually applied but the corresponding uncertainties are estimated:

7.3.1.1 δR_{digPT} accounts for the rounding error of preset value. Its expectation value of correction is zero. Limits of δI_{dig} are $\pm d/2$; rectangular distribution to be assumed, therefore it's standard uncertainty equals

$$u(\delta F_{digPT}) = d/2\sqrt{3} \tag{7.3.1-2}$$

7.3.1.2 δF_{rep} accounts for the repeatability of the instrument. 7.1.3 applies, the relevant standard deviation $s(F)$ for a single reading is to be taken from the calibration certificate, so

$$u(\delta F_{rep}) = s(F) \tag{7.3.1-3}$$

Note: The standard deviation not the standard deviation of the mean should be used for the uncertainty calculation.

7.3.1.3 δF_0 accounts for the stability of automatic zero-setting device. The automatic zero-setting device may operate at the start of automatic operation, as part of every automatic weighing cycle, or after a programmable time interval. A description of the operation of the automatic zero-setting device may be included in the type approval certificate or the instrument manual.

$$u(\delta F_0) = pd/\sqrt{3} \tag{7.3.1-4}$$

p represents a portion of d, within which the zero is maintained.

7.3.1.4 The standard uncertainty of the reading is then obtained by

$$u^2(R) = d^2/12 + s^2(I) + \left(\left|\Delta I_{ecc,b}\right|_{max}\right)^2/3 + (pd)^2/3 \tag{7.3.1-5}$$

7.3.2 Uncertainty from environmental influences

The term δF_{instr} accounts for up to 3 effects δF_{temp}, δF_{buoy} and δF_{adj}, which are discussed hereafter. No corrections are actually applied, the corresponding uncertainties are estimated based on the user's knowledge of the properties of the instrument.

7.3.2.1 The term δF_{temp} accounts for a change in the characteristic of the instrument caused by a change in ambient temperature. A limiting value can be estimated to be $\delta F_{temp} = K_T \cdot \Delta T \cdot F_p$ where ΔT is the maximum temperature variation at the instrument location and K_T is the sensitivity of the instrument to temperature variation.

Normally there is a manufacturer's specification such as $K_T = [\partial I(Max)/\partial T]/Max$, in many cases quoted in 10^{-6}/K. By default, for instruments with type approval under OIML R 61 [1], it may be assumed $|K_T| \leq mpe(Max)/(Max \cdot \Delta T_{Approval})$, where $\Delta T_{Approval}$ is the temperature range of approval marked on the instrument; for other instruments, either a conservative assumption has to be made, leading to a multiple (3 to 10 times) of the comparable value for instruments with type approval, or no information can be given at all for a use of the instrument at other temperatures than that at calibration.

The range of variation of temperature ΔT (full width) should be estimated in view of the site where the instrument is being used.

Rectangular distribution is assumed, therefore the standard uncertainty is

$$u(\delta F_{temp}) = K_T \cdot \Delta T \cdot F_p/\sqrt{12} \qquad (7.3.2\text{-}1)$$

7.3.2.2 The term δF_{buoy} accounts for a change in the adjustment of the instrument due to the variation of the air density; no correction to be applied.

The most conservative approach would be

$$u(\delta F_{buoy}) = 0{,}1\rho_0 F_p/(\rho_c\sqrt{3}) \qquad (7.3.2\text{-}2)$$

7.3.2.3 The term δF_{adj} accounts for a change in the characteristics of the instrument since the time of calibration due to drift, or wear and tear.

A limiting value may be taken from previous calibrations where they exist, as the largest difference $|\Delta E_{max}|$ in the errors for the same test load between any two consecutive calibrations. By default, ΔE_{max} should be taken from the manufacturer's specification for the instrument, or may be estimated as $\Delta E_{max} = mpe(F_p)$ for instruments conforming to a type approval under OIML R 61 [1]. Any such value can be considered in view of the expected time interval between calibrations, assuming fairly linear progress of the change with time.

Rectangular distribution is assumed, therefore the relative uncertainty is

$$u(\delta F_{adj}) = \Delta E_{max}(F_p)/\sqrt{3} \qquad (7.3.2\text{-}3)$$

7.3.2.4 The standard uncertainty related to errors resulting from environmental effects is calculated by

$$u(\delta F_{instr}) = \sqrt{u^2(\delta F_{temp}) + u^2(\delta F_{buoy}) + u^2(\delta F_{adj})} \qquad (7.3.2\text{-}4)$$

7.4 Expanded uncertainty of a weighing result

7.4.1 Errors accounted for by correction

The complete formula for a weighing result, which is equal to the preset value of fill corrected for the preset error determined by calibration, is

$$W = F_p - E_p \pm U(W) \qquad (7.4.1\text{-}1)$$

The expanded uncertainty $U(W)$ is to be determined as

$$U(W) = ku(W) \tag{7.4.1-2}$$

with $u(W)$ as applicable from (7.3-2) and the coverage factor $k = 2$.

7.4.2 Errors included in uncertainty

It may have been agreed by the calibration laboratory and the client to derive a "global uncertainty" $U_{gl}(W)$ which includes the preset error such that no corrections have to be applied to the preset value

$$W = F_p \pm U_{gl}(W) \tag{7.4.2-1}$$

The error generally forms a one-sided contribution to the uncertainty, which can only be treated in an approximate manner. The combination with the uncertainties in use may then, in principle, take on one of these forms

$$U_{gl}(W) = k\sqrt{u^2(W) + \left(E_p\right)^2} \tag{7.4.2-2}$$

$$U_{gl}(W) = ku(W) + \left|E_p\right| \tag{7.4.2-3}$$

with $u(W)$ as applicable from (7.3-2) and the coverage factor $k = 2$.

8. CALIBRATION CERTIFICATE

This section contains advice what information may be useful to be given in a calibration certificate. It is intended to be consistent with the requirements of ISO/IEC 17025, which take precedence.

8.1 General information

Identification of the calibration laboratory,
reference to the accreditation (accreditation body, number of the accreditation),
identification of the certificate (number, date of issue, number of pages),
signature(s) of authorised person(s).

Identification of the client.

Identification of the calibrated automatic gravimetric filling instrument,
information about the instrument (manufacturer, type, Max, d).

Warning that the certificate may be reproduced only in full unless the calibration laboratory permits otherwise in writing.

8.2 Information about the calibration procedure

Date of measurements,
site of calibration - place of installation,
conditions of environment and/or use that may affect the results of the calibration.

Information about the instrument operation for each measurement/test (adjustment performed, setting of software as far as relevant for the calibration, rate of operation, zero settings, tare settings), any anomalies of functions, purpose of use of the instrument as far as relevant for the calibration etc..

Reference to, or description of the applied procedure for calibration of the instrument.

Reference to, or description of the applied procedure for determination of the reference value of mass of the test fills.

Description of the test fills (e.g. material, information about containers, including drawing or photo, if applicable).

Agreements with the client e.g. over metrological specifications to which conformity is declared.

Information about the traceability of the measuring results.

8.3 Results of measurement

Preset values, mean reference value of mass, preset value error for applied preset values, as discrete values,
number of repetitions, for each measurement/test,

standard deviation(s) determined, identified as related to the average apparent mass of fills, for each measurement/test,
expanded uncertainty of measurement for the reported results.

Indication of the coverage factor, with comment on coverage probability.

9 REFERENCES

[1] *OIML R 61-1: Automatic gravimetric filling instruments. Part 1: Metrological and technical requirements – Tests*, Edition 2004 (E)

[2] *EURAMET Calibration Guide No. 18: Guidelines on the Calibration of Non-Automatic Weighing Instruments*, Version 4.0 (1/2015)

[3] *OIML R111, Weights of Classes E1, E2, F1, F2, M1, M1-2, M2, M2-3, M3,* Edition 2004 (E)

[4] *Welmec 2, Directive 2009/23/EC: Common application non-automatic weighing instruments*, 2015

[5] *OIML D 28: Conventional value of the result of weighing in air*, Edition 2004 (E)

[6] *JCGM 101:2008, Evaluation of Measurement Data – Supplement 1 to the "Guide to the expression of uncertainty in measurement" – Propagation of Distributions using a Monte Carlo method,* 1st edition, 2008

[7] *OIML R 761-1: Non-automatic weighing instruments. Part 1: Metrological and technical requirements – Tests*, Edition 2006 (E)

[8] *EN 45501:2015 Metrological aspects of non-automatic weighing instruments*

APPENDIX A: SYMBOLS

Symbols that are used in more than in one section of the main document are listed and explained hereafter.

Symbol	Definition
E_p	preset value error
F_p	preset value
I	indication of an instrument related to standard weights
L	load on an instrument
R	indication (reading) of an instrument related to test fills
U	expanded uncertainty
U_{gl}	global expanded uncertainty
Tol	specified tolerance value
W	weighing result
d	scale interval, the difference in mass between two consecutive indications of the indicating device
k	coverage factor
m	mass of an object, number of weighed empty containers
m_c	conventional value of mass
m_N	nominal value of mass
m_{ref}	reference value of mass of a test fill
mpe	maximum permissible error (of an indication, a standard weight etc.) in a given context
n	number of fills
s	standard deviation
u	standard uncertainty
ρ	density
ρ_0	reference density of air, ρ_0 = 1,2 kg/m³
ρ_a	air density
ρ_c	reference density of a standard weight, ρ_c = 8 000 kg/m³

Suffix	related to
B	air buoyancy, gross value
Cal	calibration
CI	control instrument
F	fill
L	at load
N	nominal value
T	tare

Tot	total contribution
a	air
dig	digitalisation
ecc	eccentric loading
gl	global, overall
i, j	numbering
max	maximum value from a given population
ref	reference
rep	repeatability
s	used for adjustment
0	zero, no-load, initial

APPENDIX B: METHODS FOR DETERMINATION OF REFERENCE VALUE OF MASS

Further in this section, index i is not used anymore, however equations refere to i -th test fill.

B1 *Test fills weighed on simultaneously calibratedcontrol instrument*

This section deals with the case where the reference value of mass is determined by weighing of the test fills on the calibrated control instrument. The control instrument is calibrated at time and place of calibration of the AGFI and also the test fills are weighed at the time and place of calibration of the AGFI. The control instrument should be calibrated in calibration points close to the preset values of fills and the error of indication of the control instrument is taken into account.

Taking into account [2], the conventional mass of any test load m_{cTL} is proportional to the weighing result of the control instrument W_{CI}:

$$m_{cTL} = W_{CI}\left[1 + \left(\rho_{aCI} - \rho_0\right)\left(\frac{1}{\rho_{TL}} - \frac{1}{\rho_{sCI}}\right)\right] \quad \text{(B1-1)}$$

where

$$W_{CI} = R_{CI} - E_{CI} \quad \text{(B1-2)}$$

$$R_{CI} = R_{LCI} - R_{0CI} \quad \text{(B1-3)}$$

$$E_{CI} = I_{CI} - m_{refCI} \quad \text{(B1-4)}$$

$$I_{CI} = I_{LCI} - I_{0CI} \quad \text{(B1-5)}$$

$$m_{refCI} = m_{cCalCI} + \delta m_{BCI} \quad \text{(B1-6)}$$

$$\delta m_{BCI} = -m_{cCalCI}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] \quad \text{(B1-7)}$$

with

R_{CI} – reading of the test load on the control instrument corrected for zero reading
R_{LCI} – reading of the test load on the control instrument (loaded)
R_{0CI} - reading of the test load on the control instrument (unloaded)
E_{CI} – eror of the control instrument
I_{CI} – indication of the standard weights on the control instrument corrected for zero indication
I_{LCI} – indication of the standard weights on the control instrument (loaded)
I_{0CI} - indication of the standard weights on the control instrument (unloaded)
m_{refCI} – reference value of mass of standard weights used for calibration of the control instrument,
m_{cCalCI} - conventional mass of the standard weights used for calibration of the control instrument,
δm_{BCI} – air buoyancy correction for the standard weights used for calibration of the control instrument,
ρ_{aCI} - air density at the time of weighing of the test load on the control instrument,
ρ_{aCalCI} - air density at the time of calibration of the control instrument,
ρ_{TL} - density of test load,

ρ_{sCI} - density of standard weights used for adjustment of the control instrument,
ρ_{CalCI} - density of standard weights used for calibration of the control instrument

Based on (B1-1) to (B1-7) for the conventional mass of the test load, and under condition that $(R_{LCI} - R_{0CI}) - (I_{LCI} - I_{0CI}) - m_{cCalCI}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] \ll m_{cCalCI}$ and $m_{cTL} \approx m_{cCalCI}$, we get the following general expressions for the conventional mass of filled and empty container, m_{cB} and m_{cT}, respectively

$$m_{cB} = \left(R_{LCI,B} - R_{0CI,B}\right) - \left(I_{LCI,B} - I_{0CI,B}\right) + m_{cCalCI,B} - \left(m_{N,F} + m_{N,T}\right)\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] + \left(m_{N,F} + m_{N,T}\right)(\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_F} - \frac{1}{\rho_{sCI}}\right) \quad \text{(B1-8)}$$

where

$$m_{cCalCI,B} \approx m_{N,F} + m_{N,T} \quad \text{(B1-9)}$$

and

$$m_{cT} = \left(R_{LCI,T} - R_{0CI,T}\right) - \left(I_{LCI,T} - I_{0CI,T}\right) + m_{cCalCI,T} - m_{N,T}\left[(\rho_{aCalCI} - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_{sCI}}\right)\right] + m_{N,T}(\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_T} - \frac{1}{\rho_{sCI}}\right) \quad \text{(B1-10)}$$

with
$m_{N,F}$ – nominal mass of the test fill,
$m_{N,T}$ – nominal mass of the empty container.

Based on (4.6-3) for the reference value of mass, (B1-8) and (B1-10) for m_{cB} and m_{cT}, respectively, and (4.6-4) for the air buoyancy correction, and taking into account that the reference value of mass of test fills is determined at the same time and place as calibration of the AGFI, $\rho_{aCI} = \rho_{aCalCI} = \rho_a$, we get the following general expression for m_{ref}

$$m_{ref} = \left(\left(R_{LCI,B} - R_{0CI,B}\right) - \left(I_{LCI,B} - I_{0CI,B}\right) + m_{cCalCI,B}\right) - \left(\left(R_{LCI,T} - R_{0CI,T}\right) - \left(I_{LCI,T} - I_{0CI,T}\right) + m_{cCalCI,T}\right) - m_{N,F}(\rho_a - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_s}\right) \quad \text{(B1-11)}$$

The total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (B1-11) equals

$$\delta m_{BTot} = -m_{N,F}(\rho_a - \rho_0)\left(\frac{1}{\rho_{CalCI}} - \frac{1}{\rho_s}\right) \quad \text{(B1-12)}$$

(B1-11) can be presented in a simplified way

$$m_{ref} = W'_{CI,B} - W'_{CI,T} + \delta m_{BTot} \quad \text{(B1-13)}$$

where W'_B and W'_T represents the weighing result on the control instrument for filled and empty container, respectively, with neglected air buoyancy correction for the standard weights used for calibration of the control instrument.

$$W'_{CI,B} = \left(R_{LCI,B} - R_{0CI,B}\right) - \left(I_{LCI,B} - I_{0CI,B}\right) + m_{cCalCI,B} \quad \text{(B1-14)}$$
$$W'_{CI,T} = \left(R_{LCI,T} - R_{0CI,T}\right) - \left(I_{LCI,T} - I_{0CI,T}\right) + m_{cCalCI,T} \quad \text{(B1-15)}$$

B2 Test fills weighed on previously calibrated control instrument

This section deals with the case where the reference value of mass is determined by weighing of filled and empty containers on the control instrument. The test fills are weighed at the time and place of calibration of the AGFI, but the control instrument has been calibrated previously. The calibration certificate for the control instrument is on a disposal. However, the same approach could be used also in a case when the control instrument is calibrated immediately prior to determination of the reference value of mass of test fills.

If the gross value (filled containers) and tare value (empty containers) of test fills are close to the calibration points in which the errors of control instrument were determined, then the weighing result W_{CI} (either for the gross or for tare value) could be determined based on the reading of the filled or empty containers R_{CI} corrected for the error of the control instrument E_{CI} as given by (B1-2). The error of the control instrument is reported in its calibration certificate.

$$W_{CI} = R_{CI} - E_{CI}$$

If this is not the case (e.g. when the mass of filled or empty containers is not close to the calibration point in which the error of control instrument was determined, or if so decided by the calibration laboratory), no correction is applied to the reading

$$W_{CI} = R_{CI} \tag{B2-1}$$

but errors of the control instrument need to be included in an uncertainty (i.e. a "global uncertainty" $U_{gl}(W_{CI})$, which includes the errors of indication such that no corrections have to be applied to the readings in use).

For a reading taken under the same conditions as those prevailing at calibration of the control instrument (e.g. immediatelly after its adjustment), the result may be denominated as the weighing result under conditions of the calibration W_{CI}^*.

Based on (B1-1) for the conventional mass of the test load we get the following expressions for m_{cB} and m_{cT}

$$m_{cB} = W_{CI,B} + (m_{N,F} + m_{N,T})(\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_F} - \frac{1}{\rho_{sCI}}\right) \tag{B2-2}$$

where

$$W_{CI,B} \approx m_{N,F} + m_{N,T} \tag{B2-3}$$

and

$$m_{cT} = W_{CI,T} + m_{N,T}(\rho_{aCI} - \rho_0)\left(\frac{1}{\rho_T} - \frac{1}{\rho_{sCI}}\right) \tag{B2-4}$$

with
$W_{CI,B}$ – weighing result for filled container (gross),
$W_{CI,T}$ - weighing result for empty container (tare),
$m_{N,F}$ – nominal mass of the test fill,
$m_{N,T}$ – nominal mass of the empty container,
ρ_F – density of the filled product,
ρ_T – density of the container.

Based on (4.6-3) for the reference value of mass, (B2-2) and (B2-4) for m_{cB} and m_{cT}, respectively, and (4.6-4) for the air buoyancy correction, and taking into account that the reference value of mass is determined at the same time and place as calibration of the AGFI, $\rho_{aCI} = \rho_a$, we get the following general expression for m_{ref}

$$m_{ref} = W_{CI,B} - W_{CI,T} - m_{N,F}(\rho_a - \rho_0)\left(\frac{1}{\rho_{sCI}} - \frac{1}{\rho_s}\right) \qquad \text{(B2-5)}$$

The total contribution of the air buoyancy correction δm_{BTot} to m_{ref} in (B2-5) equals

$$\delta m_{BTot} = -m_{N,F}(\rho_a - \rho_0)\left(\frac{1}{\rho_{sCI}} - \frac{1}{\rho_s}\right) \qquad \text{(B2-6)}$$

and

$$m_{ref} = W_{CI,B} - W_{CI,T} + \delta m_{BTot} \qquad \text{(B2-7)}$$

APPENDIX C: CONTROL INSTRUMENT CALIBRATED TO SPECIFIED TOLERANCES

The stadard global uncertainty of the weighing result $u_{gl}(W_{CI})$ for the control instrument, which has been previously calibrated to specified tolerance Tol, which equals to the maximum permissible error of the non-automatic weighing instrument mpe_{R76}[7,8], can be conservatively estimated by:

$$u_{gl}^2(W_{CI}) = u^2(W_{CI}) + mpe_{R76}^2 \tag{C-1}$$

with

$$u(W_{CI}) = \sqrt{u^2(W_{CI}^*) + u^2(\delta R_{inst}) + u^2(\delta R_{proc})} \tag{C-2}$$

$$u^2(W_{CI}^*) = u^2(E) + u^2(\delta R_{dig0}) + u^2(\delta R_{digL}) + u^2(\delta R_{rep}) + u^2(\delta R_{ecc}) \tag{C-3}$$

$$u^2(\delta R_{inst}) = u^2(\delta R_{temp}) + u^2(\delta R_{bouy}) + u^2(\delta R_{adj}) \tag{C-4}$$

$$u^2(\delta R_{proc}) = u^2(\delta R_{Tare}) + u^2(\delta R_{time}) + u^2(\delta R_{ecc}) \tag{C-5}$$

Approximate relation between standard uncertainties of above mentioned influencing parameters and mpe_{R76} is summarised in the table below. The following assumptions are taken into account:

- $d_T \le mpe_{R76}/5$
- $R = 20000 mpe_{R76}$
- $mpe_{R76}$is taken at L_T

$u(W_{CI}^*)$	$u(E)$	$u(\delta I_{dig0})$	$d_T/(2\sqrt{3}) \cong mpe_{R76}/(10\sqrt{3}) \cong 0$
		$u(\delta I_{digL})$	$d_T/(2\sqrt{3}) \cong mpe_{R76}/(10\sqrt{3}) \cong 0$
		$u(\delta I_{rep})$	$mpe_{R76}/(2\sqrt{3})$
		$u(\delta I_{ecc})$	0
		$u(\delta m_c)$	$(mpe_{R76}/3)/\sqrt{3}$
		$u(\delta m_B)$	$(0{,}000015/\sqrt{3})R + (mpe_{R76}/3)/(4\sqrt{3}) \le mpe_{R76}/5$
		$u(\delta m_D)$	$(mpe_{R76}/3)/\sqrt{3}$
		$u(\delta m_{conv})$	0
	$u(\delta R_{dig0})$		$d/(2\sqrt{3}) \le mpe_{R76}/(2\sqrt{3})$
	$u(\delta R_{digL})$		$d/(2\sqrt{3}) \le mpe_{R76}/(2\sqrt{3})$
	$u(\delta R_{rep})$		$mpe_{R76}/(2\sqrt{3})$
	$u(\delta R_{ecc})$		$mpe_{R76}/(2\sqrt{3})$
$u(\delta R_{inst})$	$u(\delta R_{temp})$		$mpe_{R76}/\sqrt{12}$
	$u(\delta R_{bouy})$		$(0{,}000015/\sqrt{3})R \le mpe_{R76}/5$
	$u(\delta R_{adj})$		$mpe_{R76}/\sqrt{3}$
$u(\delta R_{proc})$	$u(\delta R_{Tare})$		0
	$u(\delta R_{time})$		0
	$u(\delta R_{ecc})$		evaluated and taken into account above
$u(W_{CI})$			mpe_{R76}

$$u_{gl}(W_{CI}) \cong \sqrt{{mpe_{R76}}^2 + {mpe_{R76}}^2} mpe_{R76}\sqrt{2} \tag{C-6}$$

APPENDIX D: EXAMPLE