Recommended Guide for Determining and Reporting Uncertainties for Balances and Scales
Introduction

The goal of this guide is to provide service personnel with a method for identifying and quantifying the uncertainty components for scale and balance calibrations in both the field and laboratory environments.
Introduction

This guide includes specific information regarding uncertainty in on-site calibration of laboratory balances and large capacity scales.

Information compiled from the many reference documents has enabled the writing of this guide; a comprehensive bibliography provides supplementary reading.
The Recommended Guide to Determining and Reporting Uncertainties for Balances and Scales provides a useful methodology to enable service personnel to identify, quantify, evaluate, combine and report the uncertainty components most likely to be encountered during the calibration of a scale or balance.
Scope

The guide cannot be all-inclusive, since each calibration is unique, but it identifies the most Common uncertainty contributors and attempts to educate the user so that less significant or less frequently Ncountered uncertainty contributors may also be identified and included in an expanded uncertainty statement.
This Guide does not address scale and balance calibration methods. Procedural and specification documents for the testing of scales and balances have been in place for quite some time in the form of:

- OIML R 76-1, “Nonautomatic weighing instruments, Part 1: Metrological and technical requirements - Tests”,


- NIST Handbook 44, “Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices”, and

Background

ISO/IEC 17025, "General Requirements of the Competence of Testing and Calibration Laboratories", states that a **calibration or testing laboratory** performing calibrations

- shall have,
- shall apply,
- a procedure to estimate the uncertainty of measurement for all calibrations.

It also requires that the customer be provided calibration reports that contain the measurement results and a statement regarding the measurement uncertainty.
Background

According to the definition of traceability, measurement results must be traceable to a national standard through an unbroken chain of calibrations or comparisons, each having a stated uncertainty.

- Each value indicated by a scale or balance is an estimate of the true value of the material weighed.
- Each value also has a portion about which there is uncertainty, doubt, skepticism, suspicion or mistrust.

This guide provides a practical method for calculating the uncertainty of a scale or balance calibration, in a manner usable by scale and balance service personnel who are not trained statisticians.
General concepts

There are many possible sources of uncertainty in a balance or scale calibration. Among the most common uncertainty contributors are:

- The **uncertainty or tolerance of the applied load**, 
- **repeatability of the weighing system**, 
- **readability**, 
- **reproducibility of the weighing system**, and 
- the **effects** of:
  - **temperature changes**, 
  - **drafts or wind**, 
  - **off center loading**, 
  - **indicator drift**, 
  - **electrical noise and variation** 
  - **vibration**
General Description of Method

There are **eight basic steps** in the **process of determining the uncertainty of a calibration**.
Step 1 Specify the Process and equation:

Write down a clear, concise statement of what is being measured and the relationship between it and the parameters on which it depends. It must be remembered that the weighing device calibration process measures the ability of the weighing device to properly represent the applied calibration load. It is not measuring the mass of the applied load. A possible equation statement would be:

$$y = (mx + b) \pm U$$

where

- $y$ is the balance indication,
- $m$ is the sensitivity of the weighing device,
- $x$ is the applied load, $b$ is the zero offset, and
- $U$ is the assigned measurement uncertainty.
Step 2 Identify and characterize the uncertainty sources

Use a Cause and Effect diagram or uncertainty budget to help identify uncertainty contributors. The diagram or budget provides a systematic approach for listing all of the measurement influence factors that can cause an error in the balance or scale indication.
Step 3. Quantify the resulting uncertainty components

Looking at the list of error contributors, assign a value to each, remembering that not all of them will be measured in mass units. For example, a change in temperature is measured in degrees Celsius or Fahrenheit and must be converted to mass units in the next step.
Step 4. Convert the influences of the uncertainty components on the measurement to standard deviation equivalents

Using the example of temperature identified in step 3, convert that change in temperature to mass units. It may be necessary to consult the scale manufacturer’s Specifications to make conversions. All of the final values must be in terms of mass units.
Step 4. Convert the influences of the uncertainty components on the measurement to standard deviation equivalents

Another factor that may require estimation is the standard deviation of the weighing system (the repeatability of the device). If the process of making repeated measurements to calculate a standard deviation of the scale indication is not practical, cost-effective or feasible, as may be the case for a large capacity scale, the standard deviation may be approximated by using a portion of either the vendor’s specification or the device readability, whichever is greater.

This process is covered in detail in chapters 3, 4 and 5.
Step 5. Calculate the combined standard uncertainty (uc)

Use the root-sum-squared (RSS) method to combine the standard (one standard deviation) uncertainty components into a combined uncertainty value.

\[ U_c = \sqrt{s_p^2 + u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + \ldots + u_i^2} \]

where \( s_p \) is the process standard deviation and the terms containing 'u' are other standard uncertainties.
Step 6. Calculate the expanded uncertainty (U)

Multiply the combined standard uncertainty by the appropriate coverage factor for the confidence interval desired for the expanded uncertainty. Normally, $k=2$ for a 95 % confidence interval, will be used as the coverage factor. The use of other coverage factors requires that the selection and use be documented and justified when reported.
Step 7. Evaluate U for appropriateness

Ask the following questions:

- Does the expanded uncertainty make sense?

- Is the expanded uncertainty at least two (or ‘k’, if some other coverage factor was used) times the largest standard uncertainty component?

- Is the expanded uncertainty large enough to encompass the normal indication errors that experience tells you are possible? If so, continue to step 8. If not, investigate the calculations for mathematical errors or go back to step 2 and re-evaluate the calibration process looking for other causes of uncertainty that must be included.
Step 8. Report the uncertainty

Report the expanded uncertainty value including the ‘k’ factor used. NIST has adopted k=2 as the standard value to be used in reporting the uncertainty of measurement results reported in the United States.

If another k value is used, such as k = 3 for a 99.73 % confidence interval, the use of the nonstandard k factor must be justified.
Introduction

Laboratory balances are typically located in a controlled environment that minimizes many of the measurement influence factors that contribute to measurement uncertainty.

Additionally, it is possible to perform repeated measurements due to the relatively small capacity of these weighing devices and the availability of suitable standards for all applied loads. The controlled environment and the ability to make repeated measurements simplify the process of calculating the calibration uncertainty. Therefore, service personnel must make fewer subjective decisions.
The following steps outline the process recommended for use by balance service personnel to calculate the uncertainty associated with the balance calibration process.
1. Specify the Process and Equation

Write down a clear concise statement of what is being measured and the relationship between it and the parameters on which it depends. Remember, the balance indication is being tested, not the mass of the standard mass artifacts.

Example: \[ y = (mx + b) \pm U \]

- \( y \) is the balance indication, \( m \) is the sensitivity of the weighing device,
- \( x \) is the applied load, \( b \) is the zero offset, and \( U \) is the assigned measurement uncertainty.

Ideally, \( b = 0 \) if the balance indication was properly zeroed, and \( m = 1 \) because the balance indicates one mass unit for each mass unit applied.
The uncertainty associated with the calibration of a laboratory balance is comprised of many influence factors. A cause and effect diagram is used here to identify the measurement influence factors and to show their relationship to other factors.
Sample Cause and Effect Diagram

Factors affecting Uncertainty:
- Reported Uncertainty
- Tolerance
- Handling/condition
- Internal standards

Standards:
- Use of error weights
- Static Electricity

Facility:
- Environment/Location

Design:
- Accuracy
- Capacity
- Readability
- Draft Shield

Installation:
- Sensitivity
- Drift
- Off center loading sensitivity
- Substitution load
- RFI/EMI
- Temperature stability
- Product contamination
- Vibration
- Drafts
- Static Electricity

Staff & Procedures:
- Experience of Installer
- Repeatability
- Draft Shield
- Supports
- Levelness
- Frequency of test
- Procedure selection
- Training
- Auto zero tracking

Method of Use:
- Dynamic vs static weighing
- Repair
- Shock loading
- Gross/net weight
- Auto zero-tracking on/off

Uncertainty:
- Range of use
- Type product weighed
- Auto zero-tracking on/off
The service staff must evaluate the environment and use of the balance and eliminate or minimize as many of the measurement influence factors as possible. Engineering changes put in place to minimize a measurement influence must remain in place at all times for the calibration uncertainty to remain valid.
- **Levelness** of the balance should be checked and corrected if necessary.

- **Drafts** should be eliminated by the installation of draft shields, air diffusers or by redirecting air vents, or closing doors. These draft elimination measures must be in place at all times (including during use) for the calibration uncertainty statement to remain valid during daily use.

- **Off-center loading errors** should be evaluated and corrected before recording final calibration data.
- **Thermal equilibrium** of the balance should be ensured by maintaining the balance in an energized state (i.e., turned-on) for sufficient time to ensure that all circuitry and hardware have reached a stable temperature.

- **Vibration** sources must be identified and eliminated or minimized to limit the vibration levels to which the weighing device is exposed during daily use, as well as during calibration.
Zero-tracking features should be disabled to avoid undetectable zero indication errors. Zero-tracking is designed to eliminate minor changes in the balance indication due to drift of the weighing system and may be turned 'on' to maintain the 'zero' indication of the weighing device.
Zero-tracking

Due to the correction limits included in the system programming regarding quantity and motion detection, detrimental effects on measurement results are typically not evident. However, service personnel may encounter times while attempting to load the pan that the zero tracking circuitry will cause an offset in the indication, particularly if placing weights in a very slow, gentle manner. While this would be an unusual occurrence, service personnel must be aware of the possibility of such errors and take steps to prevent them from occurring.
Mass Standards must be brought into close proximity to the balance, even installed inside the balance chamber where possible, to ensure thermal equilibrium with the balance and surrounding environment prior to calibration.

This becomes more critical for balances and weights of higher or improved accuracy. Table B.2 of the 2002 Draft of OIML R 111, the OIML specification for weights, recommends that weights be permitted to undergo thermal stabilization for as long as 79 hours, depending on the desired use, nominal mass, weight accuracy class and temperature differential.
### Thermal stabilization in hours

<table>
<thead>
<tr>
<th>$\Delta T^\circ C$</th>
<th>Nominal Value</th>
<th>Class $E_1$</th>
<th>Class $E_2$</th>
<th>Class $F_1$</th>
<th>Class $F_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>± 20°C</td>
<td>1 000, 2 000, 5 000 kg</td>
<td>-</td>
<td>-</td>
<td>79</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>100, 200, 500 kg</td>
<td>-</td>
<td>70</td>
<td>33</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>10, 20, 50 kg</td>
<td>45</td>
<td>27</td>
<td>12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>1, 2, 5 kg</td>
<td>18</td>
<td>12</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>100, 200, 500 g</td>
<td>8</td>
<td>5</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>10, 20, 50 g</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>&lt; 10 g</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
</tbody>
</table>

* OIML R 111-2002 Draft
Standard mass errors can be minimized by using the mass values reported during calibration of the mass artifacts.
Balance indication drift errors should be corrected to the maximum extent possible. Though slight drift in the indicated value is somewhat normal, significant indication drift may be a sign of thermal instability of the weighing system. Allowing a longer temperature stabilization period for the weighing device and standard mass artifacts may minimize drift due to thermal instability.
Exercising the weighing system may also act to minimize drift. Repeatedly applying and removing loads within the range of the device causes the electronic and mechanical components of the system to acquire a thermal equilibrium of use.

If indication drift is excessive and cannot be eliminated by longer warm-up times or exercising the weighing system, other corrective action must be taken.
Magnetic fields surrounding weights or weight handling devices can cause severe, yet difficult to detect, errors in the indication generated by an applied mass load. Whenever possible, mass artifacts and handling devices made of non-magnetic materials should be used. When influences due to magnetic fields are suspected, measurements using different weight artifacts should be performed.
Magnetic effects may be detected by making a series of mass measurements of the weight, half of the measurements with the weight in an upright position and half of the measurements with the weight inverted. Magnetism is probable if a detectable difference, greater than the repeatability of the balance, is noted between the average of the upright indications and the average of the inverted indications.

If magnetism is suspected, weights should be tested more extensively for magnetic fields. A further description of the test for magnetism is beyond the scope of this document. Use weights known to be non-magnetic for calibration of balances using the force balance principle.
- **RFI/EMI susceptibility** tests should be performed. Changes in indication due to random RFI/EMI influences can be difficult to detect during normal use, and may be interpreted as repeatability errors, drift or erratic readings. Corrective action should be taken if RFI/EMI susceptibility is detected.

Note: RFI/EMI sources include two-way radios, cell phones and other electronic devices. Laboratories are available specializing in detecting and measuring RFI/EMI.

- **Power-line noise or variations** can cause random display indications to occur. The specific cause of these random indications may be difficult to determine, but they will affect the repeatability of the weighing system. Where possible, it is best that balances be powered by a dedicated power circuit or by an AC line conditioner to prevent these measurement influences.
Operator errors result when individuals are inadequately trained. All operators of weighing devices should have proper training and be knowledgeable about the weighing instrument and the process in which it is used.

Inadequately trained personnel may record data with significant errors, improperly influencing critical process decisions. Weighing system operators must be equipped with correct and complete work instructions to minimize the likelihood of operator error.
Process standard deviation (sp)

- The source of a value for sp can be based on balance repeatability, balance reproducibility or the size of a balance division. Each method is discussed below.
Repeatability is a measure of a balance’s ability to produce the same indication every time the same weight is placed on the sensing device.

Repeatability is presented as a standard deviation. Obtaining repeated measurement results is possible in the laboratory due to the small size and ready availability of the weights used.

Repeatability tests should be conducted with weights approximating the typically measured load.
If a wide range of load values are normally measured, evaluation of repeatability at several loads, e.g., 50% capacity and 100% capacity, may be desirable.

If the repeatability value at one load is more than two times the value at a second load, it may be desirable to report the repeatability results at specific load ranges of the balance.

If only a single repeatability value is to be reported, the largest measured value must be used.
When the uncertainty of the balance during routine weighing operations is desired, a check standard and control chart should be used to determine the long-term repeatability of the balance under varying operational conditions.

This is called reproducibility and is also evaluated as a standard deviation.

Reproducibility is a measure of long-term repeatability and may be used in place of the short-term repeatability when calculating measurement uncertainty.

The standard deviation value of the control chart will be included in the combined uncertainty as sp.

The load chosen for use as the check standard should represent the items typically weighed on the balance.
sp from manufacturer’s specification

1. The value for sp is best determined from repeated readings of a weight, whether short-term or long-term.
2. The manufacturer’s specification sheet is not a recommended source for determining the uncertainty contribution due to repeatability.
3. Manufacturers' specifications are established for a specific set of conditions that may not be representative of the actual environment in which the scale is tested and used.
4. Manufacturers' specifications are an excellent tool when comparing the expected performance of one weighing device to another similar device, but they are established to indicate the expected performance of a family of weighing systems, not a specific weighing system.
5. As the calibration uncertainty is being estimated for a specific weighing system, it is best to establish the calibration uncertainty contribution due to repeatability from measured data, not from an expected performance parameter.
6. Manufacturers' specifications should not be used to estimate calibration uncertainty.
Uncertainty of the standards (us)

- The uncertainty associated with the standard mass artifacts, us, may come from one of several possible sources. us may be based on the calibration uncertainty assigned to the calibrated value of the standard mass artifact as taken from the calibration report, or it may be based on the tolerance to which the standard mass has been verified.

- A calibration load may include one mass artifact or multiple mass artifacts. Each of these situations requires a different method for determining the proper way to calculate the us value.
us from mass artifact calibration uncertainty

- When using the reported calibration value of the standard mass artifact in the calibration of the balance, calculate the uncertainty of the mass standard (us) from the uncertainty associated with the reported values of the individual mass artifact.

- Normally, standard mass uncertainties are reported as expanded uncertainties with a stated coverage factor (k). Divide the expanded uncertainty of the standard mass artifacts by the reported coverage factor (k) to obtain the standard uncertainty for the mass artifact.
When basing the standard mass uncertainty \( (u_s) \) on the tolerance of the standard mass artifact, treat the tolerance as having a uniform probability distribution. The standard mass uncertainty calculated from the standard mass calibration tolerance is

\[
u_s = \frac{\text{tolerance}}{\sqrt{3}} = 0.577(\text{tolerance}).\]
Step 5. Calculating the combined uncertainty

The combined uncertainty, ‘uc’, of the weighing system calibration is calculated as the root-sum-squared of the influence factors.

\[ u_c = \sqrt{u_s^2 + s_p^2 + u_1^2 + u_2^2 + u_3^2 + \ldots + u_i^2} \]

where ui are any other uncertainty components that the scale technician includes in the uncertainty calculations.

Remember:

- All of the uncertainty components must be in like terms of the mass units. Differing units, such as °C and mg, cannot be combined. Convert the impact of the non-mass units to appropriate mass units to calculate the uncertainty.

- All uncertainty components must be in terms of standard (one standard deviation) uncertainties.
Step 6. Calculating the expanded uncertainty

The expanded uncertainty, ‘U’, is calculated by multiplying the value obtained for uc by the coverage factor, ‘k’, for the confidence interval to be used. By convention, as defined in NIST Technical Note 1297, “Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results”, a coverage factor of k = 2 is used for a confidence interval of approximately 95 %. The use of k values other than k = 2 requires an explanation of the reason for the deviation from convention.
Step 7. Evaluating the expanded uncertainty

There are several things to consider when evaluating the uncertainty

First, does the final expanded uncertainty make sense? The expanded uncertainty must be at least ‘k’ times greater than the largest uncertainty component included.
Step 7. Evaluating the expanded uncertainty

There are several things to consider when evaluating the uncertainty

Second, does the calculated expanded uncertainty seem appropriate for the tested device? An uncertainty value seems unreasonable and should be investigated if the expanded uncertainty is calculated to be significantly less than one balance division. Likewise, if the calculated uncertainty is excessively large, that value should be investigated. Investigation should include verifying the use of proper evaluation techniques. Ensure that arithmetical errors were not the cause of the questionable uncertainty value.
Step 7. Evaluating the expanded uncertainty

1. Third, does the calculated uncertainty meet the requirements for weighing with that weighing device? Different quality systems have different requirements concerning the allowable measurement uncertainty; requirements may state that the uncertainty of a measuring device may not exceed 33\%, 25\%, or even as little as 10\%, of the tolerance of the object being tested.
Step 7. Evaluating the expanded uncertainty

2. Will the calculated uncertainty meet the requirements that are in place? If not, reexamine the entire calibration process for uncertainty contributors that can be reduced. Reduction may be accomplished by selection of more accurate standards, repair of the weighing device to obtain a smaller standard deviation, or perhaps making multiple measurements to determine the true repeatability of a device rather than using an estimated repeatability.
Step 7. Evaluating the expanded uncertainty

3. Evaluate each uncertainty contributor, beginning with the most significant, to determine how it can legitimately be reduced until the required uncertainty level is obtained or until the decision is made that the weighing device cannot meet the quality requirements and must be replaced or that the weighing system must be moved to a more hospitable environment.
Step 8. Reporting Uncertainty

Reporting the expanded uncertainty value is no longer a matter of simply stating that a measurement result is ‘x ± y’ where ‘x’ is the reported value and ‘y’ is the expanded uncertainty.

The Guide to the Expression of Uncertainty in Measurement requires that you identify the various components of the uncertainty. You must also explain why that component was included and how it was evaluated. Specifically, the GUM provides a test of the stated uncertainty statement: “Has enough information been provided in a sufficiently clear manner that the result can be updated in the future if new information or data became available?”
Another test is to ask: “Would another individual, not associated with the measurement process, be able to understand how the stated uncertainty was calculated and what was included, and then properly apply it to his/her own uncertainty calculation?”
Quick Guide for Laboratory Balance Calibration Uncertainties

<table>
<thead>
<tr>
<th>Process ($s_p$) Source (in order of desirability):</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Calculated standard deviation at the test load from an up-to-date control chart</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>2 Calculated standard deviation from 10 or more readings of the same load over a short period of time</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
</tbody>
</table>
# Quick Guide for Laboratory Balance Calibration Uncertainties

<table>
<thead>
<tr>
<th>Standards (u_s) Sources (in order of desirability):</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reported k=1 uncertainty from Report of Test</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>2 Tolerance of weight(s) used</td>
<td>Uniform</td>
<td>0.577 x tolerance</td>
</tr>
</tbody>
</table>

**Additional equations when using multiple standards**

<table>
<thead>
<tr>
<th>A Multiple standard masses (if independence is proven)</th>
<th>( u_s = \sqrt{u_{sm1}^2 + u_{sm2}^2 + u_{sm3}^2 + \ldots + u_{smn}^2} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>B Multiple standard masses (if independence is unknown)</td>
<td>( u_s = u_{sm1} + u_{sm2} + u_{sm3} + \ldots + u_{smn} )</td>
</tr>
</tbody>
</table>

Additionally, there may be other known measurement uncertainty contributors. Evaluate the calibration process carefully to ensure that all significant contributors are properly included in the uncertainty calculations. Consult the text of this Guide for additional guidance.
Quick Guide for Laboratory Balance Calibration Uncertainties

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Serial</th>
<th>ECN</th>
<th>Other</th>
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</thead>
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<tr>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>
**Quick Guide for Laboratory Balance Calibration Uncertainties**

<table>
<thead>
<tr>
<th>Uncertainty Influence Description</th>
<th>Identifier</th>
<th>Estimated value</th>
<th>Distribution type</th>
<th>Estimated Standard Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty of the standards used</td>
<td>$u_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation of the process</td>
<td>$s_p$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Determined at __________ test load)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_5$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_6$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_7$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quick Guide for Laboratory Balance Calibration Uncertainties

**Combined standard uncertainty**

\[ u_c = \sqrt{u_s^2 + s_p^2 + u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + \ldots + u_i^2} \]

**Expanded uncertainty**

\[ U = k(u_c), \ k = \ldots \quad k = 2 \text{ is recommended} \]

\[ U = \]
Scale Calibrations Performed in an Uncontrolled Environment

Introduction

This chapter identifies many of the measurement influences affecting scale calibrations in an uncontrolled environment and provides instructions on how to include the resulting uncertainty contributors in a calculated expanded uncertainty for the calibration.

It is not possible to discuss all possible measurement influences, but the examples will provide adequate guidance to enable the service personnel to make informed decisions when calculating calibration uncertainty.
Scales in an uncontrolled environment

- Large capacity scales, such as truck scales or floor scales, are often installed out-of-doors in an uncontrolled environment. Thus, many influences affect the calibration uncertainty. Many of these influences are beyond the ability of service personnel to control, so they must be identified and evaluated for the impact they have on the calibration process.

- The following steps outline the process recommended for use by scale service personnel to calculate the uncertainty associated with the scale calibration process.
Step 1. Specify the Process and Equation

Write down a clear concise statement of what is being measured and the relationship between it and the parameters on which it depends. Remember, the scale indication is being tested, not the mass of the standard mass artifacts.

Example: where; \( y = (mx + b) \pm U \)

- \( y \) is the scale indication, \( m \) is the sensitivity of the weighing device,
- \( x \) is the applied load, \( b \) is the zero offset, and \( U \) is the assigned measurement uncertainty.

Ideally, \( b = 0 \) if the scale indication was properly zeroed, and \( m = 1 \) because the scale indicates one mass unit for each mass unit applied.
Step 2, 3 & 4. Uncertainty Identification, Characterization and Quantification

- The uncertainty associated with the calibration of a laboratory balance is comprised of many influence factors.

- A cause and effect diagram is used here to identify the measurement influence factors and to show their relationship to other factors.
Sample Cause and Effect Diagram

Factors affecting Uncertainty
- Reported Uncertainty/Tolerance
- Storage
- Internal Standards
- Use of error weights

Design
- Accuracy
- Readability
- Draft Shield

Capacity
- Sensitivity
- Off center loading sensitivity

Installation
- Experience of installer
- Repeatability
- Draft Shield

Design
- Foundation/Supports
- Temperature stability
- Snow

Installation
- Product contamination
- Vibration
- Wind

Uncertainty
- CLC
- Repair
- Range of use
- Type product weighed
- Gross/net weight
- Auto zero-tracking on/off

Staff & Procedures
- Attitude
- Frequency of test
- Procedure selection

Experience
- Procedure selection
- Training

Method of Use
- Dynamic vs static weighing
- Auto zero-tracking on/off

Uncertainty
- Range of use
- Type product weighed
- Gross/net weight
- Auto zero-tracking on/off

Facility Environment/Location
- Drafts
- RFI/EMI
- Rain

Standards
- Use of error weights
- Environment/Location

* Not all inclusive
The service staff must evaluate the environment and use of the scale and eliminate or minimize as many of the measurement influence factors as possible. Engineering changes

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put in place to minimize a measurement influence must remain in place at all times for the calibration uncertainty to remain valid.
The service staff must evaluate the environment and use of the scale and eliminate or minimize as many of the measurement influence factors as possible.

Engineering changes put in place to minimize a measurement influence must remain in place at all times for the calibration uncertainty to remain valid.
- **Levelness** of the scale should be checked and corrected if necessary.

- **Wind influences** are typically very difficult and expensive to eliminate for large scales in an uncontrolled environment. However, any controls in place for the calibration must remain in place for all weighing operations. Guidance for including an uncertainty component for wind influences is provided later in this chapter.

- **Off-center loading errors** should be evaluated and corrected before recording final calibration data.
Thermal equilibrium of the scale should be ensured by keeping the scale in an energized state (i.e., turned-on) for sufficient time to ensure that all circuitry and hardware have reached a stable temperature.

Vibration sources must be identified and eliminated or minimized to limit the vibration levels to which the weighing device is exposed during daily use, as well as during calibration.
Zero-tracking features should be disabled to avoid undetectable zero indication errors. Zero-tracking is designed to eliminate minor changes in the scale indication due to drift of the weighing system and may be turned 'on' to maintain the 'zero' indication of the weighing device.

Due to the correction limits included in the system programming regarding quantity and motion detection, detrimental effects on measurement results are typically not evident.

However, service personnel attempting to load the load receiver may at times find that the zero tracking circuitry will cause an offset in the indication, particularly if placing weights in a very slow, gentle manner or when using a weight cart to load the scale.

While this would be an unusual occurrence, service personnel must be aware of the possibility of such errors and take steps to prevent them from occurring.
Mass Standards must be brought into close proximity to the scale to ensure thermal equilibrium with the scale and surrounding environment. Thermal stabilization times for weights typically used for a scale in this environment are not specified, but sufficient time must be allowed to ensure that condensation is not present on the weights.
Mass standard error effects are minimized by using the mass values determined during calibration of the mass artifacts. For most large capacity scales this will not be necessary as the tolerances of the scales and standard masses have been set to minimize the effects of the standard mass errors. The concept is presented here as an option should correction be desirable. The standard mass uncertainty for large capacity scales is normally based on the tolerance of the mass standards.
Scale indication drift errors should be corrected to the maximum extent possible. Though slight drift in the indicated value is somewhat normal, significant indication drift may be an indication of thermal instability of the weighing system. Allowing a longer temperature stabilization period for the weighing device and standard mass artifacts can minimize drift due to thermal instability. Exercising the weighing system may also minimize drift.

Repeatedly applying and removing loads within the range of the device causes the electronic and mechanical components of the system to acquire a thermal equilibrium of use. If indication drift is excessive and cannot be eliminated by the means described, other corrective action must be taken.
**RFI/EMI susceptibility** tests should be performed. Changes in indication due to random RFI/EMI influences can be difficult to detect during normal use and may be interpreted as repeatability errors, drift or erratic readings. Corrective action should be taken if RFI/EMI susceptibility is detected.

**Note:** RFI/EMI sources include two-way radios, cell phones and other electronic devices. Laboratories are available specializing in detecting and measuring RFI/EMI.
Power-line noise or variations can cause random display indications to occur. The specific cause of these random indications may be difficult to determine, but they will affect the repeatability of the weighing system. Where possible, it is best that scales be powered by a dedicated power circuit or by an AC line conditioner to prevent these measurement influences.
Operator errors result when operators are inadequately trained. All operators of weighing devices should have proper training and be knowledgeable about the weighing instrument and the process in which it is used. Inadequately trained personnel may record data with significant errors, improperly influencing critical process decisions. Weighing system operators must be equipped with correct and complete work instructions to minimize the likelihood of operator error.
Process standard deviation (sp)

The source of a value for sp can be based on scale repeatability, scale reproducibility, the size of a scale division or a manufacturer’s specification. Each are discussed below.
Repeatability is a measure of a scale’s ability to produce the same indication every time an identical load, under the same conditions, is placed on the sensing device. Repeatability is presented as a standard deviation.

The most desirable method for determining repeatability is to make a number of measurements at a load that is typical of routine weighing operations. At least seven measurement results of a repeated specific scale load are required to calculate the standard deviation of a scale. Typically, due to time, energy or cost constraints, service personnel do not perform repeatability testing of large capacity scales. Instead, a method for estimating the repeatability is required.
The repeatability may be estimated from display resolution as \( s_p = \frac{d}{\sqrt{3}} = 0.577d \) (0.577 times the value of ‘d’) as described in the GUM. This equation assumes that no discrimination test, as described in NIST Handbook 44, N.1.5 and T.N.7.1 or OIML R 76-1, A.4.8, has been performed to evaluate the scale response to scale load changes smaller than one scale division.

If it is possible to perform a discrimination test, a slightly different equation may be used. That equation is: \( s_p = \frac{1}{2} \frac{d}{\sqrt{3}} = 0.29d \) (0.29 times the value of ‘d’) since passing a discrimination test indicates that the true value most probably lies near the center of the scale display interval. This estimation equation should only be used when the calculated standard deviation is zero, or the \( s_p \) is being estimated from display resolution, and the scale has passed the discrimination test.
When desiring to ascertain the uncertainty of the scale during routine weighing operations, a check standard and control chart should be used to determine the long-term repeatability of the scale under varying operational conditions. This is called reproducibility, also evaluated as a standard deviation.

Reproducibility is a measure of long-term repeatability and may be used in place of the short-term repeatability when calculating measurement uncertainty. The standard deviation of the control chart values will be used in the combined uncertainty as sp. Multiple check standard loads may be required when the scale is used to measure loads that vary widely within the range of the scale. The check standard loads should be selected to represent the loads typically weighed on the scale.
sp from manufacturer’s specification

The value for sp is best determined from repeated readings of a weight, whether short-term or long-term. The manufacturer’s specification sheet is not a recommended source for determining the uncertainty contribution due to repeatability. Manufacturers' specifications are established for a specific set of conditions that may not be representative of the actual environment in which the scale is tested and used.

Manufacturers' specifications are an excellent tool when comparing the expected performance of one weighing device to another similar device, but they are established to indicate the expected performance of a family of weighing systems, not a specific weighing system. As the calibration uncertainty is being estimated for a specific weighing system, it is best to establish the calibration uncertainty contribution due to repeatability from measured data, not from an expected performance parameter. Manufacturers' specifications should not be used to estimate calibration uncertainty.
Uncertainty due to display resolution (udr)

When estimating the value of $s_p$, display resolution, an additional uncertainty component for indicator resolution must be included. This value ($u_{dr}$) will also be equal to

$$u_{dr} = \frac{1}{2} \frac{d}{\sqrt{3}} = 0.29d \text{ (0.29 times } d)$$

This uncertainty component will not be included in the uncertainty calculations if repeated measurement results were used to determine a value for $s_p$. The effect of the display resolution uncertainty component will already have been part of the measured values and an additional uncertainty component is not required.
Uncertainty of the standards (us)

The uncertainty contribution of the standard masses used to perform the scale calibration may be estimated from one of two sources, the tolerance to which the masses have been tested, or the uncertainty associated with the calibration of the masses. Specific guidance follows.
When calibrating large capacity scales, the nominal values of the standard weights are typically used. In this situation, a portion of the tolerance to which the weights were tested is used as the standard uncertainty of the standards value, $u_s$, when calculating the calibration uncertainty. Only a portion of the tolerance is used as the tolerance is considered to follow a uniform probability distribution. The standard uncertainty of the standards is calculated as

$$u_s = \frac{\text{tolerance}}{\sqrt{3}} \quad \text{or} \quad (0.577 \times \text{tolerance})$$

or (0.577 times the tolerance of the applied weights). When using multiple weights, the tolerance used in the $u_s$ calculation will be the sum of the tolerances for all of the weights used.
us from calibration uncertainties

Standard mass uncertainties normally are reported as expanded uncertainties with reported coverage factor (k). This expanded uncertainty must be divided by the stated coverage factor to obtain the standard uncertainty for the mass artifacts (us).
us with multiple standard weights

When multiple weights are used, the most conservative value for the uncertainty of the mass calibrations is the linear sum of the uncertainties associated with each of the weights used simultaneously.

For this situation mismsmsmsuuuuu+++=.....321. While this method provides the most conservative estimate of standards uncertainty, it also typically provides the largest estimate for the standards uncertainty and may result in an uncertainty value that is greater than allowed by the customer's weighing process.
Wind \( (u_w) \)

The influence of the wind on large capacity scale systems is a very common contributor to uncertainty since most large capacity scales are installed in an outdoor environment.

Depending on wind speed, direction, and the effect of nearby structures, it is possible to experience scale indication fluctuations many times the scale tolerance. In these situations, the service technician has to make a judgement call as to whether or not calibration is possible. This situation requires balancing the cost of re-scheduling the test against the ability to make a reasonable estimate of the true scale reading. It is recommended that the scale test be rescheduled for a time when the wind is less of an influence, thus minimizing the scale indicator fluctuations.
If a technician decides to proceed with a scale calibration that is being affected by wind influences, an estimate of the additional uncertainty involved in the measurement must be included in the uncertainty calculations.

Unless some means of recording a large number of scale indications over a period of time is available, the uncertainty due to wind influences is not a value that can be derived from statistical methods. When an indication recording system is available, an average and standard deviation of thirty or more readings should be calculated for each applied load value. The average of the measurement results will be reported as the scale indication and the standard deviation of the values will be included as part of the calibration uncertainty ($u_w$).
In situations where a recording device is not available, a scale technician will typically observe the weighing system indicator for a time and mentally calculate an average value based on his observations. The scale technician will report this estimated average as the scale indication for that applied load. The technician must also mentally note the maximum and minimum values observed. The reported scale indication will have an uncertainty equal to some portion of the observed fluctuations. As the difference between the estimated average and each observed scale indication is a fixed number of scale divisions, this uncertainty influence has a uniform probability distribution. The uncertainty will be estimated as

\[ u_w = \frac{w}{\sqrt{3}} = 0.577w, \text{ (0.577 times } w) \]

where \( w \) is the maximum difference between the reported scale indication and any observed scale indication.
In the absence of wind effects that mask many uncertainty contributors, other influences, such as vibration, become more of a factor. Potential vibration sources include blasting, rock crushers, heavy equipment, railroad tracks, highways with heavy vehicular traffic, etc. An approach similar to that described for wind effects should be applied to suspected vibration effects and an uncertainty (uv) included in the calibration uncertainty calculations.
Rain

The effect of rain on a scale calibration is quite difficult to quantify, thus calibrations where rain is a factor are to be avoided. Each weight artifact used in a calibration will have its mass changed by an amount related to the quantity of water accumulated on its surface.

In the calibration laboratory, large errors have been measured for mass artifacts that were covered with a layer of water. Additionally, the zero indication of the scale itself will vary as the quantity of water pooled on, or absorbed into, the scale deck varies during the test. This can also be a factor as a scale deck dries after the rain stops. Because this error is quite variable, depending on the amount of water accumulated, it is not possible to develop a correction that can be applied to a scale indication. For the same reason, developing an uncertainty factor for the effect of accumulated water is not possible. Calibration of scales where water accumulation is a factor is to be avoided.
Substitution loads

Substitution loading involves applying a known load to a weighing system, removing that known load and then loading the weighing system with uncalibrated material to obtain a reading identical to that of the known load.

The known load is then reapplied, along with the substitution load, effectively doubling the known load. According to current procedures, this process can be repeated two more times for a total of three substitutions, effectively multiplying the calibrated load by a factor of four.

The substitution process results in an increased uncertainty as the substitution loads are being weighed by the system being calibrated. The uncertainty attributed to each substitution is equal to the repeatability factor (sp) calculated previously. Thus, the uncertainty contribution due to substitution tests (usub) will be calculated as the number of substitutions times the calculated repeatability value. The result is included in the uncertainty as usub.
Strain Load Tests

Strain load testing involves loading the scale with an unknown load, setting the scale indication with the load as the reference, followed by applying additional known load to the scale deck.

The additional uncertainty associated with a properly performed strain load test is negligible, because the possible measurement effects have been included as part of other uncertainty contributors. The error associated with an improperly performed strain load test is beyond the scope of this document.
Step 5. Calculation of the combined uncertainty

The combined uncertainty, ‘uc’, of the weighing system calibration will be calculated as the root-sum-squared of the influence factors.

\[ u_c = \sqrt{u_s^2 + s_p^2 + u_w^2 + u_{sub}^2 + u_{dr}^2 + u_v^2 + u_1^2 + u_2^2 + u_3^2 + \ldots + u_i^2} \]

where ui are any other uncertainty components that the scale technician wishes to include in the uncertainty calculations.

Remember:
- All of the uncertainty components must be in like terms of the mass units. Differing units, such as °C and mg, cannot be combined. Convert the impact of the non-mass units to the appropriate mass units to calculate the uncertainty.
- All uncertainty components must be in terms of standard (one standard deviation) uncertainties.
Step 6. Calculating the expanded uncertainty

The expanded uncertainty, ‘U’, is calculated by multiplying the value obtained for uc by the coverage factor, ‘k’, for the confidence interval to be used. By convention, as defined in NIST Technical Note 1297, “Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results”, a coverage factor of k = 2 is used for a confidence interval of approximately 95 %. The use of k values other than k = 2, requires an explanation of the reason for the deviation from convention.
Step 7. Evaluating the expanded uncertainty

There are several things to consider when evaluating the uncertainty.

First, does the final expanded uncertainty make sense? The expanded uncertainty must be at least ‘k’ times greater than the largest uncertainty component included.
Step 7. Evaluating the expanded uncertainty

Second, does the calculated expanded uncertainty seem appropriate for the device tested? An uncertainty value seems unreasonable and should be investigated if the expanded uncertainty is calculated to be significantly less than one balance division. Likewise, if the calculated uncertainty is excessively large, that value should be investigated. Investigation should include verifying the use of proper evaluation techniques.

Ensure that arithmetical errors were not the cause of the questionable uncertainty value.
Step 7. Evaluating the expanded uncertainty

Third, does the calculated uncertainty meet the requirements for weighing with that weighing device?

Different quality systems have different requirements concerning the allowable measurement uncertainty; requirements may

- state that the uncertainty of a measuring device may not exceed 33 %, 25 %, or even as little as 10 %, of the tolerance of the object being tested.
Step 7. Evaluating the expanded uncertainty

Will the calculated uncertainty meet the requirements that are in place? If not, reexamine the entire calibration process for uncertainty contributors that can be reduced.

Reduction may be accomplished by selection of more accurate standards, repair of the weighing device to obtain a smaller standard deviation, or perhaps making multiple measurements to determine the true repeatability of a device rather than using an estimated repeatability.

Evaluate each uncertainty contributor, beginning with the most significant, to determine how it can legitimately be reduced until the required uncertainty level is obtained or until the decision is made that the weighing device cannot meet the quality requirements. Relocation or replacement of the scale may be required.
Step 8. Reporting Uncertainty

Reporting the expanded uncertainty value is no longer a matter of simply stating that a measurement result is ‘x ± y’ where ‘x’ is the reported value and ‘y’ is the expanded uncertainty.

The Guide to the Expression of Uncertainty in Measurement requires that you identify the various components of the uncertainty.

You must also explain why that component was included and how it was evaluated.

Specifically, the GUM provides a test of the stated uncertainty statement: “Has enough information been provided in a sufficiently clear manner that the result can be updated in the future if new information or data became available?”
Step 8. Reporting Uncertainty (ต่อ)

Another test is to ask: “Would another individual, not associated with the measurement process, be able to understand how the stated uncertainty was calculated and what was included; and then properly apply it to his/her own uncertainty calculation?”

It must be understood that the measurement uncertainty must be calculated for each scale test load.

The needs of the customer will determine whether a table format is used to report the uncertainty at each load, or the maximum uncertainty value of all test loads is reported as a single value covering the entire range of the weighing system.

In either case, the uncertainty for each test load must be calculated and documented.
## Quick Guide for Scale Calibration Uncertainties

Reference information

<table>
<thead>
<tr>
<th>Process ((s_p)) Source (in order of desirability):</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Calculated standard deviation at the test load from an up-to-date control chart</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>2 Calculated standard deviation from 10 or more readings of same load over a short period of time</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>3 Estimated from scale division (discrimination test passed)</td>
<td>Uniform</td>
<td>0.29 x ‘d’</td>
</tr>
<tr>
<td>4 Estimated from scale division (discrimination test not performed)</td>
<td>Uniform</td>
<td>0.577 x ‘d’</td>
</tr>
</tbody>
</table>
**Quick Guide for Scale Calibration Uncertainties**

Reference information

<table>
<thead>
<tr>
<th>Standards ((u_s)) Sources (in order of desirability):</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1  Reported (k=1) uncertainty from Report of Test</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>2  Tolerance of weights used</td>
<td>Uniform</td>
<td>(0.577 \times) tolerance</td>
</tr>
</tbody>
</table>

Additional equations when using multiple standards

- **a** Multiple standard masses (if independence is proven)
  
  \[ u_x = \sqrt{u_{a1}^2 + u_{a2}^2 + u_{a3}^2 + \ldots + u_{am}^2} \]

- **b** Multiple standard masses (if independence is unknown)
  
  \[ u_x = u_{a1} + u_{a2} + u_{a3} + \ldots + u_{am} \]
Quick Guide for Scale Calibration

Uncertainties

Reference information

<table>
<thead>
<tr>
<th>Other uncertainty sources</th>
<th>Distribution Type</th>
<th>Value to use:</th>
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<tbody>
<tr>
<td>Uncertainty due to wind effects ($u_w$) ($w=\text{max deviation}$)</td>
<td>Uniform</td>
<td>$0.577 w$</td>
</tr>
<tr>
<td>Uncertainty due to substitution loads ($u_{sub}$)</td>
<td>Uniform</td>
<td>$u_{sub} = s_p$</td>
</tr>
<tr>
<td>Uncertainty due to display resolution ($u_{dr}$)</td>
<td>Uniform</td>
<td>$0$ or $u_{dr} = s_p$</td>
</tr>
<tr>
<td>Uncertainty due to vibration effects ($u_v$) ($v=\text{max deviation}$)</td>
<td>Uniform</td>
<td>$0.577 v$</td>
</tr>
</tbody>
</table>

Additionally, there may be other known measurement uncertainty contributors. Evaluate the calibration process carefully to ensure that all significant contributors are properly included in the uncertainty calculations. Consult the text of this Guide for additional guidance.
Quick Guide for Scale Calibration

Uncertainties

Reference information

<table>
<thead>
<tr>
<th>Equipment Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
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<tr>
<td>---------------</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>


## Quick Guide for Scale Calibration

### Uncertainties

Reference information

### Uncertainty Worksheet

<table>
<thead>
<tr>
<th>Uncertainty Influence Description</th>
<th>Identifier</th>
<th>Estimated value</th>
<th>Distribution type (Normal/Uniform)</th>
<th>Estimated Standard Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty of the standards used</td>
<td>$u_s$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation of the process (Determined at ________ test load)</td>
<td>$s_p$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_5$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_6$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_7$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quick Guide for Scale Calibration Uncertainties

Reference information

Combined standard uncertainty

\[ u_c = \sqrt{u_s^2 + \sigma_p^2 + u_w^2 + u_{rab}^2 + u_{dr}^2 + u_{c1}^2 + u_{c2}^2 + \ldots + u_i^2} \]

Expanded uncertainty

\[ U = k(u_c), \quad k = \underline{\text{_____}} \quad k = 2 \text{ is recommended} \]

\[ U = \underline{\text{______}} \]
Scale Calibrations in a Semi-Controlled Environment

Introduction

Many general purpose scales are located in a semi-controlled environment such as a grocery store or warehouse that minimizes many of the environmental influence factors that contribute to measurement uncertainty.

Additionally, as most of these weighing devices have a relatively small capacity, it is possible to perform repeated measurements without severely affecting the time required to perform the calibration.
Scale Calibrations in a Semi-Controlled Environment

The controlled environment and the ability to make repeated measurements simplify the process of calculating calibration uncertainty.

Thus, service personnel are required to make fewer subjective decisions.

The following outlines the process that scale service personnel should use to calculate the uncertainty associated with the scale testing process.
Step 1. Specify the Process and Equation

Write down a clear concise statement of what is being measured and the relationship between it and the parameters on which it depends. Remember, the scale indication is being tested, not the mass of the standard mass artifacts.

Example: where; \( y = (mx+b) \pm U \)

\( y \) is the scale indication, \( m \) is the sensitivity of the weighing device,
\( x \) is the applied load, \( b \) is the zero offset, and \( U \) is the assigned measurement uncertainty.

Ideally, \( b = 0 \) if the scale indication was properly zeroed, and \( m = 1 \) because the scale indicates one mass unit for each mass unit applied.
The uncertainty associated with the calibration of a general purpose scale is comprised of many influence factors. A cause and effect diagram is used here to identify the factors and to show their relationship to other factors.
Sample Cause and Effect Diagram
- Levelness of the scale should be checked and corrected if necessary.

- Drafts should be eliminated by the installation of draft shields, air diffusers or by redirecting air vents, or closing doors. These draft elimination measures must be in place at all times (including during use) for the calibration uncertainty statement to remain valid during daily use.

- Off-center loading errors should be evaluated and corrected before recording final calibration data.
Thermal equilibrium of the scale should be ensured by keeping the scale in an energized state (i.e., turned on) for sufficient time to ensure that all circuitry and hardware has reached a stable temperature.

Vibration sources must be identified and eliminated or minimized to limit the vibration levels to which the weighing device is exposed during daily use, as well as during calibration.
- **Zero-tracking** features should be disabled to avoid undetectable zero indication errors.
  - Zero-tracking is designed to eliminate minor changes in scale indication due to drift of the weighing system and may be turned 'on' to maintain the 'zero' indication of the weighing device.

- Due to the correction limits included in the system programming regarding quantity and motion detection, detrimental effects on measurement results are typically not evident.

- However, service personnel may, while attempting to load the pan in a slow, gentle manner encounter times that the zero tracking circuitry will cause an offset in the indication.

- While this would be an unusual occurrence, service personnel must be aware of the possibility of such errors and take steps to prevent them from occurring.
Mass Standards must be brought into close proximity to the scale to ensure thermal equilibrium with the scale and surrounding environment.

Thermal stabilization times for weights typically used for a scale in this environment are not specified, but sufficient time must be allowed to ensure that condensation is not present on the weights.
Standard mass error effects can be minimized by using the mass values determined during calibration of the mass artifacts.

For most scales used in a semi-controlled environment this will not be necessary as the tolerances of the scales and standard masses have been set to minimize the effects of the standard mass errors.

The concept is presented here as an option should correction be desirable.

The standard mass uncertainty for general purpose scales is normally based on the tolerance of the mass standards.
**Scale indication drift** errors should be corrected to the maximum extent possible. Though slight drift in the indicated value is somewhat normal, significant indication drift may indicate thermal instability of the weighing system.

Allowing a longer temperature stabilization period for the weighing device and standard mass artifacts can minimize drift due to thermal instability. Exercising the weighing system may also minimize drift.

Repeatedly applying and removing loads within the range of the device causes the electronic and mechanical components of the system to acquire a thermal equilibrium of use.

If indication drift is excessive and cannot be eliminated by the means described, other corrective action must be taken.
RFI/EMI susceptibility tests should be performed. Changes in indication due to random RFI/EMI influences can be difficult to detect during normal use and may be interpreted as repeatability errors or drift. Corrective action should be taken if RFI/EMI susceptibility is detected.

Note: RFI/EMI sources include two-way radios, cell phones and other electronic devices. Laboratories are available specializing in detecting and measuring RFI/EMI.
Power-line noise or variations can cause random display indications to occur.

The specific cause of these random indications may be difficult to determine, but will affect the repeatability of the weighing system.

Where possible, it is best that scales be powered by a dedicated power circuit or be powered by a AC line conditioner to prevent these measurement influences.
Operator errors result when operators are inadequately trained.

All operators of weighing devices should have proper training and be knowledgeable about the weighing instrument and the process in which it is used.

Inadequately trained personnel may record data with significant errors, improperly influencing critical process decisions.

Weighing system operators must be equipped with correct and complete work instructions to minimize the likelihood of operator error.
Process standard deviation (sp)

The source of a value for sp can be based on scale repeatability, scale reproducibility or the size of a scale division. Each are discussed below.
Repeatability is a measure of a scale’s ability to produce the same indication every time the same weight, under identical conditions, is placed on the sensing device.

Repeatability is normally presented as a standard deviation and is normally determined by repeated measurements of a specific weight.

At least seven measurement results of a weight are required to calculate the repeatability or standard deviation of the scale.

Increasing the number of measurement results provides greater confidence in the value.
A minimum of thirty measurement results is preferred when calculating a standard deviation.

The calculated standard deviation obtained in this manner is a measure of the weighing system’s ability to repeat measurement results over a short time interval and does not represent the long-term reproducibility.
Due to scale resolution, it is possible to make seven or more measurements with every measurement resulting in the same value.

A true scale standard deviation of zero is not statistically possible, though the standard deviation may be less than one display increment (d).

In this situation, assuming that a control chart of a check standard is not available, the standard deviation of the scale can be estimated as
available, the standard deviation of the scale can be estimated as \( s_p = \frac{d}{\sqrt{3}} = 0.577d \) (0.577 times the value of ‘d’) as described in the GUM.

If it is possible to perform a discrimination test as described in NIST Handbook 44, N.1.5 and T.N.7.1 or OIML R 76-1, A.4.8, another equation may be used. That equation is: \( s_p = \frac{1}{2} \frac{d}{\sqrt{3}} = 0.29d \) (0.29 times the value of ‘d’) since passing the discrimination test
When desiring to ascertain the uncertainty of the scale during everyday weighing operations, a check standard and control chart should be used to determine the long-term repeatability of the scale, under varying operational conditions.

This is called reproducibility, also evaluated as a standard deviation.

Reproducibility is a measure of long-term repeatability and is used in place of the short-term repeatability when calculating measurement uncertainty.

The value will be included in the combined uncertainty as sp.
The value for sp is best determined from repeated readings of a weight, whether short-term or long-term. The manufacturer’s specification sheet is not a recommended source for determining the uncertainty contribution due to repeatability. Manufacturers' specifications are established for a specific set of conditions that may not be representative of the actual environment in which the scale is tested and used. Manufacturers' specifications are an excellent tool when comparing the expected performance of one weighing device to another similar device, but they are established to indicate the expected performance of a family of weighing systems, not a specific weighing system. As the calibration uncertainty is being estimated for a specific weighing system, it is best to establish the calibration uncertainty contribution due to repeatability from measured data, not from an expected performance parameter. Manufacturers' specifications should not be used to estimate calibration uncertainty.
Uncertainty due to display resolution (udr)

When the repeatability (sp) is estimated from display resolution, an additional uncertainty component for indicator resolution must be included. This value (udr) will be equal to

\[ u_{dr} = \frac{1}{2} \frac{d}{\sqrt{3}} = 0.29d \]

(0.29 times the value of \(d\)). This uncertainty component should not be included in the uncertainty calculations if repeatability is measured by making repeated measurements.
Uncertainty due to display resolution (udr)

The effect of the display resolution uncertainty component will have been part of the measured values and an additional uncertainty component is not required.
Uncertainty of the standards (us)

The uncertainty contribution of the standard masses used to perform the scale calibration may be estimated from one of two sources, the tolerance to which the masses have been tested, or the uncertainty associated with the calibration of the masses. Specific guidance follows.
When calibrating large capacity scales, the nominal values of the standard weights are typically used.

In this situation, a portion of the tolerance to which the weights were tested is used as the standard uncertainty of the standards value, \( u_s \), when calculating the calibration uncertainty.

Only a portion of the tolerance is used as the tolerance is considered to follow a uniform probability distribution.

The standard uncertainty of the standards is calculated as

\[
\begin{align*}
  u_s &= \frac{\text{tolerance}}{\sqrt{3}}
\end{align*}
\]

or (0.577 times the tolerance of the applied weights). When using multiple weights, the tolerance used in the \( u_s \) calculation will be the sum of the tolerances for all of the weights used.
Standard mass uncertainties normally are reported as expanded uncertainties, having been calculated by combining the various standard uncertainties that influenced the mass calibration process.

The combined standard uncertainty has then been multiplied by a stated coverage factor (k) to obtain the expanded uncertainty. This expanded uncertainty must be divided by the coverage factor to obtain a standard uncertainty for the mass artifacts, us.
When multiple weights are used, the most conservative value for the uncertainty of the mass calibrations is the sum of the uncertainties associated with each of the weights used simultaneously. For this situation

\[ u_s = u_{sm1} + u_{sm2} + u_{sm3} + \ldots + u_{smi} \]

While this method provides the most conservative estimate of standards uncertainty, it also typically provides the largest estimate for the standards uncertainty and may result in an uncertainty value greater than is allowed by the customer's weighing process.
Step 5. Calculation of the combined uncertainty

The combined uncertainty, ‘uc’, of the weighing system calibration will be calculated as the root-sum-squared of the influence factors.

\[ u_c = \sqrt{u_s^2 + u_p^2 + u_{dr}^2 + u_1^2 + u_2^2 + u_3^2 + \ldots + u_i^2} \]

where \( u_i \) are any other uncertainty components that the scale technician wishes to include in the uncertainty calculations.

Remember:

- All of the uncertainty components must be in terms of the mass units of the scale. Differing units, such as °C and mg, cannot be combined. Convert the impact of the non-mass units to the appropriate mass units to calculate the uncertainty.

- All uncertainty components must be in terms of standard (one standard deviation) uncertainties.
6. Calculating the expanded uncertainty

The expanded uncertainty, ‘U’, is calculated by multiplying the value obtained for uc by the coverage factor, ‘k’, for the confidence interval to be used.

By convention, as defined in NIST Technical Note 1297, “Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results”, a coverage factor of \( k = 2 \) is used for a confidence interval of approximately 95 %. The use of \( k \) values other than \( k = 2 \) requires an explanation of the reason for the deviation from convention.
Step 7. Evaluating the expanded uncertainty

There are several things to consider when evaluating the uncertainty.

First, does the final expanded uncertainty make sense? The expanded uncertainty must be at least ‘k’ times greater than the largest uncertainty component included.
Step 7. Evaluating the expanded uncertainty

Second, does the calculated expanded uncertainty seem appropriate for the tested device? An uncertainty value seems unreasonable and should be investigated if the expanded uncertainty is calculated to be significantly less than one balance division.

Likewise, if the calculated uncertainty is excessively large, that value should be investigated. Investigation should include verifying the use of proper evaluation techniques.

Ensure that arithmetical errors were not the cause of the questionable uncertainty value.
Step 7. Evaluating the expanded uncertainty

Third, does the calculated uncertainty meet the requirements of the tests that will be performed using the weighing device?

Different quality systems have different requirements concerning the allowable measurement uncertainty; requirements such that the uncertainty of a measuring device may not exceed 33 %, 25 %, or even as little as 10 %, of the tolerance of the object being tested.

Will the calculated uncertainty meet any such requirements that may be in place? If not, examine the entire calibration process for uncertainty contributors that can be reduced.
Step 7. Evaluating the expanded uncertainty

Reduction may be accomplished by selection of more accurate standards, repair of the weighing device to obtain a smaller standard deviation, or perhaps making multiple measurements to determine the true repeatability of a device rather than using an estimated repeatability.

Evaluate each uncertainty contributor, beginning with the most significant, to determine how it can legitimately be reduced until the required uncertainty level is obtained or until the decision is made that the weighing device cannot meet the quality requirements and must be replaced or that the weighing system must be moved to a more hospitable environment.
Step 8. Reporting Uncertainty

Reporting the expanded uncertainty value is no longer a matter of simply stating that a measurement result is ‘x ± y’ where ‘x’ is the reported value and ‘y’ is the expanded uncertainty.

The Guide to the Expression of Uncertainty in Measurement requires that you identify the various components of the uncertainty.
Step 8. Reporting Uncertainty

You must also explain why that component was included and how it was evaluated.

Specifically, the GUM provides a test of the stated uncertainty statement:

"Has enough information been provided in a sufficiently clear manner that the result can be updated in the future if new information or data became available?"

Another test is to ask:

"Would another individual, unassociated with the measurement process, be able to understand how the stated uncertainty was calculated and what was included, and then properly apply it to his/her own uncertainty calculation?"
Quick Guide for Scale Calibration

Uncertainties

Reference information:

<table>
<thead>
<tr>
<th>Process ((s_p)) Source (in order of desirability):</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Calculated standard deviation at the test load from an up-to-date control chart</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>2. Calculated standard deviation from 10 or more readings of same weight over a short period of time</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>3. Estimated from scale division (discrimination test passed)</td>
<td>Uniform</td>
<td>0.29 x ‘d’</td>
</tr>
<tr>
<td>4. Estimated from scale division (discrimination test not performed)</td>
<td>Uniform</td>
<td>0.577 x ‘d’</td>
</tr>
</tbody>
</table>
## Quick Guide for Scale Calibration

### Uncertainties

**Reference information:**

<table>
<thead>
<tr>
<th>Standards (uₙ) Sources (in order of desirability):</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Reported k=1 uncertainty from Report of Test</td>
<td>Normal</td>
<td>As calculated</td>
</tr>
<tr>
<td>2 Tolerance of weight used</td>
<td>Uniform</td>
<td>0.577 x tolerance</td>
</tr>
</tbody>
</table>

### Additional equations when using multiple standards

<table>
<thead>
<tr>
<th>a Multiple standard masses (if independence is proven):</th>
<th>$u_s = \sqrt{u_{\text{am1}}^2 + u_{\text{am2}}^2 + u_{\text{am3}}^2 + \ldots + u_{\text{amn}}^2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>b Multiple standard masses (if independence is unknown):</td>
<td>$u_s = u_{\text{am1}} + u_{\text{am2}} + u_{\text{am3}} + \ldots + u_{\text{amn}}$</td>
</tr>
</tbody>
</table>
Quick Guide for Scale Calibration

Uncertainties

Reference information:

<table>
<thead>
<tr>
<th>Other uncertainty sources</th>
<th>Distribution Type</th>
<th>Value to use:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty due to display resolution (u_{dr}) (see text)</td>
<td>Uniform</td>
<td>0 or (u_{dr} = s_p)</td>
</tr>
</tbody>
</table>

Additionally, there may be other known measurement uncertainty contributors. Evaluate the calibration process carefully to ensure that all significant contributors are properly included in the uncertainty calculations. Consult the text of this Guide for additional guidance.
Quick Guide for Scale Calibration

Uncertainties

Reference information:

<table>
<thead>
<tr>
<th>Equipment Identification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manufacturer</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Quick Guide for Scale Calibration

Uncertainties

Reference information:

<table>
<thead>
<tr>
<th>Uncertainty Influence Description</th>
<th>Identifier</th>
<th>Estimated value</th>
<th>Distribution type</th>
<th>Estimated Standard Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty of the standards used</td>
<td>$u_s$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation of the process (Determined at ________ test load)</td>
<td>$s_p$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_1$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_2$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_3$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_4$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_5$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_6$</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uncertainty due to</td>
<td>$u_7$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Quick Guide for Scale Calibration

Uncertainties

Reference information:

<table>
<thead>
<tr>
<th>Combined standard uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ u_c = \sqrt{u_s^2 + \sigma_p^2 + u_{dr}^2 + u_1^2 + u_2^2 + u_3^2 + u_4^2 + u_5^2 + \ldots + u_i^2} ]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expanded uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>[ U = k(u_c), \quad k = \underline{\ldots} \quad k = 2 \text{ is recommended} ]</td>
</tr>
</tbody>
</table>
Sample Calculations and Recommendations for Reducing Uncertainty

- Introduction

Evaluating the uncertainty of a scale and balance calibration process can be extremely complex depending on the location, capacity, design, readability, amount of calibrated load available, air currents and a host of other factors. It is not possible to provide an example that will address all situations, but the examples given, and the accompanying discussion, provide some insight into the process to be completed for every scale or balance calibration.
Sample Calculations and Recommendations for Reducing Uncertainty

Sample Uncertainty Calculation #1 (Relates to Chapter 3)

The following example of an uncertainty calculation for a 200 g laboratory balance calibration will provide insight into the process that must be used to analyze a balance calibration and evaluate the associated uncertainty.

(The two test loads, 50 g and 200 g, are used for demonstration purposes only. Consult the appropriate procedural documents for full test requirements.)
Sample Calculations and Recommendations for Reducing Uncertainty

- This balance is a Class I balance with a maximum load of 205 grams and a readability of 1 mg.

- It is located in a facility that deals with materials that are not hazardous, but are unpleasant to work with due to an offensive odor.

- Due to the unpleasant odor, the balance is located inside a fume hood.
Sample Calculations and Recommendations for Reducing Uncertainty

- A 100 g to 1 mg set of Class E1 weights is used to perform the calibration and the nominal values of the weights will be used.

- When preparing for the calibration, the balance user switched the fume hood off so that the service personnel did not have to listen to the drone of the fan.

- In addition, other equipment was removed from the fume hood.

- Typically, a small drying oven, and a small sample shaker are also located inside the fume hood near the balance.

- All are connected to a common power source.

- The environmental conditions are stable throughout the calibration process.
Sample Calculations and Recommendations for Reducing Uncertainty

- NIST Handbook 44 tolerances will be used even though this balance is not used for commercial sale of goods and is not technically within the regulatory jurisdiction of any Weights and Measures program.

- No other tolerance guidance is available.
Sample Calculations and Recommendations for Reducing Uncertainty

The Class I balance has a tolerance of

<table>
<thead>
<tr>
<th>Class I Maintenance Tolerances</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range tested (d)</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>0 to 50 000</td>
</tr>
<tr>
<td>50 001 to 200 000</td>
</tr>
<tr>
<td>200 001 +</td>
</tr>
</tbody>
</table>

For the sample calculation, the tolerance at the applied load will be

<table>
<thead>
<tr>
<th>Test Load Applied</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>50 000d (50 g)</td>
<td>± 1d (1 mg)</td>
</tr>
<tr>
<td>200 000d (200 g)</td>
<td>± 2d (2 mg)</td>
</tr>
</tbody>
</table>
Due to the small weights employed in this calibration, multiple measurements are performed to measure the repeatability of the balance at a 100 g load. Ten readings were recorded: the ten values are identical, therefore the calculated $sp = 0$. 
Sample Calculations and Recommendations for Reducing Uncertainty

the uncertainty of the calibration be determined
Sample Calculations and Recommendations for Reducing Uncertainty

1. Specify the process and equation

The indicated values of the balance loads are a function of the applied load and the associated uncertainty.

A very basic statement of the measurement equation would be: Indication = applied load $\pm$ Uncertainty or $y = mx + b \pm U$. Uncertainty equals
Sample Calculations and Recommendations for Reducing Uncertainty

2. Identify and characterize the uncertainty sources

The uncertainty sources that are significant for this calibration are:

- the uncertainty of the standard weights,
- the standard deviation of the balance
Quick Guide for Scale Calibration

Uncertainties

Reference information:

Significant and uncorrectable factors

- Design
- Installation
- Staff & Procedures

Factors affecting Uncertainty:
- Reported
- Repeatability
- Tolerance

Standards
- Environment/Location
- Method of Use

Uncertainty
Quick Guide for Scale Calibration

Uncertainties

Reference information:

3. Quantify the identified uncertainty components

The uncertainty of the standard weights is taken to be equal to the sum of the tolerances of the OIML Class E1 weights used at each applied load.

This calculates to be: ± 0.15 mg at 200 g, and ± 0.030 mg at 50 grams.

The standard deviation of the 10 measurement results obtained at 100 g calculates to a standard deviation of zero, since all of the indications were identical.

A standard deviation of zero is not statistically possible, but is a result of having recorded only 10 indicated readings.
Quick Guide for Scale Calibration

Uncertainties

Reference information:

3. Quantify the identified uncertainty components

If all possible measurement results were obtained at 100 g, there would be an infinite number of readings.

Statistics shows that the standard deviation, $sp$, would be approximately equal to some portion of one scale division, or 1 mg.
Quick Guide for Scale Calibration

Uncertainties

Reference information:

4. Convert the measurement influences to standard deviation equivalents

Using the text and the Quick Guide, each of the quantified measurement influences is converted to one standard deviation or standard uncertainty equivalent.
4. Convert the measurement influences to standard deviation equivalents

The uncertainty of the standard weights is taken to be equal to the tolerance of the OIML Class E1 weights. This uncertainty component fits a uniform probability distribution, so use of the equation $0.577 \times \text{tolerance}$ is appropriate.

Thus, the standard uncertainty, $u_s$, due to the tolerance of the calibrated weights is: $0.577 \times 0.15 = 0.08655 \text{ mg at 200 g}$, and $0.577 \times 0.030 = 0.01731 \text{ mg at 50 g}$. 
Quick Guide for Scale Calibration

Uncertainties

Reference information:

4. Convert the measurement influences to standard deviation equivalents

Because the measured standard deviation was equal to zero and this is statistically not possible, the Guide to the Expression of Uncertainty in Measurement provides guidance for this situation.
Quick Guide for Scale Calibration

Uncertainties

Reference information:

4. Convert the measurement influences to standard deviation equivalents

Basically, the writers of the GUM state that even though there is no indicated difference in the readings due to the inability of the weighing device to detect the difference between two values, e.g., 1.55 and 2.45, each cause an indication of 2, there is still a variability associated with the indications.

The writers of the GUM recommend that the standard deviation, $sp$, be estimated as: $0.29 \times 1 \text{ mg} = 0.29 \text{ mg}.$
Quick Guide for Scale Calibration

Uncertainties

Reference information:

5. Calculate the combined standard uncertainty, $u_c$, using the equation

$$u_c = \sqrt{u_s^2 + \sigma_r^2}$$

For this example

$$u_{c\,200\,g} = \sqrt{0.08655 \text{ mg}^2 + 0.29 \text{ mg}^2}$$

$$u_{c\,200\,g} = 0.3026398891 \text{ mg}$$

$$u_{c\,50\,g} = \sqrt{0.01731 \text{ mg}^2 + 0.29 \text{ mg}^2}$$

$$u_{c\,50\,g} = 0.2905161546 \text{ mg}$$
Quick Guide for Scale Calibration

Uncertainties

Reference information:

6. Calculate the Expanded Uncertainty

Multiply the combined standard uncertainty, $u_c$, by the coverage or 'k' factor to calculate the expanded uncertainty.
Quick Guide for Scale Calibration

Uncertainties

Reference information:

For $U_{200\,g}$,

<table>
<thead>
<tr>
<th>Description</th>
<th>Identifier</th>
<th>Estimated value</th>
<th>Distribution type</th>
<th>Estimated Standard Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty of the weights used</td>
<td>$u_s$</td>
<td>0.15 mg</td>
<td>Uniform</td>
<td>0.08655 mg</td>
</tr>
<tr>
<td>Standard deviation of the process (repeatability or reproducibility)</td>
<td>$s_p$</td>
<td>1 mg</td>
<td>Uniform</td>
<td>0.29 mg</td>
</tr>
</tbody>
</table>

Combined standard uncertainty

$$u_c = \sqrt{u_s^2 + s_p^2}$$

0.3026398891 mg

Expanded uncertainty

$$U = k(u_c), \quad k = 2 \text{ (rounded to two significant digits)}$$

0.61 mg (at 200 g)
Quick Guide for Scale Calibration

Uncertainties

Reference information:

For $U_{30_g}$,

<table>
<thead>
<tr>
<th>Description</th>
<th>Identifier</th>
<th>Estimated value</th>
<th>Distribution type</th>
<th>Estimated Standard Uncertainty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncertainty of the weights used</td>
<td>$u_s$</td>
<td>0.030 mg</td>
<td>Uniform</td>
<td>0.01731 mg</td>
</tr>
<tr>
<td>Standard deviation of the process (repeatability or reproducibility)</td>
<td>$s_p$</td>
<td>1 mg</td>
<td>Uniform</td>
<td>0.29 mg</td>
</tr>
</tbody>
</table>

Combined standard uncertainty

$$u_c = \sqrt{u_s^2 + s_p^2}$$

0.2905161546 mg

Expanded uncertainty

$$U = k \ (u_c), \ k = 2$$ (rounded to two significant digits)

0.58 mg (at 50 g)
Quick Guide for Scale Calibration

Uncertainties

Reference information:

7. Evaluate U for appropriateness
Several criteria should be evaluated.

Does the expanded uncertainty make sense? Since the largest single standard uncertainty is 0.29 mg, it would not make sense to have an expanded uncertainty of 0.1 mg, when using a $k=2$ expanded uncertainty, because $2 \times 0.29 \text{ mg} = 0.58 \text{ mg}$.

The expanded uncertainty must always be at least $k$ times the largest single uncertainty contribution included in the calculations. Likewise, an expanded uncertainty of 50 mg would not make sense, since no single factor approached 25 mg.

The service technician must think!
Quick Guide for Scale Calibration

Uncertainties

Reference information:

7. Evaluate U for appropriateness

Several criteria should be evaluated.

Does the calculated uncertainty seem reasonable for the balance being tested? If the balance has 1 mg divisions, an expanded uncertainty of 28 mg or 28 divisions would probably not be reasonable.

Repair of the device and verification of the calculations is recommended. If the balance has 10 mg divisions, 28 mg might be appropriate, but the calculations should be reviewed for correctness.

The service technician must think!
Quick Guide for Scale Calibration

Uncertainties

Reference information:

Does the expanded uncertainty meet the criteria for the calibration process? NIST Handbook 44 Fundamental considerations states that "if the standard is to be used without correction, its error should be not greater than one-third of the smallest tolerance to be applied when the standard is used."

Interpreting this statement to indicate that the uncertainty of the calibration process should not be greater than one-third of the smallest tolerance to be applied to the device being tested, is the expanded uncertainty less than one-third of the tolerance for the balance being tested?
Quick Guide for Scale Calibration
Uncertainties

Reference information:

<table>
<thead>
<tr>
<th>Applied Load</th>
<th>Expanded Uncertainty</th>
<th>HB 44 Tolerance</th>
<th>1/3 Tolerance</th>
<th>U &lt; 1/3 Tolerance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 g</td>
<td>0.61 mg</td>
<td>2 mg</td>
<td>0.66667 mg</td>
<td>Yes</td>
</tr>
<tr>
<td>50 g</td>
<td>0.58 mg</td>
<td>1 mg</td>
<td>0.33333 mg</td>
<td>No</td>
</tr>
</tbody>
</table>
Quick Guide for Scale Calibration

Uncertainties

Reference information:

Does the expanded uncertainty meet the requirements of the user's process?

The answer to this question must come from the scale operator.

If the answer to either of the last two questions is 'NO', ways of decreasing the calibration uncertainty must be sought.

First, the uncertainty calculations must be reviewed for correctness.

Second, possible changes to the calibration process must be evaluated. Begin with the largest uncertainty contributor, working to the least significant.
8. Reporting Uncertainty

The uncertainty statement of the balance calibration should include sufficient information that a person not associated with the calibration will understand what uncertainty components were included, how and why. The following is a sample:

"The k=2 Expanded Uncertainty of the balance calibration was as described in the following table."
## Quick Guide for Scale Calibration

### Uncertainties

**Reference information:**

<table>
<thead>
<tr>
<th>Applied Load</th>
<th>Calibration Uncertainty $(k = 2)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 g</td>
<td>0.61 mg</td>
</tr>
<tr>
<td>50 g</td>
<td>0.58 mg</td>
</tr>
</tbody>
</table>
The uncertainty values were determined by using the root-sum-squared (RSS) combination of the significant measurement influences. Included are:

A. the estimated standard deviation of the scale,
B. estimated from the size of the scale division (d),
C. the uncertainty of the calibrated mass standards,
D. estimated from the allowable calibration tolerance of the weights
E. The RSS combined value was multiplied by a coverage factor (k) of 2 to obtain a value fitting the probability distribution for a 95% confidence interval."
Typically, the balance user must use the reported calibration expanded uncertainty as one component of the normal weighing operation process uncertainty.