White Paper

RapidCal™ Tank Scale Calibration

Accuracy You Can Rely On

METTLER TOLEDO's RapidCal™ is an innovative tank scale calibration method accredited to ISO 17025 in multiple countries, including the USA and Germany. This white paper explains how RapidCal establishes measurement uncertainty based on international calibration standards and provides traceability to the SI unit of mass.

METTLER TOLEDO

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1. Scale Calibration with Hydraulic Force

How does RapidCal work?

METTLER TOLEDO's RapidCal is an innovative calibration method for most tank, reactor, hopper, and silo scales that avoids the use of large test weights. Instead, hydraulic actuators create a downward force that is measured by high-accuracy reference load cells. RapidCal creates the same loading conditions that occur during normal weighing operation and accounts for:

- product weight,
- deformations in the supporting structure of the scale, and
- any attachments such as pipes.

As shown in Figure 1, the equipment consists of one to four RapidCal modules, each attached to the tank and to the foundation, as well as a hydraulic handpump, hoses, and an indicator. The module length is adjustable to account for different tank designs.

There are two module capacities with a maximum pulling load of 4 and 8 tons per module, thus the maximum calibration load with four of the 8-ton modules is 32 tons. The calibration load can be freely adjusted with the handpump above the minimum load of 0.5 tons.

The RapidCal reference indicator measures the individual signals of each reference load cell and shows the sum signal. This indication serves as the independent reference in the calibration process.

How does RapidCal differ from calibration with test weights?

Calibrating a scale with test weights is the most accurate calibration method. For instance, a 1,000-kilogram test weight in the OIML M1 class has a maximum tolerance of 50 grams. However, this method becomes complicated or even impossible for high-capacity tank scales. This is because loading multiple tons of test weights requires a frame fixed to the tank and a crane for lifting the weights, which poses a safety risk for calibration technicians. Furthermore, calibration at different load levels and repeatability tests may take several days and result in financial losses due to production downtime.

In contrast, a typical RapidCal calibration including repeatability testing is completed in one to three hours. The method requires only simple anchor points and can be carried out safely by one technician.

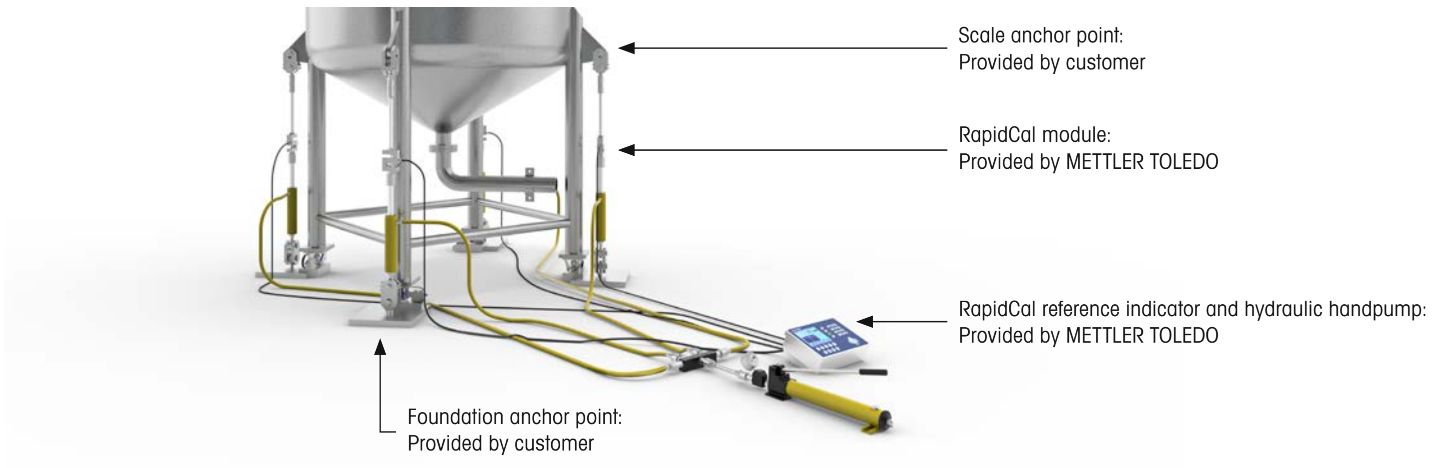


Figure 1: RapidCal system attached to a tank scale.

2. RapidCal Calibration Procedure

What steps does the calibration procedure involve?

As a precondition for RapidCal calibrations, anchor points must be added to the side of the tank as well as to the floor or substructure. Placement must adhere to RapidCal Engineering Recommendations [1].

METTLER TOLEDO provides the equipment and calibration service. Before starting the calibration, RapidCal equipment is acclimatized to local temperatures. The operator attaches the RapidCal modules to the anchor points and connects the hydraulic equipment. The scale is exercised to the largest test load three times. The as-found calibration process begins with error-of-indication testing at multiple test points followed by repeatability testing with five or more repetitions.

Due to the nature of the hydraulic system, it is not possible to apply the exact same test load twice; each test load should be reached within ±2% relative to the target load. Applied loads are normalized to calculate the standard deviation of the repeatability test. Furthermore, the applied load may not remain perfectly stable, but the RapidCal indicator monitors the rate of change. As soon as the system has stabilized below a certain threshold, both the RapidCal reference indication and the scale indication are read simultaneously, for instance by taking a picture of each display.

If a scale adjustment is needed, an as-left calibration is performed after the adjustment. METTLER TOLEDO issues a calibration certificate that includes an uncertainty statement and information on the metrological traceability of the reference load cell.

RapidCal creates the same loading conditions that occur during normal weighing operations.

3. Standards and Metrological Traceability

How closely does RapidCal follow international calibration standards?

If you seek to comply with quality management standards like ISO 9001 [2], it is essential to confirm the metrological quality of a scale. As a result, globally accepted guidelines have been established to ensure that calibration outcomes are equivalent and can be mutually recognized.

The "EURAMET Guide No. 18, Guidelines on the Calibration of Non-Automatic Weighing Instruments" [3], or CG18 in short, defines a calibration procedure using test weights and a calculation method for measurement uncertainty. EURAMET stands for the European Association of National Metrology Institutes, and these guidelines are recognized globally.

RapidCal follows CG18 closely, including error of indication and repeatability testing. While CG18 does not account for hydraulic loads yet, the uncertainty of RapidCal reference load cells replaces the uncertainty of reference test weights. Therefore, RapidCal can be seen as a "modified standard procedure" for calibrating non-automatic weighing instruments.

The calculation of combined and expanded uncertainty of the RapidCal calibration is done according to "EA-4/02 M, Evaluation of the Uncertainty of Measurement in Calibration" [4] and "NIST Technical Note 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results" [5].

How does RapidCal establish traceability to the SI unit of mass?

RapidCal is fully traceable to the SI unit of mass, as depicted in Figure 2. Scales are calibrated according to the RapidCal standard operating procedure (SOP). The issued calibration certificate provides the uncertainty at calibration, which includes the uncertainty of the reference load cells, and it lists the calibration certificate numbers of the reference load cells. The reference load cells are manufactured according to OIML R60 requirements and consist of a load cell and analog-to-digital converter coupled into a single unit. The units are calibrated by METTLER TOLEDO or external laboratories according to ISO 376 [6] using force machines that are traceable to the SI unit of mass.

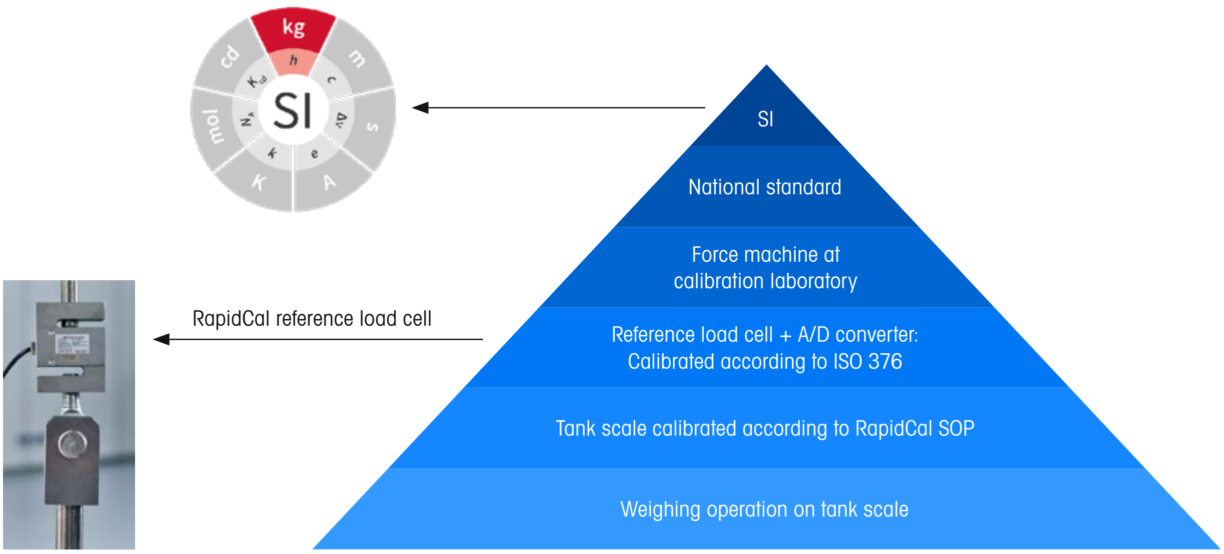


Figure 2: Metrological traceability pyramid of RapidCal calibration results.

4. ISO 17025 Accreditation

How is RapidCal accredited to ISO/IEC 17025?

ISO/IEC 17025 [7] accreditation certifies that a laboratory has the competence and quality management systems necessary to generate accurate and reliable test and calibration results. Several METTLER TOLEDO Service organizations, including those in the USA, Canada, Mexico, Germany, Austria, and Malaysia, have already been accredited to perform on-site RapidCal calibrations within the scope of ISO 17025 up to 32 tons. Additional accreditations are in progress; customers can contact their local authorized METTLER TOLEDO Service provider for more information.

What is the difference between accredited and non-accredited calibration?

The RapidCal equipment, calibration procedure, and calculation of measurement uncertainty are similar worldwide and have been approved by accreditation bodies in multiple ISO 17025 audits. Accredited calibrations strictly adhere to the accredited scope and to the instructions of CG18. Accredited service organizations may be subject to additional local requirements.

In addition, reference load cells used for accredited RapidCal calibrations are calibrated according to ISO 376 by an independent and accredited laboratory, while reference load cells for non-accredited calibrations could be calibrated internally by METTLER TOLEDO using a traceable force machine.

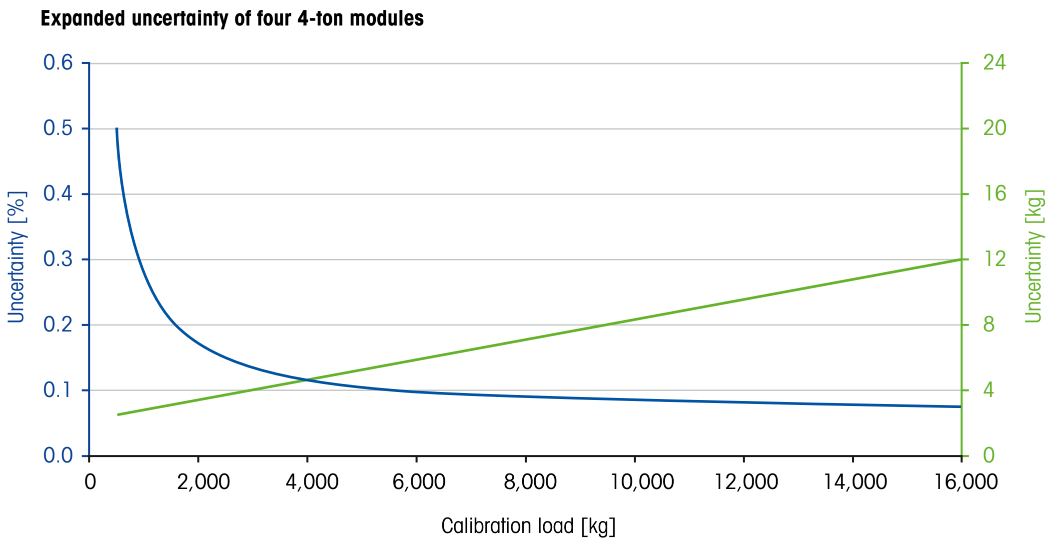
ISO 17025 accreditation gives confidence that an organization can deliver accurate and reliable calibration results.

5. Uncertainty at Calibration

How accurate is RapidCal?

RapidCal is able to deliver highly accurate calibration results, especially at high loads. The measurement uncertainty at calibration depends on the scale to be calibrated, on the RapidCal reference system, and on environmental factors. The absolute measurement uncertainty (in kilograms or pounds) of the RapidCal system is greater than zero at zero load and increases linearly with increasing loads. However, the relative uncertainty in percent decreases with higher calibration loads.

Figure 3 displays the absolute and relative measurement uncertainty of RapidCal calibrations with four modules and 4- and 8-ton systems, respectively. A perfect scale with high resolution and no repeatability error is assumed and a k-value of 2 is used. The graphs show that the relative expanded uncertainty begins at 0.5% for 500 kilograms (1,100 pounds) and decreases considerably for higher calibration loads, going below 0.1% above a calibration load of around 6,000 kilograms (13,200 pounds). Tables 1 and 2 comprise additional values for all configurations. It is worth noting that 4- and 8-ton modules present comparable uncertainties at equivalent loads.



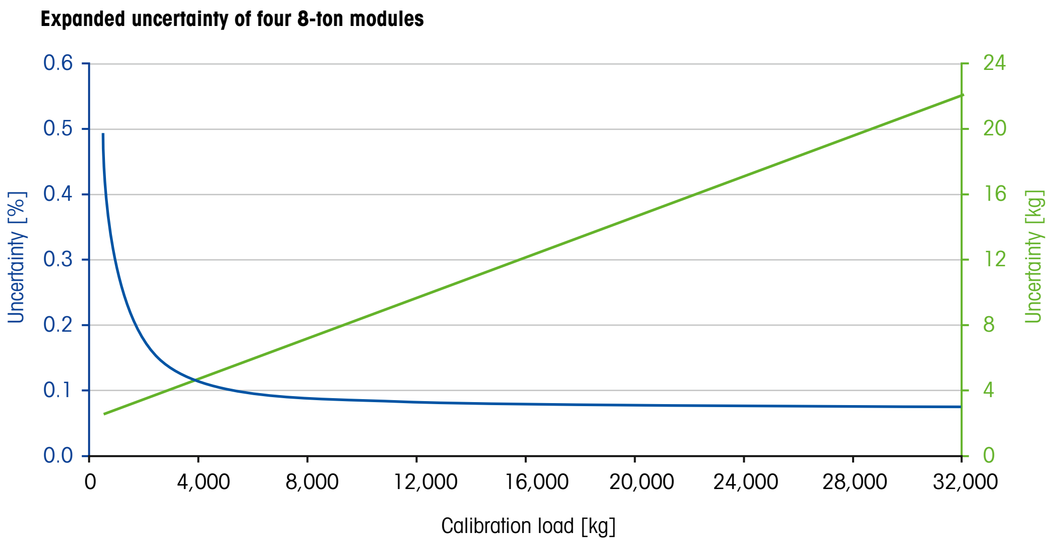


Figure 3: Expanded measurement uncertainties (k = 2) of the RapidCal 4- and 8-ton reference systems.

RapidCal 4-ton system

Load	kg	500	1,000	2,000	4,000	8,000	12,000	16,000
	lb	1,100	2,200	4,400	8,800	17,600	26,500	35,300
Expanded uncertainty (k = 2)	1 module							
	kg	1.7	2.3	3.5	6.0			
	lb	3.8	5.1	7.7	13			
	%	0.34	0.23	0.18	0.15			
	2 modules							
	kg	2.0	2.4	3.2	5.0	8.5		
	lb	4.5	5.3	7.2	11	19		
	%	0.40	0.24	0.16	0.12	0.11		
	3 modules							
	kg	2.3	2.6	3.3	4.7	7.5	10	
	lb	5.1	5.8	7.3	10	17	23	
	%	0.46	0.26	0.16	0.12	0.09	0.09	
	4 modules							
	kg	2.6	2.9	3.4	4.6	7.0	9.5	12
	lb	5.7	6.3	7.5	10	16	21	27
	%	0.52	0.29	0.17	0.11	0.09	0.08	0.08

Table 1: Expanded measurement uncertainty of the RapidCal 4-ton reference system.

RapidCal 8-ton system

Load	kg	500	1,000	4,000	8,000	16,000	24,000	32,000
	lb	1,100	2,200	8,800	17,600	35,300	52,900	70,500
Expanded uncertainty (k = 2)	1 module							
	kg	1.7	2.3	6.0	11			
	lb	3.8	5.1	13	24			
	%	0.34	0.23	0.15	0.14			
	2 modules							
	kg	2.0	2.4	5.0	8.5	16		
	lb	4.5	5.3	11	19	34		
	%	0.41	0.24	0.12	0.11	0.10		
	3 modules							
	kg	2.3	2.6	4.7	7.5	13	19	
	lb	5.1	5.8	10	17	29	42	
	%	0.46	0.26	0.12	0.09	0.08	0.08	
	4 modules							
	kg	2.6	2.9	4.6	7.0	12	17	22
	lb	5.7	6.3	10	16	27	38	49
	%	0.52	0.29	0.12	0.09	0.08	0.07	0.07

Table 2: Expanded measurement uncertainty of the RapidCal 8-ton reference system.

What factors contribute to the measurement uncertainty of RapidCal?

Table 3 provides an overview of all influencing factors that contribute to uncertainty at calibration, indicating their sources. The rounding error for no-load indication, indication at load, and repeatability of the instrument is calculated following CG18. The uncertainty of the reference mass is replaced by the error of the reference load cell, which considers factors such as the uncertainty from initial calibration, drift over time, and temperature sensitivity. The reference indication on the RapidCal indicator is subject to rounding error and time delay. Local gravitational acceleration is compensated by the METTLER TOLEDO GEO-code system described in the next section. The force direction is allowed to deviate from vertical by up to 0.5°; this angle is checked after anchor point installation.

CG18 defines additional effects that do not apply to RapidCal: The eccentric loading error is negligible for tank scales because the center of gravity remains constant with liquids or bulk material. Air buoyancy and convection are not relevant to the hydraulic load principle.

System	Contribution factor	Reference
Tank scale	Rounding error no-load indication	CG18
	Rounding error at load	CG18
	Repeatability	CG18
RapidCal reference load cells (= "reference mass")	Initial calibration	Load cell calibration certificate
	Drift over time	Empirical, long-term test data
	Temperature sensitivity	OIML R60 limits, empirical test data
RapidCal reference indication	Rounding error no-load indication	CG18
	Rounding error at load	CG18
	Time delay	Calculation, operating procedure
Environment	Local gravitational acceleration	METTLER TOLEDO GEO-code system
	Force direction	Calculation, angle check after installation

Table 3: Contributing factors to RapidCal uncertainty.

Is RapidCal accuracy affected by local gravitational acceleration?

RapidCal reference load cells are calibrated in a different location from where they are used, which could cause a measurement error due to variations in the g-value around the globe (ranging from 9.78 to 9.83 m/s^2, a 0.5% range). To compensate for this, METTLER TOLEDO uses a system called GEO-code that defines 31 local g-values for each region of the world. The RapidCal reference indicator stores the local GEO-code to compensate for this error, and the remaining error of ±0.01% is included in the uncertainty calculation.

How does anchor point location influence calibration accuracy?

The RapidCal system aims to mimic loads on the scale during operation. Therefore, the sum of forces from the RapidCal modules should act at a similar location as the center of gravity of the product being weighed, which is typically the tank center. To ensure this, anchor points should be equidistant from the tank center and equally distributed from each other. Installation deviations in the range of several centimeters or inches are insignificant for the measurement uncertainty and can be accepted.

However, it is crucial that the RapidCal modules are installed perfectly vertical since force can act in any direction, unlike gravity. A deviation of up to $\alpha = 0.5°$ is allowed, which is factored into the uncertainty calculation. The angular error is calculated as $(1 - \cos \alpha)$, resulting in an error of ±0.00381% when $\alpha = 0.5°$.

For further details on anchor point design and installation, please refer to RapidCal Engineering Recommendations [1].

6. Calibration of Scales with Very Large Capacity

Is it possible to calibrate a tank scale with a capacity beyond 32 tons?

Calibrating a tank scale with a capacity of hundreds of tons is challenging, even with the use of RapidCal. There are, however, approaches available to improve the accuracy of large tank scales.

- **Weightless adjustment.** Many industrial weighing companies offer an "automatic calibration feature" that minimizes bias during installation. It does this by adjusting scale sensitivity electronically based on sensor sensitivity, which is determined during the factory calibration of the load cells. At METTLER TOLEDO, this type of weightless adjustment is referred to as CalFree™ (for analog load cells) or CalFree Plus™ (for POWERCELL® load cells). Weightless adjustment is the easiest and often only way to ensure basic accuracy for very large tank and silo scales. However, it cannot be verified by an independent process, and deviations over time cannot be detected. Therefore, it is not recognized as a calibration method.
- **Flow meter calibration.** Flow meters have no fixed capacity and can be used for large tank scales containing liquids. However, as load increases, calibration time and measurement uncertainty increase to the point where calibration using flow meters becomes impractical.
- **Material substitution.** Calibration by material substitution is a viable solution for large tank scales. This method involves using test weights and a stable material that can be added to the scale. First, test weights are applied to the scale, and then the scale is adjusted. The weights are removed, and the tank is filled with the substitution material until it reaches the same load. The test weights are reapplied, and the process is repeated several times.

For more information on the pros and cons of different calibration methods, please refer to METTLER TOLEDO's white paper "Choosing the Right Calibration Method" [8].

Can RapidCal be used in conjunction with material substitution?

As RapidCal functions similarly to calibration using test weights, it is possible to combine the material substitution process with RapidCal. This allows for much faster calibrations of tanks with very high capacities than would be achievable with test weights.

CG18 does not limit the number of substitution steps. Since the measurement uncertainty increases with each substitution step, a maximum of three substitution steps plus the final reference load is recommended. This means that a total calibration load above 100 tons is possible by material substitution when used in conjunction with the maximum load of RapidCal (32 tons). Please note that the substitution method brings the calibration load beyond the upper limit of the ISO 17025 accreditation.

What measurement uncertainty can be expected with material substitution?

The accuracy of material substitution calibration depends heavily on the repeatability of the scale, the number of substitution steps, and the accuracy of the reference system (test weights or RapidCal). The higher the number of steps, the lower the achievable accuracy due to accumulated measurement uncertainties.

The uncertainty calculation for material substitution is outlined in CG18. Due to the influence of the scale interval and repeatability, the combined uncertainty can be much higher than the uncertainty of the reference system.

Table 4 shows typical values for the calibration uncertainty for up to three substitution steps, each with the maximum RapidCal load of 32 tons and giving the example of a tank scale interval of d = 10 kilograms (22 pounds). The expanded uncertainty for the RapidCal reference system remains the same for each step, which is 22 kilograms (49 pounds) in the case of four modules at 8 tons load each. Assuming a good repeatability of 30 kilograms (66 pounds) as the standard deviation of five repeats, the expanded uncertainty increases to 240 kilograms (529 pounds) for three substitution steps. The relative uncertainty remains in the range of 0.2%. Assuming a mediocre repeatability of 80 kilograms (176 pounds), the expanded uncertainty increases to 620 kilograms (1,370 pounds) for three substitution steps. The relative uncertainty remains in the range of 0.5% for this example.

The process of material substitution requires a suitable material and more time than a standard RapidCal calibration. The actual calibration uncertainty can only be obtained onsite. To determine the feasibility and suitability of this method, we suggest reaching out to your local authorized METTLER TOLEDO Service provider.

Number of substitution steps		**0**	**1**	**2**	**3**
Full calibration load	kg	32,000	64,000	96,000	128,000
RapidCal uncertainty at 32 tons (k = 2)	kg	22			
Tank scale interval d	kg	10			
Good scale repeatability (5 repeats)	**kg**	**30**			
Expanded uncertainty (k = 2.65)	kg	85	150	200	240
	%	0.27	0.24	0.21	0.19
Mediocre scale repeatability (5 repeats)	**kg**	**80**			
Expanded uncertainty (k = 2.87)	kg	230	400	520	620
	%	0.73	0.63	0.54	0.49

Table 4: Typical values for the expanded uncertainty (in kilograms) for material substitution with four 8-ton RapidCal modules.

References:

[1] METTLER TOLEDO, RapidCal Tank Scale Calibration: Engineering Recommendations, Document No. 30412899, 01/2019
[2] ISO 9001, Quality management systems – Requirements, 2015
[3] EURAMET, Guide No. 18, Version 4.0, Guidelines on the Calibration of Non-Automatic Weighing Instruments, 11/2015
[4] EUROPEAN ACCREDITATION, EA-4/02 M, Evaluation of the Uncertainty of Measurement in Calibration, 2022
[5] NIST, Technical Note 1297, Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results, 1994
[6] ISO 376, Metallic materials – Calibration of force-proving instruments used for the verification of uniaxial testing machines, 2011
[7] ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories, 2017
[8] METTLER TOLEDO, Choosing the Right Calibration Method for Your Tank Scales, Document No. 30531762, 03/2021

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