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Nuclear fuel technology — Tank calibration and volume determination for nuclear materials accountancy —

Part 2:
Data standardization for tank calibration

Technologie du combustible nucléaire — Étalonnage et détermination du volume de cuve pour la comptabilité des matières nucléaires —

Partie 2: Normalisation des données pour l'étalonnage de cuve

Reference number
ISO 18213-2:2007(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 18213-2 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 5, *Nuclear fuel technology*.

ISO 18213 consists of the following parts, under the general title *Nuclear fuel technology — Tank calibration and volume determination for nuclear materials accountancy*:

- *Part 1: Procedural overview*
- *Part 2: Data standardization for tank calibration*
- *Part 3: Statistical methods*
- *Part 4: Accurate determination of liquid height in accountancy tanks equipped with dip tubes, slow bubbling rate*
- *Part 5: Accurate determination of liquid height in accountancy tanks equipped with dip tubes, fast bubbling rate*
- *Part 6: Accurate in-tank determination of liquid density in accountancy tanks equipped with dip tubes*

Introduction

ISO 18213 deals with the acquisition, standardization, analysis, and use of calibration data to determine liquid volumes in process tanks for accountability purposes. This part of ISO 18213 complements the other parts, which include ISO 18213-1 (procedural overview), ISO 18213-3 (statistical methods), ISO 18213-4 (slow bubbling rate), ISO 18213-5 (fast bubbling rate) and ISO 18213-6 (in-tank determination of liquid density).

Measurements of the volume and height of liquid in a process accountancy tank are often made in order to estimate or verify the tank's calibration or volume measurement equation. The calibration equation relates the response of the tank's measurement system to some independent measure of tank volume. The ultimate purpose of the calibration exercise is to estimate the tank's volume measurement equation (the inverse of the calibration equation), which relates tank volume to measurement system response. In this part of ISO 18213, it is assumed that the primary measurement-system response variable is liquid height and that the primary measure of liquid content is volume.

Beginning with an empty tank, calibration data are typically acquired by introducing a series of carefully measured quantities of some calibration liquid into the tank. The quantity of liquid added, the response of the tank's measurement system and relevant ambient conditions, such as temperature, are measured for each incremental addition. Typically, several calibration runs are made to obtain data for estimating or verifying a tank's calibration or measurement equation. A procedural overview of the tank calibration and volume measurement process is given in ISO 18213-1.

Changes in ambient conditions, especially variations in temperature, that occur during calibration can adversely affect the quality of the calibration data and, consequently, the reliability of the calibration or volume measurement equation determined from them. Results are also affected by differences in ambient conditions prevailing during calibration and at the time of subsequent measurements made to determine process liquid volumes. The purpose of this part of ISO 18213 is to present an algorithm for standardizing tank calibration and volume measurement data so as to minimize the effects of variability in ambient conditions prevailing at the time of measurement. Data standardization, as the term is used in this part of ISO 18213, refers to the steps taken to adjust raw data to compensate for departures in measurement conditions from a fixed set of reference conditions. The goal is to obtain a set of standardized calibration data, i.e. a series of pairs of height and volume determinations from one or more calibration runs that are standardized to a fixed set of reference conditions. These standardized data can be used to make reliable estimates of the tank's calibration or measurement equation, which is used, in turn, to determine the volume (at reference conditions) of process liquid in the tank.

This part of ISO 18213 pertains to measurements of liquid height and volume obtained during the tank calibration process. For tanks equipped with pressure-measurement systems to determine liquid content, it is necessary to convert pressure measurements to measures of liquid height before the steps of this part of ISO 18213 can be applied. A procedure for determining liquid height from pressure is given in either ISO 18213-4 (slow bubbling rate) or ISO 18213-5 (fast bubbling rate), as appropriate. Other standardization steps presented herein are generally independent of the measurement systems employed. Therefore, with suitable modifications, the methods of this part of ISO 18213 are applicable to a variety of measurement systems.

Nuclear fuel technology — Tank calibration and volume determination for nuclear materials accountancy —

Part 2:
Data standardization for tank calibration

1 Scope

This part of ISO 18213 presents procedures for standardizing a set of calibration data to a fixed set of reference conditions so as to minimize the effect of variations in ambient conditions that occur during the measurement process. The procedures presented herein apply generally to measurements of liquid height and volume obtained for the purpose of calibrating a tank (i.e. calibrating a tank's measurement system). When used in connection with other parts of ISO 18213, these procedures apply specifically to tanks equipped with bubbler probe systems for measuring liquid content.

The standardization algorithms presented herein can be profitably applied when only estimates of ambient conditions, such as temperature, are available. However, the most reliable results are obtained when relevant ambient conditions are measured for each measurement of volume and liquid height in a set of calibration data.

2 Physical principles

The data standardization procedures in this part of ISO 18213 are based on generally accepted thermodynamic methods. Where appropriate, details are given either in annexes to this part of ISO 18213 or in other parts of ISO 18213.

3 Data required

The basic input data to which the procedures of this part of ISO 18213 apply are pairs of observations that relate the tank's measurement system response (e.g. liquid height) to some independent measure of its liquid capacity (e.g. volume). These data pairs are typically obtained from one or more calibration runs. A typical calibration setup is shown in Figure 1. This setup is described in greater detail in ISO 18213-1[1].

The density of the calibration liquid is required at all temperatures that are observed during the calibration exercise. Demineralized water is a preferred calibration liquid because its density has been very accurately determined at all temperatures of interest. Moreover, equations have been developed for accurately calculating the density of water from temperature (see Annex A). If some liquid other than water is used for calibration, then it is necessary to determine its density with suitable accuracy to meet calibration requirements at all measurement temperatures.

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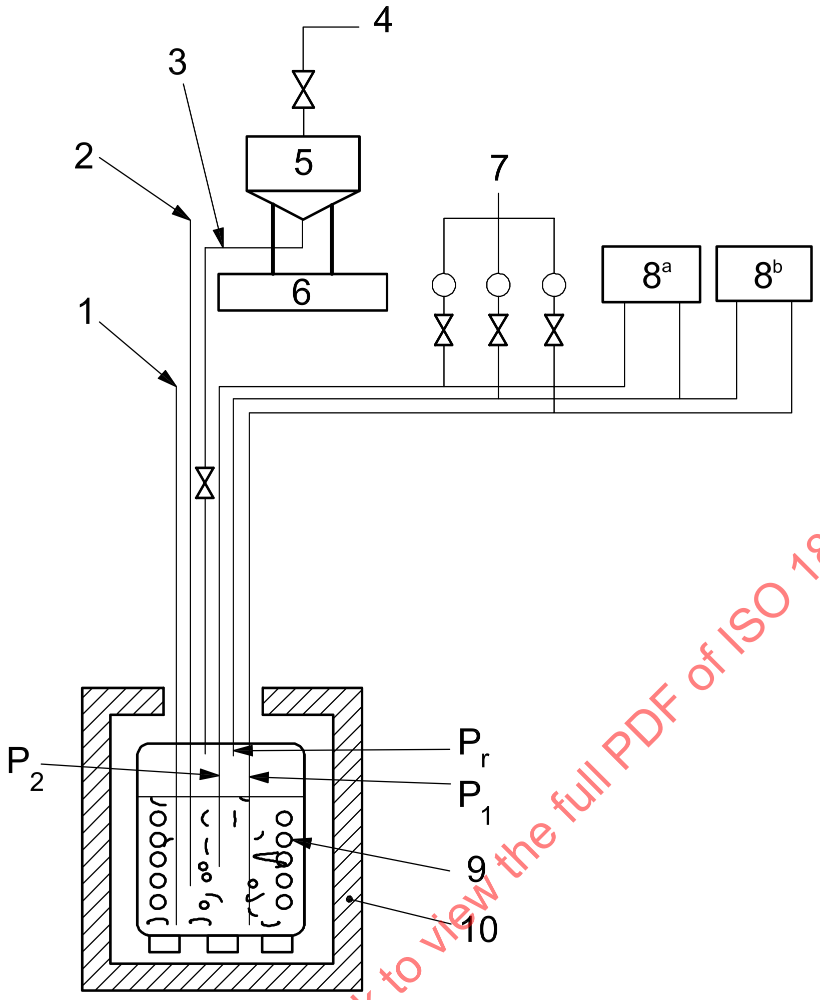
[1] The calibration setup shown in Figure 1 is used for illustrative purposes. Other configurations are possible. See, for example, Reference [1].



Key

1 liquid temperature probe(s)
2 process lines (vent, fill, empty, decontamination, sparge, sample, etc.)
3 supply-line calibration liquid
4 calibration liquid supply
5 prover vessel
6 scale
7 purge gas supply
8 differential pressure manometers
9 tank internals (coils, braces, agitator, etc.)
10 isolation barrier

P_1 major probe
P_2 minor probe
P_r reference probe

[a] Level 2 (“density”).
[b] Level 1 (“level”).

Figure 1 — Elements of a typical tank calibration setup

Measurements of the ambient conditions that prevail at the time of measurement are required for all height and volume measurement pairs. These include the temperature of the liquid in the tank and the prover, the ambient (atmospheric) temperature, barometric pressure and relative humidity. It is also necessary to determine gas flow rates in the bubbler probe lines, as well as certain physical quantities related to the tank's measurement system. The latter include the inner diameter of the bubbler probes and the elevation of the manometer above the tip of each probe; see ISO 18213-1 and either ISO 18213-4 or ISO 18213-5 for details.

The coefficient of linear (thermal) expansion for the material from which the tank and its dip tubes are manufactured is required to perform the calculations indicated in Clause 5. Similarly, if a volumetric prover is used for calibration, the coefficient of linear expansion of the material from which it is fabricated is required to make the thermal adjustments indicated in 4.3.2.

4 Calibration data

4.1 General

The standardization steps that pertain to individual measurements of liquid height and volume are described in 4.2 and 4.3. These steps should be applied to each pair of raw calibration data from one or more calibration runs before these data are used to estimate the tank's calibration or measurement equation (see ISO 18213-1). Likewise, process measurements should also be standardized before they are used in either the calibration or volume measurement equation to determine the volume of liquid in the tank (see ISO 18213-1:2007, Clause 7). The steps in the standardization process are summarized in Figure 2.

The standardization of prover measurements of liquid content (volume) depends naturally on the type of prover employed for measurement. Standardization steps for gravimetric and volumetric provers are given in 4.3.1 and 4.3.2, respectively. The appropriate measure of mass is then used to determine the delivered volume (see 4.3.3).

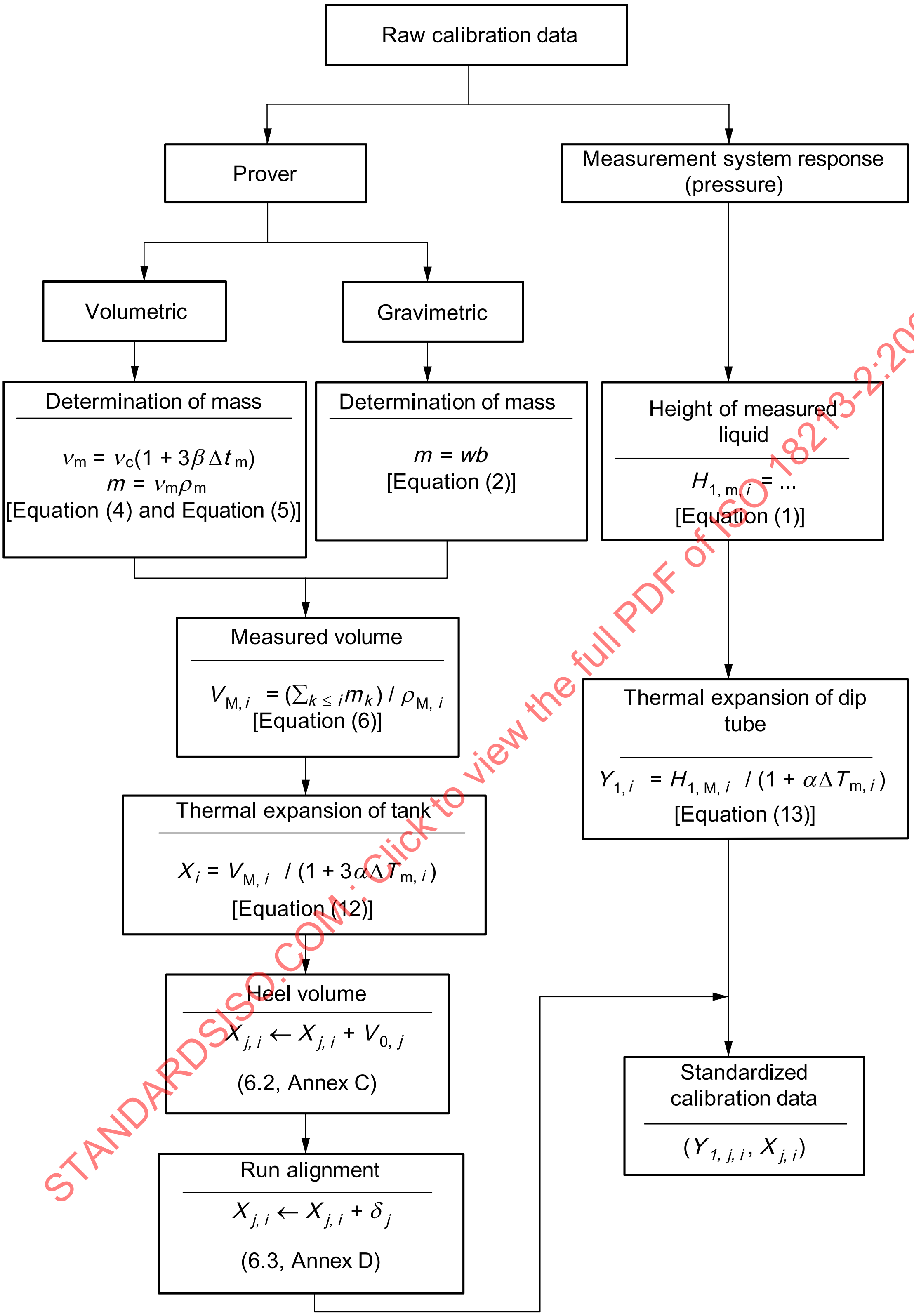


Figure 2 — Summary of steps for standardizing a set of raw calibration data

4.2 Liquid height

Before steps in this document can be applied, the output of the tank's measurement system shall first be converted to determinations of liquid height. For tanks equipped with pressure measurement systems, this should be done with the aid of either ISO 18213-4 (slow bubbling rate) or ISO 18213-5 (fast bubbling rate), as appropriate.

In ISO 18213-5, for example, the height, $H_{1,\mathrm{M}}$, of the column of liquid in the tank above the tip of the bubbling (major) probe at the measurement temperature T_m,[2), 3)] that corresponds to a given pressure measurement is determined from Equation (1):

$$H_{1,\mathrm{M}} = \left[\Delta P_1 + gE_1\left(\rho_{\mathrm{g},1} - \rho_{\mathrm{a,s}}\right) - gE_\mathrm{r}\left(\rho_{\mathrm{g,r}} - \rho_{\mathrm{a,s}}\right) + \left(\delta_\mathrm{r} - \delta_1\right) - g\lambda\left(\rho_\mathrm{M} - \rho_{\mathrm{g},1}\right) - 2\sigma/r_\mathrm{b}\right] \Big/ \left[g\left(\rho_\mathrm{M} - \rho_{\mathrm{a,s}}\right)\right] \quad (1)$$

where

ΔP_1	is the difference in pressure between the bubbling probe and reference probe lines as measured at a gauge located at elevation, E_1, above the tip of the bubbling probe; $\Delta P_1 = P_1(E_1) - P_\mathrm{r}(E_1)$;
g	is the local acceleration due to gravity;
ρ_M	is the average density of liquid at its measurement temperature, T_M, in the tank;
$\rho_{\mathrm{a,s}}$	is the average density of air in the tank above the liquid surface at the prevailing pressure;
$\rho_{\mathrm{g},1}$	is the average density of gas in the major probe line at the prevailing pressure;
$\rho_{\mathrm{g,r}}$	is the average density of gas in the reference probe line at the prevailing pressure;
E_1	is the elevation of the pressure gage above the primary reference point (the tip of the major probe);
E_r	is the elevation of the pressure gauge above the tip of the reference probe;
δ_1	is the pressure drop in the major probe line due to the gas flow resistance;
δ_r	is the pressure drop in the reference probe line due to flow resistance;
λ	is the distance of the lowest point of the bubble below the tip of the major probe;
σ	is the surface tension for the liquid and gas;
r_b	is the radius of curvature of the bubble at its lowest point.

If the tank is equipped with some alternative system for determining liquid content, then appropriate modifications to the procedure described in either ISO 18213-4 or ISO 18213-5 can be required to obtain the liquid height measurements to which the subsequent steps in this document are applied.

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2) The subscript "1" is used in this part of ISO 18213 to indicate quantities that refer to the major probe. The steps for standardizing data from a second probe are completely analogous.

3) For quantities other than temperature, the letter "m" is used as a subscript to denote temperature dependence. A lower case m (m) refers to the temperature, t_m, of liquid in the prover and an upper case m (M) refers to the temperature, T_m, of liquid in the tank.

4.3 Volume

4.3.1 Gravimetric provers

A gravimetric prover is designed to measure the mass of each increment of calibration liquid. Measurements of mass are essentially independent of temperature. However, mass indications (scale readings) shall be corrected for the buoyancy of the medium (air) in which the measurement is made and the scale is calibrated. Thus, the mass, m, of liquid delivered by a gravimetric prover is estimated by Equation (2):

$$m = wb \tag{2}$$

where

w is the indicated mass (scale reading) of the liquid delivered by the prover;

b is a correction factor for the buoyancy of the displaced air.

The buoyancy correction factor b is given by Equation (3):

$$b = \left(1 - \rho_\mathrm{a} / \rho_\mathrm{r}\right) / \left(1 - \rho_\mathrm{a} / \rho_\mathrm{m}\right) \tag{3}$$

where

ρ_a is the density of the gas (air) in which the weighing takes place;

ρ_m is the average density of the calibration liquid at its temperature, t_m, in the prover[4];

ρ_r is the density of the standard weights used to calibrate the scale or balance used to make the weighing.

Guidance for estimating the quantities in Equation (3) is given in Annex B.

4.3.2 Volumetric provers

A volumetric prover is designed to measure the volume of each increment of calibration liquid. Measurements of volume are sensitive to temperature because both the density of the liquid and the volume of the prover change with temperature. Standardization of prover measurements to compensate for temperature variations is recommended in all cases, and is required when variations are large enough (e.g. 2 °C) to have a significant effect on results. With water, for example, a variation of ± 3 °C at 25 °C corresponds to a 0,1 % change in density.

Let v_c denote the calibrated volume of the prover at the temperature, t_c[5]. Then the volume of liquid delivered by the prover at temperature, t_m, is as given in Equation (4):

$$v_\mathrm{m} = v_\mathrm{c}\left(1 + 3\beta\Delta t_\mathrm{m}\right) \tag{4}$$

where $\Delta t_\mathrm{m} = t_\mathrm{m} - t_\mathrm{c}$ and β is the coefficient of linear expansion of the prover. The mass of the delivered liquid is given by Equation (5):

$$m = v_\mathrm{m}\rho_\mathrm{m} \tag{5}$$

where ρ_m is the density of the calibration liquid at the measured (prover) temperature, t_m.

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[4] Prover temperatures are designated by lower case t to emphasize that they may differ from tank temperatures, which are designated by upper case T.

[5] See Footnote 4.

4.3.3 Delivered volume

The total volume of liquid delivered to the tank by the prover during the first i increments of a calibration run is determined by dividing the total (cumulative) mass of all i volume increments by the density of the calibration liquid, $\rho_{\mathrm{M},i}$, at $T_{\mathrm{m},i}$, the measured (tank) temperature of the liquid after the introduction of the ith increment. Thus,

$$V_{\mathrm{M},i} = (\Sigma_{k \leqslant i}\, m_k)/\rho_{\mathrm{M},i} \tag{6}$$

For each increment, k, the quantities m_k are determined from either Equation (2) or Equation (5), as appropriate, depending on the type of prover system that is employed.

5 Dimensional changes in the tank

5.1 Thermodynamic basis

Equation (7) for the volume, V_r.

$$V_\mathrm{r} = f^{-1}(H_\mathrm{r}) \tag{7}$$

valid at reference temperature, T_r, gives the volume of the tank below some point at elevation, H_r, relative to the primary reference point. In other words, when the tank is at temperature, T_r, the volume of the tank below a point at height, H_r, is given by $V_\mathrm{r} = f^{-1}(H_\mathrm{r})$. If the temperature of the tank now changes to T_m, then the volume *of the tank* below the indicated point changes is as given in Equation (8) and the height *of the indicated point*, relative to the primary reference point, changes is as given in Equation (9):

$$V_\mathrm{M} = V_\mathrm{r}(1 + 3\alpha\Delta T_\mathrm{m}) \tag{8}$$

$$H_\mathrm{M} = H_\mathrm{r}(1 + \alpha\Delta T_\mathrm{m}) \tag{9}$$

where

α is the coefficient of linear expansion for the tank and its probes;

$\Delta T_\mathrm{m} = T_\mathrm{m} - T_\mathrm{r}$.

The factor $(1 + 3\alpha\Delta T_\mathrm{m})$ in Equation (8) accounts for the volumetric change in the tank and the factor $(1 + \alpha\Delta T_\mathrm{m})$ in Equation (9) accounts for the linear expansion of the probe.

When the expressions for V_r and H_r given by Equations (8) and (9) are substituted into Equation (7), the form of the measurement equation given by Equation (7) changes to that given as Equation (10):

$$V_\mathrm{M}/(1 + 3\alpha\Delta T_\mathrm{m}) = f^{-1}\,[H_\mathrm{M}/(1 + \alpha\Delta T_\mathrm{m})] \tag{10}$$

Equivalently, the calibration equation (the inverse of the measurement equation) has the form given in Equation (11):

$$H_\mathrm{M}/(1 + \alpha\Delta T_\mathrm{m}) = f\,[V_\mathrm{M}/(1 + 3\alpha\Delta T_\mathrm{m})] \tag{11}$$

Equations (10) and (11) define the adjustments to determinations of liquid volume and height that compensate for dimensional changes in the tank induced by variations in temperature. These adjustments account for only the thermal expansion of the tank and are independent of the tank liquid and the tank's liquid measurement system. In particular, if the height of liquid in the tank at temperature, T_m, is H_M [for example, as determined from ISO 18213-5:—, Equation (8); see Equation (1)] then H_r is *not* the height of the *same* liquid at temperature T_r because liquid density also changes with temperature. In other words, because liquid density changes with temperature, the point at elevation H_M determined by the level of liquid at temperature T_m is *not* associated with the height of the *same* liquid at other temperatures.

5.2 Volume

Equations (8) and (10) are applied to the volume measurements obtained from the prover system (see 5.1) to obtain standardized determinations of volume that are valid at the reference temperature, T_r. Equation (8) is used to adjust the delivered volume, $V_{\mathrm{M},i}$ of the ith calibration increment to compensate for dimensional changes in the tank when the measured temperature of liquid in the tank, $T_{\mathrm{m},i}$, differs from the reference temperature, T_r. The standardized cumulative volume, $X_i = V_{\mathrm{r},i}$, for the ith calibration increment is given by Equation (12):

$$X_i = V_{\mathrm{r},i} = V_{\mathrm{M},i} / (1 + 3\alpha\Delta T_{\mathrm{m},i}) \tag{12}$$

where

$\Delta T_{\mathrm{m},i} = T_{\mathrm{m},i} - T_\mathrm{r}$;

$V_{\mathrm{M},i}$ is the volume of the tank liquid for the ith increment;

$T_{\mathrm{m},i}$ is the temperature of the tank liquid for the ith increment.

5.3 Height

Equations (9) and (11) are applied to liquid height measurements [for example, obtained from ISO 18213-5:—, Equation (8); see Equation (1)] to obtain standardized determinations of liquid height that are valid at the reference temperature, T_r. Equation (9) is used to adjust liquid height, $H_{1,\mathrm{M},i}$, of the ith calibration increment to compensate for changes in the length of the dip tube when the measured temperature of liquid in the tank, $T_{\mathrm{m},i}$, differs from the reference temperature, T_r. The standardized liquid height, $Y_{1,i} = H_{\mathrm{r},i}$, for the ith calibration increment is given by Equation (13):

$$Y_{1,i} = H_{\mathrm{r},i} = H_{1,\mathrm{M},i} / (1 + \alpha\Delta T_{\mathrm{m},i}) \tag{13}$$

where

$\Delta T_{\mathrm{m},i} = T_{\mathrm{m},i} - T_\mathrm{r}$;

$H_{1,\mathrm{M},i}$ is the height of the tank liquid for the ith increment;

$T_{\mathrm{m},i}$ is the temperature of the tank liquid for the ith increment.

6 Multiple calibration runs

6.1 Notation

Height and volume data obtained to estimate the calibration or measurement equation of a process tank are typically obtained from several calibration runs. Let $(Y_{1,j,i}, X_{j,i})$ denote the ith height-volume observation from the jth calibration run, after these data have been standardized according to the previous two sections.

6.2 Heel volume

In many cases, a tank's transfer mechanism (e.g. siphon) does not remove all liquid from a tank and some residual liquid (called a heel) remains after it has been "emptied". If the tank cannot be completely emptied between successive calibration runs, the standardized calibrated volume, $X_{j,i}$, does not represent total volume of the tank associated with $Y_{1,j,i}$. To obtain the actual tank volume associated with $Y_{1,j,i}$, an estimate of heel volume for each run must be added to each of the standardized cumulative volume determinations for that run.

The heel volume cannot be determined from a tank's measurement system unless the tank can be completely emptied and dried between successive runs. Rather, some auxiliary method of estimating heel volume is required. In some cases, it is possible to estimate the heel volume analytically from engineering drawings with sufficient accuracy. A spiking-and-dilution (tracer) method of determining heel volume is given in Annex C.

If the heel volume is measured independently for each calibration run, then these measurements should be added to the cumulative volumes of the appropriate run. Typically, however, the heel volume is determined only once for several calibration runs. In this case, the adjustment is the same for all runs even though the actual heel volumes differ from run to run, and it can be necessary to align the data from several runs by statistical means (see 6.3).

Standardization steps of Clause 4 that involve the cumulative tank volumes, $V_{\mathrm{M},i}$, should be applied to heel volumes as well as to calibration increments. For this purpose, it is convenient to regard the heel volume measurement for each run as an initial volume increment. Unless the heel liquid is the same as the calibration liquid, however, it is necessary to determine the density of the tank liquid for each calibration increment before Equation (1) or its equivalent is applied.

6.3 Run alignment

As a final standardization step, it can be necessary to align the data from several calibration runs by statistical means. Alignment refers to steps taken to adjust cumulative volumes for differences in heel volume from one calibration run to another so that all runs have a common starting point. When physical alignment is impossible or difficult, the data may be aligned statistically. A statistical procedure for alignment is described in Annex D.

7 Results — Standardized calibration data

The application of the above procedures to the raw data from a calibration run produces a set of pairs $(Y_{1,i}, X_i)$ of standardized height Y and volume X determinations. Replicate sets of standardized data $(Y_{1,j,i}, X_{j,i})$ are similarly obtained from multiple calibrations runs. If the runs span the operating range of the tank, these data can be used to derive an estimate of the calibration or measurement equation for the tank that is valid at reference conditions, the most important of which is temperature.

For tanks equipped with two or more probes, standardized determinations of liquid height from any two probes can be used to estimate their separation (the vertical distance between the tips of the two probes). The estimated probe separation can be used in turn to make in-tank determinations of the density of the liquid in the tank. A method for determining the probe separation and using it to make in-tank determinations of density is given in ISO 18213-6.

Statistical methods suitable for estimating the tank's calibration or measurement equations from a set of calibration data that have been standardized to a fixed set of reference conditions are presented in ISO 18213-3.

The application of the procedures in this document to process measurements is discussed in Clause 7 of ISO 18213-1:2007.

Annex A
(informative)

Density of water

Any liquid compatible with the process liquid can be used for tank calibration, provided that accurate measurements of its density can be obtained at all measurement temperatures. Demineralized water is a preferred calibration liquid because its density is well known and can be accurately determined at all temperatures of interest. Equation (A.1) gives very accurate determinations of the density of air-free (freshly distilled) water (kg/m^3) for temperatures $T = T_m$ between 4 °C and 40 °C:

$$\rho_M = A + BT + CT^2 + DT^3 + ET^4 + FT^5 \qquad (A.1)$$

where

A = 999,843 22

B = 6,684 416 × 10^{-2}

C = – 8,903 070 × 10^{-3}

D = 8,797 523 × 10^{-5}

E = – 8,030 701 × 10^{-7}

F = 3,596 363 × 10^{-10}

For temperatures between 3 °C and 30 °C, the estimated residual standard deviation for this fit is less than 0,001 kg/m^3. For other temperatures between 1 °C and 40 °C, the reported standard deviation does not exceed 0,001 4 kg/m^3.

Water can become saturated after being exposed to air for a relatively short period of time (approximately 15 h). If necessary, the density of air-saturated water at 1 atm can be calculated by adding the following correction to the estimate obtained from Equation (A.1):

$$\Delta\rho_M = -4{,}873 \times 10^{-3} + 1{,}708 \times 10^{-4} T - 3{,}108 \times 10^{-6} T^2 \qquad (A.2)$$

Equation (A.2) is applicable for temperatures between 0 °C and 20 °C. The correction for air saturation is – 0,00270 kg/m^3 at 20 °C and its effect diminishes with increasing temperature. The estimated total uncertainty of values calculated with Equation (A.2) is reported as 2 × 10^{-4} kg/m^3 at the 99 % confidence level. Thus, the effect of air saturation at temperatures greater than 20 °C can safely be ignored for most safeguards applications.

Equations (A.1) and (A.2) are based on a recent re-determination of the density of water (see References [7], and [8]). Equation (A.1), or Equations (A.1) and (A.2) in combination, can be used to compute the density of water with sufficient accuracy and precision for safeguards purposes.

If some liquid other than water is used for calibration, then it is necessary that its density be determined with suitable accuracy at all measurement temperatures before Equation (1) (in 4.2) can be successfully applied.

Annex B
(informative)

Buoyancy corrections for mass determination

Objects are weighed to determine their mass. However, to obtain an accurate measurement of an object's mass, it is necessary to correct the mass indication (reading from a scale or balance) for the buoyancy of the medium (air) in which the weighing is performed and the scale is calibrated. The mass of liquid delivered by a gravimetric prover is determined from a scale reading by means of Equation (B.1):

$$m = wb \tag{B.1}$$

where

w is the indicated mass (scale reading) of the liquid delivered by the prover;

b is a correction factor for the buoyancy of the displaced air.

The buoyancy correction factor, b, is given by Equation (B.2):

$$b = (1 - \rho_a/\rho_r)/(1 - \rho_a/\rho_m) \tag{B.2}$$

where

ρ_a is the density of the gas (air) in which the weighing takes place;

ρ_m is the average density of the calibration liquid at its temperature, t_m, in the prover;

ρ_r is the density of the standard weights used to calibrate the scale or balance used to make the weighing.

If the calibration liquid is water, its density, ρ_m, can be determined from its temperature by means of Equation (A.1). The density of the air, ρ_a, in which the weighing takes place can be determined by means of Equation (A.2) in ISO 18213-5:—, Annex A.

Standard values (also the values at which the scale or balance is calibrated at the factory) for ρ_a and ρ_r are, respectively,

$\rho_a = 1{,}2\ \text{kg/m}^3$

$\rho_r = 8\,000\ \text{kg/m}^3$ (for weights fabricated from steel) or $\rho_r = 8\,400\ \text{kg/m}^3$ (for brass weights).

In absence of actual measurements of ρ_a and ρ_r, the use of standard values as default measurements of these quantities yields acceptable results in nearly all cases.

It is common practice to use Equation (B.3) for making the buoyancy correction indicated by Equation (B.1):

$$b = (1 - \rho_a/\rho_m) \tag{B.3}$$

However, for the standard values $\rho_a = 1{,}2\ \text{kg/m}^3$ and $\rho_r = 8\,000\ \text{kg/m}^3$, the numerator in Equation (B.2) is $(1 - \rho_a/\rho_r) = 0{,}999\,850$. Thus, the use of Equation (B.3) to make the indicated buoyancy correction results in a bias of approximately 0,015 %. This bias is approximately 10 % of the magnitude of the more accurate correction factor given in Equation (B.2) and can be significant in high-precision measurement systems. Therefore, Equation (B.2) should always be used to make buoyancy corrections for mass determinations.