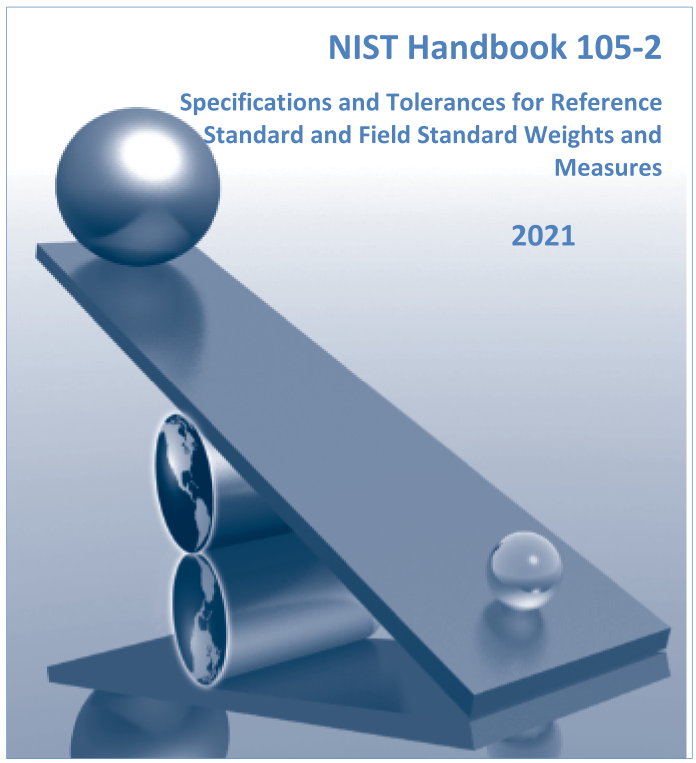
NIST Handbook 105-2

Specifications and Tolerances for Reference Standard and Field Standard Weights and Measures

Micheal Hicks
Georgia Harris



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National Institute of Standards and Technology
U.S. Department of Commerce

NIST Handbook 105-2

Specifications and Tolerances for Reference Standard and Field Standard Weights and Measures

2. Specifications and Tolerances for Field Standard Measuring Flasks

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Preface

The 2021 revision of Handbook 105-2 includes the following changes.

1. There is no provision for retroactivity. All volumetric standards used for field enforcement of weights and measures need to comply with the specifications and tolerances published in this handbook.

2. Decision rules regarding maximum permissible errors (plus/minus tolerances) were changed. The calibration uncertainty must simply be less than the applicable maximum permissible errors (rather than less than one-third). Statements of conformance to tolerances require the absolute calibration value plus the uncertainty to be within tolerance and the user must consider correction values and uncertainties in use.

3. Calibration intervals were reduced from a maximum 10-year recommended interval to a 5-year maximum interval for consistency with ASTM and ISO standards.

4. All reference documents were reviewed and updated with current and applicable references for volumetric calibrations. ASTM International, OIML, ISO, and EURAMET standards and procedures have been reviewed in consideration of international standardization.

5. Formatting was updated for Word and accessibility requirements.

The 1996 revision of Handbook 105-2 included the following changes since it was published in 1971:

1. References to the National Bureau of Standards (NBS) were replaced by the National Institute of Standards and Technology (NIST).

2. Reference to and incorporation of international standards (such as those of the International Organization for Legal Metrology, OIML) and national industry standards (such as those of the American Society for Testing and Materials, ASTM) were made where possible.

3. The addition of references to direct the user to publications that will assist with effective use of field standards.

Additionally, the process for updating the publication was changed to include the following:

1. Conversion of the previous handbook to electronic media to allow future changes to be incorporated in a timelier manner.

2. Organized peer review to ensure incorporation of the latest technology and viewpoints of technical experts.

Note regarding units of measure:

The SI unit of volume is the cubic meter (m^3) or submultiples of the unit such as the cubic decimeter (dm^3) or the cubic centimeter (cm^3). The Twelfth General (International) Conference on Weights and Measures redefined the litre [herein spelled liter] as a "special name for the cubic decimeter," but agreed to permit the continuance of the terms liter (L) and milliliter (mL), except in association with measurements of the highest precision. For volumetric glassware, the difference between the old and new meanings of liter is negligible. Therefore, either mL or cm^3 may be marked on flasks and glassware covered in this handbook.

Due to commercial applications in the United States using units other than SI or other accepted metric units, this document references other common units in current use.

Abstract

Handbook 105-2 is part of the Handbook 105-series of specifications and tolerances identified in NIST Handbooks 44, 130, and 133 for use as field standards in weights and measures enforcement actions. This handbook covers the specifications and tolerances for glass flasks used primarily in package testing commodities as a part of weights and measures enforcement activities conducted by legal weights and measures jurisdictions.

Key Words: field standard measuring flasks; flasks; graduated cylinders; volumetric standards; volumetric specifications and tolerances; weights and measures.

Acknowledgments

1971: This Handbook was initially written by Blayne C. Keysar of the National Bureau of Standards (now NIST).

1996: Special thanks regarding the 1996 edition were given to Kelleen Moody (Larson), metrologist with the State of Arizona, and to Karl Herken, metrologist with the State of Kansas, for their assistance with review of reference materials, evaluation of comments submitted during peer review, and for typing and editing the document in WordPerfect as the first electronic format. Thanks were also given to numerous metrologists (of both State and industry laboratories) for their technical review of several drafts.

2021: The updated draft was prepared by Georgia Harris and reviewed by interested parties. Specific inputs regarding applicable decision rules were submitted by multiple laboratories, with initial feedback on the need for an updated draft provided by Jeremy Nading, metrologist with the State of Oklahoma, Anthony Gruneisen, metrologist with the State of California, Nicholas Santini, metrologist with the State of Michigan, Benj FitzPatrick, metrologist with the State of Minnesota, Dustin Claycomb, metrologist with the State of Pennsylvania, and Micheal Hicks, NIST Office of Weights and Measures.

Table of Contents

1 Scope **1**

1.1 "Field Standard" Classification 1

1.2 Retroactivity 1

1.3 Safety Considerations 2

2 Reference Documents **2**

2.1 International Organization for Legal Metrology (OIML) 2

2.2 National Institute of Standards and Technology (NIST) 2

2.3 ASTM International, formerly known as American Society for Testing and Materials (ASTM) 2

3 Terminology **2**

4 Specifications **3**

4.1 Nominal Values 3
4.1.1 Metric 3
4.1.2 U.S. Customary 4

4.2 Reference Temperature 4

4.3 Material and Annealing 4

4.4 Physical Properties 4
4.4.1 General 4
4.4.2 Cylindrical Design 4
4.4.3 Construction 4
4.4.4 Base 4
4.4.5 Neck 5

4.5 Lines, Graduations, and Inscriptions 5
4.5.1 Line Widths 5
4.5.2 Line Orientation 5
4.5.3 Line Construction 5
4.5.4 Graduation Pattern 5
4.5.5 Subdivision Lines 5
4.5.6 Line Color 5
4.5.7 Graduation and Nominal Graduation Lines 5
4.5.8 Graduation and Nominal Graduation Inscriptions 6
4.5.9 Scale Divisions, Metric 6
4.5.10 Scale Divisions, U.S. Customary 6

4.5.11 Identification 6

5 Tolerances (Maximum Permissible Error) 6

6 Verification Requirements 6

6.1 Legal Requirements 6

6.2 Metrological Traceability 7

6.3 Calibration Certificates 7

6.4 Initial and Periodic Verification 7

7 Calibration Methods and References 7

8 Uncertainties 8

8.1 Legal Applications 8

8.2 Sources of Variation 8

9 Volume Units and Symbols 8

Table 1. International System of Units (SI) for volume, conversions, and symbols. 9
Table 2. Measurement units and symbols used in this document. 9
Table 3. Tolerances (maximum permissible error) for flasks and cylinders (SI). 10
Table 4. Tolerances (maximum permissible error) for flasks and cylinders (U.S. Customary). 10
Fig. 1. 100 mL glass flask. 11
Fig. 2. 50 mL graduated cylinder. 11
Fig. 3. 1/2 pt glass flask. 11
Fig. 4. 2 fl oz graduated cylinder. 11

SPECIFICATIONS AND TOLERANCES FOR REFERENCE STANDARD AND FIELD STANDARD WEIGHTS AND MEASURES

105-2. Specifications and Tolerances for
Field Standard Measuring Flasks

These specifications and tolerances are recommended as minimum requirements for standards used by State and local weights and measures officials in quantity determination of liquid commodities.

INTRODUCTION

Field standard volumetric flasks and graduated cylinders as described herein are intended to be used by weights and measures officials, manufacturers and distributors of liquid products, research and testing laboratories, and others concerned with accurate measurements of the volume of liquids. Use of these volumetric standards at all appropriate levels of manufacture, distribution, and weights and measures inspection will promote accuracy and uniformity in commerce.

1 Scope

1.1 "Field Standard" Classification

This Handbook classifies volumetric flasks with graduated necks and graduated cylinders (see Fig. 1 through 4) for legal metrology applications as "field standards." Tolerances from this document or calibration uncertainties must be less than one third of the associated field tolerance applied when the standard is used to test a package or commodity, as discussed in NIST Handbook 44 and NIST Handbook 133. Tolerances provided in Tables 3 and 4 are intended to permit use of field standards during normal testing operations as standards having nominal values. Where field standards calibration uncertainties exceed the tolerance limits set out in this document, nominal values cannot be used; instead, the reported volumetric values must be used and the uncertainties of the calibration considered when evaluating packages for compliance. Nominal values may be used only when the absolute value of the volume plus the calibration uncertainty are within maximum permissible errors (*m.p.e.*)[1]. For specifications and tolerances for glassware used in laboratory applications, and where smaller tolerances are needed, see the ASTM references listed in Section 2.

1.2 Retroactivity

This handbook applies to all flasks and graduated cylinders for use as field standards (i.e., new and in-use field standard volumetric flasks and graduated cylinders, those intended for replacement of flasks already in use, and to new flasks to be acquired as supplementary standards).

[1] Tolerances and maximum permissible errors (*m.p.e.*) are used interchangeably throughout this document. The use of tolerances within the U.S. legal metrology community implies both positive and negative values and is considered equivalent to *m.p.e.* as defined by the International Vocabulary of Metrology.

1.3 Safety Considerations

The accuracy and repeatability of field standards is critically dependent upon cleanliness. Chemicals used in the cleaning process should be evaluated for safety in use and for appropriate disposal methods by reviewing Safety Data Sheets (SDS), formerly known as Material Safety Data Sheets (MSDS).

Volumetric glassware should not be emptied by holding onto the neck alone. The bottom of the flask should always be supported to prevent glassware breakage and possible injury.

2 Reference Documents

2.1 International Organization for Legal Metrology (OIML)

- R 87 (2016), Quantity of product in prepackages.
- R 43 (1981), Standard graduated glass flasks for verification officers.

2.2 National Institute of Standards and Technology (NIST)

- NIST Handbook 44, Specifications, Tolerances, and Other Technical Requirements for Weighing and Measuring Devices (see current edition).
- NIST Handbook 133, Checking the Net Contents of Packaged Goods (see current edition).
- NIST IR 7383 (2019), Selected Procedures for Volumetric Calibrations.
- NIST Special Publication 811 (2018), Guide for the Use of the International System of Units (SI).[2]

2.3 ASTM International, formerly known as American Society for Testing and Materials (ASTM)

- E288-10 (2017), Standard Specification for Laboratory Glass Volumetric Flasks.
- E438-92 (2018), Standard Specification for Glasses in Laboratory Apparatus.
- E542-01 (2021), Standard Practice for Gravimetric Calibration of Laboratory Volumetric Instruments.
- E694-18, Standard Specification for Laboratory Glass Volumetric Apparatus.
- E1272-02 (2019), Standard Specification for Laboratory Glass Graduated Cylinders.

3 Terminology

Borosilicate glass. A glass of a low cubical coefficient of thermal expansion used for most precision laboratory glassware and known by such trade names as Kimax[3] (KG-33) or Pyrex. See ASTM E438-92 (2018) for Type I glass specifications.

[2] The BIPM SI Brochure (9th Edition) was published on May 20, 2019. The NIST SP 330 (2019) version has been published and reflects the changes incorporated in the BIPM SI Brochure (9th Edition). This publication, Special Publication 811, has not yet been updated to reflect the changes in the SI that came into effect on May 20, 2019.

[3] Certain commercial entities, equipment, or materials may be identified in this document in order to describe an experimental procedure or concept adequately. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that the entities, materials, or equipment are necessarily the best available for the purpose.

Capacity, contained. The volume of water which the flask contains at the reference temperature when filled to its nominal graduation line and is designated "to contain" or << In >>. The neck graduations of a “to contain” measure represent the volume of liquid in the measure, not the volume of liquid that can be poured from the measure. A “to contain” measure must always be cleaned and dried between successive uses of the measure for purposes of accuracy.

Capacity, delivered. The volume of water which the flask delivers at the reference temperature from the specified graduation line when emptied gradually with a 30 s (± 5 s) pour and a 10 s drain while held at a 10 ° to 15 ° angle from vertical[4]. These flasks are designated "to deliver" or << Ex >>. If a flask or graduated cylinder is to be used in a wet condition, it must be calibrated "to deliver." The advantage of using a “to deliver” measure is that the measure does not have to be dried between uses.

Capacity, nominal. The nominal capacity of a field standard flask or graduated cylinder is the volume used to designate the flask or cylinder at a given reference temperature (as calibrated to the specified reference temperature of 20 °C).

Graduation lines. Numbered lines which extend for at least 3/4 of the flask neck or cylinder circumference.

Nominal graduation line. A line extending completely around the flask neck or cylinder circumference (see 4.4.2) that indicates the nominal capacity, and which must be in a contrasting color to the other lines (see 4.5.6).

Soda-lime glass. A glass of medium cubical coefficient of thermal expansion often used in field standard flasks and graduated cylinders. See ASTM E438-92 (2018) for Type II glass specifications.

Subdivision graduation lines. Unnumbered intermediate graduation lines between nominal and other graduation lines.

4 Specifications

4.1 Nominal Values

A set of field standard flasks and graduated cylinders comprises several flasks. Nominal capacities in the series are chosen in accordance with applications and regulations.

4.1.1 Metric

A set of field standard glassware comprises several flasks and graduated cylinders, including a 50 mL graduated cylinder, a 100 mL graduated cylinder or flask, and one each 250 mL, 500 mL, 1 L, 2 L graduated neck flasks. This example does not preclude other sets or nominal sizes.

[4] Note: the correct International System of Units (SI) abbreviation for second is s.

4.1.2 U.S. Customary

A set of field standard glassware comprises several flasks and graduated cylinders, including a 2 fl oz graduated cylinder, and one each 1 gill, 0.5 pint, 1 pint, 1 quart, 0.5 gallon, and 1 gallon graduated neck flasks. This example does not preclude other sets or nominal sizes.

4.2 Reference Temperature

The temperature at which the flask or cylinder is intended to contain or deliver a volume equivalent to its nominal capacity, shall be 20 °C (68 °F).

Application note: When a product that is normally refrigerated is being tested, a packager is *given the benefit of doubt* in determining volume, unless temperature corrections are made, due to the cubical coefficient of thermal expansion for the glass and for the product; the extent is dependent on whether product is tested at its specified reference temperature, its storage temperature or at a normal indoor environment (i.e., 20 °C).

4.3 Material and Annealing

A field standard flask or graduated cylinder shall be made of transparent, well-annealed clear glass with suitable thermal and chemical properties (such as ASTM Type II, soda-lime or Type I, borosilicate glass). The flask shall be free from chips, cracks, stones, and other visible defects that detract from the appearance or use of the flask. It is particularly important that the graduated portion of the flask or cylinder be free from obvious defects.

4.4 Physical Properties

4.4.1 General

The design shall conform to the general configuration shown in Fig. 1 through 4. The inscriptions and graduations shall be placed in the same relationship to each other and to the position on the flasks as shown.

4.4.2 Cylindrical Design

The neck and body of flasks and graduated cylinders must be cylindrical. Any cross section taken in a plane perpendicular to the vertical axis shall be circular.

4.4.3 Construction

The shape of a field standard flask or graduated cylinder shall permit complete emptying and thorough cleaning.

4.4.4 Base

A standard graduated flask must maintain a stable vertical position without rocking when placed with its base on a flat level surface. Each flask shall be designed with an attached base that is perpendicular to the vertical axis for stability. (A hexagonal base is typically used for maximum stability, but the 1 gallon flask is often designed in such a way that eliminates the need for a base.)

4.4.5 Neck
The neck of the flask must be cylindrical. The top edge of the neck shall have a smooth finish and a small flange. The height of the graduated portion of a graduated cylinder shall be at least five times the inside diameter.

4.5 Lines, Graduations, and Inscriptions

4.5.1 Line Widths
Graduation and subdivision lines shall be distinct, permanent and of uniform thickness not to exceed 0.3 mm.

4.5.2 Line Orientation
Graduation lines shall be perpendicular to the vertical axis of the base of the flask.

4.5.3 Line Construction
Graduation lines shall be applied by one of the following methods: etched and filled with a permanent pigment; application of a stain fixed into the glass without etching; or application of an enamel fused onto the glass without etching.

4.5.4 Graduation Pattern
There should be no evidence of irregular spacing between graduation lines. Nominal graduation lines shall extend completely around the neck. Due to the difficulty in extending stained or enameled lines completely around the neck, a gap of 4 mm at the closure, or meeting point, is permitted. This gap must be approximately 90 ° from the line of vision when the flask is viewed from the front so as not to interfere with reading a meniscus (see Fig. 1 through 4).

4.5.5 Subdivision Lines
Subdivision lines shall be uniform and extend at least 3/4 around the neck.

4.5.6 Line Color
If a pigment or enamel is used for graduation lines, the nominal volume line shall be of a contrasting color.

4.5.7 Graduation and Nominal Graduation Lines
Graduation lines on flasks with graduated necks shall be marked above and below the nominal line as shown in Volumetric Scale Range in Tables 3 and 4.

Graduation lines on graduated cylinders shall only be marked beneath the nominal line and shall be marked with Numbered and Minimum Graduations as shown in Tables 3 and 4.

Subdivision lines on graduated cylinders shall be omitted between the base and the first main graduated line. This will eliminate reading near the base where it is difficult to read and of questionable accuracy. (Striation often occurs in the glass in this area during manufacture when the base is joined to the cylindrical portion.)

4.5.8 Graduation and Nominal Graduation Inscriptions
Each nominal capacity line shall be labeled with the appropriate volume and units. The numbers and letters indicating nominal capacity and main graduation capacities shall be placed immediately above the line to which they refer (see Fig. 1 through 4 for examples).

4.5.9 Scale Divisions, Metric
The scale divisions on a metric graduated cylinder shall be divided into milliliters (mL), and labeling shall so indicate with the appropriate abbreviation. Each subdivision shall comply with Table 3.

4.5.10 Scale Divisions, U.S. Customary
The scale divisions on a U.S. customary graduated cylinder shall be divided into fluid drams (fl dr), and labeling shall so indicate with the appropriate abbreviation. Each subdivision shall comply with Table 4.

4.5.11 Identification
Each field standard flask or graduated cylinder shall be permanently and legibly marked with the following:

1) the manufacturer's name or trademark;
2) serial or identification number;
3) clear identification of "to deliver" or "to contain" use ("to deliver" flasks with a proper *wet down* are typically used for commodity inspection);
4) nominal capacity and appropriate units;
5) reference temperature for calibration; and
6) drain time (e.g., 10 s).

On U.S. customary standard glassware all letters except unit abbreviations are to be in upper case (see Fig. 1 through 4).

5 Tolerances (Maximum Permissible Error)

The difference between the actual volume and the indicated volume at the prescribed reference temperature (20 °C) shall not be greater than that shown for Tolerance at Nominal or Partial Capacity in Tables 3 or 4. As noted in Section 6.1 for legal metrology applications, the calibration uncertainty shall be less than the applicable tolerances specified in Tables 3 or 4 and the absolute value of the calibrated measurement result plus the calibration uncertainty shall be within the stated tolerance to make conformance statements.

6 Verification Requirements

6.1 Legal Requirements

When field standard flasks and graduated cylinders are used for commercial applications, they must be inspected for damage prior to each use and prior to calibration. Stopcocks and covers may only be used on glassware designed for their use. Glassware must be evaluated for conformance to this document and be calibrated by a NIST recognized or ISO/IEC 17025 accredited laboratory, using appropriate calibration methods such as those shown in Section 7, with calibration certificates provided that include conformity assessment statements, calibration measurement results, and calibration uncertainty values that are less than tolerances listed in this document.

6.2 Metrological Traceability

Field standards shall be calibrated by a recognized or ISO/IEC 17205 accredited laboratory. Field standard measurement results used for legal metrology shall be traceable to the International System of Units (SI) with associated supporting documentation.

6.3 Calibration Certificates

Acceptable accuracy and traceability to the SI through national or international standards shall be documented in a calibration certificate using accepted calibration methods as shown in Section 7. Calibration values, uncertainty, and tolerance status must be noted on the calibration certificate for the user's evaluation and include a conformity assessment statement to ensure the standards fully meet both specifications and tolerances necessary to support legal metrology applications. Volumetric standards that do not comply with the specifications and tolerances should not be used for legal weights and measures enforcement activities. Labeled nominal values may be used when the absolute volumetric value plus the calibration uncertainty are within maximum permissible errors; alternatively, the reported calibrated volume and associated uncertainty must be considered by the end user.

6.4 Initial and Periodic Verification

Field standard flasks and graduated cylinders must undergo initial verification for conformance to these specifications and tolerances. Field standards must be inspected prior to use and verified periodically as prescribed by regulation; the frequency of periodic inspection and/or verification depends upon usage but should not exceed 5 years. Glass flasks and graduated cylinders generally do not change capacity values during this period unless damaged. Intermediate comparisons against other standards may be performed occasionally to detect standards in need of recalibration.

7 Calibration Methods and References

Initial verification, to determine whether field standard flasks and graduated cylinders meet applicable tolerances, shall be performed using accepted gravimetric calibration procedures such as those listed below. The uncertainty of the calibration must be less than the applicable tolerances shown in this publication. If commercial measurements are to be made, there may be additional verification requirements (dependent on the jurisdiction in which the field standards will be used). Referenced methods are as follows:

- Standard Operating Procedure (SOP) 14, Standard Operating Procedure for Gravimetric Calibration of Volumetric Ware Using an Electronic Balance (published within NISTIR 7383 (2019) as noted in references).
- ASTM E542 (2021), Standard Practice for Gravimetric Calibration of Laboratory Volumetric Instruments.
- ISO 4787 (2021), Laboratory glass and plastic ware — Volumetric instruments — Methods for testing of capacity and for use.
- EURAMET Calibration Guide No. 19, Version 3.0 (2018), Guidelines on the Determination of Uncertainty in Gravimetric Volume Calibration.

8 Uncertainties

8.1 Legal Applications

Uncertainties of the calibration must be evaluated according to the Guide to the Expression of Uncertainties in Measurements[5] and following the procedures described in the previous section to ensure compliance with recognition and accreditation requirements. The uncertainty for volume calibrations must be less than the tolerances published in this documentary standard. Evaluation of applicable requirements when used to support NIST Handbook 133[6] package testing or NIST Handbook 44[7] device testing must be considered by the field officials and service companies as applicable (e.g., especially in situations where the absolute value of the volume plus the calibration uncertainty exceeds the applicable tolerance in *this* handbook (105-2). The calibration corrections may need to be used in lieu of nominal volume when the absolute value of the standard with corrections plus the associated uncertainties are not fully within the applicable tolerances.

8.2 Sources of Variation

For volumes such as those listed in this handbook, the largest sources of uncertainty are inaccurate reading of the meniscus (see Good Measurement Practice, GMP 3 in NISTIR 7383 and Annex A.1 in ASTM E694-18), cleanliness of the container, and proper technique when emptying and draining the flask or cylinder. A 30 s (± 5 s) pour followed by a 10 s drain, with the measure held at an angle between 10 ° and 15 ° from vertical, is required during calibration and application. The uncertainties reported by the laboratory do not reflect the uncertainty in field applications. Field application uncertainties include the same type of factors and are additive to those reported by the laboratory with additional consideration needed for viscosity and opacity of liquids being measured. For microliter (µL) volumes measured without a meniscus, the largest source of uncertainty and potential bias may be evaporation; if time of use is limited, evaporation is generally not a concern in weights and measures field applications.

9 Volume Units and Symbols

The cubic meter, m^3, is the SI derived unit for volume. The Liter is a non-SI unit accepted for use with the SI by the International Committee on Weights and Measures (CIPM) as noted in NIST Special Publication (SP) 811 (2008). Alternative units in common use are listed in Table 1 with their equivalence in L, mL, and m^3. See NIST SP 811 to verify conversions. Items in bold shown in Table 1 are exact conversions. Additional units and their symbols are provided for the user in Table 2. See NIST Special Publication 811 for more information about units and symbols.

[5] JCGM_100_2008_E, Evaluation of measurement data — Guide to the expression of uncertainty in measurement.
[6] Version adopted by regulatory agency.
[7] Version adopted by regulatory agency.

Table 1. International System of Units (SI) for volume, conversions, and symbols.

Measurement Unit	Symbol	Accepted and common alternative metric units for volume (L, mL)	Equivalence (m^3)
Cubic meter	m^3	**1000 L**	**1 m^3**
Liter	L	**1 L or 1000 mL**	**10^{-3} m^3**
Cubic Decimeter	dm^3	**1 L or 1000 mL**	**10^{-3} m^3**
Cubic Centimeter	cm^3	**1 mL**	**10^{-6} m^3**
Milliliter	mL	**1 mL**	**10^{-6} m^3**
Cubic Millimeter	mm^3	**0.001 mL**	**10^{-9} m^3**
Fluid Dram	fl dr	3.696 69 mL	$3.696\ 69^{-6}$ m^3
Fluid Ounce	fl oz	29.573 53 mL	$2.957\ 353^{-5}$ m^3
Gill	gi	118.294 118 25 mL	$1.182\ 941^{-4}$ m^3
Pint	pt	473.176 473 mL	$4.731\ 765^{-4}$ m^3
Quart	qt	946.352 946 mL	$9.463\ 529^{-4}$ m^3
Gallon	gal	3 785.411 784 mL	$3.785\ 412^{-3}$ m^3
Cubic inch	in^3	16.387 064 mL	$1.638\ 706^{-5}$ m^3

Table 2. Measurement units and symbols used in this document.

Measurement Unit	Symbol
second	s
degrees Celsius	°C
degrees Fahrenheit	°F
angular degrees	°

Table 3. Tolerances (maximum permissible error) for flasks and cylinders (SI).

Capacity at 20 °C	Tolerance at Nominal Capacity ± mL	Tolerance at Partial Capacity ± mL	Volumetric Scale Range (above and below nominal) mL	Numbering mL	Minimum Graduations (subdivisions) mL
50 mL cylinder[a]	0.25	0.25	See 4.5.7	5.00 or 10.00	1.00
100 mL flask	0.20	0.06	4.00	2.00	0.50
250 mL	0.30	0.10	6.00	5.00	0.50
500 mL	0.50	0.15	10.00	5.00	1.00
1 000 mL	0.80	0.22	20.00	5.00 or 10.00	1.00
2 000 mL	1.20	0.33	30.00	10.00	2.00

[a] For volumetric measures less than 50 mL, full capacity tolerances do not apply. For these volumetric measures, apply 0.10 mL to individual graduations.
Note: For a capacity intermediate between two capacities listed above, the tolerances prescribed for the lower capacity shall be applied.

Table 4. Tolerances (maximum permissible error) for flasks and cylinders (U.S. Customary).

Capacity[a] at 20 °C	Tolerance at Nominal Capacity ± mL	Tolerance at Partial Capacity ± mL	Volumetric Scale Range (above and below nominal) fl dr	Numbering fl dr	Minimum Graduations (subdivisions) fl dr
2 fl oz cylinder (59 mL)	0.25	0.25	See 4.5.7	1.00 or 2.00	0.50
1 Gill flask (118 mL)	0.20	0.10	0.50	0.50	0.25
0.5 pt (236 mL)	0.30	0.10	1.00	0.50	0.25
1 pt (473 mL)	0.40	0.15	2.00	1.00	0.50
1 qt (946 mL)	0.70	0.30	4.00	2.00	1.00
0.5 gal (1 892 mL)	1.00	0.30	6.00	2.00	1.00
1 gal[b] (3 785 mL)	1.20	0.30	8.00	2.00	1.00

[a] Glassware is calibrated using gravimetric methods resulting in mL or cm^3 volumes and uncertainties. Therefore, equivalent nominal volume capacities and tolerances are presented in mL. Marking and graduations for U.S. Customary volumetric standards are required and presented in fl dr (see 4.5.10).
[b] For volumes greater than 1 gal (3 785 mL), apply ± 0.02 percent (%) of nominal capacity for tolerances at full capacity and ± 0.3 percent (%) of the minimum graduation for tolerances for individual graduations.
Note: For a capacity intermediate between two capacities listed above, the tolerances prescribed for the lower capacity shall be applied.

Fig. 1. 100 mL glass flask.

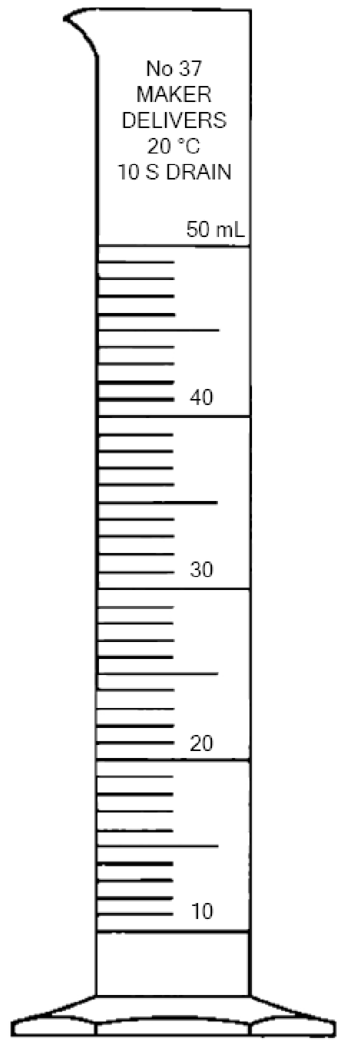

Fig. 2. 50 mL graduated cylinder.

Fig. 3. 1/2 pt glass flask.

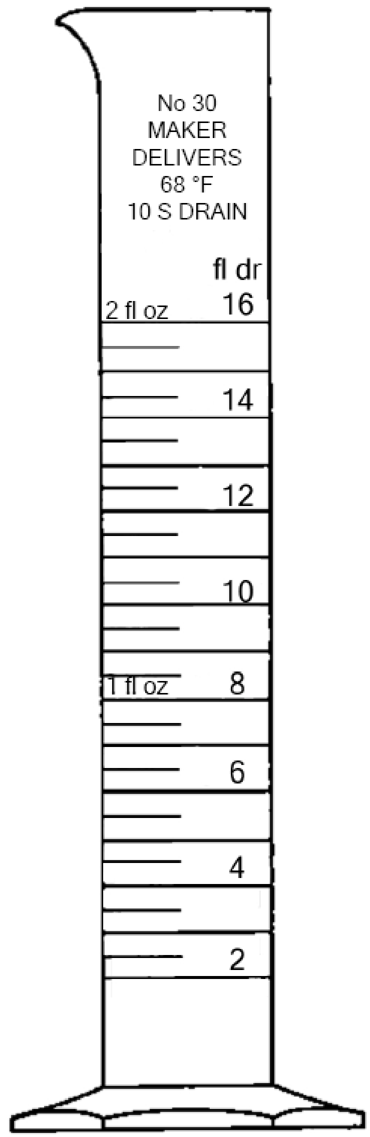

Fig. 4. 2 fl oz graduated cylinder.