

Manual of Petroleum Measurement Standards Chapter 13.3

Measurement Uncertainty

FIRST EDITION, MAY 2016



AMERICAN PETROLEUM INSTITUTE

Special Notes

API publications necessarily address problems of a general nature. With respect to particular circumstances, local, state, and federal laws and regulations should be reviewed.

Neither API nor any of API's employees, subcontractors, consultants, committees, or other assignees make any warranty or representation, either express or implied, with respect to the accuracy, completeness, or usefulness of the information contained herein, or assume any liability or responsibility for any use, or the results of such use, of any information or process disclosed in this publication. Neither API nor any of API's employees, subcontractors, consultants, or other assignees represent that use of this publication would not infringe upon privately owned rights.

API publications may be used by anyone desiring to do so. Every effort has been made by the Institute to assure the accuracy and reliability of the data contained in them; however, the Institute makes no representation, warranty, or guarantee in connection with this publication and hereby expressly disclaims any liability or responsibility for loss or damage resulting from its use or for the violation of any authorities having jurisdiction with which this publication may conflict.

API publications are published to facilitate the broad availability of proven, sound engineering and operating practices. These publications are not intended to obviate the need for applying sound engineering judgment regarding when and where these publications should be utilized. The formulation and publication of API publications is not intended in any way to inhibit anyone from using any other practices.

Any manufacturer marking equipment or materials in conformance with the marking requirements of an API standard is solely responsible for complying with all the applicable requirements of that standard. API does not represent, warrant, or guarantee that such products do in fact conform to the applicable API standard.

Users of this Standard should not rely exclusively on the information contained in this document. Sound business, scientific, engineering, and safety judgment should be used in employing the information contained herein.

All rights reserved. No part of this work may be reproduced, translated, stored in a retrieval system, or transmitted by any means, electronic, mechanical, photocopying, recording, or otherwise, without prior written permission from the publisher. Contact the Publisher, API Publishing Services, 1220 L Street, NW, Washington, DC 20005.

Copyright © 2016 American Petroleum Institute

Foreword

This standard is in response to the call by industry and regulators for a standardized method to determine the uncertainty associated with various aspects of petroleum measurement. This method is based on the 2008 edition of the International Organization of Standards (ISO) *Guide to the Expression of Uncertainty in Measurement (GUM)*-JCGM 100:2008-which was developed to be a guide for the writers of technical standards.

Although this document could be used for analysis of an entire system or facility, that use is outside the scope of the document.

The uncertainty estimate is only as good as the underlying data and engineering judgment. All of the numerical values used and assumptions made must be documented. The statement in Section 3.4 of the ISO GUM reproduced below applies to this standard:

“Although this Guide provides a framework for assessing uncertainty, it cannot substitute for critical thinking, intellectual honesty and professional skill. The evaluation of uncertainty is neither a routine task nor a purely mathematical one; it depends on detailed knowledge of the nature of the measurand and of the measurement. The quality and utility of the uncertainty quoted for the result of a measurement therefore ultimately depend on the understanding, critical analysis and integrity of those who contribute to the assignment of its value.”

Nothing contained in any API publication is to be construed as granting any right, by implication or otherwise, for the manufacture, sale, or use of any method, apparatus, or product covered by letters patent. Neither should anything contained in the publication be construed as insuring anyone against liability for infringement of letters patent.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the specification.

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the specification.

This document was produced under API standardization procedures that ensure appropriate notification and participation in the developmental process and is designated as an API standard. Questions concerning the interpretation of the content of this publication or comments and questions concerning the procedures under which this publication was developed should be directed in writing to the Director of Standards, American Petroleum Institute, 1220 L Street, NW, Washington, DC 20005. Requests for permission to reproduce or translate all or any part of the material published herein should also be addressed to the director.

Generally, API standards are reviewed and revised, reaffirmed, or withdrawn at least every five years. A one-time extension of up to two years may be added to this review cycle. Status of the publication can be ascertained from the API Standards Department, telephone (202) 682-8000. A catalog of API publications and materials is published annually by API, 1220 L Street, NW, Washington, DC 20005.

Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

Contents

	Page
1	Scope 1
2	Normative References 1
3	Terms, Definitions, Acronyms, Abbreviations, and Symbols 2
3.1	Terms and Definitions 2
3.2	Acronyms, Abbreviations, and Symbols 6
4	Basic Concepts 7
4.1	General 7
4.2	Measurement Method 7
4.3	True Quantity Value 8
4.4	Error 8
4.5	Statistical Basis 8
4.6	Uncertainty 8
4.7	Confidence Level (Confidence Interval) 8
4.8	Type A vs Type B Uncertainties 9
4.9	Representative Samples 9
4.10	Mean 9
4.11	Standard Deviation 9
4.12	Standard Uncertainty 10
4.13	Degrees of Freedom 11
4.14	Determining Confidence Interval 11
4.15	Correlation Coefficient 13
4.16	Independent and Dependent Variables 13
4.17	Combining Uncertainties 13
4.18	Probability Distributions 15
5	Evaluating Uncertainty 17
5.1	General 17
5.2	Determine the Measurement Model 18
5.3	Record Elemental Error Sources 18
5.4	Create a Primary Uncertainty Table 20
5.5	Classify and Evaluate Uncertainty Components 21
5.6	Determine Sensitivity Coefficients 24
5.7	Determine Correlation Coefficients 26
5.8	Determine Combined Standard Uncertainty 27
5.9	Determine Expanded Uncertainty 28
5.10	Reporting Results 28
	Annex A (informative) Monte Carlo Method 30
	Annex B (informative) Examples 31
	Annex C (normative) Formal Proof of Equation 7(a) 48
	Annex D (informative) Report Significant Figures 50
	Annex E (normative) Using a Simplified Estimate of Standard Deviation 54
	Bibliography 57

Figures

1	Normal Distribution	16
2	Triangular Distribution	16
3	Rectangular Distribution.	17
4	Relationship between Measurement Model and Inputs	19
5	Relationship between the Uncertainty of the Measurement Model and the Uncertainty of the Inputs.	19
6	Hierarchal Relationship of all Uncertainty Components of a Measurement Model.	19
D.1	Uncertainty of the Transmitter Verification.	52
D.2	Uncertainty of the Transmitter After Adjustment.	52

Tables

1	t -Distribution Values	12
D.1	U_{95} , Probable Error and Effective Increment	53
E.1	Range to Standard Deviation Conversion Factors, $D(n)$	55
E.2	Student t Factors for Individual Measurements at Various Confidence Levels.	56

Matrices

1	Universe of Components	26
2	Correlation Matrix (Informative).	27

Measurement Uncertainty

1 Scope

This standard establishes a methodology to develop uncertainty analyses for use in writing API *Manual of Petroleum Measurement Standards (MPMS)* documents that are consistent with the ISO *GUM* and NIST Technical Note 1297.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *Manual of Petroleum Measurement Standards (MPMS)* Chapter 12, *Calculation of Petroleum Quantities, Section 2—Calculation of Liquid Petroleum Quantities Measured by Turbine or Displacement Meters*, 1981

API *MPMS* Chapter 13, *Statistical Aspects of Measuring and Sampling, Section 1—Statistical Concepts and Procedures in Measurements*, 1985, Reaffirmed 2011

API *MPMS* Chapter 13, *Statistical Aspects of Measuring and Sampling, Section 2—Methods of Evaluating Meter Proving Data*, 1994, Reaffirmed 2011

API *MPMS* Chapter 14.3, (AGA Report No. 3, Part 1), *Concentric, Square-Edged Orifice Meters, Part 1—General Equations and Uncertainty Guidelines*, 2012

API *MPMS* Chapter 22.1, *Testing Protocols—General Guidelines for Developing Testing Protocols for Devices Used in the Measurement of Hydrocarbon Fluids*, 2006, Reaffirmed 2011

Coleman, H.W., and Steele, W.G., *Experimentation and Uncertainty Analysis for Engineers*, Third Edition, New York: John Wiley & Sons, 2009

Harter, H.L., "Tables of Range and Studentized Range," *Annals of Mathematical Statistics*, vol. 31, Beachwood, OH, 1960, pp. 1122–1147

JCGM 100:2008, *Evaluation of measurement data—Guide to the expression of uncertainty in measurement, GUM 1995 with minor corrections*, 2008

JCGM 101:2008, *Evaluation of measurement data—Supplement 1 to the "Guide to the expression of uncertainty in measurement"—Propagation of distributions using a Monte Carlo method, GUM 1995 with minor corrections*, 2008

JCGM 200:2012, *International vocabulary of metrology—Basic and general concepts and associated terms (VIM)*, 2012

Olkin, I., "Range Restrictions for Product-Moment Correlation Matrices," *Psychometrika*, December 1981, vol. 46, Issue 4, pp. 469–472

Taylor, B.N., and Kuyatt, C.E., *Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results*, NIST Technical Note 1297, 1994

Wheeler, D.J., *EMP III: Evaluating the Measurement Process & Using Imperfect Data*, SPC Press, 2006