ASME B89.7.1-2016

(Technical Report)

Guidelines for Addressing Measurement Uncertainty in the Development and Application of ASME B89 Standards

The American Society of Mechanical Engineers

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Guidelines for Addressing Measurement Uncertainty in the Development and Application of ASME B89 Standards

The American Society of
Mechanical Engineers

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FOREWORD

This Technical Report provides general principles for addressing measurement uncertainty that apply to the use of ASME B89 standards. This Technical Report also provides recommendations regarding measurement uncertainty for use in the development of ASME B89 standards. This Technical Report is concerned with the application and documentation of measurement uncertainty but not with methods for the estimation of measurement uncertainty.

A number of challenging requirements have been introduced to dimensional metrology practice in recent years through new developments in ISO/IEC 17025 accreditation, measurement uncertainty, and conformance decision rules. Many of these requirements are related to the broad concept of measurement uncertainty management. The ASME B89.7 series of standards and technical reports has been developed to help users understand and meet these new uncertainty-related requirements.

To achieve its purpose, this Technical Report introduces general concepts associated with calibration and verification testing. This Technical Report clarifies existing terms and introduces new terms and definitions in an attempt to standardize practices within ASME B89 standards and across the dimensional metrology field.

There are efforts ongoing to develop standards and to prepare industry to address the issues related to measurement uncertainty and the increasing recognition of its importance in commerce. These efforts aim to support the consideration of measurement uncertainty in measurement plans. Until recently, many existing ASME B89 standards did not address measurement uncertainty. This Technical Report provides guidelines for documenting the treatment of uncertainty contributions. These guidelines support the use and documentation of a methodology recognized as consistent with the concepts outlined in JCGM 100, Guide to the Expression of Uncertainty in Measurement (GUM).

Applying common guidelines in development of all ASME B89 standards, where appropriate, will ensure consistency, facilitate the approval process, and improve intelligibility for buyers and sellers who use ASME B89 standards.

Acknowledgment. This work was initiated and originally chaired by the late John Buttress, and his contribution is recognized and appreciated by the ASME B89 Committee.

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General. ASME Codes, Standards, and Technical Reports are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Technical Report may interact with the Committee by proposing revisions and attending Committee meetings. Correspondence should be addressed to:

Secretary, B89 Standards Committee
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Proposing Revisions. Revisions are made periodically to the Technical Report to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Technical Report. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Technical Report. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

Attending Committee Meetings. The B89 Standards Committee regularly holds meetings and/or telephone conferences that are open to the public. Persons wishing to attend any meeting and/or telephone conference should contact the Secretary of the B89 Standards Committee. Future Committee meeting dates and locations can be found on the Committee Page at http://go.asme.org/B89committee.

GUIDELINES FOR ADDRESSING MEASUREMENT UNCERTAINTY IN THE DEVELOPMENT AND APPLICATION OF ASME B89 STANDARDS

1 SCOPE

This Technical Report provides recommendations associated with addressing measurement uncertainty and direction in the application of the existing ASME B89.7 series of uncertainty-related standards and technical reports. This Technical Report also provides general principles and recommendations regarding measurement uncertainty and its documentation for use in the development of ASME B89 standards and technical reports. This Technical Report does not cover methods to be used in the estimation of measurement uncertainty. To achieve these objectives, this Technical Report

(a) outlines guidelines for documenting measurement uncertainty in ASME B89 standards and technical reports

(b) defines general calibration and verification testing principles, terms, and concepts for use in dimensional metrology

(c) discusses general topics associated with addressing measurement uncertainty, such as operating conditions, conformance testing, decision rules, and traceability

This Technical Report takes advantage of the technical content developed in other ASME B89.7 standards and technical reports, whenever possible. That technical content is referenced, but not repeated, in this Technical Report.

2 DEFINITIONS

For the purposes of this Technical Report, the definitions in JCGM 200:2012 (VIM3) apply; any differences or additions are included below. When definitions from JCGM 200 are included in this Technical Report, some notes may not be shown for brevity. When notes have been added to the JCGM 200 definitions in this Technical Report, a parenthetical statement indicates the notes are specific to this Technical Report.

artifact verification: provision of sufficient objective evidence that a given material measure (artifact) conforms to a specified maximum permissible error or tolerance limit.

calibration: operation that, under specified conditions, in a first step, establishes a relation between the quantity values with measurement uncertainties provided by measurement standards and corresponding indications with associated measurement uncertainties and, in a second step, uses this information to establish a relation for obtaining a measurement result from an indication. (This definition is identical to JCGM 200:2012, definition 2.39, but with the notes not shown for brevity. The note below is specific to this Technical Report.)

NOTE: Verification tests are frequently used as calibrations when they satisfy both the first and second step in the above definition (see para. 4.4.2).

decision rule: documented rule that describes how measurement uncertainty will be accounted for with regard to accepting or rejecting an item, given a specified requirement and the result of a measurement. (This definition is identical to JCGM 106:2012, definition 3.3.12. The note below is specific to this Technical Report.)

NOTE: See further discussion of decision rules in ASME B89.7.3.1.

indication: quantity provided by a measuring instrument or measuring system.

NOTES:
(1) An indication is often given as the position of a pointer for an analog output or the displayed or printed number for a digital output.
(2) An indication is also known as a reading.

(The definition above, including the Notes, is identical to JCGM 106:2012, definition 3.2.9.)

instrument verification: provision of sufficient objective evidence that a given indicating measuring instrument conforms to a specified maximum permissible error or tolerance limit.

maximum permissible error (MPE): for a measuring instrument, maximum difference, permitted by specifications or regulations, between the instrument indication and the quantity being measured. (This definition is identical to JCGM 106:2012, definition 3.3.18, but with notes not shown for brevity. The note below is specific to this Technical Report.)

NOTE: A maximum permissible error is a specific type of tolerance limit.

measuring equipment: any instrument, artifact, or auxiliary apparatus, or any combination thereof, necessary to implement a measurement process for carrying out a specified and defined measurement.

NOTES:
(1) This definition is broader than that of *measuring instrument* in JCGM 200:2012 because it includes all the means necessary for producing a measurement result.
(2) The concept of measuring equipment includes, for example, indicating measuring instruments and material measures (JCGM 200:2012, definitions 3.3 and 3.6, respectively).

(The definition above, including the Notes, is adapted from ISO 14978:2006, definition 3.1.)

metrological characteristic: characteristic of measuring equipment that may influence the results of measurement.

NOTES:
(1) The influence on the results of measurement is an uncertainty contribution.
(2) Measuring equipment usually has several metrological characteristics.
(3) Metrological characteristics can be subject to calibration and verification.

(The definition above, including the Notes, is adapted from ISO 14978:2006, definition 3.12.)

reference value: quantity value used as a basis for comparison with values of quantities of the same kind. (This definition is identical to JCGM 200:2012, definition 5.18, but with the notes not shown for brevity. The Notes below are specific to this Technical Report.)

NOTES:
(1) In this Technical Report, a reference value is a quantity value associated with an indicating measuring instrument or artifact, that is determined by calibration and may be reported on a calibration certificate.
(2) Reference value uncertainty is the uncertainty associated with a reference value.

test value: a quantity value associated with a verification test that is used as a basis for assessing instrument verification or artifact verification.

NOTES:
(1) The test values associated with a verification test may be reported on a calibration certificate.
(2) Test value uncertainty (or test uncertainty) is the uncertainty associated with a test value.

tolerance limit (specification limit): specified upper or lower bound of permissible values of a property. (This definition is identical to JCGM 106:2012, definition 3.3.4.)

verification test (test): an operation that, under specified conditions, establishes either instrument verification or artifact verification.

3 REFERENCES

The publications listed in paras. 3.1 and 3.2 are referenced in this Technical Report. Unless otherwise noted, the most recent edition applies.

3.1 Normative References

ASME B89.7.3.1, Guidelines for Decision Rules: Considering Measurement Uncertainty in Determining Conformance to Specifications
ASME B89.7.3.2, Guidelines for the Evaluation of Dimensional Measurement Uncertainty
ASME B89.7.3.3, Guidelines for Assessing the Reliability of Dimensional Measurement Uncertainty Statements
ASME B89.7.4.1, Measurement Uncertainty and Conformance Testing: Risk Analysis
ASME B89.7.5, Metrological Traceability of Dimensional Measurements to the SI Unit of Length
Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

JCGM 100:2008, Evaluation of measurement data — Guide to the expression of uncertainty in measurement (GUM)
JCGM 106:2012, Evaluation of measurement data — The role of measurement uncertainty in conformity assessment
JCGM 200:2012, International vocabulary of metrology — Basic and general concepts and associated terms, 3rd edition (VIM3)
Publisher: Joint Committee for Guides in Metrology (JCGM), Bureau International des Poids et Mesures (BIPM), Pavillon de Breteuil, F-92312 Sèvres Cedex, France (www.bipm.org)

3.2 Informative References

ANSI/NCSL Z540.3, Requirements for the Calibration of Measuring and Test Equipment
Publisher: National Conference of Standards Laboratories (NCSL International), 5766 Central Avenue, Suite 150, Boulder, CO 80301 (www.ncsli.org)

ASME B89.1.5-1998 (R2014), Measurement of Plain External Diameters for Use as Master Discs or Cylindrical Plug Gages
ASME B89.1.6-2002 (R2012), Measurement of Plain Internal Diameters for Use as Master Rings or Ring Gages
ASME B89.1.9-2002 (R2012), Gage Blocks
ASME B89.1.13-2013, Micrometers
ASME B89.4.10360.2-2008, Acceptance Test and Reverification Test for Coordinate Measuring Machines (CMMs) — Part 2: CMMs Used for Measuring Linear Dimensions

Publisher: The American Society of Mechanical Engineers (ASME), Two Park Avenue, New York, NY 10016-5990 (www.asme.org)

ISO 3290-1:2014, Rolling bearings — Balls — Part 1: Steel balls

ISO 14253-5, Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 5: Uncertainty in verification testing of indicating measuring instruments

ISO 14978:2006, Geometrical product specifications (GPS) — General concepts and requirements for GPS measuring equipment

ISO/IEC 17025, General requirements for the competence of testing and calibration laboratories

Publisher: International Organization for Standardization (ISO), Central Secretariat, Chemin de Blandonnet 8, Case Postale 401, 1214 Vernier, Geneva, Switzerland (www.iso.org)

4 CALIBRATION AND VERIFICATION TESTING

4.1 General

The concepts of calibration and verification are not uniformly adopted across international and national metrology standards, and this often causes confusion, particularly in calibration practice. This Technical Report incorporates calibration and verification concepts from important standards such as JCGM 100, JCGM 200, ANSI/NCSL Z540.3, ISO 14978, and ISO/IEC 17025 to develop and apply a consistent approach for use with ASME B89 standards. The general relationship between calibration and verification is shown in Figure 4.1-1. Some calibration examples are shown in Nonmandatory Appendix A.

4.2 Calibration Measurements

The measurements associated with the calibration process have one or more of the following purposes (see examples in Nonmandatory Appendix A):

(a) They are used to determine reference values.

(b) They are used to determine test values associated with a verification test.

(c) They are used to determine necessary adjustments to measuring equipment.

4.3 Reference Value

In dimensional metrology, reference values and the associated reference value uncertainties are usually reported on a certificate of calibration for the measuring equipment. A reference value and associated uncertainty are generally used to satisfy the second step in the definition of *calibration* (see section 2), i.e., they are used in the subsequent measurement "to establish a relation for obtaining a measurement result from an indication." In this manner, reference values are the output of a calibration that may be used as corrections when the calibrated measuring equipment is used on subsequent measurements. The corrections generally improve accuracy and reduce measurement uncertainty.

EXAMPLE: For a gage block, the output of a calibration may involve measuring and assigning a reference value to the gage length, l_g, as defined in ASME B89.1.9. This reference value is then applied as an input to the subsequent use of the gage block, which allows for more accurate use of the gage block than does using the nominal size and grade of the gage block alone.

4.4 Verification Test

4.4.1 Acceptance and Reverification Tests. Verification tests are used to establish that measuring equipment conforms to specified tolerance limits, e.g., MPEs. There are two types of verification tests: acceptance tests and reverification tests. Acceptance tests are typically used in the purchase process of measuring equipment, and the specifications are stated by the manufacturer. For reverification tests, the specifications are stated by the user and may or may not be the same as those used in the acceptance test.

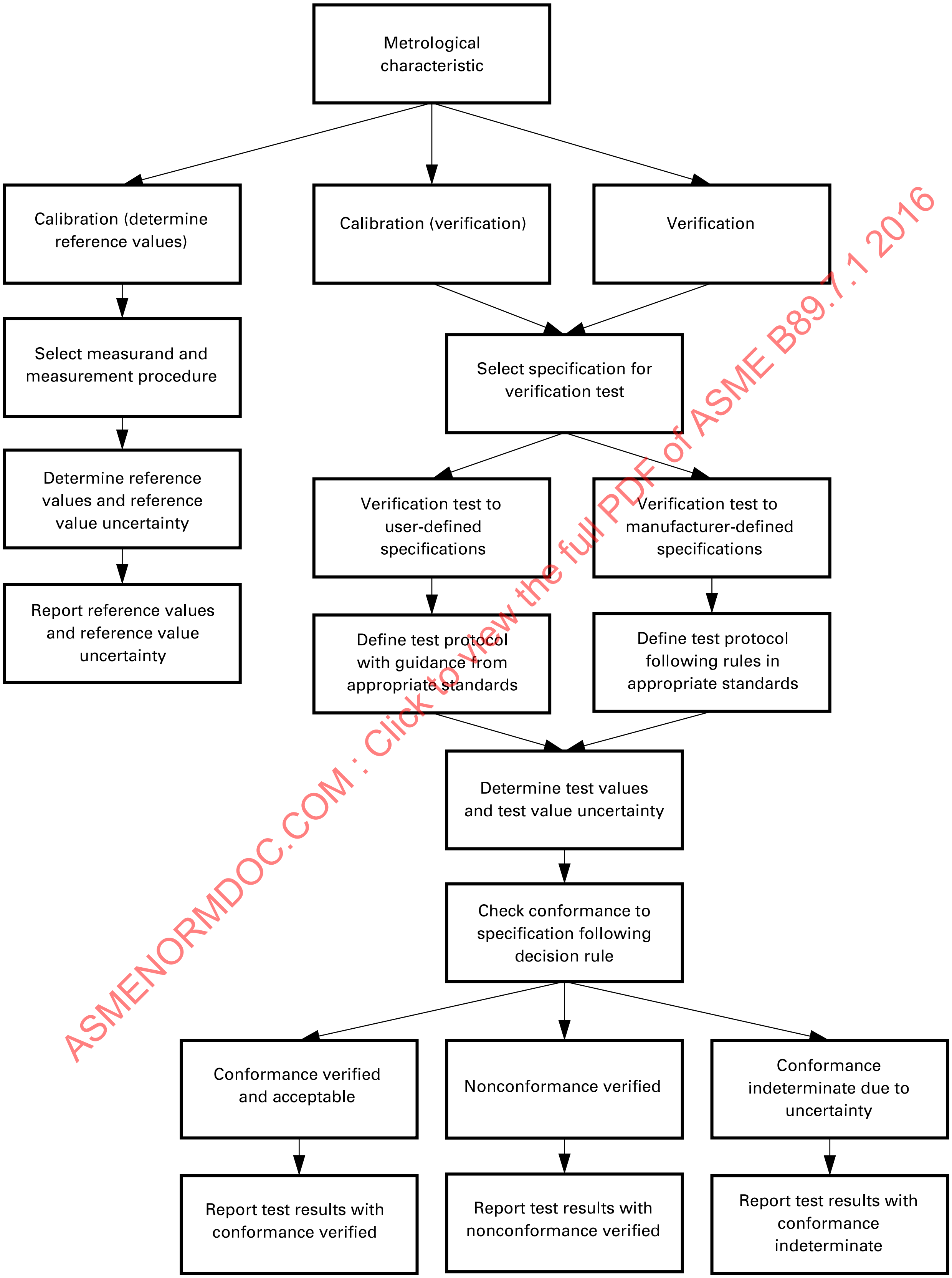
4.4.2 Verification and Calibration. In many cases, particularly in the case of indicating measuring instruments, a verification test is completed and no reference values are assigned. For verification tests, the test values that are determined are not used as reference values and are not used to improve the accuracy of subsequent measurements using the measuring equipment; however, this does not preclude the verification test from being considered a calibration, as a verification test is a calibration if it meets the requirements of a calibration and is used as such. The results of a verification test, i.e., determination of compliance with specification, and the associated test uncertainty are generally used to satisfy the second step in the definition of *calibration* (see section 2). The use of verification tests as calibrations is common in dimensional metrology practice.

EXAMPLE: For a gage block, the calibration may involve measurements to determine conformance to the specification for the limit deviation of any point from the nominal length, t_e, as defined in ASME B89.1.9. The measured test values are used to determine conformance to specification but are not used to assign a reference value. In this manner, the nominal size of the calibrated gage block is used in subsequent measurements.

4.5 Adjustments

JCGM 200 and ISO/IEC 17025 do not consider adjustments to measuring equipment part of a calibration; however, adjustments are often important to the calibration process. This Technical Report recognizes the historical use of the term *calibration* to indicate making

Figure 4.1-1 Relationship Between Calibration and Verification



adjustments to dimensional measuring equipment, but that use of the term is not consistent with the definition used herein. This Technical Report uses the term *adjustments* when discussing the service activities undertaken to modify the metrological characteristics of measuring equipment; the typical purpose of adjustments is to bring measuring equipment back within specified MPEs or tolerance limits. Measurements used for determining necessary adjustments to measuring equipment, if not also used either for determining reference values or as test values, are not necessarily recorded or reported in a calibration.

4.6 Calibration Results

In this Technical Report, the result of a calibration is one of the following:

(a) a reference value with an associated reference value uncertainty

(b) an artifact verification based on test values and associated test uncertainty

(c) an instrument verification based on test values and associated test uncertainty

The measurand associated with test values is conceptually different than the measurand associated with reference values, and therefore, the influence quantities one should consider when estimating test uncertainty are typically quite different than those one should consider when estimating reference value uncertainty. Guidelines for the evaluation of measurement uncertainty in dimensional metrology are discussed in ASME B89.7.3.2, and test uncertainty is further discussed in ISO 14253-5.

4.7 Suitability of the Calibration for Subsequent Measurements

A calibration is for a specific measurand and set of conditions under which the uncertainty statement is valid (see para. 5.1.3). The use of calibration results should be carefully considered when the calibrated measuring equipment is used to obtain measurement results in a subsequent measurement. The measurand of any subsequent measurements and the associated conditions under which the measuring equipment is used need to be compared to the measurand and conditions associated with the calibration. If the measurand or measurement conditions differ from those of the calibration, additional influence quantities associated with the measuring equipment and its use in the subsequent measurement should be identified and quantified in the evaluation of the uncertainty of the subsequent measurement result.

5 DOCUMENTING MEASUREMENT UNCERTAINTY AND METROLOGICAL TRACEABILITY IN ASME B89 STANDARDS AND TECHNICAL REPORTS

5.1 Minimum Information

When documenting uncertainty analyses, ASME B89 standards and technical reports should address the following information, at minimum:

(a) definition of the measurand

(b) measurement method and equipment

(c) validity conditions associated with the uncertainty analysis

(d) correlated and independent inputs

(e) documentation traceability for the length standards

(f) summary matrix for uncertainty evaluation

5.1.1 Definition of the Measurand. Proper evaluation of measurement uncertainty begins with clearly defining and understanding the measurand. For example, is the measurand evaluated as a measurement result for a workpiece feature measured on a coordinate measuring machine (CMM) or as an error produced in a CMM verification test? In many cases, standards and technical reports should go so far as to state what the measurand is not. For example, if the ASME B89 standard provides an example uncertainty analysis of the calibration result for an artifact, the text should clarify that the uncertainty analysis is not associated with a subsequent measurement result using the calibrated artifact as a reference standard.

5.1.2 Measurement Method and Equipment. The measurement method and associated equipment determine how the measurement values relate to the measurand, and understanding this relationship is the first step in establishing the "context" of the uncertainty analysis. ASME B89 standards and technical reports should include all important details of the measuring method and measurement equipment to sufficiently identify the important metrological requirements.

5.1.3 Validity Conditions. The documentation of validity conditions serves to complete the description of the "context" for the uncertainty analysis, and in doing so, describes the permissible conditions within which the uncertainty analysis is valid. This should include addressing the limits of influence quantities. The documentation should make it clear whether the analysis addresses a measurement taken at a particular time (and the conditions at that time) or measurements taken over a longer period of time, within the stated conditions. For example, this documentation should state whether the analysis is limited to a particular instrument or to any number of similar instruments calibrated within all the stated influence quantity limits. If the measurement is performed contrary to the stated conditions, the quantified measurement uncertainty cannot be associated with the measurement result.

5.1.4 Correlated and Independent Input. One of the first steps in calculating the combined uncertainty requires identifying independent and correlated input quantities. Documenting how input quantities are related is as important as documenting how their associated uncertainties are quantified.

5.1.5 Documentation Traceability. Metrological traceability is a property of a measurement result, and ASME B89.7.5 describes requirements for metrological traceability. Of particular importance is documentation traceability, which is the evidence, e.g. calibration reports, required in a traceability chain. Length standards that directly influence measurement results should have sufficient documentation traceability to an appropriate metrological terminus; see ASME B89.7.5 for details. Length standards are the measurement standards used in calibration that are associated with introducing the unit of length into the measurement result.

5.1.6 Summary Matrix for Uncertainty Evaluation. Measurement uncertainty documentation should include a summary matrix outlining the contributing standard uncertainties. A comprehensive matrix should include how each standard uncertainty was quantified (e.g., Type A or Type B), its sensitivity coefficient, and, where applicable, correlated input quantities and their correlation coefficients. In situations where the expanded uncertainty is required to have a specific level of confidence, e.g., 95%, the matrix should include the degrees of freedom (DOF) for each uncertainty contributor, including the effective DOF for the combined uncertainty and the appropriate coverage factor selected and reported to achieve the desired level of confidence. A simplified matrix is also acceptable and commonly used. In situations where the expanded uncertainty is required to use a specific coverage factor, e.g., $k = 2$, then the DOF for the combined uncertainty is not computed or reported. An example format for a simplified summary matrix is shown in Nonmandatory Appendix C.

5.2 Computer Simulation

If computer simulation is used in the measurement uncertainty analysis, then the documentation should describe how this was accomplished (including models, where applicable). Any software package(s) used in the analysis should be named, including its revision level. In addition, the documentation should list simulation sampling techniques used (e.g., Monte Carlo), input quantities, distribution types, and the number of iterations or trials.

5.3 Guidelines for ASME B89 Standards and Technical Reports

Guidelines for documenting measurement uncertainty in ASME B89 standards and technical reports are included in Nonmandatory Appendix B.

5.4 Reliability of Uncertainty Statements

Guidelines for assessing the reliability of dimensional measurement uncertainty statements can be found in ASME B89.7.3.3.

6 UNCERTAINTY-RELATED RECOMMENDATIONS FOR ASME B89 STANDARDS

6.1 Traceability

It is recommended that ASME B89 standards include a requirement for metrological traceability for all measurement standards used in calibration that are associated with introducing the unit of length into the measurement result, e.g., gage blocks used to calibrate a micrometer. For more information, see ASME B89.7.5. For more complex cases, e.g., coordinate measuring machines, more detailed discussion may be needed; in those cases, this Technical Report recommends an informative appendix be included in the standard.

6.2 Uncertainty Guidance

ASME B89 standards associated with the determination of either reference values or test values should include guidance on evaluating the measurement uncertainty of these values. The uncertainty should follow the recommendations of this Technical Report as well as those of any other appropriate ASME B89.7 standard or technical report. This Technical Report recommends this uncertainty guidance be included in an informative appendix. The coverage factor of the expanded uncertainty should be clearly stated.

6.3 Verification Test Protocol

6.3.1 General. ASME B89 standards that include verification tests should address how the test protocol is defined. The test protocol is a predefined detailed specification of a verification test that defines the set of permissible test instances. The test protocol includes the general test method, specification of an indication, number of test points, and the conformance decision rule. The test protocol should be defined in sufficient detail to ensure the measurand associated with a verification test has negligible ambiguity.

6.3.2 Decision Rules. ASME B89 standards that include verification tests should include a decision rule that describes how measurement uncertainty will be accounted for with regard to accepting or rejecting a product according to its specification and the result of a measurement. This Technical Report recommends explicitly stating a simple 4:1 acceptance decision rule in accordance with ASME B89.7.3.1 for all ASME B89 standards unless there is a specific justification for alternative decision rules. Simple acceptance has a long history of practical use and is the most widely used and understood decision rule. In addition, simple acceptance generally optimizes cost in calibration. The appropriate measurement capability index, C_m, should be considered in cases where achieving 4:1 may be considered impractical. See ASME B89.7.4.1 for additional discussion of the measurement capability index.

6.3.3 Rated Operating Conditions. Rated operating conditions are the operating conditions at which the manufacturer guarantees specified tolerance limits or MPEs. ASME B89 standards that include verification tests should include important rated operating conditions or provide guidance on the rated operating conditions to include with stated specifications. The use of measuring equipment during testing under rated operating conditions includes all procedures, as documented in the operating manual, employed during normal usage of the measuring equipment.

EXAMPLE 1: CMM specifications are associated with multiple rated operating conditions that are defined by the manufacturer in accordance with ASME B89.4.10360.2-2008. Rated operating conditions for a CMM may include, for example, an ambient temperature range, temperature gradients, workpiece loading, and probing system.

Generally, when a rated operating condition is defined as an interval, this interval defines a range of conditions within which the MPE or tolerance is specified, and these conditions are required to be met during the verification testing. In contrast, when a rated operating condition is defined as an exact value, the MPE or tolerance is specified at this exact value and this requirement is included in the definition of the test measurand.

EXAMPLE 2: Gage block specifications have a rated operating condition associated with temperature. In accordance with ASME B89.1.9, the specifications of a gage block apply at 20°C exactly, and therefore the measurand is defined at 20°C. When a gage block is being tested to specification, the test values should be corrected to 20°C and the appropriate contributors included in the measurement uncertainty.

The use of rated operating conditions defined over an interval versus the use of those defined at an exact value should be considered carefully in ASME B89 standards. When a rated operating condition is defined over an interval, the variation in the performance of the measuring equipment due to operating conditions changing within the rated operating conditions is part of the verification test; it is therefore not necessary to perform any corrections to the test values or estimate any uncertainty associated with this variation. This may lead to an easier but less reproducible test. When a rated operating condition is defined at an exact value, the verification test must account for any differences between the actual test condition and the rated operating condition. In general, this will introduce uncertainty contributors associated with these differences, and corrections to the test values are necessary. The following factors should be considered when choosing whether to specify an interval or an exact value for rated operating conditions: the complexity of corrections, the associated impact on test uncertainty, the method by which the verification testing is likely to be completed, and the method by which the operating conditions are to be controlled during testing.

A complication of selecting an exact value for a rated operating condition is that verification testing of measuring equipment should be about experimental verification of the performance of the equipment and not prediction (which is necessary for corrections). The accuracy of the prediction needs to be without controversy, and/or verifying the accuracy of the prediction needs to be reasonably possible. Furthermore, the consequences of an incorrect prediction must be unambiguous, including with respect to the user's expectation of the measurement accuracy. Corrections also generally require additional technical information and insight about measuring equipment that may not be readily available or is possibly proprietary to the equipment manufacturer, and for more complex measuring equipment, corrections may not be reasonably possible. In addition, the verification is valid only with the proper corrections, and this may create an undesirable burden on the user of the measuring equipment, as all subsequent measurements would also need the correction applied to achieve the expected accuracy. It is recommended that defining a rated operating condition at an exact value be restricted to simpler measuring equipment whose structural details are self-evident, and be disclosed enough to allow the user to simply and accurately evaluate the correction and its uncertainty in verification testing and in subsequent use.

6.3.4 Operator Skill. For manually operated measuring instruments, operator skill needs to be carefully considered when the rated operating conditions are being defined. The specifications of many instruments are implicitly understood to apply when a reasonably trained and skilled operator is using the instrument. This implicit understanding is a type of rated operating condition that impacts the evaluation of the test uncertainty. See ISO 14253-5 for more discussion of test uncertainty.

6.3.5 Avoiding Ambiguity. ASME B89 standards should encourage the elimination of ambiguity regarding rated operating conditions. The rated operating conditions should be explicitly stated to the extent possible. For the sake of brevity, rated operating conditions considered as "common use" of the measurement equipment may not be explicitly stated in some standards or manufacturer specifications. While this is unavoidable in practice, the ambiguity associated with what is considered acceptable or common use is a concern, and thus ASME B89 standards should explicitly state rated operating conditions.

6.3.6 Specification of an Indication. The measurand should be sufficiently specified in ASME B89 standards to eliminate ambiguity in the specification of an indication associated with measuring equipment being tested. For instrument verification, the specifications should generally apply to all unique measured indications made under reasonable use of the measuring instrument. Any rules or requirements that impact the specification of an indication should be clearly stated in ASME B89 standards, e.g., averaging of multiple indications to determine a test value or other data treatment. For more complex instruments, additional details are usually needed to define an indication, e.g., sampling strategies and data filtering.

6.3.7 Test Values. ASME B89 standards that address verification tests should define the number of test values associated with a particular verification test that is sufficient to determine conformance to the tolerance limit or the MPE.

6.3.8 Sufficient Objective Evidence. Instrument and artifact verification requires sufficient objective evidence of compliance to a specified MPE or tolerance limit. The testing protocols in ASME B89 standards that address verification tests are designed to provide the necessary tests and conditions to establish the sufficient objective evidence. ASME B89 standards should consider the balance between thoroughness and practicality and ensure the objective evidence is sufficient to convey an appropriate level of confidence.

6.4 Subsequent Measurements

For ASME B89 standards that address verification tests, the subsequent use of the tested measuring instrument or artifact is generally outside the scope of the ASME B89 standards; however, the user may look to the ASME B89 standards for some guidance. This Technical Report recommends that ASME B89 standards consider addressing traceability and measurement uncertainty of subsequent measurements, particularly in cases where these issues may be complex, in an informative appendix.

6.5 Data Sheet

The documentation of specifications of measuring instruments and artifacts, usually done by manufacturers in accordance with the appropriate ASME B89 standard, may be complex in some cases. This is particularly so when the specifications include complicated operating conditions or various optional specifications. This Technical Report recommends that ASME B89 standards consider including a recommended (or possibly mandatory) "Data Sheet" format, typically in an appendix, to eliminate possible ambiguity for complex specifications.

6.6 Reporting of Results

ASME B89 standards should address how measurement results should be reported, including providing an example, e.g., a standardized test results form, whenever possible. In general, the results should include the following:

(a) the metrological characteristic(s) being calibrated or verified

(b) a reference to the appropriate documentary standard that pertains to the measuring equipment

(c) evidence of traceability (see ASME B89.7.5)

(d) the reference values, when applicable, and the associated reference value uncertainty

(e) for verification tests, the specification, test values, test value uncertainty, decision rule, and statement that conformance is verified, not verified, or not determined

6.7 Corrections

An adjustment to measuring equipment should not be confused with a correction (see JCGM 200:2012, definition 2.53), which is applied during measurement to compensate for a systematic effect. ASME B89 standards that require determination of either reference values or test values should include guidance on the appropriate use of any corrections. This is most important for ASME B89 standards that address verification tests, as the application of a correction could change the test value and the outcome of the verification test. ASME B89 standards that allow corrections should explicitly state the type of corrections that are allowed. The input values, and their associated permitted ranges, to the correction should be stated.

6.8 Adjustments

The use of adjustments to measuring equipment during verification tests should be carefully considered in the development of ASME B89 standards. While adjustments may be made to measuring equipment, any adjustments made under actual testing conditions should be evaluated to ensure the measuring equipment is operating sufficiently under different permissible conditions. In addition, ASME B89 standards that address verification should explicitly forbid adjustments during actual testing. Any adjustments should be completed prior to, and not during, any verification tests.

NONMANDATORY APPENDIX A
CALIBRATION EXAMPLES

A-1 GENERAL

This Nonmandatory Appendix provides examples of common dimensional calibrations. Table A-1-1 summarizes the examples and lists the relevant paragraph numbers.

A-2 CMM

A CMM is specified in accordance with ASME B89.4.10360.2. As part of the CMM calibration, conformance to the length measurement error, $E_{0,MPE}$, is tested. ASME B89.4.10360.2 requires 105 measured test lengths. This test is one of the verification tests used to establish the instrument verification of the CMM. There are no reference values determined in this test, and the verification test is used as the calibration of the CMM. If conformance to $E_{0,MPE}$ cannot be demonstrated, then adjustments may be required. Adjustment measurements, e.g., the squareness between two axes of motion, may be made prior to retesting; such measurements are typically not reported as part of the calibration results.

A-3 GAGE BLOCK

A-3.1 Reference Value

Some applications of gage blocks, e.g., when they are used as a reference standard in a mechanical comparator, require a reference value for the length at the defined reference point on the gage block, l_g, in accordance to ASME B89.1.9. In this case, the purpose of the calibration is to determine the reference value and no verification test is performed.

A-3.2 Artifact Verification

A gage block is specified to a particular grade per ASME B89.1.9, and as part of the gage block calibration, conformance to the limit deviation of any point from the nominal length, t_e, is tested. This test is one of the verification tests used to establish the artifact verification of the gage block. In accordance to ASME B89.1.9, five lengths are tested: the four corners and the defined reference point.

A-3.3 Calibration Certificate

In gage block calibration practice, a single calibration certificate is often issued that reports the reference value at the defined reference point in addition to providing information regarding the verification test. The artifact verification test results may be presented in various

Table A-1-1 Summary of Dimensional Calibration Examples

Paragraph	Measuring Equipment	Calibration Type	Calibration Purpose	Calibration Method
A-2	CMM	Instrument verification	$E_{0,MPE}$ per ASME B89.4.10360.2	105 test lengths across measuring volume
A-3.1	Gage block	Reference value	l_g per ASME B89.1.9	Measured length at the defined reference point
A-3.2	Gage block	Artifact verification	t_e per ASME B89.1.9	Five test lengths: four corners and the reference point
A-4.1	Ring gage	Artifact verification	Diameter tolerance limit per ASME B89.1.6	Two-point diameter at six locations in three planes and 90 deg apart
A-4.2	Ring gage	Reference value	Identified diameter per ASME B89.1.6	Two-point diameter at location identified by scribe line
A-5	Plug gage	Artifact verification	Diameter tolerance limit per ASME B89.1.5	Two-point diameter at six locations in three planes and 90 deg apart
A-6	Sphere	Artifact verification	Tolerance limit for deviation from spherical form per ISO 3290-1	Out-of-roundness measured in three planes
A-7	Micrometer	Instrument verification	MPE for length measurement error per ASME B89.1.13	Five test lengths across measuring range