INTERNATIONAL STANDARD

ISO/ASTM 51707

First edition
2002-03-15

Guide for estimating uncertainties in dosimetry for radiation processing

Guide pour l'estimation des incertitudes en dosimétrie pour le traitement par irradiation

Reference number
ISO/ASTM 51707:2002(E)

PDF disclaimer

This PDF file may contain embedded typefaces. In accordance with Adobe's licensing policy, this file may be printed or viewed but shall not be edited unless the typefaces which are embedded are licensed to and installed on the computer performing the editing. In downloading this file, parties accept therein the responsibility of not infringing Adobe's licensing policy. Neither the ISO Central Secretariat nor ASTM International accepts any liability in this area.

Adobe is a trademark of Adobe Systems Incorporated.

Details of the software products used to create this PDF file can be found in the General Info relative to the file; the PDF-creation parameters were optimized for printing. Every care has been taken to ensure that the file is suitable for use by ISO member bodies and ASTM members. In the unlikely event that a problem relating to it is found, please inform the ISO Central Secretariat or ASTM International at the addresses given below.

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. +41 22 749 01 11
Fax +41 22 749 09 47
E-mail copyright@iso.ch
Web www.iso.ch

ASTM International, 100 Barr Harbor Drive, PO Box C700,
West Conshohocken, PA 19428-2959, USA
Tel. +610 832 9634
Fax +610 832 9635
E-mail khooper@astm.org
Web www.astm.org

Printed in the United States

Contents

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.

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.

ASTM International is one of the world's largest voluntary standards development organizations with global participation from affected stakeholders. ASTM technical committees follow rigorous due process balloting procedures.

A pilot project between ISO and ASTM International has been formed to develop and maintain a group of ISO/ASTM radiation processing dosimetry standards. Under this pilot project, ASTM Subcommittee E10.01, Dosimetry for Radiation Processing, is responsible for the development and maintenance of these dosimetry standards with unrestricted participation and input from appropriate ISO member bodies.

Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. Neither ISO nor ASTM International shall be held responsible for identifying any or all such patent rights.

International Standard ISO/ASTM 51707 was developed by ASTM Committee E10, Nuclear Technology and Applications, through Subcommittee E10.01, and by Technical Committee ISO/TC 85, Nuclear Energy.

Annexes A1, A2, A3, A4 and A5 of this International Standard are for information only.

ISO/ASTM 51707:2002(E)

Standard Guide for Estimating Uncertainties in Dosimetry for Radiation Processing[1]

This standard is issued under the fixed designation ISO/ASTM 51707; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision.

1. Scope

1.1 This guide defines possible sources of error in dosimetry performed in gamma, x-ray (bremsstrahlung) and electron irradiation facilities and offers procedures for estimating the resulting magnitude of the uncertainties in the measurement results. Basic concepts of measurement, estimate of the measured value of a quantity, "true" value, error and uncertainty are defined and discussed. Components of uncertainty are discussed and methods are given for evaluating and estimating their values. How these contribute to the standard uncertainty in the reported values of absorbed dose are considered and methods are given for calculating the combined standard uncertainty and an estimate of overall (expanded) uncertainty. The methodology for evaluating components of uncertainty follows ISO procedures (see section 2.3). The traditional concepts of precision and bias are not used. Examples are given in five annexes.

1.2 This guide assumes a working knowledge of statistics. Several statistical texts are included in the references **(1, 2, 3, 4)**.[2]

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

E 170 Terminology Relating to Radiation Measurements and Dosimetry[3]

E 177 Practice for Use of the Terms Precision and Accuracy as Applied to Measurement of a Property of a Material[4]

E 178 Practice for Dealing With Outlying Observations[4]

E 456 Terminology Relating to Quality and Statistics[4]

E 666 Practice for Calculating Absorbed Dose from Gamma or X Radiation[3]

E 876 Practice for Use of Statistics In the Evaluation of Spectrometric Data[5]

E 1026 Practice for Using the Fricke Reference Standard Dosimetry System[3]

E 1249 Practice for Minimizing Dosimetry Errors in Radiation Hardness Testing of Silicon Electronic Devices Using Co-60 Sources[3]

2.2 *ISO/ASTM Standards:*

51204 Practice for Dosimetry in Gamma Irradiation Facilities for Food Processing[3]

51205 Practice for Use of a Ceric-Cerous Sulfate Dosimetry System[3]

51261 Guide for Selection and Calibration of Dosimetry Systems for Radiation Processing[3]

51275 Practice for Use of a Radiochromic Film Dosimetry System[3]

51276 Practice for Use of a Polymethylmethacrylate Dosimetry System[3]

51310 Practice for the Use of a Radiochromic Optical Waveguide Dosimetry System[3]

51401 Practice for Use of a Dichromate Dosimetry System[3]

51431 Practice for Dosimetry in Electron and Bremsstrahlung Irradiation Facilities for Food Processing[3]

51607 Practice for Use of the Alanine-EPR Dosimetry System[3]

2.3 *ICRU Reports:*[6]

ICRU Report 14 Radiation Dosimetry: X-Rays and Gamma Rays with Maximum Photon Energies Between 0.6 and 50 MeV

ICRU Report 17 Radiation Dosimetry: X-Rays Generated at Potentials of 5 to 150 kV

ICRU Report 34 The Dosimetry of Pulsed Radiation

ICRU Report 35 Radiation Dosimetry: Electron Beams with Energies Between 1 and 50 MeV

ICRU Report 37 Stopping Powers for Electrons and Positrons

ICRU Report 60 Radiation Quantities and Units

3. Terminology

3.1 *Definitions:*

3.1.1 *absorbed dose, D*—quantity of radiation energy imparted per unit mass of a specified material. The unit of absorbed dose is the gray (Gy) where 1 gray is equivalent to the

[1] This guide is under the jurisdiction of ASTM Committee E10 on Nuclear Technology and Applications and is the direct responsibility of Subcommittee E10.01 on Dosimetry for Radiation Processing, and is also under the jurisdiction of ISO/TC 85/WG 3.

Current edition approved Jan. 22, 2002. Published March 15, 2002. Originally published as ASTM E 1707–95. Last previous ASTM edition E 1707–95$^{\epsilon 1}$. ASTM E 1707–95$^{\epsilon 1}$ was adopted by ISO in 1998 with the intermediate designation ISO 15572:1998(E). The present International Standard ISO/ASTM 51707:2002(E) is a revision of ISO 15572.

[2] The boldface numbers in parentheses refer to the bibliography at the end of this guide.

[3] *Annual Book of ASTM Standards*, Vol 12.02.

[4] *Annual Book of ASTM Standards*, Vol 14.02.

[5] *Annual Book of ASTM Standards*, Vol 03.06.

[6] Available from International Commission on Radiation Units and Measurements, 7910 Woodmont Ave., Suite 800 Bethesda, MD 20814, U.S.A.

absorption of 1 joule per kilogram (= 100 rad). The mathematical relationship is the quotient of $d\bar{\epsilon}$ by dm, where $d\bar{\epsilon}$ is the mean energy imparted by ionizing radiation to matter of mass dm (see ICRU 60).

$$D = d\bar{\epsilon}/dm \quad (1)$$

3.1.2 *accuracy of measurement*—closeness of the agreement between the result of a measurement and the true value of the measurand.

3.1.3 *calibration curve*—graphical representation of the relationship between dosimeter response and absorbed dose for a given dosimetry system. For a mathematical representation, see *response function*.

3.1.4 *coefficient of variation*—sample standard deviation expressed as a percentage of sample mean value (see 3.1.38 and 3.1.39).

$$(CV) = S_{n-1}/\bar{x} \times 100\ \% \quad (2)$$

3.1.5 *combined standard uncertainty*—standard uncertainty of the result of a measurement when that result is obtained from the values of a number of other quantities, equal to the positive square root of a sum of terms, the terms being the variances or covariances of these other quantities weighted according to how the measurement result varies with changes in these quantities.

3.1.6 *confidence interval*—an interval estimate that contains the mean value of a parameter with a given probability.

3.1.7 *confidence level*—the probability that a confidence interval estimate contains the value of a parameter.

3.1.8 *corrected result*—result of a measurement after correction for the best estimate of systematic error.

3.1.9 *correction*—value that, added algebraically to the uncorrected result of a measurement, compensates for systematic error.

3.1.9.1 *Discussion*—The correction is equal to the negative of the systematic error. Some systematic errors may be estimated and compensated by applying appropriate corrections. However, since the systematic error cannot be known perfectly, the compensation cannot be complete.

3.1.10 *correction factor*—numerical factor by which the uncorrected result of a measurement is multiplied to compensate for a systematic error.

3.1.10.1 *Discussion*—Since the systematic error cannot be known perfectly, the compensation cannot be complete.

3.1.11 *coverage factor*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an overall uncertainty.

3.1.11.1 *Discussion*—A coverage factor, k, is typically in the range of 2 to 3 (see 8.3).

3.1.12 *dosimeter batch*—quantity of dosimeters made from a specific mass of material with uniform composition, fabricated in a single production run under controlled, consistent conditions and having a unique identification code.

3.1.13 *dosimetry system*—a system used for determining absorbed dose, consisting of dosimeters, measurement instruments and their associated reference standards, and procedures for the system's use.

3.1.14 *error (of measurement)*—result of a measurement minus a true value of the measurand.

3.1.14.1 *Discussion*—Since a true value cannot be determined, in practice a conventional true value is used. The quantity is sometimes called" absolute error of measurement" when it is necessary to distinguish it from relative error. If the result of a measurement depends on the values of quantities other than the measurand, the errors of the measured values of these quantities contribute to the error of the result of the measurement.

3.1.15 *expected value*—sum of possible values of a variable weighted by the probability of the value occurring. It is found from the expression:

$$E(v) = \Sigma_i P_i V_i \quad (3)$$

where:
V_i = i^{th} value, and
P_i = probability of i^{th} value.

3.1.16 *influence quantity*—quantity that is not included in the specification of the measurand but that nonetheless affects the result of the measurement.

3.1.16.1 *Discussion*—This quantity is understood to include values associated with measurement reference standards, reference materials, and reference data upon which the result of the measurement may depend, as well as phenomena such as short-term instrument fluctuations and parameters such as temperature, time, and humidity.

3.1.17 *(measurable) quantity*—attribute of a phenomenon, body or substance that may be distinguished qualitatively and determined quantitatively; for example, the specific quantity of interest in this guide is absorbed dose.

3.1.18 *measurand*—specific quantity subject to measurement.

3.1.18.1 *Discussion*—A specification of a measurand may include statements about other quantities such as time, humidity, or temperature. For example, equilibrium absorbed dose in water at 25°C.

3.1.19 *measurement*—set of operations having the object of determining a value of a quantity.

3.1.20 *measurement procedure*—set of operations, in specific terms, used in the performance of particular measurements according to a given method.

3.1.21 *measurement system*—system used for evaluating the measurand.

3.1.22 *measurement traceability*—The ability to demonstrate and document on a continuing basis that the measurement results from a particular measurement system are in agreement with comparable measurement results obtained with a national standard (or some identifiable and accepted standard) to a specified uncertainty.

3.1.23 *method of measurement*—logical sequence of operations used in the performance of measurements according to a given principle.

3.1.23.1 *Discussion*—Methods of measurement may be qualified in various ways such as: substitution method, differential method, and null method.

3.1.24 *outlier*—a measurement result that deviates markedly from others within a set of measurement results.

3.1.25 *overall uncertainty*—quantity defining the interval about the result of a measurement within which the values that could reasonably be attributed to the measurand may be expected to lie with a high level of confidence.

3.1.25.1 *Discussion*—Overall uncertainty is referred to as "expanded uncertainty" (see Guide to the Expression of Uncertainty in Measurement) **(5)**.[7] To associate a specific level of confidence with the interval defined by the overall uncertainty requires explicit or implicit assumptions regarding the probability distribution characterized by the measurement result and its combined standard uncertainty. The level of confidence that may be attributed to this interval can be known only to the extent to which such assumptions may be justified.

3.1.26 *primary–standard dosimeter*—a dosimeter of the highest metrological quality, established and maintained as an absorbed dose standard by a national or international standards organization.

3.1.27 *principle of measurement*—scientific basis of a method of measurement.

3.1.28 *quadrature*—a method of estimating overall uncertainty from independent sources by taking the square root of the sum of the squares of individual components of uncertainty (for example, coefficient of variation).

3.1.29 *random error*—result of a measurement minus the mean result of a large number of measurements of the same measurand that are made under repeatable or reproducible conditions (see 3.1.33 and 3.1.34).

3.1.29.1 *Discussion*—In these definitions (and that for systematic error), the term" mean result of a large number of measurements of the same measurand" is understood to mean "the expected value or mean of all possible measured values of the measurand obtained under conditions of repeatability or reproducibility." This ensures that the definition cannot be misinterpreted to imply that for a series of observations, the random error of an individual observation is known and can be eliminated by applying a correction. The view of this guide is that error is an idealized concept and that errors cannot be known exactly.

3.1.30 *reference–standard dosimeter*—a dosimeter of high metrological quality, used as a standard to provide measurements traceable to and consistent with measurements made using primary–standard dosimeters.

3.1.31 *reference value (of a quantity)*—value attributed to a specific quantity and accepted, sometimes by convention, as having an uncertainty appropriate for a given purpose; for example, the value assigned to the quantity realized by a reference standard.

3.1.31.1 *Discussion*—This is sometimes called "assigned value," or "assigned reference value."

3.1.32 *relative error (of measurement)*—error of measurement divided by a true value of the measurand.

3.1.32.1 *Discussion*—Since a true value cannot be determined, in practice a reference value is used.

3.1.33 *repeatability (of results of measurements)*—closeness of the agreement between the results of successive measurements of the same measurand carried out subject to all of the following conditions: the same measurement procedure, the same observer, the same measuring instrument, used under the same conditions, the same location, and repetition over a short period of time.

3.1.33.1 *Discussion*—These conditions are called "repeatability conditions." Repeatability may be expressed quantitatively in terms of the dispersion characteristics of the results.

3.1.34 *reproducibility (of results of measurements)*—closeness of agreement between the results of measurements of the same measurand, where the measurements are carried out under changed conditions such as differing: principle or method of measurement, observer, measuring instrument, location, conditions of use, and time.

3.1.34.1 *Discussion*—A valid statement of reproducibility requires specification of the conditions changed. Reproducibility may be expressed quantitatively in terms of the dispersion characteristics of the results. In this context, results of measurement are understood to be corrected results.

3.1.35 *response function*—mathematical representation of the relationship between dosimeter response and absorbed dose for a given dosimetry system.

3.1.36 *result of a measurement*—value attributed to a measurand, obtained by measurement.

3.1.36.1 *Discussion*—When the term "result of a measurement" is used, it should be made clear whether it refers to: the indication, the uncorrected result, the corrected result, and whether several values are averaged. A complete statement of the result of the measurement includes information about the uncertainty of the measurement.

3.1.37 *routine dosimeter*—dosimeter calibrated against a primary-, reference-, or transfer-standard dosimeter and used for routine dosimetry measurement.

3.1.38 *sample mean*—a measure of the average value of a data set which is representative of the population. It is determined by summing all the values in the data set and dividing by the number of items (n) in the data set. It is found from the expression:

$$\bar{x} = \frac{1}{n}\sum_i x_i,\ i = 1, 2, 3 \ldots n \tag{4}$$

3.1.39 *sample standard deviation*, S_{n-1}—measure of dispersion of values expressed as the positive square root of the sample variance.

3.1.40 *sample variance*—the sum of the squared deviations from the sample mean divided by ($n-1$), given by the expression:

$$S^2_{n-1} = \frac{\Sigma\,(x_i - \bar{x})^2}{(n-1)} \tag{5}$$

where:

x_i = individual value of parameter with i = 1, 2...n, and
$\bar{x}$ = mean of n values of parameter (see 3.1.38).

3.1.41 *standard uncertainty*—uncertainty of the results of a measurement expressed as a standard deviation.

3.1.42 *systematic error*—mean result of a large number of repeated measurements of the same measurand minus a true value of the measurand.

[7] Available from International Organization for Standardization, Case Postal 56, CH-1211 Geneva 20 Switzerland.

3.1.42.1 *Discussion*—The repeated measurements are carried out under the conditions of the term "repeatability". Like true value, systematic error and its causes cannot be completely known. The error of the result of a measurement may often be considered as arising from a number of random and systematic effects that contribute individual components of error to the error of the result (see Terminologies E 170 and E 456, and ASTM Practice E 177).

3.1.43 *traceability*—see *measurement traceability*.

3.1.44 *transfer–standard dosimeter*—a dosimeter, often a reference–standard dosimeter, suitable for transport between different locations for use as an intermediary to compare absorbed dose measurements.

3.1.45 *true value*—value of measurand that would be obtained by a perfect measurement.

3.1.45.1 *Discussion*—True values are by nature indeterminate and only an idealized concept. In this guide the terms "true value of a measurand" and" value of a measurand" are viewed as equivalent (see 5.1.1).

3.1.46 *Type A evaluation (of standard uncertainty)*—method of evaluation of a standard uncertainty by the statistical analysis of a series of observations.

3.1.47 *Type B evaluation (of standard uncertainty)*—method of evaluation of a standard uncertainty by means other than the statistical analysis of a series of observations.

3.1.48 *uncertainty (of measurement)*—a parameter, associated with a measurand or derived quantity, that characterizes the distribution of the values that could reasonably be attributed to the measurand or derived quantity.

3.1.48.1 *Discussion*—For example, uncertainty may be a standard deviation (or a given multiple of it), or the width of a confidence interval. Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of the results of series of measurements and can be characterized by experimental standard deviations. The other components, which can also be characterized by standard deviations, are evaluated from assumed probability distributions based on experience or other information. It is understood that all components of uncertainty contribute to the distribution.

3.1.49 *uncorrected result*—result of a measurement before correction for the assumed systematic error.

3.1.50 *value (of a quantity)*—magnitude of a specific quantity generally expressed as a number with a unit of measurement, for example, 25 kGy.

4. Significance and Use

4.1 Gamma, electron and x-ray (bremsstrahlung) facilities routinely irradiate a variety of products such as food, medical devices, aseptic packaging and commodities (see ISO/ASTM Practices 51204 and 51431). Process parameters for the products must be carefully controlled to ensure that these products are processed within specifications (see ANSI/AAMI ST31-1990, ANSI/AAMI ST32-1991 and ISO 11137 **(6, 7, 8)**.[8] Accurate dosimetry is essential in process control (see ISO/ASTM Guide 51261). For absorbed dose measurements to be meaningful, the overall uncertainty associated with these measurements must be estimated and its magnitude quantified.

NOTE 1—For a comprehensive discussion of various dosimetry methods applicable to the radiation types and energies discussed in this guide, see ICRU Reports 14, 17, 34, 35 and Reference **(9)**.

4.2 This guide uses the methodology adopted by the International Organization for Standardization for estimating uncertainties in dosimetry for radiation processing (see section 2.3). ASTM traditionally expresses uncertainty in terms of precision and bias where precision is a measure of the extent to which replicate measurements made under specified conditions are in agreement and bias is a systematic error (see ASTM Terminologies E 170 and E 456, and Practice E 177). As seen from this standard, sources of uncertainty are evaluated as either Type A or Type B rather than in terms of precision and bias. Both random and systematic error clearly are differentiated from components of uncertainty. The methodology for treatment of uncertainties is in conformance with current internationally accepted practice. (See Guide to the Expression of Uncertainty in Measurement **(5)**.)

4.3 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 method and procedure used. The quality and utility of the uncertainty quoted for the result of a measurement therefore ultimately depends on the understanding, critical analysis, and integrity of those who contribute to the assignment of its value.

5. Basic Concepts—Components of Uncertainty

5.1 *Measurement*:

5.1.1 The objective of a measurement is to determine the value of the measurand, that is, the value of the specific quantity to be measured. A measurement therefore begins with an appropriate specification of the measurand, the method of measurement, and the measurement procedure.

5.1.2 In general, the result of a measurement is only an approximation or estimate of the value of the measurand and thus is complete only when accompanied by a statement of the uncertainty of that estimate.

5.1.3 In practice, the specification or definition of the measurand depends on the required accuracy of the measurement. The measurand should be defined with sufficient exactness relative to the required accuracy so that for all practical purposes the measurand value is unique.

NOTE 2—Incomplete definition of the measurand can give rise to a component of uncertainty sufficiently large that it must be included in the evaluation of the uncertainty of the measurement result.

5.1.3.1 Although a measurand should be defined in sufficient detail that any uncertainty arising from its incomplete definition is negligible in comparison with the required accuracy of the measurement, it must be recognized that this may not always be practicable. The definition may, for example, be

[8] Available from Association for the Advancement of Medical Instrumentation, 3330 Washington Boulevard, Suite 400, Arlington, VA 22201-4598, U.S.A.

incomplete because it does not specify parameters that may have been assumed, unjustifiably, to have negligible effect; or it may imply conditions that can never fully be met and whose imperfect realization is difficult to take into account.

5.1.4 In many cases, the result of a measurement is determined on the basis of repeated observations. Variations in repeated observations are assumed to arise from not being able to hold completely constant each influence quantity that can affect the measurement result.

5.1.5 The mathematical model of the measurement procedure that transforms the set of repeated observations into the measurement result is of critical importance since, in addition to the observations, it generally includes various influence quantities that are inexactly known. This lack of knowledge contributes to the uncertainty of the measurement result along with the variations of the repeated observations and any uncertainty associated with the mathematical model itself.

5.2 *Errors, Effects, and Corrections*:

5.2.1 In general, a measurement procedure has imperfections that give rise to an error in the measurement result. Traditionally, an error is viewed as having two components, namely, a random component and a systematic component.

5.2.2 Random error presumably arises from unpredictable or stochastic temporal and spatial variations of influence quantities. The effects of such variations, hereafter referred to as random effects, give rise to variations in repeated observations of the measurand. The random error of a measurement result cannot be compensated by correction but it can usually be reduced by increasing the number of observations; its expectation or expected value is zero.

NOTE 3—The experimental standard deviation of the arithmetic mean or average of a series of observations is not the random error of the mean, although it is so referred to in some publications on uncertainty. It is instead a measure of the uncertainty of the mean due to random effects. The exact value of the error in the mean arising from these effects cannot be known. In this guide great care is taken to distinguish between the terms “error” and “uncertainty;” they are not synonyms but represent completely different concepts; they should not be confused with one another or misused.

5.2.3 Systematic error, like random error, cannot be eliminated but it too can often be reduced. If a systematic error arises from a recognized effect of an influence quantity on a measurement result, hereafter referred to as a systematic effect, the effect can be quantified and, if significant in size relative to the required accuracy of the measurement, an estimated correction or correction factor can be applied. It is assumed that after correction, the expectation or expected value of the error arising from a systematic effect is zero.

NOTE 4—The uncertainty of an estimated correction applied to a measurement result to compensate for a systematic effect is not the systematic error. It is instead a measure of the uncertainty of the result due to incomplete knowledge of the value of the correction. In general, the error arising from imperfect compensation of a systematic effect cannot be exactly known.

5.2.4 It is assumed that the result of a measurement has been corrected for all recognized significant systematic effects.

NOTE 5—Often, measuring instruments and systems are adjusted or calibrated using measurement reference standards to eliminate systematic effects; however, the uncertainties associated with these standards must still be taken into account.

5.3 *Uncertainty*:

5.3.1 The uncertainty of the result of a measurement reflects the lack of exact knowledge of the value of the measurand. The result of a measurement after correction for recognized systematic effects is still only an estimate of the value of the measurand because of the uncertainty arising from random effects and from imperfect correction of the result for systematic effects.

NOTE 6—The result of a measurement (after correction) can unknowingly be very close to the value of the measurand (and hence have a negligible error) even though it may have a large uncertainty. Thus the uncertainty of the result of a measurement should not be interpreted as representing the remaining unknown error.

5.3.2 In practice there are many possible sources of uncertainty in a measurement, including:

5.3.2.1 incomplete definition of the measurand;

5.3.2.2 imperfect realization of the definition of the measurand;

5.3.2.3 sampling—the sample measured may not represent the defined measurand;

5.3.2.4 inadequate knowledge of the effects of environmental conditions on the measurement procedure or imperfect measurement of environmental conditions;

5.3.2.5 personal bias in reading analog instruments;

5.3.2.6 instrument resolution or discrimination threshold;

5.3.2.7 values assigned to measurement standards;

5.3.2.8 values of constants and other parameters obtained from external sources and used in the data reduction algorithm;

5.3.2.9 approximations and assumptions incorporated in the measurement method and procedure; and

5.3.2.10 variations in repeated observations of the measurand under apparently identical conditions.

NOTE 7—These sources are not necessarily independent and some may contribute to 5.3.2.10. Of course, an unrecognized systematic effect cannot be taken into account in the evaluation of the uncertainty of the result of a measurement but contributes to its error.

5.3.3 Uncertainty components are classified into two categories based on their method of evaluation, “Type A” and “Type B” (see Section 3). These categories apply to uncertainty and are not substitutes for the words “random” and “systematic”. The uncertainty of a correction for a known systematic effect may be obtained by either a Type A or Type B evaluation, as may be the uncertainty characterizing a random effect.

5.3.4 The purpose of the Type A and Type B classification is to indicate the two different ways of evaluating uncertainty components. Both types of evaluation are based on probability distributions and the uncertainty components resulting from each type are quantified by a standard deviation or a variance.

5.3.5 The population variance u^2 characterizing an uncertainty component obtained from a Type A evaluation is estimated from a series of repeated observations. The best estimate of u^2 is the sample variance s^2(see 3.1.40). The population standard deviation u, the positive square root of u^2, is thus estimated by s and for convenience is sometimes referred to as a Type A standard uncertainty. For an uncertainty