



## Standard Guide for Assessment of Measurement Uncertainty in Fire Tests<sup>1</sup>

This standard is issued under the fixed designation E2536; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reappraisal. A superscript epsilon ( $\epsilon$ ) indicates an editorial change since the last revision or reappraisal.

### INTRODUCTION

The objective of a measurement is to determine the value of the measurand, that is, the physical quantity that needs to be measured. Every measurement is subject to error, no matter how carefully it is conducted. The (absolute) error of a measurement is defined in [Eq 1](#).

All terms in [Eq 1](#) have the units of the physical quantity that is measured. This equation cannot be used to determine the error of a measurement because the true value is unknown, otherwise a measurement would not be needed. In fact, the true value of a measurand is unknowable because it cannot be measured without error. However, it is possible to estimate, with some confidence, the expected limits of error. This estimate is referred to as the uncertainty of the measurement and provides a quantitative indication of its quality.

Errors of measurement have two components, a random component and a systematic component. The former is due to a number of sources that affect a measurement in a random and uncontrolled manner. Random errors cannot be eliminated, but their effect on uncertainty is reduced by increasing the number of repeat measurements and by applying a statistical analysis to the results. Systematic errors remain unchanged when a measurement is repeated under the same conditions. Their effect on uncertainty cannot be completely eliminated either, but is reduced by applying corrections to account for the error contribution due to recognized systematic effects. The residual systematic error is unknown and shall be treated as a random error for the purpose of this standard.

General principles for evaluating and reporting measurement uncertainties are described in the Guide on Uncertainty of Measurements (GUM). Application of the GUM to fire test data presents some unique challenges. This standard shows how these challenges can be overcome. An example to illustrate application of the guidelines provided in this standard can be found in [Appendix X1](#).

$$\epsilon = y - Y \quad (1)$$

*where:*

where:

- $\epsilon$  = measurement error;
- $y$  = measured value of the measurand; and
- $Y$  = true value of the measurand.

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## 1. Scope

1.1 This guide covers the evaluation and expression of uncertainty of measurements of fire test methods developed and maintained by ASTM International, based on the approach presented in the GUM. The use in this process of precision data obtained from a round robin is also discussed.

1.2 The guidelines presented in this standard can also be applied to evaluate and express the uncertainty associated with fire test results. However, it may not be possible to quantify the uncertainty of fire test results if some sources of uncertainty cannot be accounted for. This problem is discussed in more detail in [Appendix X2](#).

1.3 Application of this guide is limited to tests that provide quantitative results in engineering units. This includes, for example, methods for measuring the heat release rate of burning specimens based on oxygen consumption calorimetry, such as Test Method [E1354](#).

1.4 This guide does not apply to tests that provide results in the form of indices or binary results (for example, pass/fail). For example, the uncertainty of the Flame Spread Index obtained according to Test Method [E84](#) cannot be determined.

1.5 In some cases additional guidance is required to supplement this standard. For example, the expression of uncertainty of heat release rate measurements at low levels requires additional guidance and uncertainties associated with sampling are not explicitly addressed.

1.6 This fire standard cannot be used to provide quantitative measures.

1.7 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

## 2. Referenced Documents

[ASTM E2536-21](#)

<https://standards.iteh.ai/catalog/standards/sist/22ec493a-5145-47e2-876f-ee42dff86548/astm-e2536-21>

### 2.1 ASTM Standards:<sup>2</sup>

[E84 Test Method for Surface Burning Characteristics of Building Materials](#)

[E119 Test Methods for Fire Tests of Building Construction and Materials](#)

[E176 Terminology of Fire Standards](#)

[E230 Specification for Temperature-Electromotive Force \(emf\) Tables for Standardized Thermocouples](#)

[E691 Practice for Conducting an Interlaboratory Study to Determine the Precision of a Test Method](#)

[E1354 Test Method for Heat and Visible Smoke Release Rates for Materials and Products Using an Oxygen Consumption Calorimeter](#)

[E2989 Guide for Assessment of Continued Applicability of Reaction to Fire Test Reports Used in Building Regulation](#)

### 2.2 ISO Standards:<sup>3</sup>

[ISO 29473 Fire tests — Uncertainty of measurements in fire tests](#)

[ISO/IEC 17025 General requirements for the competence of testing and calibration laboratories](#)

[GUM Guide to the expression of uncertainty in measurement](#)

### 2.3 CEN Standard:<sup>4</sup>

[EN 13823 Reaction to fire tests for building products – Building products excluding floorings exposed to the thermal attack by a single burning item](#)

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, [www.astm.org](http://www.astm.org), or contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org). For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> Available from International Organization for Standardization, P.O. Box 56, CH-1211, Geneva 20, Switzerland. Standardization (ISO), ISO Central Secretariat, Chemin de Blandonnet 8, CP 401, 1214 Vernier, Geneva, Switzerland, <https://www.iso.org>.

<sup>4</sup> Available from European Committee for Standardization (CEN), Avenue Marnix 17, B-1000, Brussels, Belgium, <http://www.cen.eu>.

### 3. Terminology

3.1 *Definitions*: For definitions of terms used in this guide and associated with fire issues, refer to the terminology contained in Terminology E176. For definitions of terms used in this guide and associated with precision issues, refer to the terminology contained in Practice E691.

#### 3.2 *Definitions of Terms Specific to This Standard*:

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

3.2.2 *combined standard uncertainty, n*—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.

3.2.3 *coverage factor, n*—numerical factor used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty.

3.2.4 *error (of measurement), n*—result of a measurement minus the true value of the measurand; error consists of two components: random error and systematic error.

3.2.5 *expanded uncertainty, n*—quantity defining an interval about the result of a measurement that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand.

3.2.6 *measurand, n*—quantity subject to measurement.

3.2.7 *precision, n*—variability of test result measurements around reported test result value.

3.2.8 *random error, n*—result of a measurement minus the mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions.

3.2.9 *repeatability (of results of measurements), n*—closeness of the agreement between the results of successive independent measurements of the same measurand carried out under repeatability conditions.

3.2.10 *repeatability conditions, n*—on identical test material using the same measurement procedure, observer(s), and measuring instrument(s) and performed in the same laboratory during a short period of time.

3.2.11 *reproducibility (of results of measurements), n*— closeness of the agreement between the results of measurements of the same measurand carried out under reproducibility conditions.

3.2.12 *reproducibility conditions, n*—on identical test material using the same measurement procedure, but different observer(s) and measuring instrument(s) in different laboratories performed during a short period of time.

3.2.13 *standard deviation, n*—a quantity characterizing the dispersion of the results of a series of measurements of the same measurand; the standard deviation is proportional to the square root of the sum of the squared deviations of the measured values from the mean of all measurements.

3.2.14 *standard uncertainty, n*—uncertainty of the result of a measurement expressed as a standard deviation.

3.2.15 *systematic error (or bias), n*—mean that would result from an infinite number of measurements of the same measurand carried out under repeatability conditions minus the true value of the measurand.

3.2.16 *type A evaluation (of uncertainty), n*—method of evaluation of uncertainty by the statistical analysis of series of observations.

3.2.17 *type B evaluation (of uncertainty)*, *n*—method of evaluation of uncertainty by means other than the statistical analysis of series of observations.

3.2.18 *uncertainty of measurement*, *n*—parameter, associated with the result of a measurement, that characterizes the dispersion of the values that could reasonably be attributed to the measurand.

#### 4. Summary of Guide

4.1 This guide provides concepts and calculation methods to assess the uncertainty of measurements obtained from fire tests.

4.2 **Appendix XI** of this guide contains an example to illustrate application of this guide by assessing the uncertainty of heat release rate measured in the Cone Calorimeter (Test Method **E1354**).

#### 5. Significance and Use

5.1 Users of fire test data often need a quantitative indication of the quality of the data presented in a test report. This quantitative indication is referred to as the “measurement uncertainty”. There are two primary reasons for estimating the uncertainty of fire test results.

5.1.1 ISO/IEC 17025 requires that competent testing and calibration laboratories include uncertainty estimates for the results that are presented in a report.

5.1.2 Fire safety engineers need to know the quality of the input data used in an analysis to determine the uncertainty of the outcome of the analysis.

#### 6. Evaluating Standard Uncertainty

6.1 A quantitative result of a fire test  $Y$  is generally not obtained from a direct measurement, but is determined as a function  $f$  from  $N$  input quantities  $X_1, \dots, X_N$ :

$$Y = f(X_1, X_2, \dots, X_N) \quad (2)$$

where: <https://standards.iteh.ai/catalog/standards/sist/22ec493a-5145-47e2-876f-ee42dff86548/astm-e2536-21>

$Y$  = measurand;  
 $f$  = functional relationship between the measurand and the input quantities; and  
 $X_i$  = input quantities ( $i = 1 \dots N$ ).

6.1.1 The input quantities are categorized as:

6.1.1.1 quantities whose values and uncertainties are directly determined from single observation, repeated observation or judgment based on experience, or

6.1.1.2 quantities whose values and uncertainties are brought into the measurement from external sources such as reference data obtained from handbooks.

6.1.2 An estimate of the output,  $y$ , is obtained from **Eq 2** using input estimates  $x_1, x_2, \dots, x_N$  for the values of the  $N$  input quantities:

$$y = f(x_1, x_2, \dots, x_N) \quad (3)$$

Substituting **Eq 2** and **3** into **Eq 1** leads to:

$$y = Y + \varepsilon = Y + \varepsilon_1 + \varepsilon_2 + \dots + \varepsilon_N \quad (4)$$

where:

$\varepsilon_i$  = contribution to the total measurement error from the error associated with  $x_i$ .

6.2 A possible approach to determine the uncertainty of  $y$  involves a large number ( $n$ ) of repeat measurements. The mean value

of the resulting distribution ( $\bar{y}$ ) is the best estimate of the measurand. The experimental standard deviation of the mean is the best estimate of the standard uncertainty of  $y$ , denoted by  $u(y)$ :

$$u(y) \approx \sqrt{s^2(\bar{y})} = \sqrt{\frac{s^2(y)}{n}} = \sqrt{\frac{\sum_{k=1}^n (y_k - \bar{y})^2}{n(n-1)}} \quad (5)$$

where:

$u$  = standard uncertainty,  
 $s$  = experimental standard deviation,  
 $n$  = number of observations;  
 $y_k$  =  $k^{\text{th}}$  measured value, and  
 $\bar{y}$  = mean of  $n$  measurements.

The number of observations  $n$  shall be large enough to ensure that  $\bar{y}$  provides a reliable estimate of the expectation  $\mu_y$  of the random variable  $y$ , and that  $s^2(\bar{y})$  provides a reliable estimate of the variance  $\sigma^2(\bar{y}) = \sigma^2(y)/n$ . If the probability distribution of  $y$  is normal, then standard deviation of  $s(\bar{y})$  relative to  $\sigma(\bar{y})$  is approximately  $[2(n-1)]^{-1/2}$ . Thus, for  $n = 10$  the relative uncertainty of  $s(\bar{y})$  is 24 %, while for  $n = 50$  it is 10 %. Additional values are given in Table E.1 in annex E of the GUM.

6.3 Unfortunately it is often not feasible or even possible to perform a sufficiently large number of repeat measurements. In those cases, the uncertainty of the measurement can be determined by combining the standard uncertainties of the input estimates. The standard uncertainty of an input estimate  $x_i$  is obtained from the distribution of possible values of the input quantity  $X_i$ . There are two types of evaluations depending on how the distribution of possible values is obtained.

6.3.1 *Type A evaluation of standard uncertainty*—A type A evaluation of standard uncertainty of  $x_i$  is based on the frequency distribution, which is estimated from a series of  $n$  repeated observations  $x_{i,k}$  ( $k = 1 \dots n$ ). The resulting equation is similar to Eq 5:

$$u(x_i) \approx \sqrt{s^2(\bar{x}_i)} = \sqrt{\frac{s^2(x_i)}{n}} = \sqrt{\frac{\sum_{k=1}^n (x_{i,k} - \bar{x}_i)^2}{n(n-1)}} \quad (6)$$

where:

$x_{i,k}$  =  $k^{\text{th}}$  measured value; and  
 $\bar{x}_i$  = mean of  $n$  measurements.

6.3.2 *Type B evaluation of standard uncertainty*:

6.3.2.1 A type B evaluation of standard uncertainty of  $x_i$  is not based on repeated measurements but on an a priori frequency distribution. In this case the uncertainty is determined from previous measurements data, experience or general knowledge, manufacturer's specifications, data provided in calibration certificates, uncertainties assigned to reference data taken from handbooks, etc.

6.3.2.2 If the quoted uncertainty from a manufacturer specification, handbook or other source is stated to be a particular multiple of a standard deviation, the standard uncertainty  $u_c(x_i)$  is simply the quoted value divided by the multiplier. For example, the quoted uncertainty is often at the 95 % level of confidence. Assuming a normal distribution this corresponds to a multiplier of two, that is, the standard uncertainty is half the quoted value.

6.3.2.3 Often the uncertainty is expressed in the form of upper and lower limits. Usually there is no specific knowledge about the possible values of  $X_i$  within the interval and one can only assume that it is equally probable for  $X_i$  to lie anywhere in it. Fig. 1 shows the most common example where the corresponding rectangular distribution is symmetric with respect to its best estimate  $x_i$ . The standard uncertainty in this case is given by:

$$u(x_i) = \frac{\Delta X_i}{\sqrt{3}} \quad (7)$$

where:

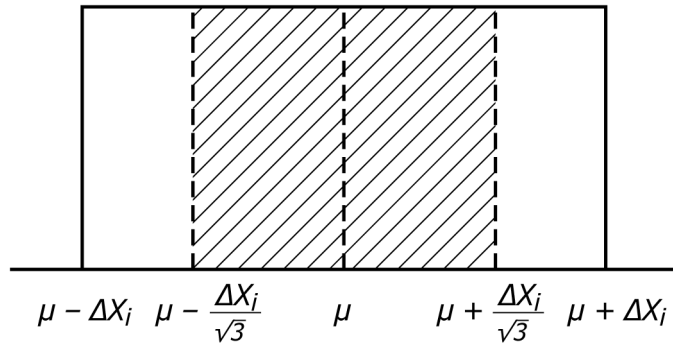


FIG. 1 Rectangular Distribution

$\Delta X_i$  = half-width of the interval.

If some information is known about the distribution of the possible values of  $X_i$  within the interval, that knowledge is used to better estimate the standard deviation.

6.3.3 Accounting for multiple sources of error—The uncertainty of an input quantity is sometimes due to multiple sources error. In this case, the standard uncertainty associated with each source of error has to be estimated separately and the standard uncertainty of the input quantity is then determined according to the following equation:

$$u(x_i) = \sqrt{\sum_{j=1}^m [u_j(x_i)]^2} \tag{8}$$

where:

$m$  = number of sources of error affecting the uncertainty of  $x_i$ ; and

$u_j$  = standard uncertainty due to  $j^{\text{th}}$  source of error.

## 7. Determining Combined Standard Uncertainty

7.1 The standard uncertainty of  $y$  is obtained by appropriately combining the standard uncertainties of the input estimates  $x_1, x_2, \dots, x_N$ . If all input quantities are independent, the combined standard uncertainty of  $y$  is given by:

$$u_c(y) = \sqrt{\sum_{i=1}^N \left[ \frac{\partial f}{\partial X_i} \right]^2 u^2(x_i)} \equiv \sqrt{\sum_{i=1}^N [c_i u(x_i)]^2} \tag{9}$$

where:

$u_c$  = combined standard uncertainty, and

$c_i$  = sensitivity coefficients.

Eq 9 is referred to as the *law of propagation of uncertainty* and based on a first-order Taylor series approximation of  $Y = f(X_1, X_2, \dots, X_N)$ . When the nonlinearity of  $f$  is significant, higher-order terms must be included (see clause 5.1.2 in the GUM for details).

7.2 When the input quantities are correlated, Eq 9 must be revised to include the covariance terms. The combined standard uncertainty of  $y$  is then calculated from:

$$u_c(y) = \tag{10}$$

$$\sqrt{\sum_{i=1}^N [c_i u(x_i)]^2 + 2 \sum_{i=1}^{N-1} \sum_{j=i+1}^N c_i c_j u(x_i) u(x_j) r(x_i, x_j)}$$

where:

$r(x_i, x_j)$  = estimated correlation coefficient between  $X_i$  and  $X_j$ .

Since the true values of the input quantities are not known, the correlation coefficient is estimated on the basis of the measured values of the input quantities.

## 8. Determining Expanded Uncertainty

8.1 It is often necessary to give a measure of uncertainty that defines an interval about the measurement result that may be expected to encompass a large fraction of the distribution of values that could reasonably be attributed to the measurand. This measure is termed expanded uncertainty and is denoted by  $U$ . The expanded uncertainty is obtained by multiplying the combined standard uncertainty by a coverage factor  $k$ :

$$U(y) = ku_c(y) \quad (11)$$

where:

$U$  = expanded uncertainty, and  
 $k$  = coverage factor.

8.1.1 The value of the coverage factor  $k$  is chosen on the basis of the level of confidence required of the interval  $y - U$  to  $y + U$ . In general,  $k$  will be in the range 2 to 3. Because of the Central Limit Theorem,  $k$  can usually be determined from:

$$k = t(v_{eff}) \quad (12)$$

where:

$t$  =  $t$ -distribution statistic for the specified confidence level and degrees of freedom, and  
 $v_{eff}$  = effective degrees of freedom.

**Table 1** gives values of the  $t$ -distribution statistic for different levels of confidence and degrees of freedom. A more complete table can be found in Annex G of the GUM.

8.1.2 The effective degrees of freedom can be computed from the Welch-Satterthwaite formula:

$$v_{eff} = \frac{[u_c(y)]^4}{\sum_{i=1}^N \frac{[u(x_i)]^4}{v_i}} \quad (13)$$

where:

$v_i$  = degrees of freedom assigned to the standard uncertainty of input estimate  $x_i$ .

8.1.3 The degrees of freedom  $v_i$  is equal to  $n - 1$  if  $x_i$  is estimated as the arithmetic mean of  $n$  independent observations (type A standard uncertainty evaluation). If  $u(x_i)$  is obtained from a type B evaluation and it can be treated as exactly known, which is often the case in practice,  $v_i \rightarrow \infty$ . If  $u(x_i)$  is not exactly known,  $v_i$  can be estimated from:

$$v_i \approx \frac{1}{2} \frac{[u_c(x_i)]^2}{[\sigma(u(x_i))]^2} \approx \frac{1}{2} \left( \frac{\Delta u(x_i)}{u(x_i)} \right)^{-2} \quad (14)$$

The quantity in large brackets in **Eq 14** is the relative uncertainty of  $u(x_i)$ , which is a subjective quantity whose value is obtained by scientific judgement based on the pool of available information.

8.2 The probability distribution of  $u_c(y)$  is often approximately normal and the effective degrees of freedom of  $u_c(y)$  is of significant size. When this is the case, one can assume that taking  $k = 2$  produces an interval having a level of confidence of approximately 95.5 %, and that taking  $k = 3$  produces an interval having a level of confidence of approximately 99.7 %.

## 9. Reporting Uncertainty

9.1 The result of a measurement and the corresponding uncertainty shall be reported in the form of  $Y = y \pm U$  followed by the

**TABLE 1 Selected Values of the  $t$ -distribution Statistic**

| Degrees of Freedom | Confidence Level |       | Degrees of Freedom | Confidence Level |      | Degrees of Freedom | Confidence Level |      |
|--------------------|------------------|-------|--------------------|------------------|------|--------------------|------------------|------|
|                    | 95%              | 99%   |                    | 95%              | 99%  |                    | 95%              | 99%  |
| 1                  | 12.71            | 63.66 | 6                  | 2.45             | 3.71 | 20                 | 2.09             | 2.85 |
| 2                  | 4.30             | 9.92  | 7                  | 2.36             | 3.50 | 30                 | 2.04             | 2.75 |
| 3                  | 3.18             | 5.84  | 8                  | 2.31             | 3.36 | 40                 | 2.02             | 2.70 |
| 4                  | 2.78             | 4.60  | 9                  | 2.26             | 3.25 | 50                 | 2.01             | 2.68 |
| 5                  | 2.57             | 4.03  | 10                 | 2.23             | 3.17 | $\infty$           | 1.96             | 2.58 |