# INTERNATIONAL STANDARD

# ISO 29473

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# Fire tests — Uncertainty of measurements in fire tests

*Essais au feu — Incertitude de mesures dans les essais au feu*



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## 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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. 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.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

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## Introduction

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:

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

— 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.

General principles for evaluating and reporting measurement uncertainties are described in ISO/IEC Guide 98-3:2008. Application of ISO/IEC Guide 98-3:2008 to fire test data presents some unique challenges. This International Standard shows how these challenges can be overcome.

# Fire tests — Uncertainty of measurements in fire tests

## 1 Scope

This International Standard gives guidance on the evaluation and expression of uncertainty of fire test method measurements developed and maintained by ISO/TC 92, based on the approach presented in ISO/IEC Guide 98-3.

Application of this International Standard 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, as in ISO 5660-1:2002.

This International Standard does not apply to tests that provide results in the form of indices or binary results (e.g. pass/fail).

In some cases, additional guidance will be required to supplement this International Standard. For example, the expression and use of uncertainty at low levels may require additional guidance and uncertainties associated with sampling are not explicitly addressed.



NOTE 1 The procedures described in this International Standard involve some complex mathematics. Basic concepts of measurement uncertainty are provided in Annex A.



NOTE 2 The guidelines presented in this International Standard may also be used to evaluate and express the uncertainty associated with fire test results. However, it is not always possible to quantify the uncertainty of fire test results as some sources of uncertainty cannot be accounted for.

## 2 Normative references

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

ISO 5660-1:2002, *Reaction-to-fire tests — Heat release, smoke production and mass loss rate — Part 1: Heat release rate (cone calorimeter method)*

ISO 5725-2:1994, *Accuracy (trueness and precision) of measurement methods and results — Part 2: Basic method for the determination of repeatability and reproducibility of a standard measurement method*

ISO 13943, *Fire safety — Vocabulary*

ISO/IEC 17025:2005, *General requirements for the competence of testing and calibration laboratories*

ISO/IEC Guide 98-3:2008, *Uncertainty of measurement — Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)*

ISO/IEC Guide 99:2007, *International vocabulary of metrology — Basic and general concepts and associated terms (VIM)*

 

## 3 Terms, definitions and symbols

For the purposes of this document, the following terms, definitions and symbols apply.

### 3.1 Terms and definitions

**3.1.1**
**measurement uncertainty**
**uncertainty of measurement**
**uncertainty**
non-negative parameter characterizing the dispersion of the quantity values being attributed to a measurand, based on the information used

NOTE Adapted from ISO/IEC Guide 99:2007: the Notes are not included here.

**3.1.2**
**standard measurement uncertainty**
**standard uncertainty of measurement**
**standard uncertainty**
measurement uncertainty expressed as a standard deviation

[ISO/IEC Guide 99:2007, definition 2.30]

**3.1.3**
**Type A evaluation of measurement uncertainty**
**Type A evaluation**
evaluation of a component of measurement uncertainty by a statistical analysis of measured quantity values obtained under defined measurement conditions



NOTE Adapted from ISO/IEC Guide 99:2007: the Notes are not included here.



**3.1.4**
**Type B evaluation of measurement uncertainty**
**Type B evaluation**
evaluation of a component of measurement uncertainty determined by means other than a Type A evaluation of measurement uncertainty

NOTE Modified from ISO/IEC Guide 99:2007: the Example and Note are not included here.

**3.1.5**
**combined standard measurement uncertainty**
**combined standard uncertainty**
standard measurement uncertainty that is obtained using the individual standard measurement uncertainties associated with the input quantities in a measurement model

[ISO/IEC Guide 99:2007, definition 2.31]

**3.1.6**
**expanded measurement uncertainty**
**expanded uncertainty**
product of a combined standard measurement uncertainty and a coverage factor one

NOTE Adapted from ISO/IEC Guide 99:2007: the Notes are not included here and the definition is slighty modified.

 

**3.1.7**
**coverage factor**
number larger than one by which a combined standard measurement uncertainty is multiplied to expand the coverage probability to a specified value

NOTE 1 A coverage factor is usually symbolized k (see also ISO/IEC Guide 98-3:2008, 2.3.6).

NOTE 2 Adapted from ISO/IEC Guide 99:2007.

## 3.2 Symbols

$C$ cone calorimeter orifice coefficient ($m^{1/2} \cdot kg^{1/2} \cdot K^{1/2}$)

$c_i$ sensitivity coefficient of $X_i$

$f$ functional relationship between the measurand and the input quantities (Equation 2)

$k$ coverage factor

$m$ number of sources of error affecting the uncertainty of $X_i$ (Equation 8)

$N$ number of input quantities

$n$ number of observations or measurements

$\dot{Q}$ heat release rate (kW)



$\dot{Q}_b$ burner heat release rate (kW)

$r_o$ stoichiometric oxygen to fuel ratio (kg/kg)



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

$s$ experimental standard deviation

$T_e$ exhaust stack temperature at the cone calorimeter orifice plate flow meter (K)

$t$ t-distribution statistic for the specified level of confidence and effective degrees of freedom

$U$ expanded uncertainty

$u$ standard uncertainty

$u_c$ combined standard uncertainty

$u_j$ standard uncertainty due to $j^{th}$ source of error

$X_i$ $i^{th}$ input quantity

$X_{O_2}$ measured oxygen mole fraction in the exhaust duct

$X_{O_2}^{o}$ ambient oxygen mole fraction in dry air (0,209 5)

$\bar{x}_i$ mean of $n$ measurements

$x_{i,k}$ $k^{th}$ measured value of $X_i$

$Y$ true value of the measurand

$y$ measured value of the measurand

$\bar{y}$ mean of $n$ measurements

$y_k$ $k^{th}$ measured value

$\beta$ number of moles of gaseous combustion products generated per mole of $O_2$ consumed

$\Delta h_c$ net heat of combustion (kJ/kg)

$\Delta P$ pressure drop across the cone calorimeter orifice plate (Pa)

$\Delta X_i$ half-width of the interval [Equation 7)]

$\varepsilon$ measurement error

$\varepsilon_i$ contribution to the total measurement error from the error associated with the input estimate $x_i$

$v_{eff}$ effective degrees of freedom

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

## 4 Principles



The objective of a measurement is to determine the value of the measurand, i.e. 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 as follows:

$$\varepsilon \equiv y - Y \tag{1}$$



where

$\varepsilon$ is the measurement error;

$y$ is the measured value of the measurand;

$Y$ is the true value of the measurand.

All terms in Equation (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 unknown 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 measurement" and provides a quantitative indication of its quality.

Errors of measurement may 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 may be 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 it can be reduced by applying corrections to account for the error contribution due to recognized systematic effects. The residual systematic error is unknown and may be treated as a random error for the purpose of this International Standard.

# 5 Evaluating standard uncertainty

## 5.1 General

A quantitative result of a fire test $Y$ is not normally obtained from a direct measurement, but is determined as a function ($f$) from $N$ input quantities $X_1$, $X_2$, …, $X_N$:

$$Y = f(X_1, X_2, \cdots, X_N) \tag{2}$$

where

$Y$ is measurand;

$f$ is the functional relationship between the measurand;

$X_i$ is input quantities ($i$ = 1 … $N$).

The input quantities may be categorized as quantities whose values and uncertainties are:

— directly determined from single observation, repeated observation or judgment based on experience; or

— brought into the measurement from external sources such as reference data obtained from handbooks.

An estimate of the output, $y$, is obtained from Equation (2) using input estimates $x_1$, $x_2$, …, $x_N$ for the values of the N input quantities:



$$y = f(x_1, x_2, \cdots, x_N) \tag{3}$$

Substituting Equations (2) and (3) into Equation (1) leads to:



$$y = Y + \varepsilon = Y + \varepsilon_1 + \varepsilon_2 + \cdots + \varepsilon_N \tag{4}$$

where

$\varepsilon_i$ is the contribution to the total measurement error from the error associated with the input estimate $x_i$.

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 $u(y)$:

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

where

$u$ is standard uncertainty;

$s$ is the experimental standard deviation;

$n$ is the number of observations;

$y_k$ is the $k^{th}$ measured value;

$\bar{y}$ is the mean of $n$ measurements.

The number of observations $n$ should 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 $\sigma^2(\bar{y}) = \sigma^2(y)/n$.

NOTE If the probability distribution of $y$ is normal, then the 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 percent, while for $n = 50$ it is 10 percent. Additional values are given in Table E.1 in ISO/IEC Guide 98-3:2008.

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.

## 5.2 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 $x_{i,k}$ ($k = 1 \ldots n$). The resulting equation is similar to Equation (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

$x_{i,k}$ is the $k^{\text{th}}$ measured value;

$\bar{x}_i$ is the mean of $n$ measurements.



NOTE Type A evaluations of standard uncertainty are rare in fire tests as repeated measurements are not common.

## 5.3 Type B evaluation of standard uncertainty

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 measurement data, experience or general knowledge, manufacturer's specifications, data provided in calibration certificates, uncertainties assigned to reference data taken from handbooks, etc.

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 $u(x_i)$ 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, i.e. the standard uncertainty is half the quoted value.

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. Figure 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

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

 