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Fire tests — Uncertainty of measurements in fire tests

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National foreword

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INTERNATIONAL STANDARD

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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.

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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.

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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.

INTERNATIONAL STANDARD **ISO 29473:2010(E)**

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

β number of moles of gaseous combustion products generated per mole of O_2 consumed

Δh_c net heat of combustion (kJ/kg)

ΔP pressure drop across the cone calorimeter orifice plate (Pa)

ΔX_i half-width of the interval [Equation 7)]

ε measurement error

ε_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

ε 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 ($i = 1 \ldots N$).

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

ε_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 ($\overline{y}$) 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 $u(y)$:

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

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;

$\overline{y}$ 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 μ_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):

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

where

$x_{i,k}$ is the k^{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:

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

where

ΔX_i is the half-width of the interval.

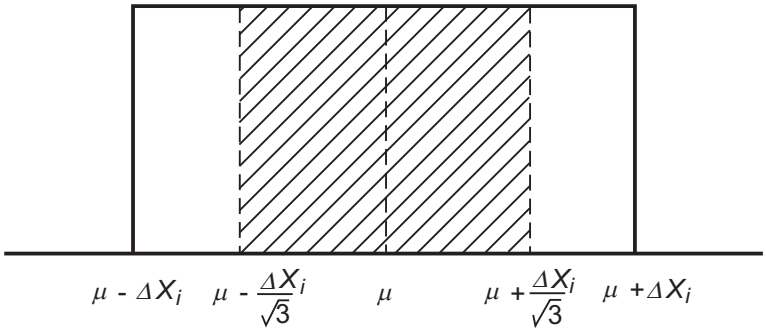


Figure 1 — Rectangular distribution

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.

5.4 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 in accordance with the following equation:

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

where

m is the number of sources of error affecting the uncertainty of x_i;

u_j is the standard uncertainty due to j^{th} source of error.

6 Determining combined standard uncertainty

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

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

where

u_c is a combined standard uncertainty;

c_i are sensitivity coefficients.

Equation (9) is referred to as the *law of propagation of uncertainty* and based on a first-order Taylor series approximation of $Y = f(X_1, X_2, \ldots, X_N)$. When the non-linearity of f is significant, higher-order terms shall be included (see 5.1.2 in ISO/IEC Guide 98-3 for details).

When the input quantities are correlated, Equation (9) shall be revised to include the covariance terms. The combined standard uncertainty of y is then calculated from:

$$u_c(y) = \sqrt{\sum_{i=1}^{N}\left[c_i u(x_i)\right]^2 + 2\sum_{i=1}^{N-1}\sum_{j=i+1}^{N} c_i c_j u(x_i)\, u(x_j)\, r(x_i, x_j)} \tag{10}$$

where

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

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

7 Determining expanded uncertainty

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 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:

$$U(y) = k u_c(y) \tag{11}$$

where

U is expanded uncertainty;

k is the coverage factor.

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 (CLT), k can usually be determined from:

$$k = t(v_{\text{eff}}, \alpha/2) \tag{12}$$

where

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

v_{eff} is effective degrees of freedom.

(confidence level: 100 (1-α) %)

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 ISO/IEC Guide 98-3:2008.

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	∞	1,96	2,58

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

$$\nu_{\text{eff}} = \frac{\left[u_{\text{c}}(y)\right]^4}{\sum_{i=1}^{N} \frac{\left[u(x_i)\right]^4}{\nu_i}} \tag{13}$$

where

ν_i is the degree of freedom assigned to the standard uncertainty of input estimate x_i.

The degrees of freedom ν_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, $\nu_i \to \infty$. If $u(x_i)$ is not exactly known, ν_i can be estimated from:

$$\nu_i \approx \frac{1}{2} \frac{\left[u_{\text{c}}(x_i)\right]^2}{\left\{\sigma\left[u(x_i)\right]\right\}^2} \approx \frac{1}{2}\left[\frac{\Delta u(x_i)}{u(x_i)}\right]^{-2} \tag{14}$$

The quantity in large brackets in Equation (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.

The probability distribution of $u_{\text{c}}(y)$ is often approximately normal and the effective degrees of freedom of $u_{\text{c}}(y)$ 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 percent, and that taking $k = 3$ produces an interval having a level of confidence of approximately 99,7 percent.

8 Reporting uncertainty

The result of a measurement and the corresponding uncertainty should be reported in the form of $Y = y + U$ followed by the units of y and U. Alternatively, the relative expanded uncertainty $U/|y|$ in percent can be specified instead of the absolute expanded uncertainty. In either case the report should describe how the measurand Y is defined, specify the approximate confidence level and explain how the corresponding coverage factor was determined. The former can be done by reference to the appropriate fire test standard.

The report should also include a discussion of sources of uncertainty that are not addressed by the analysis.

9 Summary of procedure for evaluating and expressing uncertainty

The procedure for evaluating and expressing uncertainty of fire test results involves the following steps:

1) Express mathematically the relationship between the measurand Y and the input quantities X_i upon which Y depends: $Y = f(X_1, X_2, \ldots, X_N)$.

2) Determine x_i, the estimated value for each input quantity X_i.

3) Identify all sources of error for each input quantity and evaluate the standard uncertainty $u(x_i)$ for each input estimate x_i.

4) Evaluate the correlation coefficient for estimates of input quantities that are dependent.

5) Calculate the result of the measurement, i.e. the estimate y of the measurand Y from the functional relationship f using the estimates x_i of the input quantities X_i obtained in step 2.

6) Determine the combined standard uncertainty $u_c(y)$ of the measurement result y from the standard uncertainties and correlation coefficients associated with the input estimates as described in Clause 6.

7) Select a coverage factor k on the basis of the desired level of confidence as described in Clause 7 and multiply $u_c(y)$ by this value to obtain the expanded uncertainty U.

8) Report the result of the measurement y together with its expanded uncertainty U as discussed in Clause 8.

An example from heat release measurements in the cone calorimeter illustrating the application of this procedure can be found in Annex C.

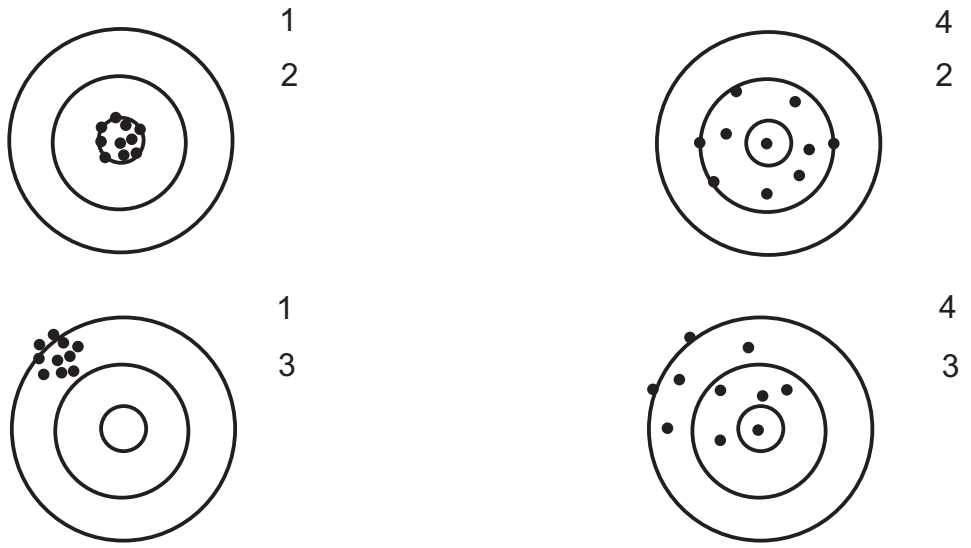
Annex A
(informative)

Basic concepts of measurement uncertainty

The objective of a measurement is to determine the value of the measurand, i.e. the quantity being measured. Measurements are not perfect and give rise to errors. The true value of a measurand can therefore never be determined because measurement errors cannot be eliminated.

The purpose of measurement uncertainty analysis is to quantify the quality of a measurement by establishing limits of the measurement errors at a specified level of confidence. Sometimes the term *accuracy* is used to describe the quality of a measurement. However, this term is ambiguous. For example, what is twice the accuracy of ± 2 %? Is it ± 1 % or ± 4 %? To avoid this ambiguity, the term *uncertainty* is preferred and used in ISO/IEC Guide 98-3 and in this International Standard.

Measurement errors can be random or systematic. A series of measurements of a measurand performed under the same conditions results in values that are randomly scattered around a mean value. The scatter is due to the effects of sources of random error. Random errors cannot be eliminated, but the corresponding uncertainty can be reduced by increasing the number of measurements and applying a statistical analysis. Systematic errors remain unchanged when measurements are repeated. Systematic errors should be eliminated as much as possible, for example through calibration of the measuring equipment. Remaining systematic errors for the purpose of uncertainty analysis are lumped with random errors. Figure A.1 illustrates the effect of random and systematic errors on measurement uncertainty. The centre of the target is the true value.



Key

1 low random error
2 low systematic error
3 high systematic error
4 high random error

Figure A.1 — Effect of random and systematic errors on measurement uncertainty

The first step in an uncertainty analysis is to identify all sources of error. The sources are grouped into two categories based on the method used to evaluate the associated uncertainty. A Type A evaluation is based on a statistical analysis of repeated observations. A Type B evaluation is based on other means, e.g. manufacturer's specifications, engineering judgement, data in the literature, etc. The uncertainty for each source of error, regardless of the type of evaluation, is expressed as a standard deviation and is referred to as the *standard uncertainty*. The standard uncertainties for all sources of error are then combined into an overall value of uncertainty called the *combined standard uncertainty*. The level of confidence of the combined standard uncertainty, i.e. the probability that the true value is within one combined standard uncertainty on either side of the measured value, is approximately 68 %. The confidence level is usually increased by multiplying the combined standard uncertainty by a constant, referred to as the *coverage factor*. A coverage factor of 2 is commonly used to raise the confidence level to approximately 95 %.

Annex B
(informative)

Uncertainty of fire test results

This International Standard provides guidance for evaluating the uncertainty of measurements in fire tests. The process of estimating the overall uncertainty of final fire test results is more complex and involves at least the following three sources:

— uncertainties in the test conditions;

— uncertainties associated with the specimen being tested;

— uncertainties in the measurements according to this International Standard.

In some cases it is possible to determine how the uncertainties from these three sources affect the overall uncertainty of the final fire test result. Total heat release measured in the cone calorimeter (ISO 5660-1:2002) is an example of that.

a) The uncertainty of the total heat release associated with the test conditions is primarily due to errors in the heat flux measurements. ISO 5660-1:2002 specifies that the accuracy of the heat flux meter shall be within ± 3 %. The uncertainty associated with the heat flux measurements can therefore be accounted for.

b) The uncertainty of the heat release rate associated with the specimen being tested is primarily due to variations in the thickness and area of the specimen. The actual thickness can be measured with great accuracy and since the total heat release is proportional to the volume of the specimen, corrections can be made to account for the uncertainty due to variations in specimen size.

c) The uncertainty of heat release measurements in the cone calorimeter is illustrated in Annex C by means of an example.

However, it is often not possible to account for all sources contributing to the uncertainty of fire test results. Measuring the fire resistance of a building element based on a furnace test in accordance with ISO 834 [1] is a good example. In this case it is not possible to quantify the contribution to the overall uncertainty due to variations in the thermal exposure conditions, specimen construction details, exact location of the unexposed surface thermocouples, etc. The sources of uncertainty that cannot be accounted for might in fact be the major contributors, in which case it is not feasible to develop a meaningful estimate of the overall uncertainty. The usefulness of this International Standard is then limited to evaluating and expressing the uncertainty of measurements that are made during the test.

Annex C
(informative)

Example of estimating the uncertainty in heat release measurements in the cone calorimeter

NOTE Heat release rate measured in the cone calorimeter in accordance with ISO 5660-1:2002 is used here to illustrate the application of the guidelines provided in this document.

C.1 Express the relationship between the measurand Y and the input quantities X_i

The heat release rate is calculated in accordance with Equation (7) in ISO 5660-1:2002:

$$\dot{Q} = \left(\frac{\Delta h_c}{r_o} \right) 1{,}10\ C \sqrt{\frac{\Delta P}{T_e}} \left[\frac{X^o_{O_2} - X_{O_2}}{1{,}105 - 1{,}5 X_{O2}} \right] \tag{C.1}$$

where

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

Δh_c is the net heat of combustion (kJ/kg);

r_o is the stoichiometric oxygen to fuel ratio (kg/kg);

C is the orifice coefficient ($m^{1/2} \cdot kg^{1/2} \cdot K^{1/2}$);

ΔP is the pressure drop across the orifice plate (Pa);

T_e is the exhaust stack temperature at the orifice plate flow meter (K);

$X^o_{O_2}$ is the ambient oxygen mole fraction in dry air (0,209 5);

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

The ratio of Δh_c to r_o is referred to as “Thornton's constant”. The average value of this constant is 13,100 kJ/kg O_2, which is accurate to within ± 5 % for a large number of organic materials [2].

Equation (C.1) is based on the assumption that the standard volume of the gaseous products of combustion is 50 % larger than the volume of oxygen consumed in combustion. This is correct for complete combustion of methane. However, for pure carbon there is no increase in volume because one mole of CO_2 is generated per mole of O_2 consumed. For pure hydrogen the volume doubles as two moles of water vapour are generated per mole O_2 consumed. A more accurate form of Equation (C.1) that takes the volume increase into account is as follows [3]:

$$\dot{Q} = \left(\frac{\Delta h_c}{r_o} \right) 1{,}10\ C \sqrt{\frac{\Delta P}{T_e}} \left[\frac{X^o_{O_2} - X_{O_2}}{1 + (\beta - 1) X^o_{O_2} - \beta X_{O2}} \right] \tag{C.2}$$

where β is the number of moles of gaseous combustion products generated per mole of O_2 consumed.

This is the equation that is used to estimate the uncertainty of heat release rate measurements in the cone calorimeter. Hence, the output and input quantities are as follows:

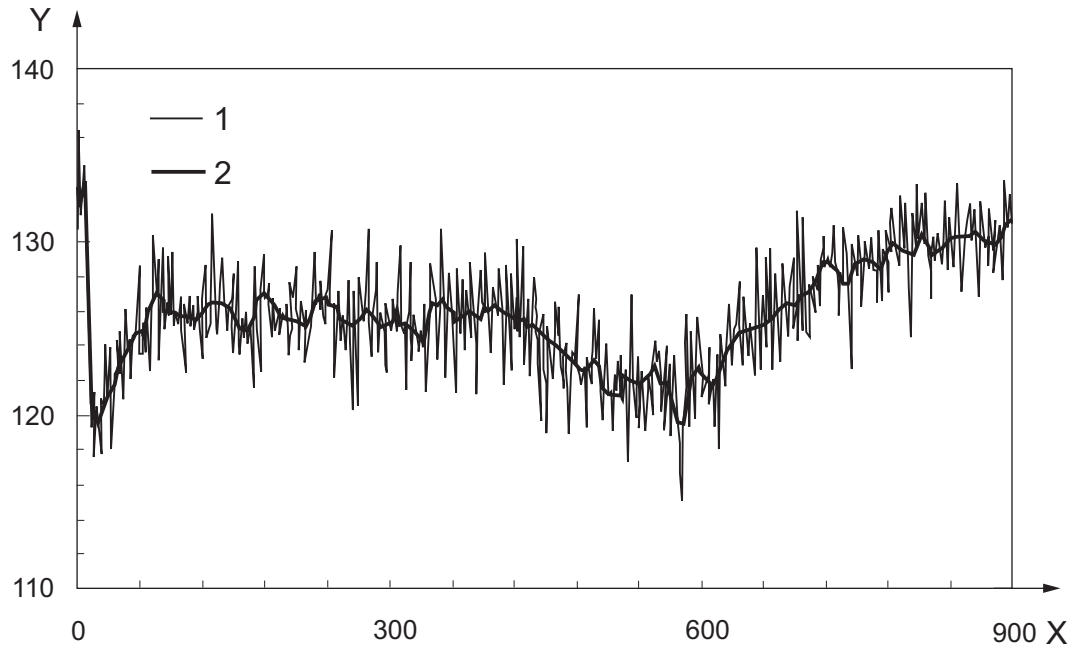
$$Y \equiv \dot{Q},\ X_1 \equiv \frac{\Delta h_c}{r_o},\ X_2 = C,\ X_3 \equiv \Delta P,\ X_4 = T_e,\ X_5 = X_{O_2},\ X_6 = \beta \tag{C.3}$$

Note that in a test $\dot{Q}$ is calculated as a function of time based on the input quantities measured at discrete time intervals Δt.

C.2 Determine x_i, the estimated value of X_i for each input quantity

For the purpose of this example, a 19 mm thick slab of western red cedar was tested at a heat flux of 50 kW/m^2. The test was conducted in the horizontal orientation with the retainer frame. The spark igniter was used and the test was terminated after 15 min. The corresponding measured values of ΔP (X_3), T_e (X_4) and X_{O_2} (X_5) are shown as a function of time in Figures C.1, C.2 and C.3, respectively. Note that the latter is shifted over the delay time of the oxygen analyzer to synchronize X_5 with the other two measured input quantities.

The first input quantity is estimated as $X_1 = \Delta h_c/r_o \approx$ 13,100 kJ/kg $= x_1$, which is based on the average for a large number of organic materials [2]. The orifice constant was obtained from a methane gas burner calibration as described in 10.2.4 of ISO 5660-1:2002 and is equal to $X_2 = C \approx$ 0,0443 0 m$^{1/2}$ kg$^{1/2}$ K$^{1/2}$. Finally, the mid value of 1,5 is used to estimate the expansion factor β.



Key

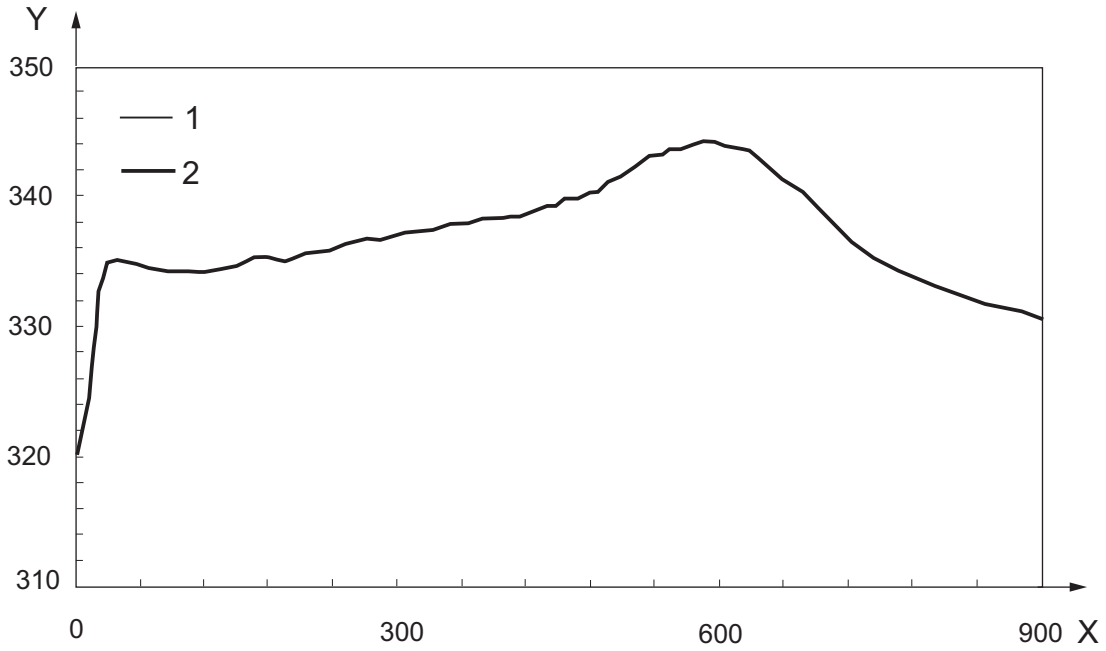
X time(s)

Y differential pressure (Pa)

1 differential pressure

2 eleven-point moving average

Figure C.1 — Differential pressure measurements



Key

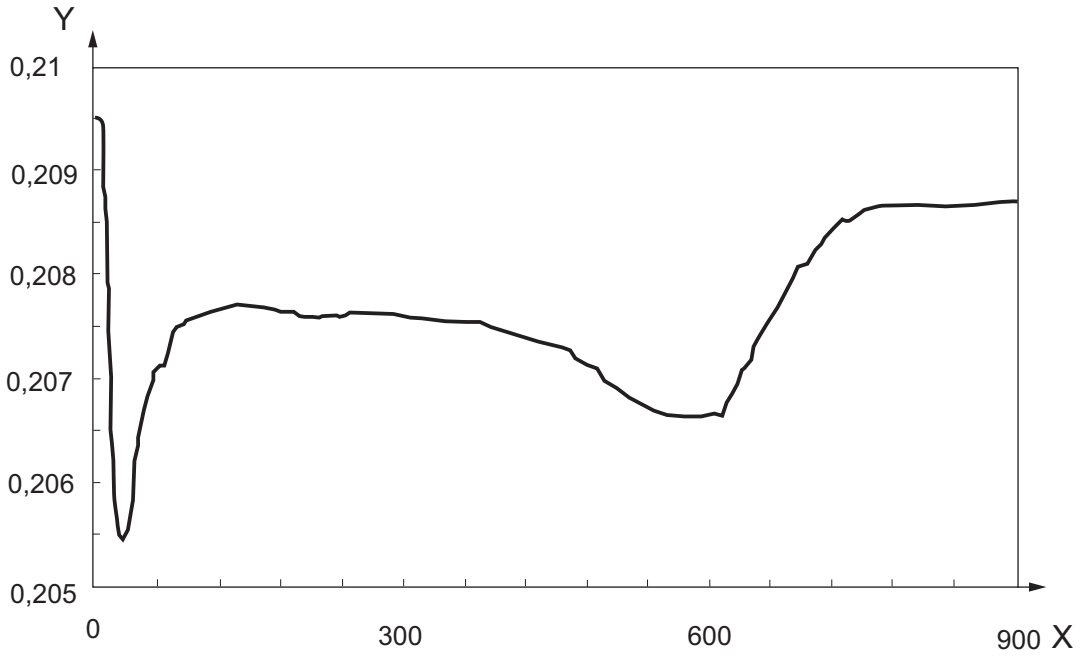
X time(s)

Y stack temperature (K)

1 stack temperature

2 eleven-point moving average

Figure C.2 — Stack temperature measurements



Key

X time(s)

Y oxygen mole fraction

Figure C.3 — Oxygen mole fraction measurements

C.3 Identify all sources of error and evaluate the standard uncertainty for each X_i

C.3.1 Standard uncertainty of $\Delta h_c/r_o$

The average value of 13,100 kJ/kg is reported in the literature to be accurate to within ± 5 % for a large number of organic materials[2]. The probability distribution is assumed to be rectangular, which, in accordance with Equation (7) leads to:

$$u(x_1) \approx \frac{\Delta x_1}{\sqrt{3}} = \frac{0{,}05 \times 13{,}100}{\sqrt{3}} = 378 \frac{\text{kJ}}{\text{kg}} \tag{C.4}$$

C.3.2 Standard uncertainty of C

The orifice constant was obtained from a methane gas burner calibration. The burner was supplied with 99,99 % pure methane at a flow corresponding to a heat release rate of approximately 5 kW. The value of C was calculated in accordance with Equation (5) in ISO 5660-1:2002:

$$C = \frac{\dot{Q}_b}{12{,}540 \times 1{,}10} \sqrt{\frac{T_e}{\Delta P}} \left[\frac{1{,}105 - 1{,}5 X_{O_2}}{X^o_{O_2} - X_{O_2}} \right] \tag{C.5}$$

where $\dot{Q}_b$ is the burner heat release rate (kW).

Note that Equation (5) in ISO 5660-1:2002 assumes that $\dot{Q}_b$ is exactly 5 kW. Equation (C.5) is preferred because the burner heat release rate is never exactly 5 kW.

After a two-minute baseline period, the methane supply valve was opened and the gas burner was ignited. For the next five minutes, the burner was supplied with methane at a flow rate corresponding to a heat release rate of approximately 5 kW. The methane supply valve was then closed and the calibration was terminated two minutes later. During the entire nine minutes, data were collected at one-second intervals.

The orifice constant was estimated as 0,044 30 $m^{1/2}$ $g^{1/2}$ $K^{1/2}$ on the basis of the average of 180 values calculated every second in accordance with Equation (C.5) during the final three min. of the burn. The uncertainty due to the variations of C during this three-minute period can be calculated in accordance with Equation (C.5) and is equal to ± 0,000 07 $m^{1/2} \cdot kg^{1/2}$ $K^{1/2}$.

Some uncertainty is associated with the fact that C is not a true constant, but varies slightly as a function of the heat release rate. To determine this component of the uncertainty, methane gas burner calibrations were performed at heat release rate levels of nominally 1, 3, 5, 7, and 9 kW. The resulting C values are given in Table C.1. The corresponding uncertainty can be estimated from the standard deviation and is equal to 0,000 20 $m^{1/2}$ $kg^{1/2}$ $K^{1/2}$.

The uncertainty of C is also partly due to errors in measuring $\dot{Q}_b$, T_e, ΔP, and X_{O_2}. These measurement errors consist of two components: the calibration error of the sensor and the measurement error of the data acquisition system. The former is determined from the sensor's calibration certificate or standard. The latter can be found on the manufacturer's data acquisition system specification sheet and is usually a function of the analog signal that is measured. For example, the stack thermocouple that was used for the measurements described in this annex conforms to ASTM E 230, which specifies a limit of error for Type K thermocouples of ± 2,2 K. Assuming a rectangular probability distribution, in accordance with Equation (7), this corresponds to a standard uncertainty of ± 1,27 K. The accuracy of Type K thermocouple measurements in accordance with the data acquisition specification sheet based on a normal distribution and three standard deviations is equal to ± 1 K, which leads to a standard uncertainty of ± 0,33 K. The combined uncertainty based on Equation (8) is ± 1,31 K.

Table C.1 — Uncertainty of C due to non-linearity

$\dot{Q}_b$ (kW)	C ($m^{1/2}·kg^{1/2}·K^{1/2}$)
1,03	0,043 82
2,97	0,044 06
4,92	0,044 30
6,94	0,044 08
8,82	0,044 27
Mean	0,044 11
Standard Deviation	0,000 20

The standard uncertainties of the methane flow and differential pressure measurements are determined in a similar manner as for the stack temperature, except that the data acquisition measurement uncertainty component is determined based on the manufacturer's specifications as a function of the sensor signal in volts. The standard uncertainty of the oxygen mole fraction measurement is also determined in a similar manner, except that the sensor calibration uncertainty component is based on the drift that is specified in ISO 5660-1:2002. Clause 6.11 of the same standard specifies that the drift shall not exceed 50 ppm over a 30 min period. Since the methane calibration was performed over less than 30 min, the corresponding standard uncertainty should not exceed $\pm$ 50/√3 ppm ≈ $\pm$ 29 ppm.

Note that the uncertainties due to noise of the $\dot{Q}_b$, T_e, ΔP, and X_{O_2} measurements are not explicitly considered because they are accounted for by the uncertainty associated with the variations of C during the three-minute period over which the orifice constant is determined. The combined standard uncertainty of C due to measurement errors of the input quantities can now be determined from the law of propagation of uncertainty for independent input quantities, Equation (9). The sensitivity coefficients are given by:

$$\frac{\partial C}{\partial \dot{Q}_b} = \frac{1}{12,540 \times 1,10}\sqrt{\frac{T_e}{\Delta P}}\left[\frac{1,105 - 1,5X_{O_2}}{X^o_{O_2} - X_{O_2}}\right] \tag{C.6}$$

$$\frac{\partial C}{\partial T_e} = \frac{1}{2}\frac{\dot{Q}_b}{12,540 \times 1,10}\sqrt{\frac{1}{T_e \Delta P}}\left[\frac{1,105 - 1,5X_{O_2}}{X^o_{O_2} - X_{O_2}}\right] \tag{C.7}$$

$$\frac{\partial C}{\partial \Delta P} = -\frac{1}{2}\frac{\dot{Q}_b}{12,540 \times 1,10}\sqrt{\frac{T_e}{\Delta P^3}}\left[\frac{1,105 - 1,5X_{O_2}}{X^o_{O_2} - X_{O_2}}\right] \tag{C.8}$$

and

$$\frac{\partial C}{\partial X_{O_2}} = \frac{\dot{Q}_b}{12,540 \times 1,10}\sqrt{\frac{T_e}{\Delta P}}\left[\frac{1,105 - 1,5X^o_{O_2}}{\left(X^o_{O_2} - X_{O_2}\right)^2}\right] \tag{C.9}$$

The resulting combined uncertainty due to flow rate, temperature, pressure and oxygen mole fraction measurement error is 0,000 19 $m^{1/2}·kg^{1/2}·K^{1/2}$. Finally, combination with the uncertainties due to noise and non-linearity leads to the following total combined uncertainty of C:

$$u(x_2) = \sqrt{0,000\,20^2 + 0,000\,07^2 + 0,000\,19^2} = 0,000\,28 \ \ m^{1/2} \cdot kg^{1/2} \cdot K^{1/2} \tag{C.10}$$

C.3.3 Standard uncertainty of ΔP

The standard uncertainty of ΔP consists of three components: the calibration error of the sensor, the measurement error of the data acquisition system, and uncertainty due to noise. The first two components are determined as discussed in the previous clause. To estimate the third component, an 11-point moving average is calculated as ΔP versus time (see Figure C.1). The uncertainty due to noise is then determined as the standard deviation of the difference between the actual differential pressure measurement and the moving average over the entire test duration.

C.3.4 Standard uncertainty of T_e

The standard uncertainty of T_e consists of the same three components as ΔP. The three components are estimated as described in C.3.3.

C.3.5 Standard uncertainty of X_{O_2}

The standard uncertainty of X_{O_2} also consists of the same three components. The uncertainty due to the noise in this case is estimated as ± 50 ppm, based on the fact that 6.11 of ISO 5660-1:2002 specifies that the noise of the oxygen analyser output based on the root-mean-square value shall not exceed ± 50 ppm over a 30-min period. Based on the same clause of ISO 5660-1:2002, the uncertainty due to drift is estimated to increase linearly over time at a rate of 50 ppm over 30 min.

C.3.6 Standard uncertainty of β

The expansion factor ranges between 1 and 2. The probability distribution is assumed to be rectangular, which, in accordance with Equation (7) leads to:

$$u(x_6) \approx \frac{\Delta x_6}{\sqrt{3}} = \frac{0,5}{\sqrt{3}} = 0,29 \qquad \text{(C.11)}$$

C.4 Evaluate the correlation coefficient for dependent input quantities

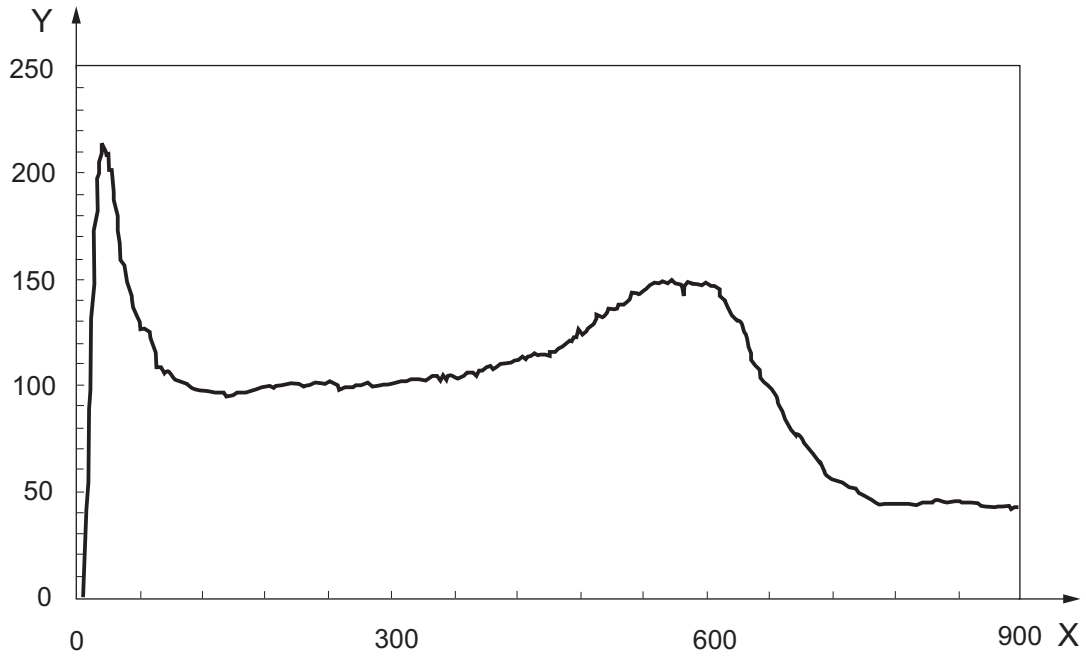
$\Delta h_c/r_o$, C, and β are constants and do not result in any covariance terms in Equation (10). The correlation coefficients for the measured input quantities are given in Table C.2.

Table C.2 — Correlation coefficients for measured input quantities

	ΔP	T_e	X_{O_2}
ΔP	1,00	–0,57	0,76
T_e	–0,57	1,00	–0,64
X_{O_2}	0,76	–0,64	1,00

C.5 Calculate y using the input estimates x_i obtained in C.2

Figure C.4 shows the resulting heat release rate vs. time calculated in accordance with Equation (C.2) using the input estimates obtained in C.2.



Key

X time(s)

Y heat release rate (kW/m^2)

Figure C.4 — Heat release rate versus time

C.6 Determine the combined standard uncertainty $u_c(y)$

The combined standard uncertainty of the heat release rate at every time step can now be determined from the law of propagation of uncertainty, Equation (10). The sensitivity coefficients are given by:

$$\frac{\partial \dot{Q}}{\partial\left(\frac{\Delta h_c}{r_o}\right)} = 1{,}10C\sqrt{\frac{\Delta P}{T_e}}\left[\frac{X_{O_2}^o - X_{O_2}}{1+(\beta-1)X_{O_2}^o - \beta X_{O_2}}\right] \tag{C.12}$$

$$\frac{\partial \dot{Q}}{\partial C} = \left(\frac{\Delta h_c}{r_o}\right)1{,}10\sqrt{\frac{\Delta P}{T_e}}\left[\frac{X_{O_2}^o - X_{O_2}}{1+(\beta-1)X_{O_2}^o - \beta X_{O_2}}\right] \tag{C.13}$$

$$\frac{\partial \dot{Q}}{\partial \Delta P} = \frac{1}{2}\left(\frac{\Delta h_c}{r_o}\right)1{,}10C\sqrt{\frac{1}{\Delta P T_e}}\left[\frac{X_{O_2}^o - X_{O_2}}{1+(\beta-1)X_{O_2}^o - \beta X_{O_2}}\right] \tag{C.14}$$

$$\frac{\partial \dot{Q}}{\partial T_e} = -\frac{1}{2}\left(\frac{\Delta h_c}{r_o}\right)1{,}10C\sqrt{\frac{\Delta P}{T_e^3}}\left[\frac{X_{O_2}^o - X_{O_2}}{1+(\beta-1)X_{O_2}^o - \beta X_{O_2}}\right] \tag{C.15}$$

$$\frac{\partial \dot{Q}}{\partial X_{O_2}} = -\left(\frac{\Delta h_c}{r_o}\right) 1{,}10 C \sqrt{\frac{\Delta P}{T_e}} \left[\frac{1 - X_{O_2}^o}{\left(1 + (\beta - 1) X_{O_2}^o - \beta X_{O_2}\right)^2} \right] \tag{C.16}$$

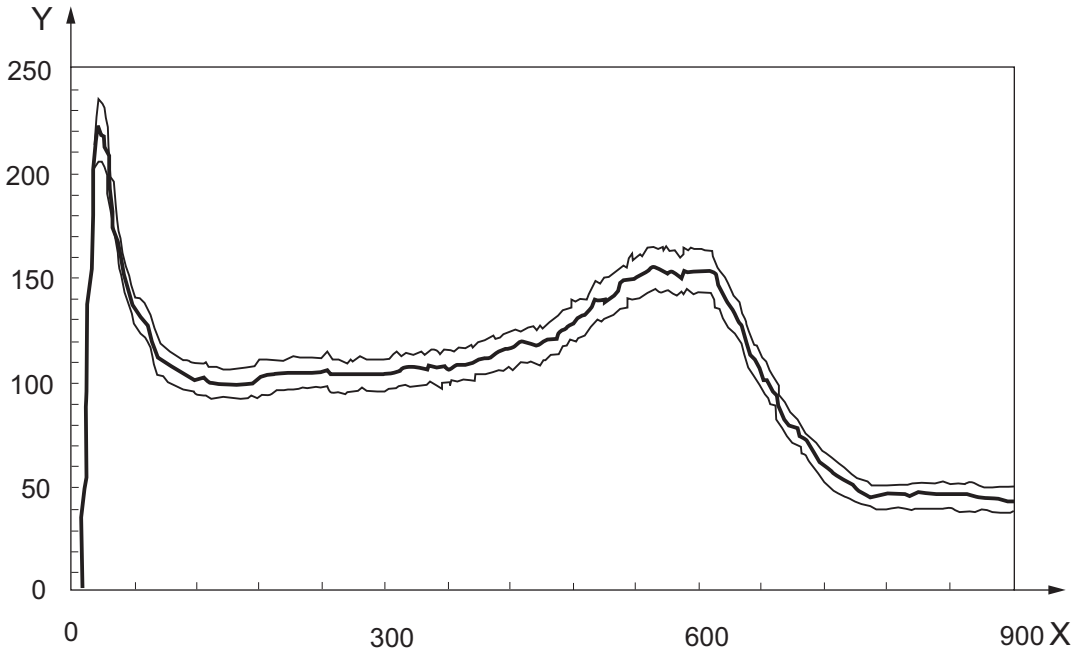
$$\frac{\partial \dot{Q}}{\partial \beta} = -\left(\frac{\Delta h_c}{r_o}\right) 1{,}10 C \sqrt{\frac{\Delta P}{T_e}} \left[\frac{\left(X_{O_2}^o - X_{O_2}\right)^2}{\left(1 + (\beta - 1) X_{O_2}^o - \beta X_{O_2}\right)^2} \right] \tag{C.17}$$

C.7 Select a coverage factor k

The coverage factor is estimated at $k = 2$ for a level of confidence of approximately 95 %, based on the assumption that the probability distribution of the combined standard uncertainty is approximately normal and the degrees of freedom is significant.

C.8 Report the result of the measurement y together with its expanded uncertainty U

Figure C.5 shows the resulting heat release rate per unit specimen area versus time and the expanded uncertainty at a confidence level of 95 %. Table C.3 gives the values and corresponding expanded uncertainty for some heat release rate parameters that shall be reported as specified in Clause 13 of ISO 5660-1:2002.



Key

X time (s)

Y heat release rate (kW/m^2)

Figure C.5 — Heat release rate versus time and with expanded uncertainty at the 95 % confidence level

Table C.3 — Expanded uncertainty of some heat release parameters

	Value	U (physical units)	U (%)
Peak heat release rate (kW/m^2)	222,4	13,6	6,1%
One-minute average heat release rate (kW/m^2)	156,1	10,2	6,6%
Three-minute average heat release rate (kW/m^2)	122,0	8,5	6,9%
Five-minute average heat release rate (kW/m^2)	118,9	8,3	7,0%
Total heat release (MJ/m^2)	92,3	7,3	7,7%

The uncertainty calculations presented in this annex do not account for dynamic effects, i.e. the fact that all sensors and the oxygen analyser in particular do not respond instantaneously to variations of the measured quantity. Uncertainties due to dynamic errors can be significant but are difficult to estimate. A detailed discussion of uncertainties of heat release rate measurements due to dynamic errors can be found in Reference [4].

The example presented in this example is based on a test conducted at a heat flux level of 50 kW/m^2. However, the heat flux meter that is used to calibrate the heater is subject to error. Clause 6.12 of ISO 5660-1:2002 specifies that the accuracy of the heat flux meter shall be within $\pm$ 3 %. This implies that the actual heat flux in the test was between 48,5 and 51,5 kW/m^2. Moreover, the heat flux is not fully uniformly distributed over the specimen surface and varies slightly during the test. Uncertainties associated with heat flux setting and control are not considered in the analysis presented in this annex.

Bibliography

[1] ISO 834-2:2009, *Fire-resistance tests — Elements of building construction — Part 2: Guidance on measuring uniformity of furnace exposure on test samples*

[2] HUGGETT, C. "Estimation of Rate of Heat Release by Means of Oxygen Consumption," *Fire and Materials*, **4**, pp. 61-65, 1980.

[3] ENRIGHT, P. and FLEISCHMANN, C. "Uncertainty of Heat Release Rate Calculation of the ISO 5660-1 Cone Calorimeter Standard Test Method," *Fire Technology*, **35**, pp. 153-169, 1999.

[4] SETTE, B. *Evaluation of Uncertainty and Improvement of the Single Burning Item Test Method,* Ph.D. Thesis, University of Ghent, Belgium, 2005.

[5] ASTM E 2536, *Standard Guide for Assessment of Measurement Uncertainty in Fire Tests*, ASTM International, West Conshohocken, PA, USA, 2007.

[6] ASTM E 230, *Standard Specification and Temperature-Electromotive Force (EMF) Tables for Standardized Thermocouples*, ASTM International, West Conshohocken, PA, USA, 2007.

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