INTERNATIONAL STANDARD

ISO 14253-2

First edition
2011-04-15

Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment —

Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification

Spécification géométrique des produits (GPS) — Vérification par la mesure des pièces et des équipements de mesure —

Partie 2: Lignes directrices pour l'estimation de l'incertitude dans les mesures GPS, dans l'étalonnage des équipements de mesure et dans la vérification des produits

Reference number
ISO 14253-2:2011(E)

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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.

ISO 14253-2 was prepared by Technical Committee ISO/TC 213, *Dimensional and geometrical product specifications and verification*.

This first edition of ISO 14253-2 cancels and replaces ISO/TS 14253-2:1999, which has been technically revised. It also incorporates the Technical Corrigendum ISO/TS 14253-2:1999/Cor.1:2007.

ISO 14253 consists of the following parts, under the general title *Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment*:

— *Part 1: Decision rules for proving conformance or non-conformance with specifications*

— *Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification*

— *Part 3: Guidelines for achieving agreements on measurement uncertainty statements*

— *Part 4: Background on functional limits and specification limits in decision rules* [Technical Specification]

Introduction

This part of ISO 14253 is a global GPS standard (see ISO/TR 14638:1995). This global GPS standard influences chain links 4, 5 and 6 in all chains of standards.

The ISO/GPS Masterplan given in ISO/TR 14638 gives an overview of the ISO/GPS system of which this document is a part. The fundamental rules of ISO/GPS given in ISO 8015 apply to this document and the default decision rules given in ISO 14253-1 apply to specifications made in accordance with this document, unless otherwise indicated.

For more detailed information on the relation of this International Standard to other standards and to the GPS matrix model, see Annex D.

This part of ISO 14253 has been developed to support ISO 14253-1. This part of ISO 14253 establishes a simplified, iterative procedure of the concept and the way to evaluate and determine uncertainty (standard uncertainty and expanded uncertainty) of measurement, and the recommendations of the format to document and report the uncertainty of measurement information as given in the *Guide to the expression of uncertainty in measurement* (GUM). In most cases, only very limited resources are necessary to estimate uncertainty of measurement by this simplified, iterative procedure, but the procedure may lead to a slight overestimation of the uncertainty of measurement. If a more accurate estimation of the uncertainty of measurement is needed, the more elaborated procedures of the GUM need to be applied.

This simplified, iterative procedure of the GUM methods is intended for GPS measurements, but may be used in other areas of industrial (applied) metrology.

The uncertainty of measurement and the concept of handling uncertainty of measurement are important to all the technical functions within a company. This part of ISO 14253 is relevant to several technical functions, including management, design and development, manufacturing, quality assurance and metrology.

This part of ISO 14253 is of special importance in relation to ISO 9000 quality assurance systems, e.g. it is a requirement that methods for monitoring and measurement of the quality management system processes are suitable. The measurement uncertainty is a measure of the process suitability.

In this part of ISO 14253, the uncertainty of the result of a process of calibration and a process of measurement is handled in the same way:

— calibration is treated as a “measurement of the metrological characteristics of a measuring equipment or a measurement standard”;

— measurement is treated as a “measurement of the geometrical characteristics of a workpiece”.

Therefore, in most cases, no distinction is made in the text between measurement and calibration. The term “measurement” is used as a synonym for both.

Geometrical product specifications (GPS) — Inspection by measurement of workpieces and measuring equipment —

Part 2: Guidance for the estimation of uncertainty in GPS measurement, in calibration of measuring equipment and in product verification

1 Scope

This part of ISO 14253 gives guidance on the implementation of the concept of the “Guide to the estimation of uncertainty in measurement” (in short GUM) to be applied in industry for the calibration of (measurement) standards and measuring equipment in the field of GPS and the measurement of workpiece GPS characteristics. The aim is to promote full information on how to achieve uncertainty statements and provide the basis for international comparison of measurement results and their uncertainties (relationship between purchaser and supplier).

This part of ISO 14253 is intended to support ISO 14253-1. Both parts are beneficial to all technical functions in a company in the interpretation of GPS specifications [i.e. tolerances of workpiece characteristics and values of maximum permissible errors (MPEs) for metrological characteristics of measuring equipment].

This part of ISO 14253 introduces the Procedure for Uncertainty MAnagement (PUMA), which is a practical, iterative procedure based on the GUM for estimating uncertainty of measurement without changing the basic concepts of the GUM. It is intended to be used generally for estimating uncertainty of measurement and giving statements of uncertainty for:

— single measurement results;

— the comparison of two or more measurement results;

— the comparison of measurement results — from one or more workpieces or pieces of measurement equipment — with given specifications [i.e. maximum permissible errors (MPEs) for a metrological characteristic of a measurement instrument or measurement standard, and tolerance limits for a workpiece characteristic, etc.], for proving conformance or non-conformance with the specification.

The iterative method is based basically on an upper bound strategy, i.e. overestimation of the uncertainty at all levels, but the iterations control the amount of overestimation. Intentional overestimation — and not under-estimation — is necessary to prevent wrong decisions based on measurement results. The amount of overestimation is controlled by economical evaluation of the situation.

The iterative method is a tool to maximize profit and minimize cost in the metrological activities of a company. The iterative method/procedure is economically self-adjusting and is also a tool to change/reduce existing uncertainty in measurement with the aim of reducing cost in metrology (manufacture). The iterative method makes it possible to compromise between risk, effort and cost in uncertainty estimation and budgeting.

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 14253-1:1998, *Geometrical Product Specifications (GPS) — Inspection by measurement of workpieces and measuring equipment — Part 1: Decision rules for proving conformance or non-conformance with specifications*

ISO 14660-1:1999, *Geometrical Product Specifications (GPS) — Geometrical features — Part 1: General terms and definitions*

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 and definitions

For the purposes of this document, the terms and definitions given in ISO 14253-1, ISO 14660-1, ISO/IEC Guide 98-3 and ISO/IEC Guide 99 and the following apply.

3.1
black box model for uncertainty estimation
model for uncertainty estimation in which the uncertainties associated with the relevant input quantities are directly represented by their influence on the quantity value being attributed to a measurand (in the units of the measurand)

NOTE 1 The “quantity value being attributed to a measurand” is typically a measured value.

NOTE 2 In many cases, a complex method of measurement may be looked upon as one simple black box with stimulus in and result out from the black box. When a black box is opened, it may turn out to contain several “smaller” black boxes or several transparent boxes, or both.

NOTE 3 The method of uncertainty estimation remains a black box method even if it is necessary to make supplementary measurements to determine the values of influence quantities in order to make corresponding corrections.

3.2
transparent box model for uncertainty estimation
model for uncertainty estimation in which the relationship between the input quantities and the quantity value being attributed to a measurand is explicitly expressed with equations or algorithms

3.3
measuring task
quantification of a measurand according to its definition

3.4
overall measurement task
measurement task that quantifies the final measurand

3.5
intermediate measurement task
measurement task obtained by subdividing the overall measurement task into simpler parts

NOTE 1 The subdivision of the overall measuring task serves the goal of simplification of the evaluation of uncertainty.

NOTE 2 The specific subdivisions are arbitrary, as is whether to subdivide at all.

3.6
target uncertainty
U_T
⟨for a measurement or calibration⟩ uncertainty determined as the optimum for the measuring task

NOTE 1 Target uncertainty is the result of a management decision involving e.g. design, manufacturing, quality assurance, service, marketing, sales and distribution.

NOTE 2 Target uncertainty is determined (optimized) taking into account the specification [tolerance or maximum permissible error (MPE)], the process capability, cost, criticality and the requirements of ISO 9001, ISO 9004 and ISO 14253-1.

NOTE 3 See also 8.8.

3.7
required uncertainty of measurement
U_R
uncertainty required for a given measurement process and task

NOTE See also 6.2. The required uncertainty may be specified by, for example, a customer.

3.8
uncertainty management
process of deriving an adequate measurement procedure from the measuring task and the target uncertainty by using uncertainty budgeting techniques

3.9

uncertainty budget

⟨for a measurement or calibration⟩ statement summarizing the estimation of the uncertainty components that contributes to the uncertainty of a result of a measurement

NOTE 1 The uncertainty of the result of the measurement is unambiguous only when the measurement procedure (including the measurement object, measurand, measurement method and conditions) is defined.

NOTE 2 The term “budget” is used for the assignment of numerical values to the uncertainty components and their combination and expansion, based on the measurement procedure, measurement conditions and assumptions.

3.10
uncertainty component
xx
source of uncertainty of measurement for a measuring process

3.11
limit value (variation limit) for an uncertainty component
a_{xx}
absolute value of the extreme value(s) of the uncertainty component, xx

3.12
uncertainty component
u_{xx}
standard uncertainty of the uncertainty component, xx

NOTE The iteration method uses the designation u_{xx} for all uncertainty components.

3.13
influence quantity of a measurement instrument
characteristic of a measuring instrument that affects the result of a measurement performed by the instrument

3.14
influence quantity of a workpiece
characteristic of a workpiece that affects the result of a measurement performed on that workpiece

4 Symbols

For the purposes of this document, the generic symbols given in Table 1 apply.

Table 1 — Generic symbols

Symbol/ abbreviated term	Description
a	limit value for a distribution
a_{xx}	limit value for an error or uncertainty component (in the unit of the measurement result, of the measurand)
a^*_{xx}	limit value for an error or uncertainty component (in the unit of the influence quantity)
α	linear coefficient of thermal expansion
b	coefficient for transformation of a_{xx} to u_{xx}
C	correction (value)
d	resolution of a measurement equipment
E	Young's modulus
ER	error (value of a measurement)
G	function of several measurement values [$G(X_1, X_2, ... X_i, ...)$]
h	hysteresis value
k	coverage factor
m	number of standard deviations in the half of a confidence interval
MR	measurement result (value)
n	number of ...
N	number of iterations
ν	Poisson's number
p	number of total uncorrelated uncertainty components
r	number of total correlated uncertainty components
ρ	correlation coefficient
t	safety factor calculated based on the Student t distribution
TV	true value of a measurement
u, u_i	standard uncertainty (standard deviation)
s_x	standard deviation of a sample
$s_{\overline{x}}$	standard deviation of a mean value of a sample
u_{c}	combined standard uncertainty
u_{xx}	standard deviation of uncertainty component xx — uncertainty component
U	expanded uncertainty of measurement
U_{A}	true uncertainty of measurement
U_{C}	conventional true uncertainty of measurement
U_{E}	approximated uncertainty of measurement (number of iteration not stated)
$U_{\mathrm{E}N}$	approximated uncertainty of measurement of iteration number N
U_{R}	required uncertainty
U_{T}	target uncertainty
U_{V}	uncertainty value (not estimated according to GUM or this part of ISO 14253)
X	measurement result (uncorrected)
X_i	measurement result (in the transparent box model of uncertainty estimation)
Y	measurement result (corrected)

5 Concept of the iterative GUM method for estimation of uncertainty of measurement

By applying the GUM method completely, a conventional true uncertainty of measurement, U_C, can be found.

The simplified, iterative method described in this part of ISO 14253 sets out to achieve estimated uncertainties of measurements, U_E, by overestimating the influencing uncertainty components ($U_E \geqslant U_C$). The process of overestimating provides “worst-case contributions” at the upper bound from each known or predictable uncertainty component, thus ensuring results of estimations “on the safe side”, i.e. not underestimating the uncertainty of measurement. The method is based on the following:

— all uncertainty components are identified;

— it is decided which of the possible corrections shall be made (see 8.4.6);

— the influence on the uncertainty of the measurement result from each component is evaluated as a standard uncertainty u_{xx}, called the uncertainty component;

— an iteration process, PUMA (see Clause 6) is undertaken;

— the evaluation of each of the uncertainty components (standard uncertainties) u_{xx} can take place either by a Type A evaluation or by a Type B evaluation;

— Type B evaluation is preferred — if possible — in the first iteration in order to get a rough uncertainty estimate to establish an overview and to save cost;

— the total effect of all components (called the combined standard uncertainty) is calculated by Equation (1):

$$u_C = \sqrt{u_{x1}^2 + u_{x2}^2 + u_{x3}^2 + \ldots + u_{xn}^2} \tag{1}$$

— Equation (1) is only valid for a black box model of the uncertainty estimation and when the components u_{xx} are all uncorrelated (for more details and other equations, see 8.6 and 8.7);

— for simplification, the only correlation coefficients between components considered are

$$\rho = 1, -1, 0 \tag{2}$$

If the uncertainty components are not known to be uncorrelated, full correlation is assumed, either $\rho = 1$ or $\rho = -1$. Correlated components are added arithmetically before put into the formula above (see 8.5 and 8.6);

— the expanded uncertainty U is calculated by Equation (3):

$$U = k \times u_C \tag{3}$$

where $k = 2$; k is the coverage factor (see also 8.8).

The simplified, iterative method normally will consist of at least two iterations of estimating the components of uncertainty:

a) the first very rough, quick and cheap iteration has the purpose of identifying the largest components of uncertainty (see Figure 1);

b) the following iterations — if any — only deal with making more accurate “upper bound” estimates of the largest components to lower the estimate of the uncertainty (u_C and U) to a possible acceptable magnitude.

The simplified and iterative method may be used for two purposes:

1) management of the uncertainty of measurement for a result of a given measurement process (can be used for the results from a known measuring process or for comparison of two or more of such results) — see 6.2;

2) uncertainty management for a measuring process. For the development of an adequate measuring process, i.e. $U_E \leqslant U_T$, see 6.3.

6 Procedure for Uncertainty MAnagement — PUMA

6.1 General

The prerequisite for uncertainty budgeting and management is a clearly identified and defined measuring task, i.e. the measurand to be quantified (a GPS characteristic of a workpiece or a metrological characteristic of a GPS measuring equipment). The uncertainty of measurement is a measure of the quality of the measured value according to the definitions of a GPS characteristic of the workpiece or a metrological characteristic of the GPS measuring equipment given in GPS standards.

GPS standards define the "conventional true values" of the characteristics to be measured by chains of standards and global standards (see ISO/TR 14638). GPS standards in many cases also define the ideal — or conventional true — principle of measurement (see ISO/IEC Guide 99:2007, 2.4), method of measurement (see ISO/IEC Guide 99:2007, 2.5), measurement procedure (see ISO/IEC Guide 99:2007, 2.6) and standard "reference conditions" (see ISO/IEC Guide 99:2007, 4.11).

Deviations from the standardized conventional true values of the characteristics, etc. (the ideal operator) are contributing to the uncertainty of measurement.

6.2 Uncertainty management for a given measurement process

Management of the uncertainty of measurement for a given measuring task (box 1 of Figure 1) and for an existing measurement process is illustrated in Figure 1. The principle of measurement (box 3), measurement method (box 4), measurement procedure (box 5) and measurement conditions (box 6) are fixed and given or decided in this case, and cannot be changed. The only task is to evaluate the consequence on the uncertainty of measurement. A required U_R may be given or decided.

Using the iterative GUM method, the first iteration is only for orientation, and to look for the dominant uncertainty components. The only thing to do — in the management process in this case — is to refine the estimation of the dominant components to come closer to a true estimate of the uncertainty components thus avoiding an excessive overestimate — if necessary.

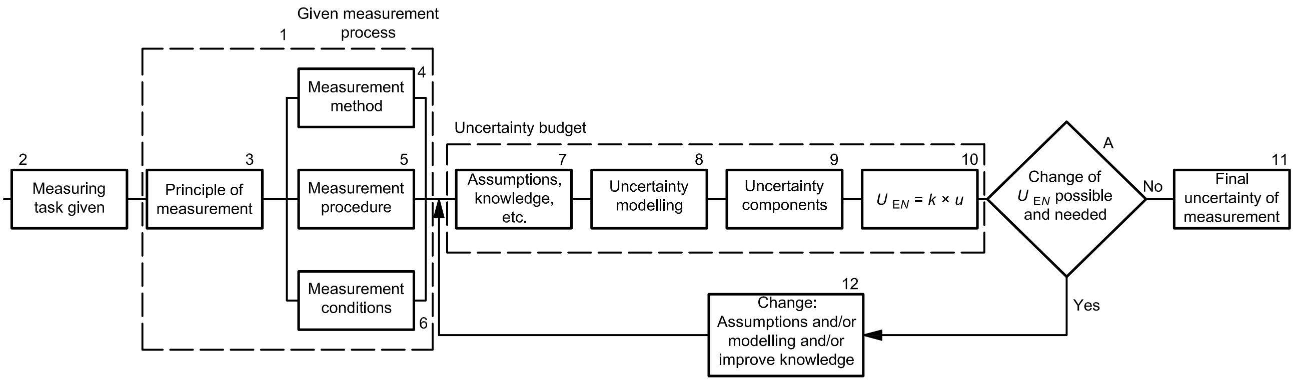

Figure 1 — Uncertainty management for a measurement result from a given measurement process

The procedure is as follows.

a) Make a first iteration based preferably on a black box model of the uncertainty estimation process and set up a preliminary uncertainty budget (boxes 7 to 9) leading to the first rough estimate of the expanded uncertainty, U_{E1} (box 10). For details about uncertainty estimation, see Clause 9. All estimates of uncertainties U_{EN} are performed as upper bound estimates.

b) Compare the first estimated uncertainty, U_{E1}, with the required uncertainty U_R (box A) for the actual measuring task.

   1) If U_{E1} is acceptable (i.e. if $U_{E1} \leqslant U_R$), then the uncertainty budget of the first iteration has proven that the given measurement procedure is adequate for the measuring task (box 11).

   2) If U_{E1} is not acceptable (i.e. if $U_{E1} > U_R$) or if there is no required uncertainty, but a lower and more true value is desired, the iteration process continues.

c) Before the new iteration, analyse the relative magnitude of the uncertainty components. In many cases, a few uncertainty components dominate the combined standard uncertainty and expanded uncertainty.

d) Change the assumptions or improve the knowledge about the uncertainty components to make a more accurate (see ISO/IEC Guide 99:2007, 2.13) upper bound estimation of the largest (dominant) uncertainty components (box 12).

   Change to a more detailed model of the uncertainty estimation process or a higher resolution of the measuring process (box 12).

e) Make the second iteration of the uncertainty budget (boxes 7 to 9) leading to the second, lower and more accurate (see ISO/IEC Guide 99:2007, 2.13) upper bound estimate of the uncertainty of measurement, U_{E2} (box 10).

f) Compare the second estimated uncertainty U_{E2} (box A) with uncertainty required U_R for the actual measuring task.

   1) If U_{E2} is acceptable (i.e. if $U_{E2} \leqslant U_R$), then the uncertainty budget of the second iteration has proven that the given measurement procedure is adequate to the measuring task (box 11).

   2) If U_{E2} is not acceptable (i.e. if $U_{E2} > U_R$), or if there is no required uncertainty, but a lower and more true value is desired, then a third (and possibly more) iteration(s) is (are) needed. Repeat the analysis of the uncertainty components [additional changes of assumptions, improvements in knowledge, changes in modelling, etc. (box 12)] and concentrate on the currently largest uncertainty components.

g) When all possibilities have been used for making more accurate (lower) upper bound estimates of the measuring uncertainties without coming to an acceptable measuring uncertainty $U_{EN} \leqslant U_R$, then it is proven that it is not possible to fulfil the given requirement U_R.

6.3 Uncertainty management for design and development of a measurement process/procedure

Uncertainty management in this case is performed to develop an adequate measurement procedure [measurement of the geometrical characteristics of a workpiece or the metrological characteristics of a measuring equipment (calibration)]. Uncertainty management is performed on the basis of a defined measuring task (box 1 in Figure 2) and a given target uncertainty, U_T (box 2). Definitions of the measuring task and target uncertainty are company policy decisions to be made at a sufficiently high management level. An adequate measurement procedure is a procedure which results in an estimated uncertainty of measurement less than or equal to the target uncertainty. If the estimated uncertainty of measurement is much less than the target uncertainty, the measurement procedure may not be (economically) optimal for performing the measuring task (i.e. the measurement process is too costly).

The PUMA, based on a given measuring task (box 1) and a given target uncertainty U_T (box 2), includes the following (see Figure 2).

a) Choose the principle of measurement (box 3) on the basis of experience and possible measurement instruments present in the company.

b) Set up and document a preliminary method of measurement (box 4), measurement procedure (box 5) and measurement conditions (box 6) on the basis of experience and known possibilities in the company.

c) Make a first iteration based preferably on a black box model of the uncertainty estimation process and set up a preliminary uncertainty budget (boxes 7 to 9) leading to the first rough estimate of the expanded uncertainty, U_{E1} (box 10). For details about uncertainty estimation, see Clause 9. All estimates of uncertainties U_{EN} are performed as upper bound estimates.

d) Compare the first estimated uncertainty, U_{E1}, with the given target uncertainty, U_T (box A).

   1) If U_{E1} is acceptable (i.e. if $U_{E1} \leqslant U_T$), then the uncertainty budget of the first iteration has proven that the measurement procedure is adequate for the measuring task (box 11).

   2) If $U_{E1} << U_T$, then the measurement procedure is technically acceptable, but a possibility may exist to change the method or the procedure (box 13), or both, in order to make the measuring process more cost effective while increasing the uncertainty. A new iteration is then needed to estimate the resulting measurement uncertainty, U_{E2} (box 10).

   3) If U_{E1} is not acceptable (i.e. if $U_{E1} > U_T$), the iteration process continues, or it is concluded that no adequate measurement procedure is possible.

e) Before the new iteration, analyse the relative magnitude of the uncertainty components. In many cases, a few uncertainty components predominate the combined standard uncertainty and expanded uncertainty.

f) If $U_{E1} > U_T$, then change the assumptions or the modelling or increase the knowledge about the uncertainty components (box 12) to make a more accurate (see ISO/IEC Guide 99:2007, 2.13) upper bound estimation of the largest (dominant) uncertainty components.

g) Make the second iteration of the uncertainty budget (boxes 7 to 9) leading to the second, lower and more accurate (see ISO/IEC Guide 99:2007, 2.13) upper bound estimate of the uncertainty of measurement, U_{E2} (box 10).

h) Compare the second estimated uncertainty U_{E2} with the given target uncertainty, U_T (box A).

   1) If U_{E2} is acceptable (i.e. if $U_{E2} \leqslant U_T$), then the uncertainty budget of the second iteration has proven that the measurement procedure is adequate for the measuring task (box 11).

   2) If U_{E2} is not acceptable (i.e. if $U_{E2} > U_T$), then a third (and possibly more) iteration(s) is (are) needed. Repeat the analysis of the uncertainty components [additional changes of assumptions, modelling and increase in knowledge (box 12)] and concentrate on the currently largest uncertainty components.

i) When all possibilities have been used for making more accurate (lower) upper bound estimates of the measuring uncertainties without coming to an acceptable measuring uncertainty $U_{EN} \leqslant U_T$, then it is necessary to change the measurement method or the measurement procedure or the conditions of measurement (box 13) to (possibly) bring down the magnitude of the estimated uncertainty, U_{EN}. The iteration procedure starts again with a first iteration.

j) If changes in the measurement method or the measurement procedure or conditions (box 13) do not lead to an acceptable uncertainty of measurement, it is possible to change the principle of measurement (box 14) and start the above-mentioned procedure again.

k) If changing the measuring principle and the related iterations described above still does not lead to an acceptable uncertainty of measurement, the ultimate possibility is to change the measuring task or target uncertainty (box 15), or both, and to start the above-mentioned procedure again.

l) If changing the measuring task or target uncertainty is not possible, it has been demonstrated that no adequate measurement procedure exists (box 16).

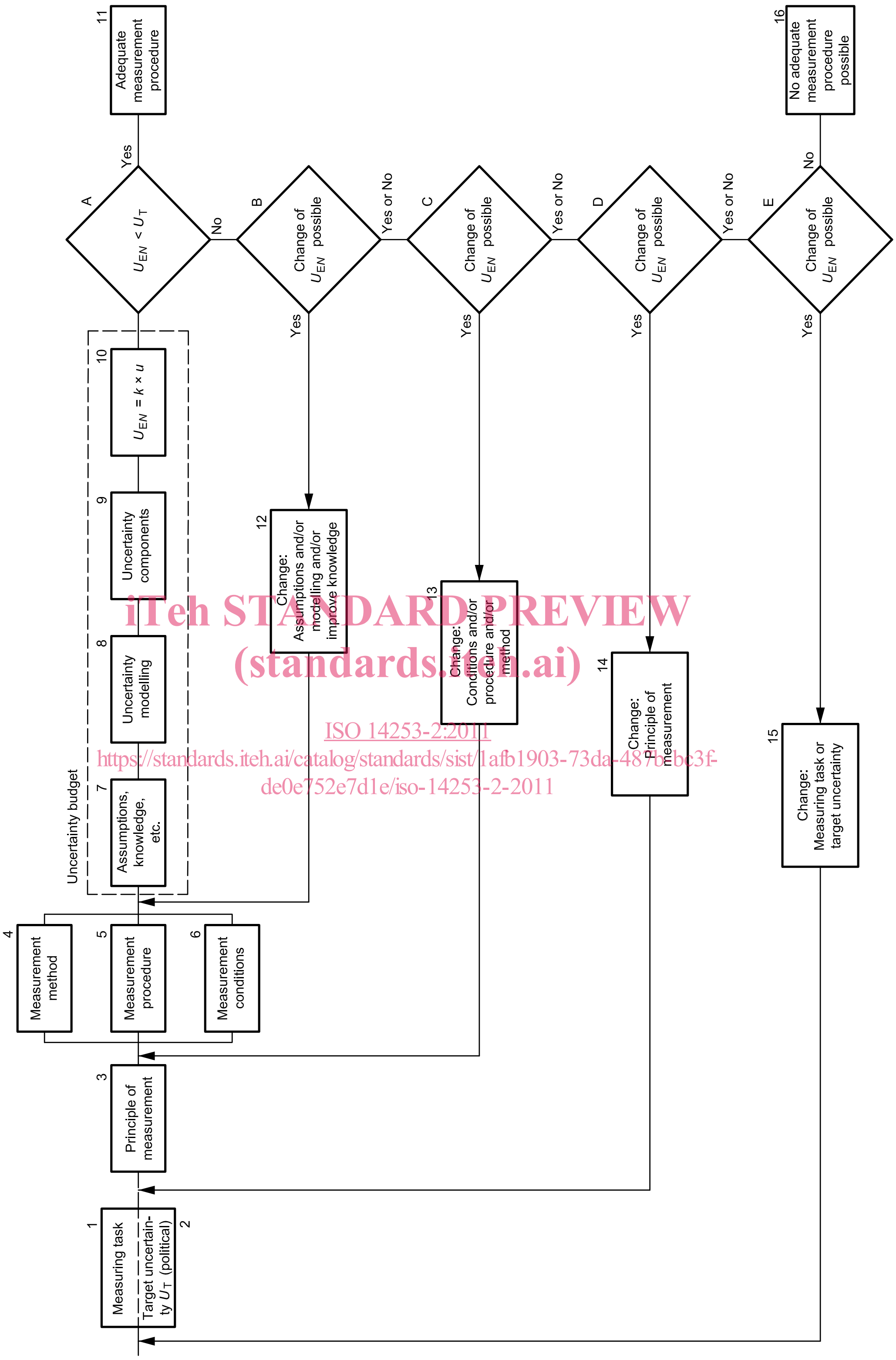

Figure 2 — Procedure for Uncertainty of Measurement MAnagement (PUMA) for a measurement process/procedure