codex alimentarius commission

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

WORLD HEALTH ORGANIZATION

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Agenda Item 9 **CX/MAS 09/30/10**

JOINT FAO/WHO FOOD STANDARDS PROGRAMME

CODEX COMMITTEE ON METHODS OF ANALYSIS AND SAMPLING
Thirtieth Session
Balatonalmádi, Hungary, 9 - 13 March 2009

GUIDANCE ON UNCERTAINTY OF SAMPLING

(Prepared by the United Kingdom)

BACKGROUND

Uncertainty of sampling has been introduced and discussed at previous Sessions of the Codex Committee on Methods of Analysis and Sampling. It has been recognised that this is an important topic, but it has not yet been addressed formally within the Codex forum. The Report of the 29th Session of CCMAS, when this topic was discussed, states:

103) The Committee recalled that its last session had been informed of the latest developments concerning uncertainty from sampling at the international level and, recognizing the importance of addressing this subject in the framework of Codex, had agreed that the Delegation of the United Kingdom would prepare a document addressing this question in conjunction with sampling uncertainty.

104) The Delegation of the United Kingdom indicated that the following guides had been published since the last session: EURACHEM/EUROLAB/CITAC/Nordtest *Guide on the Estimation of Measurement Uncertainty Arising from Sampling;* and Nordtest handbook for sampling planners on sampling quality assurance and uncertainty estimation *Uncertainty from sampling* (Based upon the EURACHEM international guide *estimation of measurement uncertainty arising from sampling).* It was noted that The Nordtest Guide is intended to be rather more practical than the procedures outlined in the EURACHEM Guide.

105) The Delegation stressed the importance of addressing sampling uncertainty in Codex in view of the publication of these guides, and indicated that the document considered methods of estimating uncertainty, using real case studies as examples (CRD 18), addressed the role of measurement uncertainty in the decision making process and the assessment of fitness for purpose. The second part of the document examined whether global fitness for purpose criteria could be set for sampling uncertainty.

106) The Delegation of Hungary pointed out that the estimation of sampling uncertainty depended on the portion of the sample on which the analysis applied, for example in the case of MRLs, and that the establishment of fitness for purpose criteria should be further clarified.

107) The Delegation of Australia supported further work in this area and pointed out that the estimation of sampling uncertainty would depend on how compliance was defined, either on the average concentration of the lot or against a maximum value in a sample.

108) The Committee recognized that at this stage it was premature to undertake new work but that this question should kept under consideration and therefore agreed that the Delegation of the United Kingdom, with the assistance of an electronic working group, would revise the discussion paper for consideration by the next session.

Committee on Milk and Milk Products

109) The Committee considered the question from the Committee on Milk and Milk Products concerning conformity assessment in the presence of significant measurement error (see Agenda Item 2). The Committee agreed that this could be considered in conjunction with the general approach to uncertainty of sampling. The Delegation of New Zealand pointed out that the General Guidelines on Sampling did not address this issue and recalled that the document presented to the CCMMP made specific proposals. The Committee welcomed the offer of the Delegation of New Zealand to prepare a discussion paper clearly outlining the problem and indicating how it could be addressed in a horizontal manner.

ACTION

The Delegation of the United Kingdom circulated all participants at the twenty-ninth Session of CCMAS to ask for comment following the 29th Session of CCMAS. In the event few comments were received.

SAMPLING IN CODEX

"Methods of sampling" have had a long and troubled history within Codex. The majority of the work described within Codex is based on the use of acceptance sampling plans, and is frequently very complex. As a result Codex Commodity Committees frequently refer to the use of CAC/GL 50-2004 (the Codex General Guidelines on Sampling) but then do not progress further than that. They do not choose from the options given in 50-2004 as should happen.

With the publication of the EURACHEM/EUROLAB/CITAC/Nordtest *Guide on the Estimation of Measurement Uncertainty Arising from Sampling;* and Nordtest handbook for sampling planners on sampling quality assurance and uncertainty estimation *Uncertainty from sampling,* the UK considers that it would be unwise to ignore this area of measurement uncertainty. To do so will result in the same issues and confusion that have already arisen when analytical measurement uncertainty has been considered.

DISCUSSION

As stated above sampling has long been recognised as part of the measurement process, when the measurand (or true value to be determined) is defined in terms of the sampling target (e.g., a batch/lot of material) rather than in terms of the laboratory sample. Several methods have been proposed to estimate measurement uncertainty arising from all steps in the measurement process, including the primary sampling. Once an estimate of the uncertainty has been made, it is necessary to address whether that level of uncertainty is acceptable in order to decide whether the measurements are fit for the purpose for which they are intended. (One approach to this question, not discussed in this paper, is to designate this optimal value of uncertainty, as the point that minimises the overall financial loss to the user of the measurements).

However, for Codex purposes it is possible to pre-define a fit-for-purpose value for the measurement uncertainty, including both the "analytical" and "sampling", such that any sampling plan which is developed will meet that criterion. Clearly this then becomes an iterative process.

Thus as a result of the international activities it is critical for CCMAS to recognises that a decision has to be taken as to whether sampling uncertainty should be taken into account when assessing compliance, or whether it wishes to take the non-scientific/simplistic route of defining sampling uncertainty as being zero. In addition it could suggest that Codex Commodity Committees recommend the maximum uncertainty that is fit-for-purpose.

There it has been agreed that the existing Codex Guidelines on Measurement Uncertainty be re-drafted. It is suggested that the same approach be taken with respect to extending those Guidelines to include measurement uncertainty including sampling uncertainty. The arguments/discussion about sampling uncertainty are given in the explanatory notes to the Guidelines.

By doing to would enable sampling to be addressed effectively within Codex and in a way which could be readily appreciated.

RECOMMENDATIONS

It is recommended that the Committee:

- notes the publication of the EURACHEM/EUROLAB/CITAC/Nordtest Guide on the "Estimation of Measurement Uncertainty Arising from Sampling" and the Nordtest handbook.

- discusses the issue of uncertainty and sampling and decides whether it should develop recommendations in the area in the same way that it already has for [Analytical] Measurement Uncertainty.

- discusses whether sampling uncertainty should be taken into account when a lot is assessed for compliance with a Codex specification.

- whether it should prepare Guidance for Codex Committee Committees on sampling uncertainty, possibly through the preparation of general guidelines an initial draft of which are attached.

In the light of discussions, whether the Committee should also decide whether it wishes to progress the topic as a defined New Work Item.

ANNEX: GUIDELINES ON MEASUREMENT UNCERTAINTY INCLUDING SAMPLING UNCERTAINTY

Introduction and terminology

The international definition for Measurement Uncertainty is:

"Parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand"[1]

With the Notes:

1. The parameter may be, for example, a standard deviation (or a given multiple of it), or the half-width of an interval having a stated level of confidence.

2. Uncertainty of measurement comprises, in general, many components. Some of these components may be evaluated from the statistical distribution of results of a series of measurements and can be characterised by experimental standard deviations. The other components, which can also be characterised by standard deviations, are evaluated from assumed probability distributions based on experience or other information.

3. It is understood that the result of a measurement is the best estimate of the value of a measurand, and that all components of uncertainty, including those arising from systematic effects, such as components associated with corrections and reference standards, contribute to the dispersion. ."

Although frequently interpreted as only meaning analytical measurement uncertainty, for goods moving in international trade it is the total uncertainty that it important.

For these [draft] Guidelines "measurement uncertainty" will be taken to encompass both analytical and sampling uncertainties unless otherwise stated.

It is important and required by ISO/IEC 17025:2005 that analysts are aware of the measurement uncertainty associated with each analytical result and estimates that uncertainty. The measurement uncertainty may be derived by a number of procedures. Food analysis laboratories are required, for Codex purposes, to be in control[2], use collaboratively tested or validated methods when available, and verify their application before taking them into routine use. Such laboratories therefore have available to them a range of analytical data which can be used to estimate their measurement uncertainty. However, when extended to include the total measurement uncertainty, other procedures may also be used.

These guidelines only apply to quantitative analysis.

Most quantitative analytical results take the form of "a ± 2u or a ± U" where "a" is the best estimate of the true value of the concentration of the measurand (the analytical result) and "u" is the standard uncertainty and "U" (equal to 2u) is the expanded uncertainty. The range "a ± 2u" represents a 95% level of confidence where the true value would be found. The value of "U" or "2u" is the value which is normally used and reported by analysts and is hereafter referred to as "measurement uncertainty" and may be estimated in a number of different ways.

[1] International vocabulary of metrology - basic and general concepts and associated terms, JCGM 200:2008.

[2] As outlined in Codex GL 27-1997 "Guidelines for the Assessment of the Competence of Testing Laboratories Involved in the Import and Export of Food".

Recommendations

1. The measurement uncertainty associated with all analytical results is to be estimated.

2. The analytical measurement uncertainty of an analytical result may be estimated by a number of procedures, notably those described by ISO (1) and EURACHEM (2). These documents recommend procedures based on a component-by-component approach, method validation data, internal quality control data and proficiency test data. The need to undertake an estimation of the measurement uncertainty using the ISO component-by-component approach is not necessary if the other forms of data are available and used to estimate the uncertainty. In many cases the overall uncertainty may be determined by an inter-laboratory (collaborative) study by a number of laboratories and a number of matrices by the IUPAC/ISO/AOAC INTERNATIONAL (3) or by the ISO 5725 Protocols (4).

3. The total measurement uncertainty, including uncertainty derived from sampling may be estimated by a number of procedures, notably those described by EURACHEM (5) and Nordtest (6).

4 The total measurement uncertainty and its level of confidence must, on request, be made available to the user (customer) of the results.

References

1. "Guide to the Expression of Uncertainty in Measurement", ISO, Geneva, 1993.

2. EURACHEM/CITAC Guide Quantifying Uncertainty In Analytical Measurement (Second Edition), EURACHEM Secretariat, BAM, Berlin, 2000. This is available as a free download from http://www.eurachem.ul.pt/

3. "Protocol for the Design, Conduct and Interpretation of Method Performance Studies", ed. W. Horwitz, *Pure Appl. Chem.*, 1995, 67, 33 1-343.

4. "Precision of Test Methods", Geneva, 1994, ISO 5725, Previous editions were issued in 1981 and 1986.

5. EURACHEM/EUROLAB/CITAC/Nordtest *Guide on the Estimation of Measurement Uncertainty Arising from Sampling.* Downloadable from: http://www.eurachem.org/guides/UfS_2007.pdf

6. Nordtest handbook for sampling planners on sampling quality assurance and uncertainty estimation *Uncertainty from sampling* (Based upon the EURACHEM international guide *estimation of measurement uncertainty arising from sampling).* Downloadable as Report 604 from: http://www.nordicinnovation.net/nordtestfiler/tr604.pdf

EXPLANATORY NOTES TO THE CODEX GUIDELINES ON MEASUREMENT UNCERTAINTY INCLUDING SAMPLING UNCERTAINTY

These Explanatory Notes are written not for metrological experts but routine providers of analytical data, sampling officers, customers of laboratories reporting analytical data and delegates to Codex Commodity Committees.

1. Introduction

It is widely accepted that repeat analyses of the same sample will almost always produce varying results. These variations may be due to e.g. changes in the operating conditions, and an inhomogeneous sample from which only a small test portion is taken. Persons responsible for producing, appraising and interpreting the results of chemical analyses will be familiar with terms such as reproducibility and repeatability - both are measures of this random variability. They will also be familiar with the use of 'reference materials' and terms such as 'bias' and 'recovery', which are used to check if analytical results are systematically higher or lower than they should be, when compared to a known reference value. The random variability and systematic effects in analytical results are characterised as analytical uncertainty.

Chemical analysis is usually the end part of the measurement process, following the taking of samples (sampling) and grinding, blending and treatment of samples in preparation for chemical analysis (physical preparation). The term 'measurement' (as in measurement uncertainty) encompasses the whole procedure. Each step in the measurement process will introduce variability in the final measurement result, the measurement uncertainty. The International Standards Organisation defines uncertainty of measurement as 'parameter, associated with the result of a measurement that characterises the dispersion of the values that could reasonably be attributed to the measurand' (ISO GUM 1993).

The Codex General Guidelines on Sampling (CAC/GL 50-2004) are based on the principals of acceptance sampling. They are designed to ensure that fair and valid sampling procedures are used when food is being tested for compliance with a particular Codex commodity standard. These Guidelines make the distinction between sampling error and measurement error. For the purpose of the Guidelines measurement error (caused by the measured value of the characteristic failing to accurately represent the true value of the characteristic within the sample) is analogous to analytical uncertainty. Like analytical uncertainty, sampling error (caused by the sample failing to accurately represent the population from which it was collected) has input from both systematic and random effects. The CAC Guidelines advise it is desirable that the sampling errors associated with any sampling plan, as well as measurement errors associated with analysis, should be quantified and minimised. Laboratories are required, as part of 3rd party accreditation, to participate in inter-laboratory trials, data from these and other internal quality control measures allow the estimation of analytical uncertainties. Methods for estimating sampling uncertainty have been published.

The Eurachem/EUROLAB/CITAC/Nordtest Working Group on Uncertainty from Sampling was formed in September 2003. This Working Group includes representatives from a wide range of disciplines, including those from the food sector. The Eurachem Working Group has prepared guidance for the evaluation of uncertainties in measurement arising from the process of sampling. This guidance is applicable to all chemical measurements that require the taking of a sample. It provides guidance on the assessment of the uncertainty of the measurement that is caused by the process of sampling, and any physical preparation of the sample prior to analysis, and how this can be combined with estimates of uncertainty arising from the analytical process. The guide was developed in collaboration with relevant international bodies and will be updated as experience is gained in their use.

The Guide looks firstly at the methods of estimating uncertainty and uses real case studies to exemplify each. The role of measurement uncertainty in the decision making process is also addressed, as is the assessment of fitness for purpose. The second part of this document examines whether it is a good idea to set global fitness for purpose criteria for sampling uncertainty. This document is focussed on measurement processes that result in quantitative data. Qualitative data (e.g. yes / no responses) are not addressed.

In addition Nordtest has prepared a handbook for sampling planners on sampling quality assurance and uncertainty estimation *Uncertainty from sampling*, which is based upon the EURACHEM Guide *estimation of measurement uncertainty arising from sampling*, but which is rather more "practical".

2. Does Measurement Uncertainty Apply to both Sampling and Analysis?

Yes, measurement uncertainty applies to the whole measurement process. For analysts only "analytical" measurement uncertainty has been considered but it is now increasingly being recognised that the whole system must be considered, and so "sampling" measurement uncertainty is gaining an increasing importance.

3. What is Measurement Uncertainty?

Even ignoring sampling uncertainty it is not always appreciated that analytical results are variable, and just how large that variability may be, particularly when low concentrations of a measurand (i.e. ppb levels) are being determined. As stated in the present Codex Measurement Uncertainty Guidelines, most quantitative analytical results take the form of "a ± 2u" or "a ± U" where "a" is the best estimate of the true value of the concentration of the measurand (the analytical result) and "u" is the standard uncertainty and "U" (equal to 2u) is the expanded uncertainty. The range "a ± 2u" represents a 95% level of confidence in which the true value would be found. The value of "U" or "2u" is the value which is normally used and reported by analysts, normally referred to as "measurement uncertainty" and may be estimated in a number of different ways.

In food analysis it is the (approximately) 95% probability (i.e. 2u) which is used to calculate the expanded uncertainty. Other sectors may specify a different probability.

Thus measurement uncertainty may be regarded as the variability around the reported results which is quantified as the value "U" when considering the expanded uncertainty and within which the "true" result should lie.

The values "U" or "2u" need to take into account the total uncertainty including that contributed by the sampling uncertainty. This will probably make the value of "U" rather large than if the sampling uncertainty is ignored.

4. Does Measurement Uncertainty Apply to both Sampling and Analysis?

Measurement uncertainty applies to the whole measurement process. For analysts only "analytical" measurement uncertainty has been considered but it is now increasingly being recognised that the whole system must be considered, and so "sampling" measurement uncertainty is gaining an increasing importance.

5. What is the Relationship between Measurement Uncertainty, the Analytical Result and the Method Used to Obtain the Result?

It is the estimation of the measurement uncertainty associated with an analytical result that is important. Measurement uncertainty is not associated with a method, but the values that are obtained in the validation of a method may be used to estimate the uncertainty of a result in some situations. This differentiation between "result" and "validated method" is frequently not appreciated and so causes some confusion. It does mean that different laboratories, even if using the same (validated) method on the "same" sample may report different measurement uncertainties.

The same applies when sampling is also taken into account. No sampling procedure will be exactly replicated when applied to the same batch.

5. Procedures for Estimating Measurement Uncertainty

There are many procedures available for estimating the measurement uncertainty of a result.

The Codex guidelines for analytical measurement uncertainty do not recommend any particular approach, but it is important that whatever approach is used, the procedure is scientifically credible. No one approach may be said to be better than any other provided the procedure used is appropriate and credible - i.e. there is no "hierarchy" of the recognised procedures. All such procedures may be considered to be equally valid. However, the procedure that an individual laboratory uses will have to be considered appropriate by its Accreditation Agency as part of its 17025 accreditation. In general procedures are based on a component-by-component ("bottom-up") approach or on a "top-down" approach using collaborative trial data.

In Codex there is a requirement to use fully validated methods and so it is usually more cost-efficient to use data from the validation rather than using another approach (i.e. the component-by-component approach). The caveats to using such validation data are best described in the Eurachem Guide to quantifying uncertainty in analytical measurement, where in Section 7.6.1 of the Second Edition of the EURACHEM Guide it is stated:

However, with respect to total measurement uncertainty there are several ways of estimating sampling uncertainty but both Guides (Eurachem and Nordtest) include the "duplicate method" which has been found to be broadly applicable across the food sector.

The duplicate method – general principles

A sampling protocol (detailing, how many samples, how to sample, sample mass etc.) is a prerequisite for all food surveys, assessments etc. The duplicate method requires a second (duplicate) sample to be taken for 10% (or a minimum of 8) of the total number of sampling targets. This second 'duplicate' sample should be taken to represent the ambiguity in interpreting the protocol, what this means is perhaps better explained using the examples.

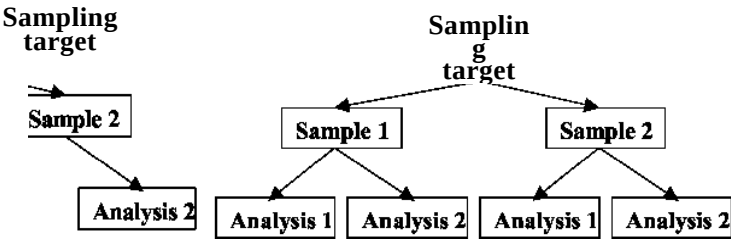
The duplicate samples are then each subject to independent physical preparation (i.e. they are not combined). Two analytical test portions are drawn from each of the duplicate 'prepared' samples.

All test portions are anonymised (so it is unclear which are duplicates) and subsequently analysed in a randomised order.

Statistical procedures are applied to the resultant data to separate out between-target variances, sampling (or within-target) variances and analytical variances.

The inclusion of certified reference materials (CRM) and /or spike samples within the analytical run will allow the systematic effects of analysis to be quantified. This is generally routine in most laboratories. As described, the duplicate method does not permit the estimation of systematic effects from the sampling process. When the duplicate method of uncertainty estimation is utilised, the costs will increase by 10% for sampling and 30% for analysis.

Details of the procedure are given in the EURACHEM and Nordtest Guides. It is illustrated diagrammatically below for replicate design with one (left) and two (right) split levels.



6. Considerations when Estimating Measurement Uncertainty within the Context of Codex

When deciding on which procedure is to be used when estimating measurement uncertainty within the Codex context it is important to recognise that Codex has adopted a number of formal quality assurance measures which have to be implemented by control laboratories. In particular, such laboratories have to be:

- accredited to an Internationally recognised Standard (now with ISO/IEC 17025 Standard); such accreditation is aided by the use of internal quality control procedures,
- participate in proficiency schemes, and
- use validated methods.

It is essential that the information provided as a result of these requirements being implemented is used by laboratories when estimating their measurement uncertainties in order to avoid unnecessary work being carried out by laboratories. In Codex, where there is a high emphasis being placed on the use of "fully

validated" methods of analysis, i.e. methods which have been validated through collaborative trials, information obtained from such trials can be used in many situations.

In addition information derived from internal quality control procedures may also be used to estimate uncertainties in some situations.

This section re-emphasises that for the analyst it is important that no unnecessary duplication of existing work is undertaken.

7. Values of Measurement Uncertainty Estimations

Stipulating information on the anticipated values of measurement uncertainty estimations is frequently not appreciated. However, the users of analytical data and the customers of the laboratories producing such data frequently ask for such information. They have concerns that some laboratories underestimate the size of their uncertainties and so report unrealistically small uncertainties to their customers.

For chemical analyses, using the values of S_R from collaborative trials, it would not be unreasonable to anticipate that the (expanded) analytical measurement uncertainties reported by laboratories would be of the following orders:

Concentration	Expanded Uncertainty	Range of Acceptable Concentrations*
100g/100g	4%	96 to 104g/100g
10g/100g	5%	9.5 to 10.5g/100g
1g/100g	8%	0.92 to 1.08g/100g
1g/kg	11%	0.89 to 1.11g/kg
100mg/kg	16%	84 to 116mg/kg
10mg/kg	22%	7.8 to 12.2mg/kg
1mg/kg	32%	0.68 to 1.32mg/kg
< 100µg/kg	44%	56 to 144µg/kg

* this effectively means that values falling within these ranges may be regarded as being of the same analytical population.

However, for total measurement uncertainties it has not yet been possible to "predict" what the uncertainties are likely to be. Experimental work has suggested that for a range of systems within the food sector the sampling uncertainty is between equal to the analytical uncertainty to 4 times the analytical measurement uncertainty. Three examples are given at the end of these Notes, values calculated using the Nordtest "range" procedure.

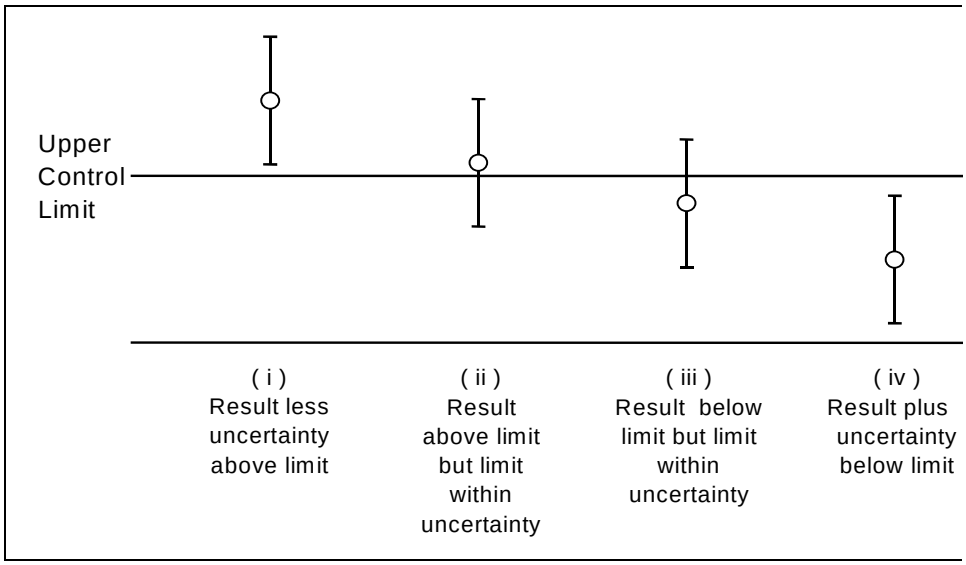
8. Significance of the Section in the Procedural Manual of the "use of analytical results: sampling plans, relationship between the analytical results, the measurement uncertainty, recovery factors and provisions in Codex Standards" (from Codex Procedural Manual, 17th Edition)

This section attempts to explain the significance of the adopted Codex text with respect to the measurement uncertainty.

8.1 Measurement Uncertainty

It is stated that an allowance is to be made for the measurement uncertainty when deciding whether or not an analytical result falls within the specification. This requirement may not apply in situations when a direct health hazard is concerned, such as for food pathogens. This does mean that it is important for Codex Commodity Committees, when setting specifications, to recognise that there is a difference between the numeric value in the specification and numeric value at which the specification will be enforced. Put simply this difference equates to the measurement uncertainty of the result obtained by the "enforcing laboratory". Thus, when enforcing a maximum limit, the enforcement laboratory (normally the importer) will have to deduct the value of the measurement uncertainty before deciding whether the sample meets the specification.

This is best illustrated diagrammatically, where the figure below illustrates four different situations:



Situation I

The analytical result together with the total measurement uncertainty exceeds the maximum level. All authorities will consider the sample as being non-compliant with the specification.

Situation II

The analytical result exceeds the maximum level by less than the total measurement uncertainty. Some authorities would have accepted the sample as being compliant with the specification, if they routinely take into account the measurement uncertainty. Others would have ignored the measurement uncertainty and so would not accept the sample. The effect of the accepted text is that all authorities will accept the result as being compliant (i.e. the result is not non-compliant *"beyond reasonable doubt"*).

Situation III

The analytical result is below the maximum level by less than the measurement uncertainty. In general authorities will consider the sample to be compliant with the specification, but would probably be wary of future samples.

Situation IV

The analytical result is less than the maximum value by an amount greater than the measurement uncertainty. All authorities will consider the sample as being compliant without any hesitation.

It should be noted that the above situation will have to be interpreted with sensitivity in some instances. However, the risk of inadequate protection of the consumer may be reduced by a suitable selection of the specification – thus it is essential that the significance of measurement uncertainty deduction from the analytical result before assessing compliance is appreciated.

However, if the total measurement uncertainty is to be taken into account, the "error bars" become very much greater. This means that there is much more chance of situations *II and III* occurring. In addition, there are two other possibilities if the total measurement uncertainty is separated into both analytical and sampling uncertainties, i.e.

- Result less analytical uncertainty is above limit, but limit is within total uncertainty when sampling uncertainty is also considered, and

- Result is below limit but limit plus analytical uncertainty still below limit but within total uncertainty when sampling uncertainty is also considered

8.2 Enforcement Situation

The significance of this section in the Procedural Manual is that the laboratory at importation will deduct the measurement uncertainty. If the value after deduction is still greater than the specification, then it may be stated, ***beyond reasonable doubt***, that the sample is not compliant with the specification. If sampling uncertainty is taken into account then without an alteration to a (maximum) control level, more samples will be deemed to be compliant with the control level.

It is important for the exporter to realise that in order to be sure that the exported product meets the specification the "certificated value" obtained by the producer/exported must have the uncertainty of the result added to it, and for that value to be below the specification.

By using the total uncertainty to assess compliance it means that the situation II will occur more frequently than previously.

8.3 Action to be taken by Authority Setting the Specification Level

In order to protect the consumer either:

The total measurement uncertainty when estimated must not be significantly greater that the analytical uncertainty when estimated alone, or

The (maximum) specification level must be reduced to take into account the increased value of the total measurement uncertainty as compared to the analytical measurement uncertainty.

9. Useful References

A number of references are given below. [NB: these are general references and do need up-dating.]

Methods for the Estimation of Measurement Uncertainty

Guide 98, Guide to the Expression of Uncertainty in Measurement (GUM) ISO, Geneva (1995).

EURACHEM/CITAC Guide Quantifying Uncertainty In Analytical Measurement (Second Edition), EURACHEM Secretariat, BAM, Berlin, 2000. This is available as a free download from http://www.eurachem.ul.pt/

Analytical Methods Committee of the Royal Society of Chemistry "Uncertainty of Measurement - Implications of its use in Analytical Science", Analyst, 1995, **120 (9)**, 2303-2308.

ISO/TS 21748:2004 Guidance for the Use of Repeatability, Reproducibility and Trueness estimates in Measurement Uncertainty Estimation, ISO, Geneva (2004).

NIST Technical note 1297 (1994 Edition): "Guidelines for Evaluating and Expressing the Uncertainty of NIST Measurement Results"

NMKL Procedure No. 5, 2nd edition (2003): "Estimation and Expression of Measurement Uncertainty in Chemical Analysis"

UKAS (United Kingdom Accreditation Service) 2000 The Expression of Uncertainty in Testing Edition 1, UKAS Publication ref: LAB 12

EURACHEM/EUROLAB/CITAC/Nordtest *Guide on the Estimation of Measurement Uncertainty Arising from Sampling.* Downloadable from: http://www.eurachem.org/guides/UfS_2007.pdf

Nordtest handbook for sampling planners on sampling quality assurance and uncertainty estimation *Uncertainty from sampling* (Based upon the EURACHEM international guide *estimation of measurement uncertainty arising from sampling).* Downloadable as Report 604 from: http://www.nordicinnovation.net/nordtestfiler/tr604.pdf

Procedures for the Validation of Analytical Methods and Method Performance

"Precision of Test Methods", Geneva, 1994, ISO 5725, Previous editions were issued in 1981 and 1986. (not adopted by Codex).

"Protocol for the Design, Conduct and Interpretation of Method Performance Studies", ed. W. Horwitz, *Pure Appl. Chem.,* 1995, 67, 33 1-343. (adopted by Codex).

European Commission Decision 2002/657/EC implementing directive 96/23/EC Concerning the Performance of Analytical Methods and the Interpretation of Results, Off J Eur Comm, L221 (2002) 8-36.

T.P.J. Linsinger, R.D. Josephs: Limitations of the application of the Horwitz

Accreditation etc

ISO/IEC 17025:2005, General Requirements for the Competence of Testing and Calibration Laboratories, ISO, Geneva (2005).

EURACHEM Guidance Document No. 1/WELAC Guidance No. WGD 2: "Accreditation for Chemical Laboratories: Guidance on the Interpretation of the EN 45000 series of Standards and ISO/IEC Guide 25"

Z., Ben-David, H., Mates, A. 2001 Proficiency testing as tool for ISO 17025 implementation in National Public Health Laboratory: a mean for improving efficiency. Accreditation & Quality Assurance, **6**: 190-194

NMKL Procedure no. 3 (1996) "Control charts and control samples in the internal quality control in chemical food laboratories"

Örnemark, U., Boley, N., Saeed, K., van Berkel, P.M., Schmidt, R., Noble, M., Mäkinen, I., Keinänen, M., Uldall, A., Steensland, H., Van der Veen, A., Tholen, D. W., Golze, M., Christensen, J.M., De Bièvre, P., De Leer, W. B (ed). 2001 Proficiency testing in analytical chemistry, microbiology, and laboratory medicine – working group discussions on current status, problems, and future directions. Accreditation & Quality Assurance, **6**: 140-146.

Compliance

EURACHEM/CITAC Guide on the Use of uncertainty information in compliance assessment EURACHEM Secretariat, BAM, Berlin, 2007. This is available as a free download from http://www.eurachem.ul.pt/

Terminology

ISO (2nd ed., 1993) VIM "International Vocabulary of Basic and General Terms in Metrology". Geneva.

ISO Guide 99, International Vocabulary of Basic and General Terms in Metrology, 3rd Ed., VIM3, ISO, Geneva (2008).

THREE EXAMPLES FROM THE FOOD SECTOR USING DOUBLE SPLIT DESIGN AND RANGE STATISTICS

Three examples of where the range procedure given in the Nordtest Guide 604 have been applied are given below.

These indicate the problems that may arise when sampling uncertainty is identified.

Example 1 – Nitrate concentration in glasshouse lettuce

Aim: To estimate the average concentration of nitrate (in mg kg^{-1}) in a bay of lettuce.
For this study each 'bay' was considered equivalent to a batch of lettuce, and a bay of lettuce was the sampling target.

The routine sample: The sampling was planned for the winter growing season (October – April). The concentration of nitrate in glasshouse grown lettuce is regulated by EC Regulation 563/2002.

The routine sampling protocol applied for this analyte-commodity combination required 10 heads of lettuce to be cut from each bay of lettuce. The protocol instructs samplers to cut the samples whilst walking either a 'W' or '5-point die' through the bay under investigation. The first sample (S1 - usually be the only sample taken from the bay) was collected by the samplers using their routine interpretation of the protocol.

The duplicate sample: The protocol did not give any specific information on how to orient either design. In this respect either a W or 5-point die could be applied, and orientated in any direction (examples are given in Figure 2). All are equally valid under the protocol.

For the purpose of estimating sampling uncertainty the duplicate sample (S2) was taken by the samplers using a different interpretation of the protocol (as instructed by the researchers).

Both samples (S1 and S2) were transported to the analytical laboratory in identical ice-packed cool boxes.

Sample preparation and analysis: On receipt at the laboratory each 10-head sample was reduced in size (i.e. each head was cut into four and opposite quarters selected) and macerated. Two 30g test samples were drawn from the homogenate, i.e. A1 and A2, for each of the duplicate sample. Extraction was by routine accredited procedures (water extraction with quantification by HLPC). Spike samples were run concurrently with the samples to provide an estimate of recovery.

No significant analytical bias could be detected and so bias correction was considered unnecessary for the resultant data.

This measurement process was repeated for eight sampling targets (bays). In practice the eight duplicate samples were achieved during two sampling exercises.

Sample 1				Sample 2				
x_{i11}	x_{i12}	$D_{i1} = \lvert x_{i11} - x_{i12} \rvert$	$\bar{x}_{i1}$	x_{i21}	x_{i22}	$D_{i2} = \lvert x_{i21} - x_{i22} \rvert$	$\bar{x}_{i2}$	$D_i = \lvert \bar{x}_{i1} - \bar{x}_{i2} \rvert$
3898	4139	241	4019	4466	4693	227	4580	561
3910	3993	83	3952	4201	4126	75	4164	212
5708	5903	195	5806	4061	3782	279	3922	1884
5028	4754	274	4891	5450	5416	34	5433	542
4640	4401	239	4521	4248	4191	57	4220	301
5182	5023	159	5103	4662	4839	177	4751	352
3028	3224	196	3126	3023	2901	122	2962	164
3966	4283	317	4125	4131	3788	343	3960	165
$\overline{D}_{i1} = \frac{\sum D_{i1}}{n}$		213		$\overline{D}_{i2} = \frac{\sum D_{i2}}{n}$		164	$\overline{D} = \frac{\sum D_i}{n}$	523

Mean range of analysis

$$\overline{D}_{analysis} = \frac{\overline{D}_{i1} + \overline{D}_{i2}}{2} = 189$$

Standard deviation of analysis

$$s_{analysis} = \frac{\overline{D}_{analysis}}{1.128} = 167.2$$

Mean range of measurement

$$\overline{D} = 523$$

Standard deviation of measurement based on duplicate analysis

$$s_{measurement} = \frac{\overline{D}}{1.128} = 463.3$$

Standard deviation of sampling $s_{sampling} = \sqrt{s_{measurement}^2 - \left(\frac{s_{analysis}}{\sqrt{2}}\right)^2} = 448.0$

Comment: Since the analyses are based on a mean of duplicates the standard deviation of analysis is divided by square root of 2 in the formula above – standard error of the mean.

Example 2 – infant wet meals (retail survey)

Aim: To estimate concentrations of cadmium in infant wet meals (in mg kg^{-1}), as part of a survey. Survey data may be used in risk/exposure assessment. Wet meals can be considered as food given to an infant at mealtimes, which does not require the addition of water/fluid. For this study a batch of a particular wet meal (identified by unique batch code) was considered to be the sampling target.

The routine sample: Each sampling target (in terms of provenance, brand name, product type, size) was identified prior to the sampling event. Samplers were instructed to purchase three of each target, all from the same batch, i.e. 3 glass jars, metal cans etc. Two of the pots were analysed independently to produce two discrete concentration estimates. This could allow a rudimentary estimate of within-batch variability. For the purpose of uncertainty estimation one of the pots was randomly selected as S1. The third pot was retained by the laboratory as a reference sample.

The duplicate sample: The protocol did not specify specific batch codes from which to sample. At each retail establishment, there was more than one batch available for purchase. The likelihood of the sampler or a member of the public selecting from either batch was considered equivalent. Therefore the 'duplicate sample' was taken from a second batch (S2) which allowed the preservation of the original experimental design. Duplicate samples were taken for 8 wet meals (sampling targets). The estimate of sampling uncertainty represented between-batch variability.

Sample preparation and analysis: The Cd concentration was determined for each sample using a UKAS accredited methods, quantification was by ICP-MS (ELAN 6000). Both S1 and S2 samples were analysed in duplicate. All other samples were analysed singularly.

Sample 1				Sample 2				
x_{i11}	x_{i12}	$D_{i1} = \lvert x_{i11} - x_{i12} \rvert$	$\overline{x}_{i1}$	x_{i21}	x_{i22}	$D_{i2} = \lvert x_{i21} - x_{i22} \rvert$	$\overline{x}_{i2}$	$D_i = \lvert \overline{x}_{i1} - \overline{x}_{i2} \rvert$
5.73	5.68	0.05	5.71	6.57	6.15	0.42	6.36	0.66
10.07	10.12	0.05	10.10	8.02	7.91	0.11	7.97	2.13
4.36	4.11	0.25	4.24	4.80	4.44	0.36	4.62	0.39
11.32	5.77	5.55	8.55	10.53	10.42	0.11	10.48	1.93
3.86	8.02	4.16	5.94	4.97	4.08	0.89	4.53	1.42
9.00	9.83	0.83	9.42	12.56	12.33	0.23	12.45	3.03
9.06	1.98	7.08	5.52	9.92	8.67	1.25	9.30	3.78
8.01	11.51	3.50	9.76	9.55	8.59	0.96	9.07	0.69
10.90	3.90	7.00	7.40	9.41	8.88	0.53	9.15	1.75
2.51	8.19	5.68	5.35	5.87	5.32	0.55	5.60	0.25
$\overline{D}_{i1} = \frac{\sum D_{i1}}{n}$		3.42		$\overline{D}_{i2} = \frac{\sum D_{i2}}{n}$		0.54	$\overline{D} = \frac{\sum D_i}{n}$	1.60

Mean range of analysis

$$\overline{D}_{analysis} = \frac{\overline{D}_{i1} + \overline{D}_{i2}}{2} = 1.98$$

Standard deviation of analysis

$$s_{analysis} = \frac{\overline{D}_{analysis}}{1.128} = 1.754$$

Mean range of measurement

$\overline{D} = 1.60$

Standard deviation of measurement based on duplicate analysis

$$s_{measurement} = \frac{\overline{D}}{1.128} = 1.418$$

Standard deviation of sampling $s_{sampling} = \sqrt{s_{measurement}^2 - \left(\frac{s_{analysis}}{\sqrt{2}} \right)^2} = 0.689$

Comment: Since the analyses are based on a mean of duplicates the standard deviation of analysis is divided by square root of 2 in the formula above – standard error of the mean.

Example 3 – Moisture in wholesale butter (offered for EU subsidy)

Aim: To estimate the moisture content of a batch of butter put forward for subsidy payment (EC 2571/97). To achieve the minimum quality standards required, the batch must contain a maximum of 16% moisture (m/m). It should be noted that other quality requirements should be satisfied before a subsidy is paid.
For this study a c. 20 tonne batch of unsalted butter (typically a day's production) was considered to be the sampling target. Each batch was comprised of 25 kg (individually cased) blocks of butter, i.e. 40 * 25 kg per 20 tonne batch.

The routine sample: Prior to the physical taking of the sample, an appropriate number of 25 kg blocks were selected from the batch under inspection. The number of blocks is dependent on the mass of the batch, e.g. for a 20 tonne batch, 6 blocks were selected. The six blocks were left to temper for 48 hours. On the day of sampling a 500 g increment was cut from the edge of each of the blocks. The six increments were later processed and combined to produce two 3-fold composite samples.

The duplicate sample: For this case study an estimate of within-batch sampling uncertainty was required. Decisions on whether to award the subsidy are made on a batch-by-batch basis. As two independent results are routinely presented, the two 3-fold composite samples can be considered as the duplicate samples. Although this is not an implementation of the duplicate method in the purest sense, it is time, cost and space efficient for routine surveys.

Sample preparation and analysis: The six 500 g increments were transported to the laboratory. For each increment, 200 g was removed for further analysis and the remainder was used for sensory analysis. Two 3-fold composites were produced using the 6 increments. Each composite sample was analysed for moisture, as determined by drying of a known mass of butter at 102°C ± 2°C and weighing to determine loss. Moisture is expressed in units of % m/m.

Sample 1				Sample 2				
x_{i11}	x_{i12}	$D_{i1} = \lvert x_{i11} - x_{i12} \rvert$	$\overline{x}_{i1}$	x_{i21}	x_{i22}	$D_{i2} = \lvert x_{i21} - x_{i22} \rvert$	$\overline{x}_{i2}$	$D_i = \lvert \overline{x}_{i1} - \overline{x}_{i2} \rvert$
16.05	16.05	0.00	16.05	15.88	15.91	0.03	15.90	0.16
15.95	15.93	0.02	15.94	15.94	15.94	0.00	15.94	0.00
16.00	15.97	0.03	15.99	16.02	15.96	0.06	15.99	0.01
15.63	15.66	0.03	15.65	15.76	15.72	0.04	15.74	0.10
15.74	15.72	0.02	15.73	16.11	16.01	0.10	16.06	0.33
15.80	15.74	0.06	15.77	15.85	15.79	0.06	15.82	0.05
15.64	15.57	0.07	15.61	15.25	15.15	0.10	15.20	0.41
14.78	14.85	0.07	14.82	15.79	15.74	0.05	15.77	0.95
$\overline{D}_{i1} = \frac{\sum D_{i1}}{n}$		0.04		$\overline{D}_{i2} = \frac{\sum D_{i2}}{n}$		0.05	$\overline{D} = \frac{\sum D_i}{n}$	0.25

Mean range of analysis

$$\overline{D}_{analysis} = \frac{\overline{D}_{i1} + \overline{D}_{i2}}{2} = 0.05$$

Standard deviation of analysis

$$s_{analysis} = \frac{\overline{D}_{analysis}}{1.128} = 0.041$$

Mean range of measurement

$\overline{D} = 0.25$

Standard deviation of measurement based on duplicate analysis

$$s_{measurement} = \frac{\overline{D}}{1.128} = 0.221$$

Standard deviation of sampling $\quad s_{sampling} = \sqrt{s_{measurement}^{\ 2} - \left(\frac{s_{analysis}}{\sqrt{2}} \right)^2} = 0.219$

Comment: Since the analyses are based on a mean of duplicates the standard deviation of analysis is divided by square root of 2 in the formula above – standard error of the mean.