Assessment of performance and uncertainty in qualitative chemical analysis: The Eurachem/CITAC Guide

Ricardo Bettencourt da Silva¹,², Stephen Ellison¹,³

(1) Eurachem/CITAC Qualitative Analysis Working Group
(2) CQE, IMS, FC, Universidade de Lisboa
(3) LGC Limited

Outline

Types of chemical analysis
Eurachem/CITAC Guide aim

Content
  Types of qualitative analysis
  Performance assessment for qualitative analysis
  Expressions of confidence in qualitative analysis
  Reporting the qualitative analytical result
  Conclusions and recommendation
  Examples
  Final message
Types of chemical analysis

• Quantitative (Measurements)

• Qualitative (Examinations)


Types of chemical analysis

Qualitative analysis is defined as:

“Classification according to specified criteria”

Analytical methods (procedures) used in qualitative analysis must be:

• Applicable to an adequate scope

• Have fit for purpose quality/ uncertainty
Eurachem/CITAC Guide aim

• Highlight the need to check if qualitative analyses are fit for the intended use

• Describe tools, including their limitations, for assessing qualitative analysis performance

Content

Scope
1. Introduction
2. Types of qualitative analysis
3. Performance assessment for qualitative analysis
4. Expressions of confidence in qualitative analysis
5. Reporting the qualitative analytical result
6. Conclusions and recommendation
7. Examples
   Annex A and B
   Bibliography
Types of Qualitative Analysis

Qualitative analysis can be based on:

- Qualitative data
  Ex. Detection of aliphatic aldehydes in a solution by colour change after the addition of Schiff’s reagent.

- Quantitative data
  Ex. Identification of a pesticide residue in fruit using measured fragment masses and relative fragment abundances in GC-MS.

The transformation of the comparison of a measured value with a threshold in a qualitative output (‘conforming’ or ‘nonconforming’) is described in Annex B.

Performance assessment for qualitative analysis

The performance of qualitative analysis is conveniently described using a contingency table:

<table>
<thead>
<tr>
<th>Case</th>
<th>Positive (pc)</th>
<th>Negative (nc)</th>
<th>Results totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Result</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive (p)</td>
<td><em>tp</em></td>
<td><em>fp</em></td>
<td><em>p</em></td>
</tr>
<tr>
<td>Negative (n)</td>
<td><em>fn</em></td>
<td><em>tn</em></td>
<td><em>n</em></td>
</tr>
<tr>
<td>Case totals</td>
<td><em>pc</em></td>
<td><em>nc</em></td>
<td></td>
</tr>
</tbody>
</table>

True positive rate = TP = *tp*/*pc*
False positive rate = FP = *fp*/*nc*
Performance assessment for qualitative analysis

The performance of qualitative analysis is conveniently described using a contingency table:

<table>
<thead>
<tr>
<th>Case</th>
<th>Positive (pc)</th>
<th>Negative (nc)</th>
<th>Results totals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive (p)</td>
<td>$tp = 228$</td>
<td>$fp = 1$</td>
<td>$p = 229$</td>
</tr>
<tr>
<td>Negative (n)</td>
<td>$fn = 5$</td>
<td>$tn = 300$</td>
<td>$n = 305$</td>
</tr>
<tr>
<td>Case totals</td>
<td>$pc = 233$</td>
<td>$nc = 301$</td>
<td></td>
</tr>
</tbody>
</table>

True positive rate = $TP = \frac{tp}{pc} = \frac{228}{233} = 97.8\%$
False positive rate = $FP = \frac{fp}{nc} = \frac{1}{301} = 0.33\%$

Performance assessment for qualitative analysis

Performance can be assessed:

- experimentally
- database search
- quantitative data modelling
Expressions of confidence in qualitative analysis

• Likelihood ratio

\[ LR(+) = \frac{TP}{FP} \]

Advantage: Only requires performance data
Easy to consider the use of independent pieces of evidence
Disadvantage: Does not characterise the analysed sample
Difficult to interpret

Expressions of confidence in qualitative analysis

• Posterior probability of positive case, \( PP \)

If the prevalence of positive cases is known, \( P(+) \), if can be estimated the probability of a sample that produced a positive result being a positive case:

\[ PP = \frac{\frac{P(+)}{1-P(+)}LR(+)}{\frac{P(+)}{1-P(+)}LR(+)+1} \]
Reporting the qualitative analytical result

**Example 3** (the italic text mentions the qualitative analysis uncertainty):

Cocaine is present in sample 123

(identification with a likelihood ratio of $4.9 \times 10^4$ and considered ‘very strong’ evidence of analyte presence)

**Example 4** (the italic text mentions the qualitative analysis uncertainty):

Gasoline residues were identified in the fire debris with sample code 456

(identification with a posterior probability of 99.998%, estimated from signal model simulation and assuming analyte presence or absence are equally probable)

Conclusions and recommendation

- The most critical false response rates should be checked
- Parameters that affect analysis performance should be controlled
- The reporting of analysis uncertainties should avoid misinterpretation
- Test results can be reported as ‘inconclusive’/insufficiently certain
Examples

E1: Identification of compounds by low-resolution mass spectrometry using database searching or the presence of characteristic ions
E2: Identification of purified compounds by infrared spectrometry
E3: Identification of drugs of abuse in urine by the enzyme multiplied immunoassay technique (EMIT) and an alternative technique
E4: Identification of human SRY gene in biological material by qPCR
E5: Identification of pesticide residues in foodstuffs by GC-MS/MS based on retention time and ion abundance ratio
E6: Identification of SARS-CoV-2 RNA by nucleic acid amplification testing

FINAL MESSAGE

The QAWG wishes the new guide is useful for the community

Eurachem and CITAC members are invited to join the working group