The road to developing performance standards in Europe for low cost sensors-Part 1: Example of implementation of an existing reference instrument standardisation method

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Introduction

▪ What is NPL and what does it do?
▪ European Standardisation Activities and NPL’s role
▪ How are instruments type-tested at NPL and certified?
▪ Why do we need a different approach for low cost sensors?
▪ Conclusions
What is NPL and what does it do?

- Founded in 1900, UK’s NMI, respected centre of excellence in research and development, including applications in environmental monitoring
- NPL sits at the heart of an important infrastructure designed to ensure accuracy and consistency with traceability in all physical measurements, in support of business and society
- Government owned, government operated (“GOGO”) with ~1000 personnel (scientists, students, and maintenance)
- International role in standardisation, developing laboratory and field test facilities, traceable Primary Standard gas Mixtures (PSMs), runs AQ networks (and QA/QC)
European Standardisation Activities

- Goal of European Commission is harmonised implementation of AQ legislation in EU through responsible bodies and by use of reference measurement methods

- European Committee for Standardization, Comité Européen de Normalisation (CEN)

- NPL is well represented on TC264 which is the standardisation committee responsible for all European documentary standards on emissions to air and ambient air measurements

- “Translating” technical requirements of EU Directives into European Standards carried out by the various WGs including WG42 on AQ Sensors, WG11(diffusive samplers), WG12 (benzene)
How are instruments certified?

- Continuous ambient monitors (CAMs) generate measurements with the lowest uncertainties to comply with EU AQ Directives (2008/50/EC and its daughters) [REFERENCE METHODS defined]
- Comprehensive, pollutant-specific, and rigorous type-testing procedures carried out before the method is allowed to be used in AQ Networks that report monitoring data to the European Commission
- Tests in accordance with UK certification scheme called MCERTS and the harmonised European Standard EN14662-3 (for benzene), by accredited laboratories (e.g., ISO17025)
How are instruments certified?

- Procedures include laboratory tests covering extremes of conditions and field tests lasting three months
- 2 instruments tested at key benzene concentrations: 1/10xLV, LV, Span

<table>
<thead>
<tr>
<th>Performance characteristic</th>
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</tr>
</thead>
<tbody>
<tr>
<td>Repeatability standard deviation at 10% of AL</td>
<td>≤ 0.20 µg/m³</td>
<td>Interference of H₂O at 19 mmol/mol (80% RH) for AL</td>
<td>≤ 0.015 µg/m³/mmol/mol</td>
</tr>
<tr>
<td>Repeatability standard deviation at AL</td>
<td>≤ 0.25 µg/m³</td>
<td>Interference of organic compound mixture for AL</td>
<td>≤ 0.50 µg/m³</td>
</tr>
<tr>
<td>Lack of fit</td>
<td>≤ 5% of measured value</td>
<td>Carry over (memory effect)</td>
<td>≤ 1.0 µg/m³</td>
</tr>
<tr>
<td>Sensitivity coefficient of sample gas pressure</td>
<td>≤ 0.40 µg/m³/kPa</td>
<td>Short term drift at span level</td>
<td>≤ 2.0 µg/m³ over 12 h</td>
</tr>
<tr>
<td>Sensitivity coefficient of surrounding temperature</td>
<td>≤ 0.08 µg/m³/K</td>
<td>Difference sample/calibration port</td>
<td>≤ 1%</td>
</tr>
<tr>
<td>Sensitivity coefficient of electrical voltage</td>
<td>≤ 0.08 µg/m³/V</td>
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</table>
How are instruments certified?

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<tr>
<td>Reproducibility standard deviation under field conditions</td>
<td>( \leq 0.25 \mu g/m^3 )</td>
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<td>Reproducibility standard deviation under field conditions</td>
<td>( \leq 0.25 \mu g/m^3 )</td>
</tr>
<tr>
<td>Long term drift at span level</td>
<td>( \leq 10% ) of maximum of certification range</td>
</tr>
<tr>
<td>Period of unattended operation</td>
<td>&gt;14 days or less if manufacturer indicates a shorter period</td>
</tr>
<tr>
<td>Availability of the analyser (% useful data retrieved during trial)</td>
<td>&gt;90%</td>
</tr>
</tbody>
</table>
How are instruments certified?

- Test results for the performance criteria are used to calculate individual standard uncertainty components (µg/m$^3$), including the calibration gas.
- Combined uncertainty, $u_c$, calculated by summing in quadrature:

\[ u_c = \sqrt{\sum_{i=1}^{N} u_i^2} \]

- Then divide by Annual Limit for benzene (5 µg/m$^3$).
- Expanded uncertainty at 95% confidence level, $U = 2 \times u_c$.
- Must be less than ± 25% as required by EU Directives for benzene reference measurements.
- PASS (Report -> Certification Body CSA awards MCERTS)
Why we need a different approach for low cost sensors

- New sensor developments focused on spatially dense networks generating large scale data with high time resolution to complement reference measurements
- Used for atmospheric modelling and predicting air pollution in real time, air management for “intelligent buildings” to reduce energy consumption, adaptive air control systems on aircraft, neighbourhood “citizen science” projects
- Limited data already available suggests that many systems perform less well than has been claimed by their manufacturers, peer review process bypassed, IP retained
- WG42 (since 2015) TS “Performance evaluation of sensors for the determination of concentrations of gaseous pollutants and particulate matter in ambient air.”
### Why do we need a different approach for low cost sensors?

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Required uncertainty of reference methods</th>
<th>Expanded uncertainty of indicative methods (Class 1 sensor system)</th>
<th>Expanded uncertainty of objective estimations (Class 2 sensor system)</th>
<th>Expanded uncertainty of Class 3 sensor system</th>
</tr>
</thead>
<tbody>
<tr>
<td>SO$_2$, NO$_2$/NO$_x$, CO</td>
<td>15%</td>
<td>25%</td>
<td>75%</td>
<td>N/A</td>
</tr>
<tr>
<td>Benzene</td>
<td>25%</td>
<td>30%</td>
<td>100%</td>
<td>N/A</td>
</tr>
<tr>
<td>PM$<em>{10}$/PM$</em>{2.5}$</td>
<td>25%</td>
<td>50%</td>
<td>100%</td>
<td>N/A</td>
</tr>
<tr>
<td>O$_3$</td>
<td>15%</td>
<td>30%</td>
<td>100%</td>
<td>N/A</td>
</tr>
<tr>
<td>Thresholds$^+$</td>
<td>&gt;UAT</td>
<td>UAT&lt;[ ]&lt;LAT</td>
<td>&lt;LAT</td>
<td>N/A</td>
</tr>
</tbody>
</table>

$^+$UAT = Upper Assessment Threshold, LAT = Lower Assessment Threshold, [ ] = concentration.  
**EU DQO (2008/50/EC)**

- Current methodology focuses on the measurement of a pollutant, using a well-characterised measuring system
- A network of sensor systems is more than just the sum of its individual nodes
- Information at one node of the network can be exchanged with other nodes, and used to make inferences at nearby nodes
Conclusions

- Current robust approach to the certification of reference instruments needs to be adapted to meet the new requirements of networks of low cost sensors
- Standardisation will overcome market barriers by defining performance requirements to demonstrate that they are fit for purpose for a range of applications (so results are accepted by stakeholders)
- Promote research into new technologies (not just fine tuning of existing methods) because developers will see a potential market to pay for their investment
- To maximise the potential benefits new thinking is required to take into account linkages between sensor systems