Monte-Carlo model of a gas analyser operating under EN 14181:2014 to investigate achievable uncertainty during emission monitoring

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Introduction

- EN 14181:2014
- Monte-Carlo Simulation
- NPL Model
- Conclusions

EN 14181:2014

- European standard for measuring stationary source emissions
- Focus on quality assurance of automated measuring systems
- Updated in 2014

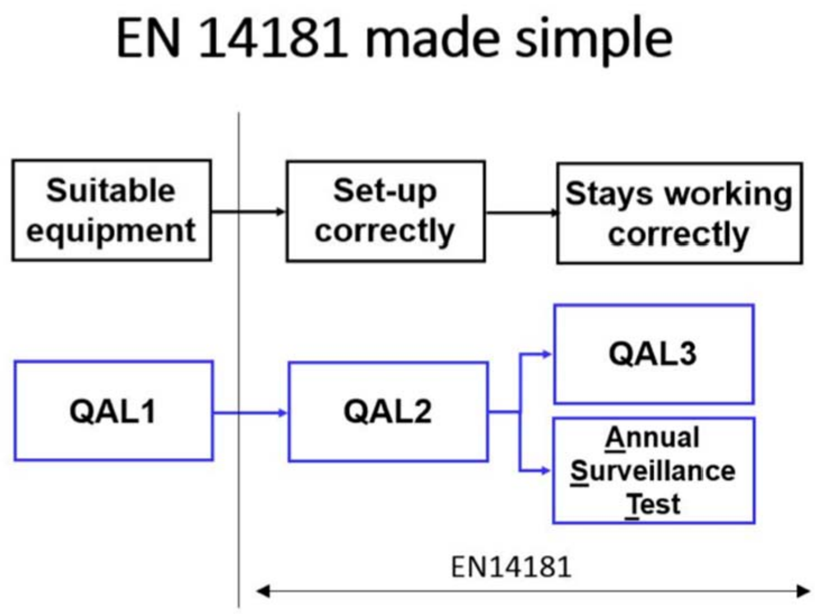


Figure from S-T-A website

EN 14181:2014
Overview of major changes

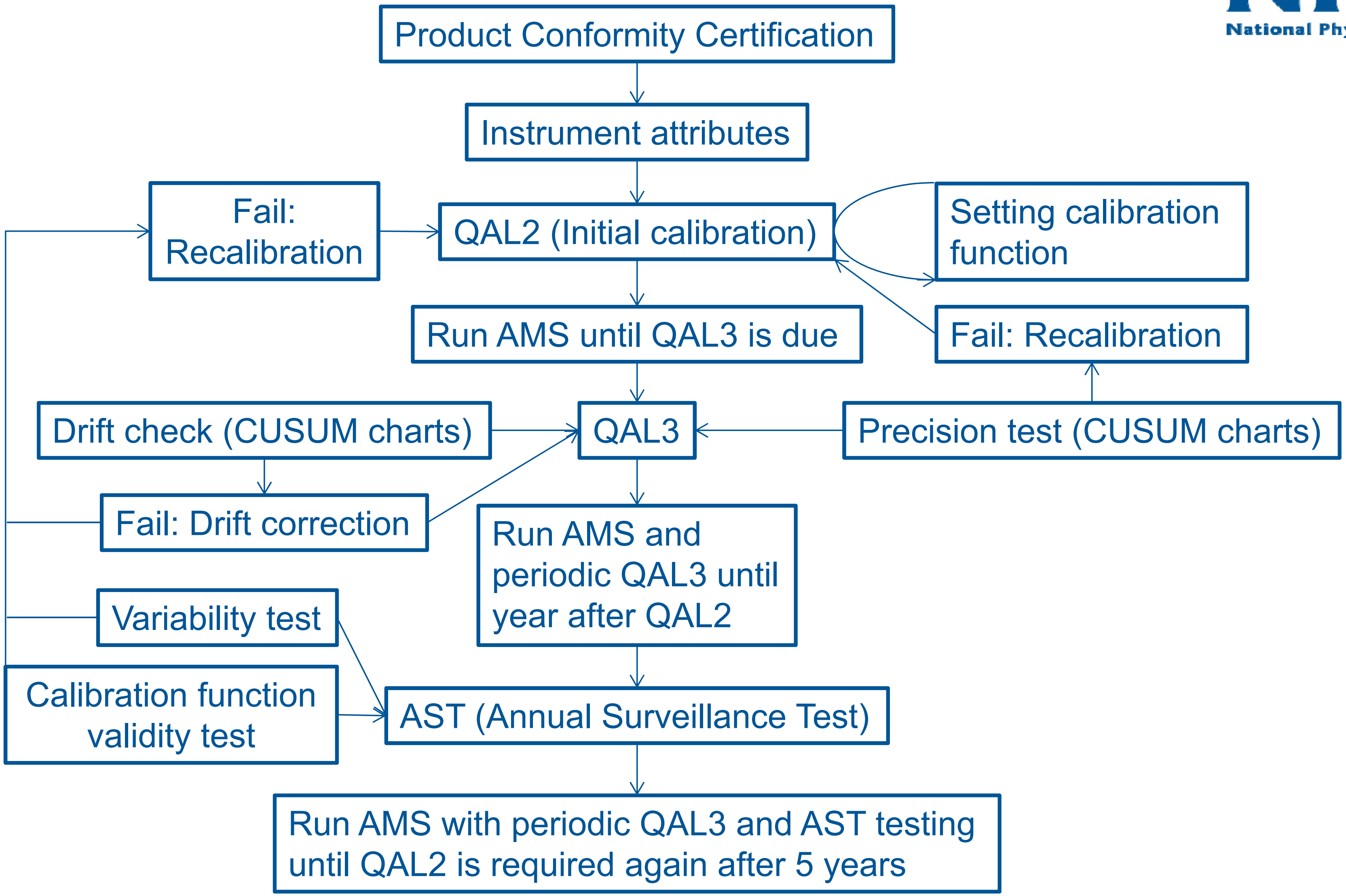
- Testing for and excluding outliers in QAL2 and AST
- Addition of new QAL2 procedure for data in a low level cluster
- EN 15267-1, EN 15267-2 & EN 15267-3 added for QAL1 assessment
- Alignment of the QAL2 and AST functional tests
- AST can be used to extend the valid calibration range to maximum measured concentration plus 10%, but below 50% of ELV

What is Monte-Carlo Simulation?

- Probabilistic tool to demonstrate the range and likelihood of potential outcomes
- Model is run multiple times with the same underlying data
- Each run has slightly different variables controlled by uncertainty in the relevant measurements
- The range and distribution of answers produced by the model represents a probability density function for the total modelled emissions

NPL Model

- Why build it?
  - Investigate the accuracy of measurement processes
  - Ensure the quality system achieves uncertainty levels required by legislation
  - No real alternative for testing the uncertainty of the whole measurement system including the instrument
- What does it do?
  - Simulated the whole process from QAL2 to the next QAL2
  - Includes every measurement made during the period



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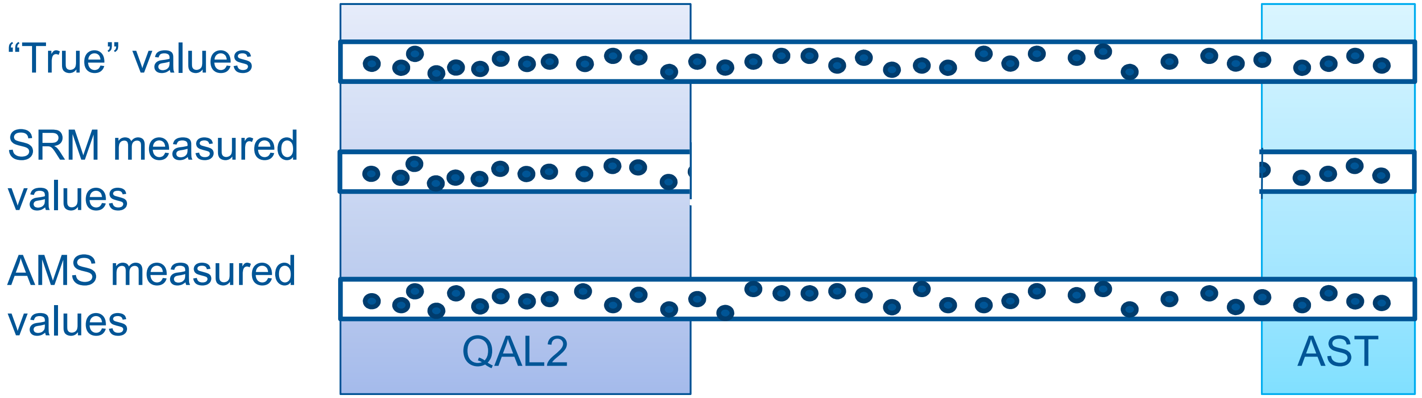
Quality assurance test frequency



Every week a QAL3 test is completed

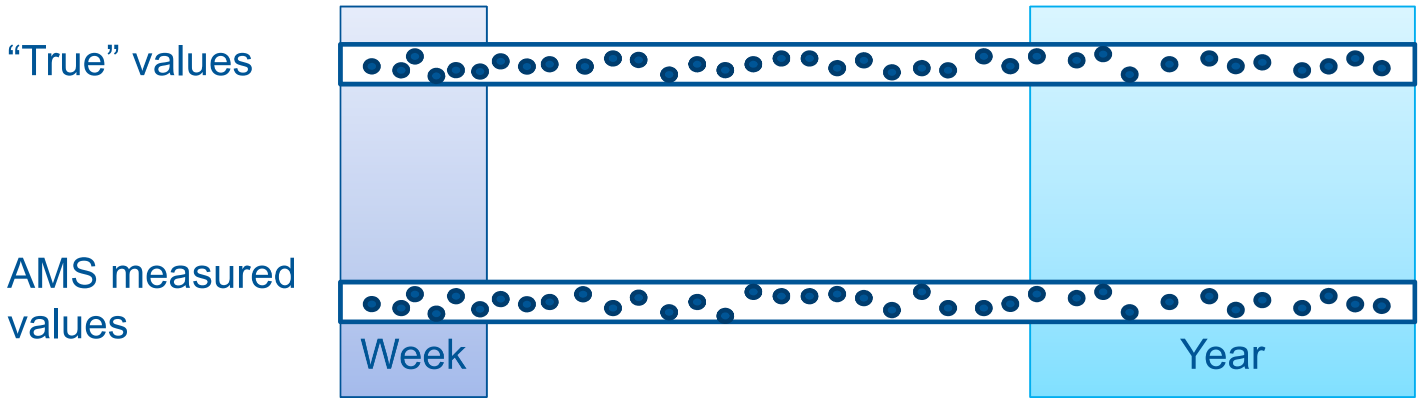
At the end of every year an AST is completed

QAL2 is done at the start of the model run and then when either QAL3 or AST fails or after 5 years

NPL Model: MCS Implementation

- Represent a population of instruments measuring the same emission source
- This means the model includes many systematic errors that would not be included when looking at a single instrument
- Example: There are few laboratories that measure stack samples so looking at a population of instruments you may see a systematic bias from a shared laboratory error that would be difficult to identify on a single instrument

Explaining the MCS elements



Zero and span time drift errors are fixed for a week and equally divided over all measurements in that period

Individual measurements have separate MCS errors for linearity, detection limit, cross sensitivity, temperature zero and span drift, zero and span time drifts and a repeatability error

The SRM measurements just have a MCS repeatability error value

Effect of SRM uncertainty

- SRM readings are assumed to be an un-bias estimator of the true reading
- AMS therefore has to closely match SRM results
- If the SRM performs poorly it can cause the AMS to fail variability tests
- Overall uncertainty for reference methods can be high:

  e.g. SO_2: EN 14791:2005 allows up to ±20% at the daily emission limit value

- This demonstrates the need to check quality procedures can successfully maintain AMS performance even if SRM quality is poor
- Model represents SRM error as a single random term for each SRM measurement

Case study

- Measuring SO2 with an instrumental AMS
- SRM represents wet chemistry method as detailed in EN 14791
- AST incorporating 5 parallel measurements
- QAL2 incorporating 15 parallel measurements
- Daily QAL3 check of zero and span measurements using CUSUM charts
- ELV = 200 $mg.Nm^{-3}$

Test plan

- Measure constant amounts of SO_2
- Keep all AMS variables constant
- Vary the SRM uncertainty
- Repeat for several constant emission levels

- SRM uncertainty levels:

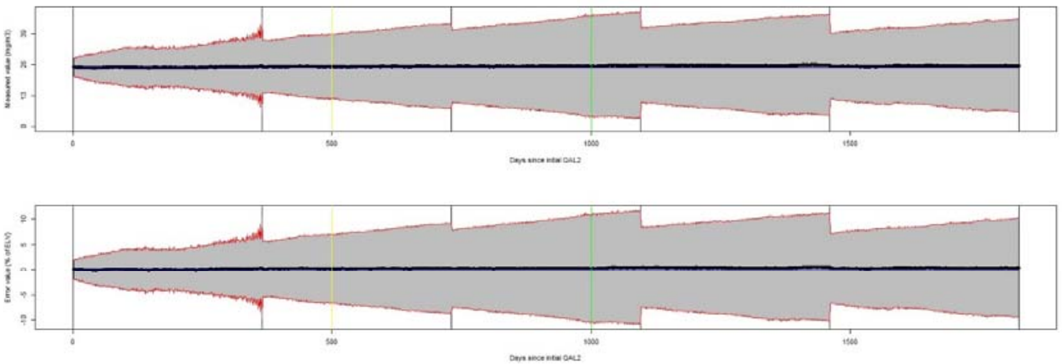
  0 – 30% @ 2.5% intervals

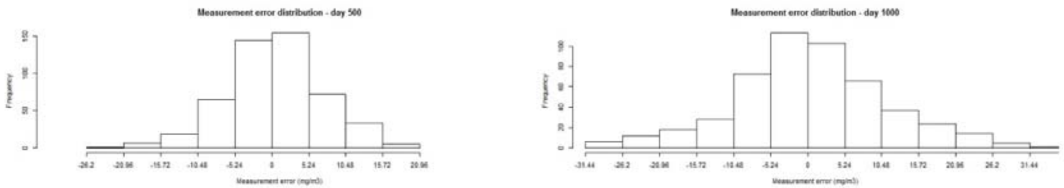
- SO_2 emission levels

  25 – 150mg/m^3 @ 25mg/m^3 intervals

Results

Good quality SRM (uncertainty = 2.5%)

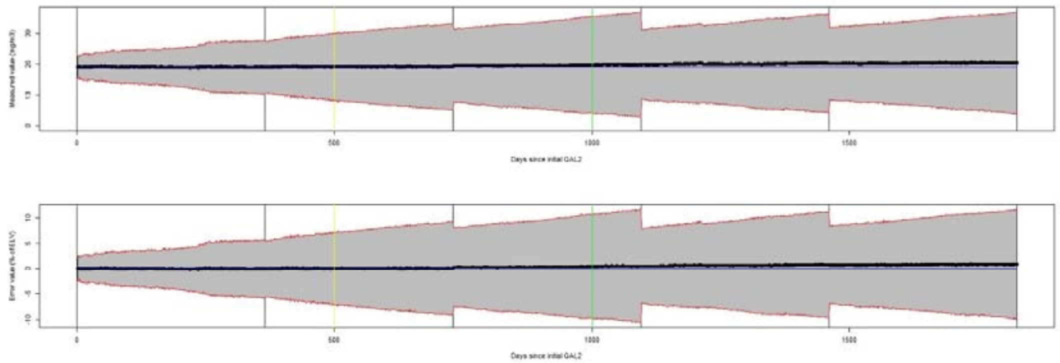


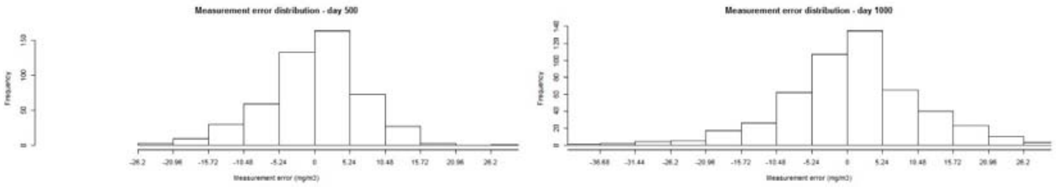


2σ = 13.5 mg.Nm^{-3}

2σ = 21.5 mg.Nm^{-3}

Poor quality SRM (uncertainty = 20%)



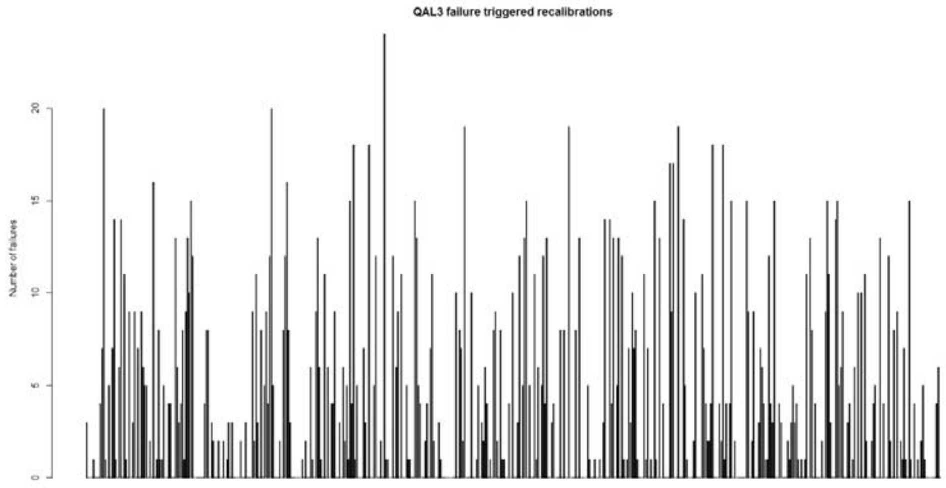


2σ = 14.1 mg.Nm^{-3}

2σ = 20.3 mg.Nm^{-3}

Additional QAL2 requirements:
AST and QAL3 failures lead to many extra QAL2

QAL3 failures



Max QAL3 fails: 24; Average QAL3 fails: 3.7;
Daily QAL3 so this is out of 1825 tests;

AST failures

Max AST fails: 3; Average AST fails: 0.4;

Discussion

- At low levels the SRM uncertainty has little effect on overall AMS uncertainty
- As SRM uncertainty increases towards limit (±20% for SO_2) measurement error magnitude rises, but within the quality control limits
- Failures of the initial QAL2 self selects for better uncertainties as poor input sets are caught by the quality control mechanism
- This effect is valid as an SRM with such high uncertainty is likely to be recognised as faulty

Conclusions

- Model shows that operating within the constraints of EN 14181 will maintain measurement standards, even with poorly performing AMS and SRM instruments
- Poor instruments lead to high failure rates and additional expensive QAL2s
- Currently working to perfect the model
- Added flow to the model to output mass emissions
- When complete it will be a powerful tool to investigate different scenarios
  - e.g. Looking at the effect of changing QAL3 frequency

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Questions