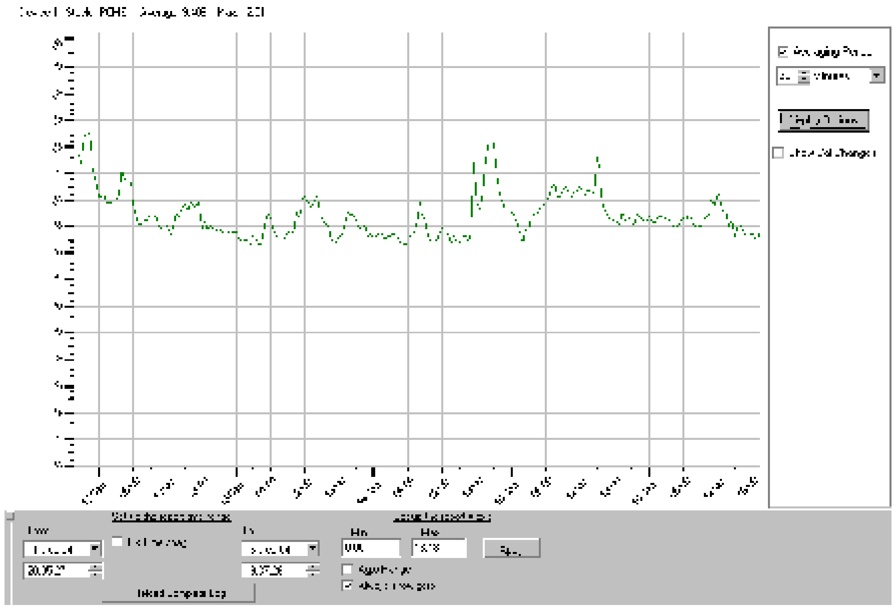
Particulate measurement technology and calibration

William Averdieck



Presentation Structure

- Requirements and scope of standards
- Technologies for monitoring particulate
- How to approach successful EN-14181 implementation

Regulatory requirement for continuous monitoring

- Relevant EU Directives
  - Large Combustion Plant (LCP) 2001/80/EC
  - Waste Incineration Directive (WID) 2000/76/EC
    - Incineration (and cement kilns)
- Integrated Pollution Prevention and Control –IPPC
  - Chemicals
    - Metals
    - Minerals
    - Combustion (permits)
    - Incineration (permits)
- Smaller processes (Part B UK, crematoria Germany)

WID and LCP require monitoring to defined uncertainty (EN-14181)

	Transition	Future and new plant	**Standardised conditions & Confidence at 95%**
WID Incineration	Daily 20mg/m^3	Daily 10mg/m^3 30mg/m^3 half hourly	273K 10% 02 30%
Co- incineration (cement kilns)	Daily 50mg/m^3	Daily 30mg/m^3	
LCP: 50-100MW >100MW >500MW	100mg/m^3 100mg/m^3 50mg/m^3 (solid fuel)	50mg/m^3 30mg/m^3 30mg/m^3 (all fuel)	273K 6% 02 30%

IPPC processes require other types of monitoring

- Directive states monitoring regime to be designed to support minimisation of emissions
  - UK: continuous monitoring where-ever practical

EA approach to EN-14181 in UK,

	EN-14181	Dust MCERTS (April 2003)	comment
UK	WID (2006) LCPD (2008)	All other IPPC	Regulator concerned on cost of EN-14181

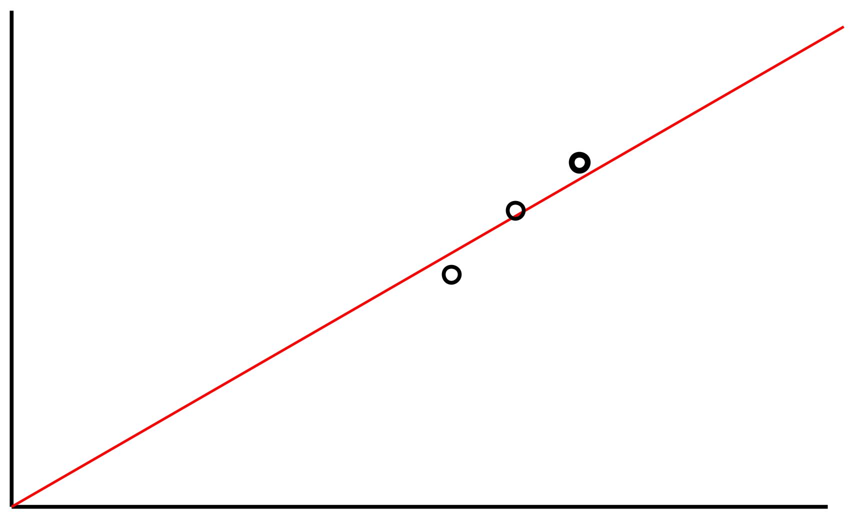
Plant operators have cost reasons for ensuring EN-14181 only applied to relevant processes.

		13284-2 standard for dust AMS	April 2003 MCERTS standards
Operator responsibilities		Qal 1, Qal 2, Qal 3, AST	Purchase certified system
Statistical analysis for calibration		15 (5) SRMs Variability test (every installation)	3 IS0-10155 (during one off field test)
Costs	Instrument	£5k -£15K	£5K
	Calibration	£5 -£10K	£1 -£2K
	Annual	£5K	
	Other	£5K if outside cal range	
Auditing		Automatic zero and span with statistical treatment 5 reference materials to audit linearity	Internal zero and reference point

Recommended approaches to monitoring

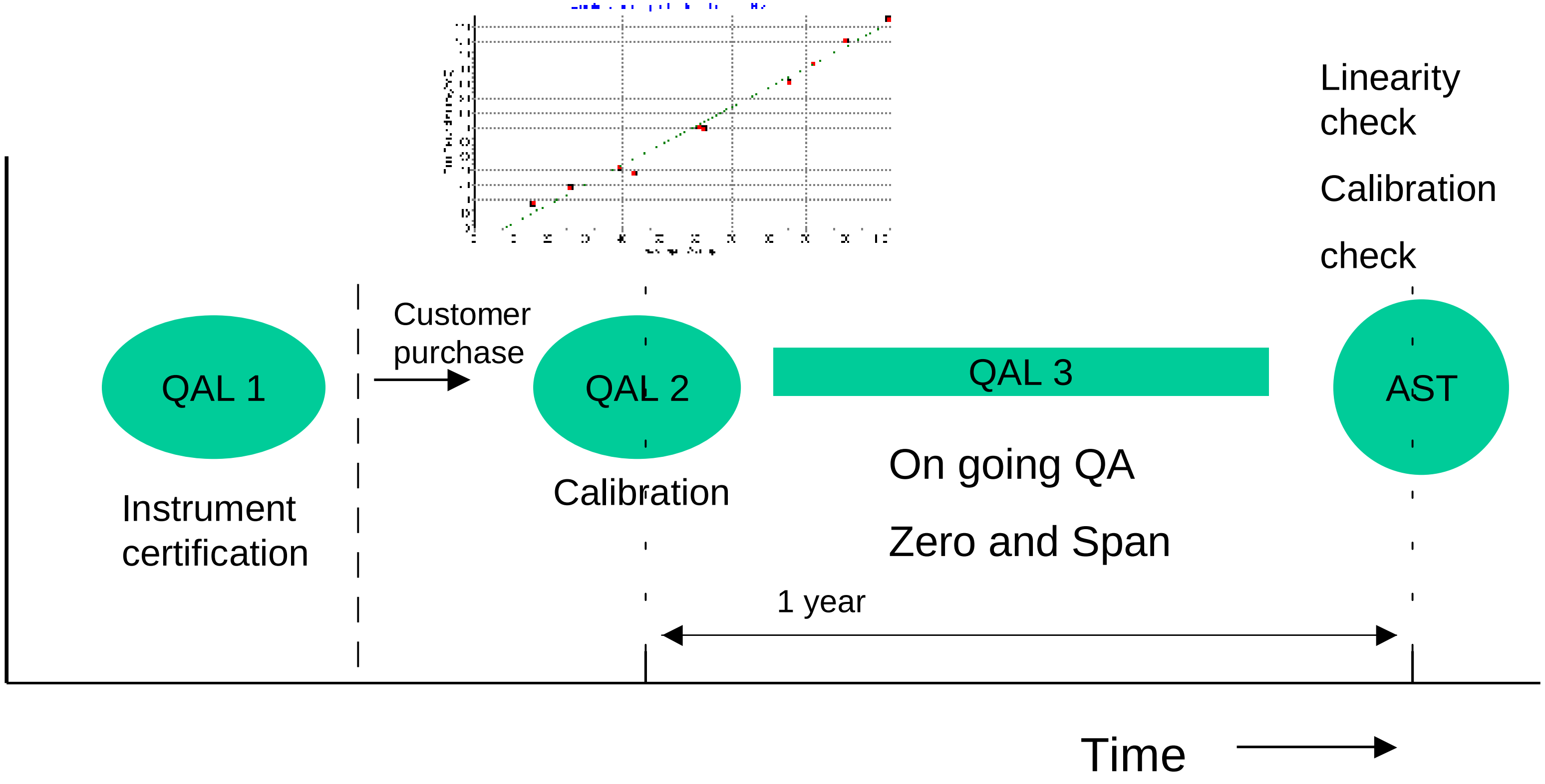
Cement Kiln stack monitoring	Cement mill emissions	Steel sinter plant emissions
		
WID;	IPPC	IPPC
QAL1 MCERTS	Dust MCERTS	Dust MCERTS

3 point calibration is pragmatic solution for most processes



Scaling factor is adjusted to reflect calibration result

EN-14181 (EN-13284-2 for particulate) quality assurance levels



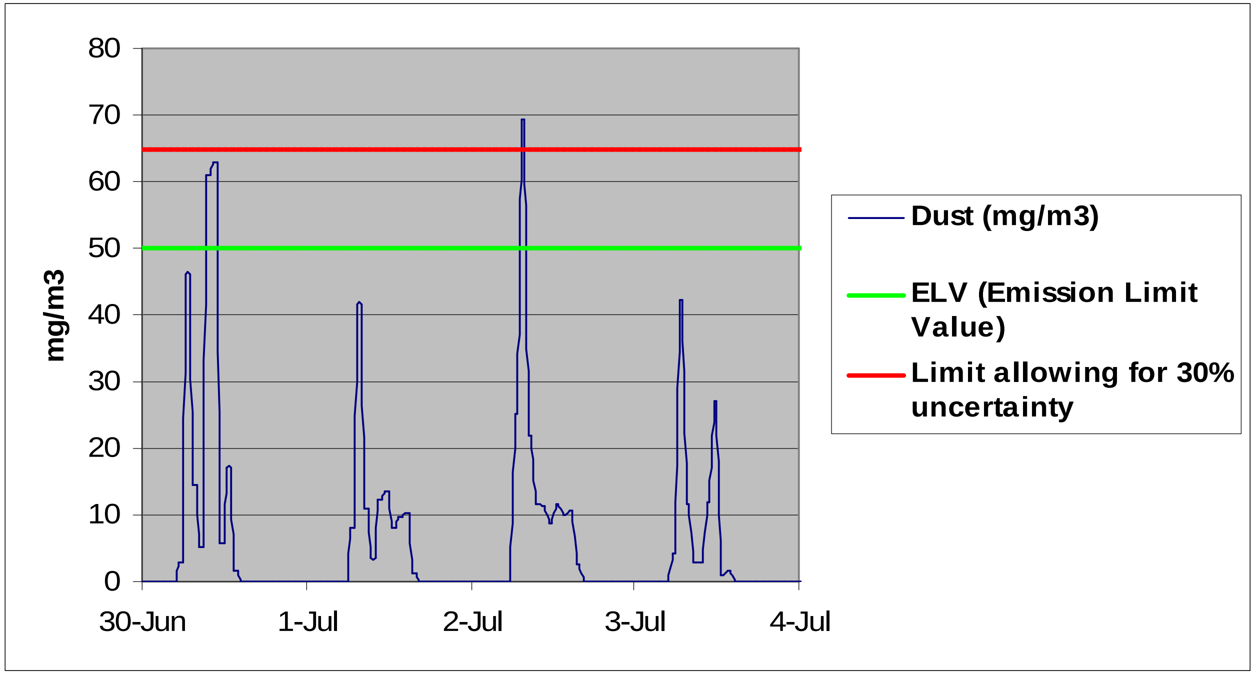
Relevant new standards

Standard/ requirement	Scope	Status
EN-14181	**Quality Assurance of Automatic Monitoring Systems (AMS):**	CEN standard published MID published (M20)
EN-13284-2	Standard for Particulate AMS derived from 14181 specifically for particulate	CEN standard published. MID published
EN-13284-1	Isokinetic sampling standard for dust <50mg/m^3 (emphasis 5mg/m^3) Standard Reference Method (SRM)	CEN standard published MID being revised

Objective of EN14181 EN13284-2

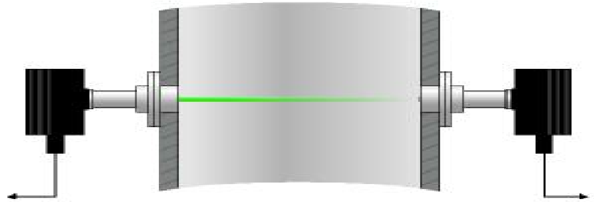
(Selection, commissioning, calibration and on- going service of Particulate AMS)

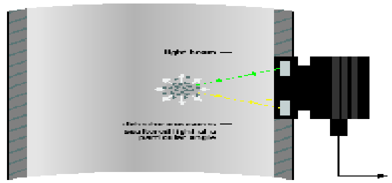
Ensure AMS measures at the Emission Limit Value with total uncertainty less than 30%

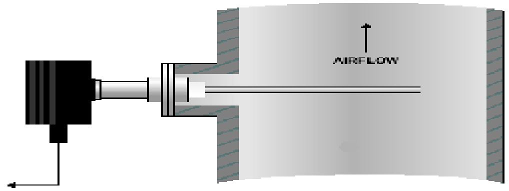


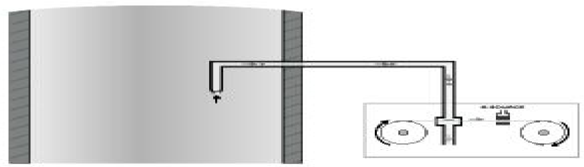
TECHNOLOGY REVIEW

- **Insitu**
  - **Optical**
    - **Opacity**
    - **Dynamic Opacity (Scintillation)**
  - **Light scatter**
    - **Back/side/forward scatter**
  - **Probe electrification**
    - **Triboelectric (DC)**
    - **Electrodynamic**
- **Extractive**
  - **BETA absorption**









OPACITY

Based on the Beer Lambert Relationship

OPACITY % = 100% - TRANSMITTANCE %

OPTICAL DENSITY = LOG 1 / T

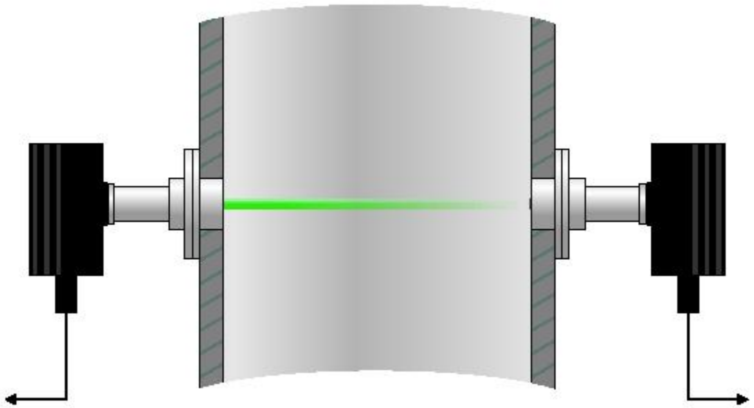
OPTICAL DENSITY = 2.3 x (e x n x a x l)

Where: e = Extinction Coefficient

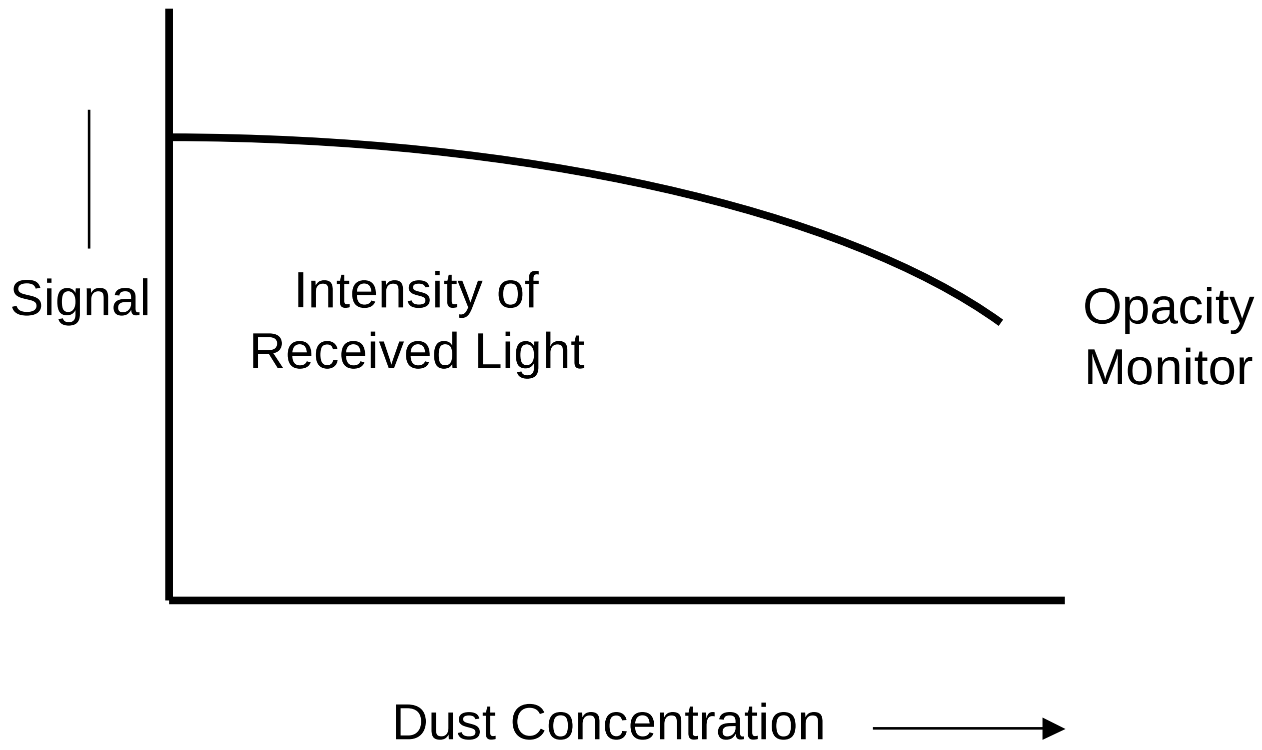
n = Number of Particles

a = Area of Particle

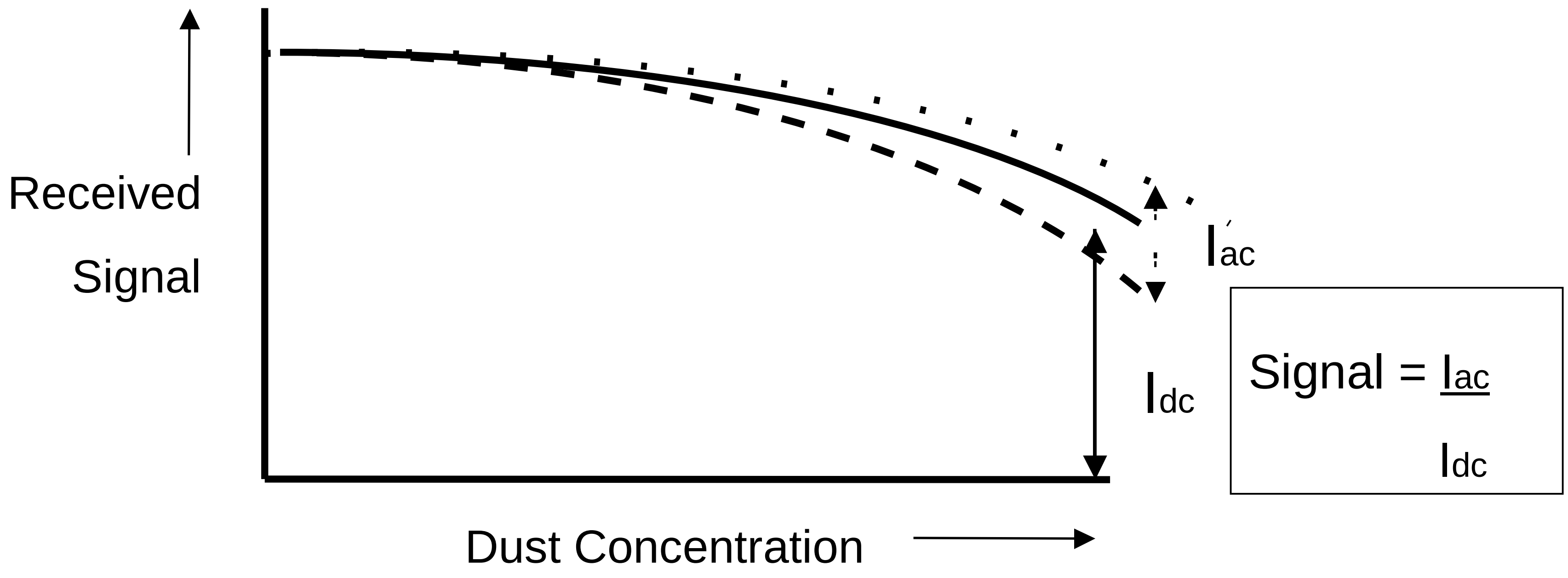
l = Path Length

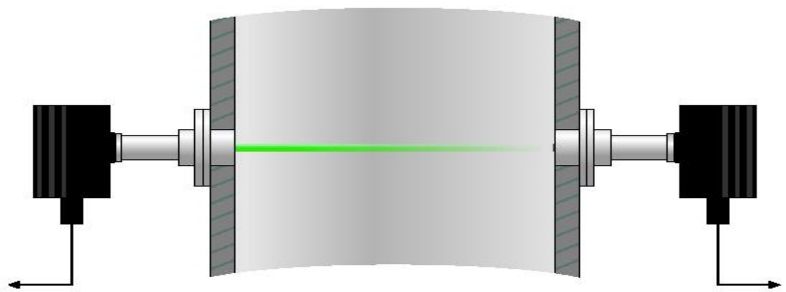


A TYPICAL OPACITY CURVE

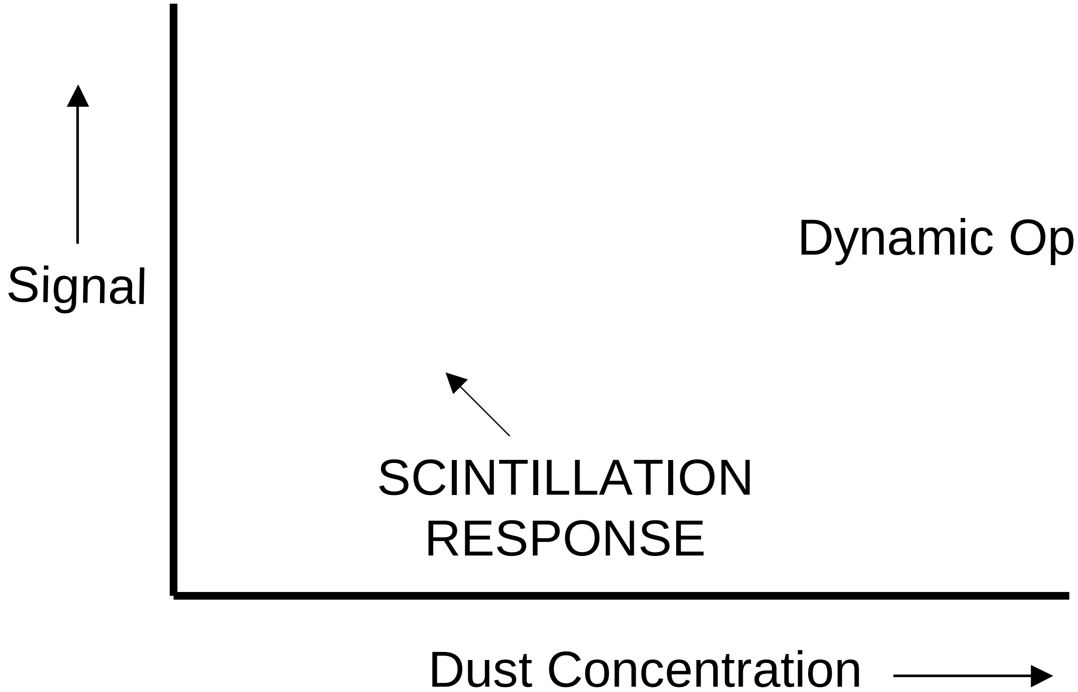


Dynamic Opacity





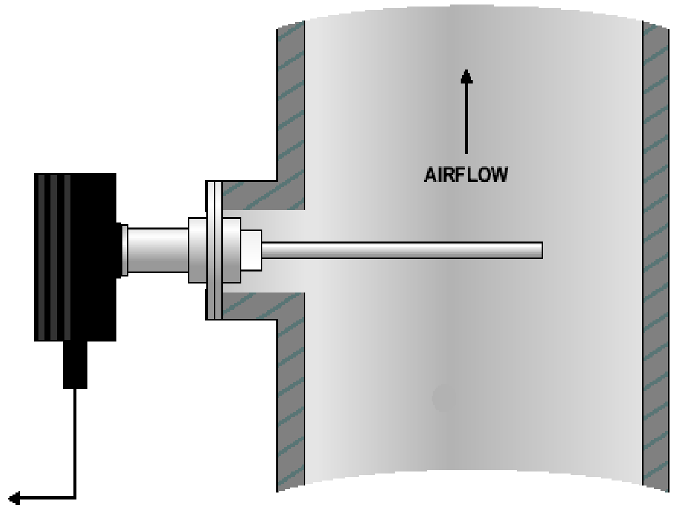
Dynamic Opacity Response



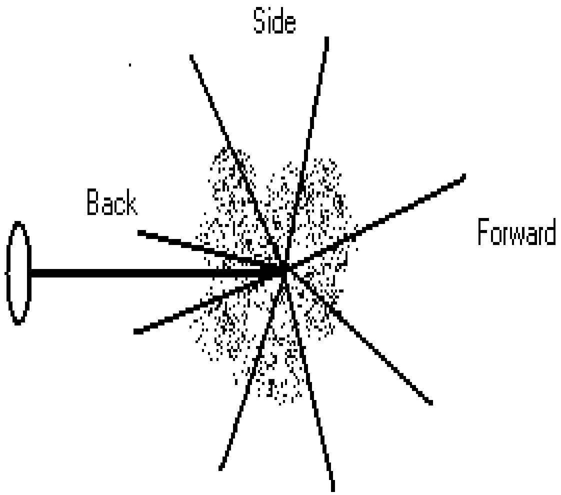
$$\text{Dynamic Opacity} = \frac{\text{Variation}}{\text{Intensity}}$$

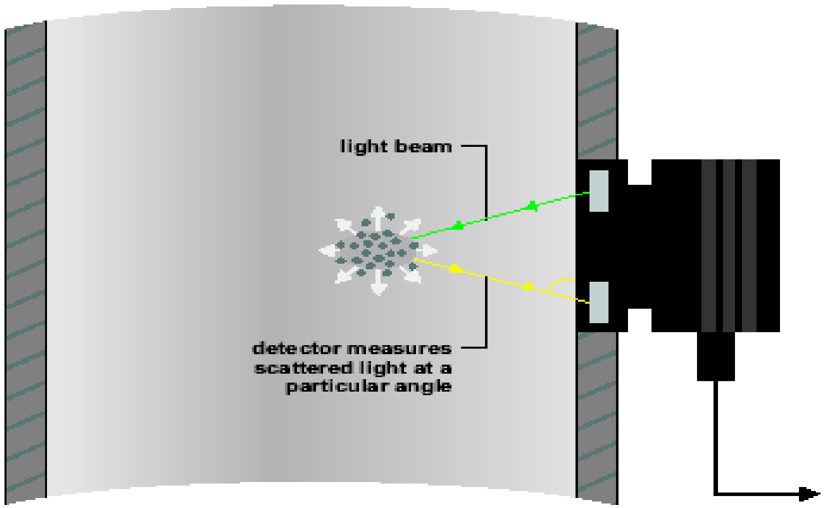
Charge electrification instruments

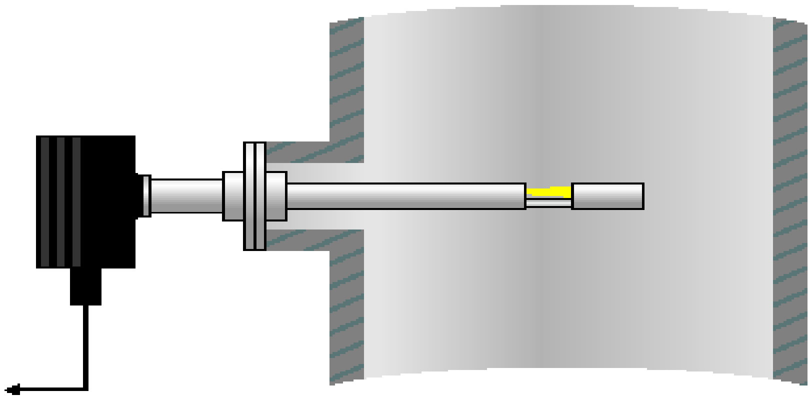
- Particles interacting with rod create
  - DC current (collision)
  - AC current (induction)
- Triboelectric
  - Measure total signal
- AC tribolectric
  - Measures ac signal (electronically filters dc)
- Electrodynamic
  - Form of AC with defined frequencies



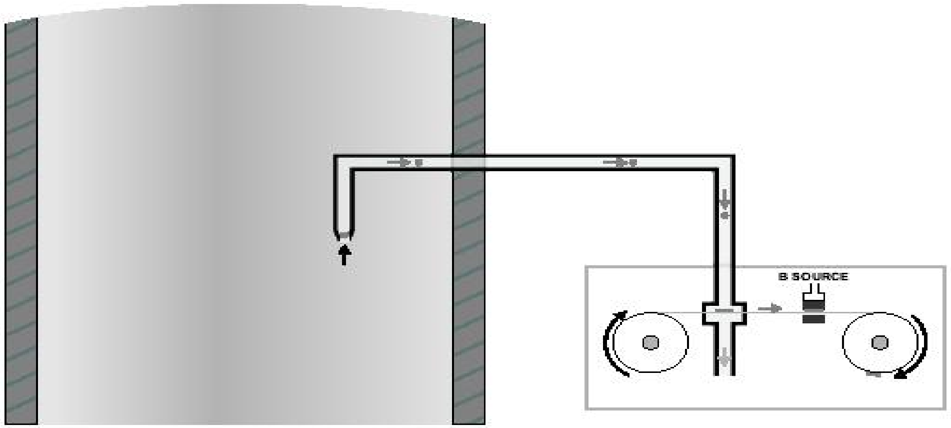
Light scattering







Beta Attenuation



Manual application of
Shewart or Cusum charts

A range of particulate monitors required to cover all WID/ LCPD industrial applications

Industries applications	Process conditions	Candidate technologies
Incinerators	0-10mg/m^3 (bagfilters after dry scrubbing)	Light scatter Charge electrification (bag filters) Beta (wet systems)
Cement kilns	0-20mg/m^3 (for incin). 0-50mg/m^3 (other)	Light scatter Charge electrification (Bagfilters) Opacity (higher emissions/ large stack) Dynamic Opacity (higher emissions)
Coal fired power plant	0- 50mg/m^3 0-150mg/m^3 (historical)	Opacity (higher emissions) Dynamic Opacity (higher emissions)
Refineries	0- 50mg/m^3 (EX gas zone)	Opacity Light scatter Charge electrification

EN 14181 – QA Levels in Practice

Level	Application	Requirement
QAL 1	**Suitability of Devices**	• Approval with correct certification range • AMS to have QAL3 and linearity features • Uncertainty Calculations **for specific process**
QAL 2	**Set – up & Calibration (CAL Function)**	• Correct Installation • Sensible data (at least 1 week) • Planning of plant operation • Functionality Checks • Calibration by SRM • Variability & Uncertainty • Data Validation
QAL 3	**On - site Operation**	• Zero & Span Drift • Precision of AMS • Control Charts / Records
AST	**Checks of AMS & Validity of CAL**	• Functionality Checks (as QAL2) • 5 x SRM Samples

QAL 1
(Instrument approval)

Transition arrangements

- Germany (TUV)
  - BImSchV 17 approvals extended with calculated uncertainty for recent approvals (less than 5 years)
- UK (MCERTS)
  - Existing MCERTS approvals satisfy QAL1 provided certification range less than 1.5 x daily ELV (Emission Limit Value)
  - ‘lower the certification range = better instruments with lower uncertainty’
  - Need to be careful on QAL 3 /linearity issues
  - Instruments supplied against historical MCERTS are not necessarily fit for purpose

Future

- TC-264/WG-22 defining European Certification scheme
- EN- 15627-3 defines QAL 1 requirements
- Implementation within 12 months

Evolution of MCERTS for particulate CEMS

Performance standards version	Reason for change	Implication of change
1997	Original standard	
April 2003	Required zero and reference point	Some products originally certified did not meet new standard
July 2007	Upgraded to include QAL1	Different standard for ? –QAl 1 –Dust –Indicative (bag leak)

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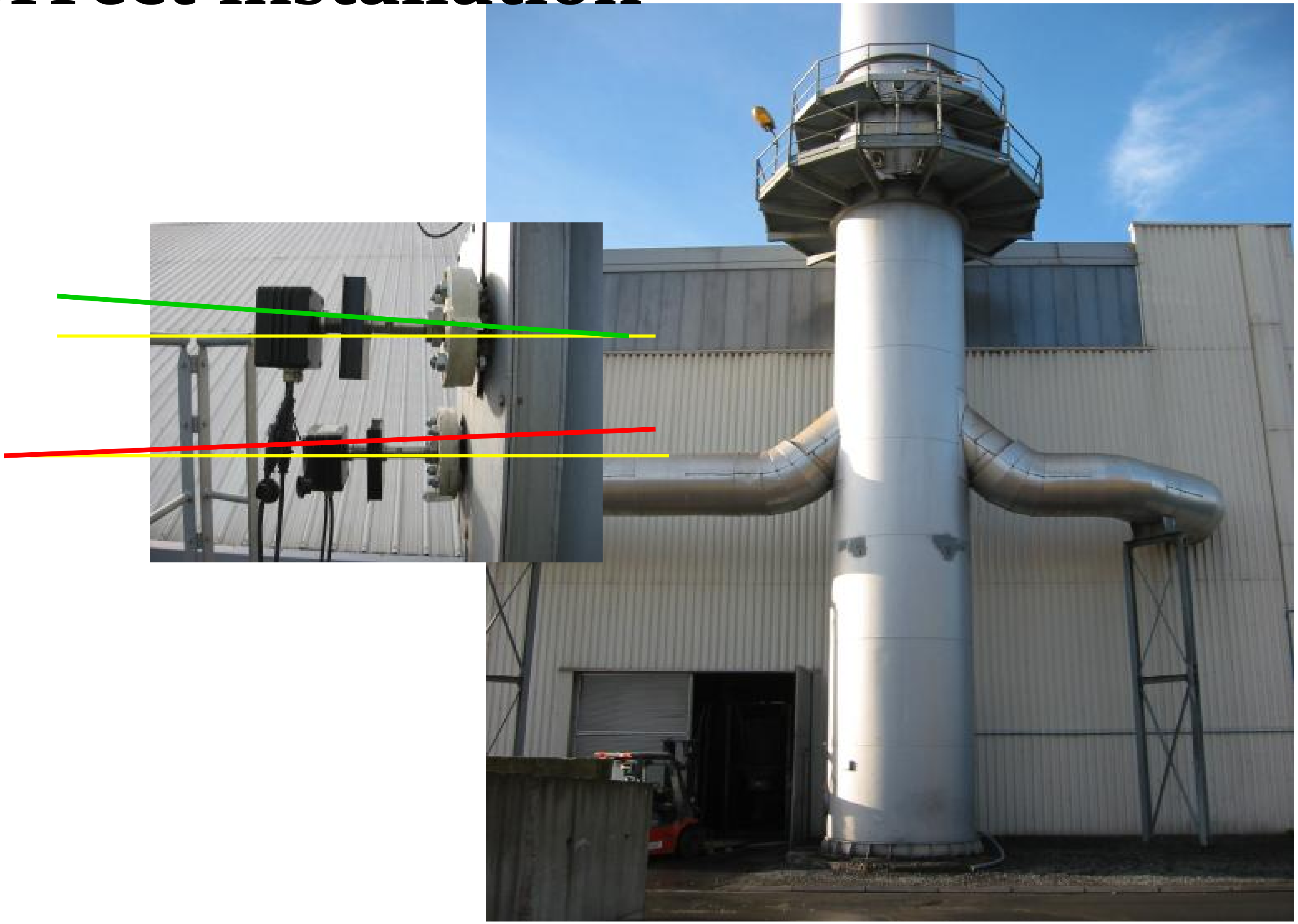
Pre QAL 2

1) Correct installation (air purges/ orientation)
Correct location of AMS and SRM ports

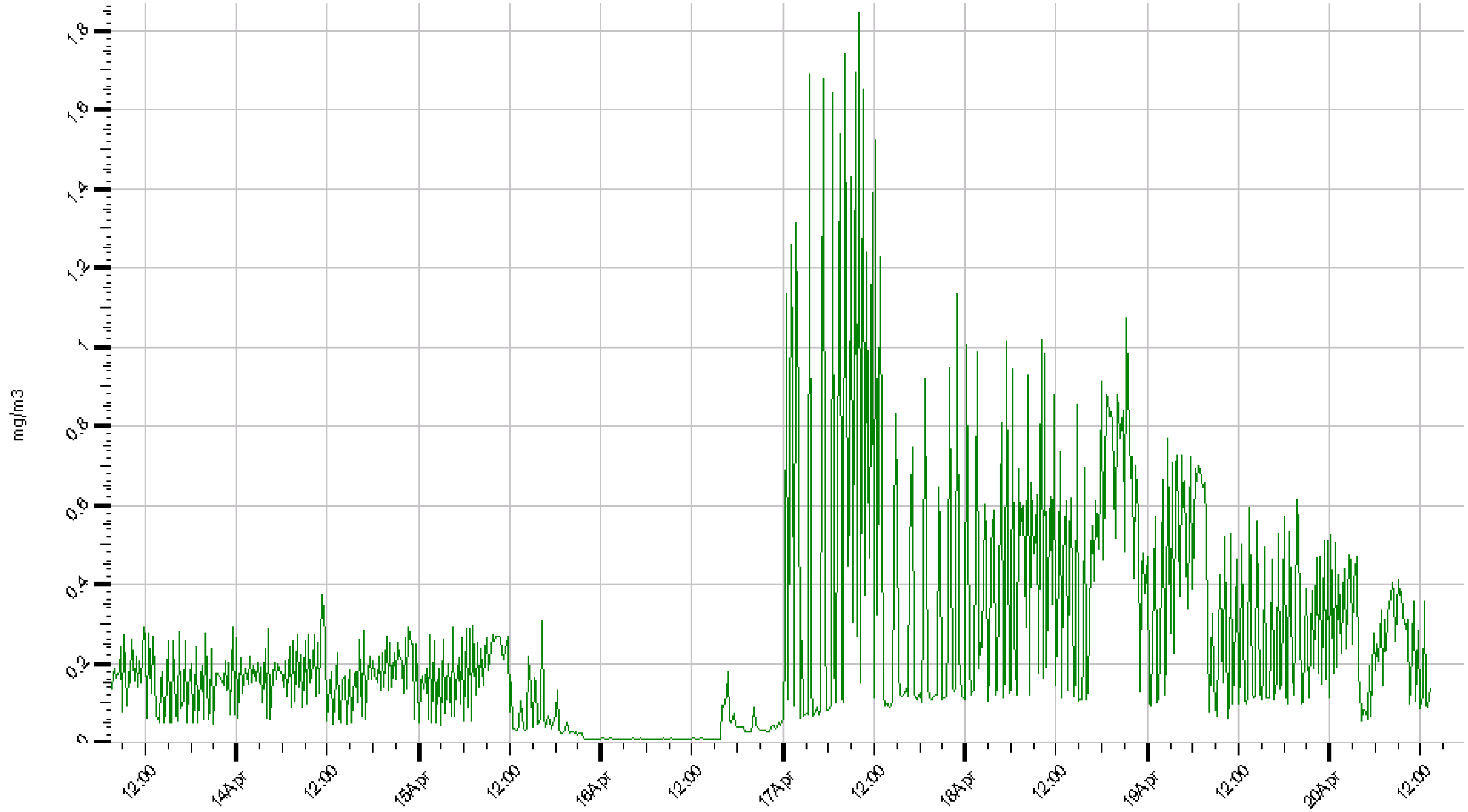
Correct installation



Review historical data

1) Ensure instrument suitable for actual conditions

2) Information to plan plant operation during calibration



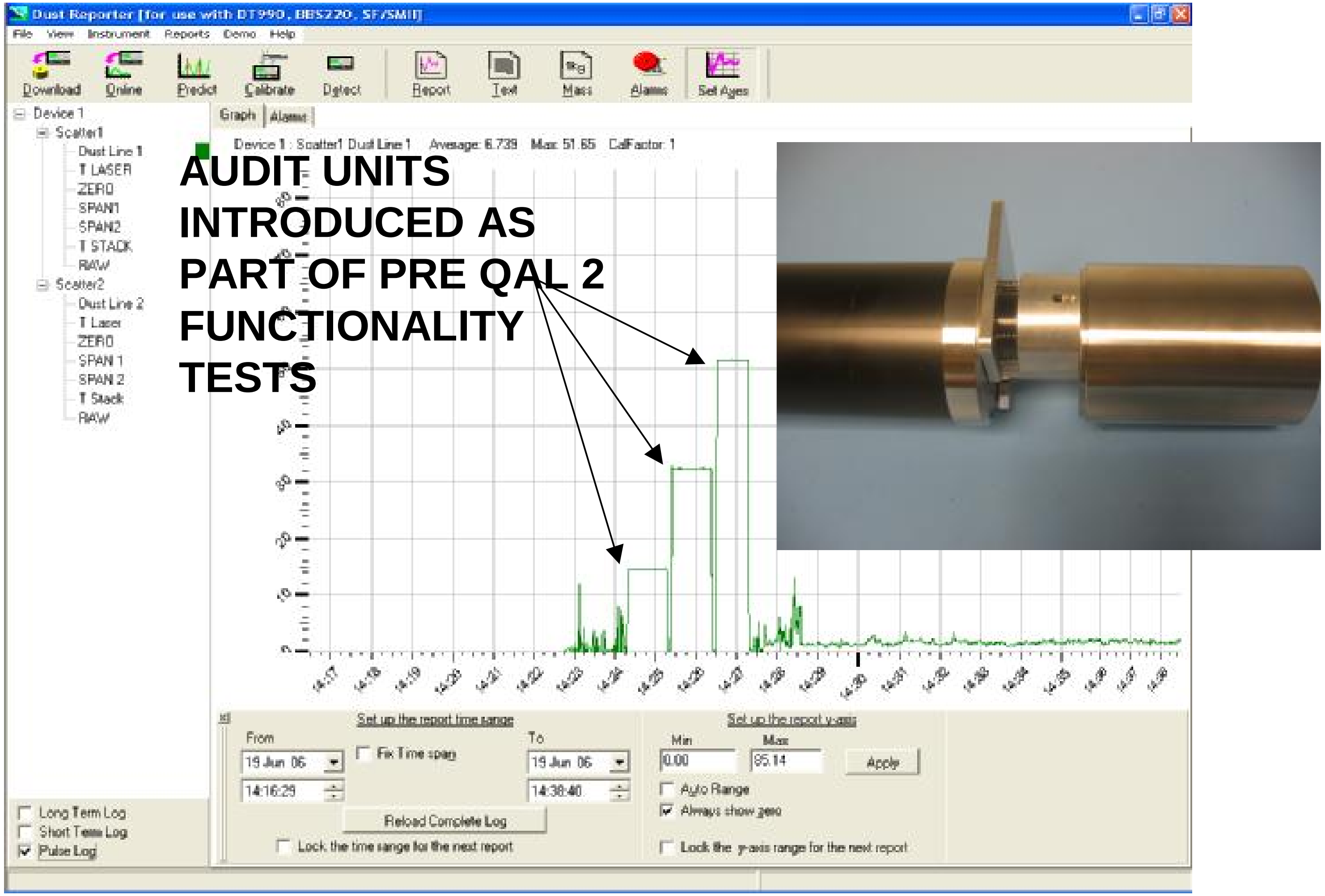
Pre QAL 2 checks

Functionality Check List

Activity	QAL 2		AST	
	Extractive AMS	Non-extractive AMS	Extractive AMS	Non-extractive AMS
Alignment and cleanliness		√		√
Sampling system	√		√	
Documentation and records	√	√	√	√
Serviceability	√	√	√	√
Leak test	√		√	
Zero and span check	√	√	√	√
Linearity			√	√
Interferences			√	√
Zero & span drift (audit)			√	√
Response time	√	√	√	√
Report	√	√	√	√

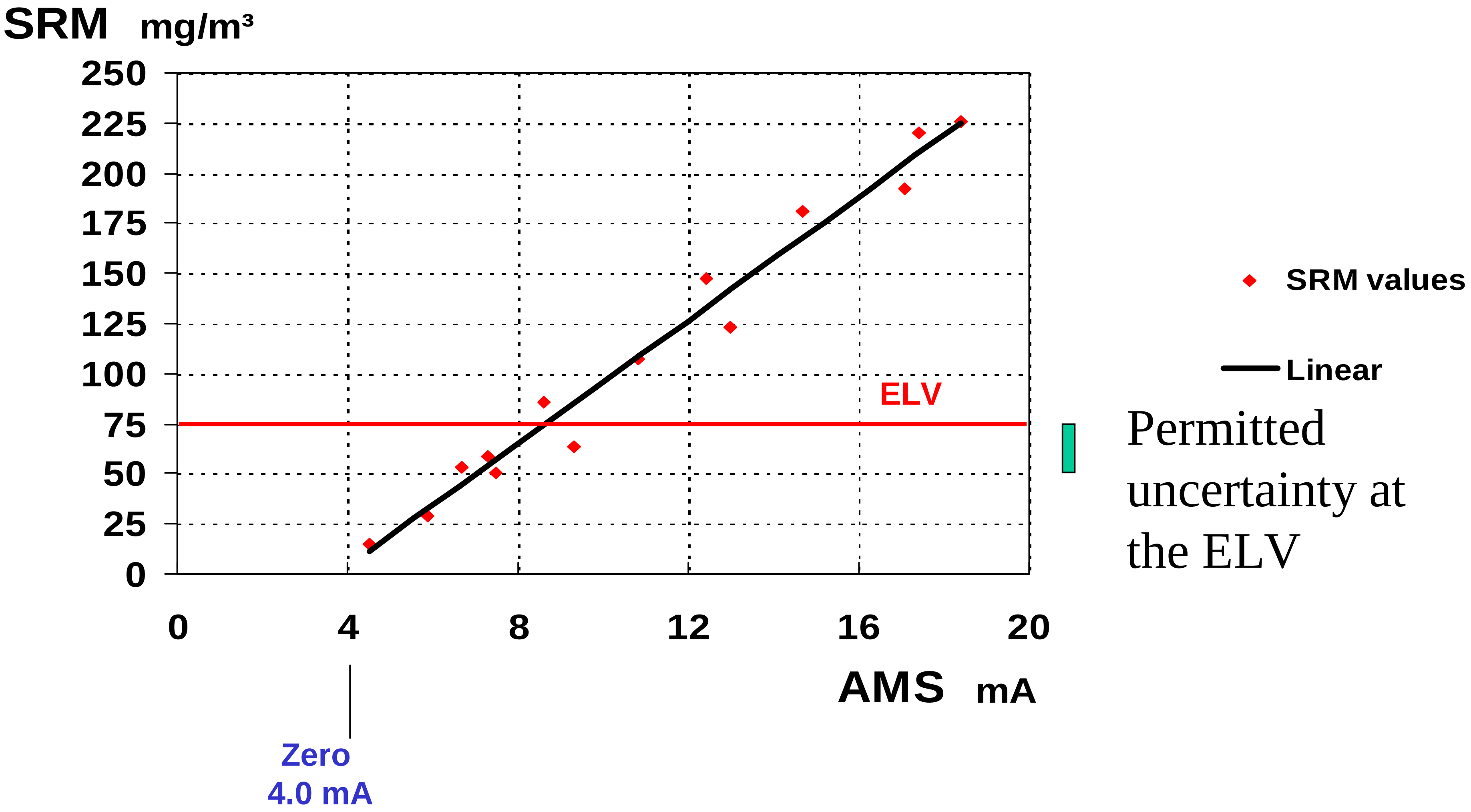
Courtesy: W.Jockel TUV

Linearity test

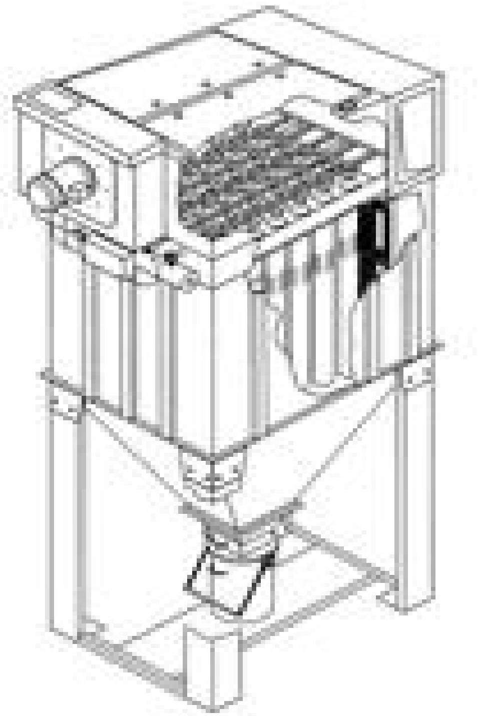


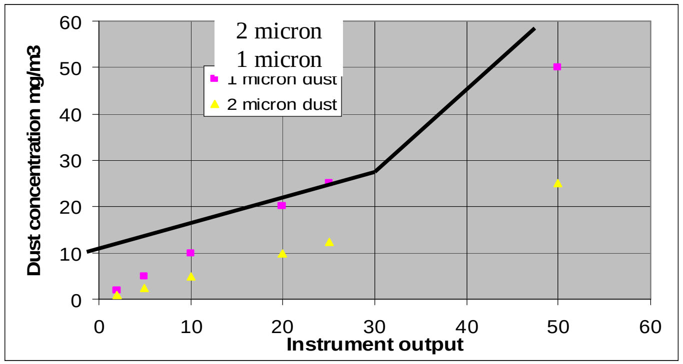
QAL 2 :– AMS Calibration

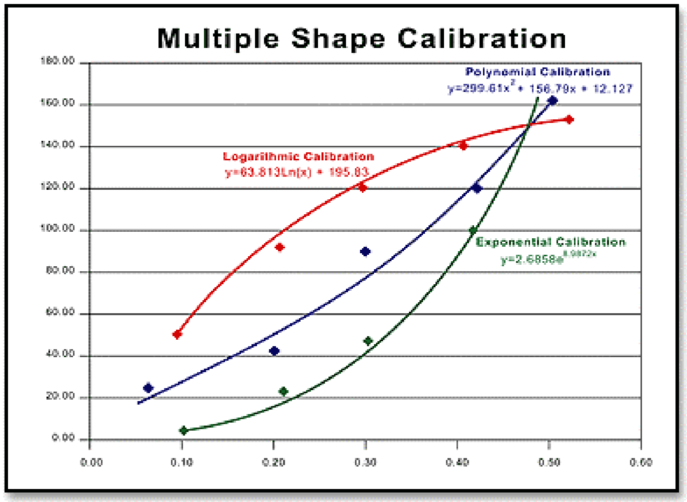
15 point calibration over 3 days (5 points if <30% of ELV)



Caution required when extending calibration range







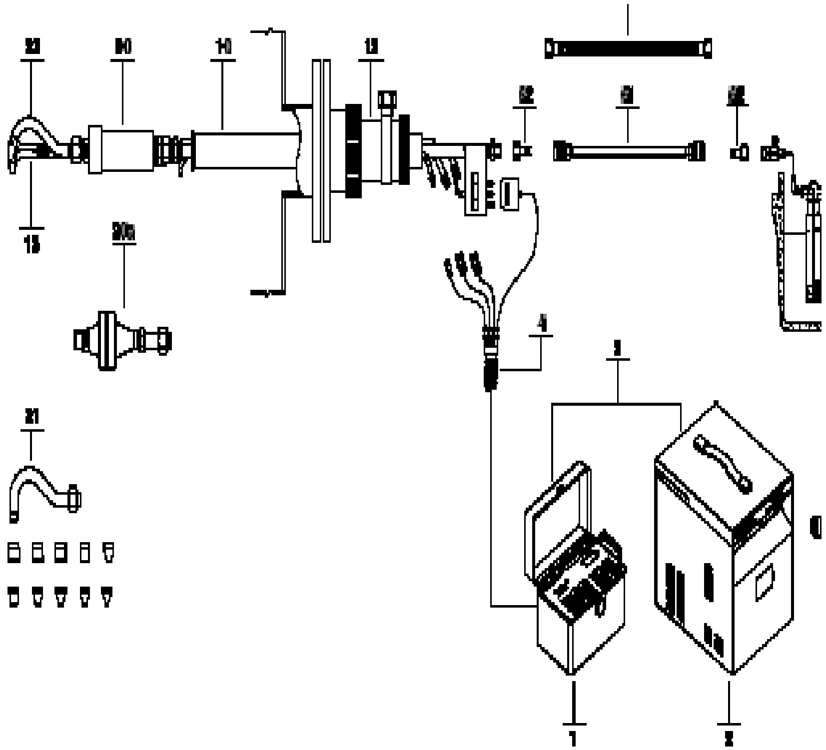
omial to compensate for particle size dependency (if repeatable for plant conditions)

In practice

- Calibration is normally a cluster of points
- More important to get SRM right than takes lots of samples

QAL2 practical problems

- Basic premise
  - Accurate and precise standard reference method
    - **Problem for Particulate**
      - **Issues: Type of equipment**
        - » **Filter material**
        - » **Filter holder**
        - » **Flow rate?**
    - **Solution use: VDI-2066 (Nov 2006 (consistent with EN-14181 but provides higher data quality)**
    - **Review sampling protocol of test house**
    - **EN-13284-2 to be revised**



Variability test compares uncertainty in readings to permisable uncertainty at ELV

Variability Test											
Calculation of Sd using normalised values											
SRM (stardard conditions)	AMS calibration value (standard conditions)	Di	square(Di-D)								
7.04	6.39	0.65	0.43		Require Sd < sigma*Kv						
8.03	6.89	1.14	1.31								
9.14	10.58	-1.44	2.07		Sd	**1.02**					
4.78	3.47	1.30	1.70		sigma	1.53	30% of ELV as 95% confidence			**ELV =**	**10**
5.49	4.15	1.33	1.78		Kv (15)	0.98					
0.53	1.84	-1.32	1.73		sigma*Kv	**1.49**					
2.69	1.58	1.12	1.25								
0.55	1.66	-1.11	1.22			**1.02**	<	**1.49**		**Variability test pass**	
0.34	1.48	-1.14	1.30								
3.74	4.23	-0.48	0.23		Instructions						
1.31	2.23	-0.93	0.85		Enter the daily Emission Limit Value (ELV)						
1.40	0.64	0.76	0.58		The variability test passes if Sd < Sigma*Kv						
0.70	0.96	-0.26	0.07								
1.42	1.12	0.30	0.09								
1.74	1.71	0.03	0.00								
		-0.0030	1.02	Sd							

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How do you check zero and span for a dust AMS?

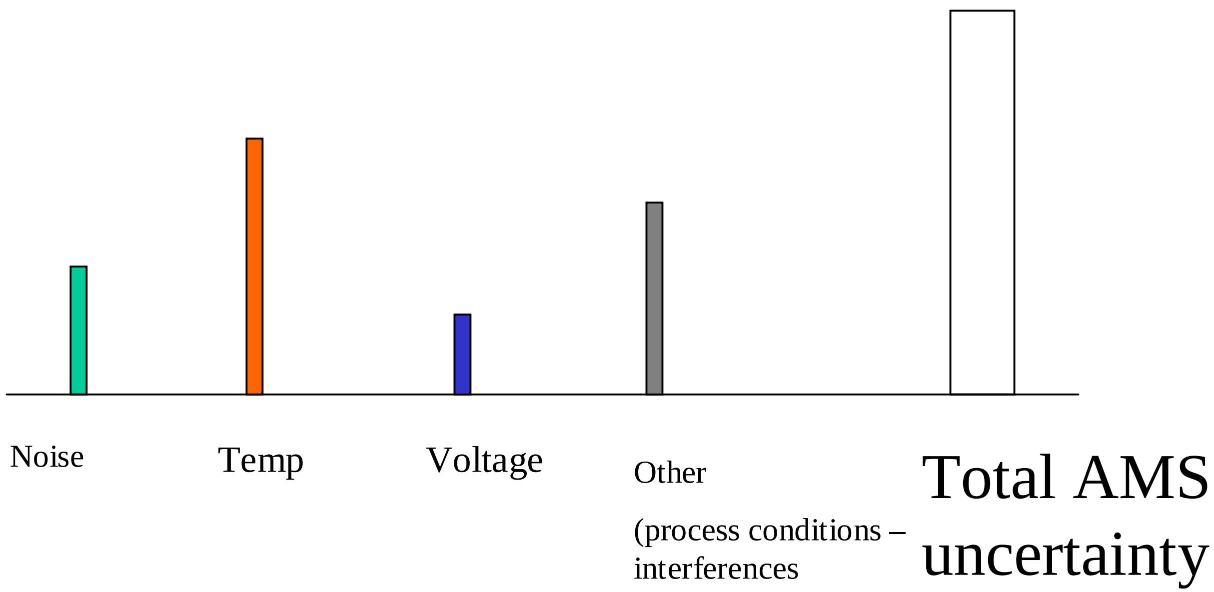
Features

- Dual-beam transmissometer
- Auto zero and span check

Zero, Span and linearity materials are surrogates

	Zero material	**Span material**	**Issue evaluated**
Gas AMS	Sample of gas with concentration of 0mg/m^3 of required pollutant	Gas of known concentration	Uncertainty in calibration
Dust AMS	Condition simulating no dust	Introduction of surrogate which simulates elevated dust concentration	Change in instrument performance (calibration shifts cannot be measured due to cross-sensitivities)

Sources of uncertainty (example)

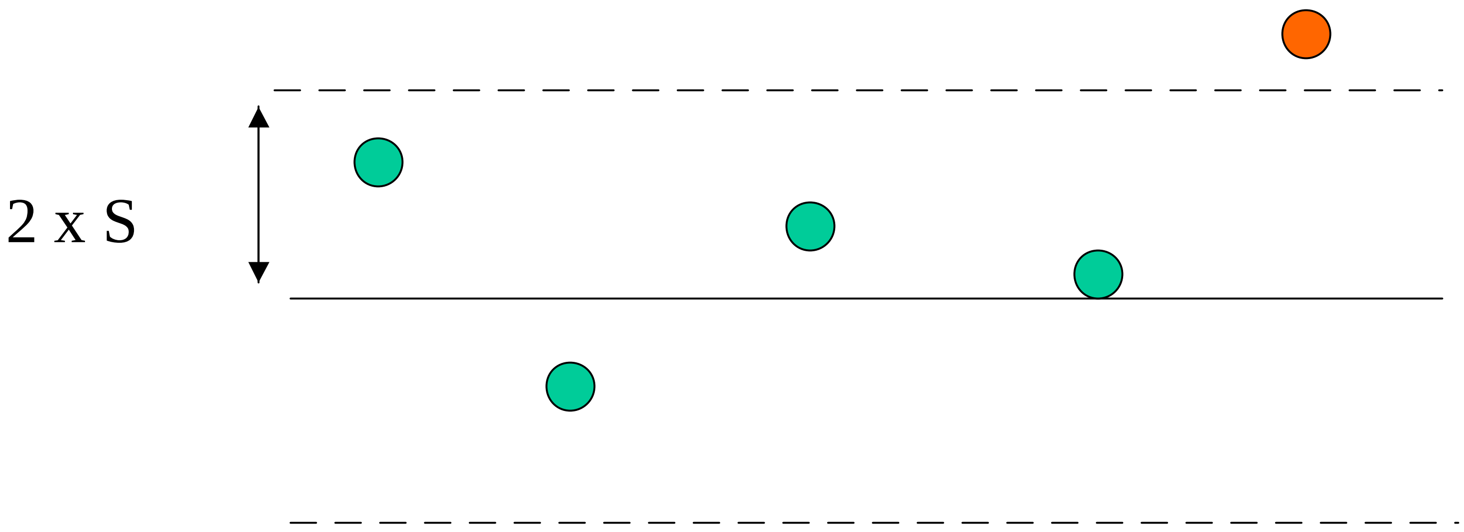


Shewart statistics

Manual or

Automatic

(eg result of span check)



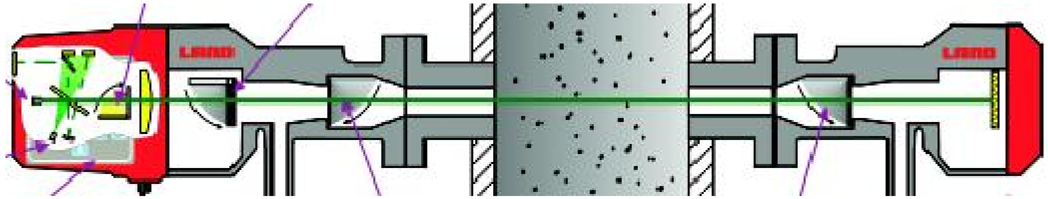
Where s is determined in QAL 1 or

from performance standards

Zero and span check within double pass opacity

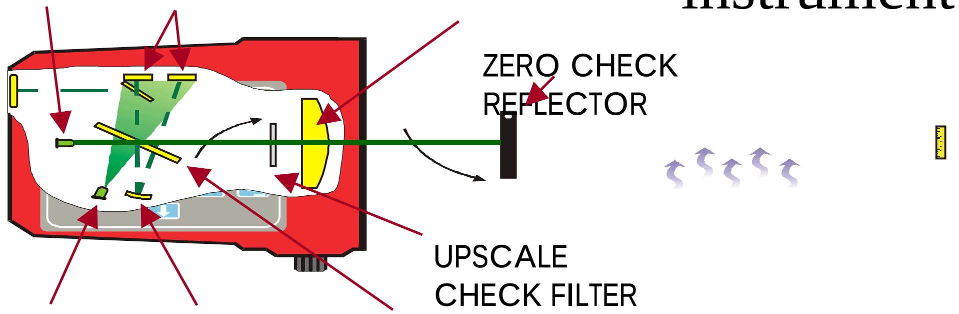
Optics contamination and alignment

Light source

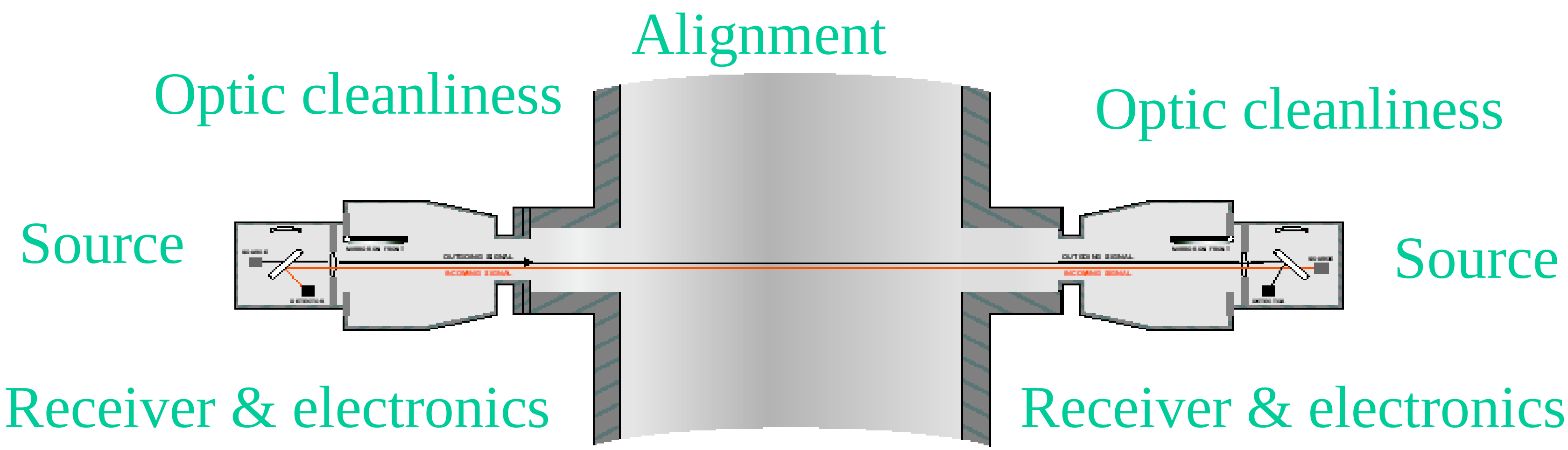


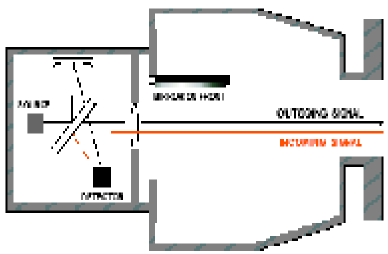
Receiver and electronics

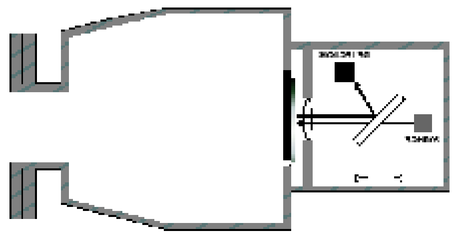
Apply shewart approach to automatic checks within instrument



Span check method for dual beam opacity







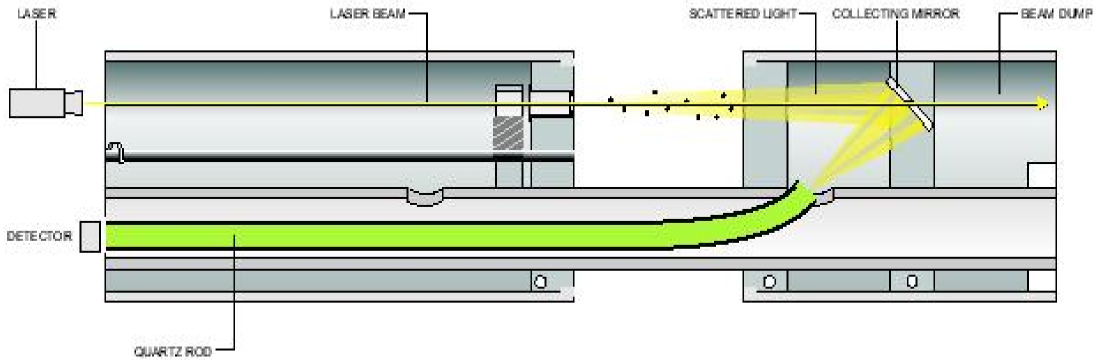
Span and zero check on LMS-181

Beam Optics

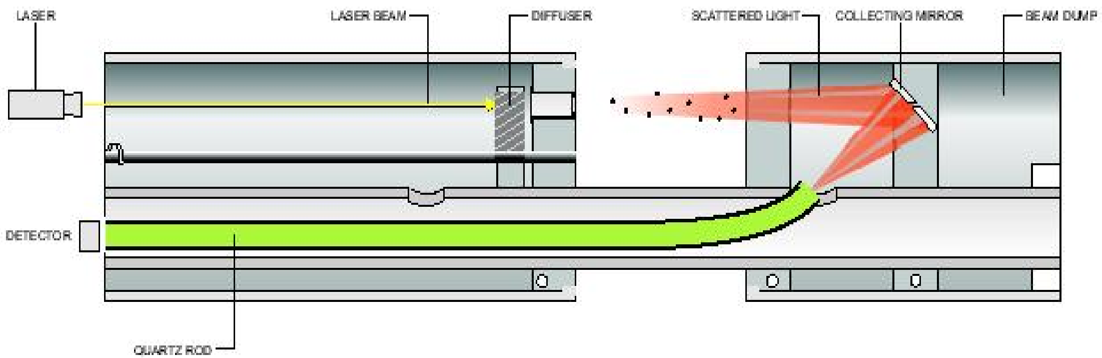
Receiver optics

Light source

Detector and electronics



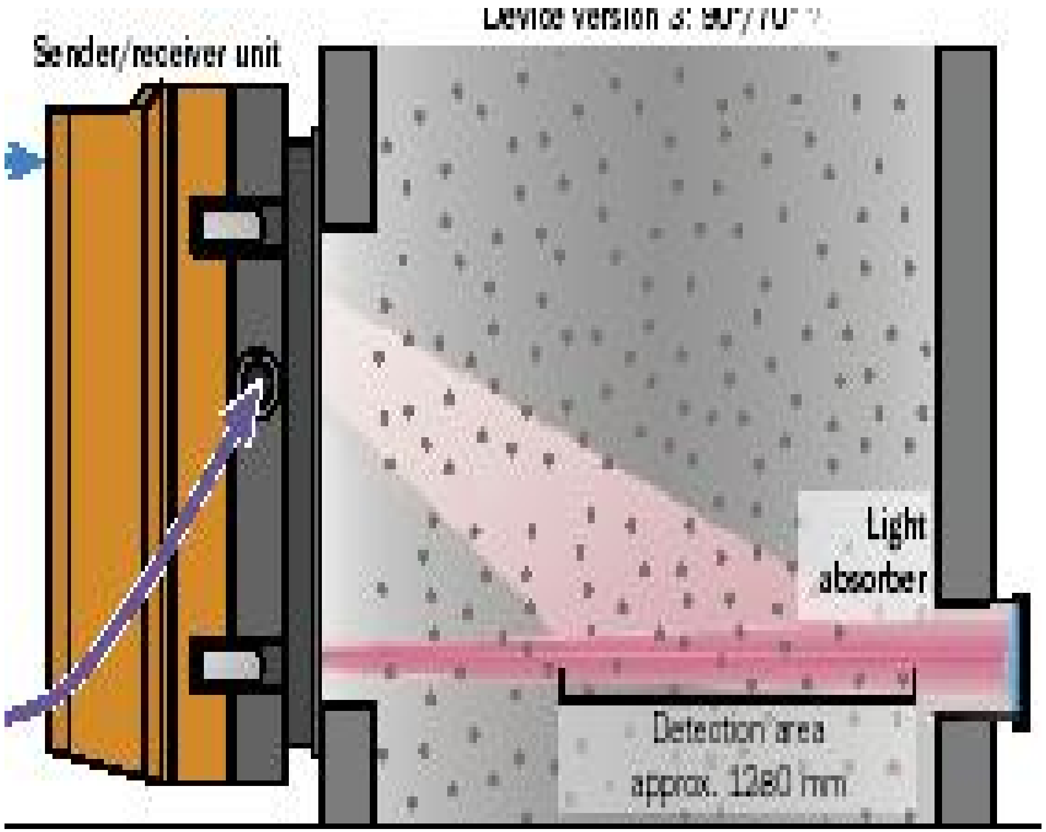
Measurement mode



Span check

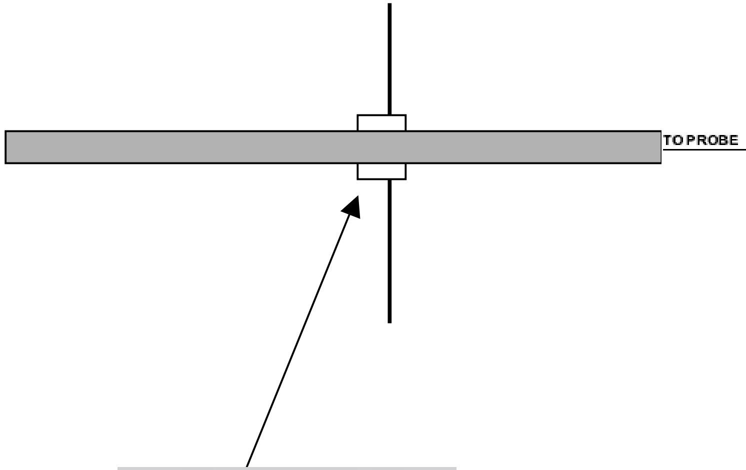
Automatic checks: sensor remains in stack. Results recorded for shewart chart

Zero and span on side/back scatter

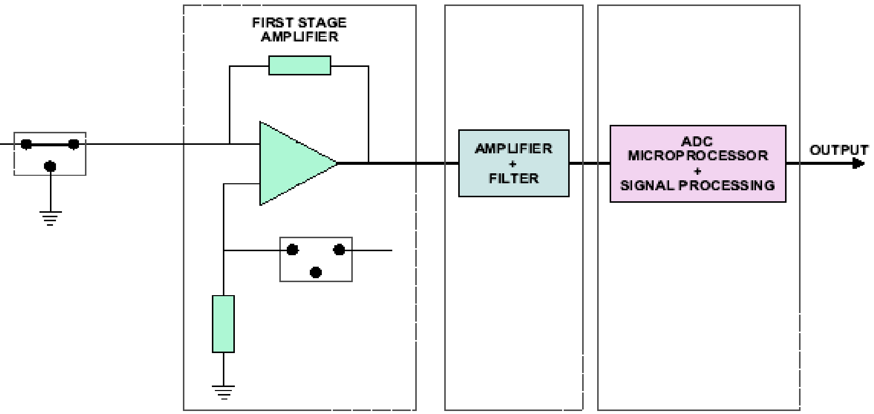


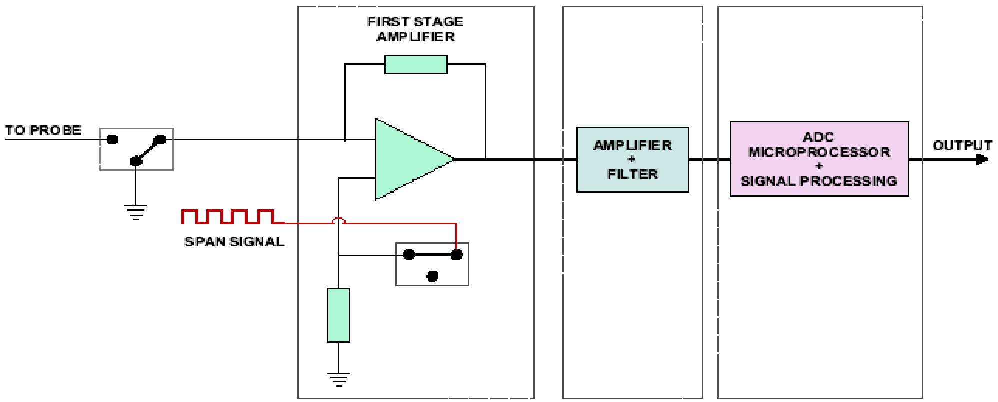
Span and Zero check on DT-991

Rod integrity



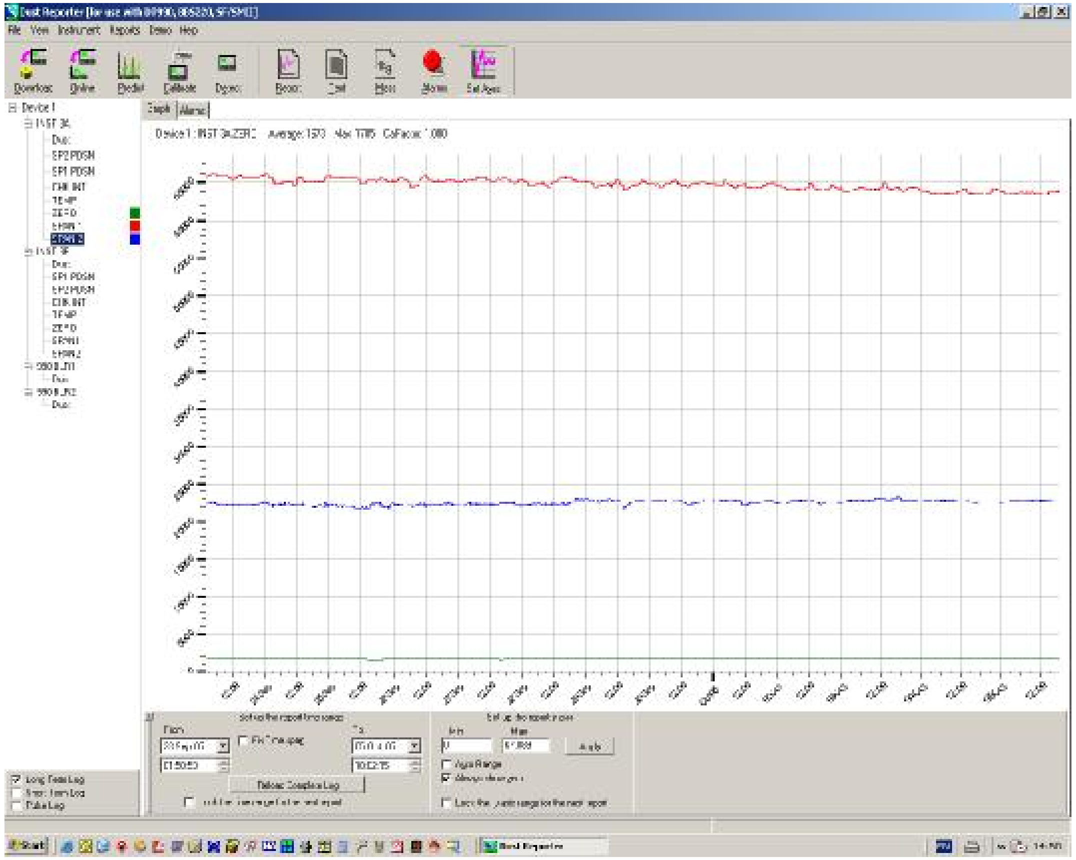
Signal processing





Probe contamination check

It is operator's responsibility to record QAL 3 results (manual or automatic)
Should be running before QAL2



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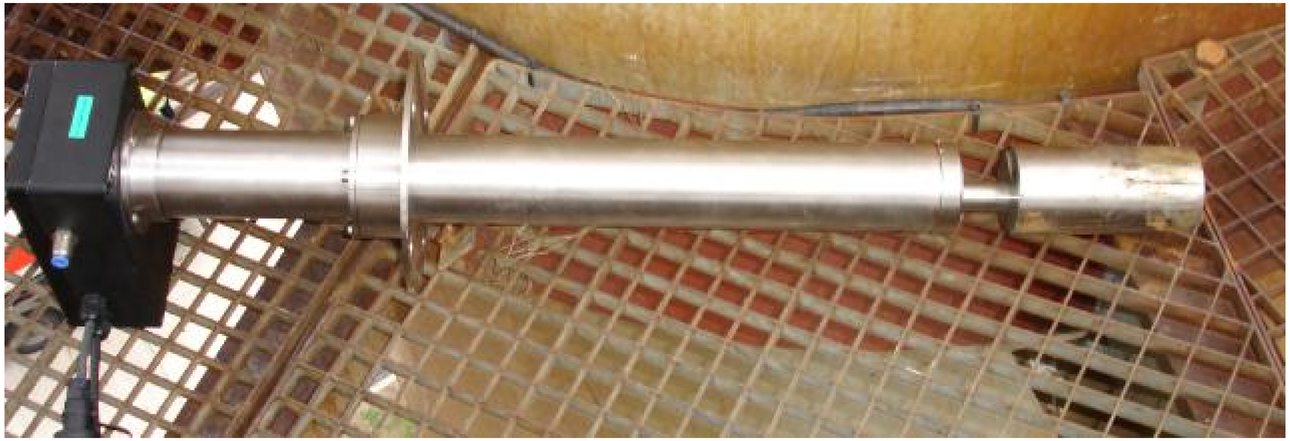
Auditing: AST linearity test



Remove sensor from stack and insert audit material

A practical way forward to meet EN-13284-2

- QAL 2
  - Plan for QAL 2 using dynamic data from continuous monitor
  - Caution (ranges, process conditions, SRM, instrument performance)
  - Assess protocol and equipment to be used for sampling since these effect results at low dust
- QAL 3
  - Consider automatic or manual approach
  - Data treatment
- New users of AMS
  - Investigate 'total' cost of ownership
  - Stability of calibration
  - QAL 3 features
  - Ease of auditing (linearity check for AST)
- Existing users of CEMs
  - Zero and span checks required (not original part of MCERTS)
  - Presence of internal zero and reference doesn't necessarily provide QAL 3 feature
  - Explore upgrade path for existing instruments to AMS
    - Zero and Span features
    - QAL 3 Data analysis
    - Reporting
    - AST linearity tests

Summary of calibration approaches

	13284-2 standard for dust AMS	April 2003 MCERTS standards
Operator responsibilities	Qal 1, Qal 2, Qal 3, AST	Purchase certified system
Statistical analysis for calibration	15 (5) SRMs Variability test (every installation)	3 IS0-10155 (during one off field test)
Costs Instrument Calibration Annual Other Auditing	£5k -£15K £5 -£10K £5K £5K if outside cal range Automatic zero and span with statistical treatment 5 reference materials to audit linearity	£5K £1 -£2K Internal zero and reference point

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