

EXTENDED STATEMENT ON ACCURACY, PRECISION, CALIBRATION AND TRACEABILITY OF DUSTLIGHT

INDIVIDUALLY CALIBRATED, INDEPENDENTLY VALIDATED

Every particulate matter sensor unit used in Dustlight is individually calibrated and individually tested against reference instrumentation, using a defined KCl verification aerosol. The calibration chain is traceable to recognised national measurement standards, including those realised at NPL, PTB and NIST. Material-specific calibrations are additionally validated at an independent, ISO/IEC 17025 accredited laboratory using a Grimm reference spectrometer, gravimetric reference sampling and internationally standardised test dusts.

Since there is no uniform standard for the specification and measurement of particulate matter sensors, it is often difficult for users to understand and compare the performance characteristics stated by different manufacturers. The aim of this document is to present the calibration and specification of Dustlight in a clear and comprehensible manner: how Dustlight measures, how its algorithms are developed and validated, how each sensor unit is calibrated, how the device-specific respirable dust calibration is applied, and what the resulting traceability statement does and does not cover.

A note on terminology. Because of the absence of a uniform standard, this document distinguishes carefully between *precision* — the agreement between devices and between repeated measurements — and *accuracy* — the agreement with a reference method. Where a figure applies to only one of the two, this is stated.

CONTENTS

1	How Dustlight sensors work	2
2	Dual-track validation philosophy	3
3	Algorithm development and scientific reference validation	4
4	Sensor-level calibration and verification	7
5	Respirable dust calibration of Dustlight	10
6	Calibration chain and traceability	11
7	Long-term stability	12
8	Calibration, verification and field check recommendations	13
9	Summary: individually calibrated, independently validated	14

1 HOW DUSTLIGHT SENSORS WORK

Dustlight sensor technology is based on optical particle counting (OPC) using laser scattering. To make the compact design possible, Dustlight relies on a small, powerful laser diode and a photodiode that captures the backscattered light. The laser diode sends light beams through the drawn-in air. Particles present in the air scatter part of that light, which the photodiode captures and converts into electrical signals. A fan inside the device provides a steady airflow, so Dustlight always measures the actual dust concentration of the surrounding environment and reacts to changes within seconds (see Figure 1).

The recorded signal is converted into mass concentration ($\mu\text{g}/\text{m}^3$) in real time. While particle counting works similarly across manufacturers, the algorithm for conversion to mass concentration is a key distinguishing feature of Dustlight. The optical properties of particles — such as refractive index and shape — as well as the material of the particles have a significant influence on the resulting mass. Indirect optical measurement therefore always shows a discrepancy compared to direct gravimetric (weight-based) methods.

Despite this limitation, we consider optical particle counters to be the preferred technology for commercial dust measurement today, given their practicality and state of development. To make the performance of our sensor technology clearly understandable, specifications are required that can be verified with standardised procedures. This document sets out those procedures.

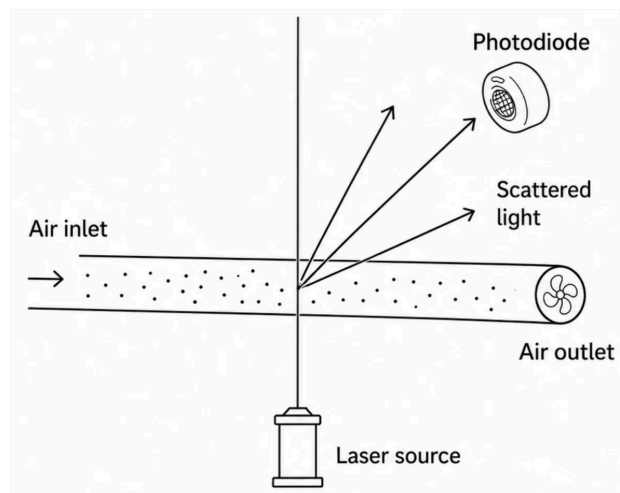


Figure 1: Measurement principle of Dustlight. An optical measurement method with laser and photodiode technology enables real-time measurement of airborne particle concentration. An intelligent protection and maintenance concept ensures reliable results even in dusty environments.

2 DUAL-TRACK VALIDATION PHILOSOPHY

The accuracy and reliability of Dustlight are ensured through a dual-track validation concept, which clearly separates:

TRACK 01

Algorithm development and scientific reference validation, carried out at an independent accredited institute.

TRACK 02

Sensor-level calibration and verification, carried out for every individual sensor unit in production.

This approach combines high real-world relevance with reproducible, traceable performance based on internationally accepted reference methods.

The calibration itself proceeds in two steps. First, every sensor unit is calibrated and verified individually against reference instrumentation. Second, the assembled Dustlight receives its device-specific respirable dust calibration, derived from the algorithm work described in section 3.

3 ALGORITHM DEVELOPMENT AND SCIENTIFIC REFERENCE VALIDATION

3.1 External institute and accreditation

The development and continuous refinement of Dustlight measurement algorithms are performed at the laboratories of the Institute for Hazardous Substances Research (IGF) at Ruhr University Bochum, an institute of the German Social Accident Insurance Institution for the Raw Materials and Chemical Industry (BG RCI). These are among the leading occupational dust measurement facilities in Germany.

The gravimetric reference values used for algorithm development and validation are determined under the laboratory's DAkkS-accredited test procedures in accordance with DIN EN ISO/IEC 17025:2018 (accreditation number D-PL-14436-01-00).

3.2 Test infrastructure

Algorithm development and validation measurements are conducted using the IGF dust channel test rig, consisting of:

- Controlled aerosol generation
- A defined dust channel
- A sedimentation chamber
- Adjustable airflow with variable fan speeds

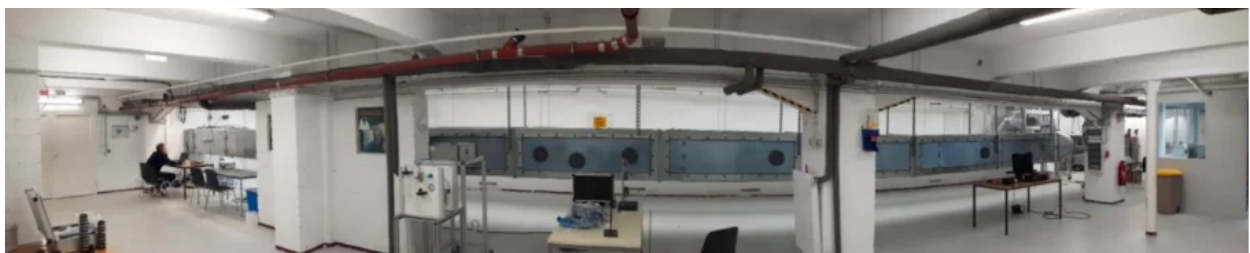


Figure 2: The IGF dust channel test rig.

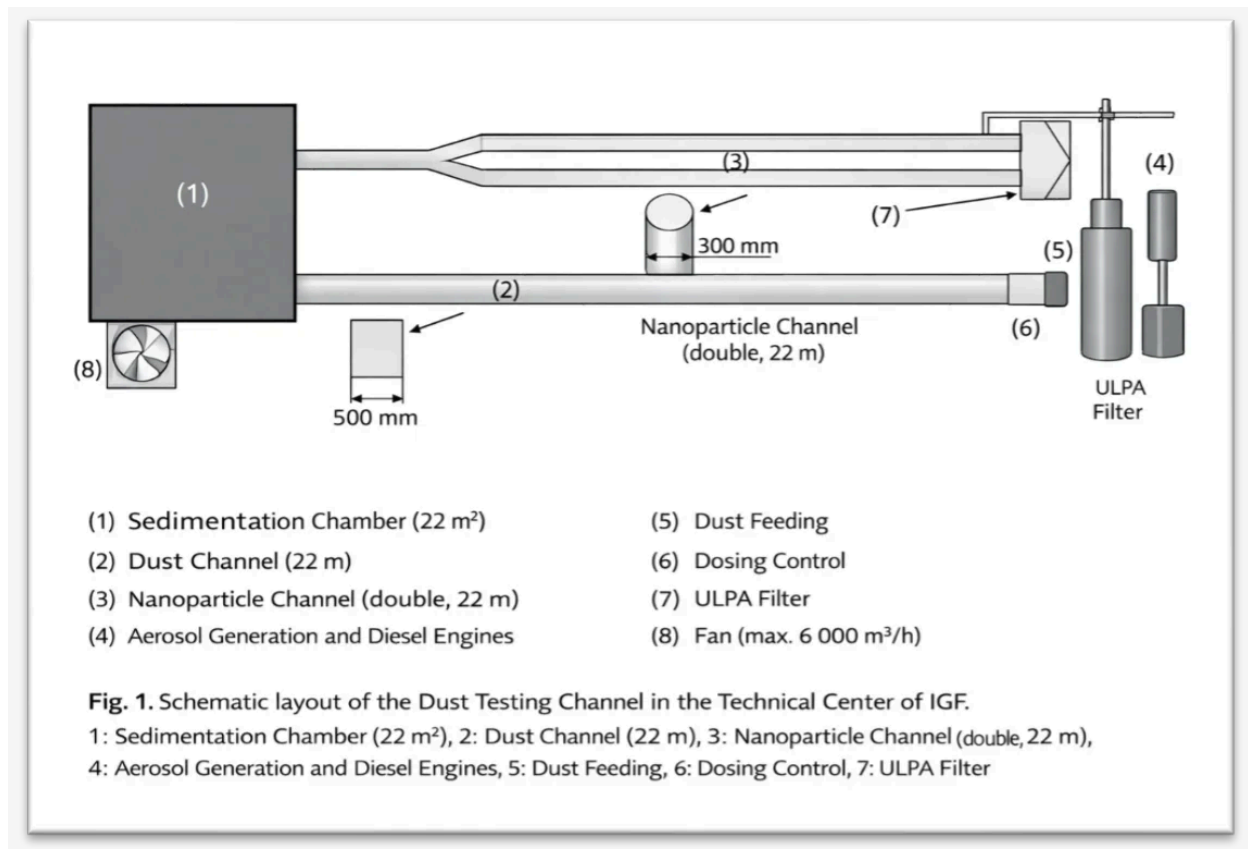


Figure 3: Schematic of the dust channel arrangement. Source: J. Pelzer, C. Monz: Erfahrungsaustausch und Ringversuch zur Messtechnik für ultrafeine Partikel. Gefahrstoffe – Reinhaltung der Luft 75 (2015), No. 9, September.

3.3 Reference instrumentation

Reference measurements are performed using a Grimm Aerosol Spectrometer Model 11-D (Dust Recorder) and gravimetric reference sampling with calibrated sampling pumps (GSA Messgeräte). This setup allows direct comparison between optical particle size and number distributions and mass-based gravimetric reference values.

The Grimm Model 11-D operates as an optical particle counter based on 90° light scattering using a 660 nm laser diode. Key characteristics of the instrument used during validation:

CHARACTERISTIC	VALUE
Measurement principle	Optical scattering (single-particle detection)
Particle size range	0.25 – 35 µm
Number of size channels	31 particle size classes
Sampling flow rate	1.2 L/min
Time resolution	≥ 6 seconds
Reproducibility	± 3 %
Integrated gravimetric reference filter	47 mm PTFE filter

Table 1: Key characteristics of the Grimm Model 11-D aerosol spectrometer as used during validation.

The Grimm instrument calculates mass concentrations based on the measured size distribution and assumed particle density and shape factors. During validation and reference measurements it provides mass concentration outputs for TSP (total suspended particles), PM₁₀, PM₄, PM_{2.5} and PM₁, each in µg/m³. In addition, the occupationally relevant fractions inhalable dust and respirable dust are derived, also in µg/m³. These metrics form the reference basis for Dustlight algorithm tuning and validation.

3.4 Aerosol types and concentration ranges for algorithm development

To ensure realistic and robust performance, algorithm development deliberately uses a wide range of industrial dust aerosols, including:

- Various wood dusts
- Welding fumes
- Diesel particles
- Amorphous silica (fumed, precipitated and others)
- Eskal dusts
- Multiple Arizona test dust grades
- And, critically, mixtures of different dust types

This exposes Dustlight algorithms to particles with widely varying size distributions, shapes, optical properties and densities. Over the past years, a large number of such tests have been conducted, each lasting one to two hours, typically at concentration levels of 125 µg/m³, 625 µg/m³, 1,250 µg/m³, 2,500 µg/m³ and 5,000 µg/m³, at an air velocity of 2 m/s.

3.5 Reference dust for reproducible verification: Arizona Test Dust A1

For repeatable verification and long-term consistency checks, Arizona Test Dust A1 ultrafine is used. It is defined in ISO 12103-1 and is internationally standardised and widely used as a reference material for comparability between laboratories. Its quartz content of approximately 69–77 % also makes it directly relevant to silica-exposed workplaces.

PARTICLE SIZE (µm)	CUMULATIVE VOLUME FRACTION [%]
22.00	100
11.00	95.5 – 97.5
5.50	65.0 – 69.0
2.75	23.0 – 27.0
1.38	7.0 – 10.0
0.97	3.0 – 5.0

Table 2: Particle size distribution of Arizona A1 ultrafine: cumulative volume fraction as specified in ISO 12103-1 and as used in verification tests.

It is explicitly acknowledged that Arizona A1 does not represent the full complexity of workplace dust aerosols. However, a single, well-defined reference dust is essential to achieve reproducible, comparable and traceable results. Arizona A1 was selected because it is defined by an international standard, widely used in inter-laboratory comparisons, and stable and well characterised.

4 SENSOR-LEVEL CALIBRATION AND VERIFICATION

In addition to the IGF laboratory validation, every individual sensor unit passes a calibration and verification process in production. This process is carried out batch-wise using:

- A controlled verification aerosol (approx. 3 % atomised KCl solution)
- A TSI DustTrak DRX 8533 (Ambient Mode) as reference instrument
- A TSI Optical Particle Sizer Model 3330

All sensor units of a production batch are tested simultaneously under identical conditions using a decaying aerosol concentration curve. For evaluation, measurements are used only once the aerosol is homogeneous and stable in the test chamber. The concentration is then time-averaged over a minimum period of 150 seconds, which filters out the statistical noise of the individual measurement. The resulting time-averaged mass concentration value ($\bar{M}\bar{C}_p$) forms the basis of both evaluations described below.

After calibration, every sensor unit is checked against the specification and sorted accordingly. Units that do not meet the specification are not used in Dustlight.

The reference instrument itself is regularly maintained, adjusted and calibrated. This matters: reference instruments of the same model can drift apart through configuration differences, ageing, high dust exposure or irregular maintenance, and a reference that is not kept within its own specification propagates its error into every unit calibrated against it.

4.1 Accuracy: deviation from the reference

A sensor unit passes verification when its measurement deviation against the reference instrumentation lies within the following limits of the Dustlight specification:

FRACTION	CONCENTRATION RANGE	PERMISSIBLE DEVIATION
PM1 and PM2.5	0 – 100 $\mu\text{g}/\text{m}^3$	$\pm 5 \mu\text{g}/\text{m}^3$ and $\pm 5 \%$
PM1 and PM2.5	100 – 5,000 $\mu\text{g}/\text{m}^3$	$\pm 10 \%$
Respirable dust and PM10	0 – 100 $\mu\text{g}/\text{m}^3$	$\pm 25 \mu\text{g}/\text{m}^3$
Respirable dust and PM10	100 – 5,000 $\mu\text{g}/\text{m}^3$	$\pm 25 \%$

Table 3: Permissible deviation of an individual sensor unit from the reference instrumentation.

The wider tolerance for the coarser fractions reflects the physics of optical detection: larger particles contribute disproportionately to mass, so small deviations in the counting and sizing of a comparatively small number of particles have a much greater effect on the calculated mass concentration than they do in the fine fractions.

These limits apply to the verification aerosol described above. Deviations under field conditions additionally depend on the optical properties, shape and density of the dust actually present, which is why the algorithm validation described in section 3 covers a wide range of real industrial dusts.

4.2 Precision: device-to-device variation (D2D)

Alongside the deviation from the reference, the agreement of the sensor units with each other is evaluated. Device-to-device variation describes the deviation of a single unit from the mean value of all units in a production batch. Its main causes are physical: the homogeneity of the aerosol, the ambient conditions, and the stability of both the reference instrument and the sensors themselves.

Because all units of a batch are measured simultaneously in the same chamber, their time-averaged values can be compared directly. The deviations are evaluated collectively, as a distribution around the batch mean rather than as individual pass or fail results. The criterion is the width of that distribution: the maximum range must fit within the specification band. A batch is accepted only if it does.

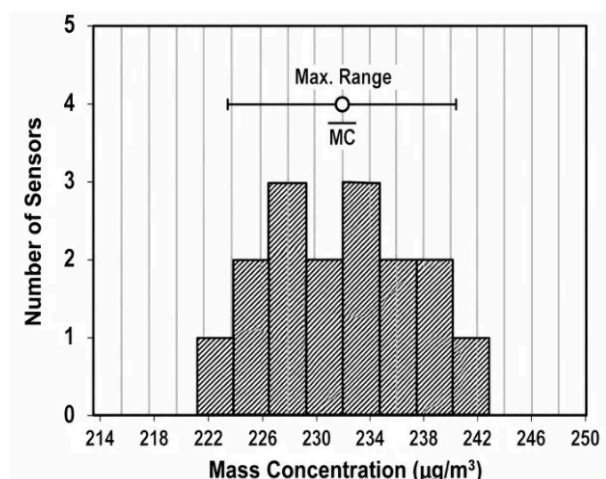


Figure 4: Distribution of sensor deviation around the batch mean. The maximum range must fit within the specification band.

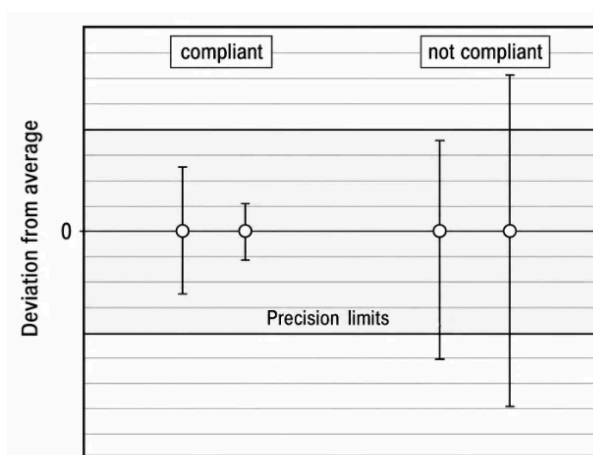


Figure 5: Examples of batch distributions that meet the specified band (left) and that do not (right). Open points represent mean values; the error bars indicate the maximum range and must remain within the limits.

This is the figure that determines whether two Dustlight devices standing side by side in the same dust show the same reading — which, in practice, is what users notice first.

Note on comparability. Quantitative comparison of sensor output with different high-end reference instruments is inherently challenging. Reference instruments from different manufacturers may show substantial discrepancies among each other — often greater than 20 % — when not consistently adjusted, calibrated and maintained according to their specifications.

5 RESPIRABLE DUST CALIBRATION OF DUSTLIGHT

The dust fraction that matters most in occupational safety, and therefore on the Dustlight display, is respirable dust. These particles are small enough to penetrate the finest branches of the lung, the alveoli, and to exert their harmful effect there.

Respirable dust is not a sharp cut-off but a size distribution: the larger a particle, the lower its probability of reaching the alveoli. Dustlight reproduces this sampling convention in its algorithm, so that the displayed value corresponds as closely as possible to the fraction of airborne dust that can actually reach the lung.

Once the individual sensor units have been calibrated, the assembled Dustlight receives its device-specific respirable dust calibration. In the *General dusts* configuration this is based on a defined dust mixture. For the specific configurations — welding fumes or wood dusts, for example — it is derived from comparative measurements carried out on those materials. The underlying data come from the many hours of testing at the IGF laboratories described in section 3, through which the measurement algorithms have been refined over several iterations.

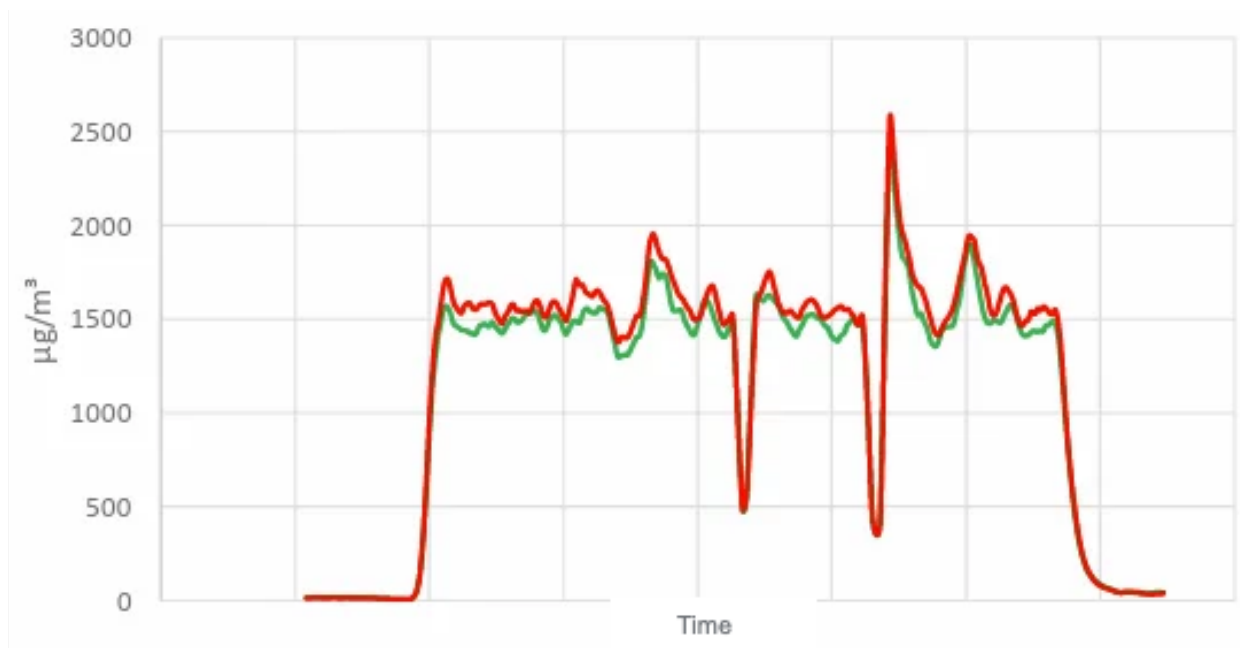


Figure 6: Respirable dust levels measured by Dustlight (red) and the Grimm Model 11-D reference spectrometer (green) using the calibration dust mixture, in the mixed dusts configuration.

Further information on dust and occupational exposure limits is available in the Dustlight blog; detailed measurement specifications are given in the data sheet.

6 CALIBRATION CHAIN AND TRACEABILITY

6.1 Calibration of the sensor unit

The particulate matter sensor units installed in Dustlight are produced and calibrated at Sensirion AG, Laubisruestrasse 50, CH-8712 Stäfa, Switzerland. All sensor unit types used in Dustlight, including the variant with integrated temperature and humidity measurement, are covered by that calibration certification.

Each sensor unit is calibrated to meet the specifications of the corresponding data sheet, and each unit is individually tested after its calibration. The calibration is performed against transfer standards, which are themselves subject to a scheduled calibration procedure. The calibration of the reference used for these transfer standards is carried out within an ISO 9001:2015 registered calibration system. The Dustlight-specific calibration levels are set using the reference arrangement described in section 4.

6.2 Traceability of the calibration chain

The calibration chain behind the sensor units is traceable to recognised national measurement standards. The accreditation body concerned is a full member of the International Laboratory Accreditation Cooperation (ILAC). Under the ILAC Mutual Recognition Arrangement (MRA), calibration certificates issued by facilities accredited by a signatory to that arrangement are accepted by all other signatories.

This provides traceability of measurement to recognised national standards and to units of measurement realised at the National Physical Laboratory (NPL) or other recognised national standards laboratories such as the Physikalisch-Technische Bundesanstalt (PTB) or the National Institute of Standards and Technology (NIST).

6.3 Understanding traceability

Traceability means that the references used in calibration can be linked to national measurement standards through an unbroken chain of documented comparisons. It is what allows a measurement taken with Dustlight to be related to an internationally agreed basis rather than to a manufacturer-internal scale. Two points are worth stating precisely, because the term is used loosely in this market.

Traceability describes the calibration chain, not an accredited device certificate. The statement above concerns the chain behind the reference standards used in calibration. It is not a claim that an individual Dustlight carries an accredited calibration certificate in accordance with ISO/IEC 17025.

In aerosol measurement, traceability runs through the underlying physical quantities.

Mass, volumetric flow, particle size and ambient conditions are traceable, as is the gravimetric determination of collected mass. There is no primary national standard for airborne dust mass concentration as such. This is a property of the measurement task itself and applies equally to every optical dust measurement instrument on the market. The dual-track concept described in this document is our answer to it: a traceable calibration chain on one side, and validation against gravimetric reference methods across a wide range of real industrial dusts on the other.

Accordingly, Arizona A1 test dust serves as a standardised test contaminant that provides reproducibility and comparability between measurements and laboratories. It is not itself a certified reference material carrying a traceable mass concentration value.

7 LONG-TERM STABILITY

Long-term stability, or long-term drift, describes changes in sensor performance over extended periods. This is verified by performing several accelerated ageing tests on samples of sensors. All sensors in a given sample must pass.

HTOL High Temperature Operating Lifetime

A thermal ageing test in which sensors are operated at an elevated temperature for a defined period (e.g. 60 °C for 1,000 hours). This simulates a significantly longer service life under typical operating conditions (25 °C). The test duration under accelerated ageing conditions is calculated according to JESD22-A108F.

THB Lifetime under high temperature and humidity

A temperature- and humidity-related ageing test. Sensors operate under elevated temperature and humidity conditions for a defined period (e.g. 60 °C, 90 % relative humidity, 860 hours) to simulate a longer lifespan. The test duration is calculated according to JESD22-A101D.

TC Temperature Cycling

A thermomechanical ageing test in which sensors are repeatedly subjected to low and high temperature cycles (e.g. 380 cycles at -40 °C / +60 °C, 30 minutes each). This simulates the typical cyclic temperature load during service life. The simulated temperature difference is calculated according to JESD22-A104E.

RD **Resistance to Dust**

An environmental ageing test that exposes sensors to a high concentration of particles to simulate dust exposure over their lifetime. The test conditions correspond to a PM concentration of approximately 45 µg/m³ over 10 years.

A stress test is considered passed when all sensors in the sample meet the long-term drift specification from the data sheet after accelerated ageing. The test duration is determined, using appropriate extrapolation models, to correspond to a simulated service life of 10 years.

PARAMETER	VALUE
Long-term drift per data sheet	1.25 % per year
Simulated test duration	10 years
Permissible accuracy limit after load test	± 12.5 %

Table 4: Long-term drift specification and permissible accuracy limit after accelerated ageing.

These tests ensure that the sensors installed in Dustlight deliver reliable performance across their entire service life, even under demanding conditions, and require no maintenance or calibration between the prescribed maintenance intervals.

8 CALIBRATION, VERIFICATION AND FIELD CHECK RECOMMENDATIONS

The following guidance outlines recommended practice for calibration, verification and field checks to ensure reliable long-term measurement performance.

Field functional check. A test spray may be used to verify that the sensor responds. Only residue-free aerosol test sprays should be used; sprays containing oils or solvents can contaminate the optical path. A field functional check confirms sensor response only — it is not a verification of measurement accuracy and does not replace calibration.

Recommended calibration interval. Annual calibration and maintenance is recommended, depending on application criticality and regulatory requirements.

9 SUMMARY: INDIVIDUALLY CALIBRATED, INDEPENDENTLY VALIDATED

The Dustlight accuracy concept rests on the following pillars:

-
- 01 **Individual calibration.** Every particulate matter sensor unit is individually calibrated in production and individually tested after calibration.
 - 02 **Traceable calibration chain.** The calibration chain is traceable to recognised national measurement standards, including those realised at NPL, PTB and NIST.
 - 03 **Batch verification.** Sensor units are verified batch-wise against reference instrumentation under identical, controlled conditions using a defined KCl aerosol.
 - 04 **Application-specific calibration.** Every device receives a respirable dust calibration matched to its configuration, so that the displayed value reflects the fraction of dust relevant to occupational exposure.
 - 05 **Independent validation.** Measurement algorithms and material-specific calibrations are developed and validated at the accredited laboratories of the IGF, using optical and gravimetric reference methods and internationally standardised test dusts in accordance with ISO 12103-1.
-

Together these provide a transparent, technically robust and internationally defensible basis for our accuracy claims, while openly acknowledging the aerosol dependence inherent to all optical dust measurement technologies.