Australian/New Zealand Standard™

Methods for sampling and analysis of ambient air

Method 18: Measurement of road tunnel air quality

PREFACE

This Standard was prepared by the Joint Standards Australia/Standards New Zealand Committee EV-007, Methods for Examination of Air.

The objective of this Standard is to provide regulatory and testing bodies with standard methods for continuously monitoring air in road tunnels for air velocity, carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO_2) concentrations and visibility.

This Standard has been developed as a performance based Standard that allows for use of a number of direct-reading instrumental methods.

Statements expressed in mandatory terms in notes to tables and figures are deemed to be requirements of this Standard.

FOREWORD

In order to improve traffic flow in central business districts and through sensitive environments, road tunnels are increasingly being used in Australia and New Zealand to achieve the desired outcomes. There are a significant number of tunnels in operation, with a number of others in the planning stages.

Road tunnel projects are subject to environmental and/or planning approval conditions by regulatory authorities that specify the parameters to be monitored in-tunnel, typically including air velocity, CO, NO, NO_2 and visibility, with a requirement that the tunnel ventilation system be controlled to—

(a) reduce public exposure to CO and NO_2 concentrations within the tunnel, enabling conformity with criteria for various averaging periods;

(b) prevent or reduce portal emissions and resultant environmental impacts; and

(c) ensure appropriate visibility for different tunnel operating conditions.

The first requirement is typically determined by averaging measured CO and NO_2 concentrations from a number of instruments located on possible travel paths throughout the tunnel system.

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METHOD

1 SCOPE

This Standard describes methods for determining air velocity and flow direction, carbon monoxide (CO), nitric oxide (NO) and nitrogen dioxide (NO_2) concentrations and visibility in road tunnels using direct-reading instruments.

This Standard applies to the measurement of air quality and air velocity inside road tunnels.

2 REFERENCED DOCUMENTS

The following documents are referred to in this Standard:

AS	
3580	Methods for sampling and analysis of ambient air
3580.5.1	Method 5.1: Determination of oxides of nitrogen—Direct-reading instrumental method
3580.7.1	Method 7.1: Determination of carbon monoxide—Direct-reading instrumental method
AS/NZS	
3580	Methods for sampling and analysis of ambient air
3580.2.2	Method 2.2: Preparation of reference test atmospheres—Compressed gas method
ISO/IEC	
Guide 98	Uncertainty of measurement
Guide 98-3: 2008	Part 3: Guide to the expression of uncertainty in measurement (GUM:1995)
EN	
14211	Ambient air. Standard method for the measurement of the concentration of nitrogen dioxide and nitrogen monoxide by chemiluminescence
14626	Ambient air. Standard method for the measurement of the concentration of carbon monoxide by non-dispersive infrared spectroscopy
Austroads	Guide to Road Tunnels, 2010
NZ Transport Agency	Guide to Road Tunnels, December 2013
National Environment Protection Council	National Environment Protection (Ambient Air Quality) Measure, Technical Paper No. 5, Data Collection and Handling.

3 DEFINITIONS

For the purpose of this Standard, the definitions below apply.

3.1 Accuracy

The degree of closeness of measurements of a quantity to its actual (true) value.

3.2 Certified reference material

Reference material, characterized by a metrologically valid procedure for one or more specified properties, accompanied by a reference material certificate that provides the value of the specified property, its associated uncertainty, and a statement of metrological traceability.

3.3 Check

Confirmation of acceptable instrument response, without adjustment.

3.4 Fall time

The time interval, after a step decrease in input concentration, between initial instrument response and 10% of initial instrument response.

3.5 Full scale

The nominated maximum concentration for which an instrument has been calibrated. The full scale (FS) is selected to cover the normal range of values expected in the sampling environment.

3.6 Interference equivalent

Positive or negative instrument response caused by a substance other than the one being measured.

3.7 Linearity

The deviation of an instrument's output from a linear best fit line when subjected to varying reference test atmospheres.

3.8 Lower detectable limit

The minimum pollutant concentration that produces a signal of exactly twice the noise level.

3.9 Noise

Spontaneous, short duration deviations in instrument output, about the mean output, which are not caused by input concentration changes. Noise level is determined as the standard deviation about the mean and is expressed in concentration units.

3.10 Parameter

One of the characteristics related to an air sample, for example, concentration of constituent or other quantifiable property (e.g. air velocity).

3.11 Parts per million (ppm)

A ratio expressing the volume of gaseous pollutant contained in 1 000 000 volumes of atmosphere. It may be expressed in terms of millilitres per cubic metre as the values are identical. Alternatively, it is one million times the ratio of the partial pressure of gaseous pollutant to the pressure of the atmosphere in which it is contained.

3.12 Precision

Variation about the mean of repeated measurements of the same pollutant concentration on the same instrument, expressed as one standard deviation about the mean.

3.13 Range

Nominal minimum and maximum concentrations that a method is capable of measuring.

NOTE: The nominal range is specified by the lower and upper range limits in concentration units, e.g. 0 to 250 ppm.

3.14 Reference test atmosphere

A test atmosphere containing a known concentration of pollutant, typically generated by diluting the contents of a cylinder containing a gaseous certified reference material.

3.15 Rise time

The time interval, after a step increase in input concentration, between instrument initial response and 90% of final instrument response.

3.16 Road tunnel

Any fully enclosed length of roadway with a minimum length of between 80 m and 150 m, as the length above which the structure is considered to be a tunnel (refer to Austroads, *Guide to Road Tunnels* and NZ Transport Agency, *Guide to Road Tunnels*).

3.17 Span drift

The percentage change in instrument response to an on-scale pollutant concentration over a period of continuous unadjusted operation.

3.18 U_{95}

A measurement of uncertainty at a confidence interval of 95% according to ISO/IEC Guide 98-3.

3.19 Zero air

Air free from contaminants likely to cause a detectable response on the test instrument.

3.20 Zero drift

The change in instrument response to a zero pollutant concentration over a period of continuous unadjusted operation.

4 TEST PARAMETER—AIR VELOCITY

4.1 Scope

This clause describes a continuous, direct-reading instrumental method for determining air velocity and flow direction in road tunnels.

4.2 Principle

Air velocity and flow direction in road tunnels are typically measured as average values over the tunnel width using ultrasonic flow sensors, with transceiver pairs installed on opposing walls at an angle of 45° to 60° to the tunnel axis, at various locations along the tunnel length, including portals and exit ramps. Single point ultrasonic flow sensors can also be used in road tunnels, however it should be recognized that the potential for error in the instantaneous measurement of both air velocity and flow direction is increased due to turbulence created by nearby vehicles.

Ultrasonic sensor systems are based on the principle that the velocity of air movement changes the transit time of a sound pulse across a fixed distance, allowing calculation of the air velocity and determination of flow direction.

Instrument outputs are used to control the direction of operation and speed of the axial flow jet fans installed on the roof of the tunnel. Depending on their location, the jet fans either assist the movement of polluted air in the direction of traffic flow, typically towards the ventilation stack, or reduce or eliminate pollutant emissions from the tunnel portals by creating air movement in the opposite direction to traffic flow.

NOTES:

1 Ultrasonic flow sensors are typically located high on tunnel walls; consequently the measured air velocity may not be representative of that for the overall tunnel cross-section.

2 In order to eliminate the measuring errors that could be caused by variation of ultrasonic sound speed caused by temperature and pressure, the transceiver units need to be installed on each side of the tunnel wall and the transit time needs to be measured in both directions.

Providing the instrument performance is within the specifications given in Table 4.3.1, alternate methods may be used within the context of this Standard.

4.3 Apparatus

4.3.1 *Instrument*

A continuous direct-reading instrument that meets or exceeds the specifications given in Table 4.3.1. The manufacturer's published performance specifications shall be deemed as acceptable evidence of conformance to the given requirements, if accompanied by a statement of measurement uncertainty.

TABLE 4.3.1

INSTRUMENT PERFORMANCE SPECIFICATIONS FOR TUNNEL AIR VELOCITY SYSTEMS

Parameter	Minimum requirements
Range	−20 to 20 m/s
Accuracy	2% of reading or ±0.2 m/s*
Resolution	≤0.1 m/s

* Whichever is the greater.

4.3.2 *Reference path length measurement device*

A reference path length measurement device traceable to national standards with an uncertainty of ±0.5% U_{95} is required to make an accurate determination of the path length. The reference path length measurement device shall be checked over a path length of at least the instrument measurement path length.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

4.3.3 *Transfer standard flow sensor*

A hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the air velocity sensor traceable to national standards with an uncertainty of ±2% U_{95} is required to check the operation of air velocity sensors. The transfer standard flow sensor shall be calibrated over a range exceeding the maximum air flow experienced in the tunnel.

The transfer standard sensor shall be routinely calibrated such that it is traceable to SI units. This calibration shall be evidenced by a calibration certificate which states the sensitivity of the device by a procedure which establishes traceability to a recognized standard and for which a measurement uncertainty is given at a stated level of confidence, and the period during which the calibration is valid.

4.4 Procedure

The procedure shall be as follows:

(a) Ensure that the transceivers are installed such that the path for the sonic pulse is unimpeded by tunnel equipment or other obstructions, whilst allowing ease of access for instrument maintenance and calibration.

(b) Check instrument horizontal and vertical alignment, in accordance with the manufacturer's instructions.

(c) Accurately measure and record the distance between the transceivers using a reference path length measurement device (Clause 4.3.2).

(d) Set up the instrument and carry out initial checks in accordance with the manufacturer's instructions (e.g. setting the path length, configuring and scaling of analogue outputs, setting of alarm values and level of damping) and the requirements of Clause 4.5.

(e) Take measurements in accordance with the manufacturer's instructions and ensure that the values obtained relate to the correct date and time.

4.5 Instrument checks and calibrations

4.5.1 *General*

Calibration of an instrument establishes the quantitative relationship between the air velocity and the instrument's response.

Instrument checks and calibrations shall be carried out in accordance with the frequencies specified in Table 4.5.6.

In addition, operational precision checks shall be carried out as follows:

(a) Prior to decommissioning or physical relocation of the instrument, if operational.

(b) Following physical relocation of the instrument.

(c) After any repairs that might affect the instrument's response.

(d) Upon any indication of an instrument malfunction or change in response that may cause the instrument to drift by more than the values given in Table 4.5.6.

NOTE: The air flow and direction monitor may incorporate an automatic daily zero and span check function for daily quality control and assurance purposes.

4.5.2 *Measurement path length*

The measurement path length is normally defined as the distance between the faces of opposing transceiver units, however this should be confirmed with the manufacturer. The measurement path length shall be determined upon installation (see Table 4.5.6) using a reference distance measurement device as described in Clause 4.3.2.

A check of the measurement path length shall also be conducted whenever an instrument is reinstalled following maintenance or repair, if the maintenance or repair could result in a change of measurement path length.

4.5.3 *Initial check*

Conduct an initial check on the ultrasonic flow sensor prior to road tunnel opening using a collocated transfer standard (CTS) method at a minimum of three air velocities evenly spread over the tunnel design operational range.

For open path ultrasonic flow sensors, measurements shall be taken at a minimum of two points per trafficable lane over the measurement path. For a single point ultrasonic flow sensor, the CTS needs to be within 1 m of the subject sensor in the horizontal and 0.5 m in the vertical, but the same distance from the tunnel wall.

The CTS method requires a calibrated hand held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the ultrasonic flow sensor, located in the vicinity of the measurement path for the sensor being assessed.

For both single point and open path ultrasonic flow sensors it is important to site the CTS to be representative of the air flow at the subject sensor, without interfering with either instrument's response.

The procedure shall be as follows:

(a) Ensure that the CTS is oriented such that the reading is obtained in the direction of air flow.

(b) Connect the CTS to an independent data logger. Record check data for a period of not less than 15 minutes. Simultaneously record the response from the in situ sensor over the same period.

(c) Average the recorded data over the selected period, and, if applicable, across all CTS measurement points. Calculate the difference between the in situ sensor and CTS average readings.

(d) Check that the difference conforms to the tolerance given in Table 4.5.6. If the result is not within the prescribed tolerance, conduct repairs and/or instrument calibrations as required and repeat the above procedure until compliance with the specified tolerance is indicated.

4.5.4 *Zero check*

If a zero air flow environment can be attained, the zero response of the ultrasonic flow sensor shall be checked on a 12-monthly basis, in accordance with the manufacturer's instructions.

Check that the zero response is within the tolerance given in Table 4.5.6. If the result is not within the tolerance, conduct repairs and/or instrument calibrations as required and repeat the procedure until the zero response is within the tolerance.

4.5.5 *System component check*

Cables, recorders, signal conditioning and data processing devices can corrupt the sensor's output.

A system component check shall be conducted on a 12-monthly basis to ensure the transmitted sensor output matches that received at the data recording device. For example, if the ultrasonic flow sensor gives a 20 mA output with an air velocity of 20 m/s, then apply a 20 mA signal to the system to confirm that 20 m/s is indicated at the data recording device.

Check that the response is within the tolerance given in Table 4.5.6. If the response is not within the tolerance, conduct repairs and/or instrument calibrations as required and repeat the procedure until the response is within the tolerance.

4.5.6 *Operational precision check*

An operational precision check shall be conducted on the ultrasonic flow sensor on a 12-monthly basis using the CTS method at a minimum of one air velocity, and, for open path ultrasonic flow sensors, a minimum of three equally spaced points over the measurement path. For a single point ultrasonic flow sensor, the CTS shall be within 1 m of the subject sensor in the horizontal and 0.5 m in the vertical, but the same distance from the tunnel wall.

The CTS method requires a calibrated hand-held vane or hot-wire anemometer, or equivalent, of similar or higher specification to the ultrasonic flow sensor, located in the same horizontal plane as the measurement path for the sensor being assessed.

The transfer standard sensor shall be routinely calibrated by a recognized external authority such that the CTS is traceable to SI units. This calibration shall be evidenced by a calibration certificate which states the sensitivity of the device by a procedure which establishes traceability to a recognized standard and for which a measurement uncertainty is given at a stated level of confidence, and the period during which the calibration is valid.

For both single point and open path ultrasonic flow sensors it is important to site the CTS to be representative of the air flow at the subject sensor, without interfering with either instrument's response.

The procedure shall be as follows:

(a) Ensure that the CTS is oriented such that the reading is obtained in the direction of air flow.

(b) Connect the CTS to an independent data logger. Record check data for a sufficient period that demonstrates a stable response. Simultaneously record the response from the in situ sensor over the same period.

(c) Average the recorded data over the selected period, and, if applicable, across the three CTS measurement points. Calculate the difference between the in situ sensor and CTS average readings.

(d) Check that the difference conforms to the tolerance given in Table 4.5.6. If the result is not within the prescribed tolerance, conduct repairs and/or instrument calibrations as required and repeat the above procedure until compliance with the specified tolerance is indicated.

TABLE 4.5.6

INSTRUMENT CHECK AND CALIBRATION REQUIREMENTS FOR TUNNEL AIR VELOCITY SYSTEMS

Parameter	Criterion	Frequency
Measurement path length	±0.5%	Initial
Initial check	2% of reading or ±0.2 m/s*	Initial
Zero check	±0.2 m/s	≤12-monthly
System component check	±0.2% FS	≤12-monthly
Operational precision check	6% of reading or ±0.3 m/s*	≤12-monthly

* Whichever is the greater.

4.6 Maintenance

4.6.1 *General*

Maintenance should be carried out in accordance with the frequencies specified in Table 4.6.2. Manufacturers may require additional procedures which should also be adhered to.

Where a high degree of data capture is required, back-up or replacement instruments should be available. A detailed log of all performance checks and maintenance undertaken shall be maintained and retained with the initial check air velocity and flow direction data.

4.6.2 *On site checks*

Maintenance should be carried out in accordance with the frequencies specified in Table 4.6.2. Visual examination of the ultrasonic flow sensors should be conducted on a 3-monthly basis to ensure that physical damage has not occurred. A log of the results of such checks shall be maintained, with routine entries providing the evidence of attendance needed to support data validity claims.

Routine maintenance may include the removal of dirt, bird nests and cobwebs and the checking of transceiver alignment. The maintenance interval is dependent on air quality in the tunnel, but should not exceed six months. Care should be taken when cleaning ultrasonic flow sensor components, in accordance with manufacturer’s recommendations.

NOTE: Compressed air should not be used for cleaning ultrasonic flow sensor components.

When establishing a schedule for on-site checks the following should be considered:

(a) A plot of collected data will indicate how the sensor is performing.

(b) Faults may be indicated by incorrect zero, noise (which may be evident at low air velocities), low sensitivity (at low air velocities) and low variability of the recorded air velocities.

(c) Data inter-comparisons between other sensors located within the tunnel.

TABLE 4.6.2

ROUTINE MAINTENANCE FOR TUNNEL AIR VELOCITY SYSTEMS

Maintenance component	Frequency
Visual inspection	≤3-monthly
Sensor cleaning	≤6-monthly
Alignment check	≤6-monthly

4.7 Calculation and expression of results

Results shall be expressed in units of meters per second. The positive or negative sign of the velocity, with respect to traffic flow or portal flow, shall be clearly defined in the report.

4.8 Measurement uncertainty

The measurement uncertainty of this method will vary for each installation. Factors affecting the overall uncertainty include how representative the ultrasonic flow sensor output is of the tunnel cross sectional area.

As a guide, measurement uncertainties for air velocities corresponding to the greater of ±0.2 m/s or 2% of reading can be achieved using modern equipment. In all cases, the measurement uncertainty shall be determined based on individual laboratory practices.

NOTE: A suitable method for calculating measurement uncertainty can be found in ISO/IEC 98-3.

5 TEST PARAMETERS—CARBON MONOXIDE, NITRIC OXIDE AND NITROGEN DIOXIDE

5.1 Scope

This Clause describes continuous, direct-reading instrumental methods for determining CO, NO and NO_2 concentrations in road tunnels.

5.2 Principle

CO and NO concentrations in road tunnels are typically measured using open path infra-red instruments, based on gas filter correlation technology, with measurement path lengths normally ranging from 3 m (6 m folded beam) to 10 m (single beam). NO_2 concentrations in road tunnels are typically measured using either a 10 m (20 m folded beam) open path ultra-violet instrument or an electrochemical sensor.

Other measurement techniques, including extractive systems and ambient air quality analysers, may also be used provided they meet the instrument performance specifications contained in either this Standard, AS 3580.5.1 or AS 3580.7.1. Tunnel safety requirements relating to handling, storage and transport of compressed gases also need to be considered.

Unlike ultrasonic flow sensors, the open path instrument transmitter and receiver, or transceiver and retroreflector, are typically mounted on the wall on the same side of the tunnel, preventing potential glare impacts on tunnel users from the light beam.

In the case of transceiver-based instrumentation, the infra-red (CO and NO) or ultra-violet (NO_2) radiation from an element is focused by a lens onto a retroreflector. For both equipment configurations, the received or reflected energy is then focussed by a lens onto an infra-red or ultra-violet detector. For gas filter correlation instruments a rotating wheel containing two sets of filters is located in front of the detector. On one of each of the pairs of filters sits a sealed reference gas cell containing a very high concentration of the pollutant under consideration and on the other a cell containing nitrogen. The detector compares the two infra-red radiation levels and sends a signal to the electrometer, allowing calculation of the concentration.

The open path measurement technique for all pollutants is based on the Beer-Lambert Law, which relates the absorption of light as a function of the concentration of the absorbing species, the absorption characteristics of that species, and the length of the absorption path.

The Beer-Lambert Law in this instance can be expressed mathematically as follows:

$$I(\lambda) = I_0(\lambda)e^{-\Sigma c_i a_i(\lambda)L} \quad \text{. . . 5(1)}$$

where

$I(\lambda)$ = measured light intensity at specific wavelength λ

$I_0(\lambda)$ = light intensity at specific wavelength λ without any absorption

c_i = concentration of gaseous species *i*

$a_i(\lambda)$ = absorption cross-section at wavelength λ for gaseous species *i* (quantifies the probability for light absorption at each wavelength; units are m^2 per molecule, m^2 per µg, or similar, depending on the unit of concentration)

L = the optical path length

An electrochemical sensor consists of a capillary diffusion barrier, a hydrophobic membrane and working and counter electrodes separated by a thin layer of electrolyte. NO_2 passes through the capillary barrier, diffuses across the hydrophobic membrane and reacts at the surface of the working electrode in accordance with the following equation:

$$NO_2 + 2H^+ + 2e^- \rightarrow NO + H_2 \quad \text{. . . 5(2)}$$

As the process is diffusion controlled, the instrument response is directly proportional to the NO_2 concentration, in accordance with the following:

$$R = D \times F \times c_i \times A/t \times e \quad \text{. . . 5(3)}$$

where

R = instrument response

D = diffusion coefficient

F = Faraday constant

c_i = concentration of gaseous species *i*

A = membrane area

t = membrane thickness

e = number of electrons

The limitations of electrochemical sensors include their response to temperature and interferent gases.

Providing the instrument performance is within the specifications given in Table 5.3.1, alternate methods may be used within the context of this Standard.

5.3 Apparatus

5.3.1 *Instrument*

A continuous direct-reading instrument that meets or exceeds the performance specifications given in Table 5.3.1. The instrument may be used over any range within the limits of this Standard, provided it has been calibrated and checked in accordance with Clause 5.5.

The manufacturer's published performance specifications shall be deemed as acceptable evidence of conformance to the given requirements, if accompanied by a statement of measurement uncertainty.

NO_2 electrochemical sensors have cross sensitivities to a range of pollutants that may be present in road tunnels, including NO. This aspect should be considered when selecting equipment. An interference equivalent corresponding to less than ±0.5% FS is a requirement of this Standard for each relevant interferent gas.

TABLE 5.3.1

INSTRUMENT PERFORMANCE SPECIFICATIONS FOR TUNNEL CO/NO/NO_2 SYSTEMS

Parameter	CO	NO	NO_2
Range	0 to 250 ppm	0 to 30 ppm	0 to 2 ppm
Lower detectable limit	2 ppm	1 ppm	0.05 ppm
Accuracy	±2 ppm or ±2% of reading*	±1 ppm	±0.05 ppm or ±5% of reading*
Resolution	±1 ppm	±1 ppm	±0.05 ppm
Response time: rise fall	 ≤120 s ≤120 s	 ≤120 s ≤120 s	 ≤120 s ≤120 s
Difference rise time/fall time	≤10 s	≤10 s	≤10 s
Operating temperature	−20 to 50°C	−20 to 50°C	−20 to 50°C

* Whichever is the greater.

5.3.2 *Reference barometer*

A reference barometer, traceable to national standards with an uncertainty of ±0.5 kPa U_{95}, is required for the calibration of any pressure transducers that form part of the measurement system, or to standardize flow through calibration cell conditions when performing checks or calibrations of the system.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

5.3.3 *Reference thermometer*

A reference thermometer, traceable to national standards with an uncertainty of ±0.5°C U_{95}, is required for the calibration of any temperature sensors that form part of the measurement system, or to standardize flow through calibration cell conditions when performing checks or calibrations of the system.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

5.3.4 *Reference path length measurement device*

A reference distance measuring device, traceable to national standards with an uncertainty of ±0.5% U_{95} is required to make an accurate determination of the measurement path length. The reference path length measurement device shall be checked over a path length of at least the instrument measurement path length.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

5.3.5 *Reference flow through calibration cell length measurement device*

A reference distance measuring device, traceable to national standards with an uncertainty of ±0.5% U_{95}, is required to make an accurate determination of the length of the flow through calibration cell(s). The reference path length measurement device shall be checked over a distance of at least the longest calibration cell path length.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

5.4 Procedure

The procedure shall be as follows:

(a) Ensure that the transceiver and retroreflector or transmitter and receiver units are installed such that the optical path is unimpeded by tunnel equipment or other obstructions, whilst allowing ease of access for instrument maintenance and calibration. Shorter optical paths will improve light levels, however, they can result in higher detection limits and greater measurement uncertainty.

(b) Ensure that the transceiver and retroreflector or transmitter and receiver units are firmly mounted on materials with low thermal expansion to minimize alteration of the light beam alignment due to temperature variations.

(c) Ensure that instruments are not subject to excessive vibration and that the electricity supply is stable.

(d) For equipment installed at the tunnel portals or entry/exit ramps, ensure that the optical path orientation is such that it avoids strong scattered radiation (e.g. sunlight) directly entering the transceiver or receiver unit.

(e) Check the horizontal and vertical alignments of the units.

(f) Accurately measure the distance between the transceiver and retroreflector or the transmitter and receiver using a reference path length measurement device (Clause 5.3.4).

(g) Set up the instrument and carry out initial checks in accordance with the manufacturer's instructions (e.g. setting the path length, configuring and scaling of analogue outputs, setting of alarm values and level of damping) and the requirements of Clause 5.5.

(h) Take measurements in accordance with the manufacturer's instructions and ensure that the values obtained relate to the correct date and time.

NOTES:

1 Conducting the optical path alignment under low light or dark conditions may assist when adjusting the focus.

2 Where possible, optical path alignment and focusing should be performed under temperature conditions that approximate the mid-range of the expected minimum and maximum temperature range at the monitoring location.

3 During tunnel wall washing or deluge testing for the fire system, caps should be installed on the instrument dust protection tubes to prevent water ingress, where applicable.

5.5 Instrument checks and calibrations

5.5.1 *General*

Calibration of an instrument establishes the quantitative relationship between the pollutant concentration input and the instrument's response. Only reference test atmospheres shall be used to adjust the instrument's output.

Instrument checks and calibrations shall be carried out in accordance with the frequencies specified in Table 5.5.14.

In addition, instrument checks and calibrations shall be carried out—

(a) prior to decommissioning or physical relocation of the instrument, if operational;

(b) following physical relocation of the instrument;

(c) after any repairs that might affect the instrument's response; and

(d) upon any indication of an instrument malfunction or change in response that may cause the instrument to drift by more than the values given in Table 5.5.14.

5.5.2 *Open path instruments*

Open path instruments shall be calibrated as directed by the instrument's operation or instruction manual and in accordance with the general guidance provided here.

Based on the Beer-Lambert Law, absorption is dependent on both the gas concentration and the optical path length. Consequently the light absorbed by the pollutant is a function of the total number of molecules of that gas between the transmitter and the receiver. Therefore calibrations can theoretically be carried out at high concentrations over short distances or relatively low concentrations over longer distances, provided that the product of concentration times distance is constant.

Open path instrument checks and calibrations are generally carried out utilizing relatively high concentrations over short distances, due to increased uncertainty at lower gas concentrations. In addition, short calibration path lengths are easier to achieve in the field.

Instrument span checks and calibrations are conducted using a flow through calibration cell attached to the transceiver or receiver unit, with a reference test atmosphere introduced to the cell at a low flow rate.

By varying the number and length of flow through calibration cells through which the light beam travels, different gas concentrations can be simulated from the one reference test atmosphere. Alternatively the concentration of the reference test atmosphere can be varied using dilution apparatus, with only one flow through calibration cell required.

The gas concentration over the measurement path is calculated as follows:

$$c = \frac{c_r \times L_c}{L} + \frac{c_b \times (L - L_c)}{L} \qquad \text{. . . 5(4)}$$

where

c = gas concentration over the optical path length, in ppm

c_r = reference test atmosphere concentration, in ppm

c_b = background pollutant concentration, in ppm

L_c = calibration cell length, in m

L = measurement path length, in m

Instrument checks and calibrations are normally conducted during tunnel closures, consequently the second term of the equation, which allows for the background pollutant concentration, is not normally significant at span gas concentrations. It may however become significant if there are idling vehicles or fuelled equipment operating nearby, or when conducting measurements at the lower concentrations associated with a multipoint precision check.

The background pollutant concentration is the average of the concentrations measured by the open-path instrument under test immediately before and after the period of calibration.

Open-path instruments should be tested during periods when the pollutant concentrations are relatively low and steady. Also, to avoid interference with the measurements, ensure that the outlet from the flow through calibration cell is directed away from the measurement path by attaching tubing to the cell exit port.

Sealed cells containing a high concentration of the pollutant under measurement are available from some equipment manufacturers. Sealed cells can be used to check the performance of the instrument in the period between calibrations, but shall not replace the instrument calibration requirements of this Standard.

5.5.3 *Single point instruments*

Single point instruments shall be calibrated as directed by the instrument's operation or instruction manual and in accordance with the general guidance provided here.

Instrument zero and span checks and calibrations shall be carried out at the monitoring location by allowing the instrument to sample reference test atmospheres containing known pollutant concentrations. During the check or calibration, the instrument shall sample the zero or span reference test atmosphere through all sample lines, filters, scrubbers, conditioners and other components associated with the measurement system during normal road tunnel air quality monitoring.

5.5.4 *Measurement path length*

For open path instruments the measurement path length shall be determined upon installation (Table 5.5.14) using a reference measurement device as described in Clause 5.3.4. The measurement path length is normally defined as the distance between the face of the transceiver or transmitter unit and the face of the retroreflector or receiver unit, however this should be confirmed with the manufacturer.

A check of the measurement path length shall also be conducted whenever an instrument is reinstalled following maintenance or repair.

5.5.5 *Flow through calibration cell length*

The length of the flow through calibration cell(s) used for open path instrument checks and calibrations shall be determined before initial use (see Table 5.5.14) using a reference measurement device as described in Clause 5.3.5. The cell length shall be determined as the distance between the inner surfaces of the optical glass on each side of the cell.

NOTE: It may be preferable to determine the distance between the outer surfaces of the cell and subtract the thickness of glass at each end. This method needs to be repeatable and take into account variables such as o-rings used to seal glass surfaces.

5.5.6 *Temperature and pressure checks*

If pollutant concentrations are required to be reported in units of milligrams per cubic metre (expressed at 0°C and 101.3 kPa), the average temperature shall be measured.

Temperature sensors shall be checked at intervals not exceeding twelve months. If there is a difference of more than ±1°C between the sensor and reference thermometer, the sensor shall be calibrated. A reference thermometer that complies with the requirements of Clause 5.3.3 shall be used. The manufacturer's instructions detailing the specific temperature sensor check and calibration procedure(s) shall be followed.

A check shall also be conducted whenever the temperature sensor is subject to maintenance or repair.

Changes in barometric pressure have a lesser effect, consequently continuous measurement, whilst recommended, is not a requirement of this Standard. When used, pressure transducers shall be checked at intervals not exceeding twelve months. If there is a difference of more than ±1 kPa between the transducer and the reference barometer, the transducer shall be calibrated. A reference barometer that complies with the requirements of Clause 5.3.2 shall be used. The manufacturer's instructions detailing the specific pressure sensor check and calibration procedure(s) shall be followed.

A check shall also be done whenever the pressure sensor is subject to maintenance or repair.

5.5.7 *Zero air*

Zero air shall be free from contaminants likely to cause a detectable response on the test instrument. The concentration of oxygen in the zero air shall be within ±2% v/v of the normal composition of air (20.9% v/v).

5.5.8 *Reference test atmosphere*

Reference test atmospheres of gaseous target compounds shall be produced from certified reference materials in accordance with AS/NZS 3580.2.2, using zero air as a diluent gas. Alternatively, certified reference materials can be supplied direct to the instrument without dilution, when appropriate concentrations of the target compound are available.

Laboratories providing reference material certificates shall meet the requirements of AS ISO/IEC 17025 or be a National Metrology Institute (NMI) included in the Bureau International des Poids et Mesures (BIPM) key comparison database (KCDB).

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

5.5.9 *Zero check*

5.5.9.1 *Open path instruments*

If the open path instrument is capable of performing a zero check, follow the manufacturer's instructions. However, open path instrument zero checks are normally not possible in the field. Under these circumstances the 'zero' readings under no traffic conditions shall be recorded during instrument span checks (see Clause 5.5.11.1). If the flow through calibration cell remains in the measurement path during the zero check, flush the cell with nitrogen or zero air.

Zero checks should be conducted under late night/early morning conditions when ambient pollutant concentrations are normally low.

An alternate method for the zero check is to plot the instrument readings over an extended time period (≥1 month) to obtain an estimate of the instrument zero reading.

5.5.9.2 *Single point instruments*

The zero check procedure shall be as follows:

(a) Following installation, set up the instrument in accordance with the manufacturer's instructions.

(b) Allow the instrument to operate for several hours (preferably overnight) prior to conducting the zero check, to ensure that its operation has stabilized.

(c) Supply zero air to the instrument, ensuring that it passes through any conditioning equipment. After allowing sufficient time for the instrument response to stabilise, record the instrument reading.

(d) Calculate the zero drift as follows:

$$\%\ Drift = \frac{\left(C_{\mathrm{r}} - C_{\mathrm{e}}\right)}{C_{\mathrm{fs}}} \times 100 \qquad \text{. . . 5(5)}$$

where

C_{r} = recorded zero value

C_{e} = expected zero value

C_{fs} = full scale value

5.5.10 *Zero calibration*

If the instrument zero drift exceeds the value given in Table 5.5.14, or twelve months has passed since the previous calibration, whichever occurs first, adjust the instrument response if necessary and record the final instrument reading.

5.5.11 *Span check*

5.5.11.1 *Open path instruments*

The span check procedure shall be as follows:

(a) Following installation, set up the instrument in accordance with the manufacturer's instructions.

(b) Allow the instrument to operate for several hours (preferably overnight) prior to conducting the zero check, to ensure that its operation has stabilized. Select a full-scale value to cover the range of expected concentrations in the road tunnel.

(c) Record the instrument zero reading.

(d) For sealed cells, install the cell in the instrument.

(e) For flow through calibration cells, install and flush with nitrogen or zero air and confirm the instrument zero reading. Connect the certified reference material cylinder or dilution apparatus to the flow through calibration cell and introduce a reference test atmosphere corresponding to 75% to 90% of the selected full-scale range of the instrument. The flowrate shall be such that there is no significant pressure increase in the cell (typically 1 Lpm or less).

(f) After allowing sufficient time for the instrument response to stabilize, record the instrument reading.

(g) Record a second instrument zero reading to ensure that there has been no significant change in background concentration.

(h) Calculate the zero and span drifts as follows:

$$\%\ Drift = \frac{(C_r - C_e)}{C_{fs}} \times 100 \qquad \text{. . . 5(6)}$$

where

C_r = recorded zero or span value

C_e = expected zero or span value

C_{fs} = full scale value

(i) Disconnect the reference test atmosphere supply and remove the flow through calibration cell.

5.5.11.2 *Single point instruments*

The span check procedure shall be as follows:

(a) Following installation, set up the instrument in accordance with the manufacturer's instructions.

(b) Allow the instrument to operate for several hours (preferably overnight) prior to conducting the span check, to ensure that its operation has stabilized. Select a full-scale value to cover the range of expected concentrations in the road tunnel.

(c) Supply a reference test atmosphere at 75% to 90% of the selected full-scale range to the instrument ensuring that it passes through any conditioning equipment. After allowing sufficient time for the instrument response to stabilize, record the instrument reading.

(d) Calculate the span drift as follows:

$$\%\ Drift = \frac{(C_r - C_e)}{C_{fs}} \times 100 \qquad \text{. . . 5(7)}$$

where

C_r = recorded span value

C_e = expected span value

C_{fs} = full scale value

5.5.12 *Span calibration*

If the instrument span drift exceeds the values given in Table 5.5.14, or twelve months has passed since the previous calibration, whichever occurs first, adjust the instrument response if necessary and record the final readings. Sealed cells shall not be used for instrument calibration. Recheck the instrument zero following any span adjustment in accordance with the procedure described in Clause 5.5.9.1 (open path instruments) or Clause 5.5.9.2 (single point instruments).

For instruments with individual zero and span controls for NO and NO_2, each shall be adjusted to give a readout equal to the respective reference test atmosphere concentration.

5.5.13 *Multipoint precision check*

A multipoint precision check shall only be performed immediately after a zero check/calibration and span calibration as described in Clauses 5.5.9 to 5.5.12. The procedure shall be as follows:

(a) Upon commissioning or after any repairs that might affect the instrument's linearity, an extended multipoint precision check shall be performed. Supply to the instrument at least three non-zero reference test atmospheres approximately equally spaced over the measurement range (e.g. 25%, 50% and 75%), or in the case of infra-red instruments six non-zero reference test atmospheres approximately equally spaced over the measurement range (e.g. 15%, 30%, 45%, 60%, 75%, 90%). After allowing sufficient time for the instrument response to stabilize, record the measured concentration for each reference test atmosphere and zero.

(b) For subsequent multipoint precision checks, generate at least three non-zero reference test atmospheres, approximately equally spaced (e.g. 25%, 50%, 75%) over the measurement range. After allowing sufficient time for the instrument response to stabilize, record the measured concentration for each reference test atmosphere and zero.

(c) Calculate the standard error of the y estimate using the following formula:

$$S_{y,x} = \sqrt{\left[\frac{1}{n(n-2)}\right]\left[n\sum y^2 - \left(\sum y^2\right) - \frac{\left[n\sum xy - \left(\sum x\right)\left(\sum y\right)\right]^2}{n\sum x^2 - \left(\sum x\right)^2}\right]} \quad \ldots 5(8)$$

where

$S_{y,x}$ = standard error of the y estimate

y = measured concentration

x = expected concentration

n = number of observations

The standard error for the y estimate shall be less than 2% of the full scale value (see Table 5.5.14).

5.5.14 *System component check*

Cables, recorders, signal conditioning and data processing devices can corrupt the instrument's output.

A system component check shall be conducted on a 12-monthly basis to ensure the transmitted instrument output matches that received at the data recording device. For example, if the instrument gives a 20 mA output with a CO concentration of 250 ppm, then apply a 20 mA signal to the system to confirm that 250 ppm is indicated at the data recording device.

Check that the response is within the tolerance given in Table 5.5.14. If the result is not within the tolerance, identify and rectify the cause and repeat the procedure until the response is within the tolerance.

TABLE 5.5.14

INSTRUMENT CHECK AND CALIBRATION REQUIREMENTS FOR TUNNEL CO/NO/NO_2 SYSTEMS

Parameter	Criterion	Frequency
Zero check	±2% FS	≤3-monthly**
Span check	±5% FS	≤3-monthly**
Zero calibration	±2% FS	≤12-monthly
Span calibration	±5% FS	≤12-monthly
Multipoint precision check	2% FS*	≤12-monthly
System component check	±0.2% FS	≤12-monthly
Measurement path length	±0.5%	Initial†
Flow through calibration cell length	±0.5%	Initial†
Measurement path temperature check	±1°C	≤12-monthly
Measurement path pressure check	±1 kPa	≤12-monthly

* Allowable drift for a multipoint precision check is defined by the standard error of the *y* estimate (Clause 5.5.13).

** The period between zero checks and span checks may be extended to 6 monthly once sufficient data is available to confirm the stability of instrument response.

† Recalibration and path length measurement shall be undertaken following any maintenance or changes that may affect the measurement path or calibration cell length.

5.6 Maintenance

5.6.1 *General*

Maintenance should be carried out in accordance with the frequencies specified in Table 5.6.4. Manufacturers may require additional procedures which should also be adhered to.

Where a high degree of data capture is required, back-up or replacement instruments should be available. A detailed log of all performance checks and maintenance undertaken shall be maintained and retained with the original CO, NO and NO_2 data.

5.6.2 *Window clean*

To maintain light levels, the windows/mirrors on the transmitter and receiver or transceiver and retroreflector should be regularly cleaned.

5.6.3 *Lamp change*

The lamp should be replaced periodically based on the manufacturer's recommendations.

5.6.4 *Optical alignment*

The transmitter and receiver or transceiver and retroreflector may become misaligned over time, requiring periodic realignment.

TABLE 5.6.4

ROUTINE MAINTENANCE FOR TUNNEL CO/NO/NO_2 SYSTEMS

Maintenance component	Frequency
Window clean	≤6-monthly
Lamp change	Manufacturer's instructions
Optical alignment check	≤6-monthly

5.7 Calculation and expression of results

Where relevant, results shall be expressed in accordance with statutory requirements. Instruments normally provide a readout in ppm. Where the requirement is for results in mass per unit volume, readings shall be converted using the following equation:

$$C_{\mathrm{m}} = \frac{C_{\mathrm{v}} \times MW}{22.4} \qquad \ldots 5(9)$$

where

C_{m} = concentration of pollutant in milligrams per cubic metre (expressed at 0°C and 101.3 kPa)

C_{v} = concentration of pollutant in ppm

MW = molecular weight of pollutant

NOTE: Some instruments may perform this conversion automatically. Ensure the standard conditions employed by the instrument when making this conversion are 0°C and 101.3 kPa.

5.8 Measurement uncertainty

The measurement uncertainty of this method will vary for each specific application. Factors affecting the overall uncertainty include (but are not limited to) uncertainties associated with the reference test atmosphere concentration, flow through calibration cell and measurement path lengths, allowable span and zero drifts, measurement path temperature and pressure corrections, calibration devices and recording instrumentation, and will vary from site to site. As a guide, uncertainties of 10% of reading can be achieved using this method, however, the measurement uncertainty shall be determined based on individual laboratory practices.

NOTE: A suitable method for calculating measurement uncertainty can be found in ISO/IEC 98-3.

6 TESTING PARAMETER—VISIBILITY

6.1 Scope

This clause describes a continuous, direct-reading instrumental method for determining visibility in road tunnels.

6.2 Principle

Objects become visible to an observer when light from the object is detected by the observer. A particular object is seen against its surroundings by virtue of the difference in either intensity or wavelength of the radiation emanating from it compared with that emanating from its surroundings.

Light is attenuated through scattering and absorption by both gases and particles in the atmosphere, with the result that objects viewed at a distance become less visible than when viewed close-up. A dark object appears lighter with increasing distance and a light coloured object appears darker. In either case a loss of contrast occurs between the object and its surroundings until at a sufficiently large distance the object merges into the background.

Visibility degradation in road tunnels is principally due to the light scattering properties of fine particles less than 2.5 µm in diameter, with the most efficient light scattering particles within the size range corresponding to the wavelength of visible light, 0.4 µm to 0.7 µm.

Attenuation of light passing through the atmosphere may be represented in this instance by the Beer-Lambert law:

$$I = I_o e^{-KL} \quad \ldots 6(1)$$

where

I = intensity of light at the observer

I_o = initial light intensity

L = path length of light (i.e. the object to observer distance)

K = extinction coefficient (due to absorption and scattering)

= $K_{ag} + K_{sg} + K_{ap} + K_{sp}$ where K is the extinction coefficient and the subscripts, a, s, g and p refer to absorption, scattering, gases, and particles respectively

In polluted atmospheres, such as in road tunnels, the loss of light intensity by particle scattering is the major cause of light extinction. Consequently terms other than K_{sp} are neglected.

A transmissometer is used to measure the extinction coefficient (K), the reciprocal of the distance in metres over which 63% of initial light intensity is lost by particle scattering. The extinction coefficient is dependent on particle concentration, light distribution and wavelength (λ) of the incident light. Scattering is proportional to $\lambda^{-\alpha}$ where α is typically 0.5 to 2.5 for particles, depending on the size distribution, with α increasing as the mass mean diameter of the fine particles decreases.

Transmissometers measure the amount of light transmitted through the road tunnel atmosphere over a known distance between a light source of known intensity (transmitter) and a light measurement device (receiver). Alternatively an autocollimator or retroreflector may be used with a transmitter/receiver (transceiver) to double the measurement path length.

Providing the instrument performance is within the specifications given in Table 6.3.1, alternate methods may be used within the context of this Standard.

6.3 Apparatus

6.3.1 *Instrument*

A continuous direct-reading instrument that meets or exceeds the performance specifications given in Table 6.3.1.

The instrument may be used over any range within the limits of this Standard, provided it has been calibrated in accordance with Clause 6.5.

The manufacturer's published performance specifications shall be deemed as acceptable evidence of conformance to the given requirements, if accompanied by a statement of measurement uncertainty.

TABLE 6.3.1

INSTRUMENT PERFORMANCE SPECIFICATIONS FOR TUNNEL VISIBILITY SYSTEMS

Parameter	Requirement
Range	0 to 0.015 m^{-1}
Wavelength	500 to 700 nm
Path length	≤10 m
Accuracy	±0.001 m^{-1}
Resolution	0.0001 m^{-1}
Response time: rise fall	 ≤60 s ≤60 s
Difference rise time/fall time	≤10 s
Operating temperature	−20 to 50°C

6.3.2 *Reference path length measurement device*

A reference distance measuring device, traceable to national standards with a measurement uncertainty of ±0.5% U_{95} is required to make an accurate determination of the measurement path length. The device shall be checked over a path length of at least the instrument measurement path length.

Laboratories performing the tests outlined in this clause shall meet the requirements of AS ISO/IEC 17025.

NOTE: Accreditation bodies who are signatories to the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) for testing laboratories are able to offer accreditation against the requirements of AS ISO/IEC 17025. A listing of ILAC signatories is available from the ILAC website (www.ilac.org). In Australia and New Zealand, the National Association of Testing Authorities (NATA) and International Accreditation New Zealand (IANZ) are signatories to the ILAC MRA.

6.4 Procedure

The procedure shall be as follows:

(a) Ensure that the transmissometer is installed such that the optical path is unimpeded by tunnel equipment or other obstructions, whilst allowing ease of access for instrument maintenance and calibration. Shorter optical paths will improve light levels, however, they can result in higher detection limits and greater measurement uncertainty.

(b) The transmissometer shall be firmly mounted on materials with low thermal expansion to minimize alteration of the light beam alignment due to ambient temperature variations.

(c) Ensure that the transmissometer is not subject to excessive vibration and that the electricity supply is stable.

(d) For equipment installed at the tunnel portals or entry/exit ramps, ensure that the optical path orientation is such that it avoids strong scattered radiation (e.g. sunlight) directly entering the transceiver or receiver unit.

(e) Check the horizontal and vertical alignments of the units.

(f) Accurately measure the distance between the transceiver and retroreflector or the transmitter and receiver.

(g) Set up the instrument and carry out initial checks in accordance with the manufacturer's instructions (e.g. configuring and scaling of analogue outputs, setting of alarm values and level of damping) and the requirements of Clause 6.5.

(h) Take measurements in accordance with the manufacturer's instructions and ensure that the values obtained relate to the correct date and time.

NOTES:

1 Conducting the optical path alignment under low light or dark conditions may assist when adjusting the focus.

2 Where possible, optical path alignment and focusing should be performed under temperature conditions that approximate the mid-range of the expected minimum and maximum temperature range at the monitoring location.

3 During tunnel wall washing or deluge testing for the fire system, caps should be installed on the instrument dust protection tubes to prevent water ingress, where applicable.

6.5 Instrument checks and calibrations

6.5.1 *General*

Calibration of an instrument establishes the quantitative relationship between visibility and the instrument's response.

Instrument checks and calibrations shall be carried out in accordance with the frequencies specified in Table 6.5.7.

In addition, instrument checks and calibrations shall be carried out—

(a) prior to decommissioning or physical relocation of the instrument, if operational;

(b) following physical relocation;

(c) after any repairs that might affect the instrument's response; and

(d) upon any indication of an instrument malfunction or change in response that may cause the instrument to drift by more than the values given in Table 6.5.7.

Instrument calibration is conducted using a test cell(s) or neutral density filter(s) attached to the transceiver or receiver unit, with the cell or filter providing a rated value for the measured extinction coefficient.

Calibrations are normally conducted during tunnel closures, with the background extinction coefficient assumed to be low. However, this may not be the case if there are idling vehicles or fuelled equipment operating nearby.

Consequently, for instruments where the test cell or neutral density filter does not occupy the entire measurement path, the background extinction coefficient immediately before and after the period of calibration shall be recorded.

Transmissometers should be tested during periods when particle concentrations are relatively low and steady.

6.5.2 *Measurement path length*

The measurement path length shall be determined upon installation (Table 6.5.7) using a reference measurement device as described in Clause 6.3.2. The measurement path length is normally defined as the distance between the face of the transceiver or transmitter unit and the face of the retroreflector or receiver unit, however, this should be confirmed with the manufacturer.

A check of the measurement path length shall also be conducted whenever an instrument is reinstalled following maintenance or repair.

6.5.3 *Zero check*

Instrument zero checks are normally not possible in the field, however the instrument 'zero' readings under no traffic conditions shall be recorded during instrument span checks (see Clause 6.5.4).

Zero checks shall be conducted under late night/early morning conditions when ambient particle concentrations are normally low.

An alternate method for the zero check is to plot the instrument readings over an extended time period (≥1 month) to obtain an estimate of the instrument zero reading.

6.5.4 *Span check*

The span check procedure shall be as follows:

(a) Following installation, set up the instrument in accordance with the manufacturer's instructions and allow a sufficient stabilization period. A full-scale value shall be selected to cover the range of expected values for the road tunnel.

(b) Record the instrument zero reading.

(c) Install the test cell(s) or neutral density filter(s).

(d) Begin measurements, and, after allowing sufficient time for the instrument response to stabilize, record the reading.

(e) Remove the test cell(s) or neutral density filter(s) and record the instrument zero reading, to ensure that there is no significant change in the zero reading.

(f) Calculate the zero or span drift as follows—

$$\%Drift = \frac{\left(K_{\mathrm{r}} - K_{\mathrm{e}}\right)}{K_{\mathrm{fs}}} \times 100 \qquad \text{. . . 6(2)}$$

where

K_{r} = recorded zero or span extinction coefficient

K_{e} = expected zero or span extinction coefficient

K_{fs} = full scale extinction coefficient value

6.5.5 *Zero and span calibration*

If the instrument zero or span drift exceeds the values given in Table 6.5.7, or twelve months has passed since the previous calibration, whichever occurs first, the instrument response shall be adjusted if necessary and the final readings recorded.

6.5.6 *Multipoint precision check*

A multipoint precision check shall only be performed immediately after a zero check/calibration and span calibration as described in Clauses 6.5.3 and 6.5.4. The procedure shall be as follows:

(a) Install at least three non-zero test cells or neutral density filters corresponding to visibilities approximately equally spaced over the measurement range (e.g. 25%, 50% and 75%). After allowing sufficient time for the instrument response to stabilize, record the measured visibility for each test cell or neutral density filter and zero.

(b) Calculate the standard error of the *y* estimate using the following formula:

$$S_{\mathrm{y,x}} = \sqrt{\left[\frac{1}{n\left(n-2\right)}\right]\left[n\sum y^2 - \left(\sum y^2\right) - \frac{\left[n\sum xy - \left(\sum x\right)\left(\sum y\right)\right]^2}{n\sum x^2 - \left(\sum x\right)^2}\right]} \qquad \text{. . . 6(3)}$$

where

$S_{y,x}$ = standard error of the y estimate

y = measured visibility

x = expected visibility

n = number of observations

The standard error for the y estimate shall be less than 2% of the full scale value (see Table 6.5.7).

6.5.7 *System component check*

Cables, recorders, signal conditioning and data processing devices can corrupt the sensor's output.

A system component check shall be conducted on a 12-monthly basis to ensure the transmitted sensor output matches that received at the data recording device. For example, if the instrument gives a 20 mA output with a visibility of 0.015 m^{-1}, then apply a 20 mA signal to the system to confirm that 0.015 m^{-1} is indicated at the data recording device.

Check that the final signal response is within the tolerance given in Table 6.5.7. If the response is not within the tolerance, identify and rectify the cause and repeat the procedure until the response is within the specified tolerance.

TABLE 6.5.7

INSTRUMENT CHECK AND CALIBRATION REQUIREMENTS FOR TUNNEL VISIBILITY SYSTEMS

Parameter	Criterion	Frequency
Zero check	±2% FS	≤3-monthly*
Span check	±5% FS	≤3-monthly*
Zero calibration	±2% FS	≤12-monthly
Span calibration	±5% FS	≤12-monthly
Multipoint precision check	2% FS**	≤12-monthly
System component check	±0.2% FS	≤12-monthly
Measurement path length	Not applicable	Initial†

* The period between zero checks and span checks may be extended to 6 monthly once sufficient data is available to confirm the stability of instrument response.

** Allowable drift for a multipoint precision check is defined by the standard error of the y estimate (Clause 6.5.6).

† Recalibration shall be undertaken following any maintenance or changes that may affect the measurement path or cell length.

6.6 Maintenance

6.6.1 *General*

Maintenance frequencies should be as specified in Table 6.6.4. Manufacturers may require additional procedures (e.g. replacement of activated carbon sachets and drying agent cartridges) which should also be adhered to.

Where a high degree of data capture is required, back-up or replacement instruments should be available. A detailed log of all performance checks and maintenance undertaken shall be maintained and retained with the original visibility data.

6.6.2 *Window clean*

To maintain light levels, the windows/mirrors on the transmitter and receiver or transceiver and retroreflector should be regularly cleaned at an interval not exceeding three months.

6.6.3 *Lamp change*

The lamp should be replaced periodically according to the manufacturer's instructions.

6.6.4 *Optical alignment*

The transmitter and receiver or transceiver and retroreflector may become misaligned over time, requiring periodic realignment.

TABLE 6.6.4

ROUTINE MAINTENANCE FOR TUNNEL VISIBILITY SYSTEMS

Maintenance component	Frequency
Window clean	≤3 months
Lamp change	Manufacturer's instructions
Optical alignment check	≤6 months

6.7 Calculation and expression of results

Results shall be expressed as K, the extinction coefficient (reported in units of m^{-1}), or meteorological optical range (MOR or local visual distance) or opacity. Visibility data shall not be expressed as an equivalent mass per volume.

The relationships between the various visibility units are as follows:

$$\text{MOR} = D/K (\text{m}) \quad \ldots 6(4)$$

where

D (constant) = ranges from 2.5 to 3.9, but is typically assigned a value of 3.0

$$\text{Opacity} = 100(1\text{-}e^{-KL}) (\%) \quad \ldots 6(5)$$

6.8 Measurement uncertainty

The measurement uncertainty of this method will vary for each specific application. Factors affecting the overall uncertainty include (but are not limited to) uncertainties associated with the instrument wavelength, test cell(s), neutral density filter(s) and allowable span and zero drifts and instrumentation varying from site to site. The measurement uncertainty shall be determined based on individual laboratory practices.

NOTE: A suitable method for calculating measurement uncertainty can be found in ISO/IEC Guide 98-3.

7 QUALITY ASSURANCE AND CONTROL

7.1 General

Quality assurance measures and performance criteria are summarized in Clauses 7.2 to 7.4.

7.2 Instrument log

A log of important events for each instrument used to measure air velocity and flow direction or air quality in road tunnels shall be kept. Although the precise nature of this record may vary (onsite/offsite, electronic/hand written, etc.) the concept of the log is an important part of the quality control of the instrument readings. The log shall make reference to any significant item/event that may affect the instrument's readings, including the following:

(a) The date, start/end time and initials of the person(s) that has accessed the instrument.

(b) A brief description of the condition of the equipment and any matters that could affect the data (e.g. an idling truck located near the instrument may cause high values).

(c) A description of the work accomplished at the site (e.g. calibrated or repaired the instrument).

(d) Detailed information about the instrument performance that may be needed for repairs or troubleshooting.

(e) Any instrumentation changes.

(f) Instrument check and calibration results.

When implemented, the log provides vital information for troubleshooting and fault finding. It is also a valuable tool when conducting data validation.

7.3 Data acquisition and transfer

The integrity of data recorded by the data capture system shall be checked annually. The integrity of the data transfer process shall also be checked annually.

If an external data storage medium is used in conjunction with a road tunnel monitoring system (e.g. an external data logger), involving the conversion of electrical (e.g. voltage) to digital signals then this shall be calibrated annually. This is to ensure that measurements stored on the external system are within ±0.2% of the operational full scale (FS) ranges of the various instruments.

7.4 Data validation

Data collected in accordance with this Standard shall be validated prior to its use. The data validation process shall consist of a review of the data by trained personnel using data screening criteria to identify possible incorrect values (e.g. data collected during instrument check, calibration or maintenance procedures mixed with sample data). This process should be conducted on a regular basis to assist in the early detection of anomalies to avoid the invalidation of large quantities of data. The screening process is usually based on historical data or realistically expected values. If the data does not fall within the screening criteria, the validity of the data shall be investigated. Relationships between different variables are considered when evaluating data since other parameters may either confirm or deny recorded events. Data review is an ongoing process that includes—

(a) reviewing instrument check and calibration data, recorded data and any status flags that could affect data; and

(b) reviewing all checks, calibrations, instrument notes, maintenance sheets and instrument status logs.

When validating the data, the underlying assumption shall be that all data is considered valid unless evidence or sound scientific principles can be given to support its invalidation. Copies of original (unvalidated) data sets shall be kept for audit purposes in case any aspect of the validation process is brought into question.

When instrument check tolerances for air velocity (Table 4.5.6) or span and zero check and calibration requirements for CO, NO and NO_2 (Table 5.5.14) and visibility (Table 6.5.7) are exceeded, measurements shall be invalidated back to the most recent point in time where such measurements are known to be valid. Usually this point is the previous check or calibration, unless some other point in time can be identified and related to the probable cause of the excessive drift (such as a power failure or instrument malfunction). In addition, data following an instrument malfunction or period of non-operation shall be regarded as invalid until the next subsequent check or calibration, unless unadjusted zero and span readings at that check or calibration can support its validity.

8 TEST REPORT

The following information shall be reported:

(a) Reference to this Standard, i.e. AS/NZS 3580.18.

(b) The reporting organisation.

(c) Values for each parameter measured, as follows:

(i) Air velocity in units of metres per second and flow direction (with or against traffic flow) or any other unit that complies with the International System of Units (SI).

(ii) The concentration of any or all of CO, NO or NO_2 in one or more of the following units: ppm (by volume), milligrams per cubic metre (expressed at 0°C and 101.3 kPa) (see Clause 5.7) or any other unit that complies with the International System of Units (SI).

(iii) Visibility expressed as extinction coefficient in units of inverse metres (m^{-1}) (see Clause 6.7) or any other unit that complies with the International System of Units (SI).

(d) The range and the lower detectable limit of the instrument(s).

(e) The dates, time (expressed as local or standard time) and monitoring period.

NOTE: Consideration should be given to the averaging times and date/time conventions used. Users of this Standard should ensure that these parameters are considered when applying the Standard. An example of a commonly used convention is the National Environment Protection (Ambient Air Quality) Measure, Technical Paper No. 5, Data Collection and Handling.

(f) Instrument(s) location—all relevant details, including a tunnel coordinate reference.

(g) The type of instrument(s).

(h) Any non-conformances with this Standard.

(i) The uncertainty associated with the measurement along with the confidence interval and coverage factor.

(j) Any other relevant data.

Additional relevant information that may be reported includes the following:

(i) Mean values (e.g. 15 minutes, 2-hourly or 8-hourly averages).

(ii) Maximum values.

(iii) Times per day, month or year that certain values are exceeded.

(iv) Frequency distributions (e.g. based on 15 minutes, 2-hourly or 8-hourly averages).

NOTES

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The following are represented on Committee EV-007:

Australian Aluminium Council
Australian Industry Group
Clean Air Society of Australia and New Zealand
CSIRO
Department of Environment Regulation, WA
Department of Science, Information Technology and Innovation, Qld
Environment Canterbury, New Zealand
Environment Protection Authority, Vic.
Ministry for the Environment, New Zealand
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