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Stationary source emissions — Automated monitoring of mass concentrations of particles — Performance characteristics, test methods and specifications

Émissions de sources fixes — Contrôle automatique des concentrations en masse de particules — Caractéritisques de fonctionnement, modes opératoires d'essai et spécifications

Reference number
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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

International Standard ISO 10155 was prepared by Technical Committee ISO/TC 146, *Air quality*, Subcommittee SC 1, *Stationary source emissions*.

Annex A forms an integral part of this International Standard. Annexes B, C and D are for information only.

Stationary source emissions — Automated monitoring of mass concentrations of particles — Performance characteristics, test methods and specifications

1 Scope

This International Standard specifies conditions and criteria for the automated monitoring of the mass concentration of particulate matter in stationary source gas streams. This includes performance characteristics and test procedures.

This International Standard provides the field evaluation test program and its application to automated monitoring systems. Its approach is general and not limited to a specific measurement principle or instrument system. The scope includes system operation characteristics, calibration, test procedures and data treatment.

This International Standard is applicable only on a site-specific basis by direct correlation with the manual testing method in ISO 9096. If site conditions change (i.e. change in emission controls, change in fuel type), the calibration needs to be repeated. The mass concentration range of application is only confined to those automated methods that can meet the calibration specifications. Consequently, the actual range will vary according to the measurement technique of the automated method.

Changes in the physical properties (i.e. size, shape, colour, etc.) and chemical composition of the particulate matter may exist, to the extent that the integrity of the calibration cannot be maintained for the measurement system used. In such instances this technique ceases to be applicable. Reported and suspected limitations of various measurement methods need to be evaluated on a site-by-site basis.

2 Normative references

The following standards contain provisions which, through reference in this text, constitute provisions of this International Standard. At the time of publication, the editions indicated were valid. All standards are subject to revision, and parties to agreements based on this International Standard are encouraged to investigate the possibility of applying the most recent editions of the standards indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

ISO 4225:1994, *Air quality — General aspects — Vocabulary.*

ISO 6879:1983, *Air quality — Performance characteristics and related concepts for air quality measuring methods.*

ISO 7504:1984, *Gas analysis — Vocabulary.*

ISO 9096:1992, *Stationary source emissions — Determination of concentration and mass flow rate of particulate material in gas-carrying ducts — Manual gravimetric method.*

ISO 9169:1994, *Air quality — Determination of performance characteristics of measurement methods.*

3 Definitions

For the purposes of this International Standard, the following definitions apply.

3.1 monitoring

(1) In the wide sense of the term, repeated measurement to follow changes over a period of time.

(2) In the restricted sense of the term, regular measurement of pollutant levels in relation to some standard or in order to assess the effectiveness of the system of regulation and control. [ISO 4225]

3.2 analyser: An assembly comprising:

a) lines permitting the introduction and removal of the gas to be analysed and/or of calibration gas;

b) a measuring cell which, from the physical or chemical properties of the components of the gas to be analysed, gives signals allowing their identification or measurement;

c) signal processing devices (amplification, recording) or, if need be, data processing devices. [ISO 7504]

3.3 System operating characteristics

3.3.1 response time: Time taken for an instrument to respond to a rapid change in value of the air quality characteristic. It can be divided into two parts. [ISO 6879]

3.3.1.1 lag time: Time taken to reach 10 % of the total change in instrument response.

3.3.1.2 rise time (fall time): Time taken to pass from 10 % to 90 % of the total change in instrument response.

3.3.2 zero instability (drift): Change in instrument reading in response to a zero sample over a stated period of unattended operation. [ISO 6879]

3.3.3 span: Difference between the instrument readings for a stated value of air quality characteristic and a zero sample. By convention, this value of air quality characteristic is selected to be 95 % of the upper limit of measurement. [ISO 6879]

3.3.4 span instability (drift): Change which takes place in instrument span over a stated period of unattended operation. [ISO 6879]

3.4 System calibration characteristics

3.4.1 calibration function: Instrument reading as a function of some measurable property of the particulate mass concentration under investigation and represented by the reference manual method (see ISO 9096) with all the interferents remaining constant.

3.4.2 linear function: A calibration function wherein the instrument reading is linear with respect to the particulate mass concentration measured by the reference manual method (see ISO 9096).

3.4.3 nonlinear function: A calibration function wherein the instrument reading is not linear with respect to the particulate mass concentration measured by the reference manual method (see ISO 9096). Nonlinearity may be expressed by higher order regression coefficients.

3.4.4 confidence interval: The interval with lower and upper limits within which the mean values of the regression line lie with a given level of confidence.

3.4.5 tolerance interval: The interval with lower and upper limits within which a specified percentage of the population lies with a given level of confidence.

4 Measurement system components

The system consists of the total equipment required for the determination of particulate mass concentration in a source effluent. Systems shall consist of major components as follows (see also figure D.1).

4.1 Sampling and analytical components

4.1.1 Sampling components

This is the portion of the system which samples the source effluent. The sampling is carried out by extractive or nonextractive (*in situ*) means, either on a continuous or noncontinuous basis.

4.1.1.1 Extractive sampling

This requires the transport of a volume of the gas stream outside the source environment into the instrument system for subsequent analysis. The interface includes all the elements necessary to extract, transport, and maintain the particulate mass concentration.

4.1.1.2 Nonextractive (*in situ*) sampling

This does not involve extraction and transport. Sampling consists of defining and limiting the sample volume to be analysed, which is usually done by physical methods, such as electromagnetic radiation techniques.

4.1.1.3 Continuous sampling

This is associated with both extractive and nonextractive sampling techniques and, primarily, with continuous analysis.

4.1.1.4 Sequential sampling

This is most often associated with extractive sampling techniques having discrete sampling volumes and sampling time intervals.

4.1.2 Analyser

This portion of the monitoring system shall sense the particulate quality characteristic of the gas sample and generate a detection signal output that can be correlated to mass concentration.

4.2 Data recorder

This portion of the monitoring system shall process the analyser (4.1.2) output and provide a record of the output signal in terms of particulate mass concentration.

5 Installation criteria

5.1 Sampling location

The place at which the sample is taken for the automated measurement of the mass concentration of particulate matter emissions in stationary source gas streams shall be designated as the sampling location. This is the location where there is no interference between the reference method (ISO 9096) and automated method. This arrangement ensures that both methods are operating on gases with the same characteristics. Openings shall be provided in the gas flow duct for the sampling probes of the reference measurement method (see ISO 9096) so that reference measurements can be made in the same vicinity as the continuous measurements.

The sampling location may require one of a number of sampling configurations which can vary in complexity depending upon the design of the measurement system and the spatial and time dependent distribution of the mass concentration of particulate matter in the cross-section of the gas stream. The objective ideally shall be to obtain, with the simplest configuration, a sample representative of the cross-sectional mass concentration of the particulate matter.

The sampling location shall be defined in order to minimize spatial and time dependent distribution of the mean concentration of particulate matter in the cross-section of the gas stream. The representativeness of the sampling procedure and location is verified by compliance with the calibration specifications (see 6.5 and 7.3.4).

5.2 Environmental conditions

A number of conditions shall be considered in the installation of emission measurement systems both with respect to the sampling environment and the sampling technique. In particular, the following conditions are to be met.

a) Compliance with the operational temperatures specified by the manufacturer.

b) Provision for adequate protection against weather influences.

c) Avoidance of exposure to corrosive and damaging gases on the measurement system.

d) Avoidance of exposure to interfering electric and magnetic fields in the immediate vicinity.

e) Avoidance of locations where vibration affects the instrument's stability.

Working platforms for conducting reference measurements and for checking and maintaining the continuous measurement systems shall be required to provide an ongoing and reliable measurement operation. Access to these platforms, to the measurement systems, and to the sampling locations are to be easily and safely achievable.

5.2.1 In-stack

Nonextractive techniques usually involve electro-optical measurement methods which require that special precautions be taken against stray light.

5.2.2 Out-of-stack

Extractive techniques impose a number of precautions. These include the following:

a) keeping sampling trains as short as possible to avoid long response times, chemical conversions, and particulate matter entrainment in sampling lines;

b) maintaining isokinetic sampling;

c) using heated sampling lines to avoid condensation and loss of particulate matter.

6 System performance specifications

The following specifications shall be met when measurements are made according to clause 7.

6.1 Response time

The response shall be within the manual reference sampling time.

6.2 Zero drift

The zero drift shall be within ± 2 % of the full working range when determining system calibration and within a period of one month of unattended operation.

For automated zero adjustments, the accumulated corrections shall be within 6 % of the working range.

6.3 Span

The span shall be between two and three times the allowed emission concentration.

6.4 Span drift

The span drift shall be within ± 2 % of the full working range when determining system calibration and within a period of one month of unattended operation.

For automated span adjustments, the accumulated corrections shall be within 6 % of the working range.

6.5 Calibration specifications

The following specifications shall be met.

6.5.1 The correlation coefficient shall be $\geqslant 0{,}95$.

6.5.2 The confidence interval (95 %) shall be within ± 10 % of a site emission standard for a particulate mass concentration.

6.5.3 The tolerance interval shall have 95 % confidence that 75 % of all possible values are within ± 25 % of a given emission standard.

6.5.4 In cases where any of these specifications are not met, the system performance shall be examined with regard to the following:

a) testing procedures for the manual reference method;

b) sampling location;

c) sampling strategy;

d) applicability of analytical principle;

e) change in plant operating conditions;

f) change in particulate matter composition;

g) number or level of calibration data.

7 Test procedures to validate specifications

7.1 Response time test

7.1.1 For automated monitoring/nonextractive sampling

Perform this test prior to the installation of the system on the stack. It may be performed at the monitoring site. Set up the measurement system and operate as specified by the manufacturer's written instructions for the monitor path length to be used at the installation. The analyser is spanned as specified in 7.2.1.1 and 7.3.3.

Response test. Insert a simulated reference particulate mass standard in the mass monitor five times, and record the time required for the system to respond to 95 % of the final zero and high-range particulate mass values. (See Form C-1 in annex C.)

7.1.2 For automated monitoring/extractive sampling

Perform this test on the installed system to include the impact of the sampling interface and, if applicable, the sampling time interval on the measurement.

7.2 Zero and span setting in the field

7.2.1 For automated monitoring/nonextractive sampling

Install the automated monitoring system on the facility to be tested and perform the following adjustments and measurements.

7.2.1.1 Preliminary settings

As soon as possible after installation and as often as the manufacturer recommends, perform zero and span adjustments as applicable.

Zero setting. After a clean stack condition has been determined by a steady, zero particulate mass concentration condition, perform the zero setting. If clean stack conditions cannot be achieved for a zero setting, obtain the zero setting by simulating clean stack conditions.

Span. Span the continuous monitoring system at the particulate mass concentration that is specified.

7.2.1.2 Final settings

After the preliminary settings have been completed and the affected facility has been started and has reached normal operating temperature, recheck the recommended adjustments.

7.2.1.3 Zero and span drift measurements

At the end of the specified period of operation, measure the change between the zero and span settings obtained at the end of the period and the initial settings. These values are a measure of the zero and span drift.

7.2.2 For automated/extractive sampling

Perform this test on the installed system to include the impact of the sampling interface on the measurement.

7.3 System calibration

Monitoring techniques are viable when the mass concentration of particles can be correlated with a measurable characteristic of the particles. Establish the correlation by a calibration function (see annex A) that is treated statistically for verification and valid utilization of the technique. The calibration function can be either linear or nonlinear.

Once the calibration function is identified by providing the best fit and is verified by appropriate statistical treatment, then the system is said to be in calibration and producing valid data. Statistical treatment of data associated with linear and nonlinear functions is presented in annex A.

7.3.1 Initial operating period

After completing the final settings, operate the system for an initial 168 h period in a normal mode prior to the operational test period.

7.3.2 Operational test period

After completing the initial operating period, proceed with the *in situ* calibration.

7.3.3 Zero and span drift check

Check the zero and span according to the manufacturer's instructions. Use minimum procedures preceding a check of the system, and include a procedure for producing a simulated zero condition and a simulated upscale (span) particulate mass concentration as monitored by the system. Automatic corrections made by the measurement system without intervention by the operator are allowable at any time. Determine the zero and span drift each day for seven consecutive days. Record the magnitude of any automatic or manual zero or span drift adjustments (see Form C-2 in annex C).

For automated zero and span checks, an alarm or recording shall indicate when accumulated corrections exceed the specified limits.

7.3.4 Calibration function

Carry out measurements within normal processing operations of at least three levels of particulate mass concentrations according to ISO 9096, at a location consistent with the application of this method, to determine the total particulate emissions from the source. Repeat the measurements at three concentration levels to provide a total of at least nine measurements. Simultaneously, conduct measurements with the monitoring system at the selected monitoring location. The concentrations should range from low to high and include intermediate values. These are preferably obtained by varying load conditions during the process as much as the process permits within normal operation. The alternative, if necessary, is to vary emission levels by appropriate adjustment of the particulate control system if possible.

Tabulate the data from ISO 9096 and from the monitoring system on a data sheet as demonstrated in Form C-3 in annex C. Monitoring system data shall be integrated over the corresponding periods of the manual reference tests.

Annex A
(normative)

Statistical treatment of data

A.1 Linear calibration function (regression line).

The data in table D.1 are used to plot the calibration curve. The instrument reading is plotted on the abscissa and the mass concentration is plotted on the ordinate. A line of regression is drawn through the plotted points by the method of least squares.

$\hat{y}$ is the predicted value of mass concentration based on the calibration curve, in contrast to the empirical value, y, based on the standard reference method.

The general form of the regression equation is

$$\hat{y} = b_0 + b_1 (x) \qquad \text{... (A.1)}$$

where

$$b_0 = \bar{y} - b_1 \bar{x} \qquad \text{... (A.2)}$$

and

$$b_1 = \frac{\sum (x_i - \bar{x}) (y_i - \bar{y})}{\sum (x_i - \bar{x})^2} \qquad \text{... (A.3)}$$

The mean value of the data set is given by

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

and

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i \qquad \text{... (A.4)}$$

where

x_i, y_i	are the absolute values of the individual measurements;
Σx_i, Σy_i	are the sums of the individual values;
$\bar{x}$, $\bar{y}$	are the mean values;
n	is the number of data points.

The calculations are such that:

x is the empirical value of the detection parameter (see Form C-3 in annex C);

y is the empirical value of the mass concentration according to ISO 9096;

$\hat{y}$ is the predicted mass concentration (see Form C-3).

A.2 Determination of the correlation coefficient for the linear regression.

The general form of the correlation coefficient (r) is given by:

$$r = \frac{\sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y})}{\left[\sum_{i=1}^{n} (x_i - \bar{x})^2\right]^{\frac{1}{2}} \left[\sum_{i=1}^{n} (y_i - \bar{y})^2\right]^{\frac{1}{2}}} \qquad \text{. . . (A.5)}$$

The correlation coefficient can also be expressed in terms of b_1 from equation (A.3) as follows:

$$r = \frac{b_1 \left[\sum_{i=1}^{n} (x_i - \bar{x})^2\right]^{\frac{1}{2}}}{\left[\sum_{i=1}^{n} (y_i - \bar{y})^2\right]^{\frac{1}{2}}} \qquad \text{. . . (A.6)}$$

A.3 Determination of the confidence interval for the linear regression.

The confidence interval with upper and lower limits for the mean value at point X is calculated as follows:

$$y = \hat{y} \pm t_{\frac{\alpha}{2}, n-2} \times S \left[\frac{1}{n} + \frac{(x - \bar{x})^2}{S_{xx}}\right]^{\frac{1}{2}} \qquad \text{. . . (A.7)}$$

where

$t_{\frac{\alpha}{2}, n-2}$ is the t-distribution value in table A.1.

$$S_{xx} = \sum_{i=1}^{n} (x_i - \bar{x})^2 = \sum x_i^2 - n\,\bar{x}^2 \qquad \text{. . . (A.8)}$$

$$S_{yy} = \sum_{i=1}^{n} (y_i - \bar{y})^2 = \sum y_i^2 - n\,\bar{y}^2 \qquad \text{. . . (A.9)}$$

$$S_{xy} = \sum_{i=1}^{n} (x_i - \bar{x})(y_i - \bar{y}) = \sum x_i y_i - n\,\bar{x}\,\bar{y} \qquad \text{. . . (A.10)}$$

$$S = \frac{S_{yy}}{n-2} \left(1 - \frac{S_{xy}^2}{S_{xx} S_{yy}}\right)^{\frac{1}{2}} \qquad \text{. . . (A.11)}$$

From equation (A.4)

$$\bar{x} = \frac{1}{n} \sum_{i=1}^{n} x_i$$

From equation (A.4)

$$\bar{y} = \frac{1}{n} \sum_{i=1}^{n} y_i$$

A.4 Determination of the tolerance range for the linear regression.

The tolerance range with upper and lower limits for 75 % of the population at point X is calculated as follows:

$$y = \hat{y} \pm ks \qquad \text{. . . (A.12)}$$

where

$k = U_{n'} \times v_{n-2,}$ and the condition $n' \geqslant 2$;

$U_{n'}$ is the tolerance factor (see table A.1);

v_{n-2} is a factor (see table A.1);

$$n' = \frac{n}{1 + \frac{n\,(x - \bar{x})^2}{S_{xx}}}$$ = Calculated size of random sample.

A.5 Quadratic calibration function (regression curve).

Nonlinearity may be expressed by higher order regression coefficients or by an exponential function. For a second-order expression, a quadratic regression is necessary. An example of a second-order expression is as follows:

$$y = b_1 x + b_2 x^2 + \varepsilon x \qquad \text{. . . (A.13)}$$

In this example, the mass concentration error is a constant percentage of the measured parameter, i.e. the error is proportional to x,

where

y is the mass concentration;

x is the measured parameter;

b_1, b_2 are constants;

ε is the normally distributed error term with zero mean and constant variance, i.e. a constant: when combined with x (i.e., εx), this represents a constant percentage error.

Equation (A.13) reduces to

$$\frac{\hat{y}}{x} = b_1 + b_2 x + \varepsilon \qquad \text{. . . (A.14)}$$

Thus, the quadratic regression can be reduced to a linear regression: y/x upon x.

A calculator which can perform linear regressions may be used to regress y/x upon x, obtaining b_1 as the intercept, b_2 as the slope, and R (see "confidence intervals" in A.7) as the residual sum of squares.

Alternatively, calculate

$$A = \sum x_i$$

$$B = \sum y_i$$

$$C = \sum y_i / x_i$$

$$D = \sum x_i^2$$

The values of b_1 and b_2 are then given by

$$b_1 = \frac{CD - AB}{nD - A^2} \qquad \text{. . . (A.15)}$$

$$b_2 = \frac{nB - AC}{nD - A^2} \qquad \text{. . . (A.16)}$$

A.6 Determination of the correlation coefficient for the quadratic regression.

The expression for the correlation coefficient (r) is as follows:

$$r = (1 - R/E)^{\frac{1}{2}} \qquad \text{. . . (A.17)}$$

where

$$R = \sum y_i^2 / x_i^2 - \frac{C^2 D + nB^2 - 2ABC}{nD - A^2} \qquad \text{. . . (A.18)}$$

A, B, C and D are as given in A.5;

and

$$E = \sum y_i^2 / x_i^2 \qquad \text{. . . (A.19)}$$

A.7 Determination of the confidence intervals for the quadratic regression.

A two-sided confidence interval, 100 (1 − α) %, for x, the predicted average value, is given as follows:

$$y = b_1 x + b_2 x^2 \pm t_{\frac{\alpha}{2}, n-2} \times \left(\frac{VR}{n-2} \right)^{\frac{1}{2}} \qquad \text{. . . (A.20)}$$

and a two-sided tolerance interval, 100 (1 − α) %, for any single measurement, is given as follows:

$$\hat{y} = b_1 x + b_2 x^2 \pm t_{\frac{\alpha}{2}, n-2} \times \left[\frac{(V + x^2)R}{n-2} \right]^{\frac{1}{2}} \qquad \text{. . . (A.21)}$$

where

R is as given in equation A.18;

and

$$V = \frac{Dx^2 - 2Ax^3 + nx^4}{nD - A^2} \qquad \text{. . . (A.22)}$$

A.8 Determination of the tolerance range for the quadratic regression.

The tolerance range with upper and lower limits for a specified population at point X is calculated as follows:

$$y = \hat{y} \pm kx \left[\frac{R}{n-2} \right]^{\frac{1}{2}} \qquad \text{. . . (A.23)}$$

Table A.1 — *t*-Distribution and tolerance factors

$n-2$	t_{n-2}	ν_{n-2}	n'	$U_{n'}$ (75)
7	2,365	1,797 2	7	1,233
8	2,306	1,711 0	8	1,223
9	2,262	1,645 2	9	1,214
10	2,228	1,593 1	10	1,208
11	2,201	1,550 6	11	1,203
12	2,179	1,515 3	12	1,199
13	2,160	1,485 4	13	1,195
14	2,145	1,459 7	14	1,192
15	2,131	1,473 3	15	1,189
16	2,120	1,417 6	16	1,187
17	2,110	1,400 1	17	1,185
18	2,101	1,384 5	18	1,183
19	2,093	1,370 4	19	1,181
20	2,086	1,357 6	20	1,179

Annex B
(informative)

Possible sampling configurations

Possible sampling configurations for which representative measurements may be made are as follows.

B.1 Sampling point

Sampling is conducted at a designated point in the gas stream. This applies to extractive sampling with a probe and nonextractive sampling in which the analytical volume is confined to a point in the cross-section.

B.2 Line sampling

Sampling is done simultaneously at a number of points along a line. These points constitute a line in the cross-section of the sampling plane. This type of sampling is mainly achieved by using nonextractive long-path optical techniques.

B.3 Sampling in a plane

The line sampling technique is applied to more than one line in the plane of the cross-section. At least two lines at an angle to each other are required to approximate a cross-section plane. If the particulate distribution is significantly nonuniform, more sampling lines in the plane are necessary to achieve more exact representation of the plane's particulate content. Both extractive and nonextractive techniques are potentially applicable. However, the nonextractive technique tends to be more feasible.

Annex C
(informative)

Test data forms

Form C-1 — System Response Time Test Data

Date of Test: .... Location of Test: ....

Particulate Mass Standard: .... % Full Scale

Analyser Span Setting: .... % Full Scale

Upscale	1:	.... seconds	Downscale	1:	.... seconds
	2:	.... seconds		2:	.... seconds
	3:	.... seconds		3:	.... seconds
	4:	.... seconds		4:	.... seconds
	5:	.... seconds		5:	.... seconds

Mean response time: .... seconds

Form C-2 — Zero and Span Drift Data

Zero Setting: .... Date of Test: ....

Span Setting: ....

Date and time	Zero Reading (before adjustment)	Zero Drift	Span Reading (after zero adjustment but before span adjustment)	Span Drift

Zero Drift = Mean Zero Drift*): .... + C.I. (Zero) .... = ...

Span Drift = Mean Span Drift*): .... + C.I. (Span) .... = ...

*) Absolute Value

Form C-3 — Field Test Data for Calibration Function

Run No.	Data and Time Period	(x) Value of Detection Parameter†)	(y) Standard Reference Methods (mg/m)^3
1	....	....	....
2	....	....	....
3	....	....	....
4	....	....	....
5	....	....	....
6	....	....	....
7	....	....	....
8	....	....	....
9	....	....	....

†) Monitor's continuous data averaged over concurrent sampling period of Standard Reference Method (ISO 9096).

Annex D
(informative)

Example of calculations

D.1 Calibration function

Field test data for a continuous nonextractive monitoring system using light extinction as the detection parameter are given in table D.1.

Table D.1

Run No.	Reference method (x) mg/m^3	Extinction (y)
1	64	0,3060e^{-1}
2	55	0,3060e^{-1}
3	53	0,3080e^{-1}
4	49	0,2900e^{-1}
5	17	0,1100e^{-1}
6	24	0,1360e^{-1}
7	25	0,1440e^{-1}
8	39	0,2030e^{-1}
9	16	0,9900e^{-2}

From equation A.4: $x = 0{,}021\ 13$.

From equation A.1, the line regression is $y = -\ 2{,}943 + 1\ 937x$ where $-\ 2{,}943$ is the y-intercept and 1 937 is the slope of the curve (sensitivity).

This calibration is shown in figure D.2.

D.2 Correlation coefficient

From equation A.6, the correlation coefficient (r) is calculated by using the data given for the calibration curve in figure D.2, and the result is

$r = 0{,}980\ 3$

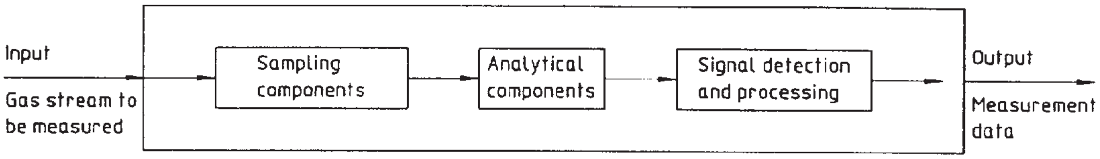
D.3 Confidence interval

From equation A.7, the confidence interval is calculated for a t-distribution with $\alpha = 0{,}05$ and $(n - 2)$ degrees of freedom. A graphical representation is shown in figure D.2. The confidence interval shows the upper and lower limits within which the mean value of the regression line lies with a 95 % level of confidence.

D.4 Tolerance interval

From equation A.11, the tolerance interval is calculated for a t-distribution with $\alpha = 0{,}05$, and $(n - 2)$ degrees of freedom. A graphical representation is shown in figure D.2. The tolerance interval shows upper and lower limits within which 75 % of the population lies with a 95 % level of confidence.

Both the confidence and tolerance intervals in figure D.2 show a divergence in the limits, as the instrument readings depart from the mean value that corresponds to about 40 mg/m^3. This suggests that this instrument measures with greater accuracy for regulatory purposes when it is calibrated with a mean value for an emission standard of about 40 mg/m^3.



Sampling configurations

- Extractive — requires interface for sample transport and/or conditioning
  - — Continuous
  - — Integrated

  } in time
  - — Point
  - — Traverse

  } in space
  - — Conditioning — physical and/or chemical
- *In situ* (nonextractive) — does not require transport or conditioning
  - — Usually continuous
  - — Point
  - — Traverse
  - — Integrated

  } in space

Analytical configurations

- Electro-optical (spectrophotometric/photometric)
- Electromagnetic
- Electrostatic
- Nuclear

Signal processing/data display configurations

- Analog — meter or recording
- Digital — recording or printout
- Continuous
- Integrated

} temporal display

Figure D.1 — Measurement system options

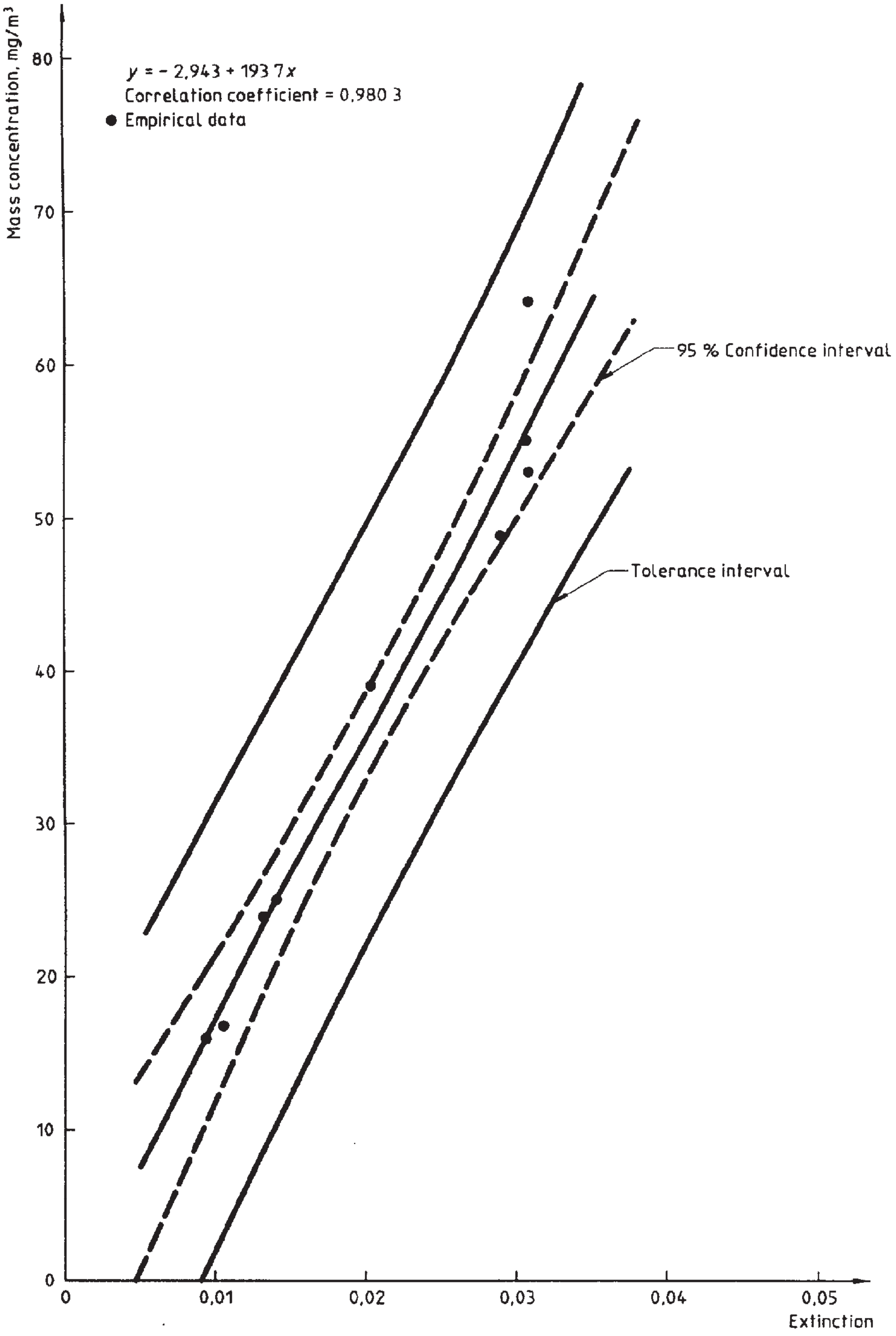


Figure D.2 — Linear calibration curve