INTERNATIONAL STANDARD

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Acoustics — *In-situ* determination of insertion loss of outdoor noise barriers of all types

Acoustique — Détermination in situ de la perte par insertion de tous types d'écrans antibruit en milieu extérieur

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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 10847 was prepared by Technical Committee ISO/TC 43, *Acoustics*, Subcommittee SC 1, *Noise*.

Acoustics — *In-situ* determination of insertion loss of outdoor noise barriers of all types

1 Scope

This International Standard specifies methods for the determination of insertion loss of outdoor noise barriers intended to shield various kinds of noise sources. It specifies detailed procedures for *in-situ* measurement of barrier insertion loss including microphone positions, source conditions and acoustic environments of the measurement sites.

This International Standard allows one to measure the insertion loss of a given noise barrier in a given site and including given meteorological conditions. It does not make it possible to compare insertion loss values of an equivalent barrier on a different site. It can be used for comparing insertion loss values of different types of barriers on a same site and under given meteorological conditions by the direct method.

This International Standard gives a method for determining insertion loss:

a) from the level difference before and after the installation of noise barriers and when this is not possible because a barrier has already been installed,

b) using an indirect method to estimate the sound pressure levels before installation of the barrier by measurement at another site which has been judged to be equivalent.

For equivalent sites, close match is required in source characteristics, microphone locations terrain profiles ground surface characteristics, surrounding artificial structures and meteorological conditions. This International Standard prescribes principles for ensuring that sufficiently equivalent conditions are maintained between "before" and "after" cases to permit certain, reliable and repeatable determination of barrier insertion loss.

This International Standard does not cover the determination of the intrinsic acoustic quantities of the barrier, for example the sound reduction index and the sound absorption coefficient. The equivalent continuous A-weighted sound pressure level, the A-weighted sound exposure level, the octave or one-third-octave band sound pressure level and/or maximum sound pressure level are used as noise descriptors.

This International Standard can be used for routine determination of barrier performance or for engineering or diagnostic evaluation. It can be used in situations where the barrier is to be installed or has already been installed.

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.

IEC 651:1979, *Sound level meters.*

IEC 804:1985, *Integrating averaging sound level meters.*

IEC 942:1988, *Sound calibrators.*

IEC 1260:1995, *Electroacoustics — Octave-band and fractional octave-band-filters.*

3 Definitions

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

3.1 sound pressure level, L_p:
Ten times the logarithm to the base 10 of the ratio of the square of the sound pressure to the square of the reference sound pressure, in decibels.

NOTE — The reference sound pressure is 20 μPa. The frequency weighting or the width of the frequency band used is to be indicated.

3.2 equivalent continuous sound pressure level, $L_{peq,T}$:
Sound pressure level, in decibels, of a continuous steady sound that, within a measurement time interval T, has the same mean-square sound pressure as a sound under consideration whose level varies with time; it is given by the following equation:

$$L_{peq,T} = 10 \lg \left[\frac{1}{T} \int_{t_1}^{t_2} \frac{p^2(t)}{p_0^2} dt \right] \text{ dB}$$

where

t_1 and t_2 are times corresponding to the beginning and end of the measurement time interval;

$T = t_2 - t_1$;

$p(t)$ is an instantaneous sound pressure;

p_0 is the reference sound pressure (20 μPa).

NOTE — The frequency weighting or the width of the frequency band used is to be indicated; for example, equivalent continuous A-weighted sound pressure level $L_{pAeq,T}$, equivalent continuous octave-band sound pressure level, etc.

3.3 A-weighted sound exposure level, L_{AE}:
The sound exposure level, in decibels, of a discrete noise event is given by the equation

$$L_{AE} = 10 \lg \left[\frac{1}{T_0} \int_{t_1}^{t_2} \frac{p_A^2(t)}{p_0^2} dt \right] \text{ dB}$$

where

$p_A(t)$ is an instantaneous A-weighted sound pressure;

$(t_2 - t_1)$ is a stated time interval long enough to encompass all significant sound of a stated event;

p_0 is the reference sound pressure (20 μPa);

T_0 is the reference duration (1 s).

3.4 maximum sound pressure level, L_{pmax}:
The maximum A-weighted, or octave or one-third-octave-band sound pressure level, in decibels, determined with time weighting S (slow) or F (fast) according to IEC 651.

NOTE — The time weighting used is recorded and reported.

3.5 insertion loss of barriers, D_{IL}:
Difference, in decibels, in sound pressure levels at a specified receiver position before and after the installation of a barrier provided that the noise source, terrain profiles, interfering obstructions and reflecting surfaces, if any, ground and meteorological conditions have not changed.

NOTE — The frequency weighting or the width of frequency band and the time weighting used are to be indicated; for example, insertion loss of barrier corresponding to equivalent continuous A-weighted sound pressure levels (D_{ILAeq}).

3.6 background noise level:
Sound pressure level, in decibels, at a reference position or receiver position without any noise source in operation.

3.7 source position:
Point at which the source is located (for stationary source), an area in which sources are located or move (for stationary and mobile sources), or a line along which sources are located or move (for stationary and mobile sources).

3.8 reference position:
Point at which the sound from the source is or will be minimally influenced by the installed barrier or planned barrier.

NOTE — The reference position will be used to monitor the source level.

3.9 receiver position:
Point at which an insertion loss is to be determined; the location of this position is not standardized but is chosen based on the objectives of a particular study.

3.10 far field:
Region in which the sound pressure level for a simple point source decays six decibels per doubling distance and for an incoherent line source three decibels per doubling distance, without ground attenuation.

4 Methods

This International Standard specifies two methods for the determination of insertion loss of outdoor noise barriers. The recommended method is the direct method. The alternative method is the indirect measurement method using measured "before" levels at an equivalent site.

The method to be adopted is chosen by considering several factors including the objectives of the measurement, the ability to make measurements prior to barrier installation, and the feasibility of equivalence of source, terrain profile, interfering obstructions and reflecting surfaces, if any, ground surface and meteorological conditions between the "before" and "after" situations.

4.1 Direct method

The direct method can only be used if the barrier has not yet been installed or can be removed for the "before" measurements. The sound pressure levels are measured at the reference and the receiver positions for both "before" and "after" barrier installations. The same reference and receiver positions shall be used in both the "before" and "after" cases. Equivalence shall be satisfied on sources, terrain profiles, interfering obstructions and reflecting surfaces, if any, ground surface and meteorological conditions.

4.2 Indirect measurement method

If the barrier has been installed and it cannot be readily removed to permit direct "before" measurement, an estimated "before" sound pressure level is obtained by the measurement at a site that is equivalent to the study site.

Site equivalence refers to equivalence of the source, the terrain profiles, interfering obstructions and reflecting surfaces, if any, ground surface and meteorological conditions.

5 Instrumentation

5.1 Sound level meter and analyzer

Sound level meters meeting type 1 or type 2 requirements of IEC 651 shall be used.

Integrating averaging sound level meters shall be used if the chosen noise descriptor is the equivalent continuous sound pressure level or the sound exposure level. Such meters shall meet type 1 or type 2 requirements of IEC 804.

The measurements uncertainty shall always be estimated. In addition, a periodic verification of the instrumentation system shall be carried out in order to verify the conformity to the relevant specification standards. The interval between verifications shall be determined by the national standards or regulations in respective countries. At the beginning of the measurements, and following any warm-up time specified by the manufacturer, the overall sensitivity of the sound level meter shall be checked using a sound calibrator. If necessary, it shall be adjusted according to the manufacturer's instructions. A further check shall be performed at the end of each measurement session. At least two measurement systems shall be used to permit simultaneous measurements at a reference and a receiver position.

Octave-band or one-third-octave band filter sets, if used, shall meet the requirements of IEC 1260.

5.2 Sound calibrator

A sound calibrator meeting the requirements of IEC 942 shall be used. The sound calibrator used shall be appropriate to the type of sound level meters.

5.3 Windscreen

A wind screen as recommended by the manufacturer shall be used on each microphone during measurements.

5.4 Other instrumentation system

If other measurement systems, such as analogue or digital recorders or digital data acquisition systems are used, the system shall be verified to ensure it meets the requirements of the IEC standards referenced above. The systematic uncertainties associated with the use of the system shall be evaluated.

5.5 Meteorological equipment

An anemometer or other device for measuring wind speed and wind direction shall have an uncertainty of not more than ± 10 %. The wind sampling rate shall be sufficient to represent wind conditions over the acoustic sampling period.

A thermometer or other temperature sensor for measuring ambient temperature shall have an uncertainty of not more than ± 1 °C.

A hygrometer for measuring relative humidity shall have an uncertainty of not more than ± 2 %.

A variable height support device is needed if wind and temperature profiles are being taken.

NOTE — Attention should be given to the placement of meteorological sensors. The height of the highest acoustic receiver is suggested.

6 Acoustic environment

6.1 General

To permit valid comparison of "before" and "after" sound pressure level measurements for insertion loss determination, the equivalence of terrain profile, interfering obstructions and reflecting surfaces, if any, ground and

meteorological conditions between the "before" and "after" cases shall be determined and shall be documented in the test report.

6.2 Terrain profile and ground surface equivalence

If the barrier has already been installed, measurements of the "before" levels shall be performed at sites similar to the actual "before" site. If possible, the simulated "before" site should be located next to the actual barrier site at an unshielded area.

The simulated "before" site is judged equivalent to the actual "before" site, if the following conditions are satisfied:

a) The simulated "before" site shall have a terrain profile, interfering obstructions and reflecting surfaces, if any, and ground surface equivalent to that of the real barrier site within a sector extending 60° on either side of the line connecting the receiver positions towards the source position (area), so that similar sound propagation including ground reflection can be achieved.

b) The environment in the region within 30 m behind and to the side of the major receiver positions shall be similar.

c) These equivalencies shall also be preserved between "before" and "after" measurements in the direct method.

NOTE 1 Ground surface equivalence is best described by determination of the specific ground impedance. If the ground impedance can not be determined, then it may be always characterized (e.g. paved, long vegetation on packed or loose soil, short or no vegetation on loose or packed soil including sand clay, gravel etc.).

NOTE 2 Extreme changes in the ground surface water content should be avoided.

6.3 Meteorological conditions

In order to provide measurement reproducibility some requirements on the meteorological conditions such as wind, temperature and cloud cover, are necessary

6.3.1 Wind

Wind conditions are judged to be equivalent for the "before" and "after" acoustical measurements if the wind class (given in table 1) remains unchanged and the vector components of the average wind velocity from the source to the receiver do not differ by more than 2 m/s.

In any case, no acoustical measurements shall be made when the average wind velocity exceeds 5 m/s, regardless of the direction. Strong wind with a small vector component in the direction of sound propagation should also be avoided because of the possibility of large errors due to wind fluctuation.

Table 1 — Class of wind conditions

Wind class	Vector component of wind velocity m/s
a) For all distances	
Downwind	+ 1 to + 5
Calm	− 1 to + 1 [1]
b) For short distances	
Downwind	+ 1 to + 5
Calm	− 1 to + 1
Upwind	+ 1 to − 5
1) Only with the case of temperature inversion.	

The conditions for short distance are:

— "before" measurement:

$$(H_S + H_R) / (d_1 + d_2) > 0{,}1$$

— "after" measurement:

$$(H_S + H) / d_1 > 0{,}1$$

$$(H + H_R) / d_2 > 0{,}1$$

where

H_S is the source height, in metres;

H_R is the receiver height, in metres;

H is the barrier height, in metres;

d_1 is the distance between source and barrier, in metres;

d_2 is the distance between barrier and receiver, in metres.

6.3.2 Temperature

There are no specific requirements, provided that the temperature is recorded for each test. However, the "before" and "after" measurements shall be made with average temperature within 10 °C of each other.

The air temperature gradient conditions as a function of the height above the ground, which influence noise propagation shall be similar for the "before" and "after" acoustical measurements.

No attempt shall be made to adjust measured sound pressure levels based on the temperature data.

6.3.3 Humidity

Humidity affects predominantly high-frequency sources (major sound components over 3 000 Hz). Therefore, "before" and "after" measurements should be restricted to similar conditions of relative humidity.

No attempt shall be made to adjust measured sound pressure levels based on the humidity data.

6.3.4 Cloud cover

The "before" and "after" measurements shall be performed for the same class of cloud cover, as determined in table 2.

Table 2 — Cloud cover class

Class	Description
1	Heavily overcast day or night (80 % cloud cover or more, for 100 % of the measurement time)
2	Moderately overcast day or night (50 % to 80 % cloud cover for at least 80 % of the measurement time)
3	Lightly overcast or sunny day or night (either with continuous sun or less than 50 % cloud cover for at least 80 % of the measurement time)
4	Clear night

6.3.5 Others

Measurements in rainy or snowy weather conditions should be avoided or if in the case of traffic noise barriers the wet road surface should be avoided.

6.4 Background noise

The sound pressure level of background noise including instrument noise should be 10 dB or more below the sound pressure level obtained from measurements.

The sound pressure level of background noise may be estimated on the basis of measurement results in the absence of source. If the difference between the sound pressure level from measurements and the background noise level is between 4 dB and 9 dB, a correction should be applied to the measurement results according to table 3. If the difference between the sound pressure level from measurements and the background noise level is below 4 dB the measurement results are not valid.

Table 3 — Background noise correction

Difference between measured sound pressure level with and without sound source dB	Correction to be made to measured sound pressure level with sound source dB
4 and 5	– 2
6, 7, 8 and 9	– 1

7 Sources and source equivalence

7.1 Source type

Three types of sources can be used for the *in-situ* determination of barrier insertion loss: a natural source, a controlled natural source and a controlled artificial source. Natural sources and controlled natural sources often have insufficient sound power output especially to complete "after" measurements, and so controlled artificial sources should be used when there is likely to be some difficulty, for example when large distances, high background noise levels or high barriers are involved.

7.1.1 Natural source

The uncontrolled naturally occurring source for which the barrier is designed is normally the best source to be used for the purpose of this International Standard. Unless stability of the source can be clearly established and documented, continual monitoring of the source at the reference position during measurements is required.

7.1.2 Controlled natural source

If conditions of the natural source have changed, or are expected to change, between the "before" and "after" measurements, the use of a controlled natural source should be considered. For example, if the traffic condition such as vehicle flow rate and the ratio of heavy to light vehicles at a road traffic noise barrier site is expected to change significantly, it may be necessary to select one or several test vehicles to be typical sources and to use them for controlled natural source for the "before" and "after" measurements.

The source equivalence shall be estimated as described in 7.2.

7.1.3 Controlled artificial source

When "before"/"after" natural source equivalence cannot be established the indirect method shall be used. For point sources when the natural source cannot be used a controlled artificial source may be used. The artificial source must be used for both the "before" and "after" measurements.

NOTE — The use of this type of source is probably not appropriate for a noise source distributed over a large area such as an industrial plant or highway traffic. In such cases, a controlled natural source should be used.

The operating parameters of the artificial source shall be controlled in such a way as to ensure relevance of the measurements to the performance of the barrier for the natural source(s) being simulated. Unless stability of the source can be clearly established and documented, continual monitoring of the source during "before"/"after" measurements is required. Normally, it is only feasible to take simulation as far as an idealized approximation to the natural source such as an omnidirectional simple point source.

In particular all significant acoustical paths between the natural source and the receiver shall be covered by the simulation including those produced by reflection from the ground or other objects in the source and receiver regions. The simulation shall also cover the relevant frequency regions of the spectrum of the natural source.

When the loudspeaker is used as the controlled artificial source it is recommended that the test sound be emitted intermittently in order to check the influence of background noise. This method is especially effective if the level of background noise fluctuates from time to time.

7.2 Source equivalence

For a valid determination of insertion loss, the source shall be equivalent for the "before" and "after" cases, that is, source characteristics shall be sufficiently similar so as not to introduce unacceptable error into the determination. Source characteristics that affect the insertion loss include spectral content, directivity, spatial and temporal patterns and operating conditions, as well as the number and types of individual sources for composite sources.

NOTE — If the source is a road, this supposes in particular that the vehicle flow rate as well as the ratio of heavy to light vehicles are more or less the same for "before" and "after" acoustical measurements.

It is important to determine the key operating parameters that affect insertion loss and to determine allowable variations in these parameters. For this purpose, two steps shall be followed during the insertion loss determination:

step 1: these key operational parameters shall be made as to whether or not any monitored variations are acceptable;

step 2: the sound shall be monitored at a reference position as described in 7.2.2.

Source equivalence is less critical when octave or one-third-octave-band level measurements are being made than when A-weighted sound pressure levels are being measured for the determination of insertion loss.

7.2.1 Operational parameters

Appropriate parameters may be defined by the parties concerned, such as trade associations, standards organizations or government agencies. For example, for the purposes of this International Standard, accepted parameters for traffic noise are average operating speeds, separate hourly flow rates and spatial distribution for automobiles (two axles, four wheels) medium trucks (two axles, six wheels), heavy trucks (three or more axles) buses and motorcycles and road gradient and pavement type.

7.2.2 Reference microphone position

The reference position shall be chosen in such a way that an unaffected sound pressure level at the barrier position from the source to be used is obtained. The reference microphone shall be located at a point on a vertical plane including the barrier to monitor the source equivalence in both "before" and "after" measurements. The height of the reference microphone shall be at least 1,5 m above the top edge of the barriers. For complex-shaped barriers such as cupped barriers or berms, the reference microphone position shall be at least 1,5 m above the highest point on the barrier.

NOTE — If the distance from the closer end of the source region to the barrier is shorter than 15 m, the reference microphone may be raised as high as possible in order that the elevation angle from the closer end of the source region to the reference microphone is 10° greater than to the top of the barrier.

8 Measurement procedure

8.1 General planning

8.1.1 Measurement

The measurement procedures are based on simultaneous measurements of sound pressure levels in the reference position and in the receiver positions chosen.

8.1.2 Receiver positions

The receiver positions shall represent an open space behind the barrier. The following are general guidelines for the choice of the receiver position:

a) Hemi free-field conditions: Hemi free-field conditions are obtained if the distance between a receiver position and vertical sound reflecting surfaces is at least 30 m, or twice the barrier—receiver distance, whichever is shorter.

b) On reflecting surfaces: This applies to receiver positions directly attached on building surfaces. The wall surface shall be solid and sound reflecting, and flat within ± 0,05 m on a measuring area of at least 0,5 m x 0,7 m. A mounting plate of this size is usable in most cases when the facade surface is judged less suitable. The mounting plate shall be made of an acoustically hard and stiff material. The distance from the microphone to any other wall (or roof) surface edge shall be at least 1 m. The microphone shall be mounted as close to the surface as possible by using a half-cut microphone windscreen. The microphone axis shall be oriented vertically.

NOTE — Minimum height of receiver positions should be 1,2 m.

8.1.3 Quantities to be measured

At a minimum, A-weighted sound pressure levels shall be measured in reference and receiver positions for all situations.

If it is required to obtain the frequency characteristics of barrier insertion loss, octave-band or one-third-octave-band sound pressure levels shall be measured. Frequency range of measurement shall be from 63 Hz to 4 000 Hz (octave-band) or from 50 Hz to 5 000 Hz (one-third-octave-band), respectively. In some special cases when it is required to extend the frequency range of measurement to higher frequencies, measurements at 8 000 Hz (octave-band) or 6 300 Hz, 8 000 Hz and 10 000 Hz (one-third-octave-band) are recommended.

NOTE — When a controlled artificial source is used, measurement of octave-band or one-third-octave-band sound pressure levels are recommended.

8.1.4 Number of measurement repetitions

Measurement repetitions at a receiver position and a reference position are required to assess the uncertainty of measurement results; these repetitions are then incorporated into the error analysis. A minimum of three repetitions under equivalent conditions is recommended. In the case of a source-receiver distance larger than 250 m, more repetitions may be required.

8.1.5 Suggested durations or sample sizes for each measurement repetition

Suggested measurement durations or sample sizes based on the temporal nature of the noise and the range in sound level fluctuations are given in table 4.

Table 4 — Suggested durations or sample sizes

Temporal nature	Suggested duration		
	Greatest anticipated range dB		
	10	10 - 30	30
Steady	2 min	Not applicable	
Non-steady, fluctuating	5 min	15 min	30 min
Non-steady, intermittent	For at least ten events		
Non-steady, impulsive and isolated bursts	For at least ten events		
Non-steady, cyclic	3 cycles of on/off		

8.2 Determination of barrier insertion loss

8.2.1 Direct method

If the sound pressure levels can be measured directly in both "before" and "after" situations, this will give the directly measured barrier insertion loss.

The barrier insertion loss, D_{IL}, is given by;

$$D_{IL} = (L_{ref,A} - L_{ref,B}) - (L_{r,A} - L_{r,B})$$

where

$L_{ref,B}$ is the "before" sound pressure level at the reference position;

$L_{r,B}$ is the "before" sound pressure level at the receiver position;

$L_{ref,A}$ is the "after" sound pressure level at the reference position;

$L_{r,A}$ is the "after" sound pressure level at the receiver position.

8.2.2 Indirect measurement method

In many cases, the "before" sound pressure level has not been measured. It may be estimated by measurements at a substitute site that is equivalent to the barrier site prior to barrier installation. A measurement of this type gives an estimate of the barrier insertion loss, which however, may be less accurate than the barrier insertion loss determined according to the direct method in 8.2.1.

Reference position and receiver positions are the same with those of the direct method. However, in the indirect measurement methods, "before" sound pressure levels are measured at a substitute site that is essentially equivalent in terrain profile, ground conditions and source to the barrier site. Equivalence of measurement sites for "before" and "after" levels shall be checked carefully. The hemi free-field sound pressure level difference between the reference position and the receiver position is given by:

$$\Delta L_B = L_{ref,B} - (L_{r,B} - C_r)$$

$$\Delta L_A = L_{ref,A} - (L_{r,A} - C'_r)$$

where

$L_{ref,B}$ is the "before" sound pressure level at the reference position (substitute site);

$L_{r,B}$ is the "before" sound pressure level at receiver position, (substitute site);

$L_{ref,A}$ is the "after" sound pressure level at reference position;

$L_{r,A}$ is the "after" sound pressure level at receiver position;

C_r and C'_r are correction factors for the type of receiver position;

for "hemi free-field": C_r = 0 dB

for "on reflecting surfaces": C'_r = 6 dB

NOTE — It is preferable to choose receiver positions where corrections C_r and C'_r are essentially the same.

The indirectly measured barrier insertion loss, D'_{IL}, is given by:

$$D'_{IL} = \Delta L_A - \Delta L_B$$

9 Information to be recorded

9.1 Type of method

a) Direct method, or

b) indirect measurement method.

9.2 Instrumentation

a) Equipment used for measurements, including name, type, serial number and manufacturer.

b) Method used for evaluation and periodic verification of the microphones and other system components.

c) Type of windscreen.

9.3 Acoustic environment

a) Description of the test environment: drawings or pictures showing the terrain profile, the ground surface and the building, other reflecting objects around the source, receiver and barrier regions.

b) Air temperature and relative humidity.

c) Wind speed and direction. Class of cloud cover.

9.4 Sound source

a) Natural source: type of source, verification of the source equivalence for the "before" and "after" measurements.

b) Controlled natural source: type of source, process of control, verification of the source equivalence for the "before" and "after" measurements.

c) Controlled artificial source: type of source, similarity with the natural sources, verification of the source equivalence for the "before" and "after" measurements.

9.5 Barrier to be tested

Description of barrier with drawing including size, thickness mass per unit area, and material specifications including sound absorption coefficient and sound reduction index (if applicable).

9.6 Site layout

a) A plan view showing the source areas, receiver positions, barrier under test, any nearby sound reflectors and any other natural barriers.

b) For each receiver position, an elevation view constructed from the vertical plane confining the receiver position and the source position, and showing the source position, the receiver position, the reference microphone position, the barrier under test, any nearby sound reflectors and any other natural barriers.