nordtest method

NT ACOU 080
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INDUSTRIAL PLANTS: NOISE EMISSION

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CONTENTS

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1 SCOPE

This Nordtest engineering method specifies a method for measuring sound pressure levels at prescribed positions surrounding stationary noise sources at industrial plants and calculating the source strength based on the measured sound pressure levels.

The source strength is useful for calculations of sound pressure levels in areas adjacent to industrial plants and for comparing noise emission by equipment from various manufacturers.

For the purpose of this Nordtest method the source strength is a measure of the part of the source sound power which is relevant for the calculation of sound pressure levels at some distance from the source. Sound radiated vertically upwards is neglected in this measure, and the measurement positions are chosen in such a way as to ensure that the sound radiated at angles between 0º and 20º above the horizontal is measured. The sound radiated in this angle interval is most relevant when calculating sound pressure levels in the environment. In general the source strength includes information on source-directional characteristics in the horizontal plane. If a noise source only radiates into nearly horizontal directions and at the same time is nearly omnidirectional in the horizontal plane, the source strength is approximately equal to the sound power level of the source.

Measurements are made in situ outdoors, and the source strength is calculated in octave bands and overall A-weighted. Whenever possible source-directional characteristics are determined.

This Nordtest method is best suited for individual industrial noise sources. In Annex A reference is given to other methods suitable for measuring noise emission from entire industrial plants or from large parts of such plants. Reference is also given to relevant standards for sound power measurements.

2 FIELD OF APPLICATION

This Nordtest method is applicable to any stationary industrial noise source although the large number of microphone positions necessary for extended sources may make it impractical for such sources.

Measured data are primarily intended for use as input in a prediction method assuming that each source can be regarded as an equivalent point source. Thus, care must be taken to define the noise source in such a way that it is possible to estimate its acoustic centre.

Measured data can also be used in noise control work and for comparisons between noise emission from different plants or machines.

2.1 Nordtest Sphere Method

The Nordtest Sphere Method specifies that sound pressure levels shall be measured at microphone positions over part of a sphere enclosing the noise source under test. The required sphere radius may be quite large. This limits the application to situations with a favourable acoustic environment. Information on source-directional characteristics is obtained when the Nordtest Sphere Method is applied.

2.2 Nordtest Box Method

The Nordtest Box Method specifies that sound pressure levels shall be measured at microphone positions on the surface of a notional box enclosing the noise source under test. The distance from source to box surface is allowed to be quite small. This means that the box method is applicable under unfavourable acoustic conditions. No information on source-directional characteristics is obtained when the Nordtest Box Method is applied.

3 REFERENCES

NT ACOU 041, Sound Level Meters: Verification procedure.

IEC Publication 225, Octave, half-octave and third-octave band filters intended for the analysis of sound and vibrations.

IEC Publication 651, Sound level meters.

IEC Publication 804, Integrating-averaging sound level meters.

IEC Publication 942, Sound calibrators [1)].

"Environmental Noise from Industrial Plants. General Prediction Method", Danish Acoustical Institute, Report No. 32, Lyngby, 1982.

4 DEFINITIONS AND NOTATION

4.1 Definitions

For the purpose of this standard the following definitions apply.

4.1.1 Acoustic centre: The position of a point source yielding the same sound pressure level in the environment as the noise source under test.

4.1.2 Characteristic dimension: Half the diagonal of the box enveloping the reference box and its images in adjoining reflecting planes.

4.1.3 Environmental correction K: Correction for deviation of test environment from an ideal free field above a reflecting plane or in front of two or three reflecting planes.

1) At present at the stage of draft.

4.1.4 Horizontal directionality: Directionality determined from results of measurements in one horizontal plane only.

4.1.5 Measurement distance: The distance between the reference box and a parallelepipedical measurement surface.

4.1.6 Measurement radius: The radius of a hemispherical measurement surface.

4.1.7 Measurement surface: A hypothetical surface of area S enveloping the source. The microphone positions are located on this surface.

4.1.8 Near-field error correction: Correction for sound energy which is not passing the measurement surface at right angles.

4.1.9 Reference box: A hypothetical surface which is the smallest rectangular parallelepiped which just encloses the source. It usually terminates on one or more reflecting planes.

4.1.10 Reflecting plane: A plane sound-reflecting surface extending at least half a wavelength (usually about 1.5 m) beyond the projection of the measurement surface on the sound-reflecting surface.

4.1.11 Source strength: The level of the part of the sound power of the source which is radiated into nearly horizontal directions and therefore is relevant for the sound pressure levels in the environment around industrial plants.

4.2 Notation

E	Near-field error correction	[dB]
K	Environmental correction	[dB]
$L_{eq,T}$	Energy equivalent sound pressure level	[dB]
L_p	Sound Pressure Level. This symbol may denote either an L_{eq}-value or an L_{pmax}-value	[dB]
$\bar{L}_p$	Energy average sound pressure level	[dB]
L_{pmax}	Maximum sound pressure level, time weighting F	[dB]
L_W	Total source strength	[dB]
$L_W(\Phi)$	Source strength in direction Φ	[dB]
N	Number of microphone positions	[–]
O	Projection of source-acoustic centre on the ground	[–]
R	Radius of hemispherical measurement surface Distance from source to microphone position	[m]
R'	Distance from source to microphone position via reflection from vertical plane	[m]
S	Area of measurement surface	[m²]
S_o	Reference surface area = 1.0	[m²]
S_{ref}	Area of reference box surface	[m²]
T	Reference time interval	[s]
V	Volume of room	[m³]
a	Distance from reference box to measurement box	[m]
b	Distance from microphone to vertical reflecting plane	[m]
d_o	Characteristic dimension of the source	[m]
$h_1 h_2$	Height of microphone positions	[m]
l_1	Length of reference box	[m]
l_2	Width of reference box	[m]
l_3	Height of reference box	[m]
n	Number of discrete sound pressure levels associated with operating conditions Nos. 1 . . . n	[–]
$t_1 \ldots t_n$	Durations of operating conditions	[s]
t_r	Reverberation time	[s]
ΔL_Φ	Directional correction in direction Φ	[dB]
λ_c	Wavelength of sound in air at octave band centre frequency	[m]
Index i	Indicates microphone position No. i	[–]

5 GENERAL REQUIREMENTS FOR MEASUREMENTS

5.1 Measurements

The overall A-weighted and octave band sound pressure levels within the frequency range 63 Hz – 8000 Hz shall be measured. The frequency bands 31.5 Hz and 16 kHz are optional.

The measurement time interval at each microphone position shall be chosen so as to contain relevant operating conditions of the source.

For steady noise the recommended measurement time interval is 1 minute. L_{eq} should be measured. For slow fluctuations depending on the operational modes of the source the measurement time interval must be long enough to include exactly one or more than three full operational cycles of the source. If various operating modes are very long-lasting, $L_{eq,T}$ may be determined according to the procedure given in Annex B.

Some industrial noise sources (e.g. pneumatic filter cleaning equipment) emit sound impulses at more or less regular intervals. Noise limits in the environment are sometimes specified as maximum sound pressure levels (time weighting F) from such sources. When relevant the source strength corresponding to maximum noise emission can be determined using this Nordtest method. In that case $L_{pmax,F}$ (in octave bands) from at least five noise impulses should be measured in each microphone position and the arithmetic mean value should be used as the measurement result from that position.

5.2 Choice of Microphone Positions

Each measurement method prescribes that certain microphone positions are used. In practice, however, these positions are not always accessible during in situ measurements, or the measurement results from some of the positions may be in error due to unfavourable conditions. Individual positions may e.g. have to be moved or even omitted due to local disturbances of various kinds. Such deviations from the method specifications must be accurately described in the measurement report, and their effects on the measurement results must be evaluated.

6 ENERGY AVERAGE SOUND PRESSURE LEVEL

Based on the measured octave band sound pressure levels an energy average value, $\overline{L_p}$, is calculated by means of Equation (6.1):

$$\overline{L_p} = 10 \lg \left(\frac{1}{N} \sum_{i=1}^{N} 10^{\frac{L_{pi}}{10}} \right) \qquad (6.1)$$

N is the number of microphone positions.

L_{pi} is the sound pressure level measured in microphone position No. i after correction for the influence of background noise, cf. Section 9.2.

In cases when environmental corrections shall be applied, cf. Section 9.1, the octave band energy average value, $\overline{L_p}$, is calculated by means of Equation (6.2):

$$\overline{L_p} = 10 \lg \left(\frac{1}{N} \sum_{i=1}^{N} 10^{\frac{L_{pi} - K_i}{10}} \right) \qquad (6.2)$$

K_i is the environmental correction to be applied to the measurement result from microphone position No. i.

7 INSTRUMENTATION

7.1 General

The instrumentation shall meet the basic requirements of IEC Publication 651 for type 1 sound level meters. As it is the energy equivalent sound pressure level which is usually measured, it is recommended that an integrating-averaging sound level meter complying with the specifications in IEC publication 804 for type 1 instruments is used. Calibrations shall comply with IEC Publication 942, type 1 calibrators. Octave band filters, realtime analyzer, etc., used shall meet the requirements of IEC Publication 225. All instruments shall be operated according to manufacturer specifications.

7.2 Calibration and Verification

At least before and after each series of measurements an acoustical calibrator shall be applied to the microphone for calibration of the entire measuring system.

At least once every two years instrument performance shall be checked to verify that they comply with the above IEC publications. Calibrator performance, however, shall be checked annually. This verification shall be made according to NT ACOU 041 or equivalent.

7.3 Microphones

The microphones shall be equipped with windscreens. During the measurements they shall point towards the source in such a way as to get the best free-field response in the direction perpendicular to the measurement surface. In corner positions on a parallelepipedical measurement surface the angles with the adjacent sides of the measurement surface shall be 45º.

8 SOURCE DEFINITION

The source under test should be defined as small as possible. It is then possible to make an accurate description of the operating conditions and the position of the acoustic centre of the source.

For practical reasons it is, however, often necessary to define the source in such a way that it is composed of several different sound sources. In such cases the inclusion of several equally strong sources at different heights above the ground should be avoided.

8.1 Reference box

The reference box is a notional parallelepipedical surface just enclosing the source under test. Protruding elements of the source, which are not significant radiators of sound energy, should be disregarded. In case the source under test is situated too close to reflecting planes for microphone positions to be allowed in the space between the source and the reflecting planes, the reference box shall be extended to terminate on these planes. Whether or not microphone positions can be allowed depends on the possibility of determining the environmental correction K (cf. Section 9.1) with sufficient accuracy.

Usually the reference box has between 3 and 5 free sides. Sometimes, however, it may degenerate into one single plane surface, cf. Figure 1.

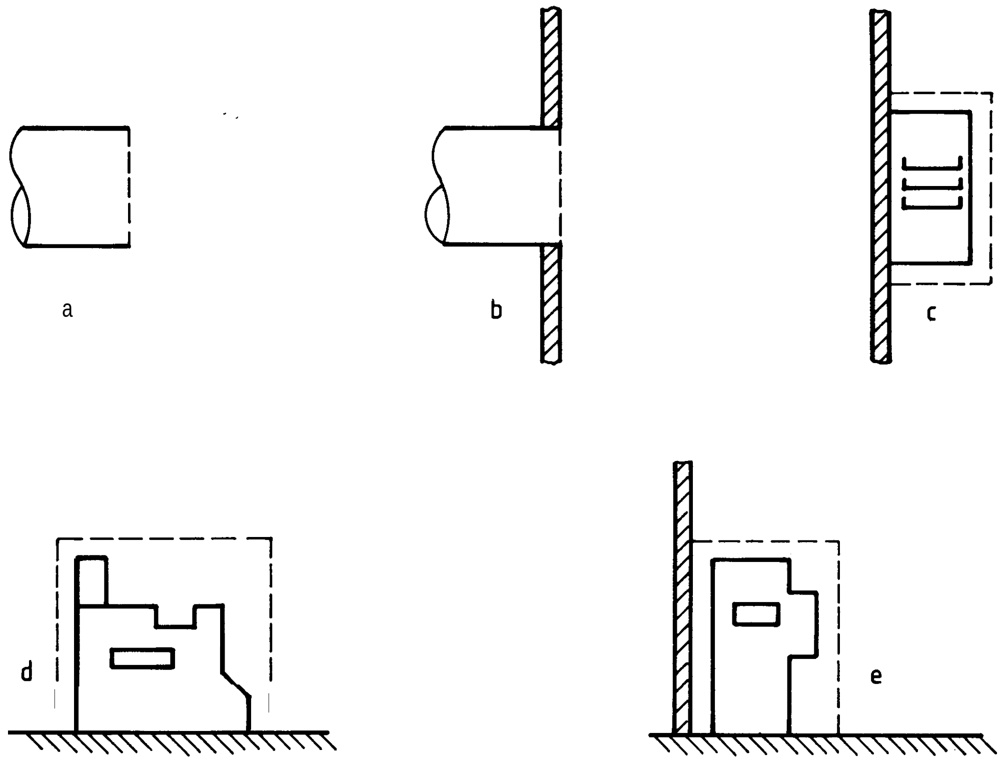

Fig. 1 Examples of reference boxes (dashed lines).

a) Free opening: flat reference "box"

b) Opening in a reflecting plane: flat reference "box"

c) Source near a reflecting plane: reference box terminating on that plane (5 free sides)

d) Source on the ground: reference box terminating on the ground (5 free sides)

e) Source near 2 or 3 reflecting planes: reference box terminating on 2 (or 3) reflecting planes, with 4 (or 3) free sides

8.2 Characteristic Dimension

The characteristic dimension d_o of the source is defined as half the diagonal of the box enveloping the reference box and its images in adjoining reflecting planes, Figure 2. Thus , if l_1, l_2, and l_3 denote the length , width and height respectively of the reference box, d_o is calculated according to Equation (8.1):

- Flat reference "box" $$d_o = \sqrt{(l_1/2)^2 + (l_2/2)^2}$$
- Reference box terminating on one reflecting plane $$d_o = \sqrt{(l_1/2)^2 + (l_2/2)^2 + l_3^2}$$
- Reference box terminating, on two reflecting planes $$d_o = \sqrt{(l_1/2)^2 + l_2^2 + l_3^2}$$
- Reference box terminating on three reflecting planes $$d_o = \sqrt{l_1^2 + l_2^2 + l_3^2}$$

(8.1)

8.3 Acoustic Centre

When sound pressure levels in the environment generated by industrial noise sources are predicted, each source is represented by an equivalent point source at the acoustic centre of the real source.

In the vertical plane the acoustic centre is assumed to be at a height of two thirds the height of the reference box unless the reference box contains a dominating noise source. In the latter case the acoustic centre is chosen as the position of this dominating noise source.

The position of the acoustic centre in the horizontal plane is often less critical. In general the horizontal position of the acoustic centre can be assumed to be at the geometric centre of the box formed by the reference box and its images in adjoining reflecting planes, i.e. the point marked “O” in Figure 2.

If the acoustic centre is taken at the position of a dominating noise source, this shall be reported.

8.4 Source Directionality

If a preliminary survey indicates that the overall A-weighted source strength in one direction exceeds that of any other direction by more than 6 dB, the directionality should, if possible, be estimated by using the sphere method, cf. Section 12.

For the purpose of this Nordtest method which is primarily intended for application in connection with calculations of sound pressure levels in the environment around industrial plants according to the joint Nordic prediction method the definition in Equation (8.2) applies:

$$L_W(\Phi) = L_W + \Delta L_\Phi \qquad (8.2)$$

$L_W(\Phi)$ is the source strength in the direction defined by the angle in the horizontal plane [dB]

L_W is the total source strength, i.e. averaged over all values of Φ [dB].

ΔL_Φ is the (horizontal) directional correction [dB]

Note: The effect of reflections from the ground surface is included in the ground correction in the joint Nordic prediction method. The definition in Equation (8.2) is different from the definition of the Directivity Index in ISO 3744.

9 ACOUSTIC ENVIRONMENT

Ideally the test environment should be free from reflecting obstacles outside the reference box and measurement surface so that the source radiates into a free field above a sound-reflecting plane. When this is not the case, the measurement distance can either be made so short that the influence of reflected sound can be neglected or the reflecting planes can be used to delimit the measurement surface. To satisfy the definition (4.1.10) for reflecting planes it may become necessary to restrict the size of the measurement surface.

It may be possible to suppress reflections by applying absorbing material or by using special measurement techniques. This is not further dealt with in this Nordtest method.

In cases when the environment does not correspond to the above ideal condition, the results of measurements shall be corrected for the influence of the non-ideal environment. The environmental correction, K, is then applied to the measurement results from each microphone position.

At sources such as ventilation pipes and flue gas exhausts with high flow speeds care shall be taken to avoid unwanted influence of the flow on the measurement results by choosing microphone positions in areas with sufficiently low flow speeds.

9.1 Environmental Correction

In principle the environmental correction can be determined by means of a reference sound source as described in ISO 3744, Annex A. The strength of the reference sound source must be known from a calibration performed in a free field above a reflecting plane, ISO 3745 or 3744.

The use of a reference sound source is, however, laborious, and the inaccuracy of the K-values determined is of the same order of magnitude as the K-values themselves. Thus, at industrial noise sources it is more reasonable to estimate the environmental correction K on the basis of theoretical and empirical considerations. The following guidelines can be applied in situations when more accurate information is unavailable.

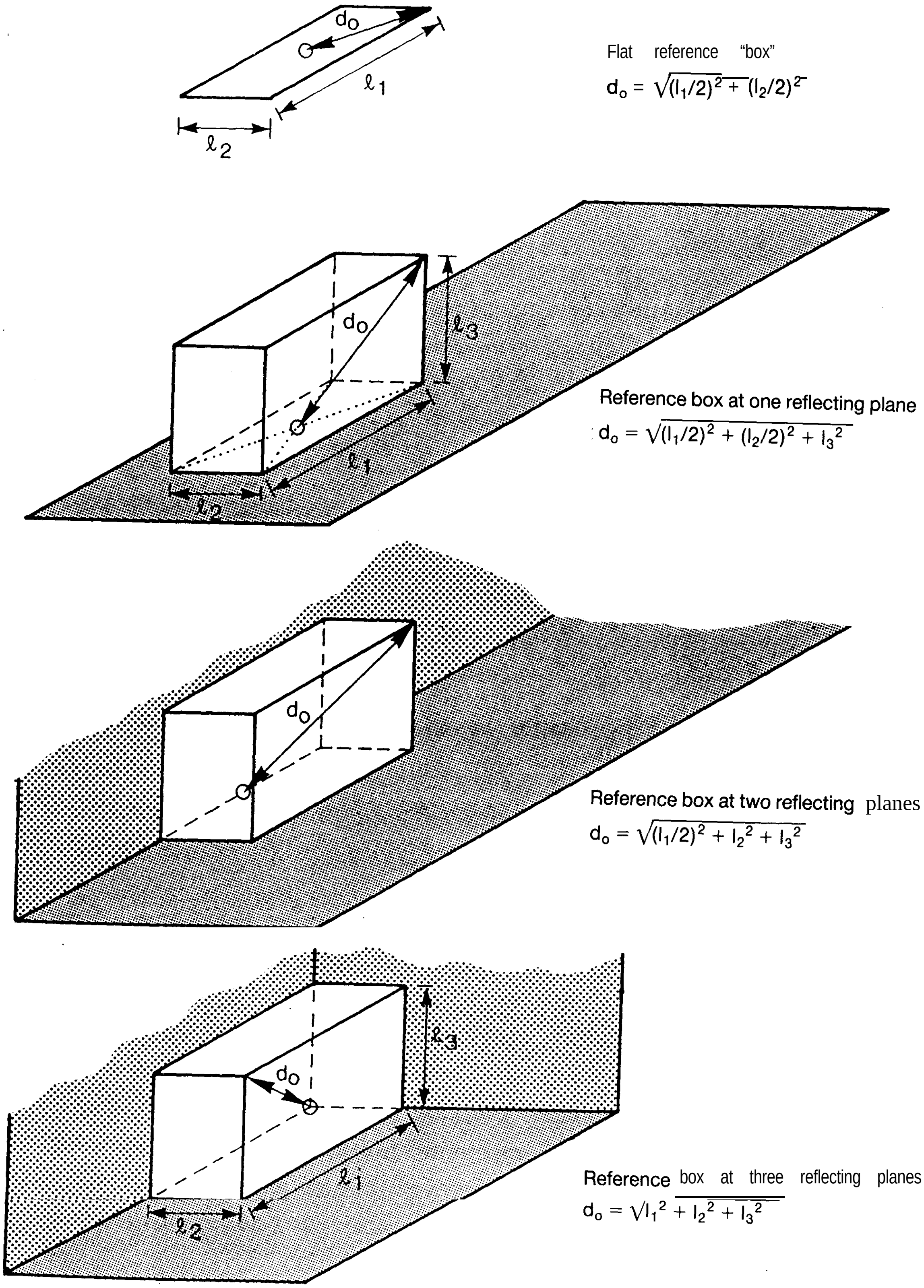

Fig. 2 Examples illustrating reference box and characteristic source dimension, d_o

Refelcting Obstacle

When a microphone position is between the noise source and a sound-reflecting obstacle, K is normally in the interval $0 < K \leq 6$ dB. In the special case of a large box-shaped sound source multiple reflections occur between the box surface and the reflecting obstacle. The increase in sound pressure level caused by multiple reflections cannot be predicted in a simple way and therefore measurements under such conditions should be avoided. In other cases the following guidelines can be applied:

- K is approx. 6 dB when the distance from the microphone position to the reflecting obstacle is smaller than 10 % of the wavelength λ_c of the sound (1/1 -octave bands), i.e. when

$$b < 0.1 \cdot \lambda_c \qquad (9.1)$$

λ_c is the wavelength of sound in air at the octave band centre frequency (cf. Annex B).

Note: K is between 6 dB and 3 dB when the microphone distance b from the reflecting obstacle is more than $0.1 \cdot \lambda_c$ and less than A,. In this interval of distances K varies so rapidly with varying distance that such microphone positions should be avoided.

- K is approx. 3 dB when the distance b from the microphone position to the reflecting obstacle is larger than the wavelength λ_c of the sound (1/1 -octave bands), but smaller than one tenth of the distance from the source to the microphone position, i.e. when

$$\lambda_c < b < R/10 \qquad (9.2)$$

R is the distance from the source to the microphone position.

- K is approx. 0 dB when the propagation distance R' of the sound reflected from an obstacle is more than twice the propagation distance R of the direct sound, i.e. when

$$R' > 2R \qquad (9.3)$$

- When the distance b from the microphone position to the reflecting obstacle is larger than R/10 and at the same time (9.3) is not satisfied, i.e.

$$R/10 < b \qquad b > \lambda_c \text{ and } R' < 2R \qquad (9.4)$$

then the value of K can be taken from Table 1.

Table 1 Environmental correction K due to a sound reflecting obstacle.

b/R [-]	< 0.1	0.1 –0.3	0.3-0.5	> 0.5
K [dB]	3	2	1	0

Porous Ground Surface

If the ground surface is not acoustically hard, the measured sound pressure levels change due to the effect of the porous ground.

- When the ground surface between source and microphone position is acoustically porous (e.g. grass), but conditions otherwise are ideal, the environmental correction can be taken from Table 2.

Table 2 Environmental correction K due to a porous ground surface.

Frequency [Hz]	63 - 500	1000 - 8 000
K [dB]	0	-1

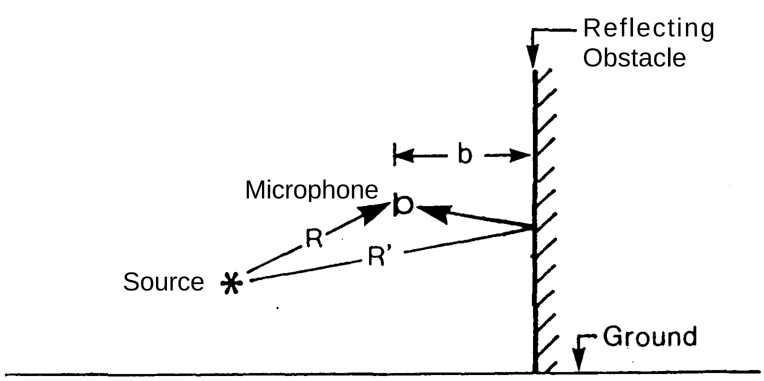

Fig. 3 Illustration of distances from source to microphone position.

R: Direct sound

R': Reflected sound

Reverberant Conditions

If a source is placed in a room, the sound pressure levels increase due to reverberation.

When the noise source is in a room with the ratio of any two dimensions not greater than 3:1, with a volume V [m^3] and reverberation time t_r [s], the environmental correction K is approx. the same in all microphone positions. K can be estimated by means of Equation (9.5):

$$K = 10 \lg \left(1 + \frac{25 \cdot t_r \cdot S}{V} \right) \text{ [dB]} \qquad (9.5)$$

S [m^2] is the area of the measurement surface. t_r is usually frequency-dependent.

9.2 Background Noise Correction

The background noise level shall be measured in at least one of the microphone positions while the source under test is not operating, and the measurement results shall be corrected for the influence of background noise.

The corrections are made as shown in Annex B.

The Nordtest Sphere Method and the Nordtest Box Method can be applied when the background noise level is at least 3 dB below the total sound pressure level from both the source under test and the background noise.

If the sound pressure level with the equipment operating is less than 3 dB above the background noise level, the measurement results may be used only to indicate that the equipment noise level is below the background noise level. If possible the measurements shall be repeated at another time or closer to the source in order to reduce the influence from background noise.

If the source under test cannot be stopped for background noise measurements, the background noise level has to be estimated. The test report shall include information on how this estimate was made and the estimated background noise level.

10 WEATHER CONDITIONS

This Nordtest method can normally be applied in all kinds of weather provided no background noise from wind or rain interferes with the measurement results.

The propagation of sound outdoors is influenced by the weather conditions. The effects of varying weather conditions are important at large distances.

In practice the measurement distances will hardly exceed 50 or 100 m in source strength measurements. This only happens when the source is large and the microphone height required is 10 m in such cases.

This means that the effects of varying weather conditions are negligible.

11 ACCURACY

The accuracy of the source strength determined according to this Nordtest method depends on many parameters.

A low background noise level and a favourable acoustic environment combined with a large measurement distance in general lead to accurate results whereas less favourable conditions give larger uncertainty.

The Nordtest Box Method does not permit source directionality measurements. This can lead to an overestimation of the strength of directive noise sources in certain directions while significant underestimation is less likely to occur.

If the strength of a broad band industrial noise source operating under the same conditions is measured according to this standard at different locations the standard deviation of results is expected to be as shown in Table 5. The measurement uncertainty expressed as a 90 % confidence interval is approx. ±1.7 times the standard deviations from Table 5.

If the noise contains prominent discrete tones in one or more octave bands the measurement uncertainty is larger than for broad band noise sources in these bands. An evaluation has to be made in each individual case.

Table 5 Standard deviation of measured strength of broad band industrial noise sources.

Frequency [Hz]	63	125	250 – 500	1000-4000	800	Total A-weighted
Standard deviation [dB]	4	3	2	1.5	3	2

12 NORDTEST SPHERE METHOD

The Nordtest Sphere Method is applicable for testing any industrial noise source provided the acoustic environment allows measurements to be made at distances from the source equal to at least twice the characteristic dimension of the source.

Under such conditions this method is recommended.

12.1 Measurement Surface

When the reference box terminates on one reflecting plane (Figure 2), the measurement surface is a hemisphere (Figure 4 and Figure 5a). When the reference box terminates on two or three reflecting planes (Figure 2), the measurement surface is a 1/4-sphere or a 1/8-sphere, respectively (Figure 5b-c).

The centre of the measurement surface is the centre of the reference box plus its images in any nearby reflecting surfaces, i.e. the point marked "O" in Figure 2.

The radius R of the sphere should be made as large as possible within the constraints given by the acoustic environment (background noise, ground effect, reflections). Equation (12.1) shall be satisfied.

$$R \geqslant 2 \cdot d_o \qquad (12.1)$$

Furthermore no point on the measurement surface shall be less than 1 m from the nearest point on'the reference box.

12.2 Key Microphone Positions

The key microphone positions are placed on a circular path at a height of 0.6 x R and a horizontal distance from the sphere centre of 0.8 x R, Figures 4 and 5.

The microphone height shall be at least 1 m even if 0.6 x R < 1 m, and the microphone height can be limited to 10 m in cases when 0.6 x R > 10m.

There are 4 key microphone positions. Key microphone position No. 1 shall be chosen as the point on the circular path (Figure 4) at which the highest value of the overall A-weighted sound pressure level occurs.

Note: In case of (rotational) symmetry in a horizontal plane, e.g. as in many vertical fan outlets, only one microphone position is needed.

The remaining 3 key microphone positions on the hemisphere are placed evenly distributed on the circular path as shown in Figures 4 and 5.

When the source is at two reflecting planes, key microphone position No. 2 is at the point dividing the circular path in two equally long parts, and key microphone positions Nos. 3 and 4 are at 1 m from the wall, Figure 5b.

When the source is at three reflecting planes, key microphone positions Nos. 2 - 4 are placed in a similar way, Figure 5c.

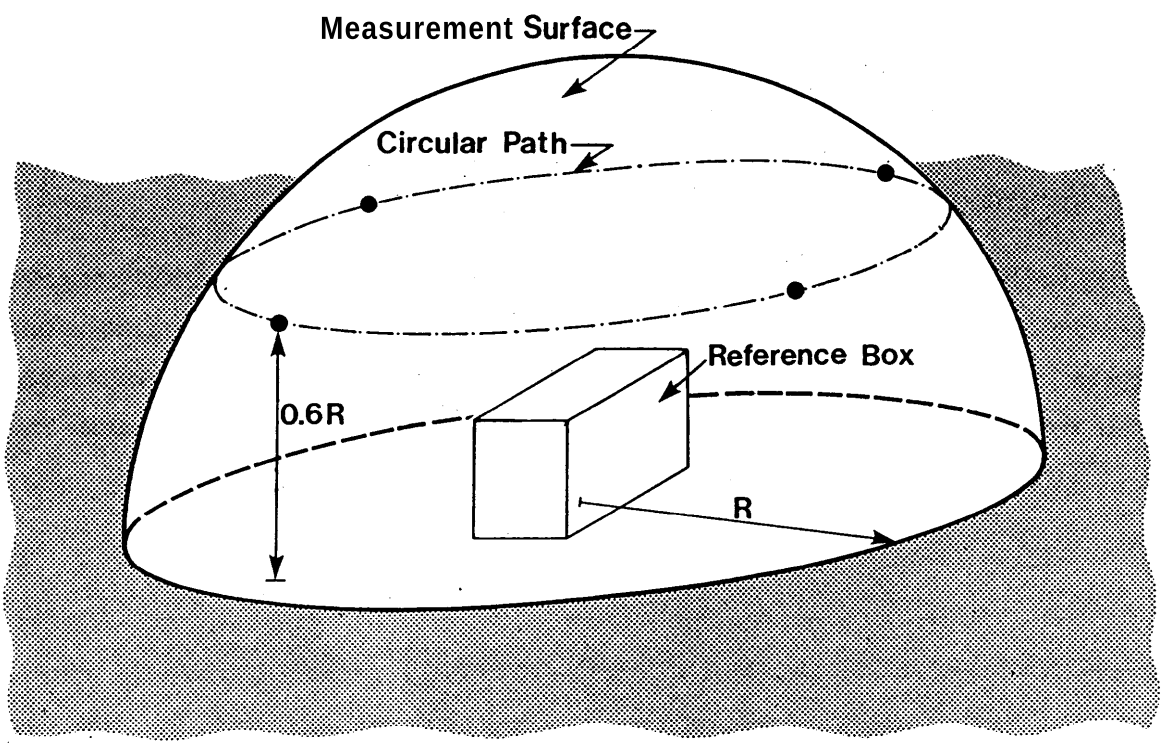

Fig. 4 Circular path on hemispherical measurement surface.

o Microphone positions

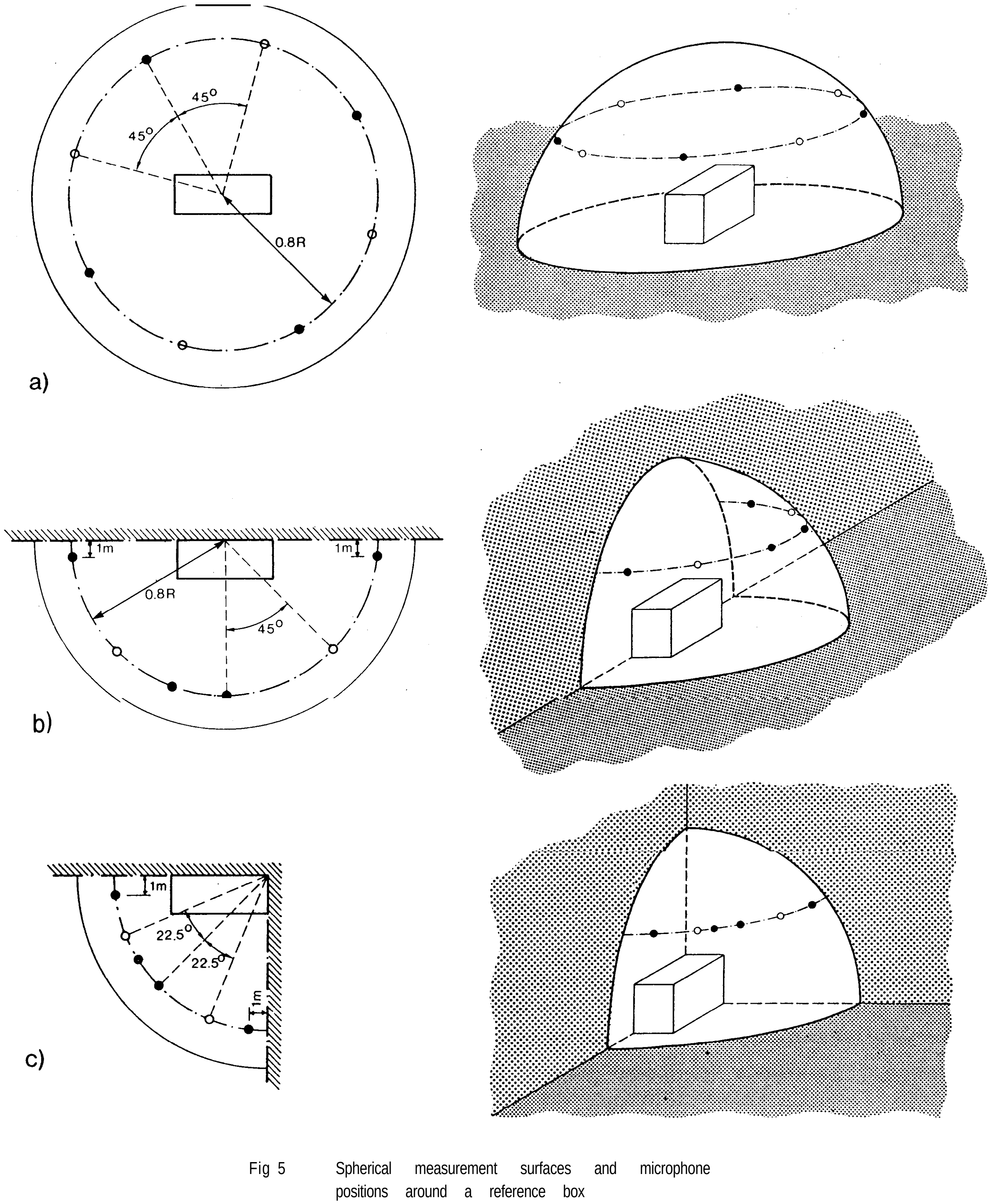

Fig 5 Spherical measurement surfaces and microphone positions around a reference box

a) on one reflecting plane
b) at two reflecting planes
c) at three reflecting planes
● key microphone positions
o additional microphone positions

12.3 Additional Microphone Positions

In cases when the difference between any two values of the overall A-weighted sound pressure level measured at the key microphone positions exceeds 6 dB, additional microphone positions are required.

When the reference box terminates on one reflecting plane, 4 additional microphone positions Nos. 5 – 8, shall be chosen as shown in Figure 5a. These positions are on the same circular path as the key microphone positions, but rotated 45º relative to these around the vertical axis.

When the source is at two or three reflecting planes, two additional microphone positions, Nos. 5 and 6, shall be chosen located on the same circular path as the key microphone positions at points dividing the circular path as shown in Figure 5b-c.

12.4 Calculation of Source Strength

Total Source Strength

The total source strength, L_W, in each octave band is calculated by means of Equation (12.2):

$$L_W = \overline{L_p} + 10 \lg \frac{S}{S_0} \text{ [dB]} \qquad (12.2)$$

$\overline{L_p}$ = Energy average value of sound pressure levels from all microphone positions, Equation (6.1) or (6.2) as appropriate [dB]

S = Area of measurement surface, Equation (12.3) $[m^2]$

S_0 = Reference area = 1 m^2

$$S = \begin{cases} 2\pi R^2 \text{ (hemisphere)} \\ \pi R^2 \text{ (1/4 sphere) } [m^2] \\ \tfrac{1}{2}\pi R^2 \text{ (1/8 sphere)} \end{cases} \qquad (12.3)$$

R is the radius of the measurement surface [ml.

Directional Characteristics

The directional correction, ΔL_Φ, shall be calculated by means of Equation (12.4) when additional microphone positions are required, cf. Section 12.3.

$$\Delta L_{\Phi i} = (L_{pi} - K_i) \ \overline{L_p} + 3n \text{ [dB]} \qquad (12.4)$$

L_{pi} = Octave band sound pressure level in microphone position No. i (after correction for background noise) [dB]

K_i = Environmental correction in microphone position No. i [dB]

$\overline{L_p}$ = Energy average sound pressure level, Equation (6.1) or (6.2) as appropriate [dB]

n = 0 when one reflecting plane is present near the source

n = 1 when two reflecting planes are present near the source

n = 2 when three reflecting planes are present near the source

Note: The value of AL $_\Phi$ according to Equation (12.4) is applicable for calculations of sound pressure levels in directions in front of the reflecting plane(s).

12.5 Information to be Reported

The following information, when applicable, shall be reported:

a) A thorough description of the sound source under test including its operating conditions, the position of its acoustic centre, and the dimensions of the reference box.

b) A sketch showing the locations of the microphone positions.

c) The measurement radius R and microphone height h.

d) The overall A-weighted source strength rounded to the nearest decibel.

e) The octave band source strengths rounded to the nearest decibel.

f) The directional correction, ΔL_Φ, based on overall A-weighted and octave band sound pressure levels.

g) Description of test environment including ground surface and reflecting obstacles.

h) Environmental corrections, K_i, applied in each microphone position.

13 NORDTEST BOX METHOD

The Nordtest Box Method is applicable for testing any industrial noise source. It is often the most appropriate method to use at sources situated in less favourable acoustic environments, e.g. where the background noise level is high or in the presence of sound-reflecting obstacles.

The Nordtest Box Method requires a large number of microphone positions at large sources and/or at short distances. No information on source-directional characteristics is obtained.

13.1 Measurement Surface

The measurement surface is a parallelepiped (box), the sides of which are parallel to and at a distance a from the sides of the reference box.

The distance a shall be larger than 0,15 m, and it should be larger than 1 m. The distance a should be made as large as possible within the constraints given by the acoustic environment (background noise, ground effect, reflections).

If a small distance a is chosen, the accuracy is reduced, especially at low frequencies and at the same time the necessary number of microphone positions becomes large.

13.2 Key Microphone Positions

The key microphone positions shall be chosen as shown in Figure 6: one position at the midpoint of each free vertical side of the measurement box and one position at each free corner of the measurement box.

Note: In case of (rotational) symmetry in the horizontal plane, e.g. as in many vertical fan outlets, only two microphone positions are needed: one at a box side midpoint and one at a free box corner.

If the measurement box is close to the reference box, extra microphone positions shall be chosen at the midpoint of each free edge of the measurement surface. This is the case when a is shorter than half the smallest side length of the reference box (i.e. $a < l_1/2$, $a < l_2/2$, or $a < l_3/2$).

The heights of the key microphone positions are:

$$\left.\begin{aligned} h_1 &= (l_3 + a)/2 \\ h_2 &= l_3 + a \end{aligned}\right\} \qquad (13.1)$$

The heights h_1 and h_2 shall be at least 1 m, and in cases when h_1 or h_2 is larger than 10 m, the microphone heights exceeding 10 m can be made 10 m or lower.

In cases when $(l_3 + a)/2 < 1$ m, h_1 is chosen in the interval 1 m $\leq h_1 \leq h_2$.

In cases when $l_3 + a \geq 10$ m, h_2 can be chosen in the interval 1 m $< h_2 \leq 10$ m.

In cases when $(l_3 + a)/2 > 10$ m, h_1 can be chosen in the interval 1 m $< h_1 \leq 10$.

When h_1 or h_2 is chosen in one of the intervals above, the microphone positions should be chosen at the height where the highest overall A-weighted sound pressure levels are expected to occur. h_1 and h_2 may then coincide.

When other heights than given by Equation (13.1) are used, this shall be stated in the test report.

Similarly, if for some reason one or more microphone positions is/are omitted, this shall be stated in the test report and the reason for the omission shall be given.

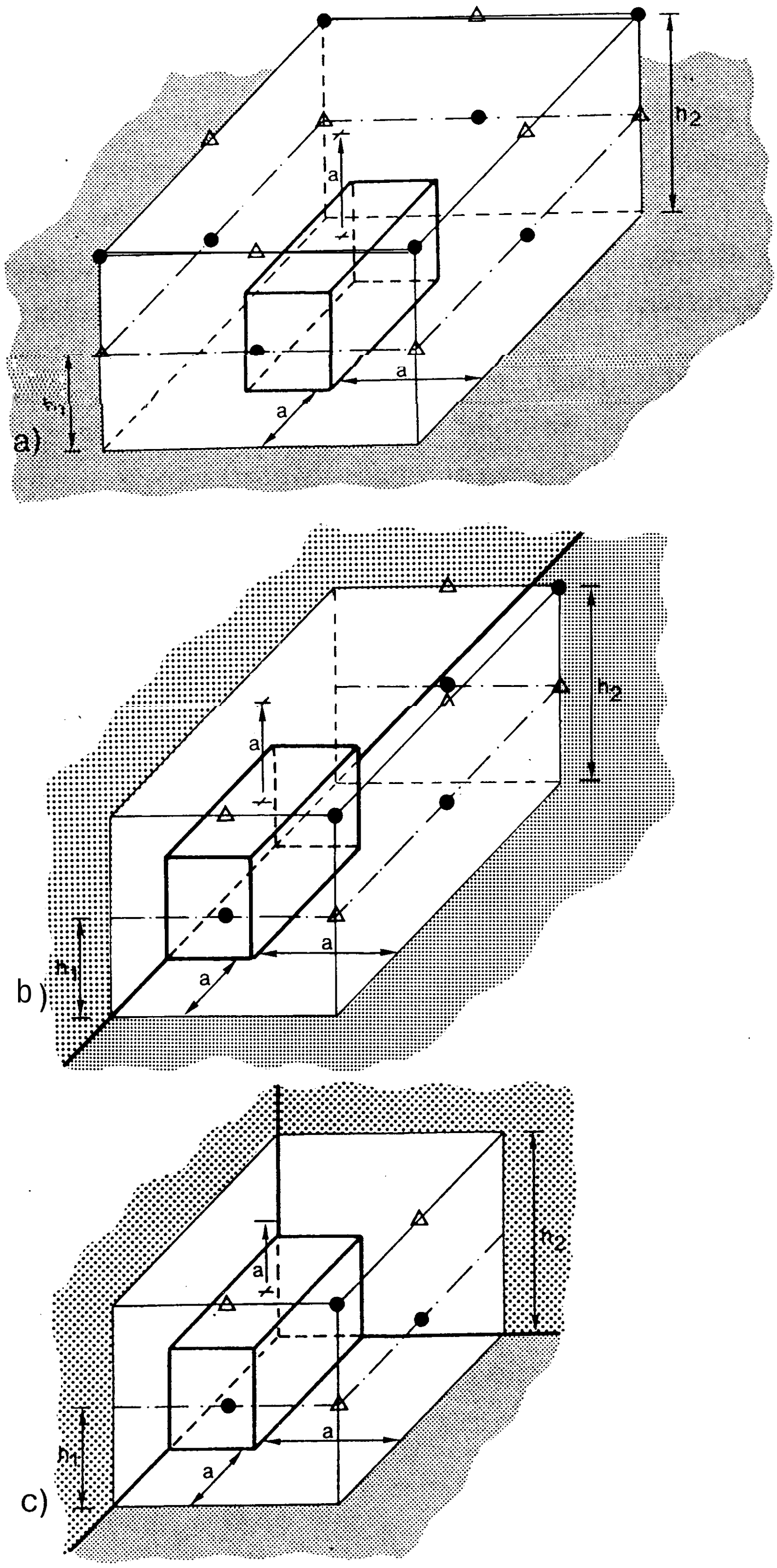

Fig 6 Measurement boxes terminating on a) one, b) two and c) three reflecting planes with key microphone positions.

● Sides and corners of the measurement box

A Extra positions to be used when the measurement box is close to the reference box

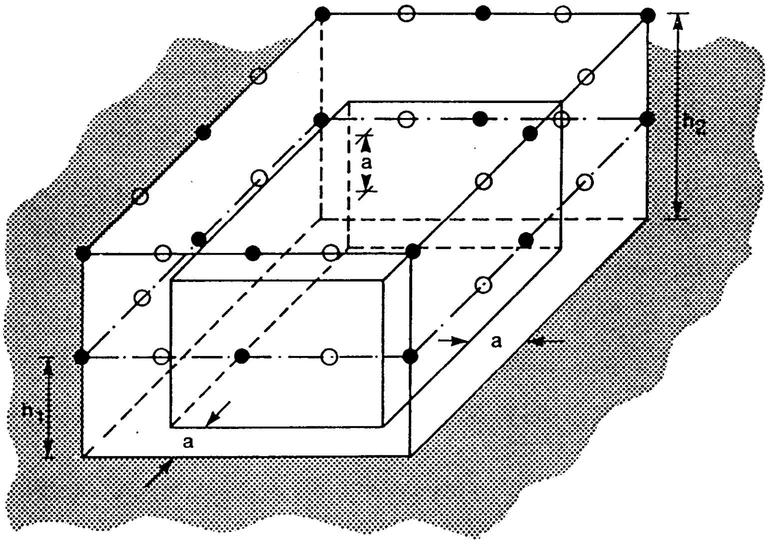

Fig 7 Example. illustration of key and additional microphone positions.

● Key positions

△ Additional positions

13.3 Additional Microphone Positions

Additional microphone positions are required if the difference between the overall A-weighted sound pressure levels measured at any two key microphone positions exceeds 6 dB and at the same time the distance measured along the measurement surface between any two adjacent key microphone positions exceeds 2a.

These additional microphone positions shall be placed at the same heights as the key microphone positions. They shall be evenly spaced between the key microphone positions in such a way that the distance measured along the measurement surface between any two adjacent microphone positions is smaller than 2a, cf. Figure 7.

13.4 Near-Field Correction

When the reference box dimensions are large compared with the measurement distance, a correction of the measured sound pressure levels shall be made. For the purpose of this Nordtest method the correction, E, can be taken from Table 7.

Note: This correction takes into account the effect of sound energy reaching omnidirectional microphones from directions other than those perpendicular to the measurement surface.

S_{ref}/S [-]	E [dB]
$0 < S_{ref}/S \leq 0.4$	0
$0.4 < S_{ref}/S \leq 0.7$	1
$0.7 < S_{ref}/S \leq 0.9$	2
$0.9 < S_{ref}/S < 1.0$	3

Table 7 Correction, E, due to near-field error.

S = area of measurement box surface [m^2]

S_{ref} = area of reference box surface [m^2]

13.5 Calculation of Source Strength

The total source strength, Lw, in each octave band is calculated by means of Equation (13.2):

$$L_W = \overline{L_p} - E + 10 \lg \frac{S}{S_0} \text{ [dB]} \qquad (13.2)$$

$\overline{L_p}$ = Energy average sound pressure level from all microphone positions, Equation (6.1) or (6.2) as appropriate [dB]

E = Near-field error correction, Table 7 [dB]

S = Area of measurement box surface [m^2]

S_0 = Reference area = 1 m^2

No reliable information on source-directional characteristics can be obtained on the basis of results of Nordtest Box Method measurements.

13.6 Information to be Reported

The following information, when applicable, shall be reported:

a) A thorough description of the noise source under test including its operating conditions, the position of its acoustic centre, and the dimensions of the reference box.

b) A sketch showing the locations of the microphone positions.

c) The measurement distance, a, and the height(s) of the microphone positions.

d) The overall A-weighted source strength rounded to the nearest decibel.

e) The octave band source strengths rounded to the nearest decibel.

f) Descripiton of test environment including ground surface and reflecting obstacles.

g) Environmental corrections, K_i, applied in each microphone position.

h) The applied near-field error correction, E.

GUIDELINES FOR SELECTING AN APPROPRIATE METHOD

(This annex is not an integral part of the method)

To select the most appropriate measurement method to use at a particular source under test, the actual test environment, the source characteristics (e.g. directional or not) and the purpose of testing should be evaluated.

In general the microphone positions should be located as far away from the source as possible in order to obtain optimum accuracy in the results of measurements.

Table A.1 summarizes various aspects of method applicability. When a particular method is applicable under the condition specified in the rows of the left column in Table A.1 a plus sign is shown in the same row of the column marked with the method name. (+) indicates limited applicability.

A.1 Nordtest Sphere Method

The Nordtest Sphere Method is an engineering method specifying that sound pressure levels shall be measured at microphone positions on a sphere enclosing the noise source under test. The required sphere radius may be quite large. This limits the application to situations with a favourable acoustic environment. Information on source-directional characteristics is obtained when the Nordtest Sphere Method is applied.

A.2 Nordtest Box Method

The Nordtest Box Method is an engineering method specifying that sound pressure levels shall be measured at microphone positions on the surface of a notional box enclosing the noise source under test. The distance from source to box surface is allowed to be quite small. This means that the box method is applicable under unfavourable acoustic conditions. No information on source-directional characteristics is obtained when the Nordtest Box Method is applied.

A.3 Process Plant Method (IS0 8297)

The Process Plant Method is an engineering method specifying that sound pressure levels shall be measured at microphone positions on a contour surrounding the plant area. This method is applicable at industrial plants with numerous noise sources and with principal dimensions in the horizontal plane. The entire plant is considered one noise source. No information on source-directional characteristics is obtained when this method is applied.

A.4 Extrapolation Method (IS0 WG20/N45)

The Extrapolation Method specifies that sound pressure levels shall be measured at one or more microphone positions in directions of particular interest, e.g. the direction of the nearest dwelling or residential area. The source strength in each direction is determined. The entire plant is considered one noise source. The measurement distance is large, and a favourable acoustic environment is required.

A.5 Intensity Methods (IS0 9614 and Nordtest proposal ELAB A86166)

The Intensity Methods specify that sound intensity level and sound pressure level shall be measured on a surface enclosing the noise source under test. The sound power level of the source is calculated from the sound intensity levels measured. These methods are applicable to noise sources placed in unfavourable acoustic environments. Both source emission and background noise have to be stationary in order for intensity measurements to be useful.

IS0 9614 prescribes intensity measurements at discrete positions whereas the proposed Nordtest method prescribes intensity measurements made while scanning along the measurement surface.

A.6 Reference Sound Source Methods (IS0 3747 and NT ACOU 060 and NT ACOU 070)

The Reference Sound Source Methods specify that sound pressure levels shall be measured at microphone positions around the noise source under test.

In the same microphone positions sound pressure levels produced by a reference sound source placed at one or more positions near the source under test are measured. The sound power level of the source under test is then calculated taking into account the deviations between measured reference sound source data and corresponding data determined during calibration of the reference sound source.

The Reference Sound Source Methods are generally applicable. They are suited for measurements in unfavourable acoustic environments. IS0 3747 is a survey method while NT ACOU 060 and 070 are engineering methods with more strict requirements concerning reference source calibration and positioning during tests than those of IS0 3747. NT ACOU 060 is applicable to noise sources which can be moved and with a characteristic dimension d_o not exceeding 2 m. NT ACOU 070 is applicable to larger noise sources and to noise sources which cannot be moved.

A.7 IS0 3744

IS0 3744 is an engineering method specifying that sound pressure levels shall be measured in microphone positions on a hemisphere or box enclosing the noise source under test.

The necessary number of microphone positions (10 – 20) is rather large, the maximum source dimension is limited to 15 m, and strict demands are made as to the quality of the acoustic environment, e.g. environmental correction $K < 2$ dB. Therefore this method is seldom useful in practical noise prediction work.

Information on soure-directional characteristics is obtained when IS0 3744 is applied.

A.8 IS0 3746

IS0 3746 is a survey method requiring that sound pressure levels are measured at 4 or more microphone positions on a hemisphere or box enclosing the noise source.

This method allows measurements in rather unfavourable acoustic environments, e.g. environmental correction K < 7 dB. No information on the source-directional characteristics and the octave band frequency spectrum is obtained, and thus this method is of limited interest in connection with calculations of sound pressure levels in the environment.

A.9 References

IS0 3744 Acoustics – Determination of sound power levels of noise sources – Engineering methods for free-field conditions over a reflecting plane.

IS0 3746 Acoustics – Determination of sound power levels of noise sources – Survey method.

IS0 3747 Acoustics – Determination of sound power levels of noise sources – Survey method using a reference sound source.

IS0 8297 [2)]
Acoustics – Determination of sound power levels of multi-source industrial plants for the evaluation of the sound pressure levels in the environment – Engineering method.

ISO/TC43/SCI/WG20/N45 [2)]
Acoustics – Determination of directional sound power levels of large industrial noise sources – Engineering method (Draft proposal presented to IS0 Working Group 20, May 1986).

ISO/DP 9614 [2)]
Acoustics – Determination of the sound power levels of noise sources using sound intensity measurement at discrete points.

NT ACOU 060
Noise sources: Sound power level; engineering method using a reference sound source.

NT ACOU 070
Noise sources: Sound power level; engineering method using a reference sound source in situ.

Proposed Nordtest-method
"The determination of radiated sound power using intensity measurements in situ". ELAB report STF44 A861 66, Trondheim 1986.

2) At present at the stage of draft.

Table A.1 Applicability of various measurement methods
under the conditions specified in the left column.

+ Applicable method

(+) Limited applicability

METHOD / CONDITION	ISO3744 (Engineering)	ISO 3746 (Survey)	ISO 3747 (Ref. Sound Source)	NT ACOU 060 (Ref. Sound Source)	NT ACOU 070 (Ref. Sound Source)	ISO 8297 (Process Plant)	ISO WG20/N45 (Extrapolation)	ISO/DP 9614 and Nordtest Proposal (Intensity)	Nordtest Sphere	Nordtest Box
$R>2d_0$	+	(+)	(+)	(+)	(+)		(+) $> d_o$		+	
$R<2d_0$		+	+	+	+	+		+		+
More than one reflecting plane			+	+	+	?	+	+	+	+
Porous ground surface			+	+	+		+	+	+	+
Multiple sources						+	+		(+)	(+)
Single source	+	+	+	+	+			+	+	+
Information on directionality	+		+	+	+		+		+	
< 3 dB above background noise								+		
Environment correction > 2 dB		+	+	+	+		+	+	+	+
Environment correction > 7 dB			+	+	+		(+)	+	(+)	(+)
Number of microphone positions	10-20	4-30	5-30	3-30	3-30	Many	1-8	Many	4-8	3-30

GENERAL CORRECTIONS AND CALCULATIONS

(This annex is not an integral part of the method)

B.l A-Weighting

To convert linear octave band levels to A-weighted levels, the following weighting corrections shall be used:

Octave band centre frequency [Hz]	31.5	63	125	250	500	l k	2k	4k	8k	16k
A-weighting correction [dB]	-39	-26	-16	-9	-3	0	+1	+1	-1	-7

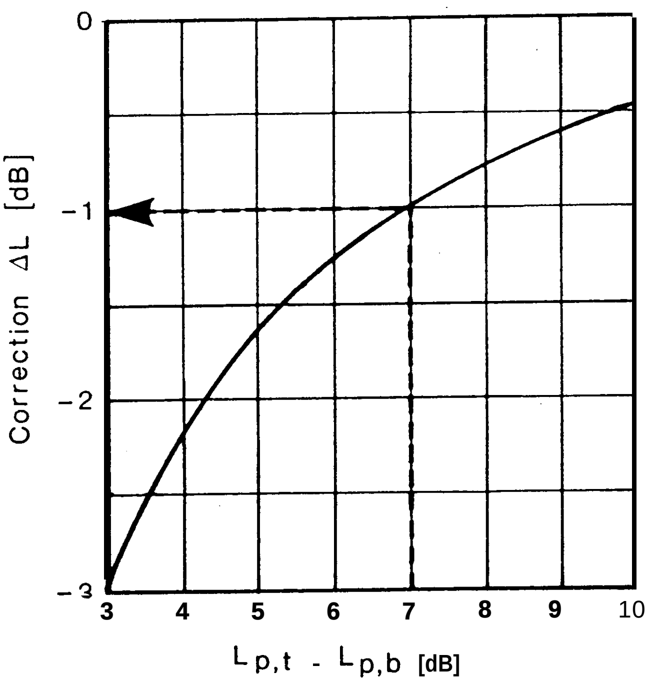

Fig B.l Diagram for determining the correction ΔL for background noise, see text.

8.2 Energy-Equivalent Sound Pressure Level

From a series of different sound pressure levels from a noise source working in various operating conditions, each associated with a particular noise emission, $L_{eq,T}$ for the reference time interval T may be calculated from Equation (B.1):

$$L_{eq,T} = 10 \lg \left(\frac{1}{T} [t_1 \cdot 10^{\frac{L_{p1}}{10}} + ... + t_n \cdot 10^{\frac{L_{pn}}{10}}] \right) \quad (B.1)$$

$L_{p1...n}$ is a discrete sound pressure level lasting for a period, $t_1 \ldots t_n$

T is the total reference time interval.

8.3 Background Noise Correction

Corrections for the effects of background noise are made by means of Equation (B.2):

$$L_{p,s} = 10 \lg [10^{\frac{L_{p,t}}{10}} - 10^{\frac{L_{p,b}}{10}}] \quad (B.2)$$

$L_{p,s}$ is the sound pressure level generated by the source under test.

$L_{p,t}$ is the total sound pressure level from source and background noise.

$L_{p,b}$ is the sound pressure level of the background noise.

If preferred Figure B.1 can be used. The abscissa is the difference $L_{p,t} - L_{p,b}$ between the sound pressure levels of the total noise (source and background) and the background noise, respectively. As shown in Figure B.l a correction ΔL is determined. This correction shall be added to the total sound pressure level $L_{p,t}$ in order to determine the sound pressure level $L_{p,s}$ of the noise from the source:

$$L_{p,s} = L_{p,t} + \Delta L \quad (B.3)$$

B.4 Wavelength of Sound in Air

For the purpose of this Nordtest-method the wavelengths of sound in air can be taken from the following table:

Octave band centre frequency [Hz]	63	125	250	500	l k	2k	4k	8k
Wavelength λ_c [m]	5.4	2.7	1.4	0.68	0.34	0.17	0.09	0.04