RCMP
ROYAL CANADIAN MOUNTED POLICE

Shooting Ranges and Sound

Royal Canadian Mounted Police · Gendarmerie royale du Canada

Canada

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ABOUT THIS DOCUMENT

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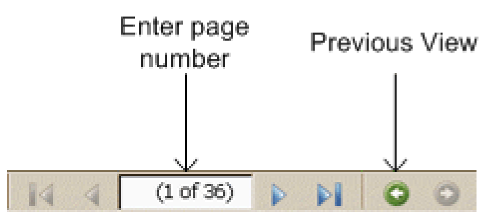


EXECUTIVE SUMMARY

"Shooting Ranges and Sound" is a document intended for those people not trained in acoustics, who would like to gain an understanding of the propagation and control of sound and firearm noise. Such persons might be involved in the planning, construction or regulation of a shooting range in development or re-development.

The introductory section of this document provides the background information needed to understand the mechanisms involved in the generation, propagation and control of shooting noise. It describes the physics of sound, mechanisms of noise generation, sound characteristics of firearms, characteristics of sound wave propagation and sound measurement techniques.

Subsequent sections in the document describe existing noise guidelines or noise regulations and limits that are found in literature and/or law. With respect to these limits and measurements of shooting noise, an assessment can be made.

The concluding sections identify basic noise control principles and noise reduction techniques, and consider the construction of a new shooting range. Typical principles, such as shooting noise levels, noise reduction with distance and sound barriers, provide real-life examples and realistic expectations for noise control.

1 INTRODUCTION

This document is a precursor to “Range Design and Construction Guidelines” and was prepared for the Government of Canada. It is intended for use by a lay person who might be involved in the planning, construction or regulation of a shooting range in development or re-development.

“Shooting Ranges and Sound” solely reviews various guidelines, regulations and limits for shooting noise; it does not set nor recommend limits. The examples included in the document are intended to provide realistic interpretations of **sound level**. This document should not be used for design purposes, as the sound levels of shooting noise are dependent on many factors, all of which must be considered in a particular application.

1.1 PHYSICS OF SOUND

This section presents background information that is essential to the understanding of shooting range noise generation, propagation and control. **Sound**, as we hear it, consists of a pressure wave with **frequency** (or pitch), travelling in a direction. Subsections 1.1.1 through 1.1.5 describe the components of sound in more detail.

1.1.1 Sound Waves

Sound is a disturbance that propagates through an elastic material, at the speed characteristic of that material. In general, such a disturbance reaches the human ear by travelling through air.

In more technical terms, let us consider a body vibrating in air. As it moves in an outward direction, it pushes a “layer” of air along with it. Since the pressure in this layer is higher than that in the undisturbed surrounding atmosphere, the air particles in the body tend to move in an outward direction and transmit their motion to the next layer. This layer then transmits its motion to the next, and so on.

As the vibrating body moves inward, the layer of air adjacent to it is rarefied to the point where its pressure is lower than that of the undisturbed atmosphere. This layer of rarefaction follows the layer of compression in the outward direction, at the same speed. The pressure at the layer of compression is higher than that of the undisturbed atmosphere. The succession of outwardly travelling layers of compression and rarefaction is called *wave motion*.

The individual vibrating particles that transmit a sound wave do not change their average positions if the transmitting medium itself is not in motion. They merely vibrate about their equilibrium positions.

1.1.2 Frequency

The subjective pitch of a simple sound is determined by the number of times per second at which the **sound pressure** disturbance oscillates between positive and negative values. The physical measure of this oscillation rate is called frequency. The unit of frequency is the cycle per second (cps), which by international standards is called *hertz* (Hz). The range of normal adult hearing extends approximately from 20 to 16,000 Hz. The human ear is most sensitive – that is, the threshold of audibility is lowest – for sounds around 3,000 Hz. For reference purposes, the frequency of the middle “C” key on a piano is 256 Hz, most vowels in speech are in the 250 to 500 Hz range, and consonants like the letter “S” are in the 2000 to 3000 Hz range.

1.1.3 Sound Pressure

Sound can be sensed by the measurement of some physical quantity in the medium that is disturbed from its equilibrium value. The physical quantity that is generally of interest is the incremental variation in **sound pressure** above and below atmospheric pressure, which is normally about 100,000 Pa (1 Pa = 1 pascal = 1 newton/metre^2, N/m^2). Sound pressures are extremely small. For normal speech, they average about 0.1 Pa above and below atmospheric pressure, at a distance of one metre from the talker.

1.1.4 Sound Pressure Levels, Decibels

The human ear is remarkably sensitive and responds to sound pressures ranging from 0.00002 Pa to 60 Pa, which is a one-million-to-one ratio. The tripling of the **sound pressure** is sensed as a doubling of the loudness; therefore, the threshold of audibility to pain is about twelve doublings of the loudness. This implies that a compressed scale will correlate better to loudness.

Taking the ratio of a given sound pressure to the threshold of hearing (technically, it is the ratio of the squares of the pressures), and then the logarithm of that ratio, results in a scale of 0 to about 12 representing the range from threshold of hearing to painful. These scale numbers are called *bels*, which is a measurement unit named after Alexander Graham Bell.

Multiplying the scale by 10 results in a range of 0 to 120 dB (**decibels** – tenths of bels), which is a much easier range to use. Each set of 10 dB represents a doubling of the subjective impression of the loudness of the sound.

1.1.5 Directivity

Directivity is a measure of the difference in sound intensity, with respect to direction, and is usually stated as a function of angular position around the acoustical centre of the source and of **frequency**. Some sources of **sound** radiate nearly uniformly in all directions. These are called *nondirective sources*. In general, such sources are small in size as compared to the wavelength of the sound that they are radiating. Most practical sources are somewhat directive; in other words, they radiate more sound in some directions than in others. However, it is natural for sources of noise to be nondirective or nearly so at low frequencies. As the frequency increases, directivity generally also increases.

1.2 MECHANISMS OF NOISE GENERATION AND SHOOTING NOISE GENERATION

In this section, two mechanisms of noise generation and shooting noise generation are discussed.

1.2.1 SHOCK WAVE

Impulse noise is a transient noise that arises as a result of a sudden release of energy into the atmosphere. The physical characteristics of these impulses are largely dependent upon the geometry and scale of the source. The resulting waveform is further dependent upon the environment in which it propagates.

More specifically, impulses fall within the domain of shock wave physics. Given a sound source and receiver, gradually increase the **sound pressure level** of the source and measure the signal transmitted to the receiver. At the lower range of the sound pressure level, there is a linear relation between the source and the received sound pressure level. As the sound pressure level increases, the source-receiver function deviates from linearity and the wave distorts. This wave distortion is due to the wave speed that changes from one point to another. The original high-level sinusoid gradually distorts into a "saw tooth"-like wave, referred to as a *shock sound wave*, or a repeated series of shock waves. Across a shock front, the properties of the system change discontinuously. There are very high gradients of property change and viscous stresses become large. The thickness of the shock front is related to the rise time of the ideally-measured pressure "jump" across the shock.

1.2.2 VIBRATING SURFACES

Sound can also be generated by a vibrating surface. A layer of air adjacent to the surface is moved and sound is subsequently radiated, as previously explained in **Section 1.1.1**. A loudspeaker mounted to a wall is an example. In a more complicated case, knocking on a door causes the surface of the door to vibrate and generate sound both inside and out. Larger surfaces generate more sound energy than smaller ones, which is the reason the tympani in an orchestra is large. Furthermore, sound can strike a surface causing it to vibrate and radiate sound from the other side. This is how sound gets through a glass window.

1.3 SOUND CHARACTERISTICS OF FIREARMS

The muzzle report can be regarded as a point source with a directional characteristic. The ballistic wave can be treated as a coherent line source, radiating a conical shock wave. The propagation of the ballistic wave is extremely directional and is limited to a well-defined geometrical area. It is radiated mainly at an angle of 60° from the bullet path. The sound of a firearm usually concentrates on high **frequency** (i.e. above 1000 Hz).

Some examples of **sound pressure levels** of firearms, measured at 10 m from the muzzle (downrange), using the **A-weighted** impulse setting, are listed in **Table 1** below [8]. This type of measurement is discussed further in **Section 1.6**. It should be noted that the sound pressure levels are mostly between 100 dBA(I) and 130 dBA(I). These are given in dBA(I) since it is the correlation between the maximum **sound level** and the subjective impression of loudness that is important. Directivity diagrams of a typical rifle and a typical shotgun are shown in **Figure 1** and **Figure 2** respectively[1].

[1] Falch, Edvard, "Noise from Shooting Ranges, a Nordic Prediction Method for Noise Emitted by Small-Bore Weapons," Nordic Council of Ministers' Noise Group, NBG, May 1984.

Table 1: Sound Pressure Levels of Firearms Being Measured at 10 m from the Muzzle (Downrange)

Name, Calibre and Ammunition of Weapon	Sound Pressure Level in dBA(I)
Rifle M/96, 6.5 mm, SK PTR M/94 PRJ M/41	126
Rifle M/96, 6.5 mm, KPTR M/14	120
Hunting rifle, 7.62 mm, 30-60 Norma Jaktmatch	127
Hunting rifle II, 5.7 mm, 222 Remington N. Jaktmatch	124
AK 4, 7.62 mm, KPTR 10	120
AK 4, 7.62 mm, SK PTR 10 PRJ	128
AK 5	125
CC 63 Junior, Cal. 22, NORMA 22 LR (pistol)	103
Pistol m/40, 9 mm, SK PTR M/39 B	126
Shotgun, Cal. 12, NIKE Skeet, 70 mm, 32 g, 2 mm	127

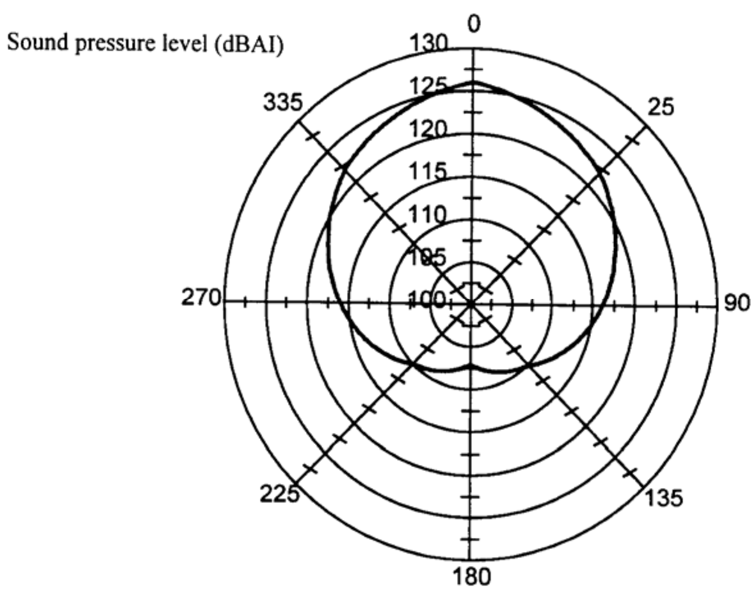


Figure 1: Directivity of a Typical Rifle at 10 m

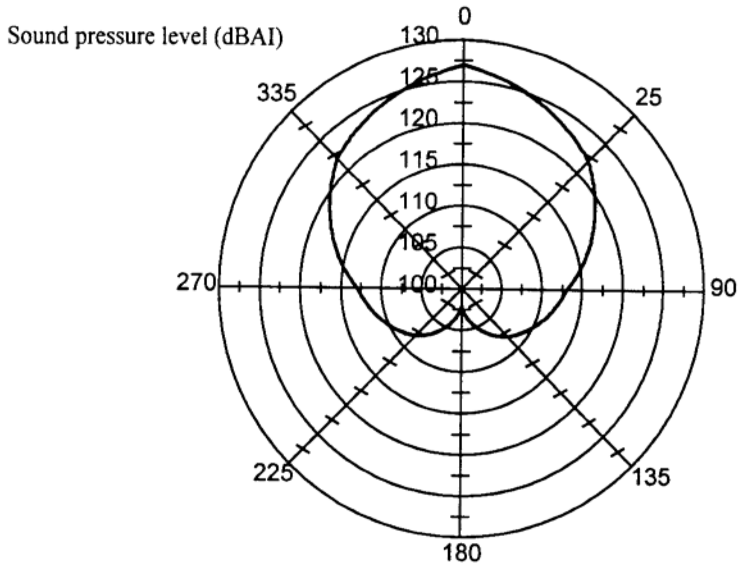


Figure 2: Directivity of a Typical Shotgun at 10 m

1.4 SOUND PROPAGATION

This section describes the environmental factors affecting the propagation of sound.

1.4.1 Distance

Sound spreads spherically at propagating distances that are large, as compared to the size of the source (point source approximation). Therefore, the **sound level** at the receiver decreases at a rate of 6 dB per doubling of distance from the source. From a line source, the propagation is more nearly cylindrical and the sound level decreases at 3 dB per doubling of distance. Although other factors can come into play, actual sound measurements often show this characteristic decay of 6 dB per doubling of distance.

1.4.2 Ground Effect

The “ground effect” occurs over soft surfaces, such as a ploughed field or grass-covered field. A reflection from the soft surface becomes out of phase and then interferes with sound going in a straight line from source to receiver. The interference almost cancels the straight line sound resulting in as much as a 25 dB reduction in sound level.

1.4.3 Air Absorption

Sound absorption occurs due to the vibration relaxation of oxygen molecules. Collisions with water vapour molecules is an important part of the energy transfer process and the **frequency** of maximum absorption is strongly dependent on the concentration of water vapour. At normal temperature and humidity, the oxygen relaxation results in strong absorption of sound at frequencies above approximately 2 kHz, which is significant for shooting range noise.

1.4.4 Weather, Wind and Temperature Inversion

Weather is an important factor in outdoor sound propagation. Under most weather conditions, both wind and temperature vary with height above the ground. These vertical gradients cause the speed of sound to vary with height, which in turn cause the sound waves to travel along curved paths from source to receiver. For downwind propagation, the speed of sound relative to the ground increases with height, and sound paths are concave downwards due to the drag on the moving air at the ground. Conversely, for upwind propagation, speed decreases with height and sound paths tend to curve upwards, thus producing a shadow zone near the ground beyond a certain distance from the source. Hence, sound levels are increased downwind and decreased upwind.

In a temperature inversion, most common at night and in the early morning due to radiation cooling of the ground, the sound speed increases with height up to a few tens or hundreds of metres, and sound paths are concave downwards. Under conditions of temperature lapse, which are most common during the day when the air near the ground is warmer, the ray paths curve upwards and produce a refractive shadow zone near the ground beyond a certain distance that depends on height of source above the ground. Sound levels are increased during a temperature inversion, and reduced in “normal lapse” conditions.

The scattering effects of atmospheric turbulence increase with increasing distances of propagation. They increase approximately as the square root of increasing sound frequency and are greater in regions of the spectrum where the sound level is determined by interference or diffraction mechanisms.

1.5 HUMAN SENSITIVITY

The greatest hearing acuity ranges from **sound pressure level** 40 dB to 80 dB and **frequency** 300 Hz to 5 kHz. Hearing acuity is poor at the extremes of the sound pressure level and frequency ranges.

The human ear requires a finite amount of time to register a **sound**. Very short sounds (those that last less than about 0.2 seconds) do not register the same loudness as they would if they were to continue for a larger period of time.

Sudden or unexpected noise can evoke a startle reflex, where the body is prepared for “fight or flight.” The body normally returns to the pre-exposure condition over a period of a few minutes. However, it is suggested that sustained or repeated exposure could lead to persistent changes in the neurophysiological, endocrine, sensory, digestive and cardiovascular systems, which in turn could cause deterioration in health.

1.6 SOUND MEASUREMENT

This section presents various sound measurement cases.

1.6.1 Constant Sounds

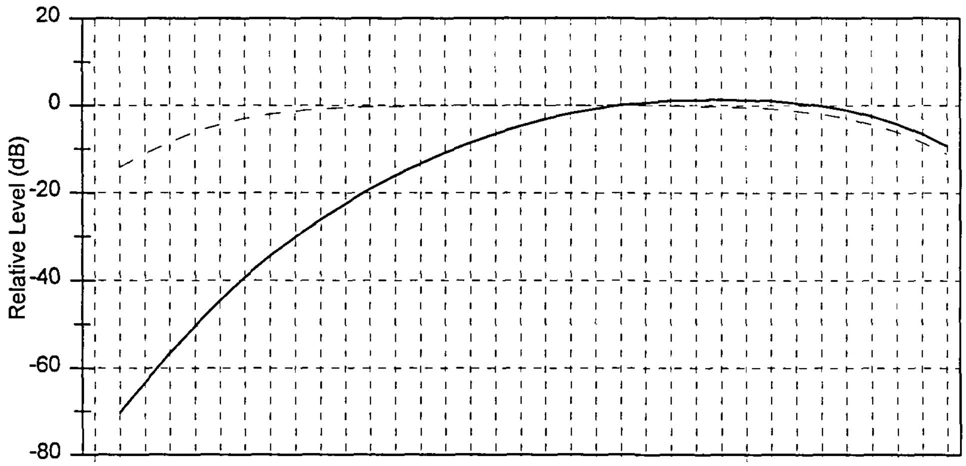
As described in **Section 1.1**, sound is a pressure wave travelling through the air from a source to a receiver. The simplest sound measurement case is that of a constant sound, such as that originating from a hydro transformer or idling truck.

Linear, A and C Frequency Weighting

The human ear does not hear all **frequencies** equally well. The human ear is significantly insensitive to low frequency sounds (from 20 Hz to 250 Hz), sensitive to mid-frequency sounds (from 500 Hz to 2 kHz) and somewhat insensitive to high frequency sounds (from 4 kHz to 16 kHz).

The frequency response of the human ear is taken into account by “weighting” the sound according to the frequency. If a sound is measured “un-weighted” – that is, with a “linear” or “Lin” frequency weighting – then the incoming **sound pressure** is not changed. The result is described as a **sound pressure level** and is expressed in dB, dB(Lin) or dBLin.

At present, the most common and widely used frequency weighting is the **A-weighting**. The frequency characteristic of the A-weighting is shown in **Figure 3**.



Frequency (Hz)

A weighting — — C weighting

Figure 3: Frequency Characteristics of A-Weighting and C-Weighting

If a **sound** is measured with the A-weighting, then the result is described as a “sound level” and is expressed in dBA or dB(A).

“C-weighting” is sometimes used for **impulse noise** measurement, although it is not often used for general **sound level** measurement. The C-weighting is similar to linear weighting, as only the low and high frequencies are reduced. C-weighting is also shown in Figure 3 above.

Sound pressure levels, expressed in dBA, for a wide range of typical sounds are shown in Table 2. The sound levels are given in dBA because they are relatively steady and the dBA value corresponds to the subjective impression of loudness.

Table 2: Typical Sound Pressure Level Encountered in Daily Life

Sound Pressure Level dB(A)	Description of Sound Source	Subjective Evaluation
140	Jet engine	Deafening
130	Jet aircraft during takeoff (300 ft. away)	Painful
120	"Hard rock" band (with electronic amplification)	Onset of pain
107	Air hammer	Temporary hearing loss
100	Crowd noise at football game	Very loud
92	Heavy city traffic	Very loud
80	Ringing alarm clock (at 2 ft.)	Very loud
70	B-757 aircraft cabin during flight	Loud
65	Busy restaurant or canteen	Loud
60	Conversational Speech	Moderate
5	Window air conditioner	Moderate
34	Soft whisper (at 5 ft.)	Faint
20	Rustling leaves	Very faint
10	Human breathing	Very faint

Slow Sound Level Meter Response

Sound level meters are originally analog measuring devices indicating the **sound level** by means of a moving needle. The maximum speed at which the needle moves is set by the "response time" of the needle. If the response time is long, then the needle moves more slowly. If the response time is short, then the needle moves more quickly. For the measurement of constant (or nearly constant) sound, a **slow response** time of 1 second is defined.

1.6.2 Time-Varying Sounds

If a time-varying **sound** is measured, such as that from a passing truck, then the **sound level** expressed in dBA will rise and fall. This presents a more difficult problem for measurement than with a constant sound level.

Fast Sound Level Meter Response

In order to measure time-varying sounds, such as those from a passing truck, the “fast” meter response time of 0.125 seconds is defined. This allows the meter needle to move faster than it does for the **slow meter response** time. Using the **fast response** will result in the **sound level meter** needle rising as the truck approaches, reaching a maximum value that can be recorded, and then dropping as the truck recedes. The “fast” response corresponds well with the subjective impression of loudness because a response time of 0.125 seconds is close to that of the human ear.

Modern digital sound level meters have a “Maximum” or “Max” Hold capability that automatically holds the maximum sound level achieved.

The Energy Equivalent Sound Level, Leq

Instead of measuring the **sound level** from a single passing truck, let us say that we need to measure the sound from traffic on a typical street. In this case, there will be many vehicles passing by, with each one having its own maximum level. Therefore, we must consider how to assess this time-varying **sound**. A method of describing time-varying sounds using a single number, which has gained widespread use, is the Energy **Equivalent Sound Level**, or “Leq.” The Leq of a sound is that single level which represents the same energy as the time-varying sound over the measurement period. **Integrating Sound Level Meters** measure Leq values directly by summing the incoming sound energy over the time of the measurement, averaging the energy, and then indicating a single Leq value for the measurement. Studies have shown a reasonable correlation between Leq sound levels in dBA and the overall community response to noise. The numerical definition of Leq is contained in **Section 6**.

Since a Leq measurement must be taken over a certain time period, the length of time for the measurement is important. Some common time scales associated with Leq measurements are 1 hour, 24 hours, a 16-hour daytime measurement (e.g. 07:00 am to 11:00 pm) and an 8-hour night-time measurement (e.g. 11:00 pm to 07:00 am).

The results of Leq measurements performed over these time periods are described as Leq (1 hour), Leq (24 hour), Leq (day) and Leq (night) respectively, and they are expressed in terms of dBA.

Single Event Level (SEL)

The Single Event Level (SEL) is a variation of the Leq, in which the level is adjusted to a standard time of 1 second. Calculation of the SEL from the **Leq** and measurement time is described in **Section 6**. The SEL has also been used for the measurement of **impulsive sound** from firearms. Levels measured in this way using **A-weighting**, are described as dBA(SEL).

1.6.3 Impulsive Sounds

The noise from firearms is described as being "impulsive," which signifies that the sound lasts for only a very short period of time, typically less than 1 second. **Impulsive sounds** are so short that even the **fast meter response** is not fast enough to give a true maximum level.

The overall energy of a series of impulsive noises from firearms is correctly described by means of a **Leq** measurement. However, there is doubt that the Leq measurement adequately describes the community response to impulsive sound because of the startling effect such noise can have. This problem can be overcome by adding a penalty to the measured Leq value. In the 1971 version of ISO 1996 [14], a 5 dB penalty is recommended for impulsive noise. Other research has indicated penalties of 7 dB [25], 10 dB [10] or 12 dB [29].

Impulse Sound Level, dBAI

A different solution to the impulse noise measurement problem is to develop a specific measurement technique for **impulsive sounds**. As previously stated, impulsive sounds have a very short duration; consequently, the 0.125 second **fast meter response** is not quick enough to keep up with them. The **"impulse" meter response** time of 0.035 seconds was originally developed to measure the hearing loss potential of impulsive noise in industry. Therefore, the **Impulse Sound Level Meters** have a meter response that is considerably faster than "fast." In order to facilitate the act of taking the maximum reading, the meter needle is arranged to fall slowly (with a 3 second meter response time).

Modern digital sound level meters contain a "Maximum" or "Max" Hold function that holds the maximum level for recording purposes. Measurements using the impulse sound level meter response are commonly taken with the **A-weighting** and expressed in terms of dBAI or dBA(I).

Since the impulse sound level meter response represents a different measurement technique than that of the **Leq**, use of the impulse time response is not generally used for a Leq measurement. Leq measurements are usually performed with either fast or **slow meter response** times.

Peak Sound Level

Impulsive noise from blasting operations and firearms has been measured using the "Peak" meter response. Peak is the fastest meter response of all, as the digital meter holds the maximum instantaneous **sound pressure** difference (or **overpressure**) from the steady state ambient air pressure. Peak sound level measurements can be made with linear weighting expressed as dB Peak, or with **A-weighting** expressed as dBA Peak.

1.6.4 Measuring Sound Levels From Firearms

Continuing from the previous section, there are two main methods of measuring **impulsive sound**, and hence firearm **sound levels**.

The first method is to measure the **Leq** of the sound from a range over a 1 hour period, and then apply a penalty between 5 dB [14] and 12 dB [29]. The second method is to measure typical shots with the **impulse (or peak) meter response** and **A-weighting** to obtain a level expressed in terms of dBAI (or dBA Peak).

If the individual **impulse (or peak) sound levels** vary, then they can be averaged to obtain a single result. Simple arithmetic averaging is one possibility; however, it is recommended to calculate the **Logarithmic Mean Impulse Sound Level** (LLM) which weights the higher levels [20]. The numerical definition of LLM is contained in **Section 6**.

There is no strict correlation between sound levels measured in dBAI and Leq (measured in dBA). But, as indicated in **Section 1.6.3**, if about 8 is added to the dBAI level (5 to 12 depending on the reference), it can be considered equivalent to the Leq. That is, a series of 62 dBAI impulses is roughly equivalent to 70 dBA Leq in community response.

Assessment of the annoyance of the sound from firearms using these techniques is discussed further in **Section 2**.

2 SOUND LEVEL ASSESSMENT

There are four stages in **sound level** assessment:

1. Determine a sound measurement technique, or parameter, which adequately describes the annoyance of a noise;
2. Develop a criterion sound level for the parameter;
3. Select the critical point of reception; and
4. Measure the sound at the critical point of reception using the parameter.

In **Section 1.6**, the methods of measuring the **impulsive sound** from firearms were discussed, and it included the description of two **impulsive sound level** measurement parameters. The first parameter is a **Leq** measurement over a time period of 1 hour, expressed in dBA, to which is added a penalty of between 5 dB and 12 dB to compensate for the startle characteristic of impulsive noise. The second parameter is the measurement of individual shots using the **impulse meter response** and **A-weighting**, suitably averaging the resulting readings to provide a single level expressed in dBAI.

In this section, the development of criterion sound levels (expressed in terms of dBAI or dBA Leq) and selection of the critical point of reception are reviewed. Procedures for the actual measurement of sound levels are discussed in **Section 3**.

2.1 PHILOSOPHY OF CRITERION SOUND LEVEL DEVELOPMENT

Criterion **sound levels** can be set by following two philosophies: by establishing a fixed sound level as the criterion and by setting the existing background sound level as the criterion level.

2.1.1 Fixed Criterion Sound Levels

Fixed criterion sound levels are based on two factors. They are based, firstly, on the level at which significant annoyance is expected to occur and, secondly, on the feasibility of achieving a particular level in actual practice.

It should be noted that criterion sound levels do not necessarily set the level at which sound will become audible. Many jurisdictions accept that criterion sound levels are set at values for which a "slight community response" or "sporadic complaints" might result.

One example of a fixed criterion level is the one contained in the Ontario Model Municipal Noise Control By-law, as follows:

> "For impulsive sound... from... the discharge of firearms on the premises of a licensed gun club... the applicable sound level limit – if it was in operation before January 1st, 1980 is 70 dBAI, and otherwise is 50 dBAI."[2]

[2] Ministry of the Environment, "Model Municipal Noise Control By-Law: Final Report," August 1978, section 7.

The Ministry of the Environment, "Model Municipal Noise Control By-Law: Final Report," August 1978, recognizes that existing gun clubs may have difficulty reaching the 50 dBAI level, and thus include a "grandfather" clause allowing the higher sound level of 70 dBAI. The 50 dBAI level is also included in the *Ministry of Environment and Energy, "Guide to Applying for Approval (Air): Noise and Vibration," November 1995* and in the *Federal-Provincial Advisory Committee on Environmental and Occupational Health, Health and Welfare Canada, "National Guidelines for Environmental Noise Control."*

Arntzen, Eystein, Sorensen, Stefan and Lindblom, Eva, "Annoyance Caused by Noise from Shooting Ranges," FASE, 84, pp. 443-448 indicates that community reaction to **impulsive sound** is "very low" when levels are less than 60 dBAI.

Smoorenburg, Guido F., "Evaluation of impulse noise, in particular shooting noise, with regard to annoyance," Internoise, 81, pp.779-782. 44 indicates that the "threshold for annoyance" due to impulsive noise is from 60 to 65 dBA (fast), which corresponds to approximately 65 to 70 dBAI.

These references specify that the range of sound levels for limited community reaction to the **sound** of firearms is between 50 dBAI and 70 dBAI.

One disadvantage of a fixed criterion is that it does not account for where the noise source is located. It might be expected that a firing range placed in rural surroundings will have a greater noise impact than one located close to a busy highway. A fixed criterion does not differentiate between these two surroundings.

2.1.2 Background Sound Levels as Criteria

One technique for avoiding the problem of a fixed criterion and for differentiating between quiet rural situations and noisy urban situations is to set the existing background **sound level** as the criterion level. The philosophy is that the existing background sound levels should not be significantly increased by the noise from the noise source.

In urban situations, the background sound level is primarily set by local and distant traffic or "urban hum." In rural situations, the background sound is primarily set by natural sounds.

One disadvantage of using background sound levels as criteria is that the background sound levels have to be measured before the noise source can be assessed. This makes the process more complicated. As a result, the rigidity of a fixed sound level criterion has been replaced by the complexity of having to measure the background sound levels.

An added difficulty may exist in very quiet rural surroundings where it is often impossible to achieve sound levels as low as the existing background. In order to overcome these difficulties, "hybrid" criteria have been developed. These are discussed in **Section 2.1.3**.

2.1.3 Hybrid Sound Level Criteria

Hybrid sound level criteria are actually a set of sound level criteria for different surroundings, such as rural, urban, downtown, etc. The sound level criteria actually represent typical background sound levels, which can be expected in surroundings of each type. The existing background sound levels no longer have to be measured; however, the different types of surroundings have to be carefully (or even legally) described so that the correct criterion for a particular surrounding area can be selected.

In summation, a set of fixed sound level criteria for different surroundings overcomes the problems associated with the rigidity of a single fixed criterion and the complexity of having to measure existing background sound levels. The existing background sound environment will generally be either traffic noise in urban environments (urban hum) or natural sounds (wind, leaves rustling, etc.) in a rural environment. These sounds are not impulsive in nature, but are normally assessed using **Leq**. Therefore, the very use of hybrid sound level criteria leads to the use of Leq, with an appropriate penalty for the impulsive nature of the sound of firearms.

Hybrid sound level criteria can be developed using ISO R1996 – 1971[3], which gives a Base Criterion range of 35 to 45 dBA with an average of 40 dBA. Corrections to the basic criterion for time of day and type of district are provided. These corrections can be applied to give the following set of sound level criteria values (in terms of 1 hour, Leq) for general sounds, depending on time of day and type of district.

Time of Day	Rural	Urban	Busy Urban
Day	40 dBA	50 dBA	55 dBA
Evening	35 dBA	45 dBA	50 dBA
Night	30 dBA	40 dBA	45 dBA

The *Ministry of Environment and Energy, "Guide to Applying for Approval (Air): Noise and Vibration," November 1995* xcontains levels below which no further requirements apply. These levels can be compared with the above ISO levels.

Time of Day	Rural	Quiet Urban	Noisy Urban
Day	45 dBA	50 dBA	50 dBA
Evening	40 dBA	47 dBA	45 dBA
Night	40 dBA	45 dBA	45 dBA

It can be seen that the two sets of levels are generally similar. The only difference is that the ISO levels are somewhat stricter than the Ontario levels.

[3] ISO R1996, "Assessment of Noise with Respect to Community Response," May 1971.

2.2 POINT OF RECEPTION SELECTION

Definition of the point of reception for noise from shooting ranges is an important step. Clearly, residences are the first choice; however, other buildings are also sensitive to noise.

> A point of reception for urban surroundings:
>
> "... any point on the premises of a person where sound or vibration originating from other than those premises is received."
>
> "... the point of reception may be located on any of the following... premises: permanent or seasonal residences, hotels/motels, nursing/retirement homes, rental residences, hospitals, camp grounds and noise sensitive buildings such as schools and places of worship."
>
> A point of reception located in rural surroundings:
>
> "... within 30m of a dwelling or a camping area."[4]

The closest point of reception within the above definitions will generally be the critical point of reception. However, it may be that the closest point of reception is shielded from firearm noise by intervening buildings, walls or favourable topography. In this situation, **sound levels** may have to be measured (or predicted) at several points of reception to determine which location is the one with the highest sound levels and thus be designated as the critical point of reception.

The typical reduction of noise from shooting ranges with distance is presented in **Section 4**.

This information indicates that points of reception up to at least 1 kilometre away from a shooting range may have to be considered.

[4] Ministry of Environment and Energy, "Guide to Applying for Approval (Air): Noise and Vibration," November 1995, section 7.

3 SOUND LEVEL MEASUREMENTS

In order to ensure the accurate and repeatable measurement of **impulsive sound levels** from firearms, the **sound level meter**, the sound level measurement procedure and the qualifications of the person performing the measurement need to be established.

3.1 SOUND LEVEL METER REQUIREMENTS

This section details the requirements for the effective use of sound level meters.

3.1.1 Sound Level Meter Types

In **Section 1.6**, two parameters were established as being suitable for the measurement of firearm-related sounds – that is, either a **Leq** measurement over a 1-hour period or a reading with the **impulse meter response**. Sound level meters with the capability of measuring Leq values over a period of time are generally called **Integrating Sound Level Meters**. Meters equipped with the impulse meter response are generally called **Impulse Sound Level Meters**. A meter equipped with both capabilities would be an "Integrating Impulse Sound Level Meter." In order to measure the noise from shooting ranges, one of these three types of sound level meters is required.

A major standard defining sound level meter characteristics is IEC 651.

Four degrees of precision for sound level meters are established as follows:

Type 0	Laboratory (highest) Grade
Type 1	Precision Grade
Type 2	Survey Grade
Type 3	Lowest Grade[5]

IEC 651 defines tolerances for Lin, A and C-weighting networks, as well as for **slow**, **fast** and impulse meter response times. The components of a sound level meter are described in **Section 1.6**.

It is generally accepted that Type 2, Survey Grade or higher grade sound level meters are suitable for the assessment of community noise. The use of Type 3 instruments is not recommended.

3.1.2 Sound Level Meter Calibration

Sound level meters require a calibration adjustment prior to every use. To do this, a **sound level calibrator**, which fits over the microphone, is often used. It produces a **sound** of a fixed level and **frequency**. A sound level calibrator must therefore be available for the measurement of shooting range noise.

3.1.3 Accessories Required for Sound Level Meters

Microphones are susceptible to the sound of wind blowing across them. To reduce the effect of wind noise, a windshield or wind screen should be available and used for all outdoor measurements. Weather conditions for meaningful **sound level** measurements are discussed in **Section 3.2.2**.

[5] IEC Standard 651, 1979, section 7.

When **Leq** measurements or other sound level measurements are being performed over a lengthy time period, the sound level meter should be mounted on a tripod.

3.2 SOUND LEVEL MEASUREMENT PROCEDURES

Detailed sound level measurement procedures are included in the Ontario Model Municipal By-law *Ministry of the Environment, "Model Municipal Noise Control By-Law: Final Report," August 1978* and in the *Ministry of Environment and Energy, "Guide to Applying for Approval (Air): Noise and Vibration," November 1995.* These, or similar references, should be followed in order to ensure meaningful sound level measurement results. Adequate sound level measurement procedures are discussed in Sections 3.2.1 through 3.2.3.

3.2.1 Calibration

The **Integrating** and/or **Impulse Sound Level Meters** used for the measurement of shooting range noise must be calibrated with a **sound level calibrator** before and after the measurements.

3.2.2 Weather Conditions

The **sound level meter** and the sound level calibrator should never be used in weather conditions outside the temperature and humidity ranges, etc. specified by the manufacturer.

A windshield or windscreen should be used for all outdoor measurements.

Weather conditions for meaningful noise measurements are generally considered to be winds below 15 to 20 km/hr (even with a windscreen) with no precipitation, in addition to the temperature and humidity limitations stated by the manufacturer.

3.2.3 Recording

The following information should be recorded for all outdoor sound level measurements:

1. Measurer's name;
2. Date;
3. Time of day for the measurements;
4. Weather conditions:
    - (a) Temperature;
    - (b) Wind speed and direction;
    - (c) Relative humidity; and
    - (d) Cloud cover;
5. Measurement location(s) with drawing or map;
6. Major noises included in the measurement (e.g. firearms, traffic, etc.);
7. Noise excluded from the measurement (e.g. trains, aircraft, dogs barking, etc.);
8. Sound level with description (e.g. dBAI or dBA, Leq – 1 hour); and
9. Any other relevant information or comments.

3.3 SOUND LEVEL MEASUREMENT PERSONNEL

Levels of **impulsive sound** due to firearms should only be measured by personnel trained in outdoor **sound level** measurement procedures. Personnel can be either at the technical level or at the engineering level.

Provincial Ministries of the Environment often list recognized consultants working in the field of acoustics and noise control. Staff of such recognized organizations can be utilized for sound level measurements of firearms.

In Ontario, noise issues have been redirected to the municipal level and courses in sound level measurement procedures are provided to train municipal staff, such as by-law officers. Personnel who have successfully completed such courses become qualified to perform sound level measurements of firearms.

Relatively few community colleges or universities offer formal training in acoustics and noise control. However, graduates of these institutions having earned credits in relevant courses, and having been under supervision or possessing relevant sound level measurement experience for at least 1 year, are deemed qualified.

Industrial hygienists are often trained in sound level measurements in factory surroundings. Any staff members who undergo additional training in outdoor sound level measurement, and/or supervision by personnel who are themselves trained as described above, are also qualified.

4 RANGE CONSTRUCTION PLANNING ADVICE

This section provides advice on the design, planning and construction of both outdoor and indoor shooting ranges.

4.1 DESIGN CONSIDERATIONS FOR OUTDOOR AND INDOOR RANGES

The design considerations for the construction of outdoor and indoor shooting ranges are detailed in Sections 4.1.1 through 4.1.2.

4.1.1 Design Considerations – Outdoor Ranges

In this section, we consider only the most general principles of sound propagation in the environment. **Sound pressure level**, or loudness, decreases as distance from the sound source increases. Yet, the sound pressure level at any distant location is greatly influenced by the terrain between source and receiver.

The examples described below show typical relationships between the **sound level** of a firearm and the distance from the firearm at which it is measured for different kinds of terrain.

It is known that noise carries best over water, but this is also true over flat frozen ground. Figure 4 shows the reduction in sound level with distance from a typical rifle firearm, up to a distance of 1000 m.

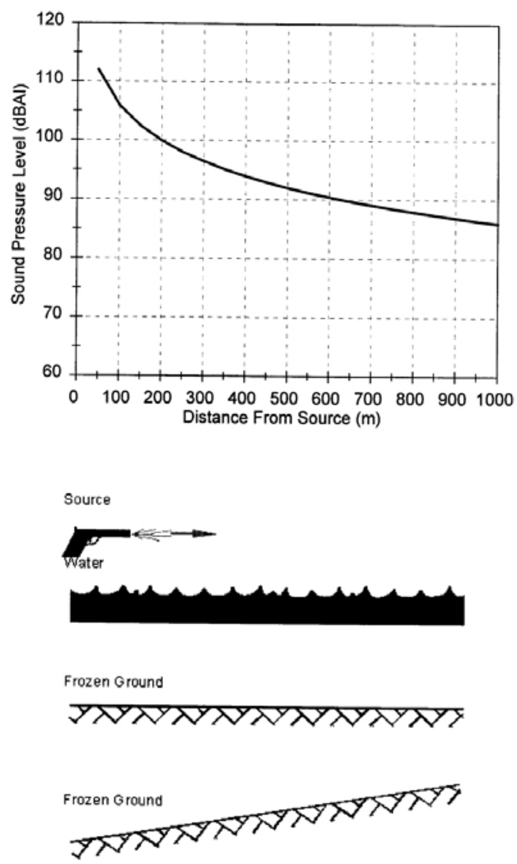


Figure 4: Attenuation Over Distance – No Ground Effect

The sound level is given in units of dBAI. This same figure takes into consideration whether the surface between source and receiver is water, frozen ground or a sloped frozen ground surface – the key characteristic is that the surface is flat.

Noise does not carry as well over flat open ground due to the “ground effect.” The ground must be essentially flat, level or sloped. Figure 5 shows sound levels as functions of distance for this condition, and it can be seen that they are significantly less than those over water.

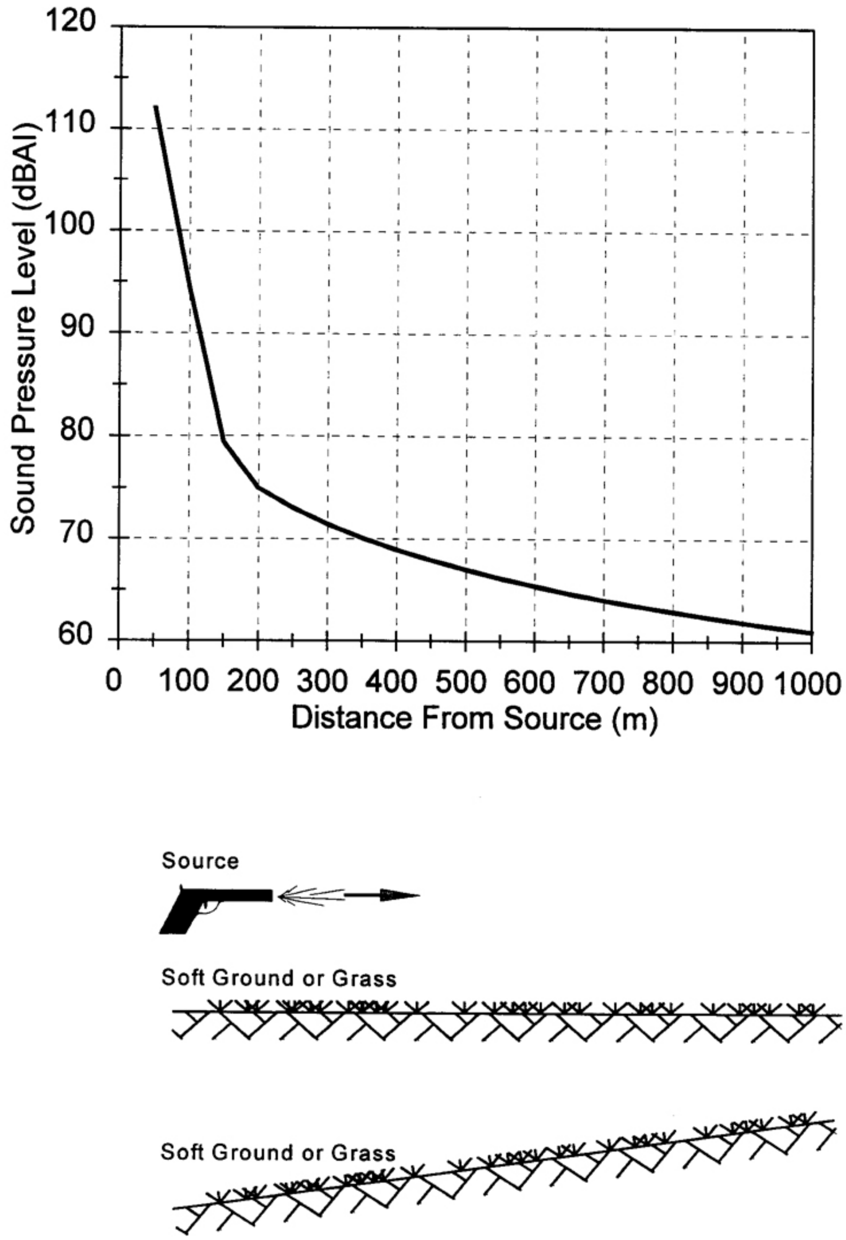


Figure 5: Attenuation over Distance with Ground Effect

Although, even at large distances from a firearm source, such as 1000 m, the sound levels can still be on the order of 60 to 70 dBAI.

A hill, berm or barrier between the source and receiver, particularly one which breaks the line of sight between source and receiver, provides further reduction in sound level. The higher the hill, the greater the reduction despite the law of diminishing returns associated with this "barrier effect." Figure 6 shows an example of a 10 m high hill located 100 m away from a noise source. These data have been calculated in the same way as the previous figures.

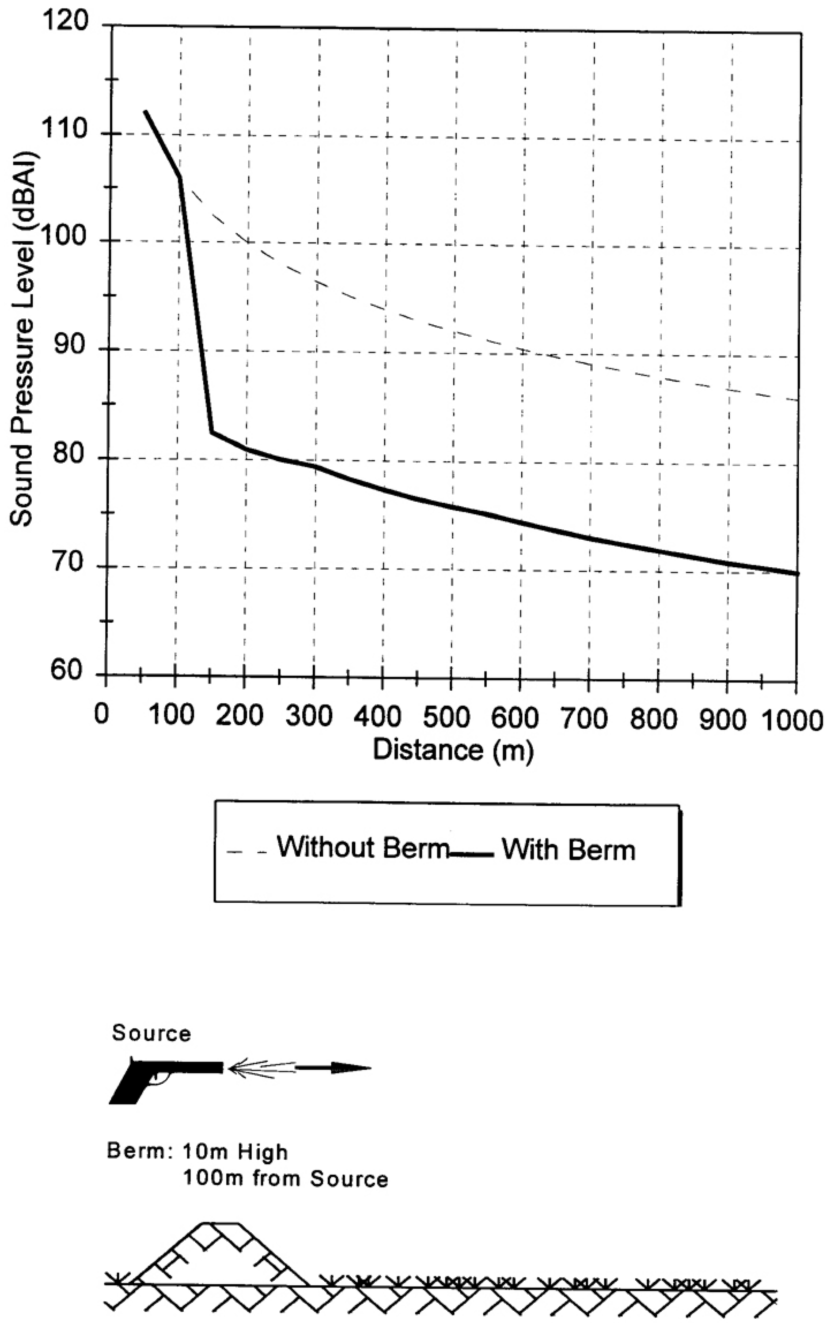


Figure 6: Attenuation Over Distance With and Without Berm

In conclusion, **sound** is reduced by a combination of effects: distance, terrain and barriers.

4.1.2 Design Considerations – Indoor Ranges

This section considers only the most general principles of noise propagation from the interior of a building to the exterior; it is not concerned with the internal noise levels of the range.

Noise is reduced in pressure or loudness as it crosses a wall. This noise reduction, when measured in a laboratory, is called *transmission loss*. The first rule of transmission loss is called "Mass Law" and indicates that partitions of higher mass (i.e. greater weight per square metre) reduce sound more. Figure 7 shows the noise reduction or transmission loss for three different wall types.

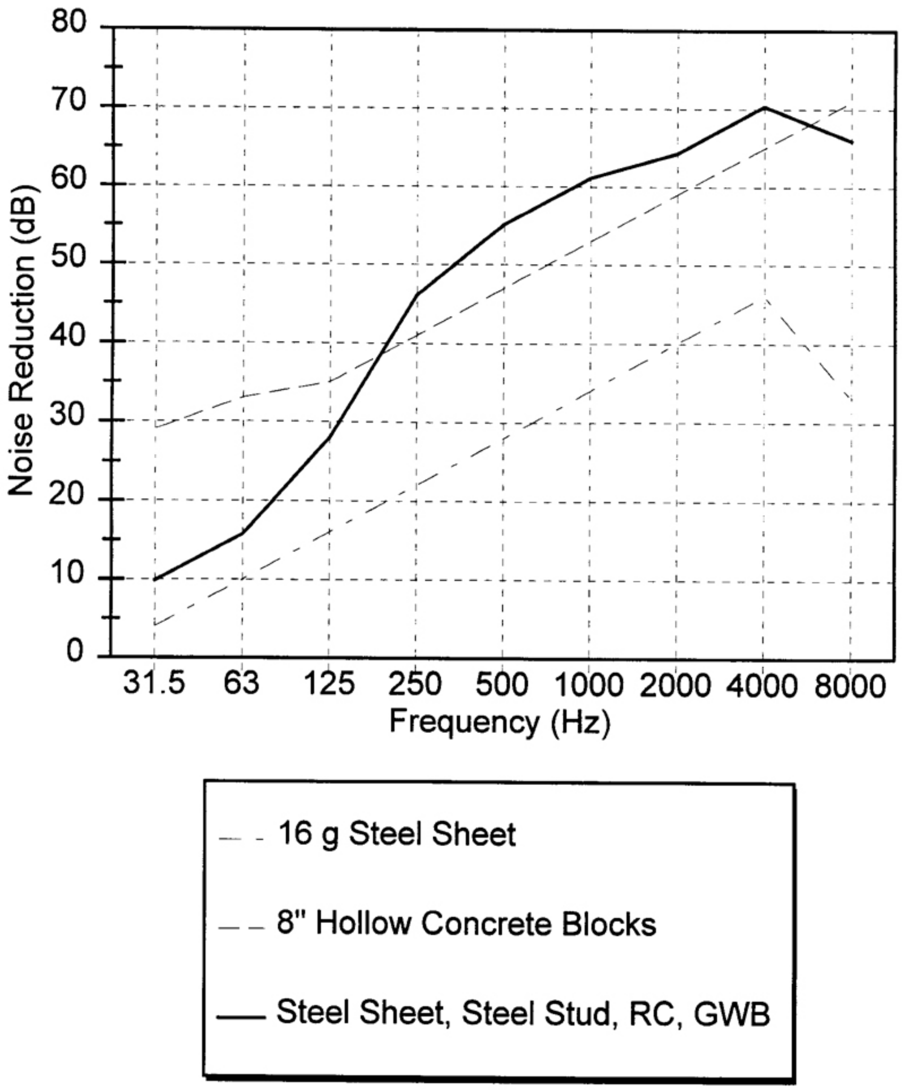


Figure 7: Noise Reduction Across the Wall

If the wall consists of 16 gauge steel sheets, such as the exterior wall of an ordinary storage shed, noise is reduced about 10 dB at 63 Hz and about 30 dB at 500 Hz. A heavier wall, such as an 8-inch hollow concrete block, provides about 35 dB of reduction at 63 Hz and about 50 dB at 500 Hz. This is the effect of Mass Law.

However, a wall made of two leaves, such as a 16 gauge steel sheet and a layer of Gypsum Wall Board (GWB), separated by a distance of approximately 150 mm and which uses a resilient element, such as commercially-available Resilient Channel, provides an entirely different characteristic. At low **frequencies**, this construction provides about the same transmission loss as any other wall of equal weight/square metres; however, in higher frequencies this wall will outperform a solid partition of much greater weight.

Sound-absorbing materials placed interior to the building will reduce the **sound level** in the building; those on the exterior help to reduce other types of noise, but they have only a small effect on the exterior noise caused by shooting noise. Sound-absorbing materials placed interior to the building reduce the build-up of reverberant noise within the space, but since they are on the surface of the building, they do not affect the initial impulse of noise from a firearm discharge.

Holes in a wall are the natural enemy of noise control. Walls, such as those described above, that can reduce sound by 60 dB are, in fact, allowing only one part in one million of the sound energy through the wall. An opening in the wall, such as a window representing just 1% of the total area of the wall, will allow so much **sound** through that the overall noise reduction of the wall will only be about 20 dB. Consequently, if a window is to be introduced it needs to be closed and sealed, as well as have a transmission loss characteristic that is essentially the same as the wall in which it is located.

Finally, almost any enclosure will actually increase the sound levels that the shooter is exposed to by virtue of the reverberation within the space. In real spaces with plenty of sound-absorbing materials, the actual reverberant sound levels are about 5 dB higher than they would be in the open.

4.2 PLANNING FOR SHOOTING RANGES

In this section, various factors affecting sound propagation and which influence the selection of a shooting range site are discussed.

4.2.1 Outdoor Ranges

Consider Receivers Up to 3 km Distant

Considering the nature of the noise source, directivity, topography and climatic conditions, receivers (particularly residences) as far as 1 to 3 km away may be affected, especially downrange.

Natural Barriers

Ideally, a range should take advantage of a natural hill, berm or escarpment in the downrange direction. Man-made barriers greater than 5 m in height become very expensive while natural hills are often very much higher, thus being more effective in reducing noise levels downrange.

Potential for Berm or Barrier

Required berms or barriers may be created in the process of levelling and preparing the shooting range site. Material removed can be used to create the berm. Additionally, excavation at the shooter location increases the height difference between shooter and berm, making the berms more effective.

Barriers

Barriers can be constructed from many materials (e.g. wood, metal and concrete), but they must have a minimum surface density of 20 kg/m^2, such as that of 37 mm thick wood. Barriers must be continuous, with no gaps or holes and must touch the ground (i.e. leaving no gap between the barrier and ground). There should be no trees near the barrier or on the top of any berm.

Climatic Conditions

In many locations, the wind tends to have a preferred direction. For example, the wind might come from a northwest direction 20% of the time and from a southeast direction only 10% of the time. These tendencies also change according to the time of year. Wind rosettes are available from Environment Canada, usually for airport locations.

Sound levels are increased at distances during temperature inversions, which commonly occur on summer nights when the wind speed is low, as indicated in **Section 1.4.4**.

All else being equal, the climatic conditions alone can cause sound levels to vary significantly. It is important to advise the surrounding community that shooting noise may be audible during an inversion or when the wind originates from a particular direction, and perhaps not audible at other times.

Shooter Enclosure

Certain types of ranges lend themselves to the construction of a shooter enclosure, which may be nothing more than a barrier behind the shooter and a roof overhead. However, each shooting station can be separated from each adjacent station by baffles in which the shooter aims through a port, or window, to the target external to the enclosure. Significant sound attenuation can be achieved in all directions, including downrange, provided the enclosure is heavy and well-sealed, and that sound-absorbing material is used extensively in the interior of the enclosure.

Existing Noise Sources, Particularly Transportation

Transportation noise is generally considered part of the background noise against which the shooting noise may be compared. Average sound levels near highways and superhighways are often in the 60 to 70 dBA range for 16 to 24 hours per day. In such areas, the shooting noise may be buried in the background noise. Therefore, it may be advantageous to locate a shooting range near a major highway.

Locations to Avoid

Several types of topography should be avoided, as they either help the propagation of **sound** or make it inherently difficult to provide noise controls. Noise control is particularly difficult when a shooting range is located near water (i.e. water between the source and receiver), bare rocks or large paved surfaces. As previously mentioned, sound propagates very well over a large valley, particularly if the shooter is aimed over the valley.

4.2.2 Indoor Ranges

In this section, several factors affecting sound propagation and which influence an indoor range site selection and building construction are discussed.

Consider All Potential Receivers Up to 1 km Away

Considering the relatively light wall and roof construction, the terrain and the climactic conditions of an existing building serving as an indoor range, receivers as far as 1 km away may be affected.

Wall and Roof Construction

The walls and roof of the indoor range building generally require a heavier and/or double-leaf construction in order to provide adequate transmission loss.

Sound-Absorbing Materials

Sound-absorbing materials on the inside of the indoor range provide some reduction of noise to the exterior and will reduce interior **sound levels**, thus making the interior much more comfortable. However, the initial impulse of **sound** is generally affected very little by sound-absorbing materials. Hearing protection for shooters and staff is advised.

Openings to the Exterior

All openings to the exterior of the building require about the same degree of transmission loss as the walls and roof. Windows, skylights, doors (especially overhead ones) and loading doors require special treatment. Similarly, openings for air intake and exhaust, ventilation fans, and washroom and kitchen exhaust fans may require special treatment.

5 ABATEMENT TECHNIQUES

This section discusses the techniques for reducing the noise produced by outdoor and indoor shooting ranges.

5.1 NOISE ABATEMENT TECHNIQUES FOR OUTDOOR SHOOTING RANGES

In this section, we consider an outdoor shooting range on flat ground (either level or sloping). The effects of a natural hill located directly downrange, a combination berm/barrier added to the side, and a barrier behind the shooters are examined.

5.1.1 Natural Hill

Figure 8 shows the **sound levels** downrange for typical rifle noise, without any other noise controls in place.

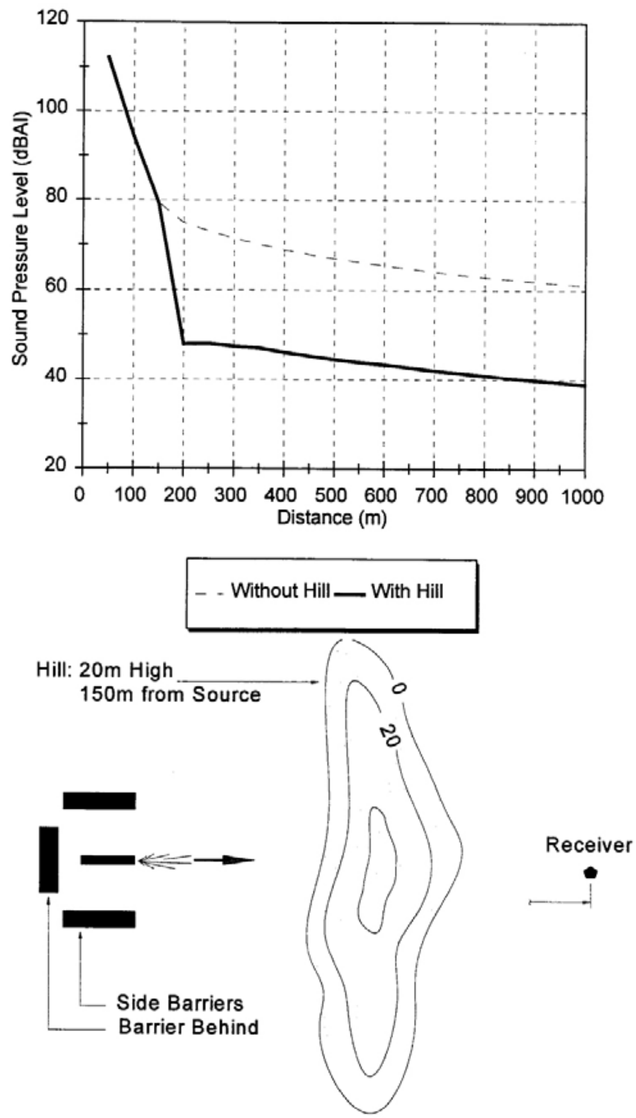


Figure 8: Attenuation Over Distance With and Without Hill

The sound levels over flat ground are shown, along with the sound levels that occur at a 20 m high natural hill located 150 m from the shooter's position. The hill provides more than 20 dB attenuation, reducing sound levels from the range of 60 to 70 dBAI to levels in the range of 40 to 50 dBAI.

5.1.2 Barriers at Sides

Figure 9 shows the effect of a 5 m barrier located 25 m from the shooter at the side of the range, assuming there is flat ground.

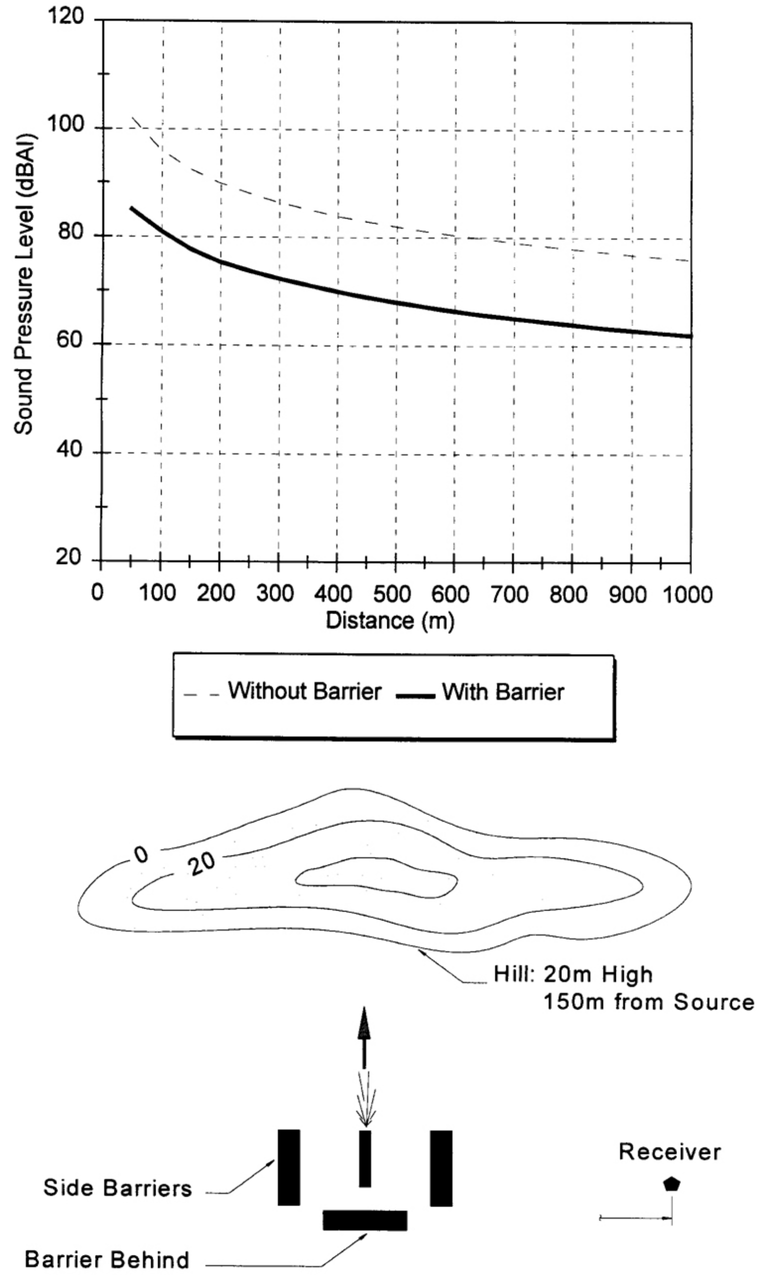


Figure 9: Attenuation Over Distance With and Without Side Barriers

Once again, the barrier provides significant reduction in noise, but since it is only 25% of the height of the hill and half the distance away, it provides less attenuation.

5.1.3 Barrier Behind Shooter

Figure 10 (see Appendix G) shows the effect of a barrier behind a shooter. Since the direction is behind the shooter, sound levels are lower due to directivity.

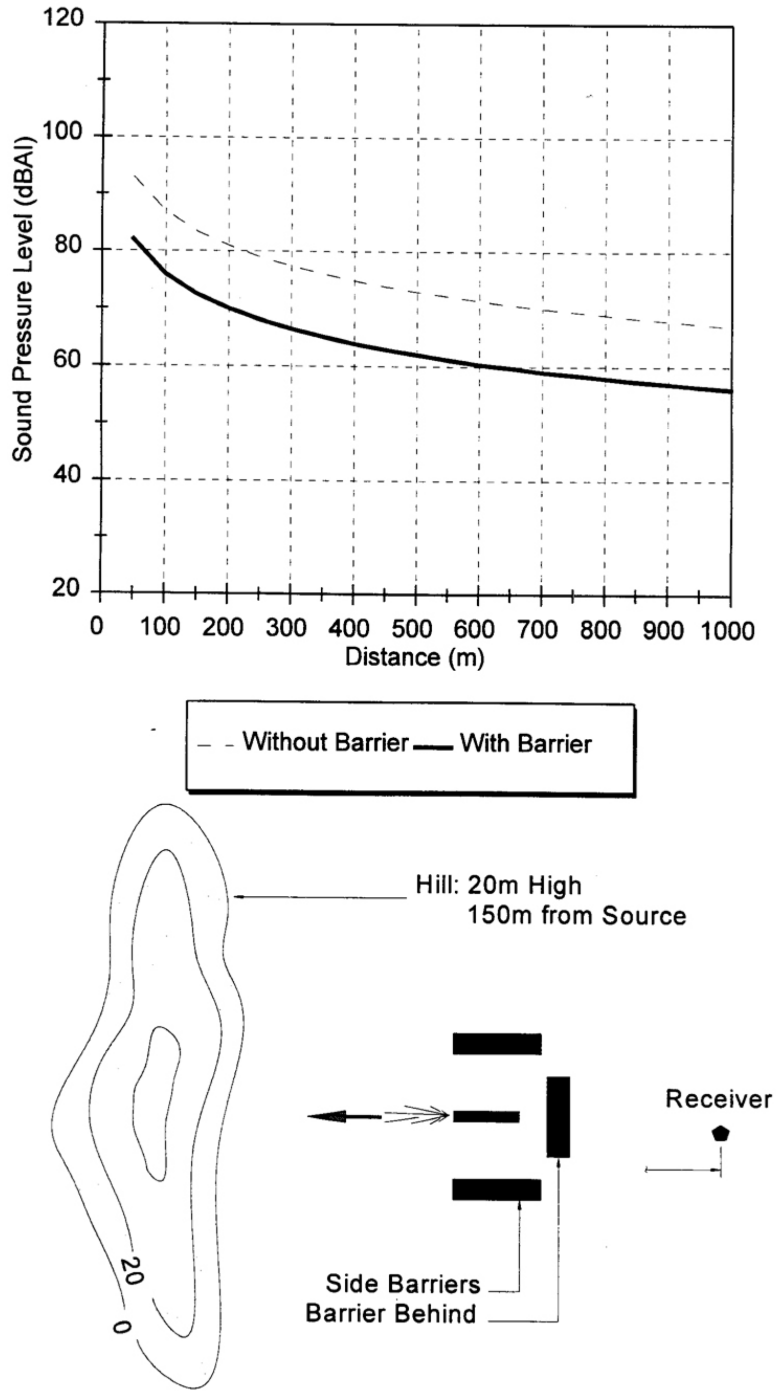


Figure 10: Attenuation Over Distance With and Without Barrier Behind Shooter

The barrier, 3 m high and 10 m behind the shooter, provides a reduction of about 10 dB.

Reviewing the calculated data downrange, to the side of the range and behind the shooter, highlights the requirement for a higher and closer barrier at the sides, in order to achieve the sound levels accomplished with the hill and behind-the-shooter barriers.

5.2 NOISE ABATEMENT TECHNIQUES FOR INDOOR SHOOTING RANGES

In this section, we consider an indoor range with and without walls, and various walls constructions.

5.2.1 Walls

Table 3 shows the calculated sound levels for various wall constructions. It shows sound levels 100 m from the shooter, assuming the handgun has a **sound level** of 160 dBA (peak) and that the **sound** is measured 2 m from the handgun at 90° to the line of fire. Both the double-leaf construction and the concrete-block construction provide sound levels of 42 dBAI at 100 m downrange from the shooter.

Again, these calculations are for demonstration purposes only and the actual sound level will vary based on the actual firearm used, the planned construction, construction quality and the exterior terrain.

Table 3: Sound Levels, dBAI, 100m from Indoor Range (Sound Pressure of the Handgun Being Measured is 160 dBAI at 600 mm)

Construction of Wall	SPL (dBAI) at 100 m from Shooter, Downrange
No Walls	109
16 gauge sheet steel	73
16 gauge sheet steel, steel studs, resilient channel, 16 mm GWB	42
8-inch hollow concrete blocks	42

5.3 PRACTICAL MEASURES OF NOISE CONTROL

This section summarizes in point-form the practical measures to take for noise control in outdoor and indoor shooting ranges.

5.3.1 Outdoor Shooting Ranges

- Range should be located facing a natural high hill.
- Berms and barriers should be as close and high as possible.
- Barriers should be covered with sound-absorbing, weatherproof material.
- Berms and barriers must be designed for drainage considerations, wind and snow accumulation.
- Shooting range should be oriented so that “downrange” is away from critical receivers.
- There should be a shooter enclosure, with interior surfaces covered with sound-absorbing material where possible.

- Locations near lakes, rivers and open ground should be avoided.
- Trees on the tops of berms or near barriers should be avoided.

5.3.2 INDOOR SHOOTING RANGES

- Consider noise both through the roof and walls.
- Heavy and/or two-leaf wall and roof construction should be employed.
- Sound-absorbing materials should be applied to the interior of the indoor range.
- All doors and windows require the same transmission loss characteristics as the roof and walls.
- All openings should be acoustically treated, especially air intakes and exhausts (e.g. locate HVAC equipment in the ceiling of any office area’s supply and return it ducted to the shooting area).

6 GLOSSARY

The majority of these technical definitions are derived from the *Ministry of the Environment, “Model Municipal Noise Control By-Law: Final Report,” August 1978.*

A-Weighted Sound Pressure Level

The sound pressure level that is modified by the application of A-weighting. It is measured in A-weighted decibels and denoted dBA.

A-Weighting

The frequency weighting characteristic as specified in IEC 123 or IEC 179 and intended to approximate the relative sensitivity of the normal human ear to different frequencies (pitches) of sound.

Acoustic Calibrator

An electro-mechanical or mechanical device intended for the calibration of sound level meters and meeting the specifications of Publication NPC-102 – Instrumentation, for Acoustic Calibrators.

Decibel

A dimensionless measure of sound level or sound pressure level; see “Sound Pressure Level.”

Effective Sound Pressure

The “effective sound pressure” at a point is the root-mean square value of the instantaneous sound pressure, over a time interval, at the point under consideration as detected with a sound level meter.

Equivalent Sound Level

Sometimes denoted as Leq. It is the value of the constant sound level that results from exposure to the same total A-weighted energy as does the specified time-varying sound, if the constant sound level persists over an equal time interval. It is measured in dBA.

The mathematical definition of Equivalent Sound Level (Leq) for an interval defined as occupying the period between two points in time t_1 and t_2 is:

$$\mathrm{Leq} = 10 \log_{10} \left[\frac{1}{t_1 - t_2} \int_{t_1}^{t_2} \frac{p^2(t)}{p_r^2} dt \right]$$

where *p(t)* is the time-varying A-weighted sound pressure and p_r is the reference pressure of 20 μPa.

Fast Response

A dynamic characteristic setting of a sound level meter.

Frequency

The “frequency” of a periodic quantity is the number of times that the quantity repeats itself in a unit interval of time. The unit of measurement is hertz (Hz), which represents the number of cycles per second.

General Purpose Sound Level Meter

A sound level meter that meets the specifications of Publication NPC-102 – Instrumentation, for General Purpose Sound Level Meters.

Impulse Response

A dynamic characteristic setting of a sound level meter meeting the specifications of Publication NPC-102 - Instrumentation, for Impulse Sound Level Meters.

Impulse Sound Level

The sound level of an impulsive sound as measured with an Impulse Sound Level Meter set to impulse response. It is measured in A-weighted decibels and denoted dBAI.

Impulse Sound Level Meter

A sound level meter that meets the specifications of any publication for Impulse Sound Level Meters.

Impulsive Sound

A single pressure pulse or a single burst of pressure pulses.

Integrating Sound Level Meter

A sound level meter that is capable of being used to derive the Equivalent Sound Level (Leq).

Logarithmic Mean Impulse Sound Level

Sometimes denoted LLM. For N impulsive sounds, LLM is ten times the logarithm to the base 10 of the arithmetic mean often to the power of one tenth the Impulse Sound Level of each impulsive sound. Algebraically, it can be written as follows:

$$\text{LLM} = 10 \log_{10}\left[\frac{1}{N}\left(10^{dBAI_1/10} + 10^{dBAI_2/10} + \ldots + 10^{dBAI_N/10}\right)\right]$$

where $dBAI_1$, $dBAI_2$, …, $dBAI_N$ are the N impulse sound levels.

Overpressure

The "overpressure" at a point, due to an acoustic disturbance, is the instantaneous difference at that point between the peak pressure during the disturbance and the ambient atmospheric pressure. The unit of measurement is the pascal. One pascal, abbreviated Pa, is the same as one newton per square metre, abbreviated N/m^2.

Overpressure Level

It is twenty times the logarithm to the base 10 of the ratio of the peak pressure to the reference pressure of 20 μPa.

Peak Pressure Level Detector

A device capable of measuring peak pressure or pressure level perturbations in air which meets the specifications of Publication NPC-102 – Instrumentation, for Peak Pressure Level Detectors.

SEL

The energy mean value of the single event noise exposure level, which may be calculated from the equation: $SEL = NL_{max} + 10 \log_{10} t_{ea}$ (dB).

Slow Response

A dynamic characteristic setting of a sound level meter meeting the applicable specifications of Publication NPC-102 – Instrumentation.

Sound

An oscillation in pressure, stress, particle displacement or particle velocity, in a medium with internal forces (e.g. elastic, viscous) or the superposition of such propagated oscillations, which may cause an auditory sensation.

Sound Level

The A-weighted sound pressure level.

Sound Level Meter

An instrument that is sensitive to and calibrated for the measurement of sound.

Sound Pressure

The instantaneous difference between the actual pressure and the average or barometric pressure at a given location. The unit of measurement is the micropascal (μPa), which is the same as a micronewton per square meter ($\mu N/m^2$).

Sound Pressure Level

It is twenty times the logarithm to the base 10 of the ratio of the effective pressure (p) of a sound to the reference pressure (p_r) of 20 μPa. Therefore, the sound pressure level in dB = $20 \log_{10}(p/p_r)$.

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